



PROBLEMS AND OPPORTUNITIES IN ADOPTING SMART AND PARTICIPATORY SYSTEM ON FLOOD RISK REDUCTION: CASE STUDY OF SURABAYA FLOOD RISK MANAGEMENT

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Abstract

Smart system and participatory process become buzz words in disaster risk management highlighting the importance of those concepts in reducing the impact of disasters effectively. Surabaya, like other cities, put a lot of effort to implement them in their administrative process especially in flood risk management. Apparently, the integration between smart system and participatory process in flood risk management need further improvements. 10 problems typologies have been formulated based on the discussion within 12 key stakeholders from government, private sectors, media, academia and community groups. Based on MICMAC analysis, the problems are structured resulting the improvement of policy direction became the key driver problem that can influent to all others problem. The policy direction becomes the umbrella to establish a proper smart and participatory system in flood risk management. 6 others are relay variables that can change other problem partially. Those relay variables are more on the technical problem on how the system applied such as data availability and human resource capacity. While excluded variables are perceived as latent social enablers. Those variables are significant once the system has been established. Without solving the excluded variables, the value of smart-participative management can be jeopardized.

Keywords: Flood, Flood Risk Management, Smart City, Participatory

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INTRODUCTION

Urban flooding is a complex socio-technical risk shaped by interacting technological, institutional, and social factors. Although cities deploy smart technologies like IoT and AI, these systems often evolve fragmentally without integrated governance (Kaluarachchi, 2020). Additionally, citizen participation frequently lacks genuine co-production, whereas AI tools require transparent, inclusive decision-making (Mupfumira et al., 2024). Surabaya presents a context-specific case study to examine how technological and participatory gaps constrain local flood resilience, offering an analytical approach for comparative urban studies. Surabaya's rapid urbanization escalates its vulnerability to tidal and pluvial flooding (Pamungkas et al., 2019; Anggraini et al., 2024). In 2022, severe flooding disrupted over 10,000 residents across 118 locations (Ginancar, 2022; Wardana, 2024). Currently, local disaster governance remains reactive rather than proactive (Pamungkas et al., 2019). Despite adopting "smart city" measures, implementation falters due to fragmented, early-stage, and opaque technological systems (Ifaldy et al., 2025). Furthermore, community involvement remains predominantly consultative rather than co-decisional (Ifaldy et al., 2025; Wessel et al., 2021). This paper identifies crucial leverage points for policy interventions, aiming to align technological deployment with citizen preparedness for genuinely smart, participative flood risk governance.

LITERATURE REVIEW

To integrate the concepts of smart city and participatory approaches into flood risk management, 8 indicators and 28 key variables were formulated in this study. These indicators and variables also serve as the basis for developing the interview protocol, which is designed to assess the implementation of participatory smart city practices in flood disaster management in Surabaya.

Table 1. Research Indicators and Variables

Indicators	Code	Variables	Source
Digital Technology Utilization (IoT)	A.1.1	Sensor Network Utilization	(Anbarasan et al., 2020; Ibrahim & Mishra, 2021; Josipovic & Viergutz, 2023; Munawar et al., 2021; Sood et al., 2018; Jaafar et al., 2024)
	A.2.1	Big Data Analytics	
	A.3.1	Digital Implementation	
	A.4.1	Remote Sensing	
	A.5.1	Artificial Intelligence (AI)	
	A.6.1	Applications & Websites	
Real-Time Monitoring Effectiveness	B.1.1	Hydrological Information	(Fairuz et al., 2020; Jan et al., 2022; Jang & Jung, 2023; Kim et al., 2022; Şensoy et al., 2018)
	B.2.1	Water Storage Automation	

Indicators	Code	Variables	Source
Early Warning Effectiveness	C.1.1	Warning Outreach	(Hammood et al., 2020; Hasan & Islam, 2024; Kuller et al., 2021; Perera et al., 2019; Rana et al., 2021; Afida et al., 2016)
	C.2.1	Warning Accuracy	
	C.3.1	Quality of Information Content	
	C.4.1	Community Response Capability	
Disaster Prediction Capability	D.1.1	Data Input Completeness	(Cha & Lee, 2021; Hossain Anni et al., 2020; Ma et al., 2021; Starzec & Kordana-Obuch, 2024; Xing et al., 2021)
	D.2.1	Predictive Modeling Quality	
	D.3.1	Drainage Infrastructure	
Resource Accessibility	E.1.1	Emergency Apps	(Cools et al., 2023; Das et al., 2024; Henriksen et al., 2018; Jiang et al., 2024; McCallum et al., 2016)
	E.2.1	Disaster Education	
	E.3.1	Disaster Facilitator	
	E.4.1	Shelter/Evacuation Facilities	
	E.5.1	Medical Facilities	
Inter-Agency Collaboration	F.1.1	Governance & Planning	(Cools et al., 2023; Puzyreva et al., 2022; Thaler & Levin-Keitel, 2016; Watkins & Collins, 2024)
	F.2.1	Planning Vision & Mission with Collaborative Solution	
	F.3.1	Bottom-Up Planning	
	F.4.1	Proactive Policies	
Community Awareness	G.1.1	Community Flood Risk Awareness	(Huang et al., 2020); Gunandar et al., 2024; Modul KRB Banjir BNPB (Flood risk model from BNPB Modul)
	G.2.1	Flood Disaster Mitigation Actions	
Active Community Engagement	H.1.1	Infrastructure Maintenance	(Begg et al., 2018; Hendra & Kismartini, 2018; Rewah, 2022)
	H.2.1	Decision Making	

Source: Author, 2026

RESEARCH METHODOLOGY

This study utilizes a mixed-method, sequential exploratory design to investigate urban flood management for Surabaya City context (Fetters et al., 2013). Data were gathered via in-depth interviews with purposively selected stakeholders directly involved in Surabaya's flood mitigation efforts (Agustina et al., 2024; Challies et al., 2016). To capture comprehensive technical, institutional, and operational perspectives, the respondents were categorized using the pentahelix model. Consequently, the sample encompasses key representatives from

government, private enterprise, local communities, academia, and media networks (Agustina et al., 2024; Challies et al., 2016; Riama et al., 2021).

Table 2. Stakeholder Profile

Stakeholders	Respondents
Local Communities	Neighborhood Unit Head; Community Unit Head; Prominent Figure
Government	Surabaya City Water Resources and Highways Officer; Head of Mulyorejo District; Head of Keputih Subdistrict
Academia	Head of Research Center for Disaster Mitigation and Climate Change; Smart City Expert
Private Enterprise	Pakuwon City Officer; Grand Pakuwon Officer
Media Networks	JTV (local television station); Memorandum (local newspaper)

Source: Author, 2026

The analytical procedure integrates quantitative content analysis with MICMAC structural analysis (Ahmad et al., 2019; Pathania & Tanwar, 2024). Interview transcripts were systematically coded in NVivo by two independent coders using a deductive-inductive strategy to identify thematic factor salience across technological, institutional, and social dimensions (Allsop et al., 2022). To ensure empirical rigor, coding underwent stringent inter-coder reliability testing via Cohen's Kappa and Gwet's AC1 coefficients. Coding discrepancies were resolved through joint re-evaluations and arbitration by the lead author until 100% agreement was achieved. High inter-coder agreement confirmed the reliability of the identified problem sets. Subsequently, MICMAC analysis mapped the systemic relationships of these factors based on relative driving power and dependence. Stakeholders evaluated pairwise relationships using a 5-point scale (0 to 4) to construct the Direct Influence Matrix (MDI). Iterative matrix multiplications validated the Indirect Influence Matrix (MII), establishing final driving and dependence scores to categorize factors into four MICMAC quadrants (Ifaldy et al., 2025).

ANALYSIS AND DISCUSSION

The statistical evaluation demonstrates that all research variables exhibit high-level reliability, with Cohen's Kappa coefficients (κ) ranging from 0.70 to 0.98 and Gwet's AC1 values consistently reaching near-perfect levels. A mean agreement rate of 99% and frequency (F) further validates the objectivity and methodological rigor maintained during the classification of stakeholder interview data into thematic variables.

Table 3. Content Analysis Result Summary.

Problem Typologies	Actual Problems	Related Variables
[P1] Policy direction and planning priority (F = 34)	Policy framework lacks focus on big data optimization (F:4) (Cκ:0,88); High procurement costs leading to budgetary constraints (F:5) (Cκ:0,81); No development plan; reliance on social media (WA groups) (F:3) (Cκ:0,91); Lack of strategic focus on AI for flood mitigation (F:3) (Cκ: 0,91); Budget priorities not aligned with integrated app development (F:1) (Cκ: 0,96); Siloed/partial smart city development priorities (F:2) (Cκ: 0,92); Budget and policy constraints regarding predictive technology (F:3) (Cκ: 0,88); Sustainability at risk due to shifting budget priorities (F:2) (Cκ: 0,92); Technical agency priorities hinder "bottom-up" planning (F:4) (Cκ: 0,85); Bottom-up proposals clash with formal agency KPIs (F:7) (Cκ: 0,73).	Big Data Analytic; Digital Twin Implementation; Remote Sensing; Artificial Intelligence (AI); Applications & Websites; Data Input Completeness; Predictive Modeling Quality; Planning Vision & Mission with Collaborative Solution; Bottom-Up Planning; Decision Making.
[P2] Technological facilities and system adequacy (F = 32)	Automated operations remain reliant on manual field personnel (F:8) (Cκ:0,80); Absence of specialized technology for predictive data processing (F:2) (Cκ:0,92); Insufficient technological facilities for virtual city modeling (F:1) (Cκ:0,96); Minimal technological infrastructure to support AI implementation (F:5) (Cκ:0,81); Pumps and sluice gates lack full automation (require operators) (F:9) (Cκ:0,96); Absence of physical warning infrastructure (e.g., sirens) in residential areas (F:1) (Cκ:0,96); Limited technological facilities to ensure information accuracy (F:1) (Cκ:0,96); Insufficient automated monitoring in flood-prone zones (F:1) (Cκ:0,96); Absence of technology for automated sedimentation tracking (F:4) (Cκ:0,85).	Sensor Network Utilization; Big Data Analytics; Digital Twin Implementation; Artificial Intelligence (AI); Water Storage Automation; Warning Outreach; Warning Accuracy; Data Input Completeness; Drainage Infrastructure.
[P3] Data availability and	Data siloed across departments without centralized integration (F:3) (Cκ:0,92); Incomplete data variables and low accuracy for modeling (F:7) (Cκ:0,91); Available data	Big Data Analytics; Digital Twin Implementation;

Problem Typologies	Actual Problems	Related Variables
completeness (freq = 16)	variables lack the complexity required for AI (F:2) (Cκ:0,92); Severe lack of hydrological variables for predictive modeling (F:3) (Cκ:0,90); Lack of clear technical data regarding drainage sediment conditions (F:1) (Cκ:0,96).	Artificial Intelligence (AI); Data Input Completeness; Drainage Infrastructure.
[P4] System integration level (freq = 27)	Institutional silos hindering cross-agency sensor integration (F:1) (Cκ:0,96); Deficient inter-agency collaboration due to fragmented data systems (F:3) (Cκ:0,95); Public fatigue due to fragmented, agency-specific applications (F:1) (Cκ:0,96); Information not connected through a unified system (F:1) (Cκ:0,91); Poor data recording due to non-integrated cross-agency sensors (F:1) (Cκ:0,96); Lack of data processing systems for disaster forecasting (F:3) (Cκ:0,91); Fragmented data across agencies hindering model accuracy (F:6) (Cκ:0,80); Tertiary channels disconnected from main drainage systems (F:1) (Cκ:0,96); Integrated system unavailable due to pending development (F:2) (Cκ:0,92); Absence of integrated systems for medical service coordination (F:7) (Cκ:0,91); Inter-departmental silos and overlapping system functions (F:1) (Cκ:0,96).	Sensor Network Utilization; Big Data Analytics; Applications & Websites; Hydrological Information; Warning Accuracy; Data Input Completeness; Predictive Modeling Quality; Drainage Infrastructure; Emergency Apps; Medical Facilities; Governance & Planning.
[P5] Information and reporting mechanisms (freq = 13)	Monitoring and reporting heavily reliant on manual WhatsApp groups (F:5) (Cκ:0,85); Information flow delayed by intermediaries in WhatsApp groups (F:1) (Cκ:0,96); Inundation info dissemination relies solely on WhatsApp messages (F:2) (Cκ:0,98); Manual monitoring/reporting via WhatsApp groups (F:1) (Cκ:0,96); Reporting remains limited to social media (WhatsApp) (F:4) (Cκ:0,88).	Applications & Websites; Hydrological Information; Warning Outreach; Predictive Modeling Quality; Emergency Apps.
[P6] Human resource capacity and quality (freq = 17)	Human resources capacity unfamiliar with large-scale data management technologies (F:3) (Cκ:0,95); Scarcity of experts proficient in digital twin management (F:6) (Cκ:0,87); Human resources unpreparedness regarding unfamiliar	Big Data Analytics; Digital Twin Implementation; Artificial

Problem Typologies	Actual Problems	Related Variables
	AI-based technologies (F:7) (Cκ:0,81); Limited human resources capacity in predictive data management (F:1) (Cκ:0,96).	Intelligence (AI); Data Input Completeness.
[P7] Limited community participation in decision-making (freq = 15)	Community proposals ignored due to rigid agency priorities (F:4) (Cκ:0,85); Participation limited to issue identification, not decision-making (F:2) (Cκ:0,92); Public involvement lacks authority in the decision-making process (F:9) (Cκ:0,70).	Planning Vision & Mission with Collaborative Solution; Bottom-Up Planning; Decision Making.
[P8] Manual field monitoring (freq = 3)	Water level monitoring is still performed manually in the field (F:3) (Cκ:0,91).	Data Input Completeness
[P9] Limitations of training activities (freq = 6)	Irregular training; limited to neighborhood officials (F:6) (Cκ:0,84).	Disaster Education
[P10] Social conflicts (freq = 5)	Public complaints regarding nighttime pump operational noise (F:4) (Cκ:0,91); Unilateral drain closures causing local conflicts and flooding (F:1) (Cκ:0,99)	Water Storage Automation; Infrastructure Maintenance.

Source: Author, 2026

Findings reveal a critical misalignment between Surabaya's smart city ambitions and its empirical reality. Flood management remains highly path-dependent on fragmented policy directions and inadequate planning priorities (P1). This political volatility discourages investment and limits public participation to symbolic, top-down gestures. Furthermore, technological facilities and system adequacy (P2) lack sufficient automation for critical infrastructure. Consequently, this reliance on traditional, manual interventions exacerbates urban flood risks by delaying operational responses (Abd-Elaty et al., 2025). System integration levels (P4) present another major barrier due to isolated sectoral data. This fragmentation relies heavily on informal reporting mechanisms (P5), particularly WhatsApp, which causes communication bottlenecks (Khan et al., 2023; Yang et al., 2025). Additionally, limited data availability and completeness (P3) hinder the development of accurate predictive

models. These data deficits are worsened by persistent manual field monitoring (P8) that lacks automated sensor support. Non-technical impediments also significantly restrict the success of smart flood management systems. Specifically, human resource capacity (P6) struggles to adapt to advanced digital technologies like digital twins. This deficiency is compounded by irregular, localized training activities (P9) that lack long-term sustainability. Socially, community participation (P7) remains marginalized and is typically limited to simply reporting grievances. This exclusionary approach inevitably triggers social conflicts (P10) regarding uncoordinated and unilateral technical interventions.

Surabaya's smart flood management is operationally complex but remains heavily governed by centralized policy direction. The MICMAC mapping (**Table 4**) reveals an asymmetric structure anchored in policy coherence rather than distributed learning. Specifically, policy direction and planning priority (P1) emerges as the dominant first-order driver in the upper-left quadrant. This strategic variable dictates resource distribution, technological adoption, and inter-agency coordination across the entire governance chain. As observed in similar contexts, such policy coherence functions as the essential "governance spine" for smart urban performance (Choi & Song, 2022).

Surrounding this governance nucleus is a dense cluster of highly interdependent relay variables forming the operational core. Variables involving technological adequacy, data completeness, and system integration create a feedback-driven architecture where isolated deficiencies quickly destabilize the entire system. This configuration represents a relay-dominant subsystem that is functionally sophisticated but structurally fragmented and weakly synchronized (Godet, 2000). Furthermore, the complete absence of purely dependent variables indicates an interactive, non-linear network rather than a strict hierarchy. Such feedback-rich configurations are characteristic of adaptive governance systems that constantly balance top-down control with cross-sectoral responsiveness (Meadowcroft, 2011).

Conversely, community participation, training, and social conflicts currently reside in the excluded quadrant with merely peripheral systemic influence. However, these participatory and institutional learning factors hold latent potential to significantly enhance governance legitimacy and long-term effectiveness (Nordbeck et al., 2022; Hedelin, 2017). To bridge this gap, real-time IoT and digital application data must be integrated into community forums via citizen science mechanisms. Transforming digital systems from purely top-down monitoring tools into bottom-up feedback channels allows citizen-generated data to directly influence policy directions and budget allocations (P1, P7), enabling genuine co-decision-making (Mupfumira et al., 2024; Wessel et

al., 2021). Ultimately, this mapping delineates a three-tier hierarchy comprising a strategic governance core, an operational relay cluster, and a peripheral social substrate. This pronounced vertical asymmetry demonstrates that Surabaya is still transitioning from technocratic management toward a truly adaptive model. Achieving genuinely participatory smart flood management requires horizontally activating these social variables to complement the existing vertical coordination.

Table 4. Asymmetric Structure of Surabaya Flood Risk Management

Quadrant	Code	Obstacles & Problems	Driving Power	Dependence
I (Key Drivers)	P1	Policy direction and planning priority	4,85	2,10
	P2	Technological facilities and system adequacy	4,45	4,60
	P3	Data availability and completeness	4,35	4,70
II Relay Variables	P4	System integration level	4,25	4,50
	P5	Information and reporting mechanisms	4,10	4,40
	P6	Human resource capacity and quality	3,95	4,25
	P8	Manual field monitoring	3,90	4,00
III Depending Variables	-	-	-	-
IV Excluded Variables	P7	Limited community participation in decision-making	2,30	2,20
	P9	Limitations of training activities	2,15	2,05
	P10	Social conflicts	2,00	2,10

Source: Author, 2026

To address existing operational gaps, a strategic roadmap is structured across smart city and participatory dimensions. This framework couples technological integration with collaborative decision-making mechanisms to achieve an adaptive flood risk management system.

Table 5. Strategic Roadmap for Smart Participatory Flood Risk Reduction

Dimension	Baseline Gaps & Obstacles	Strategic Action & Target
Smart City	Fragmented agency apps, data silos, WA-based manual reporting, and low infrastructure automation.	Integrate digital platforms & automate infrastructure to establish a unified, real-time, and adaptive flood management system (<i>Target: Integrated System</i>)
Participatory	Consultation-only involvement, infrequent training, low HR capacity, and unmitigated social conflicts.	Institutionalize co-decision-making & citizen literacy to build an inclusive, community-driven mitigation framework (<i>Target: Inclusive Governance</i>).

CONCLUSION

Surabaya's smart flood risk management exhibits a critical structural imbalance, operating as a semi-closed, top-down system where social variables are weakly institutionalized despite strong policy drivers. MICMAC analysis indicates that policy direction is the primary systemic leverage point, dictating operational relay variables such as technological facilities, data completeness, system integration, and human resource capacities. Currently, public participation remains an excluded variable, largely consultative and peripheral to formal decision-making. This dynamic creates a governance framework that is technologically complex yet socially fragile, exposing a persistent gap between administrative capability and genuine citizen engagement.

To overcome these barriers, flood risk management must transition from a technology-driven approach to a learning-based, adaptive governance model. This shift demands strategic policy frameworks linking digital systems and inter-agency interoperability with inclusive participatory mandates. Institutionalizing co-production mechanisms and accessible digital platforms will activate latent social enablers and leverage community-based knowledge. Aligning these technological and social dimensions within a unified policy framework is crucial to transforming fragmented smart city initiatives into an inclusive, sustainable resilience system.

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