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A Study on Examining Flood Resilience in Asia and Developing Assessment Indicators of South Korea

아시아지역 홍수 회복력 분석 및 국내 평가지표 개발 연구

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Foreword

Around the world, climate change and extreme weather events are causing damage beyond the scale of previously experienced disasters. As flooding becomes more frequent and less predictable, flood prevention and management (disaster resilience) is becoming increasingly important. This makes it necessary to develop strategies not only for disaster prevention but also for managing the increasing risk and costs of disasters and disaster recovery.

The present study developed evaluation indicators for strengthening flood resilience in Korea, prioritized them through a survey of experts, conducted correlation and importance analysis among factors, and evaluated flood resilience indicators in special disaster areas.

Furthermore, this study is timely as there exists a pressing need for response measures to flood and typhoon disasters, especially in Asia-Pacific countries. In establishing evaluation indicators and analyzing flood resilience policies in major countries, the report is expected to serve as an effective basis for determining directions for domestic flood resilience policy. In addition, project lead Dr. Jung, Kichul stayed at the SEI (Stockholm Environment Institute) for two months, laying the foundation for continued global cooperation in water resources management.

Finally, I am also very grateful to Dr. Gyeong-Tak Kim at the Korea Institute of Civil Engineering and Building Technology (KICT), Facility Administrator Jihwan Kim at the Ministry of Environment (MoE), Prof. Daeryong Park at Konkuk University, and Dr. Byungkuk Lee, Dr. Hwi-chul Jung, and Dr. Jinhee Lee at KEI for their expert opinions and advice.

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Executive Summary

1. Introduction

❑ Flood risks under climate change

- Climate change is no longer a distant threat, but a present-day reality demanding urgent action.
- While the Earth's climate has always fluctuated, the current pace of change is unprecedented.
- Across Asia, warming exacerbates flood risks, weaving a complex web of challenges due to the region's diverse geography and climate.
- Evaluating flood resilience is now critical to navigating these challenges and mitigating the impacts of climate change on communities across the region.

❑ Objectives of the study

- The key objectives of the present work are twofold. First, we investigate flood related projects, focusing on an analysis of flood resilience in Asia. Second, we build a suite of flood resilience indices (indicators) for a selection of Asian countries to describe their fundamental properties.
- In addition, we develop a suite of flood resilience indices based on Analytic Hierarchy Process (AHP) analysis.
- We then employ these indices to assess the recovery capabilities of local governments in areas prone to floods.

❑ Concept and content

- Flood resilience can be defined as the ability to recover from flood events. Resilience mitigates impacts on communities and infrastructure before, during, and after a flood.
- In the present work, we describe the four fundamental components of flood

resilience: Redundancy, Robustness, Rapidity, and Resourcefulness. We term this the 4R approach.

- Strengthening flood resilience capacity can enable communities to mitigate and recover from flood damage and minimize the damage of future floods.
- The report progresses as follows: First, we propose a definition for flood resilience. Second, we review the literature on existing approaches to flood resilience in Asia. Third, we describe a suite of indicators we built to assess flood resilience. Fourth, we test and evaluate the indices through real-world applications.

2. Analysis of Flood Resilience in Asia

❑ Current trends and active projects

- Public interest in floods remained consistent throughout the study period (January 2011 to July 2023), but we observed an increasing focus on “resilience” and “flood resilience”.
- To broaden our understanding of flood resilience, this report explores two in-depth case studies.

❑ Case study 1: Community flood resilience

- This study by the Asian Development Bank (ADB) explores community flood resilience in Asia.
- To evaluate flood resilience in the communities, the ADB used a grading rubric to estimate the financial recovery period and assess socioeconomic conditions in flood-stricken areas.
- The work found that urban areas demonstrated higher flood resilience scores than rural and peri-urban communities.

❑ Case study 2: Scale-based flood resilience index

- Here, we introduce a flood resilience index developed to systematically quantify and evaluate factors affecting urban and rural systems during and after floods.

- The methods used to evaluate flood resilience at the building, block, and city scale differ depending on the area under observation.
- We demonstrate that flood resilience is not a singular characteristic but rather a combination of system characteristics and the nature of the flood event.

❑ Implications

- From the case studies, we glean valuable insight into flood resilience that can be used to establish a robust foundation for the comprehensive evaluation of flood resilience across Asia.
- Furthermore, by leveraging these insights—particularly those regarding Flood Resilience Index (FRI) strategies—we can inform effective policymaking in Korea.

3. Assessment of Flood Resilience in Selected Asian Countries

❑ Flood-prone countries and urban resilience

- This section singles out a selection of flood-prone countries in South and Southeast Asia for a specific flood resilience analysis.
- The period from 2010 to 2023 saw multiple devastating floods in Indonesia, China, India, Thailand, Philippines, Bangladesh, Nepal, and Cambodia, among other countries.
- In response to these disasters, various policy programs have been implemented to promote resilience. These measures serve as a well of inspiration for new policy instruments that local, provincial, and national governments might develop to address acute shocks and stressors constraining development.

❑ Case study: Flood resilience assessment in selected countries

- In this section, we explore various approaches to flood resilience assessment in selected Asian countries.
- Founded by the Zurich Resilience Alliance in 2013, the Flood Resilience Measurement for Community (FRMC) framework has been implemented in a handful of regions in Nepal to assess flood resilience and identify areas for improvements.

- An indicator-based approach using household surveys revealed significant differences in flood resilience between formal and informal settlements.
- Following the massive flood of Thailand in 2011, we evaluate that the country's national flood plans and score its flood resilience characteristics based on the indicators of Sustainable Development Goals (SDG) 11 and 13.
- In 2022, the World Bank approved a USD 400 million project called the National Urban Flood Resilience Project (NUFReP) in Indonesia to reduce flood risks by enhancing national and municipal capacity and targeting investments in integrated urban flood risk management.
- The Asian Development Bank (ADB) recently approved a 303 million USD loan to the Philippines to enhance flood resilience. The monies are to be used to reduce the risk of floods, mitigate climate change, and protect people and their livelihoods in three major river basins.

❑ Governance of floods and disasters

- Governments across the region are changing their approach to disaster management. Formerly, the dominant paradigm revolved around disaster relief. But increasingly governments are increasingly adopting a more proactive stance focuses on disaster risk reduction (DRR). This holistic approach encompasses prevention, mitigation, preparedness, response, relief, reconstruction, and rehabilitation.

❑ SWOT analysis: Strategic assessment

- Here, we pinpoint the strengths, weaknesses, opportunities, and threats (SWOT) of regional DRR policies through an exploration of existing national DRR plans and policies as well as independent studies and projects.
- Our analysis demonstrates that collaboration is key. Sound decision making requires accurate risk assessments, effective planning, and the allocation of sufficient resources from multilateral institutions to strengthen flood resilience.

4. Building National Flood Resilience Indicators

❑ Selection of flood resilience indicators

- In this section, we detail the process of developing national flood resilience indicators. Candidate indicators were identified and gathered from previous studies.
- Indicators focused on flood vulnerability were excluded, as flood resilience emphasizes rapid recovery and prevention after flood damage.
- Following a four-stage selection process using the aforementioned 4R approach, we derived a set of 20 flood resilience indicators for analysis.

❑ Pilot area selection

- Typhoon Hinnamnor and localized heavy rainfall caused major damage across Korea in 2022. The government declared 21 regions across the country as special disaster areas to facilitate the process of damage recovery.
- As of June 2023 — one year after the typhoon, heavy rains, and flooding events — the only areas to completely recover from the floods were the Seoul districts of Dongjak-gu, Gwanak-gu, and Yeongdeungpo-gu.
- All municipalities and administrative areas were designated as special disaster areas on the same day and provided with grants and subsidies from the local, provincial, and the national governments to facilitate recovery. Despite this uniform support, the affected areas exhibited significant variation in the speed of recovery.
- To determine the drivers of this variation, we target the designated areas from 2022 for analysis, identifying the most relevant indicators to help us understand the key differences between the areas that recovered the fastest and those that recovered the slowest.

❑ Data collection

- For the analysis, we sought to employ reliable data made publicly available by various government agencies and research institutes. When such sources were not available, we requested necessary information directly from the relevant municipalities through Korea's public information disclosure portal.

5. Evaluating and Strengthening Flood Resilience

❏ Analysis of flood resilience indicators

- We assessed the suitability of the 20 selected flood resilience indicators using Statistical Package for the Social Sciences Software (SPSS).
- We performed a multicollinearity analysis to examine correlations between the selected 4R indicators. The analysis confirmed no multicollinearity issues (tolerances greater than or equal to 0.100 and VIF less than 10) in all cases. This shows that the indicators may be used without redundancy in the regression model.

❏ Multicollinearity and AHP analysis

- We employed the Analytic Hierarchy Process (AHP) tool to determine the relative importance of each flood resilience indicator.
- An expert survey was conducted from December 11 to December 15 targeting 20 experts and professionals active in industry, government, think tanks, and academia.
- Our analysis of the survey results revealed how the experts weighed the importance of the 4Rs. Robustness was ranked highest, with a score of 0.46. Rapidity was ranked second, with a score of 0.22. Redundancy was ranked third, scoring 0.17. Resourcefulness came in last, scoring 0.16.

❏ Directions for improvement

- Of the 20 flood resilience indicators, river banks ranked highest in overall importance (16.61%). River banks were followed by sanitation (9.61%) and river area ratio (9.32%).
- River bank improvement emerged as the most critical factor within the Robustness component, emphasizing the importance of mitigating flood damage

and protecting river ecosystems. This is because damaged river banks not only cause direct harm to people and property but also disrupt river health.

- Within the Rapidity component, medical services were identified as the most crucial indicator. This highlights the need for readily available medical care during flood emergencies, especially given the increasing frequency of such events.
- Within the Resourcefulness component, fiscal self-reliance of municipalities was shown to be the most impactful indicator. Producing accurate assessments of the state of local governments' flood management finances can enhance financial independence and strengthen flood response measures.
- For the Redundancy component, the analysis suggests that significant efforts should be directed toward improving drainage facilities. Relevant authorities should endeavor to understand the state of their existing drainage infrastructure and implement proper maintenance to maximize drainage capacity.

6. Conclusion

- Recent studies highlight the importance of pre-flood preparation. Such preparation includes the identification of flood-prone areas issuing regular warning notifications to raise community awareness.
- Our analysis showed that Southeast Asia and South Asia are the most flood-prone regions in greater Asia.
- Based on our SWOT analysis of flood resilience policies, we find that collaboration, risk-informed planning, investment from multilateral institutions are key factors that contribute to enhanced flood resilience and better national plans and policies in affected countries.
- We assess flood resilience in the areas under study using flood resilience indices based on the 4R framework.
- We perform an AHP analysis to determine the relative importance of each indicator and conduct a multicollinearity analysis to assess the suitability of the selected indicators.

- We find that establishing a national flood resilience indicator framework in South Korea can provide a strategic foundation for flood hazard management. This approach can lead to the development of healthier communities and more resilient environments across the country.

Keywords: Flood Resilience, Assessment Indicators, Redundancy, Robustness, Rapidity, Resourcefulness

Table of Contents

List of Tables

List of Figures

Abbreviations and Acronyms

ADB	Asian Development Bank
AHP	Analytic Hierarchy Process
AWMI	Aggregate Weighted Mean Index
BMA	Bangkok Metropolitan Administration
CWC	Central Water Commission
FGDs	Focus Group Discussions
FRI	Flood Resilience Index
FRMC	Flood Resilience Measurement for Community
GDP	Gross Domestic Product
GFCC	Ganga Flood Control Commission
GRDP	Gross Regional Domestic Product
IFRC	International Federation of Red Cross
IPCC	Intergovernmental Panel on Climate Change
KIIs	Key Informant Interviews
MOIS	Ministry of the Interior and Safety
NDMA	National Disaster Management Agency
NDMA	National Disaster Management Authority
NUFReP	National Urban Flood Resilience Project
PCA	Principal Component Analysis
PWD	Public Works Department
SDGs	Sustainable Development Goals
SFM	Sendai Framework Monitor
SSP	Shared Socioeconomic Pathway
WMO	World Meteorological Organization

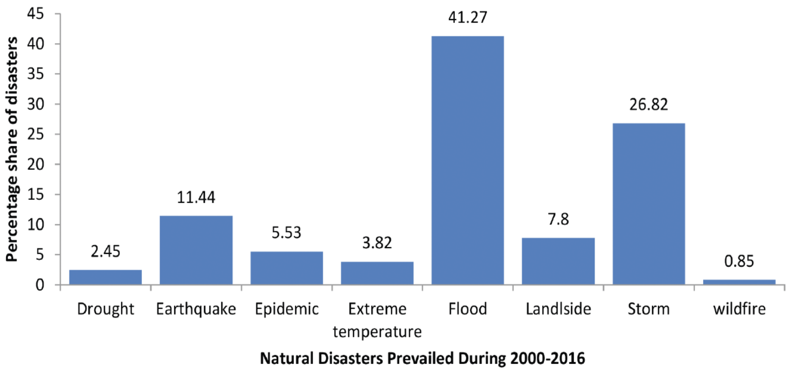
1 Introduction

1.1 Flood risks under climate change

Climate change is no longer a distant threat, but an urgent matter requiring immediate attention. Climate change can be defined as the prolonged periods of change in Earth's climate influenced by natural phenomena including the sun, volcanism, and human activities such as fossil fuel consumption (Santos and Bakhshoodeh, 2021, pp.8-219). While Earth's climate has always fluctuated, we are now experiencing warming at an unprecendented pace(Diffenbaugh and Field, 2013; Snyder, 2016). One expected consequence of climate change is an increase in the frequency and intensity of precipitation, which may lead to more frequent and severe floods (Hirabayashi et al., 2021a).

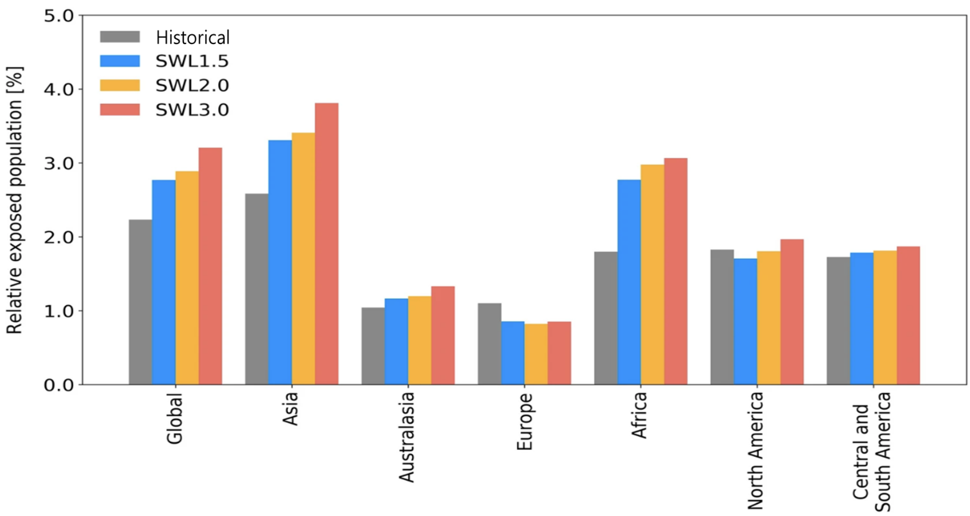
Across Asia, floods are one of the most prominent natural disasters (see Figure 1). From 2000 to 2016, there were 2,692 natural disasters recorded across Asia. These included droughts, earthquakes, epidemics, heat waves, floods, landslides, and wildfires. Of these, 41.27% of them were floods or disasters associated with floods; 26.82% of disasters were storm-related. Note the substantial difference in frequencies of floods and storms; this tells us that flooding poses a major risk across Asia. Furthermore, flood risks are only expected to worsen due to the impacts of the changing climate. In its Sixth Assessment Report (AR6) (IPCC, 2022) the Intergovernmental Panel on Climate Change (IPCC) shows strong evidence for a rise in flood-related disasters in the coming decades, at a high level of confidence. The findings of Hirabayashi et al. (2021b) support this, as the study found an increase in the proportion of the population exposed to heightened flood risks under Shared Socioeconomic Pathway (SSP) 585 scenario (SSP585), especially in Asia and Africa (see Figure 2). Under the SSP585 scenario, warming of 3°C translates to a 1.5-fold increase in the population exposed to flood damage compared to the 1971-2000 baseline. This estimate is based on the projection of more-frequent flood events in Asia. In essence, Asia faces a significant escalation in flood risk.

Figure 1. Asia's share of natural disasters, 2000-2016



Source: Adapted from Ashraf et al. (2017), p.181.

Figure 2. Potential population exposed to flood risks during baseline period and under climate change scenarios (SSP585)



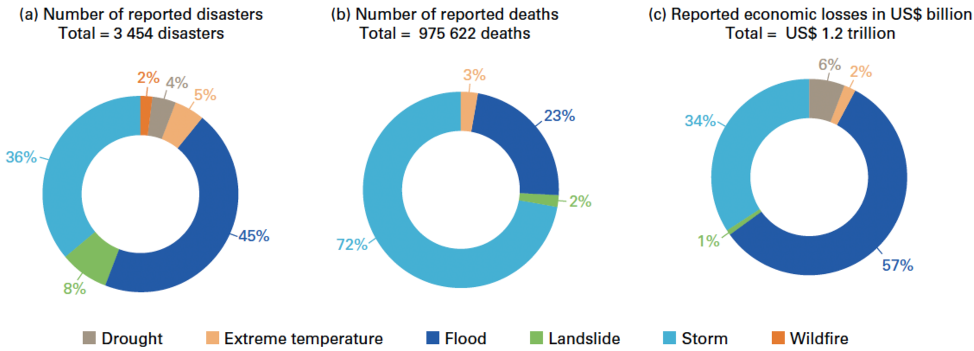
Note: Specific warnings for 1.5°C, 2.0°C, and 3.0°C of warming are represented in blue, orange, and red, respectively. Historical baseline is graphed in gray.
Source: Adapted from Hirabayashi et al. (2021b), p.3740.

Global warming exacerbates flood risks across Asia, creating a complex web of intertwined challenges owing to the region's diverse geography and climatic conditions. In the Ganges-Brahmaputra delta, one of the world's most densely populated and vulnerable regions, elevated temperatures are contributing to increased glacial melt and intensified monsoons. Combined, these phenomena contribute to increased riverine flooding (Gain et al., 2022). In the arid regions of Central Asia, which include the countries of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, greater flood risks are anticipated due to higher levels of total precipitation and more concentrated precipitation patterns, which result in more frequent flash flood events (Yao et al., 2021, pp.125-760). The coastal areas of Southeast Asia, which include the countries of Thailand and Vietnam and the Mekong Delta region are experiencing amplified flood frequency due to rising sea levels and shorter intervals between extreme events such as tropical cyclones (Braun et al., 2020; Griggs and Reguero, 2021; Tran et al., 2022). The combination of regional characteristics and rising temperatures make Asia especially flood-prone, and highlights the importance of evaluating flood resilience to address the complex challenges of climate change.

1.2 Objectives of the study

In Asia, flooding has caused significant recurring damage, with prolonged impacts on communities and economic losses incurred across the continent. Extreme precipitation has become more frequent and severe, floods have become more intense and more common (WMO, 2023). Urbanization, deforestation, and outdated or obsolete infrastructure have made the region more vulnerable to flooding these regions. According to a 2023 report by the World Meteorological Organization (WMO), floods accounted for 45% of nearly 3,500 reported disasters in Asia, and were responsible for 23% of all disaster-related casualties. The same report found that flooding caused 57% of total estimated economic losses (equivalent to USD 1.2 trillion) over the period from 1970 to 2019 (see Figure 3). These measures highlight the severity of flood impacts, and illustrate how floods are some of the most widespread and impactful disasters in Asia.

Figure 3. Disasters in Asia: Reported deaths and economic losses, 1970-2019



Source: Adapted from WMO (2023), p.27.

Table 1 summarizes major flood events in Asia that resulted in financial losses exceeding USD 10 billion US Dollars from 2011 to 2022 based on data from the Emergency Event Database (EM-DAT) (https://public.emdat.be/data). From August 5, 2011, to January 4, 2012, monsoon rains and tropical storms caused widespread damage across Southeast Asia, particularly in Thailand. This damage resulted in staggering financial losses estimated at USD 52 billion and claimed 813 lives. In China, torrential rains from July 21 to July 24, 2012 led to losses valued at USD 10.1 billion. More extreme rain events from June 28 to July 13, 2016 led to financial losses of USD 26.8 billion and 289 casualties. More recently, torrential rains from May 21 to July 30, 2020 caused economic losses of USD 10.1 billion and 151 deaths, and the tropical cyclone Cempaka caused USD 17.8 billion worth of damage and killed 352. In India, monsoon rains in September 2014 generated substantial losses of USD 19.7 billion and claimed 298 lives. From June 14 to September 14, 2022, strong monsoon rains in Pakistan caused USD 15 billion worth of damage and an astonishing loss of life, with 1,739 killed. Finally, tropical storm Prapiroon hit Japan from June 29 to July 8, 2018, causing losses of USD 11 billion and 246 deaths.

Table 1. Asian floods causing damages exceeding USD 10 billion, 2011–2022

Date	Region	Country	Origin	Financial Losses (US Dollars)	Deaths
August 5, 2011 - January 4, 2012.	South-Eastern Asia	Thailand	Monsoonal rains, tropical storms	52.0 billion	813
June 28, 2016 – July 13, 2016	Eastern Asia	China	Heavy rains	26.8 billion	289
September 2014 - September 2014 -	Southern Asia	India	Monsoonal rain	19.7 billion	298
May 21, 2020 – July 30, 2020	Eastern Asia	China	Torrential rains	19.2 billion	280
June 1st, 2021 - August 30, 2021	Eastern Asia	China	Tropical cyclone 'Cempaka'	17.8 billion	352
June 14, 2022 – September 14, 2022	Southern Asia	Pakistan	Monsoon rain	15.0 billion	1,739
July 14, 2019 – September 30, 2019	Southern Asia	India	Monsoon rain	11.4 billion	1,900
June 29, 2018 – July 8, 2018	Eastern Asia	Japan	Tropical Storm Prapiroon	11.0 billion	246
July 21, 2012 – July 24, 2012	Eastern Asia	China	Torrential rains	10.1 billion	151

Source: EM-DAT Documentation, "Hydrological Hazards", Accessed on 13 August 2023.

For this project, we thoroughly investigate flood resilience in Asia. The study has several key objectives.

First, we analyze existing flood control projects across Asia, focusing on their contributions to regional flood resilience. Second, we examine flood resilience indicators used in select Asian countries and evaluate their strengths and limitations. Third, we employ the AHP process described earlier to develop a flood resilience index specifically for South Korea. We expect that this index will be instrumental in evaluating the capacity of local governments in flood-prone areas to implement effective recovery and prevention efforts, especially in the context of climate change adaptation.

We find that flood impacts vary in severity based largely on any given nation's level of economic and technological development. China and Japan, for example, tend to experience significant losses during floods due to their large urban conurbations, industries, and modern infrastructure. These assets are vulnerable to flood damage and furthermore are highly valuable, leading to substantial economic losses when impaired. In addition, the presence of cities and industrial zones in flood-prone areas exacerbates the issue.

In contrast, developing countries such as India and Pakistan often suffer far more casualties from floods. This vulnerability stems from a combination of several factors, most importantly: dense populations, inadequate infrastructure, and poor drainage systems that struggle with severe rainfall and flooding. These regions are also especially susceptible to sudden and intense flooding due to their sheer geography, highlighting a critical need to enhance post-recovery capacity.

Finally, climate change is expected to increase the frequency and intensity of floods, particularly in developing countries. Consequently, it significantly hightens the risk to lives and livelihoods across the region. By developing flood resilience indicators that take climate-driven risks into account, this study aims to enhance climate change adaptation capacity and climate change response capacity across Asia. The study provides valuable insights into key aspects of flood disasters, with a focus on exploring and refining flood resilience indicators.

See Figure 4 for a visual representation of the study's key objectives.

Figure 4. Research objectives

Objectives of the study	
1	Investigation of flood related projects with analysis especially for flood resilience in Asia
2	Determination of flood resilience indices (indicators) with their properties in selected countries of Asia
3	Development of the flood resilience indices based on AHP (Analytic Hierarchy Process) analysis for South Korea
4	Evaluation of the developed indices for recovery capability from flood damages in difference local governments of South Korea

Source: The authors.

1.3 Concept and content

Flood resilience can be defined as the ability of a community to bounce back from flood events and minimize their potential impacts on people and infrastructure before, during, and after the disaster. This approach offers a novel perspective on risk management. Traditionally, flood control has been about flood resistance, which emphasizes the use of infrastructure such as dams and levees to mitigate damage.[1] However, flood resilience constitutes a broader strategy, as it aims to prevent both ecological and urban systems from ever reaching the tipping point where post flood recovery is impossible (Batica, 2015). In other words, while flood resistance focuses on mitigating damage through structural measures, flood resilience encompasses prevention, recovery, and adaptation. It acknowledges the inevitability of some floods and focuses on bouncing back and adaptation. The literature on flood resilience highlights several key strategies. They include raising public awareness of flood risk in urban areas, implementing regulations that improve storage and drainage capacity in new developments, and pre-allocating resources such as aid, shelter, insurance, and evacuation plans prior to flood events (see Table 2).

Table 2. Four measures for quantifying flood resilience in urban systems

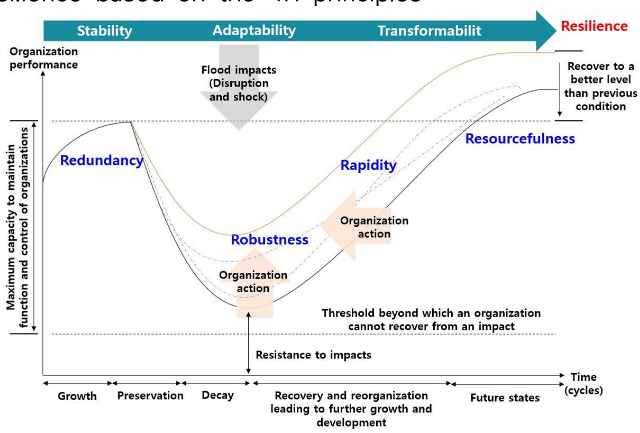
Capacity building of human resources	Land use control	Flood preparedness	Contingency measures
- Flood maps (Inundation and risk) - Informative material (brochures, public presentations, internet portals, etc.) - Education - Communication	- Spatial planning - Flood risk-adapted land use - Building regulations	- Flood resistant buildings - Wet-proofing - Dry-proofing	- Financial preparedness - Insurance of residual risk - Reserve funds - Emergency response: evacuation and rescue plans - Forecasting and warning services - Control emergency operations - Provision of emergency response staff
- Face-to-face learning - Web-based learning - Training - Collaborative platforms	- Building codes - Zoning ordinances	- Flood action plan (local scale) - Infrastructure maintenance	- Emergency infrastructure - Allocation of temporary contaminant structures - Telecommunications network - Transportation facilities - Recovery-disaster recovery plans, pecuniary provisions of government

Source: Adapted from Batica (2015), p.38.

1) Zevenbergen et al. (2020), pp.2012-2019; Kuang and Liao (2022), p.6; Khatooni et al. (2023), pp.2-41.

In the present work, we describe the basic characteristics of flood resilience using the 4R (Redundancy, Robustness, Rapidity, and Resourcefulness) framework first introduced in Keating et al. (2017) and Kim et al. (2016) (See Figure 5).

Figure 5. Flood resilience based on the 4R principles



Source: Adapted from Keating et al. (2017); Choi et al. (2021), p.7.

Figure 5 illustrates a model of flood resilience built on the four 4R principles. These principles focus on a community's ability to minimize current risks, mitigate potential future risks, and enhance community safety before a flood event even occurs. Strengthening flood resilience capacity enables communities not only to mitigate and recover from flood damage, but also prevent future losses.

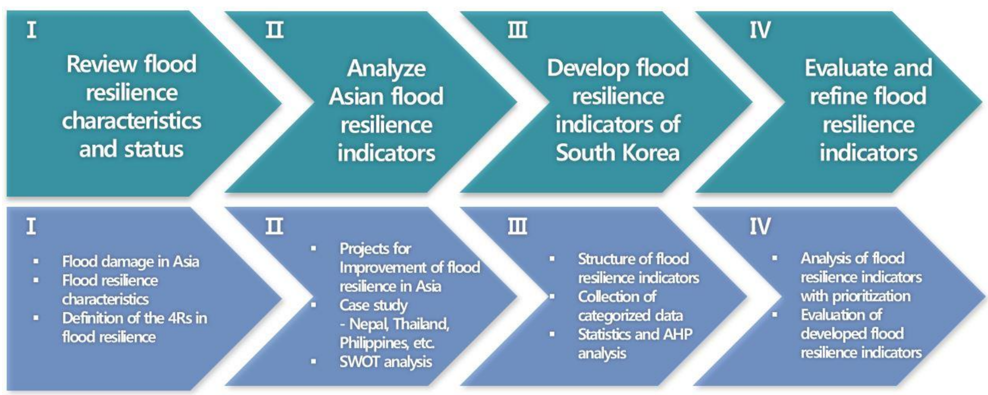
Flood resilience adaptation strategies focus on maintaining the functions and protective mechanisms of key systems. For the purposes of this study, we are particularly interested in variables that assess the prevention and recovery processes. Table 3 delves deeper into the 4Rs, providing definitions and their corresponding stages in a flood risk management system.

Table 3. The 4R principles of flood resilience

4 R Principles	Definition	Stages
Redundancy	Capacity to replace functionality in the event of disruption, interruption, or loss	Prevention, Response
Robustness	Capacity to withstand external shocks without degradation or loss of functionality in a system	Prevention, Resistance, Learning
Rapidity	Capacity to meet priorities and accomplish objectives in a timely manner	Prevention, Recovery, Learning
Resourcefulness	Capacity to identify problems and use resources based on priorities when parts of the system are disrupted	Response, Recovery, Learning

Source: Keating et al. (2017), pp.77-101; Kim (2021), p.99.

Figure 6. The research process



Source: The authors.

Figure 6 depicts the overall research process of the present study, and Figure 7 visually summarizes the specific tasks of our investigation into flood resilience in Asia and the development of flood resilience indices in South Korea. The key stages involve characterizing flood resilience, reviewing the extant literature on flood resilience in Asia, developing flood resilience indices, and evaluating and applying the developed indices.

We define flood resilience as the capacity of a system to mitigate and absorb flood disturbances and adapt to changes while maintaining multiple equilibrium states. Resilient systems can resist floods, recover quickly with minimal damage, and adapt to new circumstances. For this project, we consider both the technical and the social aspects of flood risk management. The 4Rs play a crucial role in building resilience. We also show that the time dimension is crucial, as the goal is to minimize the vulnerability of human and natural systems to sudden and gradual disruptions. This framework acknowledges the ability of systems to learn and self-organize, and ultimately become more resilient with time.

Figure 7. Main research content

Main research content

- Analyze previous studies on strengthening flood resilience with planning, indicator development, and capacity building in Asia
- Identify flood resilience assessment systems including indicators based on research results in different countries

- Analyze flood resilience based on characteristics of flood damages and conduct case studies for the resilience indicators in the countries of Asia
- Collect relevant data for flood resilience ability which can accelerate recovery from flood shocks and stresses

- Structure flood resilience system for indicators based on 4R-based category
- Prioritize flood resilience indicators using AHP analysis results
- Examine correlations between indicators using multicollinearity statistical methods

- Perform SWOT Analysis for flood resilience research in Asia
- Evaluate flood resilience indicators in study regions (local governments) of South Korea
- Summarize flood resilience analysis for strengthening climate change adaptation

Source: The authors.

2 Analysis of Flood Resilience in Asia

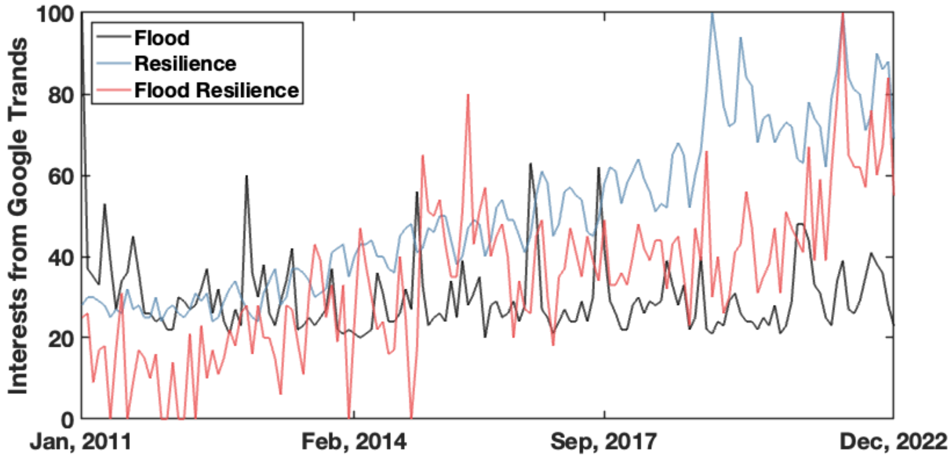
2.1 Current trends and active projects

2.1.1 Google Trends and the Web of Science database

To examine the evolving trends in flood resilience, we conducted a systematic search using keywords such as “flood”, “resilience”, and “flood resilience” in Google Trends (trends.google.com) from January, 2011 to December, 2022 (see Figure 8). Since Google Trends does not provide regional data, we focused on global trends to identify broader patterns. In addition, we supplement the trend analysis with a review of the academic literature using the Web of Science database. This will provide more in-depth insights into the types of research being conducted on flood resilience in Asia.

Figure 8 visualizes trends in research interest over time, with 100 representing peak popularity. Interest in “flood” was consistent throughout the period under study, while interest in “resilience” and “flood resilience” can be seen to have grown over time. This upward trend suggests growing recognition of the importance of flood resilience in mitigating and adapting to the increasing flood risks.

Figure 8. Google Trends search interest results: Flood, resilience, and flood resilience, 2011-2022



Source: Google Trends, "Flood, Resilience, Flood Resilience", Accessed on August 14, 2023.

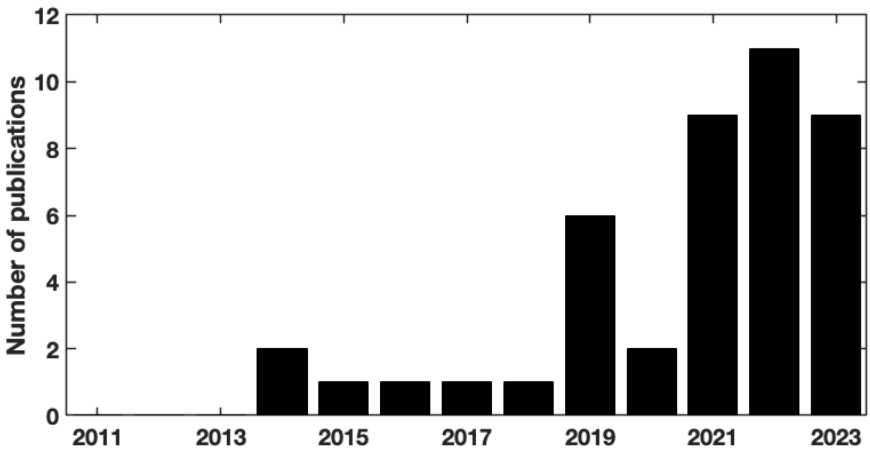
To explore the literature on flood resilience indices, we conducted a comprehensive search in the Web of Science (www.webofscience.com) and Google Scholar (scholar.google.com) databases for the period from January 2011 to July 2023. This timeframe ensured that we captured the most recent advancements in the field.

We eliminated duplicates and narrowed our focus to studies specifically related to flood resilience indices in Asia and those employing quantitative assessments. This filtering process yielded 43 relevant publications from journals and conferences, providing a solid foundation for understanding the current state of flood resilience.

Figure 9 graphs the number of studies on flood resilience published from 2011 to 2023. Note that no studies on flood resilience indices were published from 2011 to 2013, with the first paper on the topic being published in 2014, after which we can observe continued growth in research interest, mirroring the trends observed in Google Trends. Also note that more studies were published in the first half of 2023 than were published in all of 2021 and 2022.

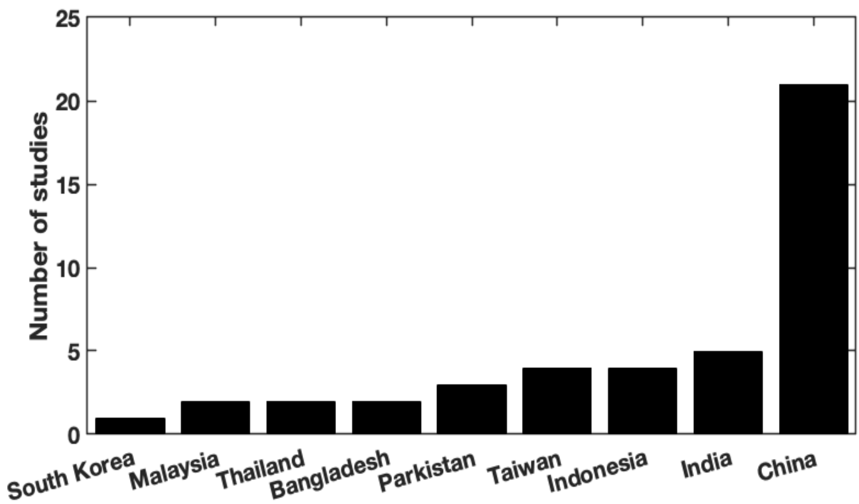
Figure 9 also highlights the geographic distribution of research. We can see that China is the most frequently studied region, with half of all publications focusing on Chinese cases. This points to a preference for studying established areas of research. Following China, the most frequently studied countries are India (5 publications), Indonesia (4 publications), and Taiwan (4 publications). We also found studies on Pakistan, Bangladesh, Thailand, Malaysia, and South Korea. This distribution underscores the growing international focus on flood resilience, with China leading the way in terms of research output.

Figure 9. Number of publications on flood resilience indices in Asia, January 2011 to July 2023



Source: The Web of Science and Google Scholar, "Flood Resilience Index", accessed on August 14, 2023.

Figure 10. Flood resilience index research subject countries in Asia, January 2011 to July 2023



Source: The Web of Science and Google Scholar. "Flood resilience index", accessed on August 14, 2023.

2.1.2 Projects related to flood resilience

To broaden our understanding of flood resilience efforts in Asia, we examined projects implemented between January 2011 and July 2023. Utilizing data from the Asian Development Bank (ADB), we identified a total of 1,734 projects related to flood resilience within the defined period. Table 4 provides a snapshot of eight specific projects that focus on improving flood resilience. These projects showcase diverse approaches to flood resilience challenges in Tajikistan, Vietnam, Pakistan, Nepal, India, and Bangladesh.

Table 4. Asian flood resilience improvement projects, January 2011 to July 2023

Date	Project Name	Country	Financing ($ million)	Impact
July 25, 2013 – April 7, 2022	Building Climate Resilience in the Pyanj River Basin	Tajikistan	21.55	Improved livelihoods of Pyanj River Basin communities vulnerable to climate variability and change.
November 27, 2015 – June 18, 2020	Sustainable and Resilient Urban Development	Viet Nam (Nation-wide)	2.50	Low-carbon economy and green growth sustainable development achieved
August 24, 2015 – February 25, 2021	Flood Emergency Reconstruction and Resilience Project	Pakistan (Azad Kashmir, Punjab)	242.27	Economic and social recovery from the 2014 floods by 2018
September 28, 2020 – September 30, 2027	Priority River Basins Flood Risk Management Project	Nepal (Bakraha, Khutiya, Mawa Toribari, Mohana, Rapti Zone, Ratuwa)	51.25	Social and economic losses due to water-induced disasters reduced
June 3, 2022 - June 30, 2026	Integrated Urban Flood Management for the Chennai-Kosasth alaiyar Basin Project	India (Chennai)	259.88	Chennai City made a safe place to live in, with reduced vulnerability to disaster
October 26, 2022 – December 31, 2029	Coastal Towns Climate Resilience Project	Bangladesh (Nation-wide)	250.00	Higher and sustainable growth trajectories achieved in the face of the various weather-related natural hazards and risk.
December 12, 2022 – April 30, 2023	Emergency Flood Assistance Project	Pakistan (Balochistan, Khyber Pakhtunkhwa, Sindh)	483.05	An inclusive and resilient recovery from the 2022 floods.
May 22, 2023 – September 30, 2026	Flood Reconstruction Emergency Assistance Project	Bangladesh (Sylhet Division)	231.00	A green, inclusive, and resilient recovery achieved

Source: ADB, “Flood Resilience”, accessed on August 21, 2023.

Table 5 summarizes various indicators frequently used to assess flood resilience. These indicators encompass several key dimensions. Indicators of natural phenomena such as precipitation during flood events and vegetation coverage are common in the literature, as are social indicators gauging population density, age structure, and education levels. The most frequently observed economic indicators used are disposable income per capita and gross domestic product (GDP), with the income measure being employed more often, but GDP is nonetheless used to estimate flood resilience in the studies that emphasize disposable income per capita. Infrastructure is typically evaluated with indicators of road characteristics and the design of drainage networks. Other indicators include hospital beds per capita and public green space per capita.

The research points to some general trends between these indicators and flood resilience. Districts with more urban green space and steeper slopes, for example, are more resilient. In economic terms, areas with GDP levels and disposable income per capita have also been shown to be more resilient to flooding (Cao et al., 2023). Urban populations with large proportions of residents aged 18 and younger and 60 and older, tend to exhibit lower flood resilience than other areas. Conversely, areas with a higher percentage of university students, healthcare workers, or mobile phone users are correlated with increased resilience (Cao et al., 2023). Larger female populations and larger numbers of people on state welfare rolls were negatively correlated with flood resilience (Cao et al., 2023). Finally, drainage pipe networks, road area per capita, and planted area were positively correlated to flood resilience in urban systems (Cao et al., 2023).

Table 5. Indicators used to estimate flood resilience

Primary indicator	Secondary indicator	Frequency	References
Nature	Precipitation	8	Li et al.(2013, 2022); Abenayake et al.(2018); Liu et al.(2019); Waghwala and Agnihotri(2019); Luo et al.(2021); Wang et al.(2021); Yang et al.(2021)
	Vegetation coverage	8	Qasim et al., 2016; Kotzee and Reyers, 2016; Abenayake et al., 2018; Liu et al., 2019; Luo et al., 2021; Li et al., 2022; Wang et al., 2021; Yang et al., 2021
	Topographic impact (slope)	4	Li et al., 2013; Abenayake et al., 2018; Waghwala and Agnihotri, 2019; Luo et al., 2021
Economy	Per capita disposable income	7	Kotzee and Reyers, 2016; Liu et al., 2019; Waghwala and Agnihotri, 2019; Lwin et al., 2020; Luo et al., 2021; Wang et al., 2021; Tu et al., 2022;
	Gross domestic product (GDP)	4	Song et al., 2019; Waghwala and Agnihotri, 2019; Luo et al., 2021; Wang et al., 2021
Society	Population density	9	Li et al., 2013; Qasim et al., 2016; Liu et al., 2019; Hadipour et al., 2020; Sarmah et al., 2020; Yang et al., 2021; Luo et al., 2021; Tu et al., 2022; Yu et al., 2023
	Age structure	8	Kotzee and Reyers, 2016; Qasim et al., 2016; Song et al., 2019; Lwin et al., 2020; Hadipour et al., 2020; Haque et al., 2022; Yu et al., 2023; Zhu et al., 2023
	Population education level	8	Kotzee and Reyers, 2016; Qasim et al., 2016; Hadipour et al., 2020; Lwin et al., 2020; Wang et al., 2021; Haque et al., 2022; Li et al., 2022; Yu et al., 2023

Table 5. (continued)

Primary indicator	Secondary indicator	Frequency	References
Society	Male to female gender ratio	3	Song et al., 2019; Hadipour et al., 2020; Lwin et al., 2020
	Poverty situation	3	Qasim et al., 2016; Wang et al., 2021; Haque et al., 2022
Infrastructure	Road characteristics (area, length, density)	6	Kotzee and Reyers, 2016; Song et al., 2019; Li et al., 2022; Tu et al., 2022; Yu et al., 2023; Zhu et al., 2023
	Design of drainage pipe network (length, density)	6	Li et al., (2013, 2022); Luo et al., 2021; Wang et al., 2021; Tu et al., 2022; Zhu et al., 2023
	Number of hospital beds per 1,000/10,000 people	4	Kotzee and Reyers, 2016; Wang et al., 2021; Tu et al., 2022; Yu et al., 2023
	Per capita public green space area	3	Liu at al., 2019; Wang et al., 2021; Yang et al., 2022

Source: Adapted from Cao et al. (2023), p.4.

2.2 Case study 1: Community flood resilience

In this section, we examine an ADB study on community flood resilience in Asia (Laurien and Keating, 2019). The study investigated 88 communities in Afghanistan, Bangladesh, Indonesia, Nepal, and Timor-Leste, comprising 40 rural, 24 peri-urban, and 24 urban communities. The study categorized the communities by population density and community functionality, allowing for a comprehensive analysis of flood resilience across diverse settings. About 220,000 people live in the communities under study.

The work employs a grading system to assess communities flood resilience. The system considered two key factors: the financial recovery period and socioeconomic conditions. The financial recover period was defined as the duration of time necessary for a community to recovery financially back to pre-flood levels. For socioeconomic conditions, factors such as poverty rate, education levels, the number of female-headed households, historical flood risk, and the proportion of minority residents were considered. Flood resilience scores were graded on a scale from A (best) to D (worst). The rubric is adapted from Zurich Insurance manuals. The grades represent:

A: Best practices in community resilience

B: Good resilience standards, no need for immediate improvement

C: Several deficiencies; room for improvement

D: Significantly substandard and at risk of imminent loss

Lauren and Keating (2019) found that rural communities faced the longest recovery periods, at 27 weeks. Peri-urban communities were next, at 18 weeks. Urban communities recovered the quickest, needing just 7.5 weeks.

Table 6 summarizes the socioeconomic characteristics of the communities under study. Note that rural areas had the lowest education levels, the highest rates of poverty, the highest proportions of minorities, and the highest proportions of female-headed households. This socioeconomic background information informs the flood resilience scores presented in the ADB report.

Table 6. Socioeconomic characteristics of rural, peri-urban, and urban communities in Asia

Settlement type	Education rate* [%]	Poverty rate [%]	Minorities rate [%]	Female-headed households [%]
Rural	20	38	57	21
Peri-urban	39	17	14	13
Urban	32	4	17	3

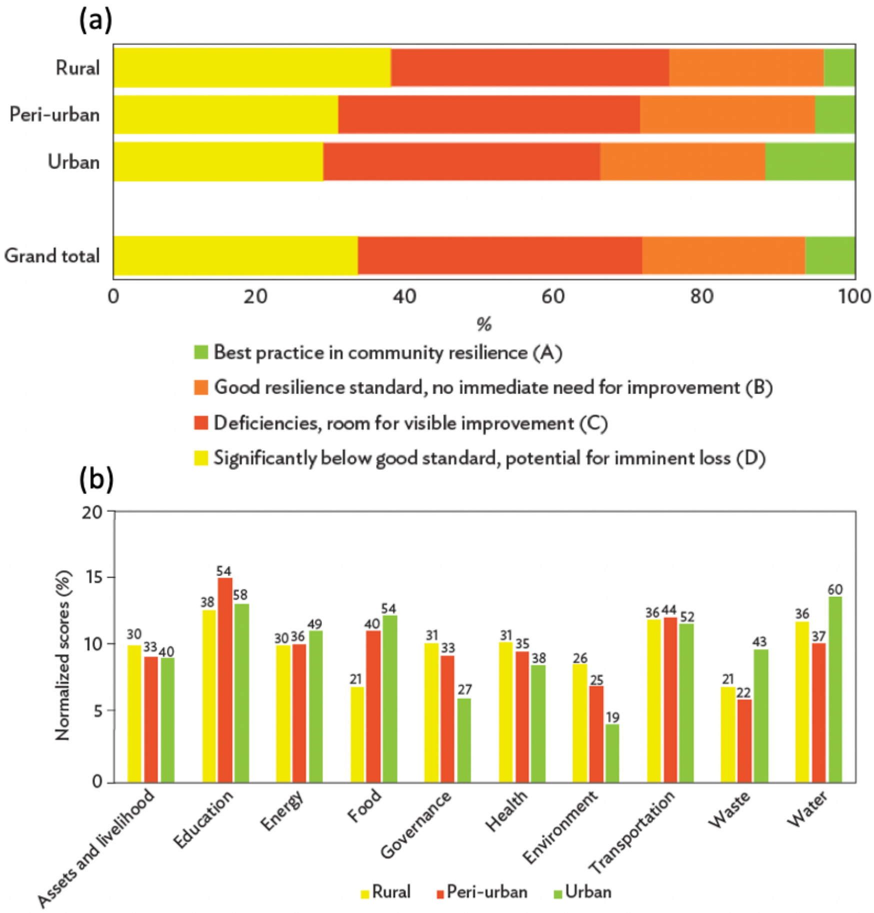
Note: 'Education rate' refers to the percentage of individuals who have completed high school education.

Source: Adapted from Laurien and Keating (2019), p.12.

Figure 11 visualizes flood resilience scores across Asia, classified by type of community (Laurien and Keating, 2019). Overall, urban communities exhibit higher flood resilience scores than rural and peri-urban communities. However, the most common grade across all communities is C, followed by D (see Figure 11(a)). This tells us that all community types will benefit from further improvement. Laurien and Keating (2019) analyzed various factors thought to influence flood resilience in Asia, including assets and livelihoods, education, energy, flood, governance, health, the environment, transportation, waste, and water resources (see Figure 11(b)). Their findings reveal that education, transportation, and water resources scores were relatively higher across the community types.

Urban communities had the highest water resources scores but the lowest environment scores. Education scores were highest in peri-urban and rural communities, while waste sector scores were lower. The most significant disparity is observed in food scores, where urban and peri-urban communities have normalized scores of 54 and 40, respectively, while rural communities scored just 21. This highlights the need to pursue improvements in food security to bolster flood resilience in rural communities. Overall, the study provides valuable insights into the strengths and weaknesses of each sector across different community types, and pinpoints areas that need the most urgent attention.

Figure 11. Flood resilience estimations



Source: Adapted and modified from Laurien and Keating (2019), p.12, p.14.

2.3 Case study 2: Scale-based flood resilience index

This section introduces a flood resilience index (FRI) designed to quantify and assess factors that affect the functionality of urban and rural systems during and after flood events (UNISDR, 2004).

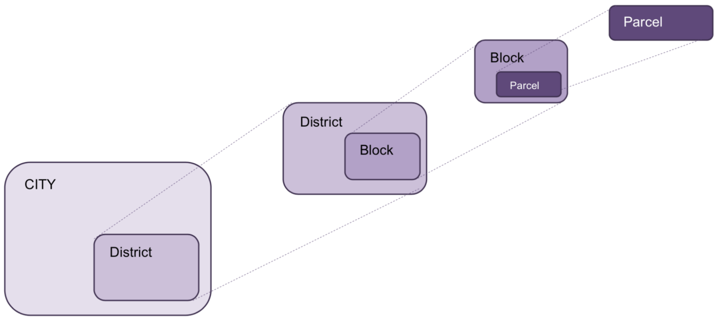
Traditionally, flood risk management has focused on community vulnerability, but the FRI framework we introduce here takes a more holistic approach, incorporating social and economic factors into assessments of both urban and rural environments. It is worth noting that the previous literature on the subject has focused largely on urban environments only.

The FRI considers various aspects, including flood damage, risk perception, and vulnerability, to assess the status of any given systemic function during and after a flood (Batica and Gourbesville, 2014). Flood resilience is not a singular characteristic; rather, it is a complex interplay between the properties of human and natural systems and the characteristics of a flood.

A system's resilience is linked to specific attributes of a flood event. These key attributes are: duration, water flow velocity, and depth (Batica and Gourbesville, 2014). A system that exhibits resilience flash floods may not perform as well against coastal floods, for example.

Figure 12 shows how this scale-based flood resilience index can be applied to evaluate flood resilience at the building, block, and city levels across various regions in Asia.

Figure 12. Urban systems: From individual parcels to whole cities



Source: Adapted from Batica et al. (2013), p.6.

2.3.1 FRI at the building (property) scale

The FRI can be applied at the building level, with the evaluation criteria varying depending on the purpose and function of building being evaluated. For example, a residential building in an urban setting would be assessed based on its ability to maintain critical urban functions and services in the event of a flood, such as energy supply, waste management, and indoor climate control. Batica (2015) proposes a six-level scale to evaluate the functionality of key urban systems:

Level 0: Nearly non-functional; major disruptions during flood events

Level 1: Limited functionality; major disruptions

Level 2: Reduced functionality, minor disruptions

Level 3: Reduced functionality; minor disruptions. Accessible during small flood events

Level 4: Reduced functionality; minor disruptions. Accessible during large flood events

Level 5: No loss of functionality; accessible during all flood events

Table 7 shows how these levels translate into FRI scores based on functionality during a flood.

Table 7. Quantifying a building-scale flood resilience index

Requirements for urban function		Availability level	Weights
External services (r_e)	Energy	0, 1, 2, 3, 4, 5	1, 2, 3, 4, 5
	Water	0, 1, 2, 3, 4, 5	1, 2, 3, 4, 5
	Waste	0, 1, 2, 3, 4, 5	1, 2, 3, 4, 5
	Communication	0, 1, 2, 3, 4, 5	1, 2, 3, 4, 5
	Transport	0, 1, 2, 3, 4, 5	1, 2, 3, 4, 5
Internal services (r_i)	Food availability	0, 1, 2, 3, 4, 5	1, 2, 3, 4, 5
	Occupation of urban function	0, 1, 2, 3, 4, 5	1, 2, 3, 4, 5
	Access to urban function	0, 1, 2, 3, 4, 5	1, 2, 3, 4, 5

Source: Adapted from Batica and Gourbesville (2014), p.14.

Flood resilience at the building scale is quantified based on external and internal service requirements (Batica and Gourbesville, 2014). At the parcel scale, FRI (FRI_{Batica}) is calculated as a weighted average across different resilience indicators (Batica and Gourbesville, 2014).

$$FRI_{Batica} = \frac{\sum_{i=0}^{5} r_e w_i + \sum_{i=0}^{3} r_i \ w_i}{\sum_{i=1}^{8} w_i} \qquad \text{Equation (1)}$$

r_e represents external service requirements, which include energy, water, waste, communication, and transport services. r_i denotes internal service requirements, such as access to food, occupation in urban areas, and the utilization of urban facilities. The weight component, w_i, reflects the relative importance of fulfilling each requirement. The weights are as follows: very low to low importance = 1,2, medium importance = 3, medium high to high importance = 4,5. Determining the weight component requires an assessment of costs, environmental impacts, and risk levels (Batica and Gourbesville, 2014).

2.3.2 FRI at the block scale

Similar to the building scale, FRI can also be applied at the block scale. A block refers to a set of buildings or parcels. In terms of scale, a block falls between a single building and a district. The method used to assess FRI at the block scale is similar (see Equation 1), but the focus is on the dominant urban function provided within the block. This is relevant when a single block houses a mix of urban functions (Batica, 2013). As with building-level assessment, block-scale FRI depends on the levels of service provided within a block and how it is impacted by flood events.

2.3.3 FRI at the city and district scale

Evaluating flood resilience at the city and district scale requires a holistic consideration of urban systems, viewing them as being comprised of natural, physical, economic, social, and institutional dimensions. The natural dimension encompasses factors such as available water bodies, topography, drainage density, and rainfall patterns. The physical dimension includes flood protection infrastructure, communication network services, and human safety. The economic dimension focuses on employment, disaster management, and mitigation plans. The social dimension encompasses intra-community connections, health, and the availability of resources. Finally, the institutional dimension includes flood management frameworks, regulations, and evacuation plans for at-risk populations in flooded areas (Batica and Gourbesville, 2014) (see Table 8).

To assess flood resilience in each dimension, an aggregate weighted mean index (AWMI) is employed (Shaw and Team, 2009). AWMI scores gauge flood resilience in each dimension, and scores range from 0 (very low) to 5 (high) (see Table 9).

Table 8. The variables considered for each dimension of an urban system

Dimension	Variable
Natural	Green space
Physical	Building
	Building of strategic functions (governance & safety, health, food, emergency shelter)
	Street pattern (e.g. roads and public transport)
	Hubs of urban services
	Public space
Economic	City scale
	District, block, parcel scale
Institutional	Mainstreaming flood risk management (FRM)
	Effective city crisis management framework
	Institutional collaboration with other organizations and stakeholders (before, during, and after a flood event)
	Environmental policies
	Good governance
Social	Individual/ building scale
	Group/ community (block/ district scale)
	Governance (city scale)

Source: Adapted from Batica and Gourbesville (2014), p.20.

Table 9. Flood resilience index evaluation scale

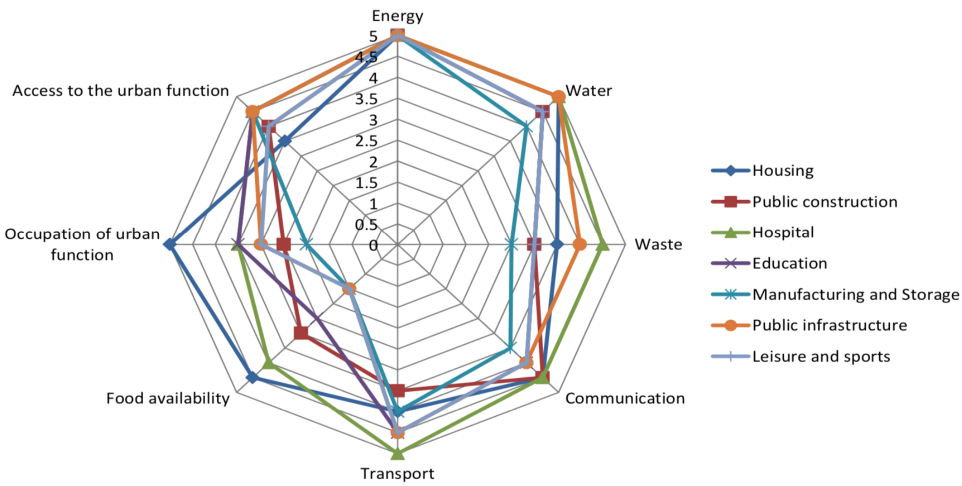
Very low 0-2	The activities are not clear and coherent in an overall flood risk management (5R: Reflect, Relief, Resist, Response, and Recovery). There is very low awareness on the issues and low motivation to address them. Interventions are limited to the short term. Actions are limited to crisis response.
Low 2-3	There is awareness of the issues and motivation to address them. Capacity building of human resources remains limited. Capacity to act is improved and substantial. Interventions are more numerous and long-term. Development and implementation of solutions are observed.
Medium 3-4	There is active integration and implementation of solutions. Interventions are extensive, covering all main aspects of the 'problem,' and they are linked within a coherent long-term strategy.
High 4-5	A "culture of safety" exists among all stakeholders, where the resilience concept is embedded in all relevant policies, planning, practices, attitudes, and behaviors.

Source: Adapted from Batica et al. (2013).

2.3.4 Application of FRI

FRI was applied at the property scale in Beijing in one case study (Batica and Gourbesville, 2014). The study estimated flood resilience scores for various urban functions classified by land use type: housing, public buildings, hospitals, educational facilities, manufacturing and storage facilities, public infrastructure, and leisure and sports facilities. Figure 13 illustrates the weight assigned to each function, reflecting their importance in the context of flood resilience.

Figure 13. FRI_{Batica} of urban functions in Yizhuang district, China



Source: Adapted from Batica and Gourbesville (2014), p.27.

In Table 10, we can see that the FRI_{Batica} scores for the Yizhuang district at the building scale vary between 0.17 and 4.95. The 0.17 figure owes to the poor FRI_{Batica} value for the manufacturing and storage sector at water depths exceeding 1m. The housing sector recorded relatively high (4.95) resilience scores for small floods (water depth under 0.2m), but housing was found to be vulnerable to large floods, with a score of just 0.76 (water depth over 1m). Manufacturing and storage facilities were found to be the least resilient to floods (4.11), even in scenarios where water depth is 0.2m or less (see Table 10). This vulnerability stems from the fact that factories and storage space can maintain full functionality only in dry conditions.

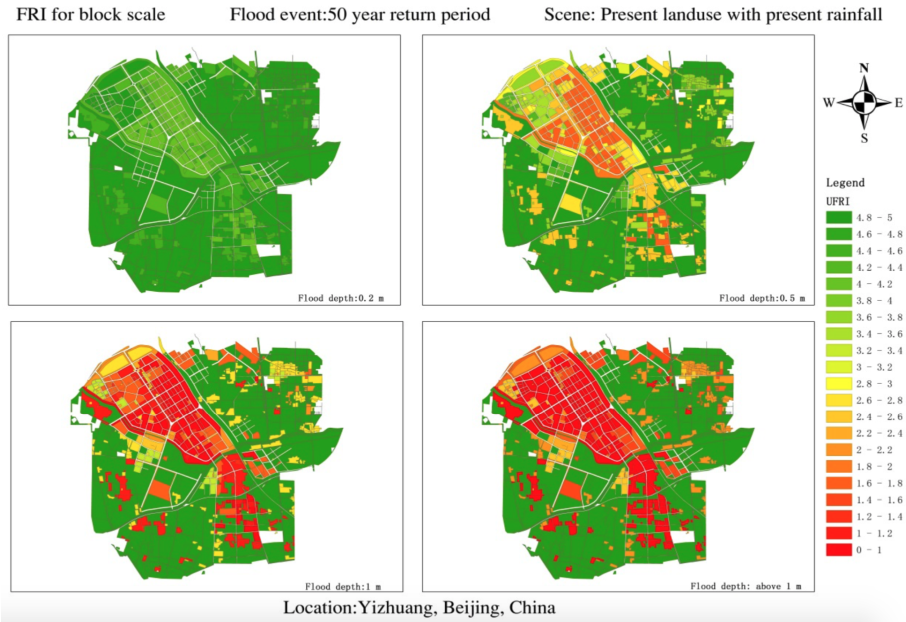
Table 10. Flood vulnerability at the building scale in Yizhuang district, China

Land use type	Water depth (m) Flooded				Water depth (m) Not flooded			
	0-0.2	0.2-0.5	0.5-1	>1	0-0.2	0.2-0.5	0.5-1	>1
Housing	4.95	3.41	1.79	0.76	5.00	4.26	3.32	2.57
Public construction	4.48	2.43	1.19	0.62	4.85	3.72	2.78	2.20
Hospital	4.44	2.51	0.88	0.48	4.64	3.34	2.19	1.99
Education	4.41	2.84	1.26	0.71	4.62	3.63	2.60	2.24
Manufacturing and storage	4.11	1.78	0.46	0.17	4.38	2.78	1.78	1.48
Public infrastructure	4.32	2.37	1.07	0.59	4.56	3.17	2.31	1.87
Leisure and sports	4.21	1.98	0.69	0.31	4.50	2.92	2.03	1.75

Source: Adapted from Batica and Gourbesville (2014), p.30.

FRI can also be applied at the block scale to evaluate flood resilience at varying water depths by comparing the performance of flooded and non-flooded blocks. The resulting FRI measures are mapped using a GIS to visualize flood resilience for differing building types and flood depth over time. Batica and Gourbesville (2014) demonstrate this application by mapping the spatial distribution of FRI_{Batica} in Yizhuang type of building and flood depth in 2014 (see Figure 14).

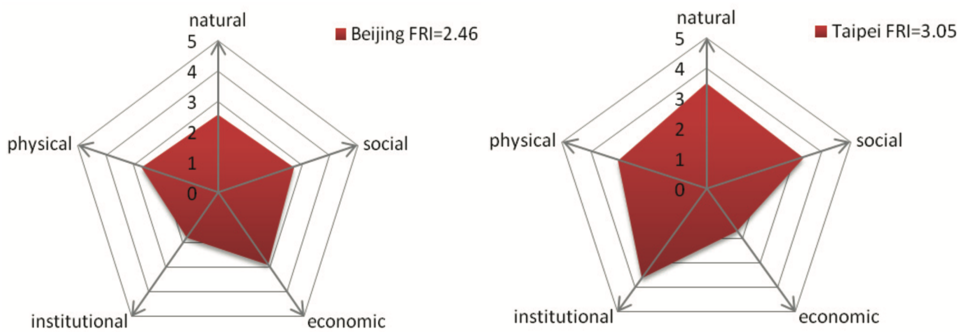
Figure 14. Spatial distribution of block-scale FRI_{Batica} in Yizhuang district in 2014



Source: Adapted from Batica and Gourbesville (2014), p.32.

FRI_{Batica} can be computed for any one flood event, with flood characteristics informing flood maps for the area under study. For the case study being explored here, FRI_{Batica} is assessed at the city scale in Beijing and Taipei based on evaluations provided by project partners (Batica and Gourbesville, 2016) (see Figure 15). To quantify FRI_{Batica}, a weight is assigned to each criterion based on consultations with reserchers from the China Academy of Urban Planning and Design (CAUPD) in Beijing. For example, the natural dimension is assigned a weight of 4, while volunteers and solid waste management are assigned a weight of 3 (Batica and Gourbesville, 2014). FRI_{Batica} scores were estimated for land use and rainfall conditions in 2014 and for a future 2050 scenario. While future projections point to more severe precipitation patterns in 2050, land use planning initiatives are expected to mitigate flood risk despite higher levels of expected rainfall.

Figure 15. FRI_{Batica} evaluation at the macro scale in Beijing and Taipei



Source: Adapted from Batica and Gourbesville (2016), pp.814-815.

2.4 Implications

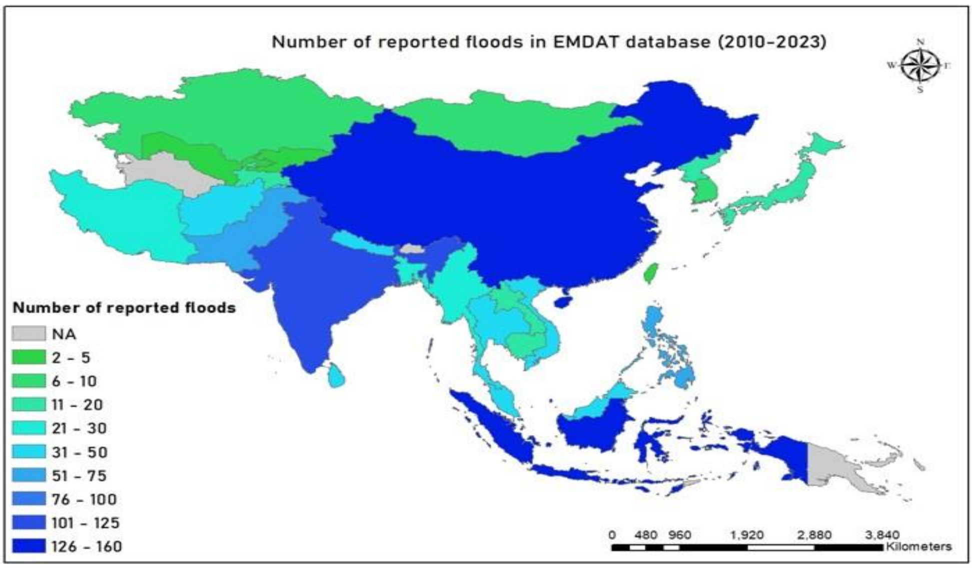
In this section, we explored current trends and important case studies related to flood resilience in Asia. The analysis draws on three main sources: Google Trends, the Web of Science database, and data on the performance of past projects in which flood resilience measures were implemented. This approach provides insights to the recent trends in flood resilience research and introduces practical examples of flood resilience efforts in Asia. Our goal was to establish a robust foundation of resources through which we can comprehensively evaluate flood resilience across Asia. We also described cases studies in which FRI was applied to evaluate flood resilience in various Asian countries. Our analysis aligns with the three methods for developing FRI in Asia. In this section, we also explored the results of previous studies that have estimated FRI values across various scales, ranging from the individual buildings to entire districts. This comprehensive analysis has produced insights that can be leveraged to formulate effective FRI development strategies for South Korea.

3 Assessment of Flood Resilience in Selected Asian Countries

3.1 Flood-prone countries and urban resilience

In this section, we identify flood-prone countries in South and South-East Asia for flood resilience analysis. A 2023 paper by the Centre for Research on the Epidemiology of Disasters (CRED), a global repository of disaster data, reports that most of the countries in the region have been impacted by numerous severe floods between 2013 and 2023. These include Indonesia, China, India, Thailand, Philippines, Bangladesh, Nepal, and Cambodia, among others. Figure 16 provides a visual summary of the number of floods experienced in these countries.

Figure 16. Number of reported floods in EMDAT database, 2010-2023



Source: EM-DAT Documentation, "Hydrological Hazards", accessed on 13 August 2023.

Frequent flooding has led each country in the region to work to reduce flood risk. This is evident in their adoption of the Sendai Framework for disaster risk reduction (UNDRR, 2021), with 87% of all countries in Asia-Pacific region using the Sendai Framework Monitor (SFM) to track progress. However, many existing national and local disaster risk reduction strategies focus on early warning systems and risk information for critical infrastructure.

The effectiveness of any disaster response hinges on well-formulated national policies and their implementation at the local level. Developing countries tend to exhibit improvements in disaster preparedness with each successive event. Floods remain a major global disaster and exact a heavy toll worldwide. Climate change is expected to exacerbate flooding, making effective flood management and risk reduction a top priority for disaster management agencies.

Traditional urban flood control strategies relied heavily on physical structures, but the dynamic interaction of different components of an urban community is what ultimately determines the success of an intervention. Key factors influencing the success or failure of an intervention include the financial resources of local government, socioeconomic conditions, culture, governance and policies, the community's adaptive capacity, and the resilience of people. Strong relationships between local authorities and communities are also crucial for the successful implementation of such strategies. Hofmann (2021) emphasizes that while conventional risk and vulnerability assessments are scientifically sound, recent initiatives like the UN SDGs and the Sendai Framework encourage the integration of social and physical factors in achieving resilience.

The United Nations Office for Disaster Risk Reduction (UNDRR) outlines ten essentials to building a resilient city:

1. Organize disaster resilience: Establish an organizational structure and processes to reduce exposure, impacts, and vulnerability to disasters.

2. Understand and use current and future risk scenarios: Local governments must be aware of the existing and potential risks and use the knowledge to inform decision-making.

3. Strengthen financial capacity for resilience: Disasters have a far greater economic impact than the costs of preparedness and mitigation. Identifying and developing

financial mechanisms to support resilience is essential.

4. Pursue reliant urban development and design: Once the current and future risks are identified and understood, the resiliency of the built environment needs to be assessed and reinforced.
5. Safeguard natural buffers to enhance ecosystem's protective functions: Identify, monitor, and protect critical ecosystems that provide protection against natural disasters.
6. Strengthen institutional capacity for resilience: All stakeholders and institutions needed for a resilient city should have the capacity to discharge their responsibilities.
7. Understand and strengthen societal capacity for resilience: Promote social connections and a culture of mutual aid, recognizing the role of cultural heritage and education in disaster risk reduction.
8. Increase infrastructural resilience: Identify and upgrade critical infrastructure to ensure their capacity, adequacy, and interconnectivity.
9. Ensure effective disaster response: Develop and maintain disaster response plans informed by a comprehensive understanding of current and future risks, and communicate them to all stakeholders.
10. Expedite recovery and Build Back Better: After a disaster, prioritize the needs of the affected population during recovery and reconstruction.

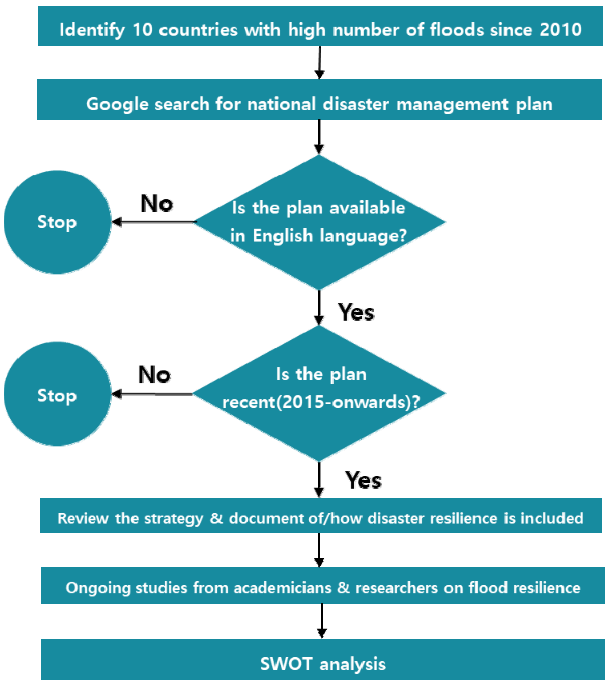
The concept of resilience is gaining traction, as can be seen in policy programs such as 100 Resilient Cities (100 RC), the Making Cities Resilient campaign, and the Resilient Cities Network. These programs aim to promote resilience as a foundation for policymaking and develop tools for cities to address acute shocks and stresses that could undermine their normal functioning and development.

Flood resilience assessments can employ either a top-down or bottom-up approach. The top-down approach involves quantitative analysis at various spatial scales, the results of which can facilitate comparative assessments using standardized data from different sources (Cutter, 2016). The bottom-up approach utilizes qualitative data and community perceptions to understand the urban social system (Li et al., 2019). Assessments may also either be classified as objective or subjective, depending on whether they measure resilience using externally-defined characteristics independent of community perceptions (Tariq et al., 2021, pp.102-358) or prioritize the perceptions of people within the system (Bottazzi et al., 2018).

3.2 Case study: Flood resilience assessment in selected countries

Figure 17 below illustrates the methodology we deploy to select countries and study the state of flood resilience assessment and its inclusion in those countries' national and local strategies.

Figure 17. Methodology adopted to understand flood resilience in Asia



Source: The authors.

Table 11 shows the countries chosen for analysis based on the methodology visualized in Figure 17.

Table 11. Countries with national flood resilience plans and policies

	Country	No. floods	National plans/policies	Explicit inclusion of flood resilience in national plan
1	Indonesia	158	A. Law Number 24, Year 2007 B. Government regulation 21, Year 2008 C. National action plan for DRR (RAN-PRB) D. National Disaster Management Plan (RENAS-PB) 2020-2024 E. Disaster Management Master Plan-RIPB 2015-2045 F. Disaster Management Plan at regional level (RPB)	a. Indonesia has DRR policies which mandates explicit mitigation planning. b. Law Number 24, 2007 and Government Regulation 21, 2008 mandate the government to prepare disaster management plans and integrate them in national and regional disaster management plans. Disaster mitigation is carried out with spatial planning, development arrangements and capacity building programs. c. RIPB (2015-2045) is in line with Sendai Framework and SDG. d. No explicit mention of flood resilience in the plans.
2	China	143	A. National Comprehensive Disaster Reduction 13th Five-year plan (2016-2020) B. Flood control law of the People's Republic of China	a. In line with Sendai Framework for DRR b. Shift from reactive to proactive DRR c. Focus on reducing mortality and economic losses d. Setting 5,000 demonstration communities to show integrated disaster risk reduction e. To enhance resilience, agriculture insurance pilot projects and catastrophic insurance pilot projects are in place. f. The flood control law has the plans for controlling the flood but it does not explicitly mention of building flood resilience.

Table 11. (Continued)

	Country	No. floods	National plans/policies	Explicit inclusion of flood resilience in national plan
3	India	109	A. National disaster management plan (2019)	a. Integrates the Sendai Framework, SDGs, and the Paris Agreement 2015 b. The thematic area of DRM expanded to include climate change risk management in addition to the understanding of risk, inter-agency coordination, and investment in DRR: structural and nonstructural measures and capacity development c. Explicit section on building resilience to floods
4	Philippines	69	A. Strategic national action plan (SNAP) for DRR 2009-2019 B. National Framework Strategy on Climate Change (NFSCC 2010-2022) C. National Disaster Risk Reduction and Management Plan (NDRRMP 2011-2028) D. National Disaster Preparedness Plan (NDPP 2015-2028) E. National Disaster Response Plan (NDRP) F. Disaster Rehabilitation and Recovery Planning Guide 2020	a. SNAP for DRR followed Hyogo framework. b. NDRRMP covers disaster prevention and mitigation, preparedness, response and rehabilitation and recovery. c. NDPP helps the national and local governments and stakeholders to increase awareness and capacity of communities and equip them to reduce the risk of hazards. d. A separate plan exists for NDRP for hydrometeorological events like floods. e. DRRP acts as a template of recovery and rehabilitation for national and local governments' use after a disaster.

Table 11. (Continued)

	Country	No. floods	National plans/policies	Explicit inclusion of flood resilience in national plan
5	Pakistan	54	A. National Disaster Management Act (NDMA) 2010 B. National Disaster Management Plan (NDMP) 2012-2022 C. National disaster management plan implementation roadmap (2016-2030) D. National disaster response plan (NDRP-2019) E. National Disaster Risk Reduction Policy NDRRP (2013)[2]	a. NDMA 2010 enabled the institution of national, provincial, and district disaster management authorities. b. The NDMP consists of the master plan, human resources development plan, multi-hazard early warning system plan, and instructors' guideline on community-based disaster risk management. c. The roadmap sets priority activities for 2016-2030 focusing on multi-hazard risk assessments, capacity building, community resilience and awareness. d. The NDRP outlines framework for disaster response based on roles and responsibilities of different stakeholders. e. The NDRRP focuses on strengthening the resilience of communities and critical infrastructures to the disasters.

source: NDMA(2019), p.32; GFEER(2020), p.3.

3.2.1 Nepal

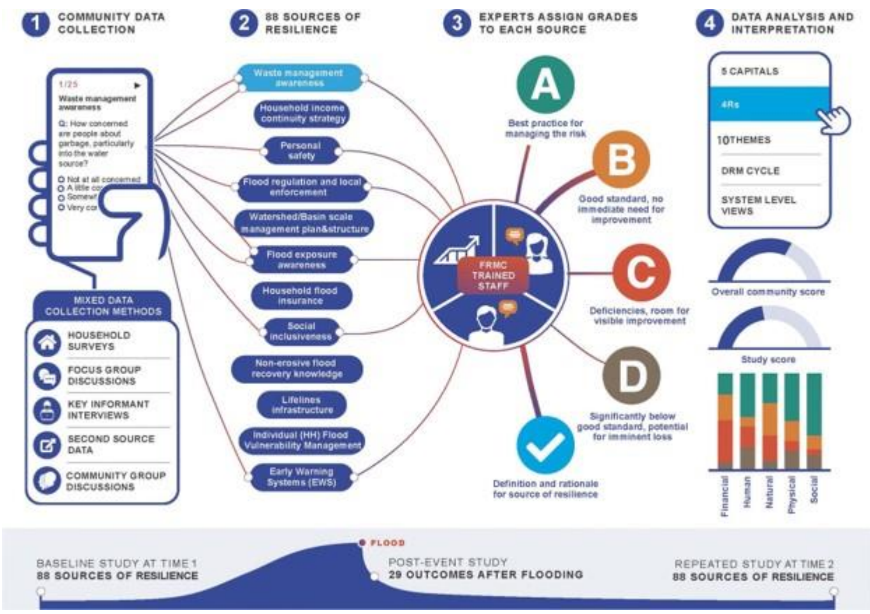
The Flood Resilience Measurement for Community (FRMC) framework, developed by the Zurich Flood Resilience Alliance (ZFRA) in 2013, has been implemented in select locations across Nepal to assess flood resilience and identify areas to focus future improvement efforts (FRMC, 2023). A web-based toolkit was used to facilitate data collection on various components of flood resilience. The FRMC (or 5C-4R) framework employs 44 indicators across five so-called "capitals", or dimensions, and the 4Rs described earlier in this paper — the four aspects of resilient systems.

2) Ministry of Climate Change and Environmental Coordination (2013), p.7.

The 5Cs are the human, social, physical, financial, and natural dimensions, and they provide a comprehensive picture of a community's resilience compared to a single metric. Each capital encompasses has generic and discrete sources of resilience categorized under the 4Rs. Robustness refers to a community's ability to withstand a shock, Redundancy denotes functional diversity, Resourcefulness is a community's ability to mobilize when threatened, and Rapidity is a community's ability to contain losses and recover.

Data used for community resilience assessment can be collected through household surveys, key informant interviews (KIIs), focus group discussions (FGDs), or secondary sources. Once data is collected and entered into the FRMC tool, the 44 sources are graded from A (best practice) to D (poor practice). These grades can then be aggregated for analysis in different ways. Users can evaluate resilience across the 5Cs and 4Rs or through a thematic lens. The framework also allows for assessment of a community's disaster risk management cycle (preparedness, response, recovery, prospective risk reduction, and corrective risk reduction). Figure 18 presents a snapshot of the FRMC framework, adopted from Laurien et al. (2020).

Figure 18. The Flood Resilience Measurement for Communities (FRMC) framework



Source: Laurien et al. (2020), p.5.

3.2.2 India

A study of Surat, India (Waghwala and Agnihotri 2019), revealed significant disparities in flood resilience between formal and informal settlements. The latter typically exhibit lower physical and institutional resilience. The work employed an indicator-based approach using household surveys to collect data and assess resilience. Formal settlements are expected to have higher resilience due to planned layouts, proper infrastructures and services, and more robust buildings. But residents of informal settlements may enjoy stronger social support networks and social cohesion during natural disasters. In addition, communities in informal settlements may have developed indigenous and local solutions that offer valuable insights into community driven DRR approaches. Understanding these unique characteristics is crucial before implementing any DRR strategies to enhance overall resilience.

The study used data extracted from household surveys to estimate flood resilience. The surveys were conducted via face-face interviews and utilized a structured questionnaire. The questionnaire included multiple choice, dichotomous, and Likert scale questions. Data were collected on various aspects of social resilience (SR), economic resilience (ER), physical resilience (PR), and institutional resilience (IR).

SR:

a. Age of household lead

b. Education level

c. Household size

d. Female-headed household

e. Awareness of flood impacts

f. Awareness of coping and adaptation strategies

ER:

a. Monthly income

b. Economic dependency ratio

c. Home ownership

d. Ownership of personal vehicle or mode of transportation

e. Diversity of income sources

PR:

a. Housing condition

b. Access to safe drinking water

c. Access to proper sanitation facilities

d. Availability of backup electricity

e. Structural measures for heavy rainfall and floods

IR:

a. Support from NGOs and the municipality

b. Early flood warning alarms

c. Availability of a waste disposal system

d. Provision of drinking water filtration facility

e. Frequency of daily water supply

f. Frequency of daily electricity supply

The data collected were quantified and transformed into a number from 0 to 1. Highly correlated indicators (greater than 0.8) were removed to avoid duplication. Principal Component Analysis (PCA) was used to derive weights for the remaining indicators. The weights were used to estimate the resilience index through linear aggregation:

$$Resilience\ index\,(RI) = \frac{\sum_{i=6}^{n} SRXi/n\,(wi) + \sum_{i=5}^{n} ERXi/n\,(wi) + \sum_{i=5}^{n} PRXi/n + \sum_{i=6}^{n} IRXi/n\,(wi)}{N} \qquad \text{Equation (2)}$$

Xi refers to the transformed score of each indicator. *n* is the number of indicators within each resilience dimension. *wi* is the weight assigned to each dimension based on its relative importance, and *N* is the total number of resilience dimensions.

To ensure the accuracy and Robustness of the FRI scores, the study performed two additional analyses. The first was a reliability analysis using Cronbach's alpha, which assessed the internal consistency of the various indicators. The second was a sensitivity analysis using Monte Carlo simulations, which was used to confirm confidence in the composite index.

3.2.3 Thailand

Following the devastating floods that rocked Thailand in 2011, Pal et al. (2022) assessed the flood resilience characteristics of Thailand's national plans based on indicators from SDGs 11 and 13. The work focused its analysis on plans that met the following criteria:

a. Developed after the 2011 floods

b. Encompass the Bangkok metropolitan area

c. Not limited to specific provinces within Bangkok

d. Directly address urban flood risk

The work defined the four main components of risk as follows: presence of a hazard, exposure to a hazard, vulnerability to a hazard, and capacity to counter a hazard.

The study analyzed 12 documents based on these characteristics and identified risk reduction measures for each flood risk component. Table 12 below presents the criteria used to evaluate these strategic plans.

Table 12. Flood risk components in Bangkok's strategic plans

Flood risk component	Measure	Description
Flood hazard control	Structural	Construction of structural measures (Flood wall, embankment, dikes, retention ponds, etc.)
		Protection and management of major water bodies
Vulnerability reduction	Structural	Maintenance of measures such as canals, drainage, embankments, etc.
		Maintenance of flood control equipment (pumps, monitoring, etc.)
Exposure management	Non-structural	Assessment and amendments of current land use and land cover policies
		Implementation of construction codes and zoning
		Proper implementation of EWS for better evacuation protocols
Increasing capacity	Non-structural	Incorporation of indigenous knowledge for flood control
		Regular information campaigns regarding flood risks
		Provision of local evacuation facilities
		Mechanism for interagency partnerships for collaboration
		Provision of trainings for trainers and other community members

Source: Pal et al. (2022), p.8.

Each criterion in Thailand's national flood resilience plans was assigned a score between 0 and 3. A score of 0 is given to criteria that are not mentioned in the strategic plan. A score of 1 is given to criteria that are mentioned in plan but lacked viable solutions. A score of 2 indicates that the strategy described measures for addressing local flooding. A score of 3 indicates a clear and comprehensive strategy with a detailed explanations, processes, and resource requirements.

Bangkok participated in in the 100 Resilient Cities (100RC) program. Laeni et al. (2019) analyzed how the Bangkog Metropolitan Administration (BMA) incorporated the concept of resilience into its Bangkok Resilience Strategy. The work compared the perspectives of insiders (policymakers and flood experts) and outsiders (local communities, civil society, and the media).

Insight from insiders revealed how the resilience concept was interpreted by Thai policymakers to structure the policy framework for operationalizing flood resilience in Bangkok. However, outsiders perceived the resulting framework as prioritizing economic growth and structural flood protection measures at the cost of flood adaptation and the needs of vulnerable communities. The study ultimately suggested that other 100RC cities develop more inclusive resilience-building processes.

Khunwishit et al. (2018) assessed flood resilience in Thai municipalities using the UNDRR 10 essentials (or MCR) framework and the concept of the Chief Resilience Officer. The study reported that municipalities have made moderate progress. Categorizing resilience factors into psychological, infrastructural, social capability and social capital, managerial and organizational, and cultural factors, the study focused on leadership, classified under the managerial and organizational category.

To assess disaster resilience leadership, the study developed and administered a questionnaire to local leaders. The questionnaire included sections on respondent information, the 10 Essentials, and disaster resilience leadership.Respondents were asked to rate progress on achieving the 10 Essentials and their disaster resilience leadership capabilities on a scale from 1 to 5. These scores were used to create FRI scores and scores for new index, the Disaster Resilience Leadership Index (DRLI).

The study found a significant positive correlation between disaster resilience leadership and progress in building flood resilience, highlighting the crucial role played by local government leaders.

Similarly, Langkulsen et al. (2022) assessed the resilience and coping capacities of communities in Krabi and Nakhon Si Thammarat provinces with regard to various hydrometeorological hazards. The work developed socio-economic resilience scores and coping capacity index scores for each district in these two provinces by integrating skills (soft capacity) and availability of structural resources (hard capacity). Social and economic data were also collected to reflect the social and economic dimensions of resilience, and the exposure sub-indicator was scored using population density metrics. Soft coping capacity was defined as the literacy rate and hard coping capacity was defined as access to hospitals at different administrative levels and telecommunication resources. The exposure and vulnerability measures were also scored on a scale from 0 to 5. Coping capacity was assigned a 0 or a 1 based on availability.

Resilience to hydrometeorological hazards was thus defined as a function of exposure, vulnerability, and coping capacity. Combining the exposure and vulnerability variables, socioeconomic resilience index scores ranged from 0 to 45, with lower scores representing greater resilience. Coping capacity scores ranged from 0 to 4, with higher scores indicating greater coping capacity.

3.2.4 Indonesia

Indonesia faces significant flood risks in its cities. The World Bank approved the USD 400 million National Urban Flood Resilience Project (NUFReP) in 2022 to address this challenge. The project focuses on improving national and municipal flood risk management capacity through flood risk analytics and planning, urban flood resilience measures, and program management and implementation support.

Indonesia recognizes the importance of spatial planning in disaster resilience, integrating land-use zoning and regulations into detailed spatial plans. The country's overall national urban resilience planning framework is called the New Urban Agenda. However, Afriyanie et al. (2022) highlights that these plans alone may be insufficient. The study found that the effectiveness of spatial plans in reducing flood risk depends on their implementation and the comprehensiveness of flood management measures included.

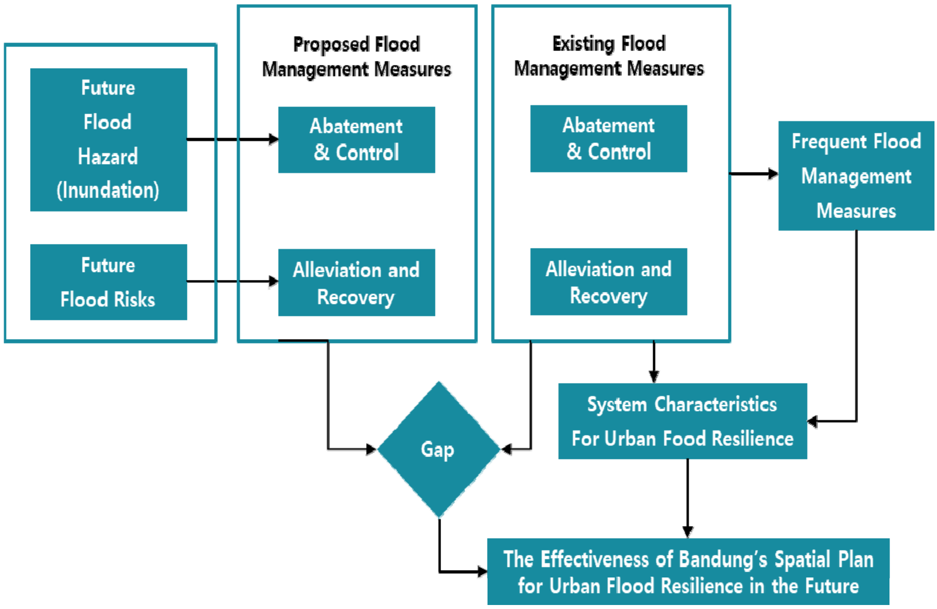
A national report on the voluntary implementation of New Urban Agenda revealed notable efforts to enhance the resilience of urban development both inland and in coastal areas through the use of tools like early warning systems, multi-hazard mapping, and spatial planning (Ministry of Public Works and Housing, 2021).

The aforementioned Afriyanie et al (2022) further explored the effectiveness of flood management measures in the capital city of West Java by analyzing the city's spatial plan through the lens of urban resilience characteristics.

The analysis focused on two overarching themes: flood risk reduction measures, and urban system resilience characteristics. for the former, these include catchment management, river maintenance, and floodplain interventions.

The approach used by the study to identify, analyze, and report patterns in the national plans is visualized in Figure 19.

Figure 19. Understanding urban flood resilience in an Indonesian city's spatial plan



Source: The authors.

Santosa et al. (2023) proposed a framework to understand urban resilience in flood-prone areas of Indonesia. The study employs a mixed methodology, combining quantitative data qualitative insights from in-depth interviews with neighborhood leaders. The quantitative data considers seven factors influencing disaster resilience based on the literature:

a. Social factors: Social status in the community, education, occupation, tenure in the community

b. Economic factors: Electricity consumed per month, number of family members, house ownership status, motorized vehicles ownership

c. Home environment factors: Type of house, number of floors, elevation difference between house and road, location of drainage canals

d. Communications and information factors: Urgency of flood prone zoning, urgency of flood early warning systems, information about flood rescue camps, pre-flood communication

e. Social capital: Normal participation in neighborhood activities, social cohesion, willingness to provide food and medicine during flood events, neighborhood cooperation during floods

f. Institutional factors: Government performance, non-government performance, quality of public-private cooperation between them, quality of aid distribution

g. Risk perception: Perception of the relationship between socioeconomic activities and floods, perception of relationship between waste disposal and floods, perception of the advantages of rainwater harvesting, perception of residual flood risk

The collected data are normalized using the min-max normalization technique and assigned a value between 1 and 0. The AHP technique is used to assign weights to the different factors contributing to flood resilience based on expert judgment from disaster management experts. Consultations were held with five Indonesian experts in the fields of geography, psychology, and disaster management. A pairwise comparison of indicators was performed on a scale of 1-9 using the Saaty scale. Multiple indicators were then aggregated into a single measure representing a complex societal issue.

3.2.5 Philippines

In 2023, the ADB approved a USD 303 million loan to the Philippines to boost the flood resilience (ADB, 2023). The project targets three major river basins and aims to reduce the risk of floods and mitigate climate change risks and protect people and their livelihoods. This project aims to strengthen the country's ability to manage flood risk through trainings for government officials, the installation of weather and flow monitoring equipment, the implementation of a flood warning system, and the introduction of an asset management information system.

The Philippine Red Cross and the International Federation of Red Cross and Red Crescent Societies (IFRC) collaborated with communities in the Philippines as part of a joint project to understand the flood resilience using the FRMC framework developed by the Zurich Flood Resilience Alliance (2022).

Tendero (2023) investigated flood risk resilience of urban households residing along the banks of the Tumaga River in Philippines. The study employed a cross-sectional design, collecting data at a single point in time using the following methods:

Surveys: A structured questionnaire assessed demographics (age, gender, education, occupation, and household size), socioeconomic factors (household income, resource access, ownership of flood protection measures), and perceptions on the likelihood and severity of flood events, preparedness, coping strategies and government interventions.

In-depth interviews: Face-to-face talks with selected households explored lived experiences, the recovery process, government response, and suggestions for improvement.

Focus group discussions: Discussions with community members living along the Tumaga River addressed community resilience, challenges, needs, and collaborative solutions.

Razafindrabe et al. (2015) proposed a framework to assess and evaluate flood resilience of the communities of the Laguna Lake region. This framework utilizes a set of biophysical and socioeconomic indices based on the Climate Disaster Resilience Index (CDRI) methodology. The indices encompass five categories: the biophysical environment (reflecting actual risks), the built environment, the social environment, the economic environment, and the institutional environment.

Data collection was performed through surveys in the area under study. Respondents (community leaders) were asked to rank the relative importance of each of the four components on a scale of 1 to 5, with 1 being least important and 5 being very important. These rankings were used to compute weighted mean index scores for each component. The overall FDRI score for each community is obtained by combining the risk-based FDRI (biophysical dimension) score with the built, social, economic, and institutional environment scores (see Table 13).

The overall flood resilience index can be calculated as follows.

$$FDRI \qquad \text{Equation (2)}$$

Table 13. Indicators used in Razafindrabe et al. (2015)

Indicators	Components
Built environment	- Electricity - Water - Sanitation and solid waste disposal - Road network - Housing and land use
Social environment	- Population - Health - Education and awareness - Social capital - Community disaster preparedness
Economic environment	- Income - Employment - Household assets - Finance and savings - Budget and subsidy
Institutional environment	- Disaster management - Mainstreaming of Disaster Risk Reduction and Climate Change Adaptation - Institutional collaboration with other organizations and stakeholders during a disaster

Source: Razafindrabe et al. (2015), p.12.

3.3 Governance of floods and disasters

Several countries have established national agencies to oversee disaster risk reduction and management (DRRM). These agencies play a crucial role in coordinating preparedness, response, prevention, mitigation, and recovery efforts.

In Indonesia, the National Agency for Disaster Management (BNPB) leads disaster recovery efforts. The BNPB supports provincial and municipal agencies in conducting risk analysis, mapping, and training, and also leads key initiatives including the Disaster Resilient Village program (UNISDR, 2013).

The National Risk Disaster Risk Reduction and Management Council (NDRRMC) is the primary body tasked with coordinating national DRRM activities in the Philippines. It is charged with handling preparedness, response, prevention, mitigation, rehabilitation, and recovery programs (CFE-DM, 2021).

In Afghanistan, the Afghan National Disaster Management Authority (ANDMA) is the primary body responsible for the country's DRRM activities (UNDRR, 2020). A 2017 World Bank report maps the potential impacts of floods at the national level for the country (The World Bank, 2017).

The UN has developed a flood response plan for Vietnam, aiming to deliver immediate lifesaving assistance to people in need through collaboration with the government, ensuring access to critical services and multi-sectoral assistance (Malhotra et al., 2020). Huong et al. (2022) summarizes the challenges of DRR and climate change policies in Vietnam.

In India, flood management involves a two-tiered institutional structure with central and state governments involved at various levels. The central government formulates policies, establishes task forces and committees to guide the states, and provides financial and technical assistance to the states through various eligibility schemes. The central government coordinates its financial assistance to state governments through the Flood Management Plan (FMP). The primary coordinating authority is the Department of Water Resources, River Development and Ganga Rejuvenation under the Ministry of Jal Shakti. The central government has also established dedicated flood control organizations to monitor flood-related issues, including the Central Water Commission (CWC), the Ganga Flood Control Commission (GFCC), the Brahmaputra Board, and the National Disaster Management Authority (NDMA), among others.

State governments are responsible for planning, constructing, and maintaining and operating all flood control and mitigation work. Some of them have set up a state flood control board that manages all flood-related issues. In most of the cases, irrigation departments function as the nodal agency for water resources management and planning, and Public Works Departments (PWD) are typically responsible for constructing and maintaining flood control structures. State governments are also charged with coordinating rescue, relief, and rehabilitation measures, which are logistically and financially supported by the central government.

India is gradually shifting its attitude to disaster management, transitioning from a relief-centric approach to a comprehensive strategy encompassing prevention, mitigation, preparedness, response, relief, reconstruction, and rehabilitation. The NDMA is the apex body for disaster management in India.

3.4 SWOT analysis of flood resilience policies

In this section, we analyze the strengths, weaknesses, opportunities, and threats (SWOT) of flood resilience projects in a handful of Asian countries based on an examination national plans, independent studies, and the performance of various flood projects.

Table 14. SWOT analysis of Asian countries' disaster risk reduction plans with respect to flood resilience

SWOT	Content
Strengths	· Most countries have recognized the need for both structural and non-structural measures to reduce disaster risk in their national plans and policies. · The majority of countries have embraced disaster risk reduction under international frameworks such as the Sendai Framework, signifying a unified global effort towards increased resilience and risk reduction. · The prioritization of early warning systems and community-based disaster management demonstrates proactive approach to preparedness and mitigation at the community level.
Weaknesses	· Very few explicitly outlined flood resilience strategies in their national disaster plans, potentially creating gaps in addressing flood-related challenges. · The allocation of responsibilities between the government and local communities regarding flood resilience is often ambiguous, hindering effective implementation.
Opportunities	· Research in many countries has assessed flood resilience at the local level. · Organizations like the Flood Resilience Measurement for Communities (FRMC) have developed tools to estimate different aspects of flood resilience across varying administrative scales. · National plans and municipal strategies are becoming more proactive regarding flood resilience. · International institutions such as ADB and World Bank (among others) are investing millions in flood resilience projects.
Threats	· The concept of flood resilience can be ambiguous, making it a challenge to define and assess its effectiveness within DRR strategies. · Evaluating the effectiveness of flood resilience strategies requires methodologies and a comprehensive understanding of factors involved.

Source: The authors.

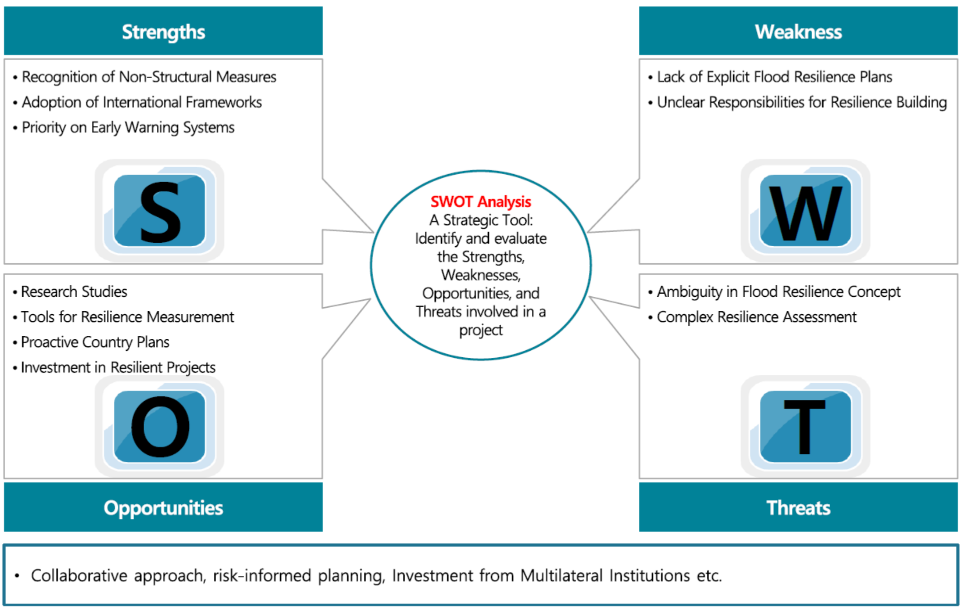
Our SWOT analysis highlights three key areas for improvement.

1. Government-community collaboration: Effective collaboration between government and local communities is crucial to ensuring the success of resilience-building initiatives. Clear and coordinated efforts are critical.

2. Integrated funding and policy structures: Integrating funding mechanisms into policy frameworks helps support comprehensive resilience-building efforts, ensuring sustained progress and impact.

3. Risk-informed planning: A risk-informed approach strengthens flood resilience by enabling proactive and evidence-based measures to mitigate flood threats.

Figure 20. SWOT analysis of flood resilience in Asian countries' plans



Source: The authors.

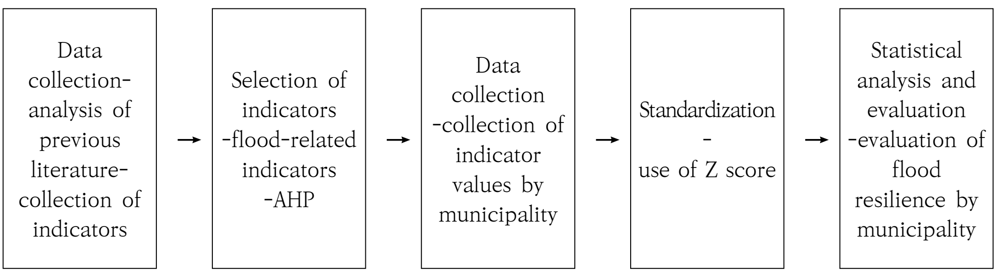
4 Building National Flood Resilience Indicators

4.1. Selection of flood resilience indicators

This chapter outlines the development of a flood resilience index of Korea. It details the selection of flood resilience-related indicators, data collection methods, the actual construction of the index, and evaluation using the established indicators and index. Figure 21 depicts a flowchart describing the process of developing the flood resilience index.

We begin by analyzing the existing literature to collect indicators related to urban resilience, disaster resilience, climate resilience, and flood resilience. Indicators highly relevant to flood resilience were selected from this pool. We then employed Analytic Hierarchy Process (AHP) method to refine the selection. We incorporated feedback on the selected indicators and classified them based on the 4Rs framework (Redundancy, Robustness, Rapidity, and Resourcefulness). Following the selection process, we chose pilot areas to evaluate the indicators. Data for each indicator was collected and aggregated for the pilot areas. Finally, we standardized the data to facilitate an analysis and comparison of flood resilience in the pilot areas.

Figure 21. The development process of the Korean flood resilience index



Source: The authors.

As previously mentioned, we considered a broad range of resilience concepts, including urban resilience, disaster resilience, and climate resilience. However, indicators focused solely on flood vulnerability were excluded, as flood resilience emphasizes rapid recovery and flood prevention after a flood event. The process yielded a shortlist of indicators from which 20 final indicators were chosen. Those indicators are shown in Table 15 below.

Table 15. Flood resilience indicators based on 4R classification

Category	Subcategory	Item	Flood resilience indicators
Redundancy	Infrastructure for temporary evacuation	Temporary shelter facilities	Number of disaster refugee accommodations + number of civil defense evacuation facilities (places)
	Resource availability	Public official capacity for disaster management	Number of public officials responsible for river management (people) (river management, firefighting, environment, outsourced workers)
		Budget for disaster and emergency management fund	Disaster management fund (KRW 1,000,000)
		Flood insurance	Status of storm and flood insurance coverage (Case)
	Temporary flood prevention facilities	Detention and retention facilities	Number of detention basins(EA) by municipality(si/gun/gu)
		Drainage facilities	Number of pumping stations(EA)
Robustness	Flood impact facilities	Water supply and sanitation service facilities (public sewerage)	Public sewerage penetration (%) by municipality (si/gun/gu)
		Water supply and sanitation service facilities (water supply)	Water supply penetration (%) by municipality (si/gun/gu)
		River bank improvement	River bank length(m)

Table 15. (Continued)

Category	Subcategory	Item	Flood resilience indicators
	Natural environment	Area of parks and green space	Green space (%)
		River area (%)	River area (m^2)/area of administrative division (km^2)
Rapidity	Resource transportation	Transportation network	Road length per national land area (km/km^2)
	Information system	Flood risk awareness	disaster drill and preparedness budget (KRW 1,000,000)
		Disaster alert	Disaster and safety communications text message (times)
		Warning system and communications network	Disaster early warning system(EA)
	Disaster response service	Medical service	Healthcare workers (people)
Resourcefulness	Support system	Volunteers	Number of volunteers(people)
		Citizen corps for disaster prevention	Local autonomous disaster prevention corps(people)
	Financial resources	Fiscal self-reliance of municipalities	Fiscal self-reliance (%)
		Gross Regional Domestic Product (GRDP)	GRDP per capita (KRW 1,000,000/person)

Source: The authors.

Table 15 presents a classification of flood resilience indicators based on the 4Rs framework: Redundancy, Robustness, Rapidity, and Resourcefulness, constituting the definition of flood resilience. While we considered categorizing indicators based on their physical, institutional, social, and economic characteristics, for this study we chose to classify the indicators based on the 4Rs framework for this study.

The stages of flood resilience development typically involve prevention, resistance, response, recovery, and learning. Redundancy, particularly relevant to prevention and response stages, refers to the ability to compensate for any losses sustained during a flood event. Examples include evacuation infrastructure and temporary shelter, resource stockpiles, and diverse economic/communication options.

Robustness refers to the ability of a system to withstand external shocks without functional degradation or loss. This component of resilience is particularly crucial for the prevention, resistance, and learning stages. It includes the natural environment's ability to protect against disasters, the Robustness of infrastructure and buildings, and a strong economic structure.

Rapidity, particularly relevant for the prevention, recovery, and learning stages, is the ability of a system to swiftly meet needs and priorities. This includes the prompt communication of information, the transportation of necessary resources, and effective management.

Resourcefulness refers to the capacity of a community to identify problems and mobilize resources in the event of a disruption. Resourcefulness is particularly relevant for the response, recovery, and learning stages. It includes the ability to secure and effectively manage relief supplies, financing, and human resources.

Detailed descriptions of each indicator and references to previous studies can be found in Section 4.3. Data collection.

4.2. Selection of pilot areas

This section describes the process used for selecting pilot areas to evaluate flood resilience indicators we described in the previous section.

In 2022, Typhoon Hinnamnor caused significant damage and localized heavy rainfall events across Korea. The government designated 21 regions across the country as special disaster areas to expedite recovery efforts. The Framework Act on the Management of Disasters and Safety outlines the process for designating special disaster areas. Following deliberation by the Central Safety Control Committee (Central Committee), the head of the Central Countermeasures Headquarters (CCH) can recommend the president designated certain areas as disaster zones based on the scale of the magnitude of the event. Table 16 details criteria used to designate special disaster areas. Local authorities can request the

CCH to designate a special disaster area if a disaster that meets meeting established criteria occurs within their jurisdiction.

Upon recommendation from the CCH, the President can declare a special disaster area. Table 17 outlines the specific scales requiring a presidential declaration as defined by the Presidential Decree.

Table 16. The designation of special disaster areas according to the Framework Act on the Management of Disasters and Safety

Category	Description of the Provision
Framework Act on the Management of Disasters and Safety	Article 60 (Declaration of Special Disaster Areas) (1) Where a disaster, the scale of which is prescribed by Presidential Decree, has occurred, and as a result thereof, the maintenance of national security or social order is seriously affected, or it is deemed necessary to take special measures to effectively control the damage, or the request of a local countermeasure headquarters under paragraph (3) is deemed reasonable, the head of the Central Countermeasure Headquarters may recommend the President of the Republic of Korea to declare the relevant area as a special disaster area following deliberation by the Central Committee. (2) The President in receipt of the recommendation for declaration of a special disaster area under paragraph (1) may declare the relevant area as a special disaster area. (3) The head of a local countermeasure headquarters may request the head of the Central Countermeasure Headquarters to recommend the declaration of a special disaster area if any cause referred to in paragraph (1) occurs due to a disaster occurring in the area under his or her jurisdiction.

Source: Korean Law Information Center, “Framework Act on the Management of Disasters and Safety”.

Table 17. Enforcement Decree of the Framework Act on the Management of Disasters and Safety

Category	Description of the Provision
Enforcement Decree of the Framework Act on the Management of Disasters and Safety	Article 69 (Scope and Declaration of Special Disasters) ①"Disaster, the scale of which is prescribed by Presidential Decree" in Article 60 (1) of the Act means any of the following: 1. Natural disasters that have caused damage exceeding 2.5 times the base amount of damage subject to subsidization from the National Treasury pursuant to Article5 (1) of the Regulations on the Standards for Payment of Expenses for Natural Disaster Relief and Recovery 1- 2. Natural disasters that have caused damage to Eup/Myeon/Dong under the jurisdiction of Si/Gun/Gu entitled to subsidization from the National Treasury under Article 5(1) of the Regulations on the Standards for Payment of Expenses for Natural Disaster Relief and Recovery, exceeding 1/4 of the base amount of damage subject to subsidization from the National Treasury pursuant to any subparagraph of the same paragraph 2. Social disasters deemed to require support at the State level because it is difficult to manage disasters with the administrative or financial capabilities of the relevant local government wherein the disasters have occurred; 3. Other disasters deemed to require special measures at the State level for the effective control of serious damage, including a loss of the basis of livelihood, and restoration therefrom, due to the occurrence of a disaster. ②Where the President declares a special disaster area pursuant to Article 60 (2) of the Act, the head of the Central Countermeasure Headquarters shall determine and publicly announce the detailed scope of the special disaster area.

Source: Korean Law Information Center, “Enforcement Decree of the Framework Act on the Management of Disasters and Safety”.

The Framework Act on the Management of Disasters and Safety also establishes a fiscal capacity index (FCI) for municipalities. For the purposes of this paper, we classify municipalities in Korea into three categories: si, gun, and gu, roughly corresponding to city, county, and district. FCI scores reflect a local government’s ability to manage administrative expenditures with its revenue sources. An FCI lower than one suggests significant difficulty in covering basic administrative expenses.

Table 18 presents the Standards for Payment of Expenses for Natural Disaster Relief and Recovery, as referenced in the Act.

Table 18. Natural disaster relief and recovery cost burdens: Regulations and standards

Fiscal capacity index (FCI) by municipality (*si*/*gun*/*gu*)	The base amount of damage subject to subsidization from the National Treasury * 2.5
FCI < 0.1	18 billion * 2.5 = 45 billion (in units of KRW)
0.1 ≤FCI < 0.2	24 billion * 2.5 = 60 billion (KRW)
0.2 ≤FCI < 0.4	30 billion * 2.5 = 75 billion (KRW)
0.4 ≤FCI < 0.6	36 billion * 2.5 = 90 billion (KRW)
FCI ≥0.6	42 billion * 2.5 = 105 billion (KRW)

Sources: Korean Law Information Center, “Regulations on Natural Disaster Relief and Recovery Cost Burden Standards”.

Typhoon Hinnamnor caused significant damage in several regions. The cities of Gyeongju and Pohang in the province of North Gyeongsang were the first regions to be designated as special disaster areas.[3] They were followed by Duseo-*myeon* (a *myeon* is rural/exurban administrative unit) and Onsan-*eup* (an *eup* is similar to *myeon*), both of which are located within Ulju-*gun*, a district of the city of Ulsan. Yokji-*myeon* and Hansan-*myeon*, both areas in the city of Tongyeong, as well as Irun-*myeon* and Nambu-*myeon* in the city of Geoje, were also declared as special disaster areas. Both Tongyeong and Geoje are located in the province of South Gyeongsang.[4]

Localized heavy rainfall events also led to the several areas being declared as special disaster areas. Initially declared special disaster areas included two major districts in Seoul, as well as areas in the surrounding province of Gyeonggi. Other districts in the provinces of Gangwon and South Chungcheong were also declared special disaster areas, with smaller *eup*, *myeon*, and *dong* subdivisions of those municipalities also affected.

The second wave of declarations included more parts of Seoul and the province of Gangwon. The city of Yeoju in the province of Gyeonggi was initially declared

3) SBS NEWS(September 8, 2022), “윤 대통령, ‘힌남노 피해’ 포항·경주 특별재난지역 선포”, accessed on July 31, 2023.

4) 한겨레(September 28, 2022), “윤 대통령, 태풍 ‘힌남노’ 피해 울산·통영·거제 특별재난지역 선포”, accessed on July 31, 2023.

a partial disaster zone, but later, a the entirety of the city was declared a special disaster area.[5)]

As of June 2023, or one year after the flooding caused by Typhoon Hinnamnor and localized heavy rainfall events, the only areas to have fully recovered are the Seoul districts of Dongjak-gu, Gwanak-gu, and Yeongdeungpo-gu. Despite the fact that municipalities that were declared as special from disaster areas on the same day were provided with grants and subsidies the national, provincial, and local governments, we can observe significant disparities in municipalities' speed of recovery. To better understand the factors influencing the pace of recovery, we analyzed the areas designated as special disaster areas in 2022. However, data collection at the *eup*, *myeon*, and *dong* levels proved challenging, so we perform this analysis at the *si* (city), *gun* (county), and *gu* (district) level. Table 19 details the criteria used to select these zones and categorizes them based on the extent of flood damage suffered.

Table 19. Designated special disaster areas

Natural disaster	2022 Special disaster areas	
Typhoon Hinnamnor	1st	North Gyeongsang Province, city of Gyeongju, city of Pohang
	2nd	Ulsan Metropolitan City: Duseo-*myeon*, Onsan-*eup* (within Ulju-*gun*) South Gyeongsang province: Yokji-*myeon*, Hansan-*myeon* (within city of Tongyeong); Irun-*myeon*, Nambu-*myeon* (within city of Geoje)
Localized heavy rainfall	1st	Seoul: Gwanak-*gu*,·Yeongdeungpo-*gu*, Gaepo 1-*dong* (in Gangnam-*gu*) Gyeonggi province: cities of Seongnam and Gwangju; Yangpyeong-*gun*, Geumsa-*myeon* and Sanbuk-*myeon* (within city of Yeoju) Gangwon province: Hoengseong-*gun* South Chungcheong province: Buyeo-*gun*, Cheongyang-*gun*
	2nd	Seoul: Dongjak-*gu*, Seocho-*gu* Gangwon province: Hongcheon-*gun* Gyeonggi province: Gocheon-*dong*, Cheonggye-*dong* (within city of Uiwang), Dongcheon-*dong* (within city of Yongin) South Chungcheong province: Cheongra-*myeon* (within city of Boryeong) Gyeonggi province: City of Yeoju

Source: The authors.

5) KBS 뉴스 (September 1, 2022), "서울 동작·서초 등 7곳 특별재난지역 추가 선포", accessed on July 31, 2023.

4.3. Data collection

Table 20 summarizes the data sources used to obtain the values for each proxy indicator. Statistical data was mainly collected from publicly available sources provided by various agencies and institutes. When these sources were unavailable, we utilized the Korean government's open information disclosure portal (open.go.kr) to request the necessary information directly from the relevant municipalities.

Table 20. Flood resilience indicator sources

Items	Flood resilience indicators	Source
Temporary shelter facilities	Number of disaster refugee accommodations + number of civil defense evacuation facilities + number of schools (places)	National Disaster and Safety Portal
Disaster management capacity of public officials	Number of public officials responsible for river management (people)	Public Data Portal
Budget for disaster and emergency management fund	Disaster management fund (KRW 1,000,000)	Disaster management fund settlement data from Local Finance 365 (Local Finance Integrated Open System)
Flood insurance	Status of storm and flood insurance coverage (cases)	Information Disclosure Portal (open.go.kr)
Detention and retention facilities	Number of detention basins (EA) by municipality (*si/gun/gu*)	open.go.kr, Korea Land and Geospatial Informatix Corporation (LX)
Drainage facilities	Number of pumping stations (EA)	Ministry of Environment (MoE) Public Sewerage Statistics
Water supply and sanitation service facilities (public sewerage)	Public sewerage penetration (%) by municipality (*si/gun/gu*)	Sewage Division, MoE
Water supply and sanitation service facilities (water supply)	Water supply penetration (%) by municipality (*si/gun/gu*)	Sewage Division, MoE

Table 20. (Continued)

Items	Flood resilience indicators	Source
River bank improvement	River bank length(m)	Water Resources Management Information System (WAMIS)
Area of parks and green space	Green space (%)	LX, Green space (%)
River area (%)	River area (m^2)/area of administrative division (km^2)	LX river area
Transportation network	Length of roads per square kilometer of land (km/km^2)	Ministry of Land, Infrastructure and Transport
Flood risk awareness	Disaster drill and preparedness budget (in KRW 1,000)	Disaster drill and preparedness budget data from the Local Finance 365 (Local Finance Integrated Open System)
Disaster alert	Disaster and safety communications text message (time)	Public Data Portal
Warning system and communications network	Disaster early warning system (EA)	Public Data Portal
Medical service	Healthcare workers (people)	Healthcare workers' statistics from the National Health Insurance Service
Volunteers	Number of volunteers (people)	Public Data Portal
Citizen corps for disaster prevention	Local autonomous disaster prevention corps (people)	Public Data Portal
Fiscal self-reliance of municipalities	Fiscal self-reliance (%)	Korean urban statistics from the Ministry of the Interior and Safety (MOIS)
Gross Regional Domestic Product (GRDP)	GRDP per capita (in KRW 1,000,000/person)	Statistics section on the website of individual municipalities, Demographic statistics from Statistics Korea

Source: The authors.

To select flood resilience indicators, we reviewed the extant research on flood damage characteristics and disaster resilience indicators. We identified the factors with the strongest influence on each component of flood resilience, and drew upon data on the relevant municipalities to assess the extent of the flood impact.

Initially, our analysis of the case studies generated a broad range of potentially useful indicators. However, we eventually consolidate this larger group into a selection of just 20 indicators, and categorized them based on the 4R framework.

Table 21 details the characteristics of each indicator and their references.

Table 21. Description of key flood resilience indicators

Classification			Brief description	References
Category	Subcategory	Item		
Redundancy	Infrastructure for temporary evacuation	Temporary shelter facilities	- These facilities can be used as a shelter for evacuation or temporary dwellings in the event of a disaster. - When setting indicators related to disaster prevention facilities, the capacity of the evacuation facilities is used.	Heo (2017); Jeon and Lee (2018)
	Resource availability	Public officials' disaster management capacity	- The number of public officials per 1,000 population indicates the capacity for the provision of civil/administrative services to the public in the event of a disaster. - The larger the number of public officials per 1,000 population, the greater the capacity to cope with and respond to natural disasters. - The number of fire officers represents the manpower capacity to be deployed for rescue and emergency services in the event of a disaster, and a higher ratio of fire officers increases disaster resilience. - Resilience increases with the number of public officials responsible for disaster management policy.	Park and Song (2014); Park and Song (2015); Park (2016); Lee and Kwon (2017)
		Budget for disaster and emergency management fund	- Although the disaster prevention/civil defense budget is not a budget directly allocated for natural disasters, it indicates the level of effort that individual municipalities devote to disaster risk management.	Choi et al. (2022)
		Flood insurance	- The storm and flood insurance system is a key indicator of total resilience capacity (related to recovery expenses).	Kang et al. (2013)
	Temporary flood prevention facilities	Detention and retention facilities	- In cases of complex human and property damage, the presence/absence of detention and retention facilities was found to be important.	Kim and Hong (2021)
		Drainage facilities	- Problems with sewers and rainwater pumping stations accounted for 56.7% of the causes of flood damage in Seoul.	Lee et al. (2006)

Table 21. (Continued)

Classification			Brief description	References
Category	Subcategory	Item		
Robustness	Flood impact facilities	Water supply and sanitation service facilities (public sewerage)	- Resilience increases with higher water supply/public sewerage penetration (%). - These facilities are crucial in disaster recovery for ensuring the supply of clean water, a basic necessity for human survival. - Public sewerage must be maintained in good condition to ensure safety from flood damage.	Park (2016); Park and Yoon (2017); Mottahedi, A. et al. (2021)
		Water supply and sanitation service facilities	- A systematic review reported that the number of prior studies on water supply networks is second only to energy systems and transportation.	
		River bank improvement	- Erosion of the river bank, loss of reservoir, and inadequacy in the cross-sectional area of the river bank are the main causes of aggravated flood damage. - Lack of river improvement work and inadequate length of river bank are major factors influencing flood damage.	Park et al. (2005)
	Natural environment	Area of parks and green space	- Green space serves as a buffer zone or area for absorbing the damage from disasters. - Parks and green spaces protect residential and community spaces from river flooding and affect sediment yield and the rainwater infiltration structure, thereby mitigating flood risk. - The larger the area of green space, the higher the disaster resilience. - Due to the nature of their use, parks and green spaces are likely to be located in the suburban area or on the outskirts of a region. - Green space reduces the physical dimension of flood vulnerability by improving the permeability of rainwater.	Park and Song (2014); Park (2016); Park and Yoon (2017); Kim and Hong (2021); Kim (2021); Choi et al. (2022);
		River area (%)	- The larger the river area, the more vulnerable the region is to storm and flood damage, and a large river area lowers the flood resilience of the applicable region. - Most studies in the literature use river length instead of river area as a variable, making it difficult to collect quality data on river area (%) - River area (%) is also used as a proxy indicator.	Park (2016); Park and Yoon (2017)

Table 21. (Continued)

Classification			Brief description	References
Category	Subcategory	Item		
Rapidity	Resource transportation	Transportation network	- To enable immediate normalization of building and equipment functionality after a disaster, the rapid transportation and delivery of material, human, and technical resources is critical. - Transportation infrastructure plays an arterial role in transporting material resources needed for post-disaster response and recovery.	Park (2016)
	Information system	Flood risk awareness	- The number of people with higher education is a parameter representing the acquisition of information about flood risk. - The ratio of expenditure on education in individual municipalities is an indicator of the adaptive capacity of citizens in the community. - The higher the investment rate in education, the greater the social capacity for disaster response. - The resilience of the community is higher with an increasing percentage of people with higher education.	Park and Song (2014); Kim and Hong (2021)
		Disaster alert	- Adaptive capacity refers to how quickly a system is able to recover from climate impact. There are social, economic, and environmental dimensions to capacity. - Adaptive capacity includes policy and institutional factors such as economic resources and crisis management programs. - Institutional capacity includes a disaster prevention/pre-warning system.	Koh and Kim (2010)
		Warning system and communications network		
	Emergency response service	Medical service	- The number of medical and healthcare workers per 1,000 population represents the capacity for medical service responses in the event of a disaster. - The higher the indicator value of medical service, the greater the social response capacity. - Coordinated actions for human casualties are carried out in the event of a disaster.	Park and Song (2014); Park and Yoon (2017)

Table 21. (Continued)

Classification			Brief description	References
Category	Subcategory	Item		
Resourcefulness	Support system	Volunteers	- It is assumed that Resourcefulness improves with an increasing number of volunteers. - Citizen volunteers have the greatest impact on improving regional resilience.	Park and Song (2015); Choi et al. (2021)
		Citizen corps for disaster prevention	- Maintaining public order and safeguarding people in a chaotic, post-disaster environment. - Disaster response capabilities are improved through community-based autonomous disaster prevention with the participation of citizens.	Jeong and Lee (2016); Lee and Kwon (2017)
	Financial resources	Fiscal self-reliance of municipalities	- Fiscal self-reliance of municipalities refers to a budget that can be used at the discretion of the individual local government. - Regions with high fiscal self-reliance have a high capability to cope, even if damage occurs, and can provide financial support. - Border regions tend to suffer significant physical and economic damage, including population decline, due to stagnant regional economic development, partially owing to their geographical vulnerability to disasters.	Park and Song (2014); Arup (2014); Park (2016); Park and Yoon (2017); Jeong and Byun (2022);
		GRDP	- GDP (GRDP) is used as a proxy variable, representing the adaptive capacity of economic resilience.	Yoo and Kim (2008)

Source: The authors.

Here, we will briefly explore the characteristics of some of the selected flood resilience indicators. In general, regional topography and infrastructure influence the severity and impact of flood damage.

Large river areas tend to increase vulnerability to storms and flooding (Park and Yoon, 2017), while parks and green spaces allow for more rainwater infiltration, which mitigates flood risks. A high ratio of green space to built-up structures is associated with greater preparedness against flood risk and damage, contributing to greater overall disaster resilience (Park and Yoon, 2017).

The same applies to regional infrastructure. River banks protect against floods, and so inadequate erosion control and other forms of river bank management can aggravate flood damage. In addition, drainage systems and detention/retention basins are critical to storing rainwater and preventing floods from reaching urban areas during heavy rainfall events.

Forecasts and pre-warnings also play a vital role in reducing storm and flood damage. Regional projects and programs (river improvement projects, disaster prevention projects, restoration projects, and river maintenance projects) undertaken by public officials also contribute to the prevention of river inundation. In addition, Choi et al. (2022) found that issuing prompt evacuation warnings and orders immediately after detecting a flood event is crucial to minimizing casualties. The study argued that regional warning systems, implemented immediately after a disaster occurs, can represent can be used as a proxy to represent the disaster response capabilities of a local government. Warning systems and communications networks, which include automatic voice notification systems, rainfall gauges, water level monitoring systems (or sensors), disaster monitoring CCTV cameras, automatic weather systems (AWS), and disaster alert dashboards can be employed to facilitate the prompt evacuation of residents when river water levels reach a critical threshold.

While past studies (Kim and Hong, 2021; Park, 2016; Lee, 2015) have often used education levels as an indicator, for this research, we focus on disaster drills and preparedness budgets to reflect a community's direct investment in flood preparedness.

For one, the availability of medical services plays a vital role in the post-flood recovery process. For this study, we consider healthcare workers affiliated with community health centers who can provide medical assistance to those affected by floods. In addition, transportation infrastructure and sanitation facilities are crucial for transportation patients, delivering resources, and ensuring the rapid normalization of social infrastructure. Access to clean water is yet another critical need highlighting the importance of water supply and public sewerage facilities (Park, 2016).

Sheltering is another important aspect of recovery. Schools and designated evacuation facilities serve as temporary shelters for flood refugees (Heo, 2017). Local disaster prevention corps and volunteers are instrumental to maximizing the effectiveness of disaster preparedness, response, and recovery efforts. These groups perform tasks ranging from providing education and guiding evacuation to managing shelters and procuring emergency supplies (Choi et al,. 2021).

Data on the number of volunteers can be obtained through two sources: 1365 (available at 1365.go.kr, a volunteer portal) and the Volunteer Management System (VMS). However, municipalities have difficulty accessing data on VMS-registered volunteers because the system is managed by the Ministry of Health and Welfare. For this reason, we used data from the 1365 portal.

The fiscal capacity of local governments determines their ability to pay disaster relief and recovery expenses (Jeong and Byun, 2022). The fiscal capacity of a municipality, can be evaluated using three indicators: the fiscal self-reliance rate, the settled value of the local government's disaster management fund, and gross regional domestic product (GRDP) per capita. Fiscal self-reliance (%) data for each municipality was extracted from urban statistics provided by the Ministry of the Interior and Safety (MOIS), were used.

The value of a government's disaster management funds is another important indicator of fiscal capacity. Choi et al. (2022) argued that measuring urban resilience requires a comprehensive evaluation that considers both economic and institutional dimensions, and an understanding of the natural environment. For this reason, the value of any given municipality's disaster fund serves as an indicator of its disaster response capacity. Money from the disaster management fund is disbursed to pay for disaster prevention activities, the construction and installation of disaster prevention facilities, and for performing research on the causes of disasters. For this paper, disaster management fund data was pulled from the Local Finance Integrated Open System.

In addition to the financial resources of municipalities, individual preparedness can also contribute to a rapid recovery after a flood event. Storm and flood insurance provides compensation that can be used to rebuild homes and businesses damaged by floods typhoons, or heavy rainfall. In this way, flood insurance policies can help individuals and communities get back on their feet after a disaster. For this study, we obtained data on storm and flood insurance coverage by municipality from the Korean government's open information disclosure portal (open.go.kr). Figures 22 to Figure 29 show the values of each indicator categorized under the 4R framework for each under study.

Table 22. Flood resilience indicator values by region

	SG-gu_1	SY-gu	SD-gu	SS-gu	SG-gu_2	GS-si	GG-si_1	GY-si_1	GY-si_2	GU-si	CB-si	GG-si_2	GP-si	GT-si	GG-si_3	GY-gun	GH-gun_1	GH-gun_2	CB-gun	CC-gun	UU-gun
Disaster refugee accommodation + civil defense evacuation facilities + number of schools	1.10	0.78	0.55	1.01	1.11	2.61	1.96	0.20	2.87	0.44	0.32	0.69	1.70	0.66	1.12	0.46	0.00	0.08	0.03	0.35	0.54
Number of public officials responsible for river management	0.75	0.78	0.64	0.86	1.71	1.11	0.71	0.27	1.81	0.27	0.22	0.90	1.61	0.33	0.34	0.38	0.23	0.22	0.09	0.00	0.70
Disaster management fund(KRW 1,000,000)	0.01	0.01	0.01	0.02	0.96	0.06	0.02	0.01	0.04	0.01	0.00	0.01	0.03	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.02
Status of storm and flood insurance coverage (case)	0.22	0.33	0.04	0.35	0.52	0.13	0.03	0.00	0.06	0.07	0.07	0.43	0.47	0.08	0.18	0.04	0.16	0.12	0.30	0.05	0.46
Number of detention basins	0.21	0.42	0.42	0.21	0.74	2.53	0.74	0.11	4.11	1.16	0.95	1.48	3.06	0.95	0.53	0.84	0.00	0.11	0.21	0.00	3.37

Table 22. (continued)

	SG -gu _1	SY -gu	SD -gu	SS -gu	SG -gu _2	GS -si	GG -si _1	GY -si _1	GY -si _2	GU -si	CB -si	GG-si_2	GP -si	GT -si	GG -si_3	GY -gun	GH -gun_1	GH-gun_2	CB -gun	CC -gun	UU -gun
Number of pumping stations	0.00	0.15	0.04	0.06	0.06	0.27	1.26	2.07	0.06	0.21	0.03	4.67	0.31	0.13	0.04	4.71	0.66	1.43	3.10	0.29	6.32
Public sewerage penetration (%)	9.61	9.61	9.61	9.61	9.61	9.53	8.81	6.35	8.15	9.51	4.50	8.44	6.57	6.80	6.55	5.36	2.98	5.24	2.24	0.00	8.44
Water supply penetration(%)	11.55	11.55	11.55	11.55	11.55	11.55	9.98	9.64	11.44	11.55	9.19	10.20	10.65	11.24	11.13	7.34	8.99	6.98	8.94	0.00	11.06
River bank length(m)	0.46	0.23	0.00	0.66	0.31	0.07	1.62	14.80	6.17	3.04	4.60	16.61	7.50	1.43	2.51	12.95	2.44	7.56	15.91	8.34	11.89
Green space (%)	2.46	1.63	0.00	3.20	1.54	4.40	5.84	5.18	5.43	5.28	3.66	5.50	2.89	3.93	3.71	5.87	3.32	5.00	5.66	4.17	4.24
River area/area of administrative division	0.31	0.00	0.77	4.66	1.44	9.07	2.09	9.32	6.25	5.48	4.64	8.27	1.81	2.20	2.16	7.21	3.24	5.81	5.37	6.99	0.00
Road length per national land area	3.12	4.63	4.38	2.38	3.20	1.33	0.26	0.25	0.27	0.99	0.00	0.23	0.34	0.64	0.35	0.15	0.14	0.11	0.00	0.00	0.18
Disaster drill and preparedness budget (KRW 1,000,000)	0.16	0.25	0.02	0.26	0.00	0.19	0.01	0.05	0.72	0.12	0.12	0.05	0.12	0.26	0.14	0.05	0.37	1.00	0.12	0.22	0.15

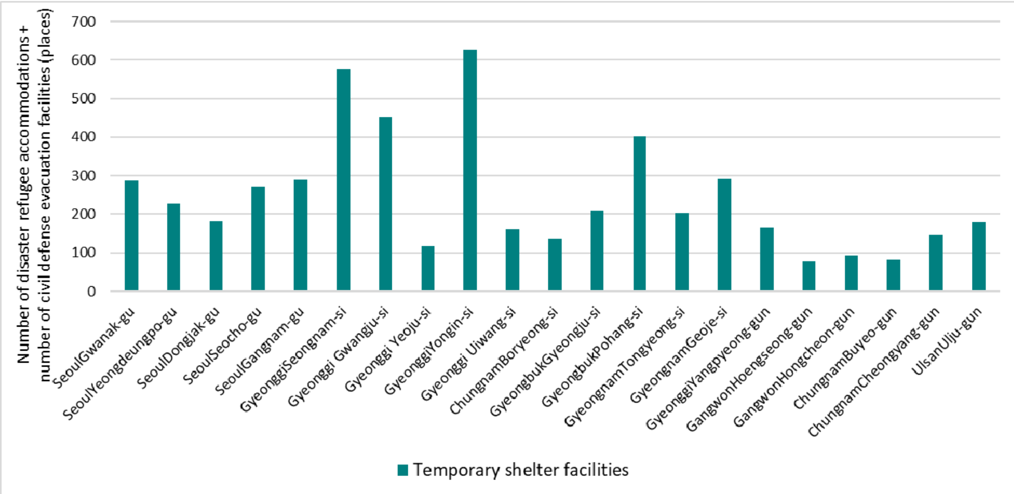
Table 22. (continued)

	SG-*gu*_1	SY-*gu*	SD-*gu*	SS-*gu*	SG-*gu*_2	GS-*si*	GG-*si*_1	GY-*si*_1	GY-*si*_2	GU-*si*	CB-*si*	GG-*si*_2	GP-*si*	GT-*si*	GG-*si*_3	GY-*gun*	GH-*gun*_1	GH-*gun*_2	CB-*gun*	CC-*gun*	UU-*gun*
Disaster and safety communications text message(times)	0.64	0.51	0.90	0.83	0.51	0.51	0.58	0.39	0.58	0.00	0.32	2.12	2.31	0.71	1.16	0.51	1.48	0.96	0.64	0.39	0.71
Disaster early warning system	0.70	0.36	0.81	0.25	0.26	0.84	1.60	0.78	3.60	0.00	0.09	3.76	0.81	2.47	4.01	1.60	0.49	2.85	2.24	0.10	2.66
Local health center staffing	2.54	2.93	2.75	3.88	4.27	7.65	2.12	2.04	7.52	1.68	0.71	0.58	3.38	0.58	0.65	2.41	1.10	1.00	0.34	0.00	0.10
Number of volunteers	0.81	0.71	0.60	0.86	1.46	2.75	0.59	0.27	2.22	0.35	0.22	0.51	1.24	0.15	0.52	0.18	0.00	0.05	0.06	0.01	0.47
Number of local autonomous disaster prevention corps	2.48	2.29	1.11	0.28	1.60	4.03	0.85	0.22	5.46	0.00	3.19	2.89	3.05	0.84	1.03	0.25	1.14	0.14	4.34	2.04	1.34
Fiscal self-reliance	1.14	3.12	2.09	5.42	5.54	5.91	2.98	1.30	4.40	3.01	0.48	1.16	1.97	0.32	0.85	0.83	0.22	0.22	0.00	0.03	2.79
GRDP	0.00	1.25	0.06	1.09	1.89	0.53	0.20	0.37	0.27	0.17	0.42	0.38	0.35	0.17	0.32	0.08	0.36	0.32	0.26	0.41	0.96

Note: SeoulGwanak-gu: SG-*gu*_1, SeoulYeongdeungpo-*gu*: SY-*gu*, SeoulDongjak-*gu*: SD-*gu*, SeoulSeocho-*gu*: SS-*gu*, SeoulGangnam-*gu*: SG-*gu*_2, GyeonggiSeongnam-*si*: GS-*si*, Gyeonggi Gwangju-*si*: GG-*si*_1, Gyeonggi Yeoju-*si*: GY-*si*_1, GyeonggiYongin-*si*: GY-*si*_2, Gyeonggi Uiwang-*si*: GU-*si*, ChungnamBoryeong-*si*: CB-*si*, GyeongbukGyeongju-*si*: GG-*si*_2, GyeongbukPohang-*si*: GP-*si*, GyeongnamTongyeong-*si*: GT-*si*, GyeongnamGeoje-*si*: GG-*si*_3, GyeonggiYangpyeong-*gun*: GY-*gun*, GangwonHoengseong-*gun*: GH-*gun*_1, GangwonHongcheon-*gun*: GH-*gun*_2, ChungnamBuyeo-*gun*: CB-*gun*, ChungnamCheongyang-*gun*: CC-*gun*, UlsanUlju-gun: UU-*gun*.

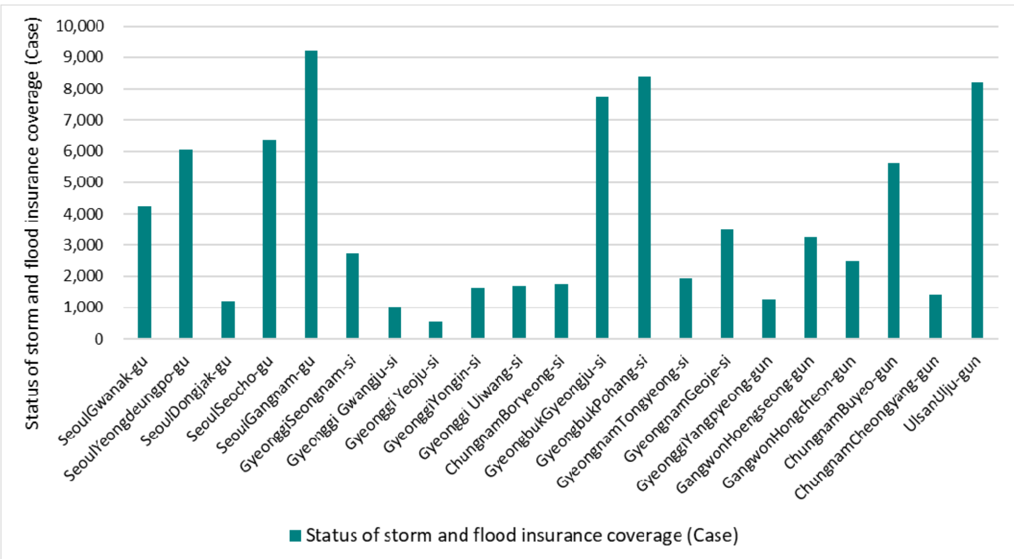
Source: The authors.

Figure 22. Redundancy – Temporary shelter facilities



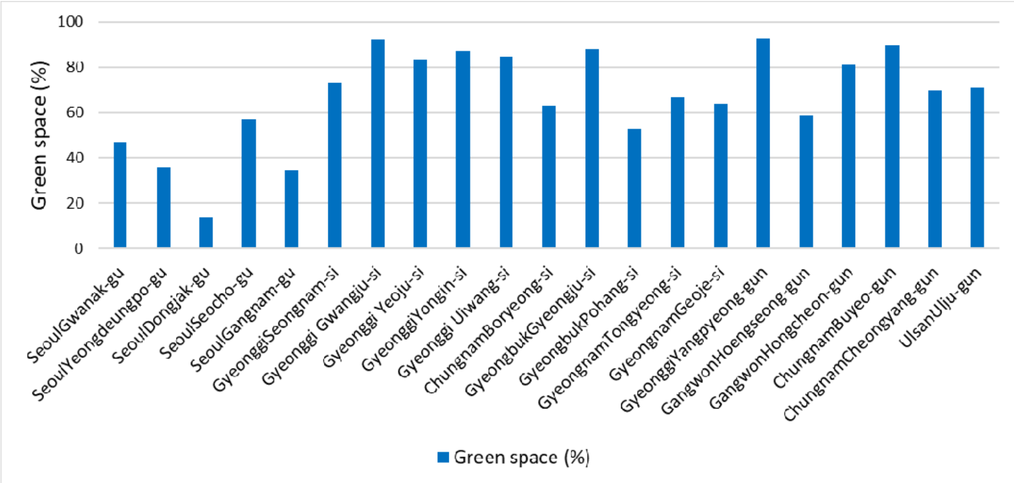
Source: The authors.

Figure 23. Redundancy – Storm and flood insurance coverage (Cases)



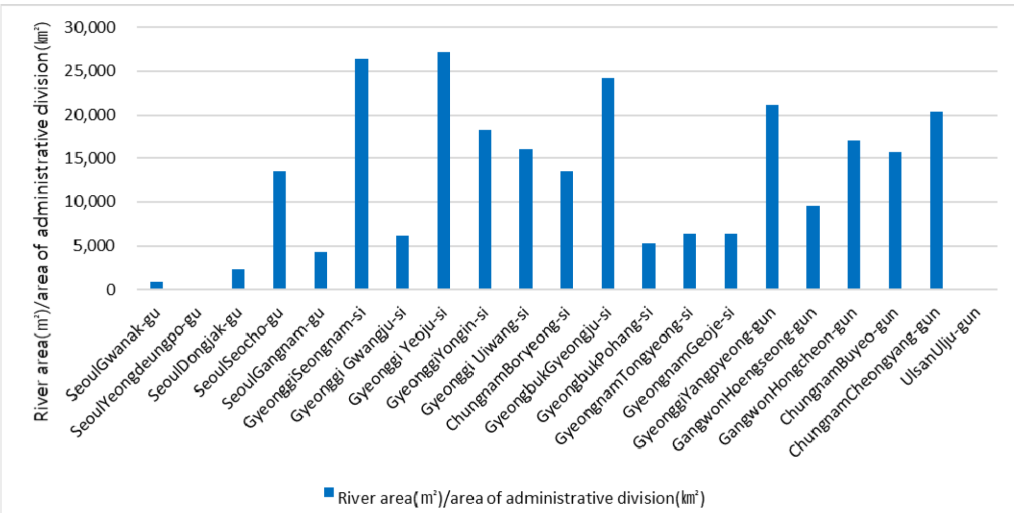
Source: The authors.

Figure 24. Robustness – Green space (%)



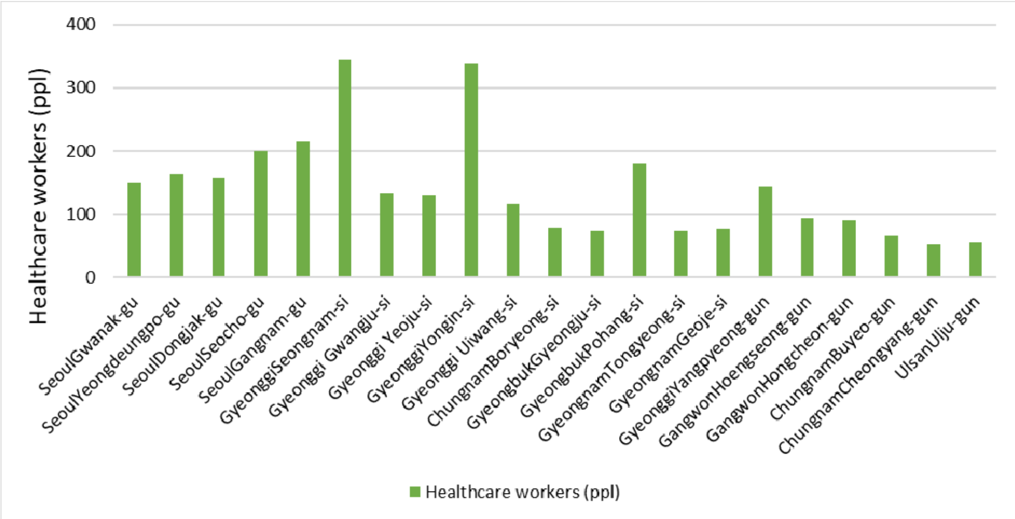
Source: The authors.

Figure 25. Robustness – River area (m^2)/area of administrative division (km^2)



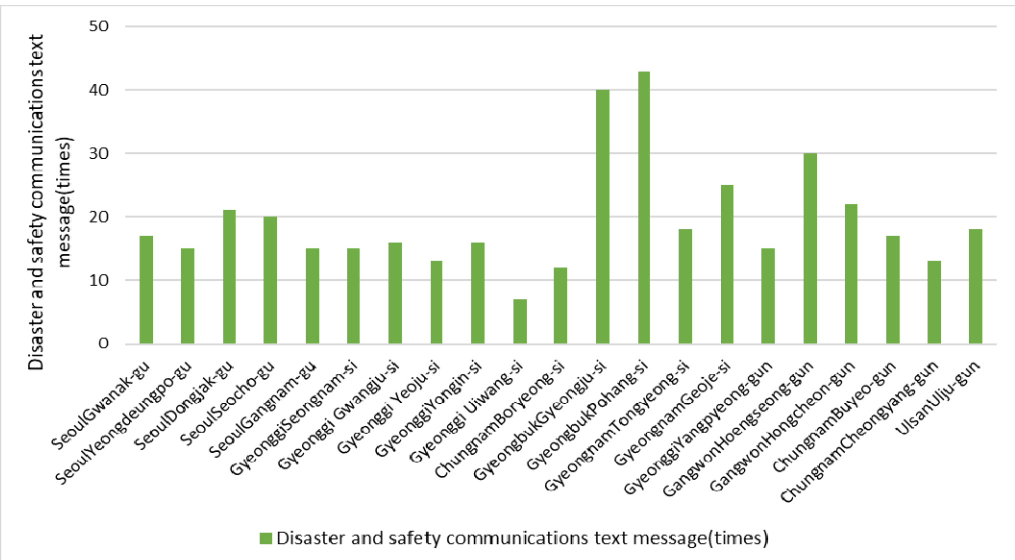
Source: The authors.

Figure 26. Rapidity – Healthcare workers (people)



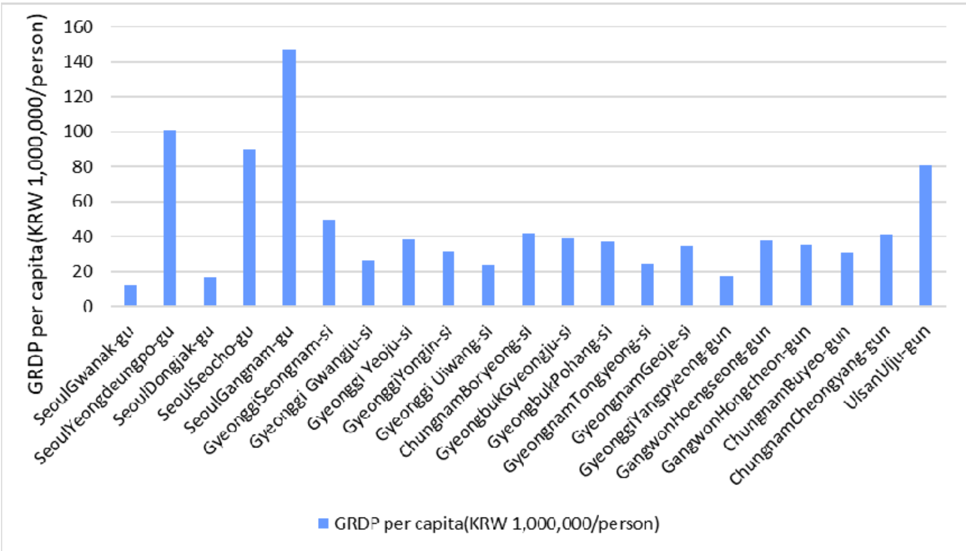
Source: The authors.

Figure 27. Rapidity – Disaster and safety communications text messages (times)



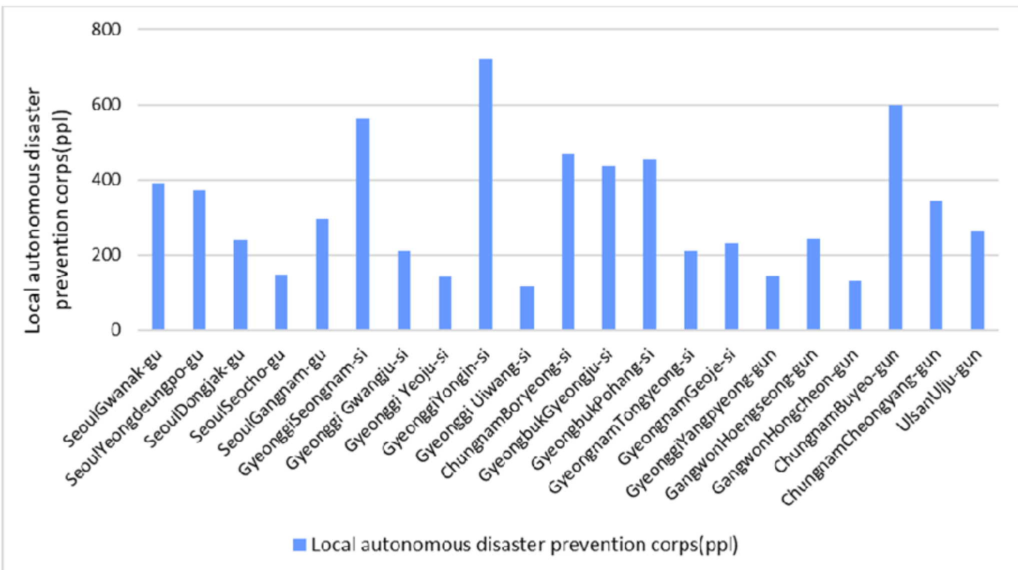
Source: The authors.

Figure 28. Resourcefulness- GRDP per capita (KRW 1,000,000/person)



Source: The authors.

Figure 29. Resourcefulness – Local autonomous disaster prevention corps (people)



Source: The authors.

5 Evaluating and Strengthening Flood Resilience

5.1. Analysis of flood resilience indicators

In this chapter, we analyze and evaluate flood resilience in the designated pilot areas. We first establish a system of flood resilience indicators, acquire data for each indicator, and then estimate the overall flood resilience of each pilot area. Since the data for each indicator uses different units (for example, percentage, number of people, and so on), it was necessary to standardize the indicators to ensure all contributed equally to the resilience score. We employed the Z-scores method for the standardization process.

$$Z = \frac{X - \mu}{\sigma} \qquad \text{Equation (3)}$$

In Equation 3 shown above, Z refers to the standardized value, and X denotes the value of the pilot area indicator. μ represents the mean value of the indicator for the entire pilot area and σ is the standard deviation of the indicator for the entire pilot area. To create a meaningful flood resilience index, we need to consider not only standardized values but also the relative importance of each indicator. Equation 4 is the formula used to multiply each standardized value by a weight that reflects its significance.We utilized the AHP method to determine these weights. The results of the standardization process and the weights assigned to each indicator are presented in Tables 22 and 23, respectively.

$$flood\ resilience\ index = \sum_{1}^{i} weight * standardized\ value \qquad \text{Equation (4)}$$

In the above equation (4), i denotes the number of indicators. Table 24 presents the values that completed the standardization process according to the above description, and Table 23 lists the values of weights.

Table 23. Range of Table 22

Category	Flood resilience indicators	Range
Redundancy	Number of disaster refugee accommodations + number of civil defense evacuation facilities (places)	-3.25 ~ 7.28
	Number of public officials responsible for river management (people) (river management, firefighting, environment, contracted workers)	-2.33 ~ 4.02
	Disaster management fund (KRW 1,000,000)	-0.28 ~ 4.28
	Status of storm and flood insurance coverage (cases)	-0.62 ~ 1.02
	Number of detention basins(EA) by municipality (*si/gun/gu*)	-3.71 ~ 10.77
	Number of pumping stations	-4.25 ~ 17.56
Robustness	Public sewerage penetration (%) by municipality (*si/gun/gu*)	-24.74 ~ 9.11
	Water supply penetration (%) by municipality (*si/gun/gu*)	-16.53 ~ 2.78
	River bank length (m)	-16.93 ~ 32.64
	Green space (%)	-14.92 ~ 7.26
	River area (m^2)/area of administrative division (km^2)	-13.11 ~ 16.35
Rapidity	Length of road per square kilometer of land (km/km^2)	-3.46 ~ 11.20
	Disaster drill and preparedness budget (KRW 1,000,000)	-2.69 ~ 10.25
	Disaster and safety communications text messages (times)	-4.51 ~ 8.02
	Disaster early warning system (EA)	-3.35 ~ 6.36
	Healthcare workers (people)	-8.36 ~ 19.48
Resourcefulness	Number of volunteers (people)	-2.6 ~ 8.11
	Local autonomous disaster prevention corps (people)	-6.71 ~ 13.22
	Fiscal self-reliance (%)	-6.62 ~ 12.13
	GRDP per capita (KRW 1,000,000/person)	-1.98 ~ 5.99

Source: The authors.

We calculated the flood resilience index for each pilot area by summing the values of all 20 indicators. Examining the overall results, the regions with the highest resilience scores were: the city of Yongin (92.36), in Gyeonggi province, the city of Gyeongju (76.26), in the province of North Gyeongsang, and the city of Seongnam (67.15), also in the province of Gyeonggi.

As seen in Table 22, the Gyeonggi cities of Yongin and Seongnam benefited from a strong presence of healthcare workers and well-equipped local disaster prevention corps. Yongin revamped its citizen disaster prevention corps in 2019 to facilitate improved disaster prevention and superior disaster response. Seongnam has a large river area, which requires robust flood management strategies.[6)]

The city of Gyeongju in North Gyeongsang Province implemented significant improvements after an area around POSCO (a major domestic steelmaker) sustained major damage in the 2022 floods. This led to the construction of a new riverbank the launch of the Hyeongsan River Environmental Improvement Project, which prompted the rehabilitation of 49.8 km of river, covering a total area just over 12,758,000 square meters. The Ministry of Environment (MoE) also designated Gyeongju as a Special Management Area for a 2022 sewer rehabilitation initiative, investing KRW 8 billion in flood prevention measures, including 1.2 km of rainwater pipes and new rainwater pumping stations in the flood-prone district of Chungyo.

The city of Ulsan ranked fourth due to comprehensive flood prevention measures taken in the wake of Typhoon Chaba in 2016. Authorities invested KRW 101.6 billion in flood prevention. Major projects included improvements to the banks of the Sinmyeongcheon and Boeuncheon rivers, which were devastated by the typhoon, and the construction of new drainage pumping stations and detention basins in the Taewha and Woojeong markets. These efforts significantly contributed to enhancing flood resilience in the city.

The three areas with the lowest resilience scores were Cheongyang-*gun* (-61.61), in South Chungcheong Province, Hoengseong-*gun* (-58.43), in the province of Gangwon, and the city of Tongyeong (-40.84), in South Gyeongsang Province.

Our analysis of Cheongyang-*gun* showed that the region suffers frrom low public sewerage penetration (%), leaving residents vulnerable to flood damage. We found that water supply and public sewerage penetration rate (%) in South Chungcheong

6) 용인시민신문 (January 23, 2019), "용인시 자율방재단 전면 재정비, 가동성 '최대치'", accessed on January 15, 2024.

as a whole to be below the national average, and Cheongyang-*gun* to be especially low, at around 55%.[7][8] Over in Gangwon province, Hoengseong-*gun* borders several long stretches of various rives — over 101 lengths of rivers and streams across 9 towns and villages — which had a significant impact on its ranking. The rural community of Hoengseong-*eup*, suffered significant damage, including river bank loss, due to a localized heavy rainfall event in August 2022.[9] In the wake of the disaster, government targeted three rivers (Iricheon, Seonggolcheon, and Ilicheon) for improvement and restoration following the disaster, pouring KRW 51.6 into the project. The rehabilitation program aims to rebuild the riverbank and revetment over a length of 14 km and rehabilitate 22 weirs and drop structures.[10] We were unable to incorporate data that reflects the results of these improvement projects for this study, however, as evident in the relatively low score for the river bank length variable. The city of Tongeong (-40.84) in South Gyeongsang province and the city of Boryeong (-40.34) in South Chungcheong had similar scores. Our analysis revealed that the length of the river bank was the primary factor influencing Tongyeong's low weight in the index. Heavy precipitation in October 2019 resulted in 217 mm of rain falling on Tongyeong, leading to widespread flooding.[11] The area was also struck by two typhoons in recent years; Typhoon Hinnamnor in 2022 and Khanun in 2023, which caused significant damage and made the area even more vulnerable to flooding. Boryeong's low score is largely due to its low public sewerage penetration rate.[12] At just 76.7%, it is lower than the already-low average rate of 83.2% in South Chungcheong Province. City officials in 2023 announced plans to expand and modernize Boryeong's sewer infrastructure with an injection of KRW 27 billion.

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7) 충청투데이 (July 6, 2023), "충남 하수도보급률 수년째 전국 '꼴찌'", accessed on January 25, 2024.
8) 충청신문 (September 11, 2023), "충남 하수도보급률 10년간 전국 최하위", accessed on September 11, 2023.
9) 횡성뉴스 (March 29, 2023), "횡성지역 곳곳의 하천은 지금 수해복구 중", accessed on January 25, 2024.
10) 지방자치TV (October 6, 2022), "횡성군, 하천 개선 복구 사업비 확보", accessed on January 25, 2024.
11) 경남도민일보 (October 4, 2019), "차량·도로 순식간에 잠겨 아수라장", accessed on January 25, 2024.
12) 연합뉴스 (February 10, 2022), "보령시, 올해 하수도 기반시설 확충에 289억원 투입", accessed on January 25, 2024.

Table 24. Standardized values by region

	SG-gu_1	SY-gu	SD-gu	SS-gu	SG-gu_2	GS-si	GG-si_1	GY-si_1	GY-si_2	GU-si	CB-si	GG-si_2	GP-si	GT-si	GG-si_3	GY-gun	GH-gun_1	GH-gun_2	CB-gun	CC-gun	UU-gun
Disaster refugee accommodation + civil defense evacuation facilities + number of schools	0.79	-0.37	-1.24	0.47	0.81	6.33	3.93	-2.50	7.28	-1.64	-2.08	-0.72	3.00	-0.81	0.87	-1.56	-3.25	-2.96	-3.15	-1.94	-1.27
Number of public officials responsible for river management	0.30	0.42	-0.08	0.68	3.69	1.57	0.16	-1.38	4.02	-1.39	-1.56	0.83	3.31	-1.16	-1.15	-0.99	-1.50	-1.57	-2.02	-2.33	0.15
Disaster management fund (KRW 1,000,000)	-0.23	-0.23	-0.24	-0.17	4.28	0.00	-0.21	-0.25	-0.10	-0.22	-0.27	-0.23	-0.13	-0.27	-0.15	-0.26	-0.28	-0.26	-0.28	-0.28	-0.21
Status of storm and flood insurance coverage (case)	0.08	0.42	-0.49	0.48	1.02	-0.21	-0.53	-0.62	-0.42	-0.41	-0.39	0.74	0.87	-0.36	-0.07	-0.49	-0.11	-0.25	0.34	-0.46	0.84

Table 24. (continued)

	SG -gu _1	SY -gu	SD -gu	SS -gu	SG -gu _2	GS -si	GG -si _1	GY -si _1	GY -si _2	GU -si	CB -si	GG-si_2	GP -si	GT -si	GG -si_3	GY -gun	GH -gun _1	GH-gun_ 2	CB -gun	CC -gun	UU -gun
Number of detention basins	-2.97	-2.23	-2.23	-2.97	-1.11	5.20	-1.11	-3.34	10.77	0.37	-0.37	1.48	7.05	-0.37	-1.86	-0.74	-3.71	-3.34	-2.97	-3.71	8.17
Number of pumping stations	-4.25	-3.72	-4.10	-4.06	-4.06	-3.33	0.09	2.89	-4.06	-3.52	-4.15	11.87	-3.19	-3.81	-4.10	12.01	-1.98	0.67	6.46	-3.23	17.56
Public sewerage penetration (%)	9.11	9.11	9.11	9.11	9.11	8.82	6.29	-2.39	3.98	8.75	-8.90	4.99	-1.60	-0.80	-1.67	-5.86	-14.26	-6.30	-16.86	-24.74	4.99
Water supply penetration(%)	2.78	2.78	2.78	2.78	2.78	2.78	0.15	-0.42	2.60	2.78	-1.17	0.53	1.28	2.26	2.07	-4.26	-1.51	-4.86	-1.58	-16.53	1.96
River bank length(m)	-15.54	-16.23	-16.93	-14.95	-16.00	-16.72	-12.08	27.25	1.48	-7.86	-3.19	32.64	5.47	-12.65	-9.44	21.71	-9.64	5.65	30.55	7.95	18.55
Green space (%)	-5.64	-8.74	-14.92	-2.82	-9.09	1.70	7.15	4.65	5.61	5.03	-1.07	5.85	-4.00	-0.06	-0.90	7.26	-2.37	3.97	6.47	0.82	1.10
River area/area of administrative division	-12.13	-13.11	-10.67	1.60	-8.55	15.56	-6.51	16.35	6.65	4.21	1.55	13.04	-7.39	-6.16	-6.27	9.69	-2.88	5.27	3.87	8.99	-13.11
Road length per national land area	6.41	11.20	10.39	4.08	6.68	0.76	-2.63	-2.66	-2.62	-0.32	-3.46	-2.75	-2.39	-1.42	-2.34	-2.99	-3.03	-3.11	-3.46	-3.46	-2.88

Table 24. (continued)

	SG-*gu*_1	SY-*gu*	SD-*gu*	SS-*gu*	SG-*gu*_2	GS-*si*	GG-*si*_1	GY-*si*_1	GY-*si*_2	GU-*si*	CB-*si*	GG-*si*_2	GP-*si*	GT-*si*	GG-*si*_3	GY-*gun*	GH-*gun*_1	GH-*gun*_2	CB-*gun*	CC-*gun*	UU-*gun*
Disaster drill and preparedness budget (KRW 1,000,000)	-0.62	0.58	-2.49	0.67	-2.69	-0.22	-2.58	-2.09	6.59	-1.19	-1.14	-2.08	-1.14	0.71	-0.83	-2.09	2.06	10.25	-1.14	0.17	-0.73
Disaster and safety communications text message (times)	-0.65	-1.19	0.42	0.15	-1.19	-1.19	-0.92	-1.73	-0.92	-3.35	-2.00	5.55	6.36	-0.39	1.50	-1.19	2.85	0.69	-0.65	-1.73	-0.39
Disaster early warning system	-2.33	-3.37	-1.97	-3.74	-3.69	-1.87	0.49	-2.06	6.75	-4.51	-4.24	7.25	-1.97	3.21	8.02	0.49	-2.96	4.39	2.48	-4.19	3.80
Local health center staffing	0.89	2.32	1.65	5.75	7.18	19.48	-0.64	-0.92	19.00	-2.26	-5.78	-6.26	3.94	-6.26	-5.97	0.41	-4.35	-4.73	-7.12	-8.36	-7.98
Number of volunteers	0.56	0.15	-0.27	0.75	3.09	8.11	-0.29	-1.55	6.05	-1.24	-1.77	-0.63	2.24	-2.01	-0.57	-1.90	-2.60	-2.42	-2.36	-2.55	-0.79

Table 24. (continued)

	SG-*gu*_1	SY-*gu*	SD-*gu*	SS-*gu*	SG-*gu*_2	GS-*si*	GG-*si*_1	GY-*si*_1	GY-*si*_2	GU-*si*	CB-*si*	GG-*si*_2	GP-*si*	GT-*si*	GG-*si*_3	GY-*gun*	GH-*gun*_1	GH-*gun*_2	CB-*gun*	CC-*gun*	UU-*gun*
Number of local autonomous disaster prevention corps	2.35	1.66	-2.67	-5.69	-0.86	8.00	-3.59	-5.89	13.22	-6.71	4.95	3.83	4.42	-3.65	-2.93	-5.79	-2.54	-6.18	9.15	0.74	-1.82
Fiscal self-reliance	-2.99	3.29	0.02	10.57	10.96	12.13	2.83	-2.50	7.34	2.94	-5.09	-2.92	-0.37	-5.59	-3.92	-3.99	-5.91	-5.91	-6.62	-6.51	2.23
GRDP	-1.98	3.29	-1.71	2.61	5.99	0.25	-1.13	-0.43	-0.86	-1.26	-0.20	-0.38	-0.51	-1.24	-0.63	-1.65	-0.46	-0.62	-0.88	-0.26	2.07
Flood resilience indicators	-26.05	-13.97	-35.60	5.33	8.34	67.15	-11.13	20.41	92.36	-11.80	-40.34	72.62	15.27	-40.84	-30.34	17.81	-58.43	-11.62	10.22	-61.61	32.23

Note: SeoulGwanak-gu: SG-*gu*_1, SeoulYeongdeungpo-*gu*: SY-*gu*, SeoulDongjak-*gu*: SD-*gu*, SeoulSeocho-*gu*: SS-*gu*, SeoulGangnam-*gu*: SG-*gu*_2, GyeonggiSeongnam-*si*: GS-*si*, Gyeonggi Gwangju-*si*: GG-*si*_1, Gyeonggi Yeoju-*si*: GY-*si*_1, GyeonggiYongin-*si*: GY-*si*_2, Gyeonggi Uiwang-*si*: GU-*si*, ChungnamBoryeong-*si*: CB-*si*, GyeongbukGyeongju-*si*: GG-*si*_2, GyeongbukPohang-*si*: GP-*si*, GyeongnamTongyeong-*si*: GT-*si*, GyeongnamGeoje-*si*: GG-*si*_3, GyeonggiYangpyeong-*gun*: GY-*gun*, GangwonHoengseong-*gun*: GH-*gun*_1, GangwonHongcheon-*gun*: GH-*gun*_2, ChungnamBuyeo-*gun*: CB-*gun*, ChungnamCheongyang-*gun*: CC-*gun*, UlsanUlju-gun: UU-*gun*.

Source: The authors.

Table 25 presents the weights for individual indicators calculated through the AHP method, and Table 26 shows the Highest and Lowest indicators based on the 4R standardized values for each pilot area. The weights of each indicator are calculated using the AHP method. We discuss the weights in more detail in the next chapter.

Table 25. Weights of flood resilience indicators

Flood resilience indicators	Weight values
Temporary shelter facilities	2.87
Public official capacity for disaster management	1.81
Budget for disaster and emergency management fund	0.96
Flood insurance	0.52
Detention and retention facilities	4.11
Drainage facilities	6.32
Water supply and sanitation service facilities (public sewerage)	9.61
Water supply and sanitation service facilities (water supply)	4.35
River bank improvement	16.61
Area of parks and green space	5.87
River area (%)	9.32
Transportation network	4.63
Flood risk awareness	3.04
Disaster alert	2.31
Warning system and communications network	4.01
Medical service	7.65
Volunteers	2.75
Citizen corps for disaster prevention	5.46
Fiscal self-reliance of municipalities	5.91
Gross Regional Domestic Product (GRDP)	1.89

Source: The authors.

Table 26. Standardized values by region (highest, lowest)

Special disaster areas	4R	Highest factor	Lowest factor
SG-gu_1	Redundancy	Temporary shelter facilities	Drainage facilities
	Robustness	Water supply and sanitation service facilities (public sewerage)	River bank improvement
	Rapidity	Transportation network	Disaster alert
	Resourcefulness	Citizen corps for disaster prevention	Fiscal self-reliance of municipalities
SY-gy	Redundancy	Public official capacity for disaster management, flood insurance	Drainage facilities
	Robustness	Water supply and sanitation service facilities (public sewerage)	River bank improvement
	Rapidity	Transportation network	Warning system and communications network
	Resourcefulness	Fiscal self-reliance of municipalities, Gross Regional Domestic Product (GRDP)	Volunteers
SD-gu	Redundancy	Public official capacity for disaster management	Drainage facilities
	Robustness	Water supply and sanitation service facilities (public sewerage)	River bank improvement
	Rapidity	Transportation network	Flood risk awareness
	Resourcefulness	Fiscal self-reliance of municipalities	Citizen corps for disaster prevention
SS-gu	Redundancy	Public official capacity for disaster management	Drainage facilities
	Robustness	Water supply and sanitation service facilities (public sewerage)	River bank improvement
	Rapidity	Medical service	Warning system and communications network
	Resourcefulness	Fiscal self-reliance of municipalities	Citizen corps for disaster prevention

Table 26. (continued)

Special disaster areas	4R	Highest factor	Lowest factor
SG-gu_2	Redundancy	Budget for disaster and emergency management fund	Drainage facilities
	Robustness	Water supply and sanitation service facilities (public sewerage)	River bank improvement
	Rapidity	Transportation network	Warning system and communications network
	Resourcefulness	Fiscal self-reliance of municipalities	Citizen corps for disaster prevention
GS-si	Redundancy	Temporary shelter facilities	Drainage facilities
	Robustness	River area (%)	River bank improvement
	Rapidity	Medical service	Warning system and communications network
	Resourcefulness	Fiscal self-reliance of municipalities	Gross Regional Domestic Product (GRDP)
GG-si_1	Redundancy	Temporary shelter facilities	Detention and retention facilities
	Robustness	Area of parks and green space	River bank improvement
	Rapidity	Warning system and communications network	Transportation network
	Resourcefulness	Fiscal self-reliance of municipalities	Citizen corps for disaster prevention
GY-si_1	Redundancy	Detention and retention facilities	Detention and retention facilities
	Robustness	River bank improvement	Water supply and sanitation service facilities (public sewerage)
	Rapidity	Medical service	Transportation network
	Resourcefulness	Gross Regional Domestic Product (GRDP)	Citizen corps for disaster prevention
GY-si_2	Redundancy	Detention and retention facilities	Flood insurance
	Robustness	River area (%)	River bank improvement
	Rapidity	Medical service	Transportation network
	Resourcefulness	Citizen corps for disaster prevention	Gross Regional Domestic Product (GRDP)

Table 26. (continued)

Special disaster areas	4R	Highest factor	Lowest factor
GG-si_3	Redundancy	Temporary shelter facilities	Drainage facilities
	Robustness	Water supply and sanitation service facilities (water supply)	River bank improvement
	Rapidity	Warning system and communications network	Medical service
	Resourcefulness	Gross Regional Domestic Product (GRDP)	Fiscal self-reliance of municipalities
GY-gun	Redundancy	Drainage facilities	Temporary shelter facilities
	Robustness	River bank improvement	Water supply and sanitation service facilities (public sewerage)
	Rapidity	Warning system and communications network	Transportation network
	Resourcefulness	Gross Regional Domestic Product (GRDP)	Citizen corps for disaster prevention
GH-gun_1	Redundancy	Flood insurance	Detention and retention facilities
	Robustness	Water supply and sanitation service facilities (water supply)	Water supply and sanitation service facilities (public sewerage)
	Rapidity	Disaster alert	Medical service
	Resourcefulness	Gross Regional Domestic Product (GRDP)	Volunteers
GH-gun_2	Redundancy	Drainage facilities	Detention and retention facilities
	Robustness	River bank improvement	Water supply and sanitation service facilities (public sewerage)
	Rapidity	Flood risk awareness	Medical service
	Resourcefulness	Gross Regional Domestic Product (GRDP)	Citizen corps for disaster prevention
CB-gun	Redundancy	Drainage facilities	Temporary shelter facilities
	Robustness	River bank improvement	Water supply and sanitation service facilities (public sewerage)
	Rapidity	Warning system and communications network	Medical service
	Resourcefulness	Citizen corps for disaster prevention	Fiscal self-reliance of municipalities

Table 26. (continued)

Special disaster areas	4R	Highest factor	Lowest factor
CC-gun	Redundancy	Budget for disaster and emergency management fund	Detention and retention facilities
	Robustness	River area (%)	Water supply and sanitation service facilities (water supply)
	Rapidity	Flood risk awareness	Medical service
	Resourcefulness	Citizen corps for disaster prevention	Fiscal self-reliance of municipalities
UU-gun	Redundancy	Drainage facilities	Temporary shelter facilities
	Robustness	River bank improvement	River area (%)
	Rapidity	Warning system and communications network	Medical service
	Resourcefulness	Fiscal self-reliance of municipalities	Citizen corps for disaster prevention

Note: SeoulGwanak-gu: SG-gu_1, SeoulYeongdeungpo-gu: SY-gy, SeoulDongjak-gu: SD-gu, SeoulSeocho-gu: SS-gu, SeoulGangnam-gu: SG-gu_2, GyeonggiSeongnam-si: GS-si, Gyeonggi Gwangju-si: GG-si_1, Gyeonggi Yeoju-si: GY-si_1, GyeonggiYongin-si: GY-si_2, Gyeonggi Uiwang-si: GU-si, ChungnamBoryeong-si: CB-si, GyeongbukGyeongju-si: GG-si_2, GyeongbukPohang-si: GP-si, GyeongnamTongyeong-si: GT-si, GyeongnamGeoje-si: GG-si_3, GyeonggiYangpyeong-gun: GY-gun, GangwonHoengseong-gun: GH-gun_1, GangwonHongcheon-gun: GH-gun_2, ChungnamBuyeo-gun: CB-gun, ChungnamCheongyang-gun: CC-gun, UlsanUlju-gun: UU-gun.

Source: The authors.

5.2. Multicollinearity and AHP analysis

To test and verify the suitability of the selected flood resilience indicators, we performed a multiconllinearity analysis using the Statistical Package for the Social Sciences (SPSS), a widely-used stats package. For our analysis, the sum of all standardized indicator values served as the dependent variable, while the individual standardized values were the independent variables. Multicollinearity refers to a strong correlation between independent variables.

For this study, we evaluated multicollinearity using two measures: tolerance and the Variance Inflation Factor (VIF), calculated using SPSS. The maximum tolerance value is 1; higher values indicate lower collinearity. VIF is the reciprocal of tolerance, and is the variation factor of regression coefficients. A larger VIF suggests strong multicollinearity.

Table 27 summarizes the results of the collinearity analysis categorized under the 4R framework. All tolerance values are greater than 0.1, and all VIF values are below 10. This allows us to conclude that multicollinearity is not a significant concern for this particular set of variables.[13] Therefore, we can confirm the suitability of all 20 indicators for inclusion in the regression model.

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13) A tolerance less than .1 or a VIF greater than or equal to 10 indicates multicollinearity.

Table 27. Results of multicollinearity analysis

Factors		Standardized coefficient	Multicollinearity statistics	
		Beta	Tolerance	VIF
Rapidity	Transportation network	.421	.734	1.362
	Flood risk awareness	.276	.830	1.205
	Disaster alert	.210	.867	1.153
	Warning system and communications network	.364	.680	1.471
	Medical service	.695	.837	1.195
Redundancy	Disaster refugee accommodations, civil defense evacuation facilities, number of schools (places)	.282	.202	4.942
	Number of public officials responsible for disaster policy (Flood response/flood control divisions)		.119	8.397
	Budget for disaster and emergency management fund		.467	2.139
	Status of storm and flood insurance coverage		.425	2.353
	Detention basins by municipality (si/gun/gu)	.404	.298	3.352
	Relay pumping station by metropolitan city/province	.621	.565	1.769
Robustness	Public sewerage penetration rate	.395	.303	3.302
	Water supply penetration rate	.179	.310	3.223
	River bank improvement	.683	.535	1.870
	Green space (%)	.241	.459	2.178
	River management status	.383	.506	1.977
Resourceful ness	Volunteers	.229	.124	8.070
	Citizen corps for disaster prevention	.454	.407	2.456
	Fiscal self-reliance	.492	.128	7.827
	GRDP per capita	.157	.493	2.028

Note: For correlation between factors (Zero-Order), + indicates a positive relationship, and - indicates a negative relationship.
In general, if tolerance ≥0.1 and VIF* ≤15, it is judged that there is no multicollinearity among variables/factors.
VIF: Variation Inflation Factor.
Source: The authors.

To determine the relative importance of each flood resilience indicator, we employed the Analytic Hierarchy Process (AHP), a tool for systematic decision-making. AHP offers several notable advantages for addressing complex multi-criteria decision problems, making it applicable in a wide range of academic disciplines. In the context of flood damage assessment, AHP leverages expert opinions to enhance the reliability of analytical results.

In the AHP method, problems are structured hierarchically, into major factors and sub-factors. Through pairwise comparisons of individual factors, we can obtain relative importance scores and derive quantitative results. The consistency ratio (CR) calculated through the AHP method is used to assess the logical consistency of the weights derived from pairwise comparisons. A CR value under 0.1 tells us that the calculated weights are reasonable.[14] Table 28 describes the six steps involved in applying the AHP method.

Table 28. AHP application procedure

Process	Description
Step 1	Develop a given decision-making problem into a hierarchical structure
Step 2	Proceed with a pairwise comparison between factors of decision-making on the same hierarchy
Step 3	Estimate the relative importance or weight of the factors that underwent pairwise comparison
Step 4	Verify the consistency using CR (Go to Sept 6 If CR ≤0.1, or Go to Step 5 if CR ≥0.1)
Step 5	Reset the initial value in the same manner as Step 2 and return to Step 3.
Step 6	Based on comprehensive consideration of weights for each factor calculated for each hierarchy, priorities are derived.

Source: Lim et al. (2020), p.117.

The pairwise comparisons used in the AHP method are the most clear and straightforward approach to quantifying the relative importance of multiple evaluation indicators in numbers. The technique is used to determine the relative importance of each indicator using a ratio scale.[15] A pairwise comparison matrix is constructed to

14) Lim et al. (2020), p.116.

15) Bae (2014), pp.35-36.

rank each item of each hierarchy. For items consisting of n components, if item i is a_{ij} times more important than item j, the pairwise comparison matrix can be represented as shown in Equation (5) below. The elements of the matrix are shown in Equation (6).

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_n \\ a_{21} & 1 & a_{23} & \cdots & a_{2n} \\ a_{31} & a_{32} & 1 & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & 1 \end{bmatrix}$$ Equation (5)

$$a_{ij} = \frac{w_i}{w_j} \ (w_i : Weight\ of\ i)$$ Equation (6)

The AHP technique has the advantage of being able to obtain valid results even with a small sample of about 10 experts. To determine the importance of the selected flood resilience indicators, we surveyed 20 flood management experts from December 11 to December 15, 2023. Table 29 details the number of participants and their affiliations.

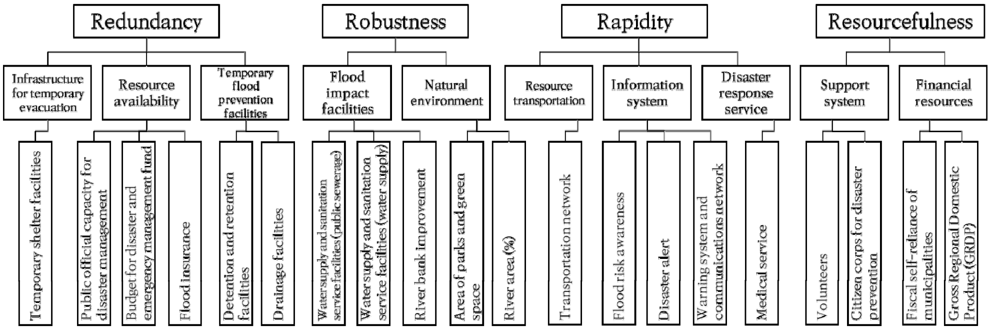
Table 29. Expert survey respondents

Category	Organizations
Universities	Kongju National University, Kookmin University, Jeonbuk National University, Chung-Ang University, Hankyong National University
Government ministries	MoE, MOIS, Ministry of Oceans and Fisheries
Research institutes	Korea Research Institute for Human Settlements, Korea Institute of Civil Engineering and Building Technology, Agency for Defense Development, K-water Institute
Private sector	Dongbu Engineering Co. Ltd., ISAN Corporation

Source: The authors.

To analyze the importance of flood resilience indicators, we developed a hierarchical structure (see Figure 30) Based on the 4R-based flood resilience indicators selected earlier, the top-level hierarchy comprises the 4Rs. The lower levels are composed of the subcategories and items as discussed earlier in Section 4.

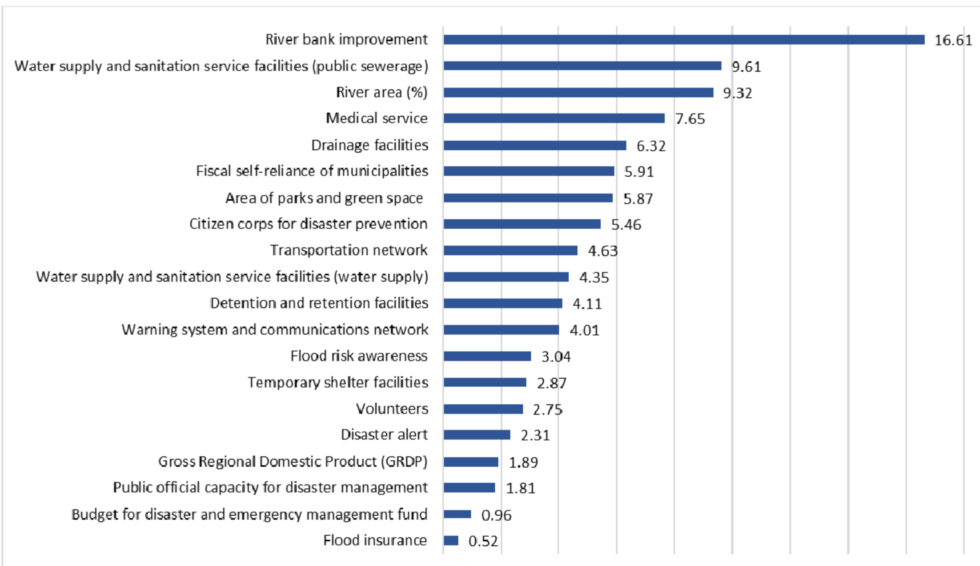
Figure 30. Flood resilience indicator hierarchy tree



Source: The authors.

Figure 30 shows the results of the expert survey. The experts ranked Robustness as the most important, with a score of 0.46. It was followed by Rapidity at 0.22, Redundancy at 0.17, and Resourcefulness at 0.16.

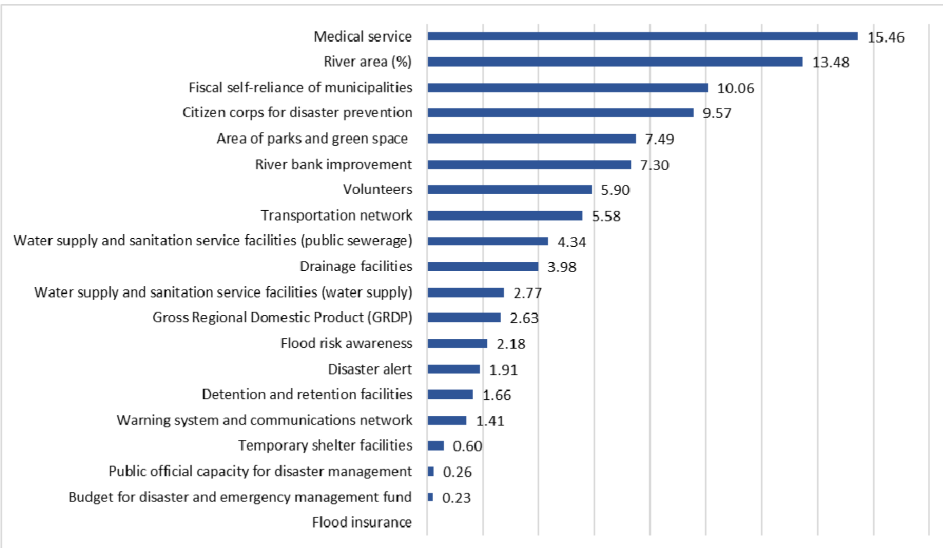
Figure 31. Prioritization of flood resilience indicators



Source: The authors.

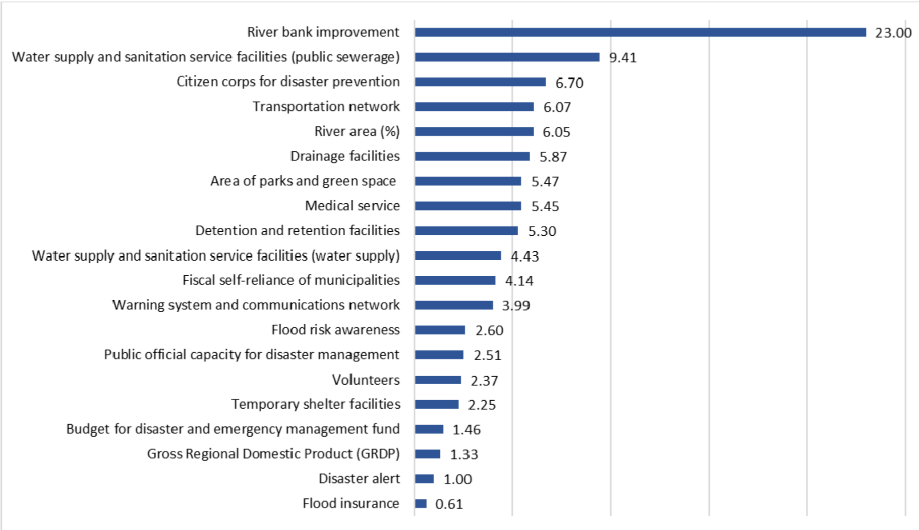
Figures 32 to 35 show how experts evaluated the importance of various sub-factors. Participants included representatives of government, the private sector, academia, and public research institutions. The breakdown of expert responses by affiliation reveals insights into divergent flood resilience priorities. Academics rated medical services as the most critical factor, while those from government ministries and the private sector cited river bank improvement as the most important factor. Experts at research institutions identified public sewerage penetration as the most important indicator. Figure 31 illustrates the composite ranking of flood resilience indicators and rankings by affiliation.

Figure 32. Expert rankings: Academia



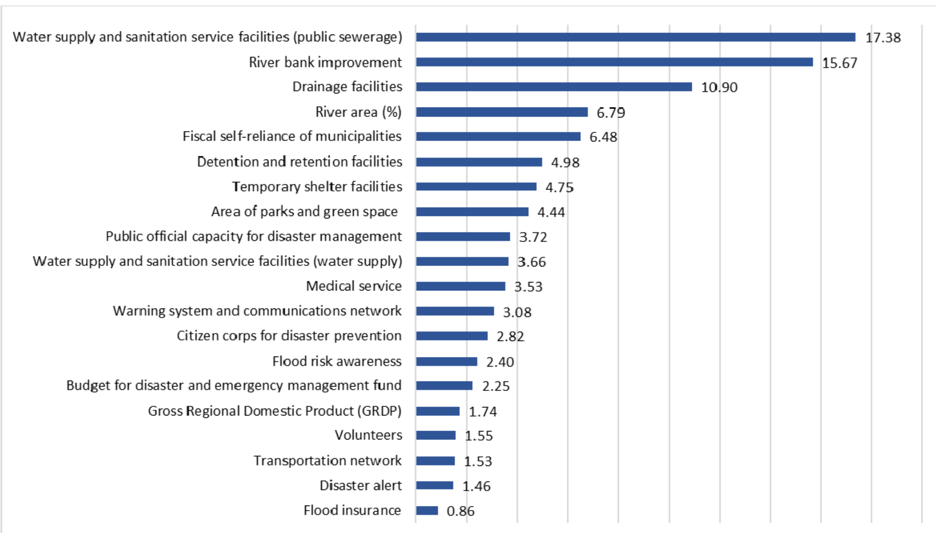
Source: The authors.

Figure 33. Expert rankings: Government ministries



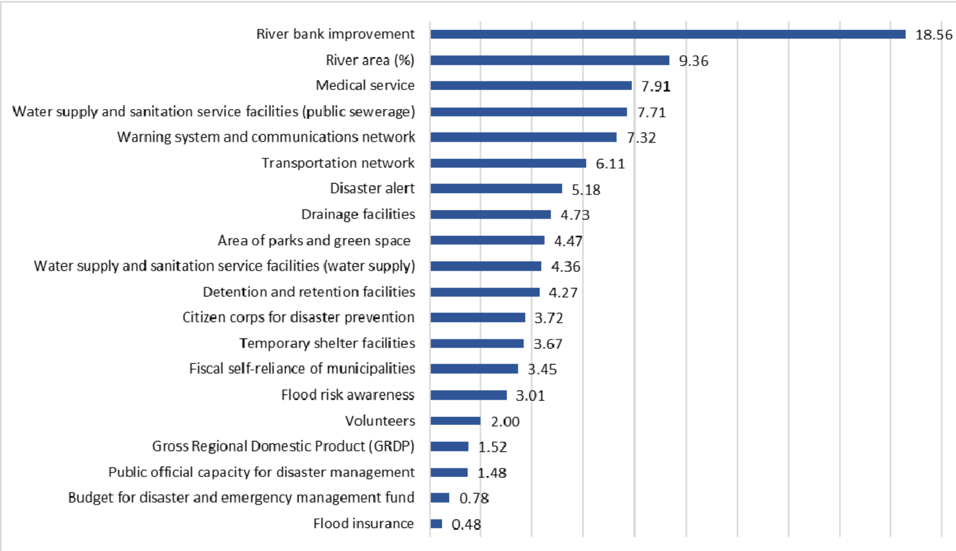
Source: The authors.

Figure 34. Expert rankings: Research institutions



Source: The authors.

Figure 35. Expert rankings: Private sector



Source: The authors.

Table 30. Prioritization of weighted flood resilience indicators

Category	Subcategory	Item	Total priority rank	Universities		Governmental ministries		Research institutes		Private companies	
				Weight	Priority	Weight	Priority	Weight	Priority	Weight	Priority
Redundancy	Infrastructure for temporary evacuation	Temporary shelter facilities	14	1.41	17	2.25	16	4.75	7	3.57	13
	Resource availability	Public official capacity for disaster management	18	0.60	18	2.51	14	3.72	9	1.48	18
		Budget for disaster and emergency management fund	19	0.26	19	1.46	17	2.25	15	0.78	19
		Flood insurance	20	0.23	20	0.61	20	0.86	20	0.48	20
	Temporary flood prevention facilities	Detention and retention facilities	11	1.91	15	5.30	9	4.98	6	4.27	11
		Drainage facilities	5	3.98	10	5.87	6	10.90	3	4.73	8

Table 30. (continued)

Category	Subcategory	Item	Total priority rank	Universities		Universities		Research institutes		Private companies	
				Weight	Priority	Weight	Priority	Weight	Priority	Weight	Priority
Robustness	Flood impact facilities	Water supply and sanitation service facilities (public sewerage)	2	4.34	9	9.41	2	17.38	1	7.71	4
		Water supply and sanitation service facilities (water supply)	10	3.22	11	4.46	10	3.66	10	4.36	10
		River bank improvement	1	7.30	6	23.00	1	15.67	2	18.56	1
	Natural environment	Area of parks and green space	7	7.49	5	5.47	7	4.44	8	4.47	9
		River area (%)	3	13.48	2	6.05	5	6.79	4	9.36	2
Rapidity	Resource transportation	Transportation network	9	5.57	8	6.07	4	1.53	18	6.11	6
	Information system	Flood risk awareness	13	2.63	13	2.60	13	2.40	14	3.01	15
		Disaster alert	16	2.18	14	1.00	19	1.46	19	5.18	7
		Warning system and communications network	12	1.66	16	3.99	12	3.08	12	7.32	5
	Emergency response service	Medical service	4	15.46	1	5.45	8	3.53	11	7.91	3

Table 30. (continued)

Category	Subcategory	Item	Total priority rank	Universities		Universities		Research institutes		Private companies	
				Weight	Priority	Weight	Priority	Weight	Priority	Weight	Priority
Resourcefulness	Support system	Volunteers	15	5.90	7	2.37	15	1.55	17	2.00	16
		Citizen corps for disaster prevention	8	9.57	4	6.70	3	2.82	13	3.72	12
	Financial resources	Fiscal self-reliance of municipalities	6	10.06	3	4.14	11	6.48	5	3.45	14
		GRDP	17	2.77	12	1.33	18	1.74	16	1.52	17

Source: The authors.

5.3. Direction of flood resilience improvement efforts

As mentioned in the previous section, through the AHP analysis, we found Robustness (0.46) to be the most critical factor for flood resilience, followed by Rapidity (0.22), Redundancy (0.16), and Resourcefulness (0.16). Among the 20 flood resilience indicators, we found river banks to be the most important (16.6%), followed by water sanitation (sewers) (9.61%) and river area ratio (9.32%).

Within the Robustness category, river bank improvement stands out as the most important of the 20 indicators analyzed in the study. The Water Resources Society's flood survey (December 2020-July 2021) highlighted the devastating impact of heavy rains and flooding, which caused river banks to collapse and dealt major damage to inland and midland regions of Korea.[16)] Collapsed riverbanks not only deal damage to lives and property, but also disrupt river ecosystems.[17)] The Korea Institute of Construction Technology (KICT) has developed new polypropylene materials to reinforce embankments and help prevent secondary flood damage.[18)] Recognizing the importance of riverbank stability, the Ministry of Environment (MoE) increased the 2023 flood response budget by 20% compared to 2022, with a focus on building or raising riverbanks. Implementing projects and plans that specifically target riverbank failure prevention can significantly enhance flood resilience.[19)] Experts cited sewers as the second most influential subcategory under Robustness, which warrants our attention. In 2022, Seoul experienced torrential rainfall (130 mm per hour, 360 mm per day) that overwhelmed its sewer systems and resulted in several casualties.[20)] Insufficient sewer capacity is a major contributor to urban flood events. The Korean government has identified 135 flood-prone urban areas and prioritized them for special management. These areas are subject to overhauls aimed at increasing capacity; improvements include the installation of new sewer systems, rainwater pumping stations, and the implementation of alternative policies.[21)]

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16) 환경부 보도자료 (August 4, 2021), p.1.

17) HelloDD (August 23, 2022), "홍수피해 6시간 더 버텼다..'친환경 제방붕괴 방지기술' 개발", accessed on January 15, 2024.

18) Ohmynews (November 14, 2023), "건설연, '제방 보강' 신기술로 지방하천 안전·2차 홍수피해 예방한다", accessed on January 15, 2024.

19) 대한민국 정책브리핑 (August 30, 2022), "환경부 내년 예산 13조7271억원…침수예방·탄소중립 등 투자", accessed on January 15, 2024.

20) KISTI (September 18, 2023), p.4.

The most important indicator in the Rapidity category and the fourth-most important indicator overall is medical services. Floods create an enormous surge in demand for medical services. This makes it necessary to shift away from the existing method of medical service provision to a disaster response system. The increasing frequency of flood disasters highlights the importance of easily accessible medical services during emergencies.

The largest impact indicator in the Resourcefulness category is fiscal self-reliance of municipalities. The central government transferred the responsibility for managing regional rivers and streams to local authorities, but local governments often lack the financial resources to systematically and effectively manage the rivers within their jurisdictions, which contributes to flood damage and casualties. Numerous studies on flood risks have emphasized the role of financial resources in supporting recovery efforts and disaster prevention. Strengthening the financial position of local governments through improved to fiscal management for flood control may help mitigate the worst outcomes of floods events.

The most influential indicator within Redundancy is drainage facilities. Seoul has suffered large-scale floods owing to heavy rains, and in response, upgraded as the rainwater retention drainage facilities to address urban floods.[22] Rainwater retention drainage facilities temporarily store rainwater and then discharge it into the river through a rainwater pumping station. Rainwater retention drainage systems have been recognized as effective contributors to flood prevention. Significant efforts are needed to improve overall drainage capacity by addressing the deterioration of the existing drainage systems and implementing maintenance programs.

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21) Ministry of Environment(August 23, 2022), p.1.

22) 한국엔지니어링협회(December 16, 2022), “국내 최초 대심도 빗물터널 ‘신월 빗물저수배류시설’…폭우 피해 악몽 지웠다”, 검색일: 2024.2.2.

6 Conclusion

Recent studies on flood resilience stress the importance of pre-flood preparation. Such preparation includes the identification of at-risk areas, and regular warnings and notifications to raise community awareness (Chan et al., 2022a). In addition, access to accurate topographical, geographical, and meteorological data is crucial to facilitate flood response evaluations; regularly collecting field spatial data is crucial to understanding local flood resilience (Chan et al., 2022b).

One successful case study is China's response in the aftermath of Typhoon In-Fa 2021, when authorities evacuated residents from high risk areas to shelters, and provided basic daily essentials at no cost (Hu, 2021; Chan et al., 2022a). Social media and smart technology also offer another avenue for communicating flood warnings to individuals (Zhou, 2021). Chinese authorities used social media to share real-time updates on disruptions to public service (such as flooded roads) in high-risk areas (BendiBao, 2021).

In our study of flood resilience policies in Asia, we first identified the most flood-prone regions and countries in Asia. We found that developing countries, in particular, exhibited weaker flood response capacity due to policy and infrastructure issues; floods in these countries can be catastrophic and incur a heavy economic tolls.

We analyzed flood resilience in some of the most flood-prone countries of Asia: Nepal, India, Thailand, Indonesia, and the Philippines. A SWOT analysis of these countries' flood resilience policies policies related to flood resilience found that collaboration, risk-informed planning, and outside investment from multilateral institutions are key to enhancing flood resilience and informing more effective national plans and policies.

Developing flood resilience indices for South Korea requires a multi-faceted approach that integrates the country's unique geographic, geological, socioeconomic, and climatic characteristics. In recent decades, we have observed more frequent and more intense flooding; flooding is expected to worsen on both measures going forward (Kim et al., 2023). Korea is expected to experience more so-called "100-year" and "200-year" floods (i.e., floods with return periods of 100 or 200 years) in the future. To prepare for this severe flooding events, it is necessary to enhance resilience at the national, provincial and local scales, and to this end, our study develop and proposed a framework to create flood resilience indices specific to Korea.

This framework utilizes the 4R (Redundancy, Robustness, Rapidity, Resourcefulness) and principles to assess flood resilience in a selection of pilot regions. We then employed the Analytic Hierarchy Process (AHP) to determine the relative importance of each indicator, and finally, we performed a multicollinearity analysis to ensure the appropriateness of the chosen indicators.

Our findings highlight Robustness as the most critical factor (0.46), followed by Rapidity (0.22), Redundancy (0.17), and Resourcefulness (0.16). We also find that river bank stability (16.61%), water and sanitation (sewers) (9.61%), and river area ratio (9.32%) to be the most important sub-categories.

To assess flood resilience tailored to the needs of South Korea, it is crucial to consider the effects of urban green infrastructure, including wetland preservation, permeable surfaces, and green roofs, along with other factors that can contribute to socioeconomic and physical resilience in the future. In addition, flood resilience indicators for Korea need to take into consideration its rapid economic development and technological advancement. A dynamic framework can help us better understand the complex interplay among economic activities, urbanization, and flood risks. Ultimately, developing a robust flood resilience framework can empower Korea to strategically manage its most severe flood hazards at a national scale. This approach can pave the way for communities to thrive in resilient environments.

To achieve lasting flood resilience, a holistic approach that integrates structural measures (levees and banks) with non-structural measures (notifications and emergency plans) is necessary (Bertilsson et al., 2019; Rinne and Nygren, 2016; Vitale et al., 2020). Both methods require a comprehensive assessment of existing infrastructure, land use, and flood management systems.

Strengthening institutional resilience is also critical. Past studies underscore the importance of investing in non-structural and institutional measures (Faisal et al., 1991;

Kundewicz, 2002; Tingsanchali, 2012). Building adaptive capacity — the ability to learn, adapt to, and manage flood risks — is essential (Gupta et al., 2010; Redman, 2014).

The experience of Seoul provides some valuable insight into institutional resilience. Here, measures to assess adaptive capacity encompass factors like variety, learning capacity, room for autonomous change, leadership, resources, and fair governance (Ro and Garfin, 2003; Gupta et al., 2010). By incorporating these factors, policymakers and urban planners can strategically target flood-prone areas and implement effective resilience-building measures.

Building flood resilience in South Korea requires active collaboration among government agencies, academic institutions, and local communities. Through a shared understanding of factors that influence flood resilience, a more comprehensive and broad-based approach can be developed, ultimately safeguarding lives, infrastructure, and the environment from the worst outcomes of future flood events.

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Executive Summary in Korean

아시아지역 홍수회복력 분석 및 국내 평가지표 개발 연구

1. 서론

❑ 기후변화에 따른 홍수 위험성

- o 기후변화는 단순히 예측하는 데 그치지 않고 대처해야 하는 현실이 되었음
- o 기후는 오랜 시간에 걸쳐 변화해 왔지만, 최근 기후변화의 속도는 현저히 빨라지고 있음
- o 아시아지역의 홍수 위험성은 지구온난화로 인해 심각해지고 있으며 지역적 특성 및 기후 조건으로 인해 다양한 문제를 동반함
- o 기온 상승과 지역적 특성이 결합하면서 아시아 전역에서 홍수 위험성이 높아지고 있음. 기후변화로 인한 다양한 문제를 완화하기 위해서는 홍수회복력을 평가하는 것이 중요함

❑ 연구 목적

- o 본 연구의 목적은 아시아지역의 홍수회복력 관련 연구 사례를 조사하고, 일부 아시아지역의 홍수복원력 지표와 그 특성을 파악하는 것임
- o 또한, AHP 분석을 기반으로 기후변화에 대응하기 위한 국내 홍수회복력 지표를 제시하고자 함. 본 연구에서 제안한 국내 홍수회복력 지표는 홍수 위험 지역으로 지정된 여러 지자체의 홍수 피해 복구 능력을 평가한 것임

❑ 개념 및 내용

- o 홍수회복력은 홍수의 전 과정에서 지역사회와 인프라에 미칠 수 있는 잠재적인 영향을 완화하고, 홍수로부터 회복할 수 있는 능력으로 정의할 수 있음
- o 본 연구에서는 홍수회복력의 특징을 4가지(가외성, 내구성, 신속성, 자원동원력)로 요약함
- o 홍수회복력을 강화하면 지역사회 차원에서 홍수 피해를 완화하고, 복구하는 동시에 이후의 홍수로 인한 피해를 예방할 수 있음

- 본 연구의 주요 내용은 홍수회복력 특성, 아시아지역의 홍수회복력 분석 및 검토, 국내 홍수회복력 지표 개발 및 적용 평가로 구성되어 있음

2. 아시아지역의 홍수회복력

❑ 홍수회복력 관련 트랜드, 프로젝트

- 아시아지역의 홍수에 관한 관심은 꾸준히 있었으며, '회복력'과 '홍수회복력'에 대한 관심도 점차 증가함
- 2011년 1월부터 2023년 7월까지 아시아에서 수행된 아시아지역의 홍수회복력 프로젝트를 조사함

❑ 사례연구 1: 지역사회 홍수회복력

- 아시아개발은행(ADB)에서 수행한 아시아지역의 홍수회복력 관련 연구를 조사함
- 홍수회복력을 평가하기 위해 재정 회복 기간과 사회·경제적 상황을 추정하는 등급 시스템을 도입함
- 전반적으로 도시 지역은 농촌지역보다 홍수회복력 점수가 높게 나타남

❑ 사례연구 2: 스케일 기반의 홍수회복력 평가

- 사례 2의 목표는 홍수 발생과 발생 이후 도시와 농촌지역에 미치는 모든 지표를 체계적으로 정리하고 평가하는 것임
- 아시아지역의 다양한 연구 지역에서 건물, 블록 및 도시 규모에서 홍수회복력을 평가하기 위해 다양한 방법을 사용함
- 홍수회복력은 도시와 농촌지역의 개별적 특성이 아닌 홍수와 지역적 특성의 결합으로 나타남

❑ 시사점

- 아시아 전역의 홍수회복력을 종합적으로 평가할 수 있는 기반을 구축해야 함
- 종합적인 홍수회복력 지표 평가를 통해 우리나라에 적합한 홍수회복력 지표 개발을 위한 전략을 마련해야 함

3. 일부 아시아지역의 홍수회복력 평가

❑ 홍수취약국가와 도시회복력

- 홍수회복력 분석을 위해 남아시아 및 동남아시아의 홍수 취약 국가를 식별함
- 인도네시아, 중국, 인도, 태국, 필리핀, 방글라데시, 네팔, 캄보디아 등은 2010~2023년 동안 여러 차례의 홍수로 인해 큰 손해를 입음
- 다양한 정책 프로그램은 회복력을 증진하고 도시의 기능과 발전을 저해할 수 있는 충격에 대처하기 위한 정책 수단을 개발하는 것을 목표로 함

❑ 사례연구: 특정 지역에서의 홍수회복력 평가

- 본 연구에서는 일부 국가의 홍수회복력 평가와 그것이 국가의 정책적 전략에 어떻게 포함되는지를 이해하기 위한 방법론을 채택하였음
- 네팔의 일부 지역에서 홍수회복력을 평가하고 향후 어떤 부분을 개선해야 하는지를 평가하기 위해 2013년에 Zurich Flood Resilience Alliance에 의해 설립된 Flood Resilience Measurement for Community (FRMC) 프레임워크를 시행함
- 인도의 경우 가구 조사를 기반으로 한 접근 방식을 사용하여 공식적 및 비공식적 거주지의 회복력이 다르다는 것을 보여줌
- 2011년 태국의 대규모 홍수 이후, SDG 11 및 SDG 13 지표를 기반으로 국가 계획이 홍수회복력 특성을 점수화하여 비교함
- 2022년 World Bank는 인도네시아에서 도시의 홍수 위험을 줄이기 위해 국가 및 도시의 능력을 강화하고 통합 도시홍수 위험 관리를 위한 투자를 증가시키기는 USD 400억의 National Urban Flood Resilience Project (NUFReP)를 승인함
- 최근에 아시아개발은행(ADB)은 필리핀에 3억 30만 달러의 대출을 승인하여 해당 국가의 세 개의 주요 하천 유역에서 홍수 및 기후변화의 위험을 줄이고 사람들과 그들의 생계를 보호하여 홍수회복력을 강화하기 위해 노력함

❑ 홍수와 재해 거버넌스

- 정부는 재난 관리 접근 방식을 구호 중심에서 예방, 완화, 대비, 대응, 구호, 재건 및 재활을 포함한 재난 위험 감소 접근 방식으로 변경하고 있음

❑ 홍수회복력 정책 SWOT 분석

- 현재 각국에서 진행 중인 재난 위험 감소를 위한 국가 계획 및 정책에 대한 강점, 약점, 기회 및 위기를 기반으로 분석 내용을 요약하여 제시함
- SWOT 분석을 기반으로 하면 협력적인 접근, 위험 인식에 기반한 계획, 다자간 기관의 투자가 홍수회복력을 강화하는 데 중요하다는 결론을 도출할 수 있음

4. 국내 홍수회복력 지표 구축

❑ 홍수회복력 지표 선정

- 홍수회복력 지표를 선정하기 위해 홍수 피해 특성과 홍수 및 재난 회복력 지표를 선정한 연구를 고찰함
- 홍수회복력 정의의 본질이 홍수 피해 발생 후 신속한 복구 및 예방 능력이라는 점을 고려하여 홍수 취약성 분석과 관련된 지표는 제외함
- 후보 지표군을 선정한 후 홍수회복력과 관련된 20개의 최종 지표를 도출하였으며, 최종 선정된 홍수회복력 지표를 대상으로 회복력 분석을 위한 지표를 목록화함

❑ 시범지역 선정

- 우리나라는 2022년 태풍 힌남노와 국지성 호우로 인해 전국적으로 큰 피해가 발생했고, 정부는 피해 복구를 위해 전국 21개 지역을 특별재난지역으로 지정함
- 2023년 6월 기준 태풍과 국지성 호우로 인한 홍수 발생 이후 서울의 동작구, 관악구, 영등포구 지역만 홍수 피해 복구에 필요한 작업을 완료함
- 특별 재난 지역으로 지정되고 국가와 시/도로부터 보조금 및 지원금을 받는데도 불구하고 홍수 피해 복구 속도는 지자체에 따라 다름
- 빠른 복구 속도에 미치는 영향이 큰 지표와 홍수 복구가 완료된 지역과 완료되지 못한 지역 간의 차이가 무엇인지 확인하기 위해 2022년 특별재난지역을 분석 대상 지역으로 선정함

❑ 데이터 수집

- 기관별 공개된 통계자료를 기반으로 자료를 수집하였으나 자료가 없는 경우, 정보공개포털을 통해 직접 지자체에 정보를 요청함

5. AHP 분석 및 지표 평가

❑ 홍수회복력 지표 분석

- ㅇ 홍수회복력 지표의 적합성을 검정하기 위해 범용 통계 프로그램인 SPSS(Statistical Package for the Social Sciences)를 활용하여 분석을 실시함
- ㅇ 4R을 기반으로 다중공선성 분석을 수행한 결과 공차한계가 모두 0.1 이상이며, VIF가 10 미만이므로 다중공선성에 문제가 없고 회귀 모형이 적합한 것으로 판단됨
- ㅇ 20개 지표 모두 다중공선성이 존재하지 않은 것으로 나타나 인자로서의 적합성을 갖는 것으로 분석됨

❑ 다중공선성 및 AHP 분석

- ㅇ 각 요인의 상대적인 중요도를 판단하기 위해 체계적인 그룹 의사결정 도구인 AHP 분석 방법을 활용함
- ㅇ 선정된 홍수회복력 지표의 중요도를 결정하기 위해 홍수 관리와 관련된 산·관·학·연 분야에서 전문성을 갖춘 20명의 전문가를 대상으로 12월 11일부터 12월 15일까지 5일 동안 전문가 설문조사를 실시함
- ㅇ 4R을 기반으로 AHP 분석을 통한 종합적인 중요도는 내구성(Robustness) 0.46, 신속성(Rapidity) 0.22, 가외성(Redundancy) 0.16, 자원동원력(Resourcefulness)이 0.16으로 내구성이 가장 큰 중요도를 나타내는 것으로 나타남

❑ 홍수회복력 개선 방향

- ㅇ 전체 20개 홍수회복력 지표 중에서도 내구성에 해당하는 하천제방이 16.61%로 중요도가 가장 높게 나타났으며, 이어서 물 위생시설(하수도)이 9.61%로 두 번째, 하천 면적 비율이 9.32%로 세 번째 중요한 요인으로 산정됨
- ㅇ 중요도가 가장 높게 나타난 내구성에서 가장 큰 영향을 미친 하위 항목은 '하천제방 정비'로 나타났으며, 전체 20개 지표 중에서도 첫 번째로 중요한 항목으로 나타남. 하천제방 붕괴를 동반한 홍수 피해는 인명 및 재산에 직접적인 피해를 발생시킬 뿐 아니라 하천 및 수생태계에도 종합적인 영향을 미치기 때문에 가장 먼저 고려되어야 함
- ㅇ 신속성에서 가장 큰 영향을 미친 하위 항목은 '보건의료서비스'로 20개 지표 중에서 4번째로 중요한 지표로 선정됨. 홍수 재난 발생 빈도가 증가하면서 위험 상황에서 쉽게 접근할 수 있는 보건의료 체계의 중요도가 증가함

- 자원동원력에서 가장 큰 영향을 미친 하위 항목은 ‘지방자치단체 재정자립도’로 각 지방 하천의 홍수 관리를 위한 지방 재정 분석은 홍수 대응을 강화할 뿐 아니라 지방 정부의 재정 독립성을 강화할 수 있음
- 가외성에서 가장 큰 영향을 미친 하위 항목은 ‘배수시설’로 기존 배수시설을 점검하고 시스템을 유지보수함으로써 배수 능력 향상을 위해 노력해야 함

6. 결 론

- 최근의 연구에서도 홍수 발생 이전의 대비가 중요함을 강조하고 있으며, 고위험 홍수 위험 지역을 구분하여 지속해서 홍수 발생 위험성을 통지하고 지역사회의 인식을 높이는 등의 준비가 필요함
- 일부 아시아 국가의 홍수회복력을 평가하기 위해 남아시아와 동남아시아의 홍수 취약 지역을 선정함
- 홍수회복력 관련 정책의 SWOT 분석 결과에 따르면 협업적 접근, 위험 정보 계획, 다자간 투자가 각 국가의 계획과 정책을 통해 홍수회복력을 향상하는 데 중요한 요인으로 나타남
- 본 연구에서는 연구 대상 지역(특별재난지역)의 홍수회복력을 평가하기 위해 4R(가외성, 내구성, 신속성, 자원동원력)에 기반하여 홍수회복력 지표를 정의함
- 각 지표의 상대적 중요도를 결정하기 위해 AHP 분석을 수행하고, 구축된 지표의 적합성을 확인하기 위해 다중공선성 분석을 수행함
- 국내 홍수회복력 지표를 구축함으로써 국가에서 홍수 위험을 전략적으로 관리할 수 있는 기초가 마련되고 이는 건강한 지역사회와 회복력 있는 환경을 조성하는 데 이바지할 것으로 기대됨

주제어 : 홍수회복력, 평가지표, 가외성, 내구성, 신속성, 자원동원력

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