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The Role of Human Behavior in Urban Infrastructure Adaptation to Climate Change

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A B S T R A C T

Climate change brings increasingly complex pressures on urban infrastructure systems, including more frequent flooding events, increased temperature extremes, and disruptions in essential public services. This study examines the role of human behavior as a critical factor in strengthening infrastructure's adaptive capacity in response to such climatic dynamics. A mixed-methods approach was employed, combining urban residents' behavioral surveys, analysis of adaptive policy frameworks, and evaluation of critical infrastructure readiness. The findings indicate that risk perception, climate literacy levels, and individual decision-making patterns significantly influence the effectiveness of adaptation strategies. These results affirm that successful adaptation is not solely determined by technology or the physical design of infrastructure, but also by the extent to which communities internalize mitigation practices and adaptive responses. This article recommends multisectoral collaboration, particularly through coordinated policy implementation, community engagement programs, and integrated urban planning among government agencies, urban planners, and communities, to develop more behaviorally responsive adaptation schemes that enhance long-term urban resilience to climate change stressors.

1. INTRODUCTION

Climate change has increasingly asserted itself as a structural challenge that threatens the sustainability of urban life across the globe. Cities—centers of economic, social, and technological activity—are facing multilayered pressures due to the rising frequency of hydrometeorological disasters, increasing temperatures, and the growing vulnerability of public services (Kim & Lim, 2016) (Sitadevi, 2016). Infrastructure systems, many of which were designed based on historical climate patterns, are now required to adapt to far more unpredictable conditions (Mauree et al., 2019) (Purwanto, 2012). Amid this evolving landscape, technical aspects often receive more attention than human behavioral factors. Yet, in practice, decisions, habits, and the way communities respond to climate risks play a fundamental role in determining the success of infrastructure adaptation, particularly in influencing how infrastructure is used, maintained, and sustained over time.

Research on infrastructure adaptation has typically centered on physical enhancements—such as elevating drainage systems, deploying disaster-resilient technologies, or modernizing transportation networks (Anaraki & Manshour, 2025) (Frantzeskaki et al., 2019). These studies have provided detailed insights into engineering solutions and nature-based approaches) (however, they tend to treat social and behavioral dimensions as secondary or external factors rather than integral components of adaptation systems. However, a growing body of evidence suggests that structural efforts will be insufficient without the support of adaptive community behavior. For instance, flood control infrastructure becomes ineffective if residents continue to dispose of waste in waterways) (early warning systems lose their relevance if the public does not trust the information provided) (and significant investments in low-

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emission transportation are wasted if urban mobility patterns remain unchanged (Supar & Razak, n.d.) (Wulandari & Ikaputra, 2023). In other words, physical design and social behavior represent two inseparable components of a holistic adaptation ecosystem.

Human behavior in the context of climate adaptation extends beyond reactive measures during disasters (Ni'mah et al., 2021) (Syaddam, 2025). It encompasses how individuals perceive risk, their level of trust in public institutions, and the collective tendencies to care for the environment. Previous studies have discussed these aspects separately—either focusing on risk perception, governance, or community-based adaptation—but have not sufficiently integrated them into a unified framework linked to infrastructure performance. Misalignment between infrastructure capacity and community behavior can create new vulnerabilities. Conversely, proactive behavior and adequate climate literacy have the potential to extend the life span of infrastructure, enhance urban resilience, and reduce long-term disaster management costs. Understanding these behavioral patterns is thus a strategic step toward designing more comprehensive adaptation policies.

This study seeks to bridge the gap between technical and social approaches to urban infrastructure adaptation (Fuentes et al., 2025) (Situmorang et al., 2024). The key research gap addressed in this study lies in the limited integration of behavioral variables—such as risk perception, trust, and adaptive practices—into the evaluation of infrastructure effectiveness in existing literature. The primary objective is to identify how human behavior influences the effectiveness of adaptation strategies, which psychological and social factors shape public responses, and how these dynamics can be integrated into future infrastructure planning. By placing human behavior at the center of the analysis, this research aims to establish a new perspective: that urban resilience is not solely the product of advanced technologies, but also the result of collective awareness and a community's commitment to adapting to a changing climate reality, thereby offering a more integrative socio-technical approach to climate adaptation.

2. METHODS

This study applied a mixed-methods approach to examine the relationship between human behavior and the adaptive capacity of urban infrastructure in response to climate change. This approach was selected to integrate the strengths of quantitative analysis with an in-depth understanding of social dynamics that cannot be fully captured through numerical data alone. Specifically, the quantitative component was designed to measure behavioral patterns, climate literacy, and risk perception among residents, while the qualitative component explored motivations, barriers, and institutional factors affecting adaptive behavior. The overall methodology was structured through systematic stages, combining surveys, field observations, interviews, and policy analysis.

Research Design

The research design was developed in three interconnected phases:

1. Phase I – Exploration and Data Collection

   This phase involved collecting primary data through surveys and interviews, as well as secondary data such as policy documents and infrastructure reports. The rationale for this phase was to obtain a comprehensive understanding of both community behavior and institutional frameworks related to urban infrastructure adaptation.

2. Phase II – Analysis of Adaptive Behavior

   This stage focused on identifying patterns of public behavior, risk perception, and social values influencing individual responses to climate change. The analysis employed thematic coding for qualitative data and descriptive statistics for survey data to reveal behavioral trends.

3. Phase III – Data Integration and Infrastructure Adaptation Assessment

   Behavioral data were integrated with infrastructure assessments to evaluate compatibility, constraints, and potential for adaptation at the urban level. This integration involved correlation and regression analyses to test the link between human behavior and infrastructure performance.

Table 1.
Stages and Descriptions

Stage	Description
Identification of Climate Issues and Urban Vulnerabilities	Examining sources of climate vulnerability, disaster risks, and urban infrastructure conditions.

Stage	Description
Data Collection (Primary & Secondary)	• Surveys on public perceptions and behaviors • Stakeholder interviews • Infrastructure observation • Policy document analysis
Analysis of Community Adaptive Behavior	• Thematic coding • Analysis of motivations, barriers, and behavioral patterns
Testing the Behavior–Infrastructure Adaptation Link	• Correlation and regression tests • Mapping gaps between behavior and physical capacity
Synthesis & Urban Resilience Modeling	• Policy recommendations • Integration of behavioral insights into infrastructure design

A diagram was used to illustrate the logical flow from problem identification, data collection, and social analysis to integration into adaptive infrastructure evaluations.

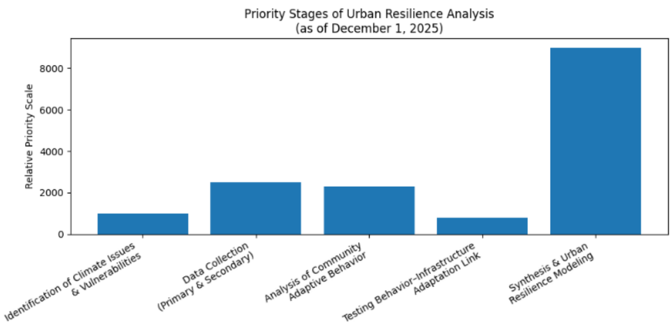

Figure 1. Distribution of Priority Stages in Urban Resilience Analysis Based on the Most Recent Data as of December 1, 2025

Research Location and Subjects

The study was conducted in urban areas highly vulnerable to extreme climate events (Anirwan, 2023) (Arifin et al., 2025). The research subjects included:

- Residents living in flood-prone areas,
- Officials from public service and disaster management agencies,
- Environmental community groups actively involved in disaster mitigation,
- Technical personnel involved in infrastructure planning and management.

Respondents were selected using purposive sampling to ensure relevance to the research focus.

Data Collection Techniques

a. Quantitative Survey

Administered to 300–500 respondents to measure:

- Climate risk perception,
- Adaptive habits,
- Climate literacy levels,
- Participation in environmental resilience programs.

A structured questionnaire was developed based on established adaptation and resilience frameworks, validated by experts, and pilot-tested prior to full administration. A five-point Likert scale was used to quantify attitudes and behaviors.

b. In-Depth Interviews

Conducted with 20–30 key informants using semi-structured techniques. The interviews explored decision-making processes, social constraints, trust in public institutions, and experiences during extreme climate events. Interview guides were developed to ensure consistency, and interviews were recorded, transcribed, and analyzed systematically.

c. Field Observation

Observations were carried out at critical infrastructure points, including drainage systems, early warning systems, and green public spaces (Bunawardi et al., 2016). Field notes documented behavioral interactions with infrastructure, maintenance practices, and any visible barriers to effectiveness.

d. Document Analysis

The study reviewed urban spatial plans, climate adaptation policies, and historical disaster records from the past 10–15 years. The purpose was to understand policy alignment and identify gaps between official plans and actual community behavior.

Data Analysis Techniques

a. Quantitative Analysis

Descriptive and inferential statistics were used to test the relationship between adaptive behaviors and infrastructure effectiveness. Analysis was conducted using SPSS or Stata. Correlation and regression analyses were performed to examine the influence of behavioral factors on infrastructure performance.

b. Qualitative Analysis

Interview transcripts were analyzed through thematic coding to identify themes such as risk perception, adaptation motivation, and social barriers (Harini et al., 2022) (Shabira & Giyarsih, 2021). Coding was performed iteratively to ensure reliability, and themes were triangulated with observational and document data.

c. Data Triangulation

Data from surveys, interviews, field observations, and documents were triangulated to enhance the robustness and reliability of findings. Triangulation ensured that conclusions were supported across multiple sources of evidence.

Research Ethics and Validity

This research upheld strict ethical standards, including:

- Informed consent from participants,
- Data confidentiality,
- Use of data solely for academic purposes.

Validity was reinforced through reliability testing of survey instruments and expert validation of tools and findings. Additionally, qualitative data were cross-checked by multiple coders to reduce bias and ensure credibility.

3. RESULT AND DISCUSSION

Overview of Adaptive Behavior in Urban Communities

Survey results from respondents living in climate-vulnerable areas indicate that adaptive behavior in urban communities is still in a transitional phase. While most respondents recognize that climate change affects their daily lives, the implementation of adaptive behavior remains inconsistent. Quantitative findings show that 78% of respondents acknowledged the recurring risk of flooding, yet only 42% reported modifying their waste disposal habits or improving drainage near their homes. Additionally, only 36% of respondents actively participated in community-based environmental programs, indicating limited collective engagement. This reveals a critical gap between knowledge and tangible action—a central issue in behavior-based adaptation studies.

Interviews with community leaders further confirmed that public responses are often reactive rather than preventive. Most residents tend to act only when threats escalate, such as when river levels rise or flooding begins to encroach on residential areas. This phenomenon highlights that infrastructure adaptation without collective behavioral support leads to limited effectiveness, especially in areas with aging or overloaded infrastructure systems. This is particularly critical in coastal urban areas where spatial limitations and sea level rise create multi-hazard scenarios, requiring context-specific adaptation strategies (KHAIRUNNIS, 2019).

Infrastructure Effectiveness and the Influence of User Behavior

Field observations showed that the declining functionality of public infrastructure—particularly drainage systems, evacuation routes, and green open spaces—is not solely due to technical factors but also results from user behavior that deviates from the intended design purpose. Observational data indicate that approximately 65% of drainage points in high-density areas were partially obstructed by solid waste, reducing their hydraulic capacity.

1. Drainage Systems and Resident Behavior

In areas experiencing annual floods, sedimentation from domestic waste was identified as the primary cause of reduced drainage capacity. Technically, drainage systems at several points were adequately designed to withstand moderate rainfall. However, their effectiveness significantly declined due to the habitual disposal of household waste and sewage into the drains. Survey data further show that more than 50% of respondents admitted to occasionally disposing of waste in drainage channels, particularly in informal settlements.

Interviews with municipal sanitation workers revealed that maintenance frequency is highest in zones with dense informal activity, especially in markets and densely populated settlements. One sanitation officer (SW-02) explained, "We clean the same drainage points repeatedly, but waste keeps accumulating because residents continue to dispose garbage improperly."

In this context, individual behavior demonstrably shortens infrastructure lifespan. These findings underscore that government investment in physical infrastructure must be accompanied by behavioral change management within communities.

2. Early Warning Systems and Public Trust

Although early warning systems had been installed at several strategic locations, only a small portion of the community followed evacuation protocols consistently. Survey data showed that only 39% of respondents expressed full trust in information disseminated by disaster management agencies, while 27% expressed partial trust and 34% indicated low or no trust.

Distrust stemmed from several factors:

- Previous experiences with inaccurate warnings,
- Perceptions of disasters as routine and tolerable events,
- Beliefs that evacuation is overly burdensome.

This was reinforced by interview data. One resident (R-11) noted, "Sometimes the warnings are issued, but nothing happens, so people start ignoring them."

These findings highlight that technology-driven adaptation can only succeed when supported by strong social legitimacy and acceptance. In other words, information infrastructure must be underpinned by a foundation of public trust to function optimally.

Social Dynamics and Motivational Patterns in Adaptive Behavior

Qualitative analysis revealed that community adaptive behavior is influenced by three main dimensions: personal experience, social norms, and institutional support. These dimensions were consistently identified across interview coding and supported by survey indicators measuring behavioral motivation.

1. Personal Experience as a Catalyst for Adaptation

Respondents who had previously suffered financial losses or asset damage due to flooding showed a greater tendency to engage in adaptive actions. Quantitative results indicate that respondents with prior flood experience were 1.8 times more likely to adopt adaptive practices compared to those without such experience.

They were more likely to prepare emergency kits, elevate their homes, or participate in mitigation training. One respondent (R-07) stated, "After my house was flooded last year, I started raising the floor level and storing emergency supplies." These empirical experiences shaped more realistic risk perceptions and promoted sustained behavioral change.

2. Social Norms and Environmental Collectivism

In certain residential areas, adaptive practices were influenced not only by individual decisions but also by prevailing community norms. Survey results show that areas with active community organizations reported up to 60% higher participation in environmental programs compared to areas without such groups.

Neighborhoods with active civic groups—such as waste bank managers or disaster preparedness teams—demonstrated stronger diffusion of adaptive behaviors. Conversely, in areas with low social cohesion, such behaviors struggled to gain traction due to the absence of collective support.

3. Institutional Support and Administrative Barriers

Interviews with local government officials revealed that bureaucratic obstacles—such as budget constraints, regulatory overlaps, and weak intersectoral coordination—hampered the speed of government response.

One official (GO-04) stated, "Coordination between agencies is still fragmented, which delays implementation of adaptation programs." Communities perceiving government services as slow or inconsistent were more likely to become apathetic and disengaged from adaptation initiatives.

4. Behavioral Linkages to Infrastructure Performance

Regression analysis showed a significant relationship between the intensity of community adaptive behavior and the functional effectiveness of infrastructure in urban areas (Li et al., 2023) (Mehryar et al., 2022). Specifically, the model indicates a positive correlation ($\beta = 0.62$, $p < 0.01$) between adaptive behavior scores and infrastructure performance indices.

Locations where adaptive behaviors were highly practiced—such as regular independent drain cleaning, neighborhood coordination, and participation in resilience training—experienced fewer infrastructure failures during extreme climate events. In contrast, areas with lower levels of adaptive behavior reported more frequent operational disruptions, including clogged waterways, damaged public facilities, and delayed evacuations. These findings suggest that behavior is not merely a supporting factor but a determinant variable in the overall strength of urban adaptation.

5. Synthesis: Integrating Behavior into Infrastructure Planning

The study's findings demonstrate that infrastructure adaptation can no longer be understood solely as a technical process reliant on physical engineering. Adaptation must be framed as the result of interaction between human behavior, public policy, and technical design. Therefore, integrating these three elements is essential for building genuinely resilient cities. In fact, spatial adaptation models that consider climatic zoning and urban morphology have shown promise in cities like Malang (Subagiyo et al., 2019).

The main implications of the research are as follows:

- Infrastructure requires behavioral support to function optimally. For example, successful implementation of climate adaptation through water sanitation and conservation has been demonstrated in local initiatives in Surabaya (Wirianto & Cundaningsih, 2025). Without community participation, infrastructure risks losing its effectiveness far sooner than its intended design life.
- Public trust is an adaptation asset. Early warning technologies, evacuation protocols, and regulations are only effective when trusted and followed.
- Social norms can accelerate adaptation. Strong communities can disseminate adaptive practices more widely through social influence mechanisms.
- Urban planning must incorporate social perspectives from the outset (Lestari, 2024) (Olanda, 2024) (Sari et al., 2025). Adaptive infrastructure is not merely about pipe diameters or levee heights, but about how people interact with and utilize these systems.

4. CONCLUSION

This study confirms that human behavior plays a decisive role in determining the effectiveness of urban infrastructure adaptation to climate change. The findings explicitly show that although a majority of urban residents are aware of climate risks, only a limited proportion translate this awareness into consistent adaptive actions. This gap between knowledge and practice directly affects infrastructure performance, particularly in systems such as drainage and early warning mechanisms.

The research further identifies that adaptive behavior is significantly shaped by four main factors: trust in government, prior disaster experience, access to information, and the strength of social networks. Communities with higher levels of trust and stronger collective engagement demonstrate more consistent adaptive practices, which in turn contribute to better infrastructure functionality and reduced disruption during climate events. Conversely, low trust, weak participation, and negative institutional experiences tend to hinder adaptation processes.

Importantly, the results reveal a measurable relationship between behavioral intensity and infrastructure effectiveness, indicating that behavior is not merely a supporting element but a key determinant in urban adaptation success. This finding directly answers the research objective by demonstrating that infrastructure resilience is co-produced by technical capacity and community behavior.

Based on these findings, this study proposes that urban resilience should be approached through an integrated framework that combines infrastructure design, policy support, and behavioral transformation. Adaptation strategies must therefore incorporate community-based interventions, including risk communication, public engagement, and behavioral change programs, to ensure long-term effectiveness.

In conclusion, the success of climate adaptation in urban areas depends not only on the quality of infrastructure but also on the readiness and responsiveness of the communities that use it. Future research is recommended to expand the scope of analysis across different urban contexts and to further quantify the impact of behavioral interventions on infrastructure resilience outcomes.

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