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Developing Living Lab-based solutions for the complex disaster of the Jakarta-Semarang coastal city belt in the era of climate crisis

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Developing Living Lab-based solutions for the complex disaster of the Jakarta-Semarang coastal city belt in the era of climate crisis

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Executive Summary

Climate change has significantly increased disasters related to disease, heat, and water management, exacerbating the risk of complex disasters where these interact. Traditional studies focused on single disasters are insufficient to effectively address these multifaceted threats. Therefore, a more integrated, triangulated approach is needed. This study systematically examines community-level response strategies to complex disasters in Indonesian coastal cities that are directly affected by, and highly vulnerable to, climate change.

This study applied an integrated research methodology combining AI-based empirical research and participatory observational studies in local communities along the Jakarta-Semarang coastal belt. First, AI techniques were used to analyze disaster-related impact factors and identify hotspot areas prone to complex disasters. Then, to validate the AI-based findings while identifying specific complex disaster issues, Living Labs were conducted in collaboration with local experts, government agencies, and community stakeholders in Indonesia. The Living Lab process explored disaster response strategies, developed practical solutions, and tested them in real-world scenarios with the participation of local residents, government agencies, private companies, NGOs, and research organizations.

Based on the empirical research results and insights from the living labs, a disaster risk index was developed using AI techniques to predict the likelihood of disaster occurrence in coastal areas and support the prioritization of policy interventions. In addition, AI-driven simulations were conducted to assess the feasibility of policy applications, and a customized mitigation plan guideline was developed to reduce the impact of complex disasters. This approach enhances the effectiveness of complex disaster response strategies and proposes a sustainable coastal city model for climate change adaptation.

This study confirms that complex disasters are the result of interactions between different disaster factors, and that single-disaster solutions are insufficient for an effective response. To address this challenge, a scientific AI-based approach was used to identify high-risk disaster areas. A living lab framework based on local partnerships was used to diagnose specific problems and develop targeted solutions. By integrating AI-driven analysis and Living Lab methodologies, this study provides a comprehensive approach to analyzing structural vulnerabilities in coastal cities and the interrelationships of complex disaster-prone areas, providing both academic and practical contributions. In addition, by proposing a guideline for international development cooperation, this study contributes to strengthening the resilience of coastal urban communities in the face of climate change, while introducing a new paradigm for complex disaster response strategies.

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I. Overview

Summary in Local Language (Sekilas tentang Bahasa Indonesia)

1. Latar Belakang dan Tujuan Penelitian

Indonesia, negara kepulauan tropis dengan lebih dari 17.000 pulau merupakan salah satu negara yang paling rentang terhadap perubahan iklim, panas ekstrem, kenaikan permukaan laut dan peningkatan bencana seperti banjir, tsunami, serta penyebaran penyakit seperti demam berdarah. Kota-kota pesisir seperti Jakarta dan Semarang menghadapi risiko multi-aspek akibat perubahan variabilitas curah hujan dan unsur iklim lainnya, pemanasan lautan (tiga kali rata-rata global di wilayah Asia-Pasifik), dan pesatnya urbanisasi yang menyebabkan penurunan muka tanah hingga peningkatan frekuensi banjir. Pada tahun 2022, tercatat 3.641 kejadian bencana dengan meninggalkan korban jiwa yang signifikan, sedangkan pada tahun 2023, tercatat sebanyak 143.000 kasus demam berdarah yang menunjukkan bahwa perubahan iklim memperparah wabah penyakit. Bencana-bencana yang saling berkaitan tersebut menekankan urgensi pendekatan terpadu untuk mengurangi dampak, serta memperkuat adaptasi, terutama pada kelompok masyarakat rentan.

Penelitian ini berfokus pada pemahaman dan mitigasi dampak bencana kompleks di Indonesia dengan penanganan di tiga tantangan utama yang terkait dengan iklim: penyakit, panas, dan air. Melalui analisis kuantitatif terpadu dan living lab, penelitian ini melibatkan kelompok masyarakat lokal dan pemangku kepentingan untuk bersama-sama menciptakan solusi-solusi, dan pada akhirnya menghasilkan Indeks Kerentanan Perubahan Iklim Kota Pesisir (Coastal City Climate Change Vulnerability/C4V) dan panduan mitigasi. Selain itu, tujuan khusus penelitian ini meliputi identifikasi hubungan antara penyakit endemik dan faktor-faktor iklim, identifikasi titik panas (hotspot) menggunakan pemodelan kecerdasan buatan (AI),

serta merekomendasikan infrastruktur hijau untuk mengurangi risiko banjir. Hasil temuan ini selanjutnya akan dipadukan untuk menghasilkan strategi adaptasi dan mitigasi yang dapat dilaksanakan di tingkat masyarakat.

2. Wilayah dan Cakupan Penelitian

Jakarta dan Semarang memiliki kerentanan tinggi terhadap bencana kompleks yang disebabkan oleh karakteristik geografis dan sosial-ekonomi kedua wilayah ini. Urbanisasi dan pertumbuhan penduduk meningkatkan risiko bencana seperti banjir akibat kenaikan permukaan laut dan ekstraksi air tanah, dampak panas dari kepadatan kota, serta penyebaran penyakit menular seperti demam berdarah.Kota-kota ini juga secara aktif melaksanakan kebijakan pengurangan risiko bencana sehingga efektifitas strategi adaptasinya memungkinkan untuk dikaji. Penelitian ini mencakup analisis kualitatif, studi empiris (misalnya, simulasi berbasis AI dan SIG), serta keterlibatan kelompok masyarakat melalui living labuntuk mengidentifikasi interaksi kompleks antara penyakit, panas, dan pengelolaan air.

3. Strategi dan Metode Penelitian

Penelitian ini menggunakan strategi multidisipliner dan partisipatif untuk mengatasi dampak perubahan iklim melalui adaptasi dan mitigasi. Penggunaan teknologi dalam metodologi penelitian seperti pembelajaran mesin, pemodelan simulasi, dan SIG digabungkan dengan pendekatan living labdan disesuaikan sehingga menghasilkan solusi berbasis masyarakat. Strategi ini menekankan pentingnya membangun kemitraan pemerintah-swasta-masyarakat demi memastikan keberlanjutan, adaptabilitas, dan dampak jangka panjang. Dengan fokus pada konteks lokal dan pembangunan ketahanan masyarakat, penelitian ini menghasilkan kerangka kerja untuk penanganan perubahan iklim di Indonesia.

Penelitian ini dilaksanakan dalam tiga fase terpadu:

Fase 1: Analisis Penyebab Bencana dan Faktor-faktor yang Memengaruhi

- Identifikasi faktor-faktor penyebab bencana kompleks menggunakan analisis PESTEL, klasterisasi K-Means, model AI (misalnya, Model Transformasi Lahan), dan simulasi (misalnya, ENVI-Met). Analisis empiris dilakukan untuk mengamati kerentanan dan interaksi antara bencana penyakit, panas, dan air. Pemilihan wilayah sasaran diidentifikasi berdasarkan tumpeng tindih kerentanan bencana, demi memastikan fokus pada kelompok masyarakat yang paling berisiko.

Fase 2: Pengembangan dan Implementasi Living Lab

- Prototipe living labdikembangkan melalui kerja sama dengan para pemangku kepentingan setempat, termasuk masyarakat, perwakilan-perwakilan pemerintah, dan para ahli. Proses umpan balik secara iteratif dilakukan untuk memastikan bahwa prototipe tersebut dapat menjawab tuntutan nyata dan mengatasi kelemahan pada kebijakaan yang telah diterapkan saat ini. Penelitian lapangan kemudian dilakukan untuk mengidentifikasi area rawan bencana, dilanjutkan dengan pengoperasian living labuntuk menguji dan menyempurnakan solusi-solusi berbasis masyarakat.

Fase 3: Pengembangan Indeks C4V dan Panduan Mitigasi

- Indeks C4V dirancang melalui hasil temuan dari fase 1 dan 2 untuk menciptakan sarana komprehensif dalam menguji kerentanan di tingkat masyarakat terhadap bencana kompleks. Panduan mitigasi disusun untuk mengatasi dampak dengan strategi jangka pendek (misalnya, penyakit dan pengelolaan air) dan jangka panjang (misalnya, pengurangan panas). Kemudian, dasbor daring disediakan untuk memastikan hasil temuan ini dapat diakses oleh publik.

Dalam pelaksanaannya, proyek ini melahirkan kemitraan antara institusi Korea Selatan dan Indonesia, di mana pihak Korea Selatan bertanggung jawab atas

tugas-tugas empiris dan analitis, sementara pihak Indonesia menyediakan data lokal, wawasan tentang kebijakan-kebijakan terkait, dan pelibatan masyarakat. Proyek ini merupakan kolaborasi antara institusi Korea Selatan (Seoul National University Graduate School of Environmental Studies, Seoul National University College of Engineering, Incheon National University, Joongbu University) dan Universitas Diponegoro di Indonesia, dengan kontribusi pakar kerja sama internasional dari Xi'an Jiaotong-Liverpool University.

Penelitian ini menyumbangkan kerangka kerja inovatif dalam memahami dan mengatasi bencana kompleks akibat perubahan iklim di kota-kota pesisir yang rentan. Melalui integrasi metode analitis terkini dan pendekatan partisipatif, studi ini menawarkan solusi-solusi berbasis masyarakat yang dapat diadaptasi dalam skala lebih luas. Perancangan indeks C4V dan panduan mitigasi menyediakan strategi-strategi yang dapat diimplementasikan oleh para pembuat kebijakan dan masyarakat dalam membangun ketahanan, sekaligus menetapkan preseden dalam menghadapi dampak perubahan iklim secara global.

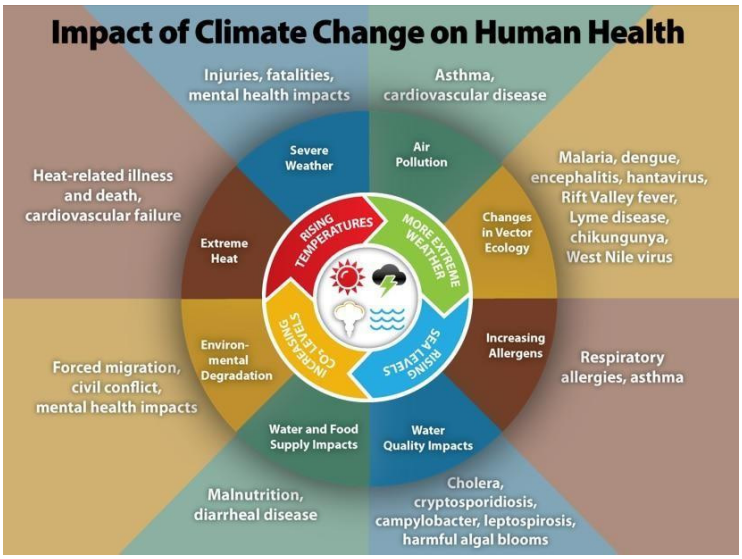
Section1. Research Background and Purpose

1. Research Background

Indonesia, a tropical island nation, is severely impacted by climate change in all aspects, including heat damage, sea level rise, and complex disasters (endemic diseases, heat-related illnesses, floods, tsunamis). Particularly, Indonesia, composed of more than 17,000 islands, is experiencing a rapid increase in damage to urban infrastructure and human health due to abnormal weather patterns and rainfall variability, especially in coastal cities. The rate of ocean warming in the Asia-Pacific region is three times the global average, meaning that the damage to coastal areas from climate change is expected to be even greater (IPCC, 2022). According to the National Disaster Management Authority of Indonesia, in 2022, 3,641 disasters occurred, resulting in 844 deaths, the highest number since 2018. Additionally, in 2023, 143,000 cases of dengue were reported, with 1,236 deaths, showing the disaster-related impacts of climate change. Particularly, Indonesia's dengue mortality rate is 0.72%, which is 1.4 to 10 times higher than countries in Southeast Asia with higher reported cases, such as Thailand (0.07%) and Bangladesh (0.52%). This result demonstrates that temperature increases due to climate change and El Niño are causing a surge in dengue, heat illnesses, and water-related disasters in Indonesia (World Health Organization (WHO), 2023).

Indonesia, due to its climatic conditions and geographical characteristics, faces a high potential for complex disaster caused by diseases, heat, and water. In particular, atmospheric instability caused by climate change is likely to trigger water-related disasters such as floods and tsunamis, which also influence the spread of heat damage and diseases (endemic diseases). Additionally, the hot and dry environment caused by heat affects water management in areas of Indonesia where the water supply rate is low and groundwater is relied upon, especially during droughts, increasing the likelihood of heat-related diseases. In this way, climate change acts as a catalyst for the interactions between disasters,

accelerating the occurrence and impact of complex disaster. The cascading disasters caused by climate change can severely affect the safety and stability of local communities, making it essential to understand the complex interactions between disasters. Moreover, tailored measures are required to both mitigate (reduce) and adapt to the impacts of climate change at the local community level. Thus, an approach from a triangulation perspective is needed to develop appropriate response (mitigation and adaptation) strategies. [Figure 1] is a system recognized by the Centers for Disease Control and Prevention (CDC), the United Nations (UN), and the World Health Organization (WHO), which identifies disease, heat, and water management as the key factors of climate change's impact on human health. These core elements are interconnected, and to improve the effectiveness of policies for disaster preparedness, it is emphasized that adaptation and mitigation strategies must be developed at the community level. Despite the vulnerability of coastal areas to complex disaster caused by climate change, studies evaluating disaster vulnerability in coastal areas have mainly focused on sea level rise (Rimda et al., 2018; Rahmadi et al., 2022) and coastal erosion (Kalther and Itaya, 2020), highlighting the need for an integrated approach.



[Figure 1] The Impact of Climate Change

(Source: National Research Council, 2020)

For the above reasons, this research project focused on complex disasters and attempted to come up with community-level countermeasures in coastal areas. Specifically, a participatory observation study (Living Lab) was conducted to analyze the vulnerable factors of climate change based on the empirical study (GIS, machine learning, AI prediction) that looks at the Jakarta-Semarang coastal city belt of Indonesia, and to derive climate change adaptation and countermeasures through microscopic investigation of the effects in local communities. This study considers disease, heat, and water management problems as a complex disaster, and in order to find practical alternatives to them, it differs from existing research tasks and projects in that it derives the Coatal City Climate Change Vulability (C4V) index through the establishment of a living lab with local residents and experts of the target country (Indonesia) and derives practical solutions. In particular, in a situation where countries belonging to temperate climates, including Korea, are changing into subtropical climates due to climate change, it is expected that Indonesia will become a test bed for global network base and growth through this research project.

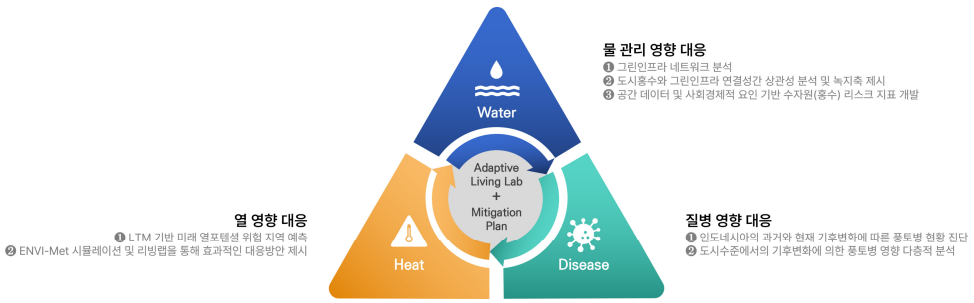
2. Research Purpose

In this research project, the core areas of complex disasters caused by climate change such as disease, heat, and water management were set as detailed topics. Ultimately, in order to find solutions through Living Lab to cope with climate change, a Living Lab prototype was developed, and a strategy for mitigating climate change was proposed through this.

The research objectives of each disaster are as follows. First, disease impact qualitatively diagnoses the current status of endemic diseases caused by past and present climate change in Indonesia and the Indonesian government's response policy, and derives vulnerable factors by identifying the relationship between endemic diseases caused by climate change and the climate, geographic, environmental, and socioeconomic characteristics of the city at the city level based

on machine learning. Second, thermal impact predicts future thermal potential risk areas (hot spots) based on the Land Transformation Model (LTM), a deep learning model, and derives thermal potential influencing factors. Finally, after analyzing the relationship between urban flood and green infrastructure network, water management presents a greenhouse axis to reduce flood impact, and develops flood vulnerability indicators based on environmental and socioeconomic factors.

By identifying the causes and effects of each disaster, we analyze the complex interactions between disasters that increase due to climate change, develop a Living Lab prototype, and then propose mitigation guidelines and indicators to effectively and effectively respond to complex disasters that require an approach from an integrated perspective.



[Figure 2] Construction of the study: Disease-heat-water management triangulation (triangle)

Section2. Research Area and Contents

1. Research Area

The spatial range of this study is Jakarta and Semarang, two costal cities of Indonesia. In Indonesian coastal cities, floods frequently occur due to rising sea levels and rainfall caused by climate change, in addition to the geographical conditions that are located on the coast of island countries vulnerable to natural disasters. Rapid urbanization is doubling the impact and frequency of floods due to indiscriminate use of groundwater and the resulting ground subsidence, and is also strengthening the thermal impact of climate change. Meanwhile, as climate change creates a favorable environment for the habitat of endemic diseases including dengue, endemic diseases are also spreading. The characteristics of these Indonesian coastal cities, where various disasters are simultaneously and interconnected, are suitable for complex disaster research.

Among Indonesian coastal cities, Jakarta and Semarang are more vulnerable to the effects of disasters than other cities, especially due to rapid urbanization and population growth. However, at the same time, the city government is actively implementing various disaster response policies such as the Wolbachia mosquito project to respond to dengue, the construction of a barrier to respond to floods, and a planting campaign to mitigate the heat impact, and it is suitable for the study in that international development cooperation to support this is also actively underway. Therefore, in this study, research was conducted centering on Jakarta and Semarang.



[Figure 3] Jakarta-Semarang Coastal City Belt

2. Research Contents

This research project includes disease, heat, and water management, which are the core areas of complex disasters caused by climate change, as detailed topics, and ultimately aims to develop a prototype of Living Lab operation for climate change adaptation and to present guidelines for mitigating the impact of climate change in target countries. The study derives the causes and influencing factors of disasters through a qualitative and empirical approach, develops a Living Lab prototype for climate change adaptation through field visit surveys and Living Lab operations, and then proceeds to three stages of developing C4V indicators and guidelines for climate change mitigation.

The first stage focuses on deriving the causes and influencing factors for each disaster according to climate change, and is organically connected to each stage, including the process of analyzing the current status of each disaster through qualitative and empirical research before field investigation, deriving the hotspot of major interest, and identifying the influencing factors, and the process of specifying problems in the region and suggesting solutions after field investigations and living labs. In the disease sector, in order to derive the causes and influencing factors of disease (dengue) caused by climate change, the past and present status

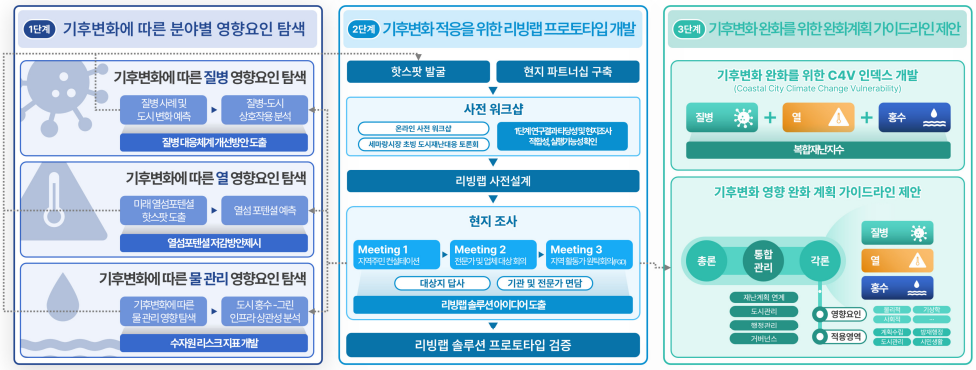
of the disease was analyzed and the possibility of disease spreading due to climate change was predicted. At the same time, vulnerable factors affecting the spread of disease were derived. After Living Lab, we tried to comprehensively identify the causes and influencing factors of disease caused by climate change and find solutions for disease response at the community level. In the column, after reviewing the factors influencing the formation of Urban Heat Island, the heat island potential hotspot and hotspot determinants were derived. After that, a plan to reduce the heat island potential was suggested through simulation. As for the water management influencing factors, after reviewing the possibility of flooding in the study area, a green system was proposed to mitigate the possibility of flooding caused by climate change.

In the second stage, a Living Lab prototype was developed and operated for climate change adaptation, and from the initial process of the study, a number of preliminary meetings and workshops were held with Indonesia's Diponegoro University and Semarang City government-related ministries, which are major partner organizations of the other country, to enhance the systematization and expertise of Living Lab prototypes. In addition, the disease, heat island, and flood risk areas derived from the first stage of the study overlapped, and a living lab prototype was developed through a microscopic approach to communities thought to be most vulnerable to complex disasters caused by climate change, and a policy foundation for Indonesia's adaptation and mitigation of climate change was provided in the future. To this end, through preliminary workshops before the fieldwork and exploration of the target site, the consistency of complex disaster-prone areas derived based on the results of the first stage of the study was confirmed, and a Living Lab prototype was developed through a three-step Living Lab prototype development process for local residents and experts. In this process, the prototype was supplemented by identifying the effects and blind spots of the policy being implemented through interviews with government-related ministries in Semarang.

In the third stage, C4V index and mitigation guideline were proposed to mitigate

the impact of complex disasters caused by climate change derived by synthesizing the results of the first and second stages. The researchers developed a C4V index to respond to complex disasters that can occur due to climate change at the community level and provided the results in the form of a dashboard so that anyone can read them through an online platform. In addition, by providing mitigation plan guidelines in consideration of the impact and policy establishment of heat (long-term), disease (short-term), and water (short-term) disasters, it was possible to establish a strategy for responding to complex disasters caused by climate change in coastal cities in Indonesia.

The guidelines were developed by two research partners, stakeholders (Korea-Indonesia advisory groups, residents), with international cooperation experts (Professor Juhyun Lee), and Professor Jeongseok Choi of Joongbu University.



[Figure 4] Research Contents

Section3. Research Strategy and Methodology

1. Research Strategy

This study focused on finding community-based adaptation and mitigation strategies to mitigate the occurrence and effects of complex disasters (disease, heat island, flood) caused by climate change. Accordingly, the factors influencing the occurrence of diseases, heat islands, and water management (flood) that are predicted to be the most influential in the community due to climate change were identified, and mitigation = strategies to reduce or convert climate change damage to opportunities were suggested. In addition, by simultaneously establishing an adaptation strategy to minimize the damage of climate change and maximize opportunities, a response to climate change that encompasses both adaptation and mitigation strategies was sought for Indonesia, the target country.

Also, based on the partnership established during the task period, a Living Lab prototype that can be used to identify factors influencing the occurrence of complex disasters caused by climate change and establish policies even after the end of the project was established, and based on the main problems and solutions derived through fieldworks and Living Lab, it was intended to provide mitigation guidelines including long-term practices and agendas proposed by the researchers. Through this, this study is differentiated in that it presents self-sustaining climate change alternatives led by the target country and lays the foundation for implementation. In particular, based on the problem-solving platform based on the public-private-resident partnership of the target country called Living Lab, sustainable alternatives for responding to climate change were derived, and a prototype was developed to enable response to climate change through Living Lab in the future. Therefore, this study aims to contribute to strengthening the target country's ability to respond to disasters caused by climate change in the long term along with highly effective policies in that it provides guidelines for establishing climate change mitigation plans centered on local fitness, effectiveness, and

feasibility at the community level.

In addition, this study attempted to identify various effects of climate change by combining empirical research on climate change and participatory observation (Living Lab) in the climate crisis community and prepare countermeasures. Climate change is a wide-area phenomenon that transcends geographic and administrative boundaries, and at the same time, its influence is a phenomenon that appears differently according to local characteristics. In addition, since the impact appears complex in the fields of politics, economy, humanities and society, culture, and environment, it is necessary to analyze the phenomenon through a multidisciplinary approach and suggest countermeasures when analyzing the ripple effect.

Accordingly, this study is a convergence study that combines literature research, empirical research, visit research, and fieldwork with using a complex research methodology focusing on big data analysis, AI, simulation GIS, and case extraction to diagnose the impact of climate change with dynamic · complex characteristics. In addition, the regional and local aspects of climate change were analyzed together using the hybrid injection study, a complex approach. This is a convergence study in the three major areas where the effects of climate change are severe, and it is judged that it will contribute to the methodological improvement in the future by introducing and combining and utilizing the optimal methodology for analyzing influencing factors and suggesting countermeasures according to climate change. A Memorandum of Agreement (MOA), which is the basis for continuous academic and research cooperation, has been signed between Seoul National University, which is the domestic subjective research institute, and Indonesia Research Institute (Diponegoro University), and in order to strengthen and develop research partnerships during the project, a research agreement was signed between the Seoul National University Convergence Planning Laboratory operated by the research manager and Diponegoro University. Through this, the regular exchanges and joint research promoted between Seoul National University and Diponegoro University have been progressively inherited to establish a continuous reciprocal partnership.

〈Table 1〉 Methodology

Phase		Influence of Disease	Influence of Heat	Influence of Water
Phase 1	Derivation of Complex Disasters Affecting Factors	- PESTEL Analysis - K-Means Clustering - System Dynamics - Decision Tree Model - Structural Equation Model	- LTM (Land Transformation Model) - ENVI-Met(Three-dimensional microscale Urban climate model) Simulation	- MSPA(Mophological Spatial Pattern Analysis) Modeling - Component based analysis)
Phase 2	Living Lab Prototype Development	- Living Lab (pre-design, local review, feedback, prototypes confirmed)		
Phase 3	C4V Index Development and Guideline Proposal	- Developing the C4V index by combining Phase 1 and 2 - Development of mitigation guidelines (policy Delphi progress)		

2. Research Method

Korean and Indonesian researchers collaborated by sharing the experiences of both countries, strengthening mutual research capabilities, and promoting close cooperative research during the task period. First, Korean researchers lead the analysis of factors affecting disease, heat, and water management according to climate change, while Indonesian researchers provided Indonesia's current status and basic data, reviewed policies, recruited local stakeholders (local governments, NGOs, international organizations, and community representatives), and established close communication channels to promote partnerships. Here, researchers from both countries participated in the feasibility evaluation and interpretation of the analysis results, comparative evaluation of the two countries' climate change experiences, and selection and verification of living lab target areas, and development of guidelines for climate change mitigation.

This study was divided into three stages to find adaptation measures through Living Lab and to propose C4V index development and mitigation guidelines through identification of factors influencing diseases, heat, and water disasters caused by

climate change.

In the first stage, through literature and empirical studies for 7 months, the impact of disease, heat, and water management on climate change was analyzed, the influencing factors for adaptation and mitigation were derived, and case study areas were detected. The case study area corresponds to the process of selecting a target site for living lab performance and also corresponds to the overlapping area of hot spots of disease, heat, and water disasters. Through a wide-area search for each field of disease, heat, and water management, particularly vulnerable areas were diagnosed from the effects of climate change, and areas with high vulnerability were selected as target sites for a case study on local analysis. In this process, based on the current status and basic data of Indonesia jointly analyzed by Indonesian researchers, three domestic research teams derived factors influencing climate change through literature and empirical research. After that, in order to secure the validity and interpretation of the analysis results, the evaluation was conducted with an Indonesian research partner.

In the second stage, based on the results of the first stage analysis, a Living Lab prototype for climate change adaptation was developed by visiting Indonesia for two weeks. In addition, after a fieldwork-based on the preliminary design of the Living Lab prototype for the vulnerable areas of climate change in the first stage, discussions were made with research partners and local experts. After the verification feedback, a prototype of the Indonesian Climate Change Adaptation Living Lab was developed and operated. After that, based on the operation results, guidelines for future Living Lab operation and application were developed.

Finally, in the three-month research process, C4V index and mitigation guidelines were developed to mitigate the impact of complex disasters on climate change based on the results of previous studies. A C4V index was developed based on the long-term disease impact mitigation strategy derived through analysis of the impact of disease, heat, and water management and the results of Living Lab consultations, and climate change mitigation guidelines were proposed, including

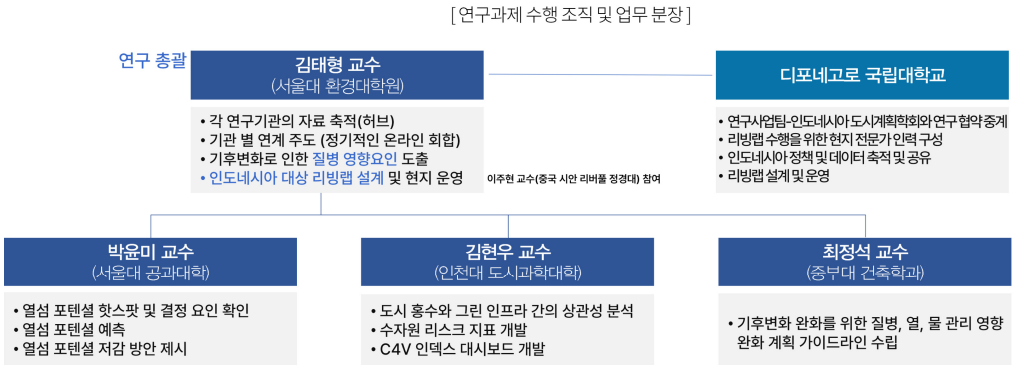
suppression and coordination of various health-affected factors, urban and regional planning directions, and continuous research partnerships were proposed through mutual verification between domestic and Indonesian researchers.

3. Organization and Division of Duties

Graduate School of Environmental Studies (GSES), Seoul National University (SNU)is the coordinator of a domestic joint research institution and conducted research projects by mediating networking with cooperative institutions. In cooperation with the other country, Diponegoro University, it plays the role of a hub for collecting local data and accumulating data, and regular online meetings were conducted to lead cooperation by institution.

GSES conducted empirical research on disease management, while College of Engineering, Seoul National University conducted heat management, and College of Urban Science, Incheon National University conducted empirical research on water management. Joongbu University has established guidelines for disease, heat, and water management impact mitigation plans for climate change mitigation. Incheon National University's School of Urban Science led the development of the C4V index dashboard, and each institution participated in the index derivation process.

In the case of Living Lab, it was conducted with an external expert, Professor Juhyun Lee of Xian Jiaotong-Liverpool University in China, and conducted with the other country, Diponegoro University for local operation. In addition, Diponegoro University formed a local expert manpower for living lab by relaying research projects and research agreements with Seoul National University. According to this division of work, Indonesian policies and data for research were accumulated and shared.



[Figure 5] Organization and Division of Duties of the Research Project

4. Research Schedule

In the first stage, the disease/heat/water management impact analysis was completed, and the main results confirmed through the second stage of the Living Lab prototype were reflected in the first stage of the study. In the second stage, a living lab prototype for climate change adaptation was derived through a verification process by visiting the Indonesian Living Lab target site. In the last three stages, the C4V index was developed by synthesizing the results of the first and second stages of the study, and at the same time, climate change mitigation guidelines were developed and verified.

분야	연구수행내용	연구추진일정 12월	1월	2월	3월	4월	5월	6월	7월	8월	9월	10월	11월	활동목표
(1단계) 기후변화에 따른 복합재난(질병, 열, 물 관리) 영향요인 도출														
질병 영향	질병 사례 진단 및 도시 변화 예측	●			●									기후변화에 따른 질병 영향 요인 규명
	질병-도시 상호작용 분석				●			●						
열 영향	미래 열섬포텐셜 핫스팟 도출	●			●									기후변화에 따른 열 영향 요인 규명
	핫스팟 결정요인 분석				●			●						
	열섬 포텐셜 저감방안 제시								●		●			
물 관리 영향	그린인프라(GI) 분석	●			●									기후변화에 따른 물 관리 영향 요인 규명
	도시홍수 취약성 지수 제시 및 취약 예측 지역 도출				●			●						
	홍수 위험(리스크) 지수 개발 및 녹지축 도출								●		●			
(2단계) 기후변화 영향 적응을 위한 리빙랩 프로토타입 개발														
공통	리빙랩 프로토타입 개발							●	●					기후변화 적응을 위한 리빙랩 프로토타입 개발
	리빙랩 프로토타입 검증								●	●				
(3단계) C4V 인덱스 개발 및 기후변화 완화 가이드라인 제안														
공통	C4V 인덱스 개발								●		●			C4V 인덱스 개발, 기후변화 완화 가이드라인 제안
	완화 가이드라인 개발									●		●		
	완화 가이드라인 검증											●	●	

[Figure 6] Research Schedule

II. [Phase 1] Impact Factors of Climate Change on Disasters

Summary in Local Language (Sekilas tentang Bahasa Indonesia)

1. Hasil Temuan Berdasarkan Jenis Bencana

1) Penyakit

Penelitian ini menganalisis interaksi antara struktur perkotaan wilayah pesisir, perubahan iklim, dan penyakit endemik dengan fokus pada kondisi sebelum dan saat ini di Jakarta dan Semarang. Faktor-faktor utama yang memengaruhi meliputi suhu, kelembapan, curah hujan, metode penyediaan air, dan variabel sosial ekonomi (seperti kepadatan penduduk dan tingkat pendapatan). Titik panas demam berdarah di Jakarta ditemukan di area permukiman padat dan kawasan industri, sementara di Semarang terkonsentrasi di wilayah pegunungan di tenggara, di mana faktor-faktor lingkungan mendukung habitat nyamuk. Analisis klaster K-means menunjukkan bahwa pencemaran air, akses buruk terhadap fasilitas kesehatan, dan proporsi tinggi keluarga berpenghasilan rendah serta daerah kumuh meningkatkan kerentanan terhadap penyakit endemik. Hasil ini mengungkapkan bahwa akses terhadap fasilitas kesehatan dan pasokan air yang bersih dan layak sangat penting dalam mengurangi wabah penyakit. Selain itu, buruknya infrastruktur sanitasi dan kurangnya pengelolaan ruang hijau memperburuk risiko penyakit. Terakhir, angka kerentanan semakin meningkat oleh disparitas sosial ekonomi dan sistem tanggap bencana yang tidak memadai.

2) Panas

Penelitian ini mengkaji efek pulau panas perkotaan (urban heat island) di Jakarta dan Semarang dengan mengidentifikasi aktivitas industry serta kurangnya perencanaan kota dan ruang hijau sebagai kontributor utama. Di Jakarta,

daerah-daerah seperti Kalideres dan Cilincing menunjukkan potensi pulau panas yang tinggi akibat fasilitas industri yang memengaruhi area permukiman di sekitarnya. Di Semarang, titik panas terkonsentrasi di sekitar bandara dan pabrik, khususnya di Tambakrejo dan Meteseh, di mana kombinasi panas industri dan zona permukiman padat penduduk memperparah risiko di daerah-daerah tersebut. Hasil simulasi berhasil mengidentifikasi strategi-strategi mitigasi panas yang efektif dan dapat disesuaikan dengan kondisi lokal setempat, yakni penghijauan atap, penanaman pohon di sepanjang jalan, dan atap dingin (cool roofs). Sebagai contoh, penghijauan atap paling efektif diimplementasikan area perkotaan yang padat, sedangkan atap dingin lebih cocok untuk zona dengan kepadatan rendah dan ruang hijau yang minim. Temuan ini menekankan pentingnya rencana mitigasi panas yang mampu disesuaikan berdasarkan karakteristik fisik dan lingkungan setempat.

3) Air

Risiko banjir di Jakarta dan Semarang dipetakan menggunakan Indeks Risiko Banjir (Flood Risk Index/FRI) dan NDVI, yang menguji infrastruktur hijau serta zona-zona rentan. Di Jakarta, wilayah seperti Penjaringan (daerah pesisir dataran rendah) dan Kakung(Cakung) Timur (dekat aliran sungai rawan banjir) sangat rentan terhadap banjir akibat gelombang pasang, penurunan tanah, dan lemahnya sistem drainase. Di Semarang, daerah seperti Tambakharjo dan Tambakrejo memiliki risiko tinggi karena elevasi tanah yang rendah, sistem drainase yang tidak memadai, serta banjir pasang yang diperburuk oleh pembuangan sampah sembarangan. Solusi-solusi yang diusulkan mencakup intervensi infrastruktur hijau seperti pengembangan parit bervegetasi, taman hujan (rain gardens), dan peningkatan pemeliharaan drainase. Inisiatif-inisiatif dengan pelibatan masyarakat untuk mengatasi permasalahan pengelolaan banjir sekitar juga diusulkan, seperti sistem pelaporan sampah dan penggunaan drone otomatis untuk pengumpulan sampah. Intervensi ini bertujuan meningkatkan ketahanan dengan menangani kerentanan secara fisik dan berbasis masyarakat.

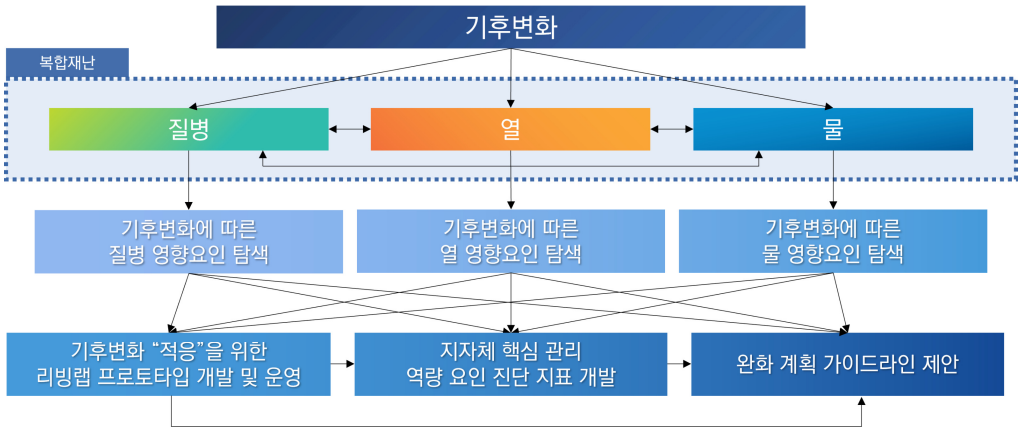
2. Kota-Kota Pesisir dan Bencana Kompleks

Penelitian ini memeriksa keterkaitan antara bencana penyakit, panas, dan air sebagai bencana kompleks di kota-kota pesisir. Banjir tidak hanya menyebabkan kerusakan properti tetapi juga mencemari pasokan air, menimbulkan genangan yang menjadi habitat nyamuk, serta memperparah penyebaran penyakit seperti demam berdarah. Pulau panas (heat island) meningkatkan variabilitas curah hujan, sehingga memperbesar risiko banjir perkotaan. Peningkatan suhu juga mempercepat tingkat reproduksi nyamuk dan memperburuk kondisi sanitasi, sehingga memperluas penyebaran penyakit vektor. Efek-efek berantai ini menunjukkan perlunya strategi terpadu dalam mengatasi interaksi-interaksi antar bencana tersebut. Penelitian ini merekomendasikan pendekatan holistik yang menggabungkan infrastruktur hijau, mitigasi panas yang mampu disesuaikan, dan pengelolaan air yang lebih baik, dengan partisipasi aktif masyarakat serta integrasi kebijakan yang komprehensif untuk mengurangi kerentanan serta meningkatkan ketahanan di wilayah perkotaan pesisir.

Section1. Research Purpose and Contents

1. Research Purpose

The first phase of the study, “Impact Factors of Climate Change on Disasters”, focuses on coastal cities in Indonesia to diagnose the current status of disaster occurrence for disease (endemic), heat (heat island), and water (flood), and then analyze the characteristics of coastal urban areas that affect disaster occurrence to identify impact factors. Along with this, a disaster-specific risk index is developed to predict and manage the likelihood of disasters caused by climate change in the region. Based on the status of major disaster areas and disaster impact factors derived from the first phase of research, we will develop a living lab prototype for climate change adaptation and utilize it to propose climate change mitigation strategies.



[Figure 7] Phase 1 Overview

2. Research Contents

Step 1 consists of diagnosing the current situation of each disaster, identifying the main occurrence points, exploring influencing factors, identifying disaster impact factors through fieldwork and identifying the possibility of compound disasters,

and developing risk indexes. For example, for diseases, endemic disease outbreaks are collected and managed by local health centers, so we used data collected at the administrative district level for analysis and analyzed the relationship between local demographic, socioeconomic, and physical characteristics and disease outbreaks in consideration of disease outbreak characteristics. On the other hand, heat was analyzed by extracting ground surface temperature and air temperature based on satellite data, which are used to identify heat island phenomena. The detailed scope of the study for each disaster follows.

① Impact Factors of Climate Change on Disease

- Diagnose the current situation: diagnose the past and current climate change-induced endemic diseases in Indonesia (PESTEL analysis)
- Identify of key endemic areas: Identification of key endemic areas in Jakarta and Semarang, the two study sites.
- Identify of influencing factors: Identification of influencing factors by analyzing the impact of socioeconomic, physical, and environmental characteristics of coastal cities on endemic disease outbreaks
- Fieldwork: Identify influencing factors for endemic disease outbreaks through fieldwork and living labs, and understand the potential for endemic disease spread and multi-disaster events due to climate change
- Develope a risk index: Synthesizing research results to develop a risk index to predict the spread of endemic diseases due to climate change.

② Impact Factors of Climate Change on Heat Impact

- Diagnose the current situation: identify the current situation of heat impacts due to climate change in Indonesia
- Identify key hotspots: Identify key heat hazard areas in the study sites of Jakarta and Semarang
- Identify influencing factors: analyzing the impact of socioeconomic, physical,

and environmental characteristics of coastal cities on heat island phenomena

- Fieldwork: identifying heat impact factors through fieldwork and living labs, identifying the potential for increased heat risks and multi-disaster events due to climate change, and proposing responses to heat island potential through simulation.
- Develope a risk index: Synthesizing research results to develop a risk index that predicts the spread of heat impacts due to climate change.

③ Impact Factors of Climate Change on Water

- Diagnose the current situation: identify the current state of climate change water management in Indonesia.
- Identify key focal points: Identify key flood-prone areas in Jakarta and Semarang, the two study cities.
- Identify influencing factors: analyzing the impact of socioeconomic, physical, and environmental characteristics of coastal cities on flooding
- Fieldwork: identifying flood impact factors through fieldwork and living labs, identifying the potential for increased flood risk and multi-hazard events due to climate change, and analyzing the potential for mitigation through green infrastructure networks.
- Develop risk index: Synthesizing research results to develop a risk index that predicts the occurrence of flooding due to climate change

Section2. Impact Factors of Climate Change on Disease

1. Research Background and Objectives

Indonesia is experiencing rising average annual temperatures, rising sea levels, and increasing land subsidence due to climate change. In April 2024, the temperature reached 27.7℃, 0.89 degrees Celsius above the 1991-2020 average of 26.9℃, breaking the record for the hottest April in 40 years, and according to the Meteorological Agency's Climate Outlook 2025 report, the national average temperature is expected to increase by 0.3℃ to 0.6℃ from May to July 2025, with Java, South Sumatra, and East and West Nusa Tenggara being most affected by the increase. In particular, in 2024, the incidence of endemic dengue increased by 2.5 times compared to 2023, and the number of deaths nearly tripled, as hot and humid temperatures under the influence of El Niño increased the number of pathogen-transmitting mosquitoes and the duration of their activity.[1)]

Despite the annual increase in dengue cases due to climate change, the lack of health infrastructure and specialized personnel to respond to the endemic disease is preventing people from receiving adequate treatment. For example, in Bandung, Java, the number of dengue cases has skyrocketed, but there are not enough hospital beds to accommodate them, so patients are being treated in hallway cots or wheelchairs.

Climate change-induced declines in food production contribute to undernutrition, which can lead to lowered immunity and increased vulnerability to endemic diseases. The incidence of endemic diseases is increasing, especially among low-income populations with low access to adequate nutrition and health services (WHO, 2023).

Against this backdrop, this study sought to identify factors that influence endemic

1) Yonhap News Agency (April 5, 2024), "Indonesia dengue 'emergency' amid El Niño...Deaths triple from last year,"

diseases due to climate change and to predict the likelihood of endemic disease spread due to climate change in the future. The study consisted of two stages [see Figure 8]: Stage 1 diagnosed the past and current endemic disease outbreaks due to climate change based on endemic disease response reports, research literature, and statistical data published by Indonesian and international organizations. In the second step, we identified endemic disease outbreaks in coastal cities through hotspot analysis and identified socioeconomic, physical, and environmental characteristics of coastal cities that affect endemic disease outbreaks. Through this, we predicted the possibility of endemic diseases spreading due to climate change and identified materials for living labs in target countries. After identifying the factors affecting endemic disease outbreaks and the likelihood of endemic disease spread and complex disasters due to climate change through fieldwork, we synthesized the research results to develop a risk index to predict the spread of endemic diseases.



[Figure 8] Endemic Research System

2. Indonesia's past and current climate change-endemic disease status

1) Research Method

To understand Indonesia's past and current experiences with endemic diseases and responses to them, this study focused on 10 key reports and data published between 2015 and 2023 by the National Disaster Management Agency, the Indonesian Ministry of Health and Welfare, local governments (Jakarta and Semarang), and the WHO (see Table 2). A review framework was then structured to guide the literature analysis, and candidate variables that may influence ongoing endemic disease outbreaks were identified in step 2.

We focused on endemic disease types and outbreaks (incidence, timing and duration of outbreaks, etc.), as well as geographic, environmental, and socioeconomic characteristics of endemic areas. Then, through macroeconomic environment analysis (PESTEL), we analyzed the impact of climate change on endemic disease outbreaks, their spillover effects, and changes in responses in six sectors of the macroeconomic environment (PESTEL: political and policy (P), economic and industrial (E), social (S), technological (T), environmental (E), and legal and regulatory (L)) by city.

〈Table 2〉 List of literature review

Title	Type	Lang.	Publication Institution	Date
National Action Plan for Acceleration of Malaria Eliminaton 2020-2024	Report	English	Ministry of Health of The Republic of Indonesia	2020
The Role of Village Malaria Cadres and Consultants in Controlling and Eliminating Malaria in Eastern Indonesia	Report	English	UNICEF	2022
Community-Based Surveillance: Indonesia Case Study — Community Epidemic & Pandemic Preparedness Programme (April 2021)	Report	English	The International Federation of Red Cross and Red Crescent Societies (IFRC)	2021

Title	Type	Lang.	Publication Institution	Date
Evidence-based Data and Information on the Impact of Climate Change in the Health Sector in Indonesia	Report	English	UNICEF, Ministry of Health, Indonesia	2021
Health Governance and Dengue in Southeast Asia	Report	English	S. Rajaratnam School of International Studies	2015
The Republic of Indonesia Health System Review	Report	English	WHO	2017
National Strategic Plan (NSP) for the Dengue Control Programme 2021-2025	Report	Bahasa	Ministry of Health of The Republic of Indonesia	2021
Dengue 2022 Annual Report	Report	Bahasa	Ministry of Health of The Republic of Indonesia	2023
Semarang Health Profile 2022	Report	Bahasa	Health Department of Semarang	2023
DKI Jakarta Province Health Profile 2022	Report	Bahasa	Health Department of Jakarta	2023

2) Main Results

① Current status of endemic diseases in Indonesia

In Indonesia, malaria and dengue (hereafter referred to as dengue) are primarily endemic and endemicized throughout the country. Both endemic diseases are climate-sensitive and mosquito-borne, meaning they are vulnerable to spread in hot and humid environments. Malaria is more prevalent in densely vegetated forests, wetlands, and coastal areas, while dengue is more prevalent in urban areas, with many cases transmitted at relatively low altitudes, confirming geographic differences in endemicity.

② PESTEL analysis

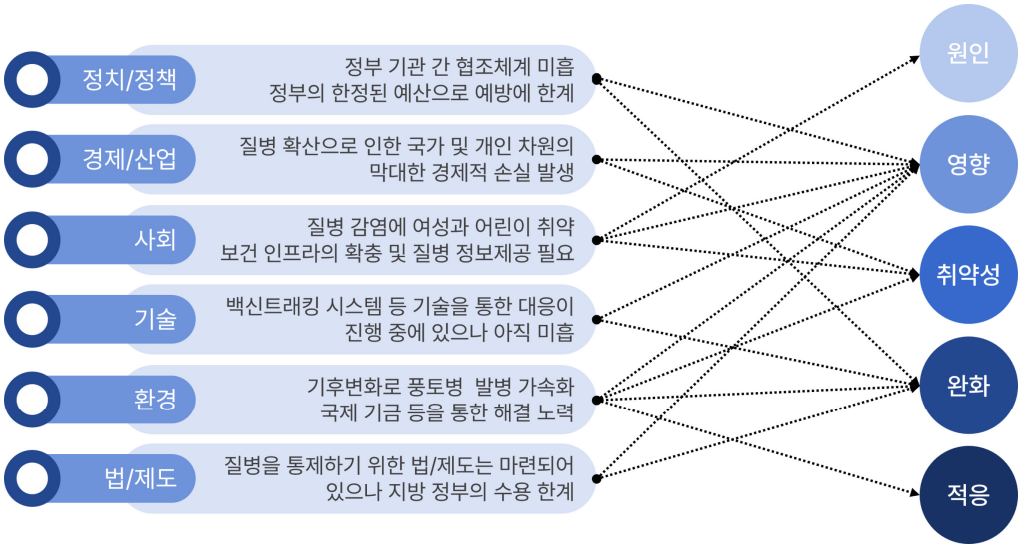
The results of the macro-environmental analysis (PESTEL) showed that in the political and policy (P) sector, inter-ministerial, local, and central government coordination is needed, and that limited budgets are limiting the response. In the economic and industrial (E) sector, endemic disease outbreaks have been found to cause significant economic losses at the national and individual levels due to

reduced productivity and increased healthcare costs. In the Social (S) dimension, it was found that women and children are particularly vulnerable to endemic diseases and that health infrastructure needs to be expanded and adequate information needs to be provided to respond to endemic diseases. In the Technology (T) category, Indonesia has a range of technical efforts to address endemic diseases, including vaccine tracking systems, surveillance systems, and epidemiologic survey pilots, while in the Environment (E) category, we learned that climate change is accelerating the outbreak of climate-sensitive endemic diseases and that climate funds are being used to address them. Finally, in the Legal and Institutional (L) category, we found that Indonesia has laws and institutions in place to respond to endemic diseases, but there are limitations in terms of acceptance, such as insufficient response capacity.

〈Table 3〉 PESTEL analysis results

Type	Dengue	Malaria
Political (P)	- Several community-based response programs tried (MoH, Red Cross) - 3M Plus response (prevention of mosquito breeding and disease transmission) - Financial support through the Indonesia Climate Change Trust Fund, with IDR 96.8 billion allocated by the central government for dengue response programs	- Declared Malaria Free by 2030, but response is limited
Economic (E)	- Dengue is a concern in tourist areas (airports, etc.) - The cost of each dengue outbreak ranges from $791 to $1250, totaling $38.1 billion in INR (2015)	- Malaria prevention contributes to national economies through increased productivity in food production, fisheries and export industries, and protection of migrant areas - Low- and middle-income people are more likely to be infected with malaria
Social (S)	- Public, private, and academic collaboration in dengue research and response (efforts to secure research ownership) - Health infrastructure and health workforce shortages due to urbanization	- Households and farmers are more likely to be infected (early season/ outdoor activities) - Lack of information about health facilities, poor housing, and participant characteristics affect malaria

Type	Dengue	Malaria
Technology (T)	- Pilot vector tracking, mapping, and epidemiologic surveys to create early warning systems and national guidelines for dengue prevention - Mosquito tracking for a 100-meter radius of an outbreak site - early health warning system developed and utilized in Semarang	- Developed and operated malaria surveillance system (SISMAL) to spread to villages and private units - Developed and operated SMILE, a malaria vaccine tracking system (WHO, MoH)
Environment (E)	- Climate vulnerable diseases mapped but not utilized - Climate change and heat islands accelerating dengue	- Climate change affects malaria vector ecology and outbreaks - Reduced food production due to climate change contributes to malnutrition, which in turn contributes to increased infectious diseases, including malaria.
Legal (L)	- Declaring a dengue emergency is legally mandatory - fines for failing to manage mosquito habitats - Surveillance system is passive and no evaluation system	- Malaria elimination programs in progress - Private health facilities are not up to national standards (lack of response capacity) - Limited difference between central and local government response levels



[Figure 9] PESTEL analysis and indicators in climate change

③ Candidate variables identification

To identify key variables for use in the second stage of the analysis, the study focused on research papers that addressed the relationship between climate change and regional characteristics and endemic disease outbreaks in Indonesia. We then reviewed the linkages between the variables reviewed in the literature and the UNSD climate change indicators, focusing on the United Nations Statistics Division's (UNSD) five domains of climate change: causes, impacts, vulnerability, mitigation, and adaptation.

The review of key research literature suggests that climate and geographic, environmental, and social characteristics of endemic areas influence the spread of endemic diseases. Among the climatic conditions, temperature, humidity, and precipitation have a major impact on the habitat of mosquitoes, which are vectors of endemic disease (Ashari Rasjid et al., 2019; Kesetyaningsih et al., 2018; Ishak and Kasman, 2018), and wind speed has been shown to influence the distance mosquitoes travel and their contact with humans (Ishak and Kasman, 2018). Among geographical conditions, land cover classification and altitude have been shown to influence the extent, i.e., magnitude, of endemicity (Kesetyaningsih et al., 2018), and seasonal patterns of endemicity have been shown to be influenced by normalized difference vegetation index (NDVI) (Astuti et al., 2019). Among environmental characteristics, the expansion of urban areas has been shown to facilitate the spread of endemic diseases, with higher housing density being associated with higher endemicity rates (Adnan, 2021). Finally, among local social characteristics, age affects the degree of exposure to endemic disease transmission (Kesetyaningsih et al., 2018),

As a result of applying UNSD's climate change area to the main variables affecting endemic outbreaks based on the review of the research literature, climate conditions consist of variables corresponding to the 'impacts' sector among climate change areas, and geographic conditions and social characteristics are characterized by multiple variables corresponding to 'vulnerability' and 'drivers.' 〈Table 4〉.

〈Table 4〉 Review of Climate Change-Urban Structure-Disease Variables

Division	Variable	UNSD Climate Change Area	UNSD Climate Change Indicator	Related Literatures
Climate Conditions	Humidity	Impacts	• Relative humidity • Air temperature	Ashari Rasjid et al. (2019), Banu et al. (2011), Ishak and Kasman (2018), Kesetyaningsih et al. (2018)
	Relative humidity	Impacts	• Relative humidity • Air temperature	Banu et al. (2011), Halide and Ridd (2008)
	Air temperature	Impacts	• Cold nights, Warm days • Relative humidity • Air temperature	Ashari Rasjid et al. (2019), Ishak and Kasman (2018)
	Average temperature	Impacts	• Cold nights, Warm days • Relative humidity • Air temperature	Banu et al. (2011), Tosepu et al. (2018)
	Min-maximum temperature	Impacts	• Cold nights, Warm days • Relative humidity • Air temperature	Tosepu et al. (2018)
	Rainfall	Impacts	• Precipitation	Ashari Rasjid et al. (2019), Ishak and Kasman (2018), Kesetyaningsih et al. (2018)
	Rainy day	Impacts	• Precipitation	Ashari Rasjid et al. (2019)
	Duration of sunlight	-	-	Ashari Rasjid et al. (2019)
	Wind speed	-	-	Ishak and Kasman (2018)
	Precipitation	Impacts	• Precipitation	Banu et al. (2011), Makhapakron and Tripathi (2005), Wu et al. (2007)
Geographical Conditions	Land cover	Impacts	• Proportion of land that is degraded over total land area	Kesetyaningsih et al. (2018)
		Vulnerability	• Water bodies vulnerable to climate change impacts • Reduction of surface water bodies	Kesetyaningsih et al. (2018)
	Altitude	-	-	Astuti et al. (2019)
	NDVI	-	-	Adnan (2021), Brage et al. (2021)

Division	Variable	UNSD Climate Change Area	UNSD Climate Change Indicator	Related Literatures
Social factors	Older age	Drivers	• Population	Adnan (2021)
	Working population	–	–	Schmidt et al. (2011) Romeo-Aznar et al. (2022)
	Urban population	Drivers	• Population	Telle et al. (2021)
	Income level: slum/wealthier area	Vulnerability	• Proportion of the population living below the international poverty line by sex, age, employment status and geographic location) • Proportion of urban population living in slums, informal settlements or inadequate housing	Adnan (2021)
Environmental factors	Density of houses	–	–	Husnina et al. (2019)
	Percentage of green space	Mitigation, Adaptation	• Forest area • Green urban area	Gubler(2011) Akhtar et al.(2016)
	Urbanization	Adaptation	• Total area of cities	Wolfe et al. (2023) Thakali et al.(2022)
	Percentage of wastewater treatment	Adaptation	• Total wastewater generated • Total wastewater treated)	Bangs et al. (2006)
ETC	ENSO (ElNiño Southern Oscillation) Houseindex	–	–	Arcari et al. (2007)
	SOI (Southern Oscillation Index)	–	–	

3. Analysis of the endemic diseases-coastal urban structures interaction and prediction of the endemic disease spread due to climate change

This study analyzed the interactions between endemic diseases and coastal city structures in a complex manner. First, the current status of endemic (dengue) outbreaks (frequency, scale, pattern) was identified in Jakarta and Semarang. Specifically, the current status of occurrence of endemic diseases according to city characteristics (population, etc.) was identified, and the current status of endemic diseases was confirmed. After that, the Living Lab target site was derived through hotspot analysis. In addition, in order to consider the overall pattern of endemic diseases occurring in coastal cities, the interaction between endemic diseases and coastal city structures was analyzed targeting coastal cities located on Java Island.

1) Diagnosis of the status of endemic diseases by city and derivation of endemic hotspots

① Methodology

In this study, in order to diagnose the status of endemic diseases by city, the status of endemic diseases was identified by ① city, autonomous district, and ② the status of endemic diseases according to urban characteristics (population, etc.) was confirmed by securing endemic data at the village level. After that, ③ endemic patterns in cities were identified through the analysis of endemic hot spots, and living lab target sites were derived based on this.

In the course of conducting the study (literature analysis, expert interview), it was confirmed that dengue was mainly occurring in Jakarta and Semarang rather than in malaria. In particular, it was confirmed through preliminary status analysis that the number of cases of malaria increased significantly in 2022 compared to 2021 in Jakarta, with a maximum of 50 cases per region between 2021 and 2022. Based

on this, the researchers performed the analysis by limiting the endemicity of the target area to dengue. As for the data used in this study, in the case of Jakarta, the Outbreak number of dengue outbreaks reported from 2018 to 2021 was used from the VILLAGE Potential Survey data of the Indonesian Statistical Office (BPS). The number of dengue outbreaks corresponds to the number of infections identified according to the official aggregation criteria of the Indonesian government. Semarang used monthly dengue outbreak data from 2019 to 2023 provided by the Dengue Integrated Data Portal (Tungal Dara) operating in Semarang City. In the analysis, data were constructed and utilized in units of villages.

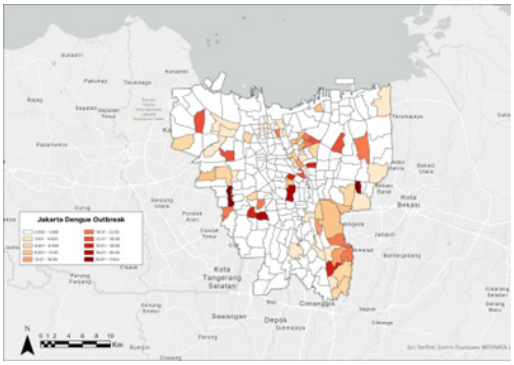
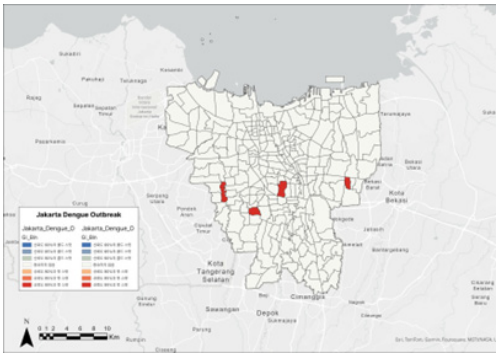
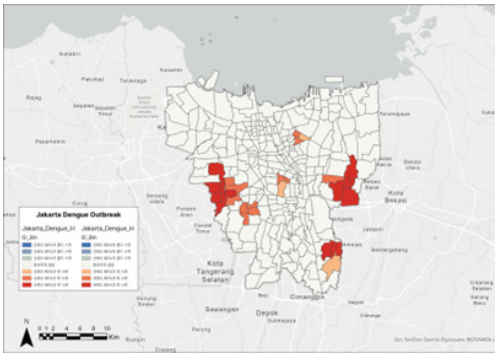
Based on the constructed data, a hotspot analysis was performed to identify the areas where endemic diseases occurred. For the analysis, hotspot areas for endemic diseases were derived by using Getis-Ord Gi and Local Moran's I analysis. Getis-Ord Gi corresponds to a technique of identifying hotspot occurrence patterns by analyzing events grouped in a specific area, and Local Moran's I analysis is a technique of deriving hot spots by identifying clusters and spatial outliers in areas with higher or lower values than those in the surrounding area. By synthesizing these analysis results, the occurrence pattern of endemic hot spots was comprehensively identified, and living lab target areas were derived.

② Analysis Results

According to hotspot analysis, Jakarta shows a pattern of concentrated dengue outbreak centering on villages located in the center of the city. In particular, the number of dengue outbreaks in 2022 increased significantly compared to 2021, and dengue occurred spatially centering around Jakarta Timur, Jakarta Barat, and Jakarta Selatan. Malaka Sari (105 cases, located in the west center) and Ulujami (97 cases, located in the east center), which are densely populated with low-rise residential areas, recorded the highest number of dengue outbreaks. In the result of controlling the number of dengue outbreaks and dengue outbreaks in Jakarta by population, the status of outbreaks by region was similar, and the results of the

Getis-Ord Gi also showed concentrated forms in the western and eastern centers of the city 〈Table 5〉. It was confirmed that hot spots were formed mainly in low-rise residential areas (Malaka Sari and Ulujami areas with high number of outbreaks in a single area), and industrial areas (Cakung Barat).

〈Table 5〉 Dengue hot spot analysis results of Jakarta

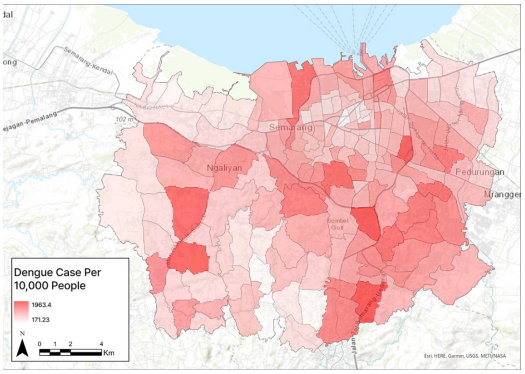
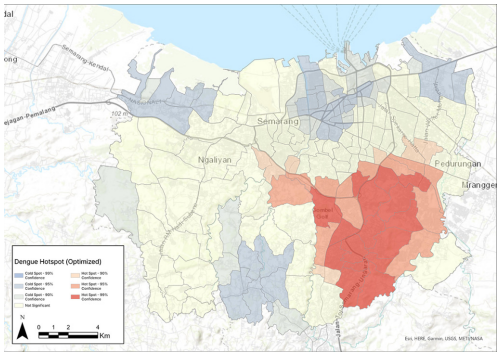
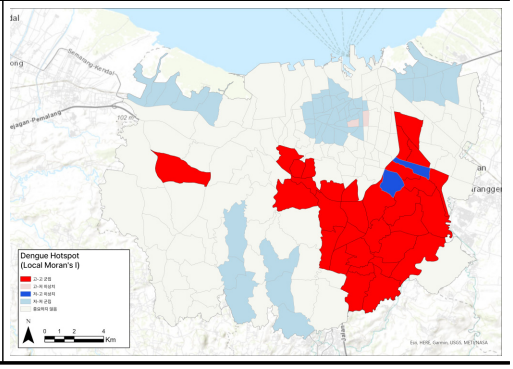
Number of dengue cases per 10,000 persons	
	
Getis-Ord Gi (Fixed Band)	Getis-Ord Gi (Contiguity Edge)
	

〈Table 6〉 Jakarta Dengue Hotspot Type

	Hotspot Type 1	Hotspot Type 2
Region	Malaka Sari, Ulujami	Cakung Barat
Characteristic	Low-rise residential area	Factories and warehouses
Satellite Imagery		

In Semarang, dengue occurred intensively in the southeastern part of the city. Although there are some differences in the pattern of dengue occurrence by region depending on the year of occurrence, dengue occurrence was concentrated in the southeastern part of the city where hills and forests are located, and it was confirmed that it occurred mainly in Sendang Mulyo (536 cases) and Tlogosari Kulon (397 cases). The results of Semarang's hotspot analysis were derived similarly to the results of the current status of the number of dengue cases per 10,000. Major hotspot areas include low-rise residential dense areas (Meteseh, Sumurboto) and residential areas (Jabungan, Jangli, Mangunharjo) adjacent to forests and green areas.

〈Table 7〉 Dengue hot spot analysis results of Semarang

Number of dengue cases per 10,000 persons	
	
Getis-Ord Gi (Fixed Band)	Local Moran's I
	

〈Table 8〉 Semarang dengue hotspot type

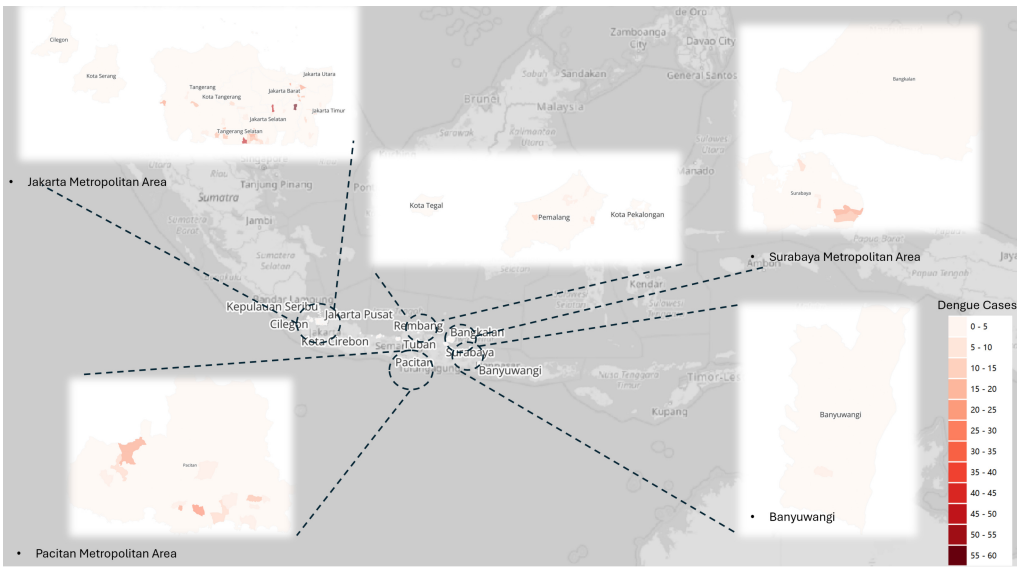
	Hotspot Type 1	Hotspot Type 2
Region	Meteseh, Sumurboto	Jabungan, Jangli, Mangunharjo
Characteristic	Low-rise residential area	Residential area adjacent to forests and greenery
Satelite Imagery		

2) Interaction Between Endemic Disease and Coastal City Structure

① Methodology

In order to derive the characteristics of coastal cities that affect endemic diseases, this study expanded the analysis target area for coastal cities on Java Island, where Jakarta and Semarang are located, and analyzed the interaction between endemic and coastal urban structures. The unit of research analysis is a village and includes Pacitan, Rembang, Surabaya, and Banyuwangi metropolitan areas, which have similar geographical and climatic environments to Jakarta and Semarang.

The research results derived through this can be used to expand future research in consideration of the characteristics of coastal cities on Java Island, Indonesia, which has a similar environment to Jakarta and Semarang, while at the same time establishing large-scale public health and urban planning policies by reflecting the characteristics of coastal cities and setting the direction of international cooperation projects based on this.



[Figure 10] The status of endemic disease (dengue) in 2020 at the study site [Unit: Number of cases]

② Methodology

This study used K-Means clustering and the decision tree model to derive the coastal city structure that affects the occurrence of endemic diseases. K-Means clustering was used to analyze the causal relationship and dynamic changes between the main characteristics affecting the occurrence of dengue, and through this, the similarity between regions in coastal cities and the current status of dengue outbreaks were examined. After that, the decision tree model was used to investigate the geographical, environmental, and socioeconomic characteristics of the region that affect the occurrence of dengue in Jakarta and Semarang. The decision tree model is an analysis technique predicting the likelihood of disease occurrence by creating a tree structure based on the patterns observed in the data. In the study, by setting the presence or absence of dengue occurrence and the number of occurrences in the village as dependent variables for each village unit, it was intended to derive the factors influencing the endemic diseases occurring in coastal cities (Jakarta, Semarang). Through this, the complex interaction between endemic diseases and coastal city structures was analyzed, and the effects of climate change were confirmed to derive the spreading of endemic diseases and vulnerable factors of cities in the future. After that, an indicator system was established based on newly identified influencing factors and vulnerable factors causing complex disasters through fieldwork, and then an endemic risk index was derived.

③ Data

During the research process, the factors influencing the occurrence of endemic diseases were derived based on the characteristics of the Jakarta-Semarang coastal area and expert advice, including the factors vulnerable to the spread of endemic diseases derived from "Step 1: Literature Review and PESTEL Analysis". After that, in consideration of the possibility of obtaining data, the final input variables were selected as shown in Table 9 below.

Indonesia's coastal areas, such as Jakarta and Semarang, are known to be vulnerable to flooding. In particular, Jakarta is located on the shore of a swamp where 13 rivers intersect, and the some areas of the city has sunk about 60 cm (Hankook Ilbo, 2021/08/19)[2)]

Semarang is also regularly flooded due to ground subsidence mainly in coastal areas. Along with geographical characteristics of ground subsidence that promotes flooding (introduction of salt water in coastal areas), it seems that the influence of excessive intake of groundwater is large due to low water supply rate and lack of water treatment facilities. The continuous occurrence of such floods affects the spread of dengue by creating pools where mosquitoes are easy to reproduce, and the use of water and lack of water treatment facilities with unknown source can affect the occurrence of dengue in that it can increase the inflow of contaminated water into villages and homes. Therefore, in this study, among the influencing factors derived in step 1, the wastewater treatment facility was deepened in terms of water supply and water pollution to derive detailed variables, and variables representing the socioeconomic characteristics of the region were selected in consideration of the impact of climate change on endemic outbreaks.

〈Table 9〉 Input variables

Code	Variable	Description
R605BK2	The presence or absence of endemic diseases	The presence or absence of endemic diseases (0: None, 1: Exist)
R605BK3	The number of endemic cases	The number of endemic cases in the village
R507A	Main ways of supplying drinking water at home	1: Mineral water for sale, 2: Water supply facilities, 3: Water pipes with meters, 4: Water pipes without meters, 5: Pump wells (ground water), 6: wells, 7: mineral springs, 8: rivers, ponds, reservoirs, dams, 9: rainwater, 10: others
R507B	Main Supply Method of Non-Drinking Water	1: Water pipes with meters, 2: Water pipes without meters, 3: Pump wells (ground water), 4: wells (ground water), 5: mineral springs, 6: rivers, ponds, reservoirs, dams, 7: rainwater, 8: others

2) Hankook Ilbo (2021/08/19), "The fastest sinking city's fate," https://www.hankookilbo.com/News/Read/A2021081711020001405

Code	Variable	Description
R509B2K2	Drinking water (cooking) feeding method: rivers	If the water supply method for cooking food is strong (0: not applicable, 1: applicable)
R509B2K4	Drinking water (cooking) feeding method: reservoir	If the water supply method for food production is a reservoir (0: Not applicable, 1: applicable)
R509B2K5	Drinking water (cooking) feeding method: rainwater	If the water supply method for food production is rainwater (0: not applicable, 1: applicable)
R509B3K2	Drinking Water Supply Method: River	If the drinking water supply method is strong (0: Not applicable, 1: applicable)
R509B3K3	Drinkable water Supply method: Canals	If the drinking water supply method is canals, applicable (0: not applicable, 1: applicable)
R509B3K4	Drinking Water Supply Method: Reservoir	If the drinking water supply method is a reservoir (0: Not applicable, 1: applicable)
R509B3K5	Drinking water feeding method: rainwater	If the drinking water supply method is rainwater, applicable (0: not applicable, 1: applicable)
R511A	Whether or not there is a place to supply the self-training center (pharmacore, etc.) in the village	Whether there is a source of self-sustaining resources such as mineral spring in the village
R512A	Existence of slum area	The existence of slum areas in the village
R512B1	Number of slum areas	Number of slum areas in town
R512B2	Number of residential buildings in slum areas	Number of residential buildings in slum areas located within the village
R512B3	Number of residents (households) in slum areas	Number of residents (households) in slum areas located in the village
R513AK2	Occurrence of water pollution	Number of residents (households) in slum areas located in the village
R510C1	The occurrence of river pollution	Number of residents (households) in slum areas located in the village
R513AK3	Causes of water pollution	Causes of water pollution in the village (0: does not occur, 1: domestic use, 2: industrial facilities, 3: others)
R513AK4	Water pollution complaints	Number of complaints about water pollution in the village
R601BK3	Annual flood count	Annual flood count
R601BK4	Annual flood victims	The annual number of residents affected by flooding in the village
R704AK2	Number of medical facilities	Number of medical facilities in town
R704AK3	Distance to a nearby medical facility	The distance from the village (centre) to the nearest medical facility
R710	Number of cases of malnutrition	The number of malnutrition cases in the village
R711	The number of low-income people	The number of low-income people in the village

④ Type of endemic outbreaks in coastal cities

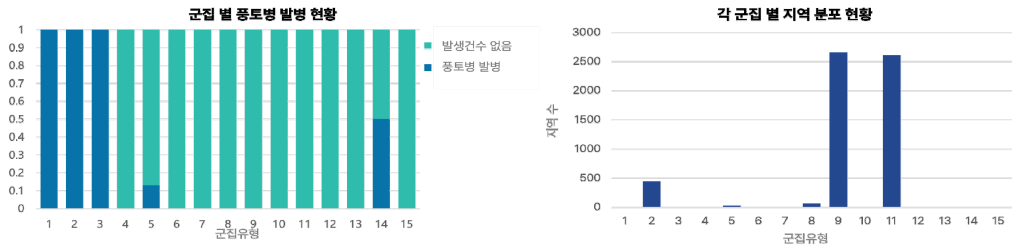
As a result of K-means clustering analysis of coastal cities on Java Island, Indonesia, cluster formation was confirmed to be related to water sources, medical facilities, water contamination, flood status, slums, and low-income residents.

〈Table 10〉 ANOVA analysis results

Variable	Cluster		Error		F	P
	Mean Square	df	Mean Square	df		
Main ways of supplying drinking water at home	1,099.32	14	1.77	9874	619.53	0.00
Main Supply Method of Non-Drinking Water	228.79	14	1.29	9874	177.64	0.00
Drinking water (cooking) feeding method: rivers	0.03	14	0.02	9874	1.66	0.06
Drinking water (cooking) feeding method: rainwater	0.01	14	0.01	9874	1.64	0.06
Drinking water (cooking) feeding method: reservoir	0.00	14	0.00	9874	0.42	0.97
Drinking Water Supply: Rivers	0.00	14	0.02	9874	0.51	0.93
Drinking Water Supply: Canals	0.00	14	0.00	9874	0.85	0.61
Drinking Water Supply: Rainwater	0.01	14	0.01	9874	0.94	0.52
Drinking Water Supply: Reservoir	0.00	14	0.00	9874	0.19	1.00
Availability of self-training center in the village	12.82	14	0.55	9874	23.54	0.00
Slum area	7.43	14	0.14	9874	52.87	0.00
Number of slum areas	466.55	14	0.34	9874	1,372.55	0.00
Number of residential buildings in slum areas	557.48	14	0.21	9874	2,642.33	0.00
Number of residents in slum areas	592.10	14	0.16	9874	3,657.16	0.00
Occurrence of water pollution	3.11	14	0.17	9874	18.64	0.00
Water Pollution: The number of cases in the river	4.11	14	0.18	9874	23.51	0.00
Causes of water pollution	8.46	14	0.42	9874	20.05	0.00
Water pollution complaints	9.05	14	0.52	9874	17.38	0.00
Annual flood count	3.42	14	0.80	9874	4.25	0.00
Annual flood victims	72,491.92	14	0.00	9874	24,190,794.10	0.00

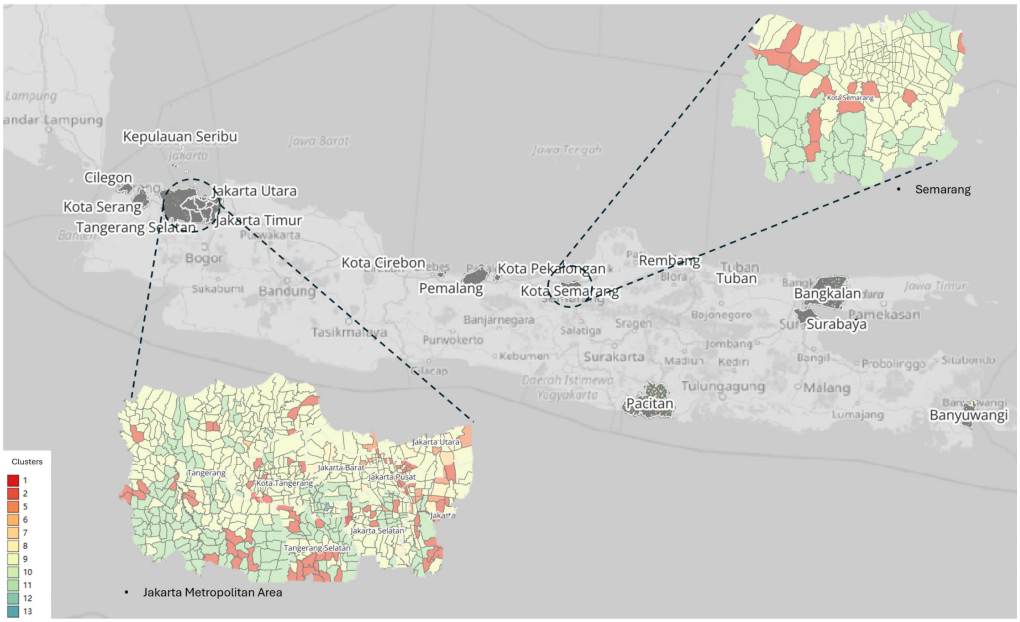
Variable	Cluster		Error		F	P
	Mean Square	df	Mean Square	df		
Number of medical facilities	4.82	14	0.19	9874	25.37	0.00
Distance to a nearby medical facility	39.24	14	0.95	9874	41.49	0.00
Number of cases of malnutrition	667.23	14	0.06	9874	120,48.68	0.00
The number of low-income people	528.06	14	0.25	9874	2,089.66	0.00
Occurrence dengue	14,094.76	14	0.14	9874	100,899.592	0.00

As a result of K-means clustering analysis, 15 clusters were formed according to the characteristics of the target area, of which the endemic outbreak area was mainly concentrated in cluster 2. This indicates that the area with many endemic outbreaks is a high-risk area for endemicity, whereas cluster 9 and cluster 11 correspond to areas relatively safe from outbreaks due to the concentration of areas without endemic outbreaks.



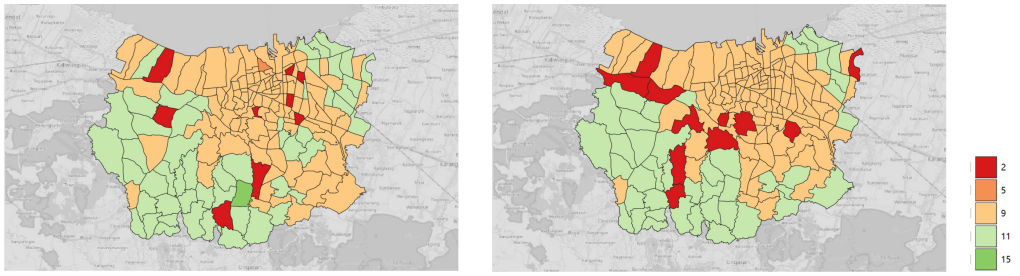
[Figure 11] Endemic outbreak status and regional distribution status

It was emphasized that all areas where endemic diseases occurred in the entire target area, including Jakarta and Semarang, were classified as [cluster 2], while areas where endemic diseases did not occur mainly belong to [cluster 9] and [cluster 11], with different characteristics of each cluster. Here, the water source (household water (drinking), non-drinking), the occurrence of each climate, and the occurrence of water pollution (river contamination) affect, and socio-economic factors related to the presence of slums, medical facilities, and poverty show somewhat different values depending on the cluster.



[Figure 12] Clustering in Jakarta and Semarang

Looking at the distribution of clusters in Semarang area, they mainly correspond to [Cluster 2], [Cluster 9], and [Cluster 11], and the endemic outbreak area mainly belongs to [Cluster 2]. [Cluster 2] is located somewhat sporadically across various regions, while [Cluster 9] is located mainly in urban areas, and [Cluster 11] mainly included the outer areas, which shows characteristics that appear throughout the target area outside Semarang.



세마랑 – 2018년 세마랑 – 2020년

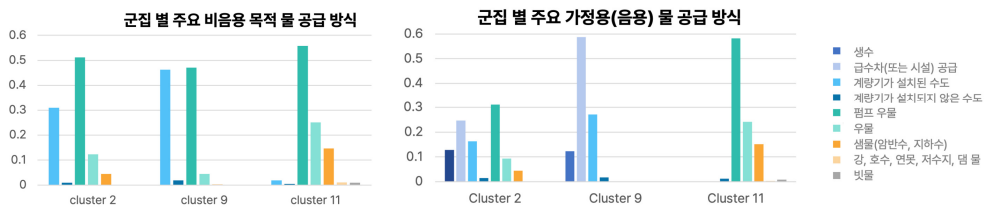
[Figure 13] Clustering in Semarang

This study conducted a basic statistical analysis for each influencing factor to analyze the regional characteristics of [Cluster 2], which includes endemic outbreak

areas in Semarang and Jakarta, and compared and analyzed the characteristics of [Cluster 2], [Cluster 9], and [Cluster 11], which include most of the regions in Semarang and Jakarta, to derive endemic vulnerable factors in the region.

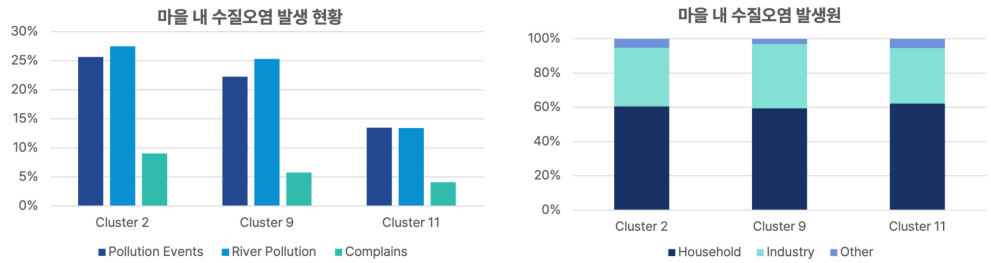
[Cluster 2] was found to be highly dependent on supply of water for non-drinking in the order of 'well (ground water)' and 'water pipe' and 'ground water' among household drinking water supply methods, and the supply of water for non-drinking purposes was found to be supplied through 'water pipe' and 'well' (Figure 14). In addition, [Cluster 2] emphasizes the need to establish and improve the water supply system in the future as it includes the outer areas where urban development has not yet been sufficiently carried out. The high dependence on the supply of water for non-drinking purposes on 'water pipes' and 'well' emphasize the importance of management of unimproved water pipes. In addition, considering the relationship with other influencing factors (current status of slum areas, low-income residents), it is judged that the burden of residents' water use costs and continuous monitoring of the water supply at the government level are necessary.

On the other hand, as a result of analyzing the main domestic and non-drinking water supply methods for each cluster, [Cluster 11] receives domestic and non-drinking water through "well (ground water)" and "spring water," which is concerned about the spread of endemic diseases due to unrefined water use in the future. Accordingly, there is a need for education for residents on the use of water that is not guaranteed safety along with securing a safe water supply chain to prevent the spread of endemic diseases.



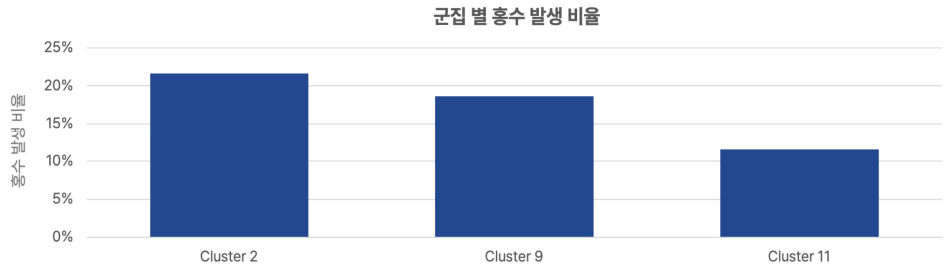
[Figure 14] Water Supply Method by Cluster

Water pollution from rivers, which are natural water sources, showed a higher incidence rate in [group 2] than in [group 9] and [group 11], where other villages in Semarang mainly belong, and water pollution at home and residents' complaints about it were at the average level of coastal cities on Java Island. In addition, in [group 2], the ratio of water supply through water pipes was high, but it was confirmed that the proportion of water supply through underground water and wells was high, and in [group 11], the ratio of water supply through natural water sources was high. Accordingly, the need for management of natural water sources is raised in terms of public health along with policies to raise awareness of residents.



[Figure 15] Current Status of Water Pollution in Villages by Cluster

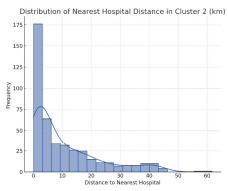
In the case of flood occurrence rates by cluster, [cluster 2] had a higher flood incidence rate than [cluster 9] and [cluster 11], confirming that endemic outbreaks can be related to water management such as water supply and flood occurrence.



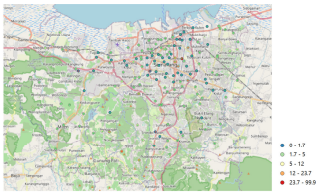
[Figure 16] Percentage of flooding by cluster

On the other hand, in terms of medical facilities, Cluster 2 showed a lower density of medical facilities than other clusters at 0.13 per village, and there is a problem

that daily medical access may be limited, including emergency situations such as endemic outbreaks. In particular, compared to villages belonging to other clusters, the medical environment and resources of Cluster 2 were relatively limited, and the average distance from Cluster 2 to the nearest medical facility was 10.4 km. This means that even if medical facilities are located, it is difficult for all residents in the village to easily access them, which can lead to a medical gap.



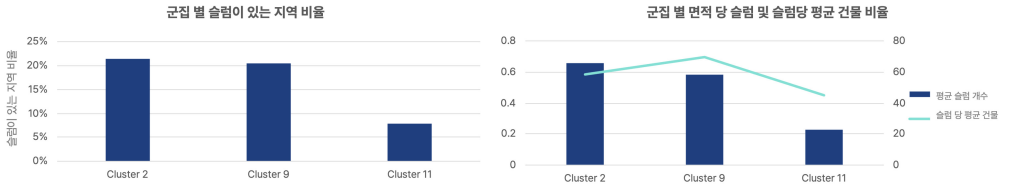
의료시설까지 거리


의료시설까지의 거리(2018)


의료시설까지의 거리(2020)

[Figure 17] Distance to Medical Facility in Cluster 2 (for Semarang Area)

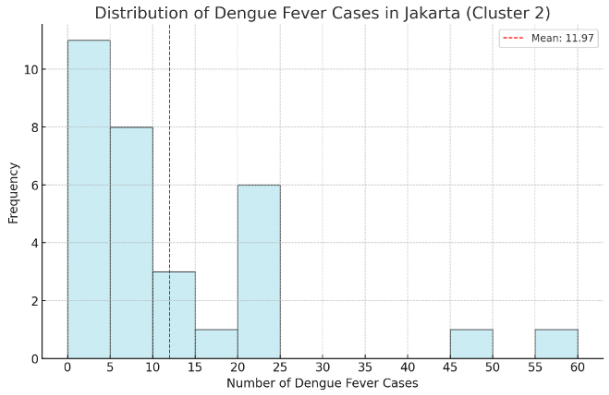
Regarding slum areas, [Cluster 2] and [Cluster 9] have a higher proportion of slum areas in the village compared to [Cluster 11], and the average low-income ratio of [Cluster 2] is higher than [Cluster 9] and [Cluster 11], so it is necessary to consider the vulnerability of socioeconomic factors in endemic outbreaks.



[Figure 18] Slum Area Status by Cluster

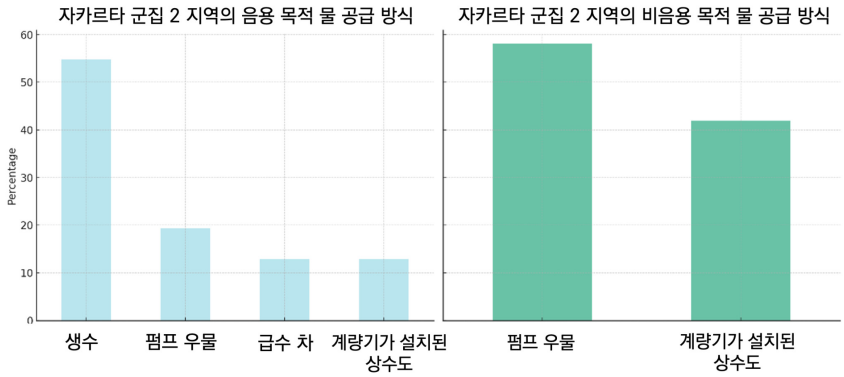
⑤ Characteristics of endemic areas [Cluster 2] in Jakarta

Jakarta's Cluster 2 is an area where dengue, an endemic disease, occurs, and shows clear characteristics in relation to the number of dengue outbreaks, water pollution, flood occurrence, slum and poverty levels (living in low-income groups), and medical facilities. In Jakarta's Cluster 2, the average number of dengue outbreaks is about 12, and the number of outbreaks varies from at least 1 to a maximum of 60, resulting in a gap between clusters



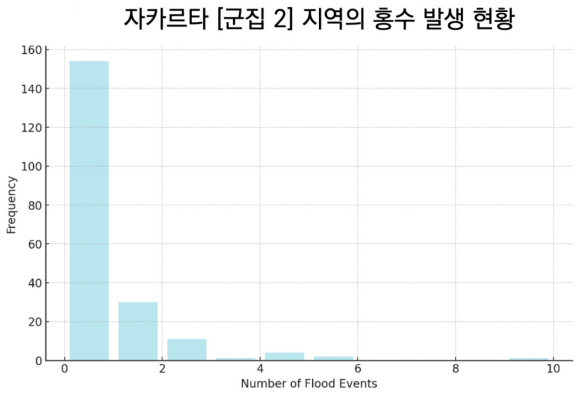
[Figure 19] Current Status of Endemic (dengue) in Jakarta [Cluster 2]

As for the water supply method, the main source of drinking water in Jakarta [Cluster 2] was found to be commercially available bottled water, and the non-drinking source was tap water supplied through the water supply. In areas where endemic diseases occurred in Jakarta, it was found that water supplied through rivers, canals, reservoirs, and rainwater was not consumed, and it was confirmed that the source of water was clearly classified according to the purpose of using water resources. For drinking purposes, bottled water is preferred due to disease and quality concerns, and for non-drinking purposes, it can be assumed that water is highly dependent on water supply due to convenience and infrastructure availability.



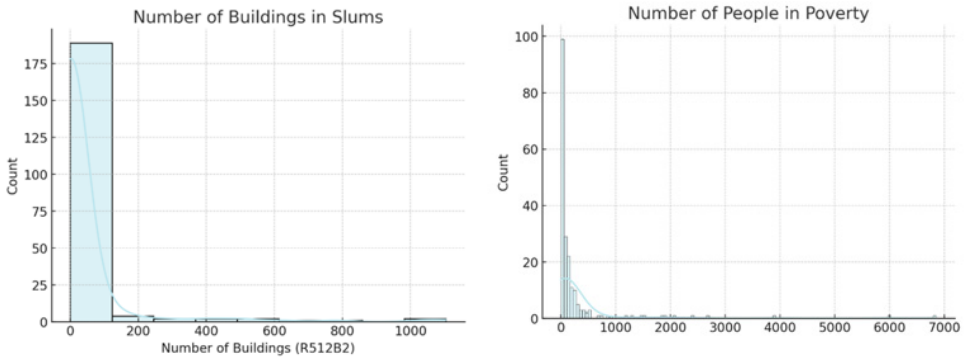
[Figure 20] The Water Supply Method of Jakarta [Cluster 2]

In addition, about 24.1% of Jakarta's [Cluster 2] experienced river pollution, and about 16.7% experienced water pollution. Water pollution can affect the spread of waterborne diseases and pose additional health risks for residents, so public health responses are needed. In the case of the average number of floods in Jakarta [cluster 2], it is lower than the average in [Cluster 2]. In some [Cluster 2], floods occur intensively, increasing the possibility of vector mediation.



[Figure 21] Current Status of Flooding in Jakarta [Cluster 2]

In the case of slum areas, 21% of the areas belonging to [Cluster 2] include slum areas and occupy a significant portion of the area. Along with high building and furniture density, there are 1,104 buildings and 2,624 households in the dense slum area.



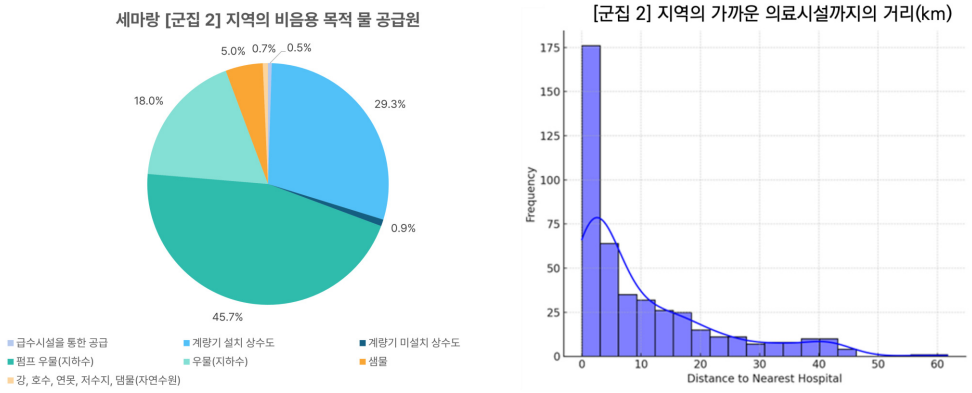
[Figure 22] The Number of Residential Buildings and Household Status in slum area of Jakarta [Cluster 2]

One-third of Jakarta's endemic areas were found to have no medical facilities in the village. The average distance to nearby medical facilities was about 1.6 km, and 50% of the villages without medical facilities were using medical facilities in other regions located on an average distance of 3 km. Although Jakarta's access to medical facilities is better than that of other coastal cities on Java Island, there are areas where medical facilities are not located. Accordingly, policy efforts to ensure access to medical facilities are also needed.

⑥ Characteristics of endemic areas in Semarang (Cluster 2)

The average number of dengue outbreaks in Semarang's endemic area [Cluster 2] is about 3.45, which is lower than in other high-risk areas. In the Semarang area belonging to Cluster 2, the dependence on water supply without meters is high enough to account for 29.5% of the water supply, which causes difficulties in effective monitoring. Fairness of billing and effective monitoring limitations for water use can act as obstacles to preventing endemic diseases caused by climate change.

In addition, it shows that non-drinking water in the region is mainly supplied through pump wells, and the use of groundwater is mainly made. Water supply with meters (29.3%) and water supply without meters (18%) also show the second highest dependence after pump wells, requiring water supply management to prevent the spread of endemic diseases.



[Figure 23] Key characteristics of Semarang [Cluster 2]

In the case of water pollution events in Semarang [Cluster 2] area, it was below average, and it was confirmed that it was relatively safe from the risk of flooding. However, considering that many areas belonging to Cluster 2 are exposed to risks such as water pollution and flood occurrence, a preemptive response to the risks from the climate change is required.

On the other hand, the poverty level in Semarang's [Cluster 2] area is lower than the average in the slum area and low-income class in [Cluster 2] for the entire Java island, but the proportion of slum areas and low-income families is concentrated in some areas. In addition, medical facilities, like Jakarta's [Cluster 2] area, have a very small average number of medical facilities per village of 0.13, and the distance to the nearest medical facility is 10.4 km. This affects the rapid response to acute diseases such as dengue, and the availability and accessibility of limited medical facilities can serve as limitations in effective disease management and prevention.

⑦ Predicting the Occurrence of Endemic Diseases through the Decision Tree Model

This study analyzed the characteristics of areas with concentrated endemicity through K-Means clustering and basic statistical analysis by cluster, and a decision tree model was applied to derive and predict urban structures vulnerable to endemicity. The accuracy of the model in which the occurrence of endemicity was set as a dependent variable was 65.8%, and it showed high predictive power in interpreting the characteristics of areas where endemicity will not occur.

〈Table 11〉 Model Accuracy

Observation	Non-epidemic Area	Epidemic Area	Prediction Accuracy
Non-epidemic Area	3,946	1,433	73.4%
Epidemic Area	1,950	2,560	56.8%
Ratio(mean)	59.6%	40.4%	65.8%

According to the analysis results (Figure 25), access to medical facilities has the most influence on the prediction of the endemic outbreak area, and was derived

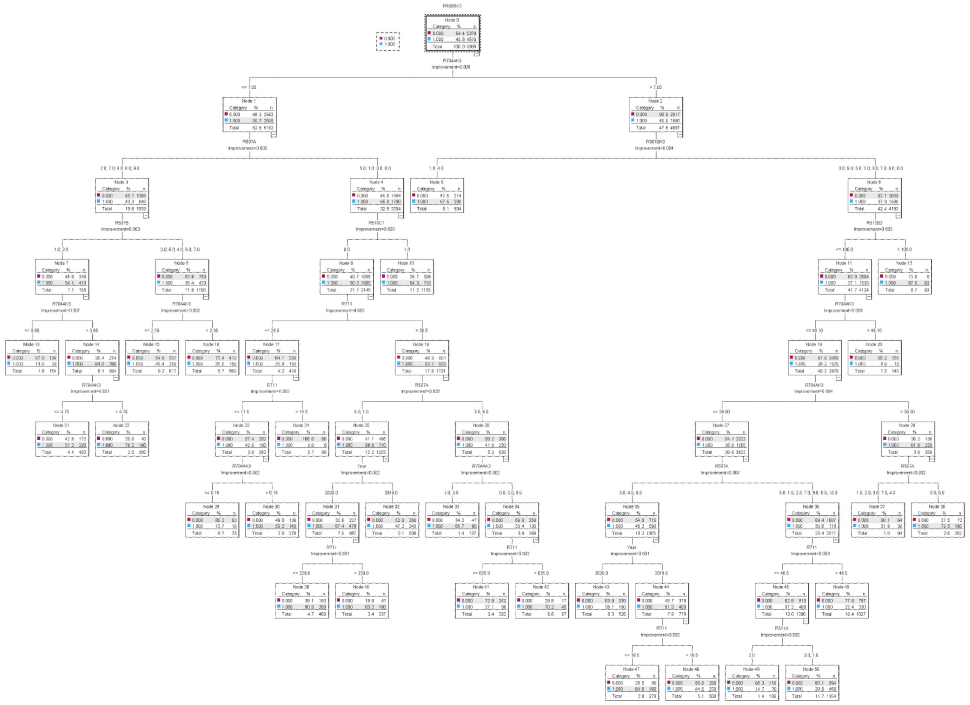
as a factor that should be considered first when preventing an endemic outbreak. In addition, the proportion of low-income families and major sources of household drinking water were also found to have an effect on the outbreak of endemicity.

In the case of household drinking water, the influence on the occurrence of endemic diseases was different according to the type of major source. In addition, drinking water secured through unverified sources was found to have an effect on the spread of waterborne diseases including dengue. For example, it was confirmed that the supply of household drinking water through wells (ground water) and water pipes without meters increases the likelihood of developing endemic diseases. These findings are similar to those confirmed in the characteristics of [Cluster 2], where the epidemic outbreak area is concentrated in K-Means clustering, and emphasize the importance of medical facilities, socioeconomic characteristics in villages, and water supply methods to prevent endemic diseases.

In the result of the decision tree model analysis (Figure 26) that predicted the occurrence of endemic diseases by setting the number of endemic outbreaks as a dependent variable, the number of malnutrition cases was derived as the top node, and the proportion of low-income families was derived as the most important influencing factor on the occurrence of endemic diseases in the village. This shows a strong correlation between socioeconomic characteristics and vulnerability to endemic outbreaks, and is a result emphasizing the need for intensive consideration of the population characteristics of the region. Along with this, access to medical facilities was derived as the second most important influencing factor, and it affects responding to endemic outbreaks, spreading outbreaks, and reducing the severity of diseases.

Both the main supply type of household drinking water and water pollution were derived as major influencing factors along with the prediction of the endemic outbreak area, and it was confirmed that both the endemic spread and the outbreak are related to water supply. In addition, the occurrence of floods has also

been shown to affect the occurrence of endemic diseases, further emphasizing the importance of a comprehensive water management system in the region.

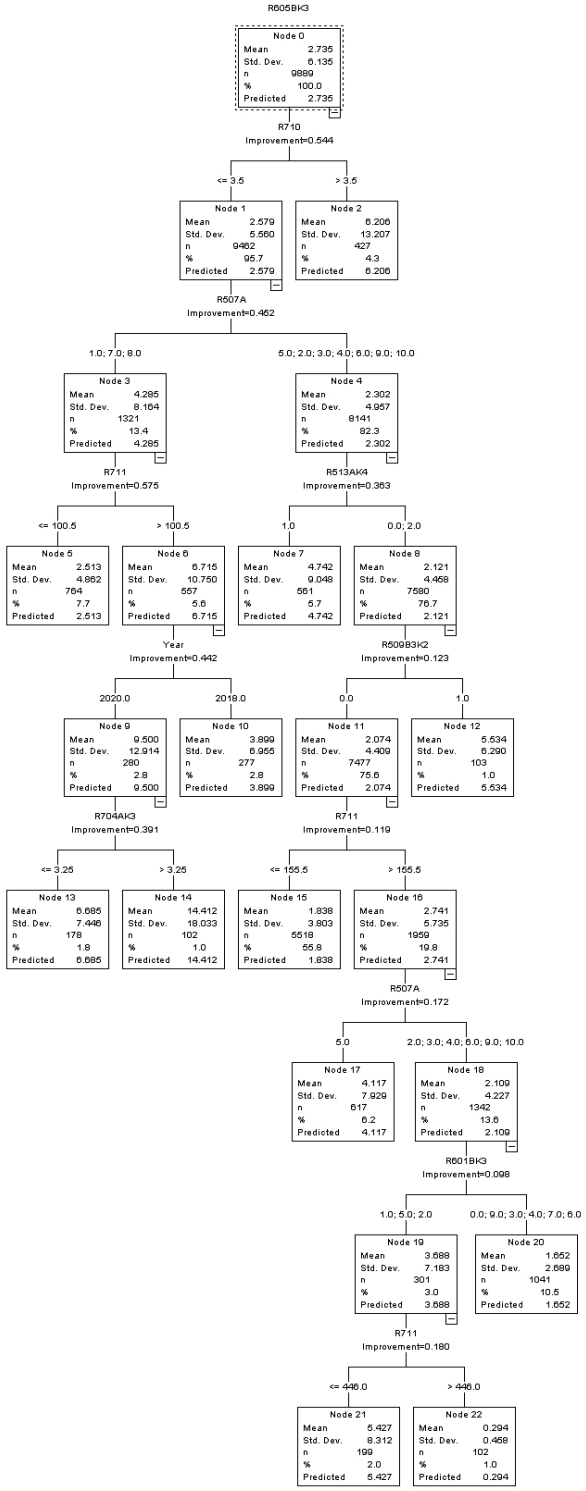


[Figure 24] Decision Tree Model Analysis Results: Forecasting Areas of Endemic Disease

These findings were also confirmed by fieldwork. In Meteseh and Tambakrejo, the study sites lacked water supply infrastructure, resulting in high rates of groundwater use and poor management of water spaces, which increases the risk of spreading waterborne diseases such as dengue. In Tambakrejo, the living lab found that puddles created by flooding and inundation remained open for long periods of time, increasing mosquito breeding grounds and contributing to the spread of dengue.



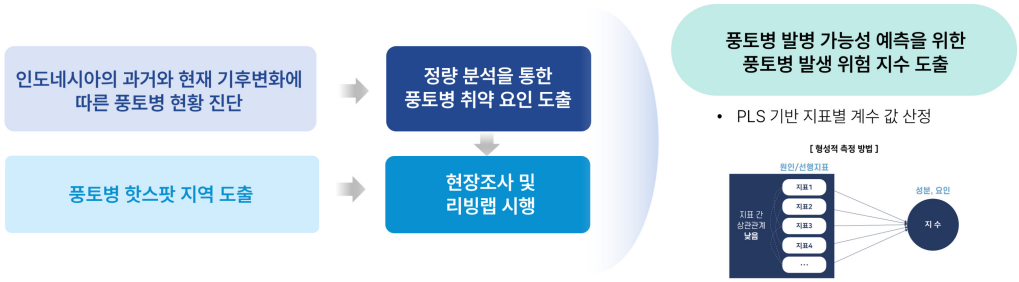
[Figure 25] Endemic related factors confirmed by fieldwork



[Figure 26] Decision Tree Model Analysis Results: The Number of Epidemic Cases

3) Prediction of the Endemic Disease Possibility

This study was conducted as shown in [Figure 27] to present the risk index for the occurrence of endemic diseases in cities by synthesizing the results of analyzing the relationship between endemic diseases and coastal cities. Based on the literature review, the current status of endemic diseases according to past and present climate change in Indonesia was diagnosed, and hotspot analysis was conducted in Jakarta and Semarang among coastal city areas. After that, social and physical factors affecting the occurrence of endemic diseases were derived through quantitative analysis, and factors affecting the occurrence of endemic diseases were derived by synthesizing the results of fieldworks and living labs in hotspot areas (Meteseh, Tambakrejo). Finally, in order to predict and cope with the area at risk of endemic outbreaks based on PLS, the coefficient value for each indicator for the occurrence of endemic diseases (dengue) was calculated and used as a weight.



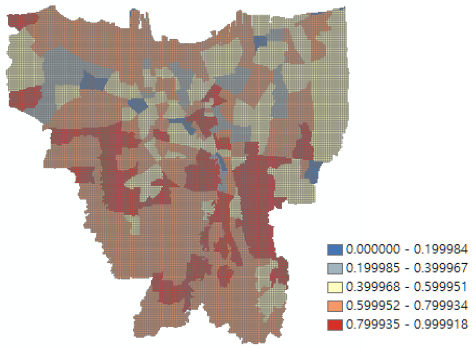
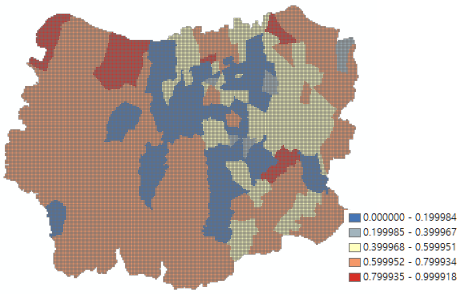
[Figure 27] Process of Endemic Risk Index Derivation

The endemic risk index in Jakarta and Semarang, Indonesia, consists of environmental factors (flood occurrence, water contamination), social and physical factors (population density, drinking water source, hospital access, etc.), and the index values were derived by obtaining data for 2022 (see Table 12). In addition, endemic data obtained from two cities were used to reflect the impact of endemicity, and an endemic risk index dataset was constructed using PODES, which is a village-level statistical data.

In this study, quantitative analysis was conducted at a village level in consideration of spatial units of policies to prevent the occurrence of endemic diseases. In the same way, data were constructed for each region for the index value, and then the endemic risk index was derived by applying 100m*100m grid units.

〈Table 12〉 Endemic Risk Index Dataset

Category		Data	Description	Note
Endemicity Influencing Factors	Environmental Factors	Flood event	Number of flood occurrences by village based on PODES (Indonesian Village Statistics)	
		Water pollution	PODES (Indonesian Village Statistics) based water pollution (for rivers, lakes, and reservoirs)	
	Sociophysical Factors	Population density	Resident density by village based on PODES (Indonesian Village Statistics) (Population (per)/area)	
		Drinking water source	Drinking water supply method by village based on PODES (Indonesian Village Statistics)	It is divided into the purchase of drinking water, supply through water channels, and use of groundwater.
		Household water source	Domestic Water Supply Method by Village Based on PODES (Indonesian Village Statistics)	Supply through waterways, underground water, lakes, reservoirs, etc. are divided into supply
		Hospital Accessibility	Hospital accessibility (number of hospitals/area accessible by village)	
		Slum	Percentage of Residence in Slums by Village Based on PODES (Indonesian Village Statistics)	Number of residents compared to the number of houses located in the slum area
		Low income	Percentage of low-income people (subject to support) by village based on PODES (Indonesian Village Statistics)	
		Rate of Malnutrition	Rate of malnutrition by village based on PODES (Indonesian Village Statistics)	
Index Weight		Dengue	Number of dengue cases/area by Village	

Jakarta	Semarang
	

[Figure 28] Endemic Risk Areas in 2022

Section3. Impact Factors of Climate Change on Heat Impact

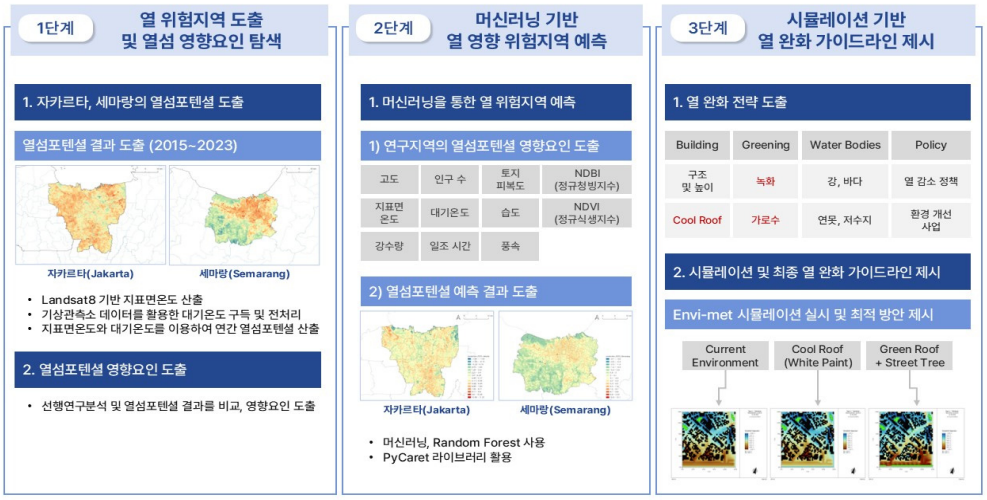
1. Research Background and Objectives

Indonesia is experiencing an increasing trend of heatwaves caused by climate change nationwide. However, residents' vulnerability to heatwaves tends to be higher in urban and coastal areas, with Jakarta and Semarang, as major coastal cities, facing significant risks (Martiwiet et al., 2023).

Due to climate change, regions like Semarang in Central Java saw temperatures reach 40°C in October, while Jakarta experienced 37°C, exposing various areas of Indonesia to the dangers of extreme heat. The rise in heatwaves due to climate change has also led to a range of complex social issues such as droughts, smog, and the spread of infectious diseases.

For example, in October 2023, Cilacap in Central Java suffered a severe drought after experiencing over 60 consecutive days without rain due to the extreme heat. Additionally, Jakarta faced widespread smog-related damages in August 2023, triggered by rising temperatures. In response, the government implemented various measures to mitigate air pollution, including directing half of Jakarta's public officials to work remotely (BMKG, 2023).

Furthermore, the heatwave-driven increase in temperatures led to the spread of dengue, resulting in 143,000 reported cases and 1,236 deaths.



[Figure 29] Research Design Framework for Heat Impact

This study aims to predict heat risk areas and propose measures to mitigate heat impacts, focusing on Heat Island Potential (HIP). In the first phase, the determinants of Heat Island Potential are identified. In the second phase, heat impact risk areas are predicted using machine learning models. Based on these results, the third phase seeks to propose simulation-based strategies to address Heat Island Potential.

2. Identifying Determinants of Heat Island Potential in Indonesia

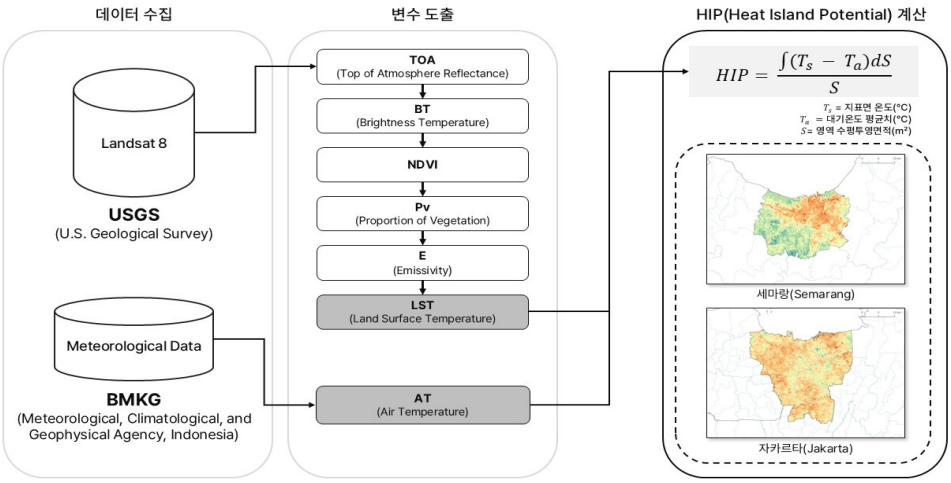
1) Research Methodology

In the first phase, Heat Island Potential (HIP) was derived using Land Surface Temperature (LST) extracted from Landsat 8 data provided by the USGS and air temperature data from the Meteorological, Climatological, and Geophysical Agency of Indonesia (BMKG).

Landsat 8, jointly developed by NASA and the US Geological Survey (USGS), is a satellite launched in 2013 to observe Earth's surface, capturing data for the same

area every 16 days. BMKG, a national agency responsible for meteorological, climatological, and geophysical research and services in Indonesia, provides a wide range of meteorological data.

Using Landsat 8 data, annual Land Surface Temperature (LST) from 2015 to 2023 was calculated, while air temperature data from BMKG was converted into annual averages. Based on this data, a calculation formula was applied to estimate the annual Heat Island Potential Index for the coastal cities of Jakarta and Semarang in Indonesia. Subsequently, a literature review was conducted to identify the determinants of Heat Island Potential, serving as a preliminary step for the second-phase analysis.



[Figure 30] Analytical Framework for Heat Island Potential Index

2) Study Results

① Heat Impact Indicators

The key heat impact indicators used in this study are UHI (Urban Heat Island), LST (Land Surface Temperature), and HIP (Heat Island Potential).

UHI (Urban Heat Island) refers to the phenomenon where urban areas exhibit

higher temperatures compared to surrounding suburban and rural regions. It is influenced by surface characteristics such as asphalt-paved roads, and many countries are increasingly affected by UHI due to urbanization (Choi et al., 2014). UHI degrades environmental quality, generates heat-related discomfort, and accelerates public health deterioration. Causes of UHI include reduced green spaces in urban areas, the materials and structures of urban components, heat generated by human activities, and weather and geographical characteristics (US EPA, 2024).

LST (Land Surface Temperature) represents the surface temperature of a specific area, calculated as the weighted average of elements like soil and vegetation. It encompasses all visible components when satellites measure the surface through the atmosphere (NASA, 2024). LST is calculated using Top-of-Atmosphere (TOA) radiation, Brightness Temperature (BT), and the Normalized Difference Vegetation Index (NDVI), representing the pure surface temperature excluding air temperature.

HIP (Heat Island Potential) quantifies the amount of sensible heat exchange between the surface and the atmosphere, enabling the prediction of potential heat island occurrences (Kim Taeheon et al., 2018). HIP is a quantitative indicator for assessing urban heat island potential, derived from satellite imagery (Ino and Hoyano, 1996). Unlike LST, HIP considers both surface and air temperatures, providing insights into regions with high heat island risks.

〈Table 13〉 Heat Impact Indicator Calculation Formulas

Classification	Calculation Formula	Notes
LST (Land Surface Temperature)	$LST = \epsilon^{\frac{1}{4}} \times T$	LST = Land Surface Temperature ϵ = Surface Emissivity T = Brightness Temperature
UHI (Urban Heat Island)	$UHI = \frac{LST - LST_m}{SD}$	LST = Land Surface Temperature LST_m = Average LST SD = LST Standard Deviation
HIP (Heat Island Potential)	$HIP = \frac{\int (T_s - T_a) dS}{S}$	T_s = Land Surface Temperature(°C) T_a = Average Air Temperature(°C) S = Horizontal Projection Area of the Region

② Derivation of Annual Heat Island Potential

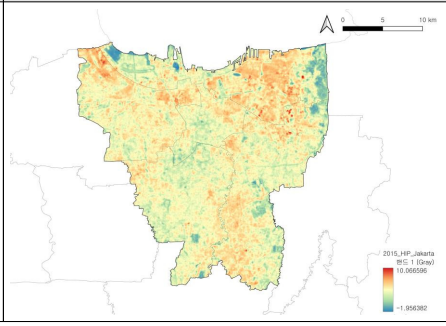
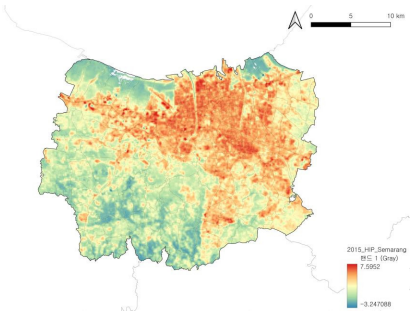
Using the Heat Impact Indicator, HIP (Heat Island Potential), heat risk areas were identified. The annual Heat Island Potential for Jakarta and Semarang was derived using the HIP calculation formula, based on the annual average Land Surface Temperature (LST) and air temperature.

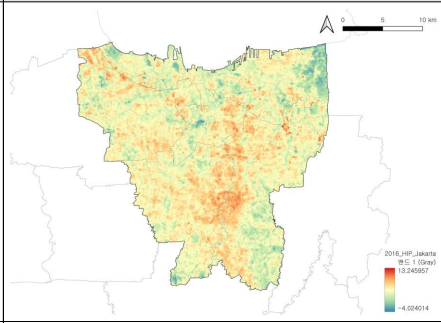
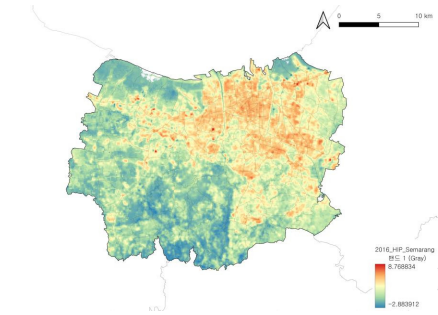
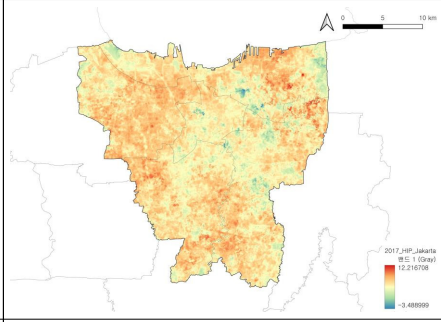
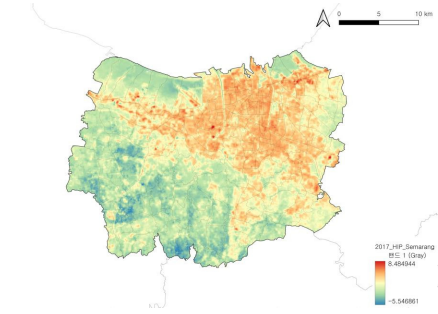
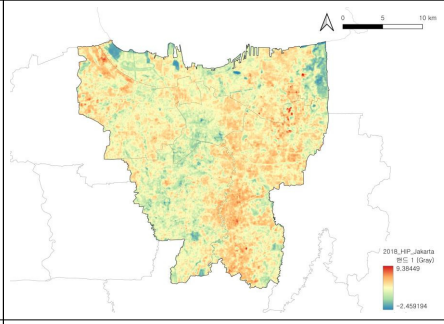
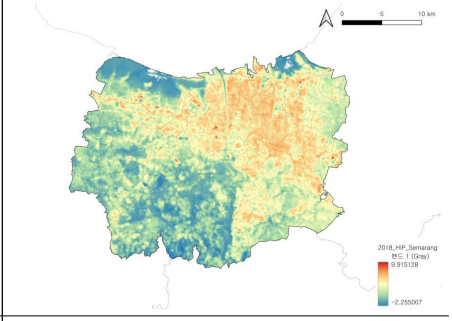
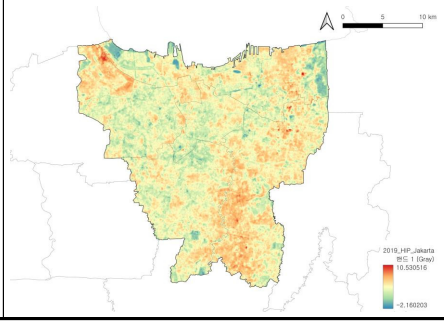
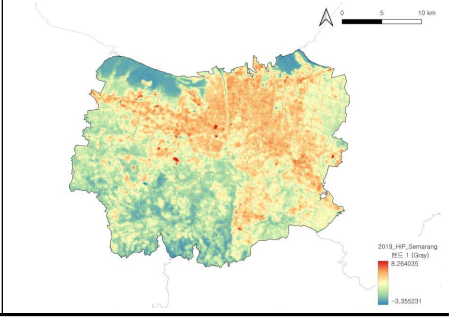
A high Heat Island Potential indicates a strong likelihood of heat island effects in the area, while a low potential suggests a relatively reduced impact. The variation in HIP serves as a measure for interpreting and managing the influence of urban environments and human activities on regional temperatures.

In Jakarta, the annual Heat Island Potential ranges from a minimum of -8 to a maximum of +12. Higher HIP values are observed in the northern regions of North Jakarta, Jakarta Timur, and West Jakarta.

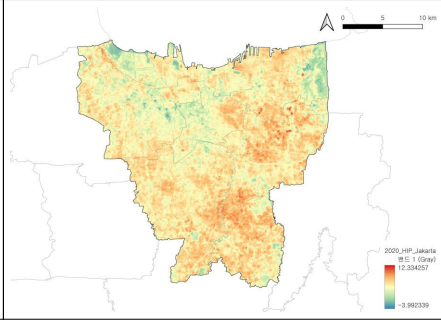
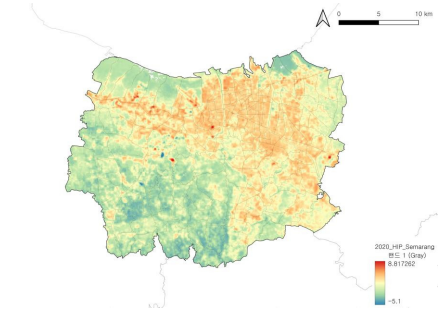
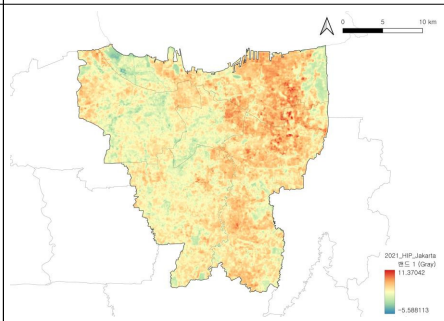
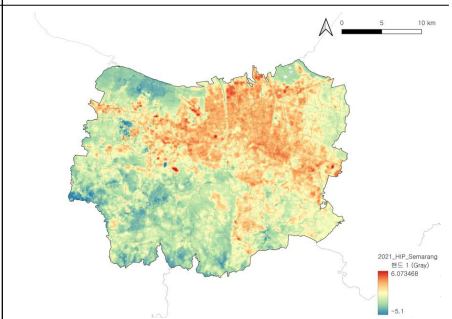
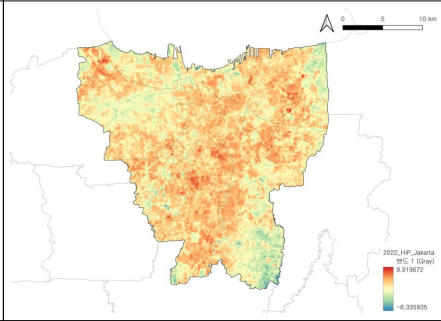
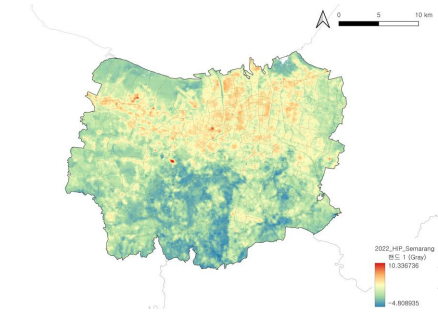
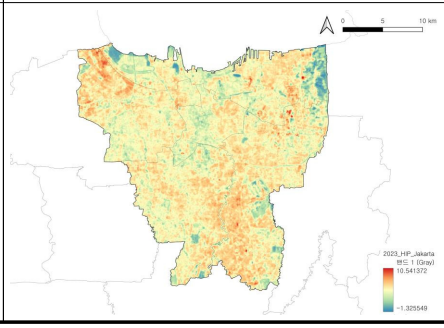
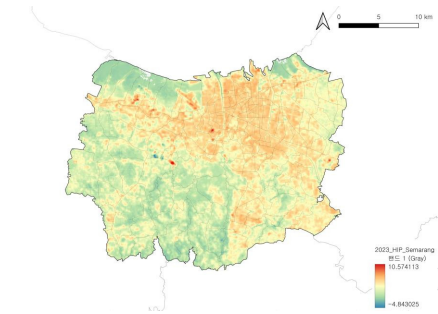
In Semarang, the southwestern areas, characterized by high-altitude mountainous terrain, exhibit lower HIP values. The annual HIP in Semarang ranges from a minimum of -5.5 to a maximum of +10.3, with urban centers generally showing values above +4, which gradually decrease toward the city outskirts.

〈Table 14〉 Annual Changes in Heat Island Potential for Jakarta and Semarang, Indonesia (2015-2019)

Year	Jakarta	Semarang
2015		

Year	Jakarta	Semarang
2016		
2017		
2018		
2019		

〈Table 15〉 Annual Changes in Heat Island Potential for Jakarta and Semarang, Indonesia (2020–2023)

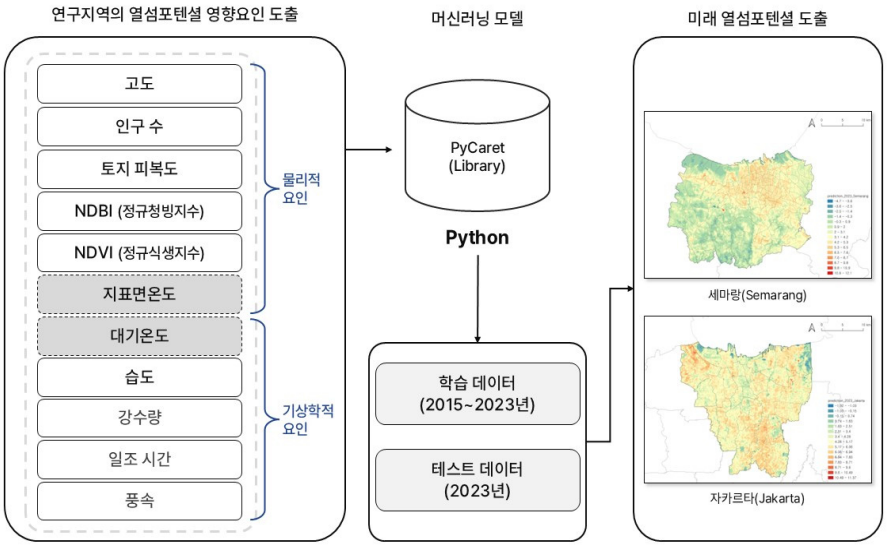
Year	Jakarta	Semarang
2020		
2021		
2022		
2023		

3. Predicting Future Heat Risk Areas Using Machine Learning Models

1) Research Methodology

To predict future heat risk areas, independent variables were constructed based on a review of previous studies. Subsequently, the future Heat Island Potential was predicted using a Random Forest model implemented with PyCaret, an open-source machine learning automation library.

The analysis identified heat-vulnerable areas in the coastal cities of Jakarta and Semarang, Indonesia. Furthermore, the key characteristics of these regions were analyzed in depth to provide a comprehensive understanding of their vulnerability to heat.



[Figure 31] Analysis Process of Future Heat Island Potential Prediction Model

2) Research Results

① Derivation of Heat Island Impact Factors

The driving factors (heat island rising elements) of Heat Island were identified through a literature review. The causes of Heat Island can be categorized into Physical Factors and Meteorological Factors.

The causes of Heat Island Potential are largely aligned with the causes of UHI (Urban Heat Island) and include artificial energy emissions from heating and ventilation systems in motors, vehicles, and industrial processes, differences in surface moisture, and heat capacity variations of urban construction materials (Miles and Esau, 2017; Mohajerani et al., 2017). Land use and land cover changes in urban areas significantly influence the regional climate, impacting not only temperature but also cloud formation, precipitation, water quality, and air quality (Arnfield, 2003; Wickham et al., 2013). Densely built-up areas experience elevated temperatures compared to their surroundings, contributing to higher air temperatures (Lemonsu et al., 2015).

Additionally, Heat Island Potential and UHI are closely linked to local meteorological conditions. For instance, in Seoul, South Korea, the UHI intensity was observed to be as high as +4.5 under cloudless conditions (Jongtanom et al., 2011; Kim and Baik, 2002). Among the key meteorological variables affecting UHI intensity, wind speed is the most critical factor, followed by cloud cover. Urban structures that do not obstruct wind flow can effectively mitigate heat impacts (Oke, 1982; Yavuzturk et al., 2005). Various atmospheric factors directly contribute to the intensity of Heat Islands, including humidity, precipitation, building arrangement, heat capacity of surfaces and construction materials, and anthropogenic heat emissions (Oke, 1982).

Based on these prior studies, this research selected a total of 11 independent variables: elevation, population, land cover, NDBI, NDVI, precipitation, air temperature, humidity, land surface temperature, daytime sunshine duration, and

wind speed. However, air temperature and land surface temperature, having already been used in the derivation of Heat Island Potential, were excluded from the final analysis.

Subsequently, a Random Forest model was constructed using PyCaret, an open-source machine learning automation library, to predict future Heat Island Potential.

〈Table 16〉 Heat Impact Variables Used for Machine Learning Prediction

Variable Category		Variable Name	Data Period	Data Source
Dependent Variable		Heat Island Potential (HIP)	2015~2023	-
Independent Variables	Physical Factors	Elevation	2020	2024 Badan Informasi Geospasial
		Population	2023	GPWv411: Population Count (google earth engine)
		Land Cover	2023	Global Land Cover and Land Use Change, 2000-2020 (google earth engine)
		NDBI	2020	Landsat8 satellite data (USGS, google earth engine)
		NDVI	2023	Landsat8 satellite data (USGS)
	Meteorological Factors	Precipitation	2015~2023	PUSAT DATABASE - BMKG
		Air Temperature	2015~2023	
		Humidity	2015~2023	
		Land Surface Temperature	2015~2023	
		Daylight hours	2015~2023	
		Wind Speed	2015~2023	

To facilitate this analysis, meteorological data were collected from six observation stations in Jakarta and three in Semarang, Indonesia. These data were utilized to generate the meteorological variables necessary for the study. Using QGIS, the Inverse Distance Weighted (IDW) interpolation method was applied to point vector layers, converting the data into raster format for preprocessing.

〈Table 17〉 Locations of Meteorological Observation Stations in Jakarta

No	Province	District	Station Name	X	Y	H
1	Jakarta	Kota Adm. Jakarta Utara	Stasiun Meteorologi Maritim Tanjung Priok	-6.10781	106.8805	3
2	Jakarta	Kota Adm. Jakarta Pusat	Stasiun Meteorologi Kemayoran	-6.15559	106.84	4
3	Banten	Kab. Tangerang	Stasiun Meteorologi Budiarto	-6.2867	106.5639	42
4	Banten	Kota Tangerang	StasiunMeteorologiSoekarno Hatta	-6.12	106.65	11
5	Banten	kotaTangerang Selata	Stasiun Klimatologi Banten	-6.26151	106.75084	27
6	Jawa Barat	Kab. Bogor	StasiunMeteorologiCiteko	-6.7	106.85	920

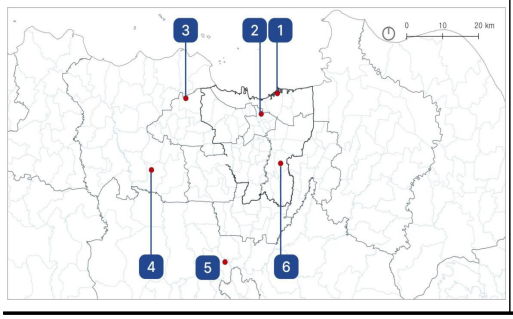
(Source: PUSAT DATABASE - BMKG, https://dataonline.bmkg.go.id/home)

〈Table 18〉 Locations of Meteorological Observation Stations in Semarang

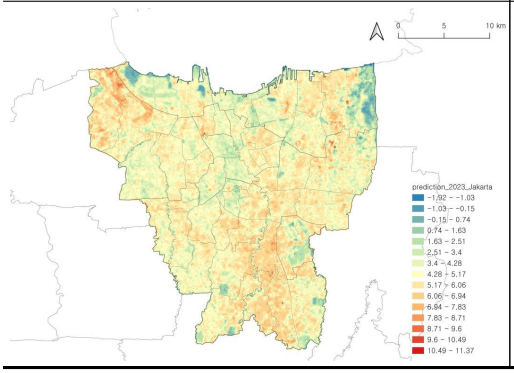
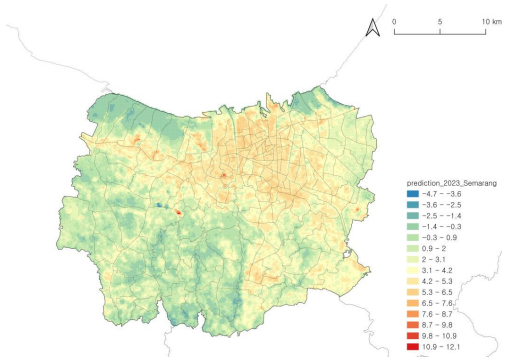
No	Province	District	Station Name	X	Y	H
1	Jawa Tengah	Kota Semarang	Stasiun Meteorologi Maritim Tanjung Emas	-6.9486	110.4199	2
2	Jawa Tengah	Kota Semarang	StasiunMeteorologiAhmad Yani	-6.97683	110.3778	5
3	Jawa Tengah	Kota Semarang	Stasiun Klimatologi Jawa Tengah	-6.9847	110.3812	6

(Source: PUSAT DATABASE - BMKG, https://dataonline.bmkg.go.id/home)

〈Table 19〉 Images of Meteorological Observation Station Locations in Jakarta and Semarang

Jakarta (-1.92 ~ 11.37)	Semarang (-4.7 ~ 12.1)
	

〈Table 20〉 Predicted Heat Island Potential Images for Jakarta and Semarang

Jakarta (−1.92 ~ 11.37)	Semarang (−4.7 ~ 12.1)
	

An analysis of the key factors influencing Heat Island Potential (HIP) in Jakarta and Semarang based on variable importance revealed that in Jakarta, NDVI (Normalized Difference Vegetation Index), Elevation, and Population were the primary variables. In Semarang, Population, NDVI, and Elevation were identified as the main factors.

For Jakarta, the model evaluation metrics demonstrated strong explanatory power, with an MAE of 0.4509, MSE of 0.4517, and R^2 of 0.8648. The RMSE was 0.1291, and the MAPE was 0.2433, indicating a good level of predictive accuracy. In Semarang, the metrics showed even higher explanatory power, with an MAE of 0.4152, MSE of 0.3292, and R^2 of 0.9146. However, the predictive accuracy was slightly lower than Jakarta, with an RMSE of 0.1957 and a MAPE of 0.8035.

Overall, both Jakarta and Semarang demonstrated high explanatory power, suggesting that the Heat Island Potential prediction model provides reliable results. Jakarta's model excels in predictive accuracy, while Semarang's model shows superior explanatory power.

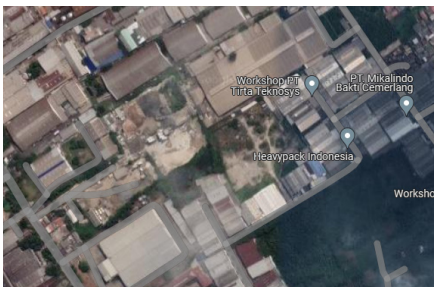
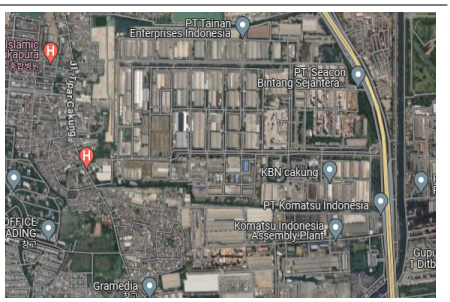
〈Table 21〉 Prediction Model Results for Heat Island Potential in Jakarta and Semarang

	자카르타	세마랑
MAE	0.4509	0.4152
MSE	0.4517	0.3292
RMSE	0.6717	0.5736
R^2	**0.8648**	**0.9146**
RMSLE	0.1291	0.1957
MAPE	0.2433	0.8035

② Analysis of Heat Impact Risk Areas

Based on the results, heat risk areas in Jakarta and Semarang were analyzed, detailing the names of specific sub-regions within each city. Satellite imagery and key spatial characteristics of these areas were compiled. This approach enables an understanding of the spatial distribution and features of regions vulnerable to heat.

〈Table 22〉 Analysis of Heat Impact Risk Areas in Jakarta

Region	Characteristics	Satellite Image (Google Map)
Kalideres, Kota Jakarta Barat	Locations of small-scale industrial zones and storage facilities	
Cilincing, Jakarta	Areas with a high concentration of medium to large industrial zones	

The analysis of Heat Island Potential (HIP) in Jakarta revealed particularly high values in areas with dense concentrations of industrial complexes, with these

effects often extending to nearby residential areas.

In Kalideres and Kota Jakarta Barat, the presence of numerous small-scale industrial complexes and warehouses resulted in high HIP values, which impacted surrounding residential zones, particularly to the southwest.

In Cilincing, Jakarta, where medium to large industrial complexes are concentrated, exceptionally high local HIP values were observed. These results suggest that heat emissions from industrial facilities significantly affect the surrounding environment.

〈Table 23〉 Analysis of Heat Impact Risk Areas in Semarang

Region	Characteristics	Satellite Image (Google Map)
Bongsari, Semarang Barat	Locations of Textile Manufacturing Plants within Residential Areas	
Tambakharjo, Semarang Barat	Proximity to Airport, Plastic Processing Facilities, and High-Density Residential Zones	
PenggaronKidul, Pedurungan	Clusters of Shopping Malls and Urban Amenities	

Region	Characteristics	Satellite Image (Google Map)
Kedungpane, Mijen	Waste Treatment Facility of Semarang and Nearby Residential Areas	

The analysis of Heat Island Potential (HIP) in Semarang identified airports and industrial facilities located near residential areas as major contributors to elevated HIP values.

In Bongsari, Semarang Barat, textile plants within densely populated residential areas resulted in localized high HIP values, with the impact extending to surrounding residential areas.

In Tambakharjo, Semarang Barat, the proximity of the airport and plastic processing facilities to residential areas led to high HIP values concentrated around the airport, with the effects spreading to adjacent residential zones.

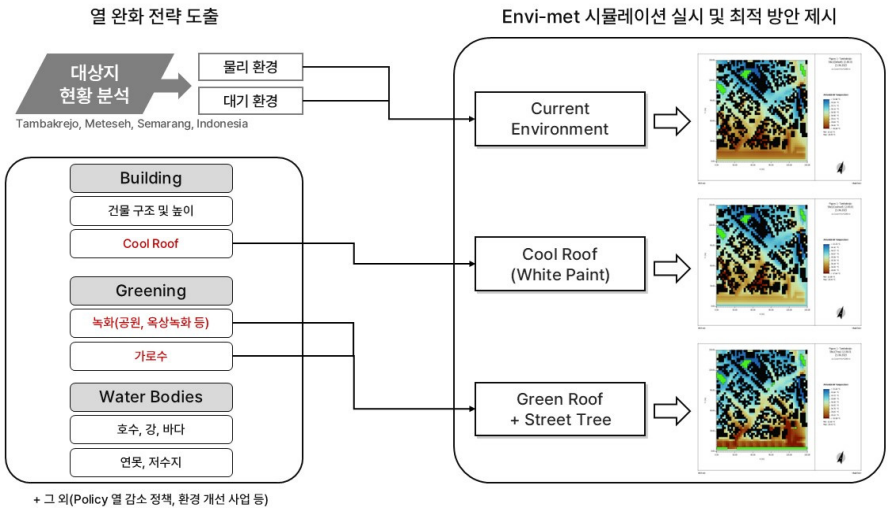
4. Simulation-Based Heat Mitigation Guideline Proposal

1) Research Methodology

In Semarang, Indonesia, the primary causes of heat impacts and corresponding mitigation strategies were identified through a local living lab. Based on prior research related to diseases, heat, and water management, climate crisis hot spot communities with a high likelihood of compound disasters were selected.

Subsequently, a review of existing studies was conducted to derive policy types for heat impact mitigation, and actionable strategies tailored to the selected sites were developed. Using Envi-met simulation software, these heat mitigation strategies were tested, revealing that the effectiveness of mitigation measures varied depending on spatial characteristics.

Building on these findings, the predicted results and analyzed heat island factors were integrated to propose heat island mitigation guidelines customized to the unique characteristics of each region.



[Figure 32] Simulation Process for Heat Impact Mitigation Strategies

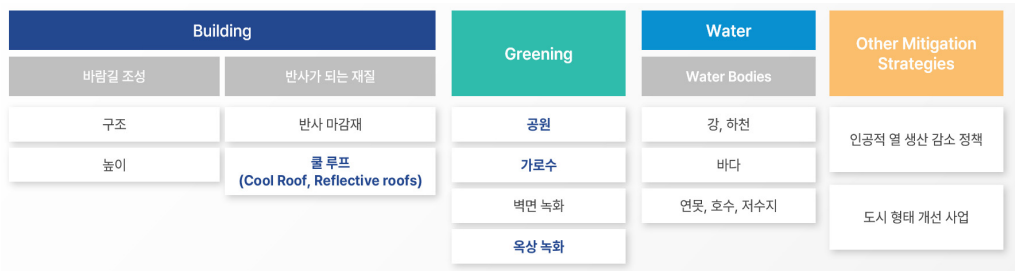
2) Research Result

① Heat Island Potential Mitigation Strategies

The research areas, Tambakrejo and Meteseh, were selected due to their shared vulnerability to diseases, heat, and flooding. A participatory observation study (Living Lab) was conducted with local residents, leading to the development of a prototype for climate change adaptation Living Labs to address complex disasters. Key strategies for heat mitigation included the introduction of cool roofs, rooftop greening, street tree planting, and the expansion of park green spaces.

Subsequent analysis of previous studies identified heat island mitigation strategies consistent with the measures proposed in the Living Lab. The analysis revealed that building composition, greenery, and water systems are primary factors directly influencing urban temperatures.

The relationship between urban surfaces and air temperature is mediated by the three-dimensional characteristics of buildings and roads, including surface roughness, wind speed, and wind direction (Stathopoulou & Cartalis, 2007; Voogt & Oke, 2003; Weng, 2009; Weng & Quattrochi, 2006). Buildings, in particular, play a crucial role in urban temperature dynamics. Key urban heat island (UHI) contributors include building height, road width, building openness, and road orientation (Eliasson, 1996; Oke, 2004; Sakakibara, 1996).



[Figure 33] Heat Impact Mitigation Strategies

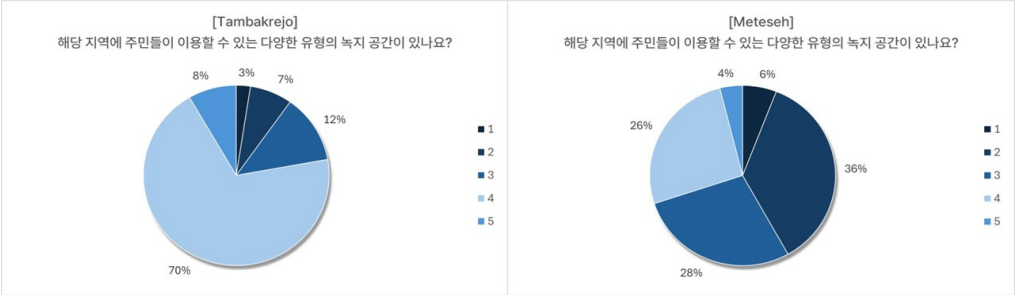
(Source: Understanding Urban Heat Island Effect: Causes, Impacts, Factors, and Strategies for Better Livability and Climate Change Mitigation and Adaptation, 2024, and prepared by the research team based on previous study analysis)

② Selection and Analysis of Simulation Target Areas

The heat impact risk areas and mitigation strategies identified through Living Labs and existing studies were experimented with using ENVI-Met simulations. A rough physical environment analysis was conducted for each target area, which was analyzed through fieldworks and questionnaire results.

Tambakrejo is an area where high building density, combined with asphalt roads and building materials with large heat capacity, increases heat impacts. According to a survey of Tambakrejo residents, perceptions of green spaces varied. Among 203 respondents, 57 (28.1%) answered that green spaces were slightly insufficient, 43 (21.2%) evaluated them as adequate, and 63 (31.0%) responded neutrally. Extreme opinions were rare, but there may be a potential bias toward neutral responses. Nevertheless, the relatively high percentage of residents mentioning a lack of green spaces suggests that green and water spaces are not sufficiently contributing to heat environment improvement.

On the other hand, in Meteseh, 158 respondents (78%) answered in a post-Living Lab survey that the green space distribution in the area was sufficient. However, due to building density, it is difficult to form wind corridors, worsening the heat environment. Therefore, simulations were conducted by adjusting building materials and green space conditions while maintaining the local building forms.



[Figure 34] Survey Results on Green Space Satisfaction (Left: Tambakrejo, Right: Meteseh)

ENVI-met is a three-dimensional simulation software designed for microclimate analysis in urban environments. It quantitatively analyzes the impact of urban components such as buildings, roads, and green spaces on environmental variables like temperature, humidity, and wind speed. This tool is widely used for UHI (Urban Heat Island) assessments and urban green space planning, providing reliable scientific evidence for urban planning through precise spatial and temporal analysis.

In this study, simulations were conducted by maintaining the existing building forms while modifying green space conditions such as rooftop greening, green areas, and street trees. The simulations analyzed the changes in spatial and temporal heat distribution under varying green space conditions and their impact on heat island potential.

For in-depth analysis, one area each from Tambakrejo and Meteseh, identified as high-heat impact zones and highlighted during Living Lab discussions by residents as significantly affected by heat, was selected.



[Figure 35] Simulation Target Area Locations

③ Simulation Conditions and Atmospheric Settings

The goal of this study is to compare and analyze the heat environment improvement effects according to these scenarios and evaluate the effectiveness of each scenario based on the structural characteristics of the target areas. The

environmental conditions of the target areas are as follows, and the simulations were set under three scenarios: (1) existing conditions, (2) introduction of Cool Roofs, and (3) introduction of Green Roofs and street trees.

〈Table 24〉 Environmental Conditions of the Target Areas

Region		Roads	Block Composition	Building Layout	Parks (Green Spaces)	Building Meterial	Roof Material
Tambakrejo	1	4-lane road (12m)	Irregular	Dispersed	Present	Concrete, Brick	Steel, Concrete, Terracotta Finish
	2	Alley (5m)	Regular	Dense	Absent		
Meteseh	3	2-lane road (6m)	Irregular	Dispersed	Absent		
	4	Alley (6m)	Regular	Dense	Present		



[Figure 36] Example Image of ENVI-met Simulation

The atmospheric conditions for the simulation target areas were based on the year 2023, specifically during Indonesia's dry season on June 21 (summer solstice). Accordingly, the meteorological conditions of Semarang were applied based on BMKG (2023) data: a minimum temperature of 26°C, a maximum temperature of 35°C, a minimum relative humidity of 70%, a maximum relative humidity of 85%, a wind speed of 2 m/s, and a wind direction of 135 degrees (southeast wind). While the physical environmental conditions varied during the simulations, the meteorological conditions were kept consistent.

Cool Roofs (Reflective Roofs) are designed to reflect sunlight, minimizing heat absorption by roofs during the daytime and thereby reducing indoor building temperatures. These roofs are typically composed of bright-colored paints or

materials with high reflectivity, which reflect heat rather than absorbing it, contributing to energy savings for cooling and mitigating urban heat island effects.

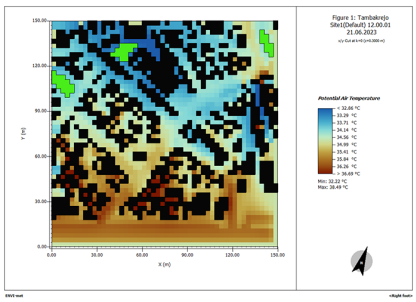
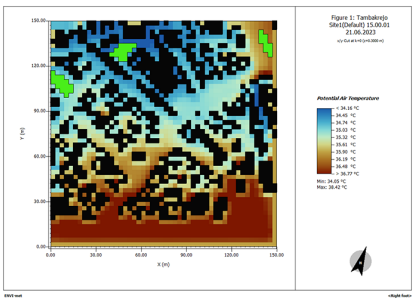
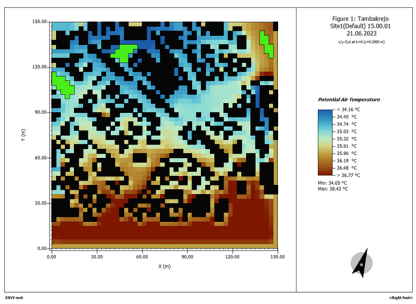
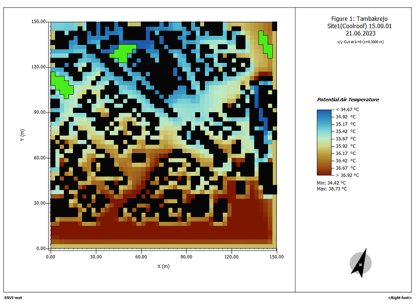
In this study, the reflectivity value of standard white paint was applied as the material for Cool Roofs, and the corresponding settings are detailed in the table below.

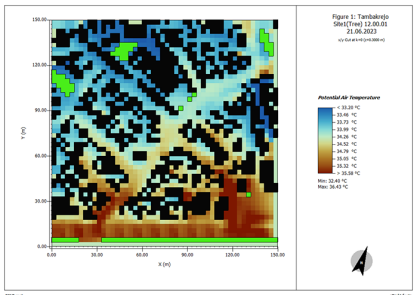
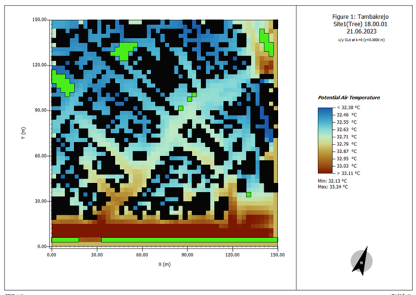
〈Table 25〉 Cool Roof Material Settings

Property	Value
Absorption	0.1 ~ 0.3
Transmission	0
Reflection(Albedo)	0.7 ~ 0.9
Emissivity	0.9 ~ 0.95
Specific Heat(J/kgK)	1000 ~ 1500
Thermal Conductivity(W/mK)	0.15 ~ 0.3
Density(kg/m^3)	1200 ~ 1500

④ Simulation Results

〈Table 26〉 Simulation Results for Tambakrejo Target Area 1 by Condition

Condition	12:00	15:00
Current Condition		
Cool Roof		

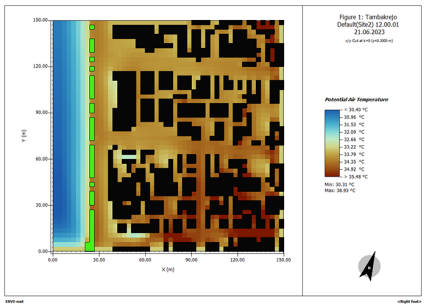
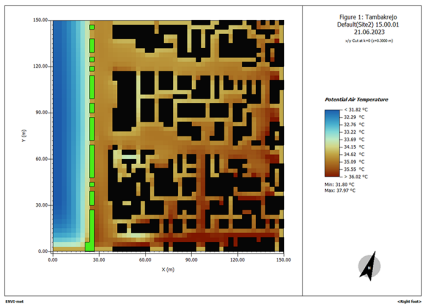
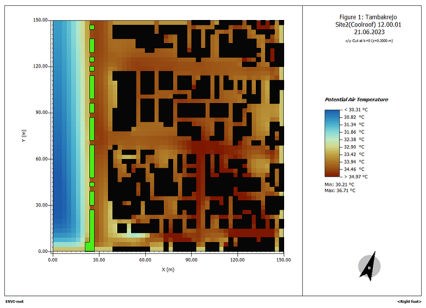
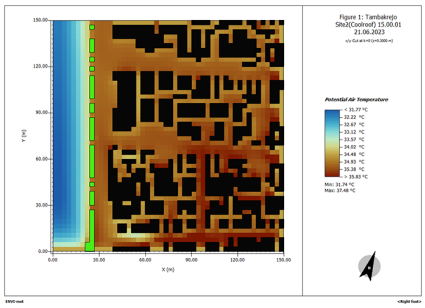
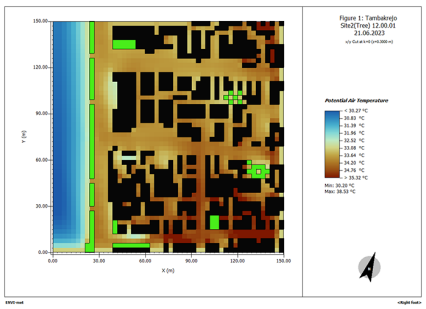
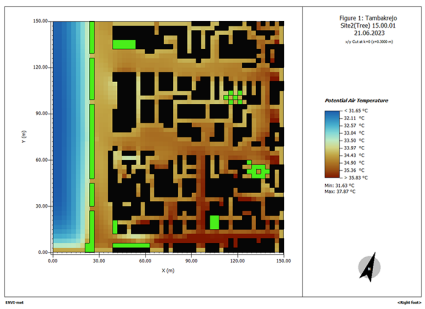
Condition	12:00	15:00
Green Roof and Street Trees		

The Tambakrejo Target Area 1 is located near a main road and is characterized as a heat-retaining area due to the lack of wind corridors. The area features irregular block structures and curved alleys, with the main road being a 4-lane road (12m wide). While there is a small park, the green space is insufficiently developed.

Simulation results indicated that rooftop greening was the most effective heat mitigation strategy in areas with dense building clusters and irregular block structures. Cool roofs contributed to improving the overall heat environment but were less effective in areas with high building density. Rooftop greening provided an additional 2°C reduction in temperature compared to cool roofs.

In conclusion, planting street trees along the main road is recommended to alleviate the urban heat island effect. For areas where wind corridors cannot be established due to building structures, creating green spaces in regions where airflow is obstructed is proposed as a desirable alternative for improving the heat environment.

〈Table 27〉 Simulation Results for Tambakrejo Target Area 2 by Condition

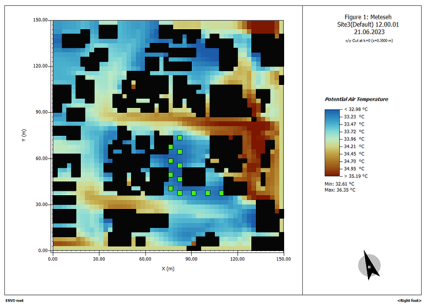
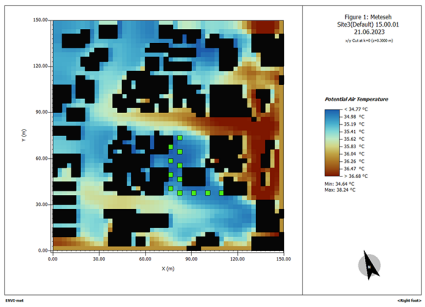
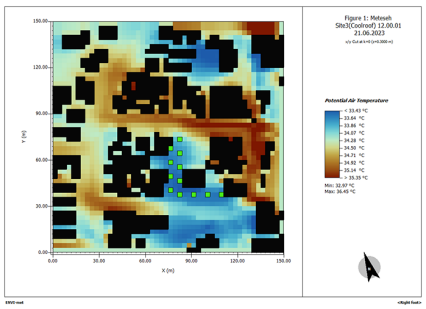
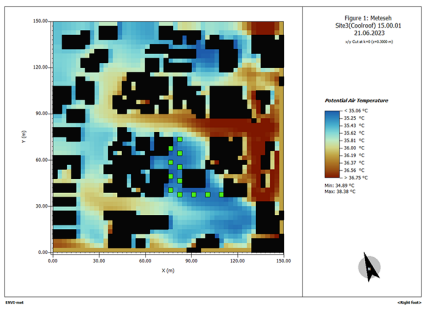
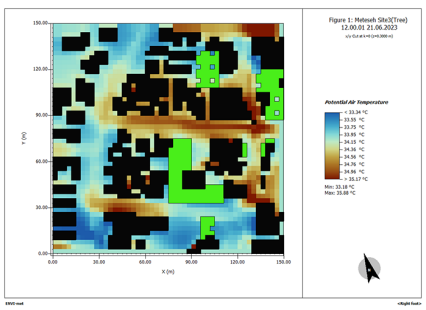
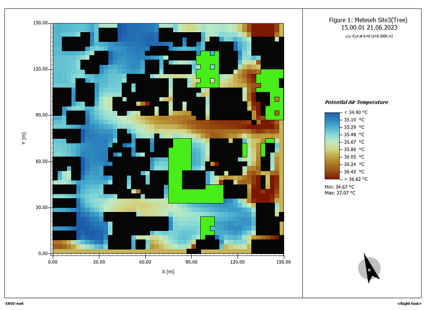
Condition	12:00	15:00
Current Condition		
Cool Roof		
Green Roof and Street Trees		

Tambakrejo Target Area 2 is a residential area with high building density and a lack of green spaces. It consists of rectangular blocks and narrow alleys and is adjacent to the Banjir Kanal Timur (Eastern Flood Canal). A notable characteristic of this area is the absence of parks or open spaces within the dense residential zones.

Simulation results indicated that the implementation of cool roofs was the most effective heat mitigation strategy for dense, regular block structures. Cool roofs demonstrated a temperature reduction of approximately 1°C compared to the

current state. In contrast, rooftop greening showed relatively minimal differences in heat mitigation effects.

〈Table 28〉 Simulation Results for Meteseh Target Area 1 by Condition

Condition	12:00	15:00
Current Condition		
Cool Roof		
Green Roof and Street Trees		

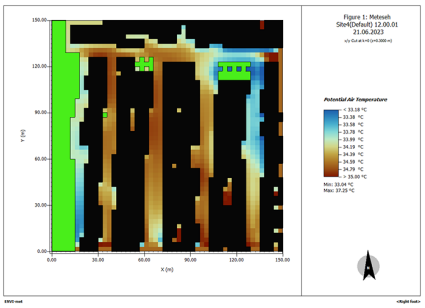
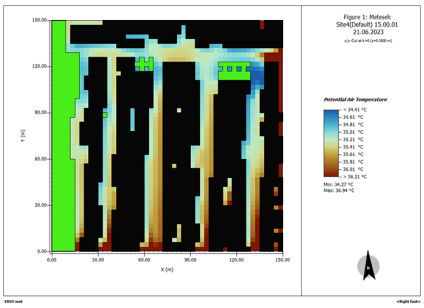
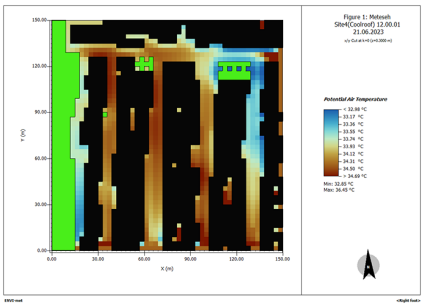
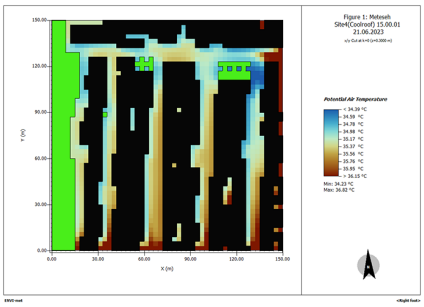
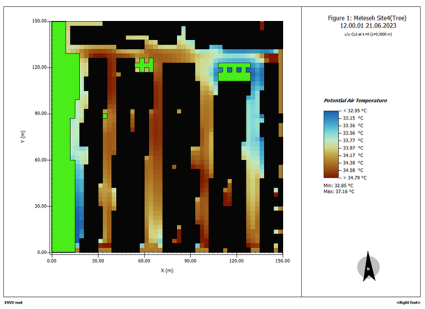
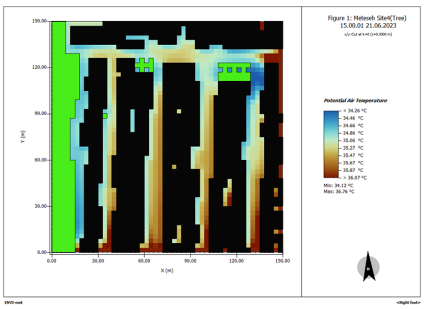
Meteseh Target Area 1 consists of a dispersed residential environment with irregular blocks and low building density. It is characterized by wide asphalt roads and paved walkways, and it lacks sufficient green spaces, although there are open spaces within the residential area.

Simulation results indicated that rooftop greening and the creation of external

green spaces were the most effective heat mitigation strategies in environments with irregular blocks and dispersed residential structures. In particular, planting vegetation to provide shade in heat-concentrated intersections and exposed areas played a significant role in heat mitigation.

In contrast, cool roofs showed minimal heat mitigation effects compared to the baseline conditions, suggesting that expanding green spaces is a more suitable solution for improving the heat environment in this area.

〈Table 29〉 Simulation Results for Meteseh Target Area 2 by Condition

Condition	12:00	15:00
Current Condition		
Cool Roof		
Green Roof and Street Trees		

Meteseh (Target Area 2) is an area where heat stagnation occurs due to high building density. It is composed of rectangular blocks and narrow alleys. Although there is a green park near the residential area, the lack of wind corridors within the blocks causes persistent heat stagnation.

In densely built-up residential areas, rooftop greening and the creation of external green spaces proved to be effective strategies for improving the heat environment. Simulation results indicated that adding green spaces could reduce temperatures by approximately 0.5°C compared to the current state. The heat mitigation effect increased progressively in the order of the current state, cool roofs, and green space creation, with green space creation showing the most significant temperature reduction.

〈Table 30〉 Environmental Conditions of the Target Areas

Region		Block Composition	Building Layout	Parks (Green Spaces)	Key Mitigation Strategies
Tambakrejo	1	Irregular	Dispersed	Present	Rooftop Greening
	2	Regular	Dense	Absent	Cool Roof
Meteseh	3	Irregular	Dispersed	Absent	Rooftop Greening and External Green Space Creation
	4	Regular	Dense	Present	Rooftop Greening and External Green Space Creation

⑤ Simulation Conclusions

This study aimed to propose heat environment improvement guidelines by simulating heat mitigation strategies such as cool roofs, rooftop greening, and street tree planting, based on prior research. The simulation focused on areas with distinct physical environmental conditions, particularly those identified in the Living Lab as having significant heat impacts.

The analysis results showed differences in heat mitigation effects based on physical environmental conditions:

- High-density residential areas with irregular blocks: Rooftop greening was

identified as the most effective heat mitigation strategy, with additional street tree planting and wind corridor creation needed.

- High-density residential areas with regular blocks and insufficient greenery: Cool roofs demonstrated the most significant heat mitigation effect, with improvements in building reflectivity being more effective than green space creation.
- Low-density dispersed residential environments with irregular blocks: Rooftop greening and external green space creation provided the greatest heat mitigation effects. In particular, densely established green spaces were found to be effective for improving the heat environment.
- High-density residential areas with regular block structures and existing greenery: Additional rooftop greening and external green space creation resulted in a temperature reduction of approximately 0.5°C. However, no dramatic effects were observed.

In conclusion, it was confirmed that the effectiveness of heat mitigation strategies varies depending on the physical environmental conditions. Therefore, applying tailored heat environment strategies that take into account the specific characteristics of each area is recommended.

Section4. Impact Factors of Climate Change on Water

1. Research Background

1) Increase in Flood Incidents in Indonesia Due to Climate Change

[Climate Change]

The frequency of coastal flooding has been rising due to climate change and sea-level rise, significantly impacting coastal cities such as Jakarta and Semarang, where the extent of flooding has also become more widespread (Pramono, 2021).

Due to climate change, floods accounted for the majority of natural disasters in Indonesia in 2022, with 1,493 incidents reported. Particularly, coastal areas such as Jakarta and Semarang have faced increasing flood damages, highlighting the growing exposure to flood risks.

2) Social Issues Induced by Flooding

[Flood Impacts]

Flood damage and the resulting disruption to daily life, along with delays in recovery plans, can lead to social issues such as the loss of housing and lack of access to education. These challenges may result in the disintegration of communities or the emergence of marginalized groups (Jakarta Globe, 2020.01.27).

2. Research Objectives

1) Sub study 3 : Identifying Water Impact Factors due to Climate Change and Developing a Flood Risk Index for Empirical Application

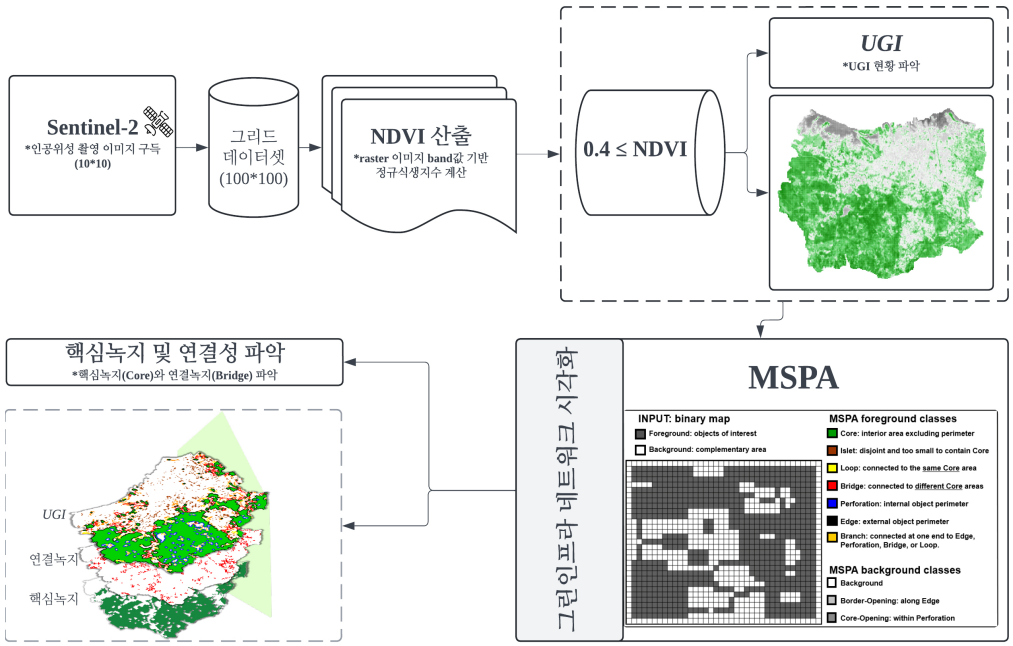
The purpose of this study is to identify factors that influence water, particularly flooding, due to climate change and to develop a flood risk index based on these

factors. To achieve this, the study is divided into three steps. In the first step, the connectivity of green infrastructure within urban areas is assessed through green infrastructure network analysis. Based on this, the second step presents an urban flood risk index and predicts high-risk areas. In the third step, flood-mitigating green axes are identified to propose measures for flood reduction and management.

3. Methodology and Results

① Step 1: Green Infrastructure Network Analysis

[Green Infrastructure Network]



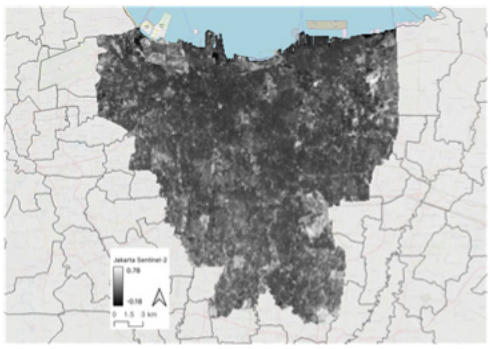
[Figure 37] Green Infrastructure Network Analysis System

To analyze the green infrastructure network, the process was divided into two sub-steps, as shown in [Figure 37]. In Step 1-1, the goal was to collect basic data on green infrastructure in Jakarta and Semarang and to analyze the current state

of green spaces. In Step 1-2, the objective was to evaluate the status of green infrastructure networks within urban areas based on Urban Green Infrastructure (UGI) and to identify key green spaces and their connectivity.

As the world's largest archipelagic nation, Indonesia is particularly vulnerable to increased flooding caused by climatic and geological factors, such as river overflow due to heavy rainfall and sediment deposition in rivers (Harwitasari and van Ast, 2011; Langlois, B. K. et al., 2023). To evaluate the green infrastructure networks of Indonesia's major cities, the study conducted a theoretical review and landscape ecology, ecological network, and spatial graph analyses, including MSPA (Morphological Spatial Pattern Analysis). Basic information on climate factors (e.g., precipitation, sea level, temperature) and geographic factors (e.g., land use, slope) affecting urban flooding was collected and reviewed. Furthermore, to capture detailed urban greenery, including Indonesia's forests, Sentinel-2 satellite images with a resolution of 10m x 10m were processed to create 100m x 100m grid datasets. Using the Normalized Difference Vegetation Index (NDVI), spatial information on Indonesia's UGI was identified.

〈Table 31〉 NDVI based on satellite imagery

Jakarta NDVI	Semarang NDVI
	

To construct the most up-to-date UGI spatial data reflecting ongoing urban development, NDVI data from 2015 to 2021 were collected for Jakarta and Semarang, the study areas. After processing NDVI raster files obtained from

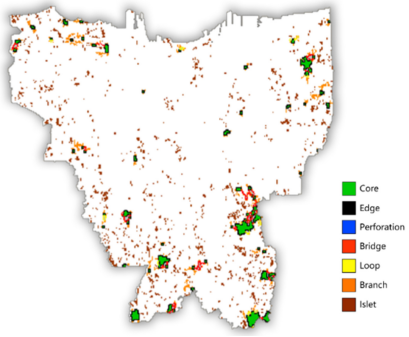
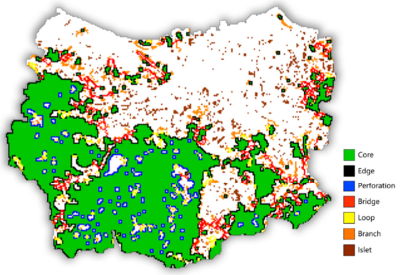
satellite imagery, healthy green areas were classified using NDVI values above 0.4, following vegetation standards defined in prior studies (〈Table 32〉, Aquino D. D. N. et al., 2018).

〈Table 32〉 NDVI classification

Class	Classification criterion
Bare soil or waterbody	NDVI ≤ 0
Very low	0 〈 NDVI ≤ 0.2
Low	0.2〈 NDVI ≤ 0.4
Moderate	0.4〈 NDVI ≤ 0.6
High	0.6〈 NDVI ≤ 0.8
Very high	0.8〈 NDVI ≤ 1

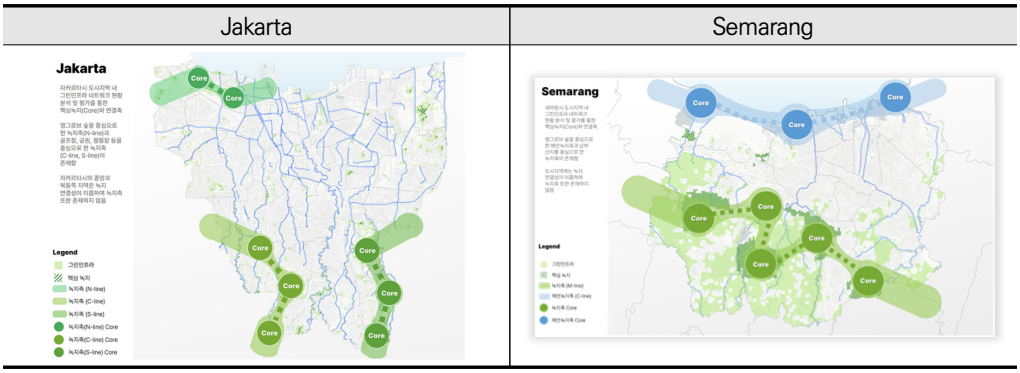
Aquino D. D. N. et al.(2018) 재구성

In Step 1-2, the NDVI results derived in Step 1-1 were utilized to visualize the green infrastructure network and its connectivity. Using MSPA, key green spaces (Core) and connecting green spaces (Bridge) within urban areas were identified. Based on the MSPA analysis conducted for 2021, the green infrastructure network status and connectivity in major cities were assessed. The analysis results for Jakarta and Semarang are presented in [Figure 38]. In Jakarta, most key green infrastructures were identified as cemetery parks and golf courses. This is due to the lack of UGI, including core green infrastructures, within the city center, caused by urban development and high building density. Excluding a golf course in East Jakarta, the connectivity between green infrastructures was also found to be inadequate. In contrast, Semarang, with mountainous areas concentrated in the southwest, exhibited relatively abundant UGI and better connectivity between green infrastructures compared to Jakarta. However, the city center lacked core green infrastructure, and connectivity between green infrastructure, apart from natural green areas, was insufficient.

Jakarta	Semarang
	

[Figure 38] MSPA Analysis Results by City

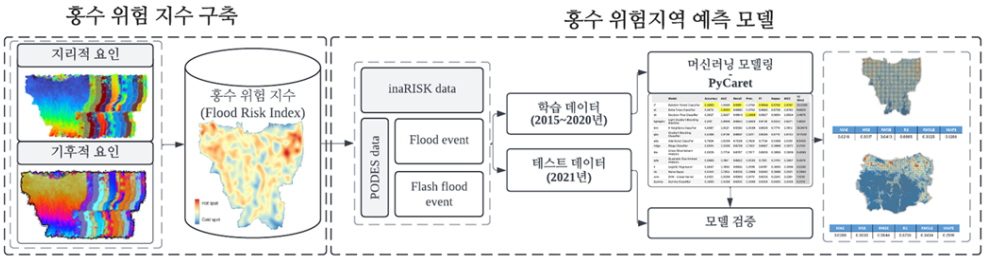
Through the MSPA-based analysis of green infrastructure status and connectivity, the key green infrastructures and green axes in each city were identified, and the current green axes for Jakarta and Semarang were derived, as shown in [Figure 39]. In Jakarta, the analysis of the UGI network identified three primary green axes: the N-Line (North-line) axis, centered around mangrove forests in North Jakarta; the C-Line (Conservation-line) axis, focusing on golf courses, parks, and camping grounds in South Jakarta; and the S-Line (South-line) axis in East Jakarta. However, Central Jakarta and the northeastern areas lack sufficient green connectivity, indicating the necessity to establish new green axesin these regions. In Semarang, two primary green axeswere identified: the C-Line (Coastal-line) axis, centered on mangrove forests, and the M-Line (Mountain-line) axis, focused on the southern mountainous areas. However, the city center exhibited weak green infrastructure connectivity, with an absence of core green infrastructures or green axes linking coastal and mountainous areas, highlighting a deficiency in interconnected green infrastructure.



[Figure 39] Results of the Current Status of Green Axis by City

② Step 2: Urban Flood Risk Index and Identification of High-Risk Areas

[Flood Risk Index]



[Figure 40] Urban Flood Risk Index Presentation and Forecasting System

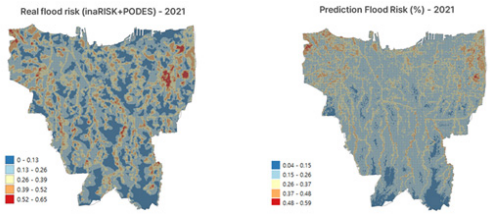
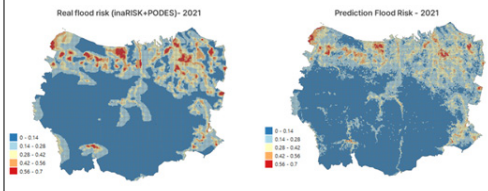
To propose the urban flood risk index, the research was conducted in three phases, as shown in [Figure 40]. In Step 2-1, the urban flood risk index was constructed based on physical (climatic and geographic) factors, and flood risk areas were predicted using flood occurrence data (inaRISK, PODES). In Step 2-2, machine learning was used to determine the importance of the factors utilized in the flood risk index. In Step 2-3, flood risk areas were predicted based on climate change scenarios. The details of each step are as follows.

〈Table 33〉 Physical elements for building flood risk indicators

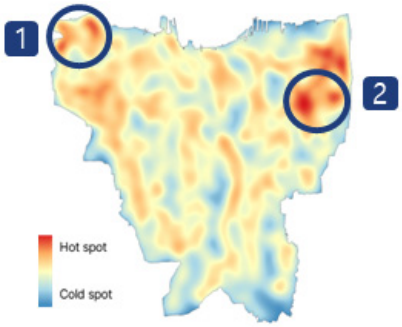
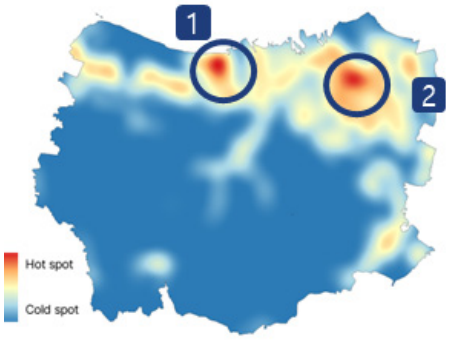
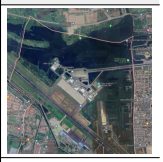
Classification		DataName	Description
Flood Impact Factors	Climate Factors	ro	Leakage amount derived by using 1D soil moisture balance model
		vpd	Saturated steam pressure
		aet	Actual evaporation yield derived using a one-dimensional soil moisture balance model
		tmmn	Average temperature
		def	Climate moisture deficiency induced using a one-dimensional soil moisture balance model
		soil	Soil moisture derived using a one-dimensional soil moisture balance model
		pr	Accumulated precipitation
		pdsi	Palmer Drought Index
		tmmx	The highest temperature
		twi	Topographic wetness index
		flow-accumulation	Cumulative flow
	Geographical Factors	S2-NDBI	Sentinel-2 NDBI
		S2-NDWI	Sentinel-2 NDWI
		S2-NDVI	Sentinel-2 NDVI
		landcover	Land cover map
		flow-pointer	Flow
		slope	Gradient
		aspect	The direction of the maximum slope
		mean-curvature	Average curvature
		dtriver	The distance to the nearest river
		Dtroad	The distance to the nearest road

To build the flood risk index for Jakarta and Semarang, climate factors (cumulative precipitation, temperature, etc.) and geographic factors (DEM, NDBI, NDVI, Slope, CN, etc.) from 2015 to 2021 were collected and used as physical elements influencing flooding (refer to Table 33). In addition, to account for flood occurrences, the Indonesian disaster risk index, inaRISK, and the village-level statistical data, PODES (including flood occurrences and flash flood occurrences), were used to construct the flood occurrence dataset. Furthermore, using the Indonesian flood occurrence dataset (2015–2021), the average values of the climate

factors (climatic) and geographic factors (geographic) were generated for a 100m x 100m grid. For flood risk area prediction, machine learning models were evaluated using PyCaret, and the Random Forest model, which was identified as the optimal model, was used to build the flood risk index prediction model. Both cities showed high model performance (refer to Figure 41). The prediction results derived from Random Forest were then converted into a 100m x 100m grid, and the Flood Risk Index (FRI) was calculated based on the physical factors. Using the FRI, Hot-spot analysis was conducted to identify flood risk areas in 2021, and the results are shown in [Figure 42]. In Jakarta, flood risk areas were identified around regions such as park and artificial fishing areas (Area 1) and areas with lakes and townhouse concentrations (Area 2). In Semarang, flood risk areas were mainly found in areas with little green infrastructure and surrounding developed urban areas, such as airports and artificial fishing areas (Area 1) and low-rise residential areas (Area 2).

Jakarta						Semarang					
											
MAE	MSE	RMSE	R2	RMSLE	MAPE	MAE	MSE	RMSE	R2	RMSLE	MAPE
0.0216	0.0017	0.0413	**0.8885**	0.0325	0.1286	0.0299	0.0030	0.0544	**0.8720**	0.0434	0.2516

[Figure 41] Flood Risk Areas 2021 by City

Jakarta		Semarang	
			
Characteristics	Satellite Image (Google Map)	Characteristics	Satellite Image (Google Map)
1. Park and artificial fishing spots		1. Airport vicinity and artificial fishing spots	
2. Lake and townhouse sites		2. Low-rise residential areas	

[Figure 42] Flood Risk Areas 2021 by City - Hotspot

Based on flood risk areas, a survey was conducted to assess the level of flood risk awareness according to socioeconomic status in the Tambakrejo and Meteseh areas of Semarang, Indonesia, which are categorized as flood risk areas. The survey question was "How would you assess the level of flood threat in your area?" and was rated on a 5-point scale (Very Serious, Serious, Average, Not Serious, Not Serious at All). To comprehensively verify the effects of independent variables, likelihood ratio tests were conducted as shown in 〈Table 34〉, and it was found that among socioeconomic factors, marital status, employment status, housing type, and education level influenced flood risk awareness.

〈Table 34〉 The result of the likelihood ratio test

Effect	Model Fit Criteria	Likelihood Ratio Test		
	-2 Log Likelihood of Reduced Model	Chi-Square	Degrees of Freedom	p-value
Average Annual Household Income	1051.536	5.21	4	0.27
Gender	1050.246	3.92	4	0.42
Marital Status	1072.623	26.30	12	0.01***
Employment Status	1080.700	34.37	20	0.02**
Housing Type	1061.965	15.64	8	0.05**
Housing Status	1062.269	15.94	12	0.19
Education Level	1089.207	42.88	28	0.04**
Age	1066.440	20.11	20	0.45

To examine the factors influencing the levels of flood risk awareness, a multinomial logistic regression model was used, and the results are shown in 〈Table 35〉. The analysis results indicate that for the group who perceive the flood risk as "Not Serious At All," the influencing factors include employment status (full-time), housing type (apartment), and education level (middle school/equivalent). The estimated value for employment status (full-time) is 0.839, meaning that full-time workers are more likely to rate flood risk as less serious compared to other occupational groups. The estimated value for housing type (apartment) is 16.430, indicating that people living in apartments are highly likely to rate flood risk as "Not Serious At All." In contrast, for the education level of middle school/equivalent, the estimated value is -1.675, indicating that people with this level of education are more likely to rate the flood risk as "Very Serious" compared to those with higher education levels. For the group that perceives the flood risk as "Not Serious," the same factors—employment status (full-time) and housing type (apartment)—are significant, and employment status (pensioner) is also a significant variable. The estimated value for pensioners is 2.111, meaning that pensioners are more likely than other occupational groups to rate the flood risk as "Not Serious," with an odds ratio showing that they are about 8.3 times more likely to choose "Not Serious" compared to "Very Serious." For the group that selected "Neither

Serious nor Not Serious," the only significant variable was marital status (married), with an estimated value of -2.274, indicating that married individuals are more likely to rate the flood risk as "Very Serious" rather than "Neither Serious nor Not Serious." Finally, for the group that selected "Serious," the results were similar to those who selected "Not Serious At All" and "Not Serious" in terms of employment status (full-time) and housing type (apartment), which were significant. The estimated values for these variables are 0.804 and 15.175, respectively, indicating that individuals in these groups are more likely to rate the flood risk as "Serious" rather than "Very Serious."

Based on these survey findings, the following implications can be drawn 1) Full-time workers and pensioners, i.e. those with a more stable economic status, are more likely to rate flood risk as low, suggesting that job security has a positive impact on flood risk perception. 2) Married people have a higher risk perception of flood risk, which suggests that the perception of responsibility due to family composition may influence risk perception.

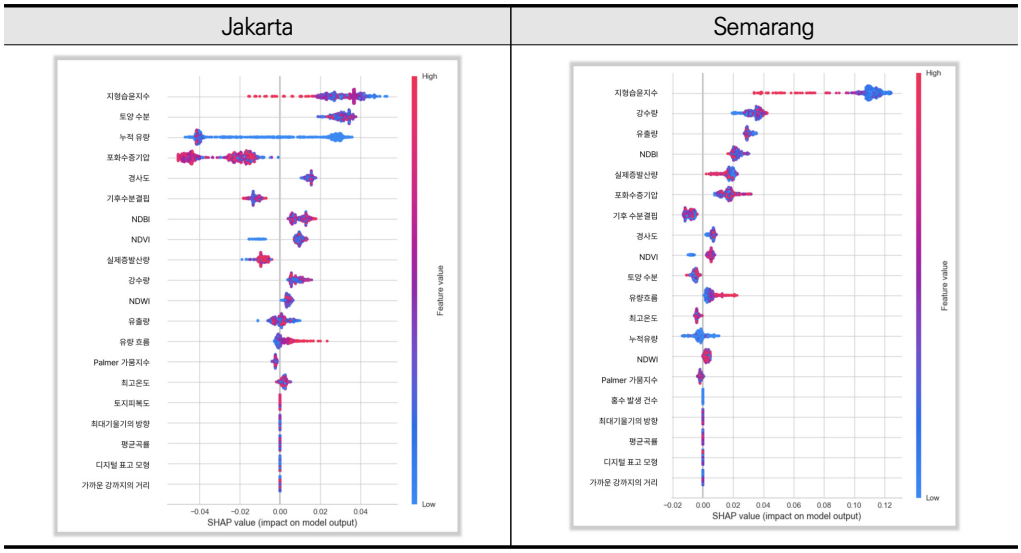
〈Table 35〉 Multinomial Logistic Analysis Results

		Not Serious At All			Not Serious			Neither Serious nor Not Serious			Serious		
		B	Wald	Exp(B)	B	Wald	Exp(B)	B	Wald	Exp(B)	B	Wald	Exp(B)
Average annual household income		0.000	0.153	1.000	0.000	2.194	1.000	0.000	0.181	1.000	0.000	1.632	1.000
Gender	Female	-0.013	0.002	0.987	-0.505	1.891	0.603	-0.155	0.105	0.856	0.216	0.444	1.241
	Male	0b			0b			0b			0b		
Marital status	bereavement	-0.482	0.118	0.617	1.189	0.750	3.285	1.116	0.631	3.052	2.406	3.208	11.094
	Divorce	13.469	0.000	706799.815	1.278	0.000	3.589	23.920	0.000	24440997065.723	1.466	0.000	4.334
	Marriage	-0.329	0.156	0.720	-0.771	0.741	0.463	-2.274***	6.303	0.103	0.631	0.454	1.879
	Single	0b			0b			0b			0b		
Occupational status	Full-time	0.839*	2.662	2.315	1.655***	8.180	5.231	-0.042	0.002	0.959	0.804*	2.644	2.234
	Part time	0.170	0.120	1.185	-0.060	0.007	0.942	-1.528	1.707	0.217	-0.246	0.231	0.782
	Pensioner	-0.178	0.036	0.837	2.111**	5.829	8.258	0.084	0.004	1.087	-0.191	0.037	0.826
	Self-employed	0.223	0.364	1.250	0.754	2.521	2.126	0.361	0.459	1.435	-0.235	0.403	0.791
	ETC	0.927	1.507	2.527	2.492***	10.096	12.089	1.196	1.560	3.307	0.354	0.186	1.425
	Unemployed	0b			0b			0b			0b		
Housing type	Townhouse	16.430***	421.352	13655114.967	12.648***	175.111	311042.148	-8.716	0.001	0.000	15.175***	259.253	3895860.188
	Detached house	15.022		3341602.706	11.654		115163.323	3.499		33.085	15.562		5733136.678
	ETC	0b			0b			0b			0b		
State of residence	ETC	12.351	0.000	231199.072	1.261	0.000	3.528	12.439	0.000	252582.210	13.420	0.000	673405.462
	Free rental housing	13.384	0.000	649647.581	15.299	0.000	4406266.295	27.492	0.001	870178679762.286	0.048	0.000	1.049
	Sleep	-0.072	0.013	0.930	1.627	2.015	5.087	12.008	0.002	164139.113	-0.286	0.213	0.752
	Paid rental house	0b			0b			0b			0b		

		Not Serious At All			Not Serious			Neither Serious nor Not Serious			Serious		
		B	Wald	Exp(B)	B	Wald	Exp(B)	B	Wald	Exp(B)	B	Wald	Exp(B)
Education Level	Elementary school dropout and below	-1.794	2.483	0.166	12.227	0.002	204148.623	-12.872	0.002	0.000	12.379	0.001	237649.998
	elementary school graduation / Same	-1.281	2.537	0.278	12.194	0.001	197556.727	0.509	0.118	1.663	12.627	0.002	304698.645
	Middle school / equal	-1.675**	4.445	0.187	12.210	0.002	200781.827	0.375	0.065	1.456	12.611	0.002	299722.706
	High school / equal	-1.209	2.383	0.299	12.568	0.002	287342.693	-0.074	0.003	0.929	12.696	0.002	326508.739
	Vocational Collegel / II	-15.868	0.000	0.000	-0.967	0.000	0.380	-14.165	0.000	0.000	-2.184	0.000	0.113
	Vocational Collegel III	-15.472	0.001	0.000	-1.438	0.000	0.237	2.172	1.379	8.778	12.681	0.002	321600.874
	Vocationalcollege IV / bachelor's degree	-0.770	0.690	0.463	12.983	0.002	434925.989	-0.335	0.040	0.716	13.086	0.002	482102.992
	Not graduated from school	0b			0b			0b			0b		
Age	Under 20	1.196	0.676	3.308	1.384	0.816	3.991	-13.480	0.000	0.000	-11.088	0.001	0.000
	20 to 29 years old	0.113	0.025	1.119	0.372	0.187	1.450	-0.432	0.134	0.649	0.530	0.570	1.698
	30 to 39 years old	0.363	0.453	1.437	0.120	0.032	1.127	0.834	1.088	2.302	0.465	0.705	1.592
	40 to 49 years old	-0.189	0.146	0.828	0.194	0.103	1.214	0.478	0.379	1.613	-0.311	0.367	0.733
	50 to 59 years old	-0.126	0.072	0.881	0.508	0.875	1.662	-0.328	0.194	0.720	0.092	0.037	1.096
	60 years of age or older	0b			0b			0b			0b		

*$p < .1$ **$p < .05$ ***$p < .01$

Based on the FRI derived in step 2-1, the global SHAP values were used to determine the importance of factors affecting urban flood risk. The analysis identified key variables that could influence urban flood risk. Furthermore, based on the analysis, physical indicators that could be prioritized for urban flood mitigation were proposed. The analysis revealed that in Jakarta, the important variables were TWI (Topographic Wetness Index), soil moisture, and flow accumulation, while in Semarang, the important variables were TWI, cumulative precipitation (PR), and runoff (RO) (see Figure 43). SHAP analysis showed that the common key variables affecting model predictions in both cities were TWI, soil moisture, flow accumulation, and runoff, which were found to be closely correlated with precipitation and temperature. Based on this, it was determined that it is necessary to identify flood-prone areas by considering precipitation and temperature (maximum temperature and average temperature), as these variables represent the key factors. These results indicate that the flood risk should be assessed based on changes in precipitation and temperature (maximum temperature and average temperature) due to climate change. In other words, the findings suggest that climate factors are relatively more important than geographical factors in both cities, and this implies that climate factors should be prioritized when developing flood mitigation strategies.



[Figure 43] Main Indicators by city

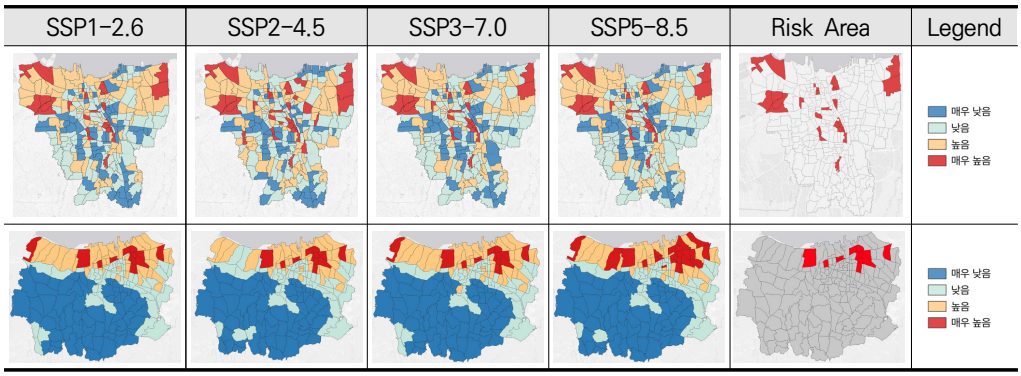
Finally, in step 2-3, the Random Forest model developed in step 2-1 was used to predict future flood risk areas and risk indices under climate change scenarios. A climate change scenario refers to future climate projections based on artificial causes such as greenhouse gas and aerosol changes, using greenhouse gas concentrations and climate change numerical models to generate future climate outlook information (Korea Meteorological Administration, Weather Nuri). To understand future climate projections, Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP) are primarily used as climate change scenarios. SSP is the latest climate change scenario used in the IPCC's 6th Assessment Report, incorporating future socio-economic system changes such as population, economy, and energy use, according to the level of radiative forcing (RCP) projected for 2100. RCP is a greenhouse gas concentration scenario based on radiative forcing for 2100, used in the IPCC's 5th Assessment Report. These two climate change scenarios serve different purposes, depending on whether the focus is on greenhouse gas concentrations or changes in future socio-economic systems. In step 2-3 of this study, both scenarios were considered necessary, so the SSP-RCP scenarios provided by the World Bank Climate Change Knowledge Portal were used. The SSP-RCP consists of four standard scenarios (SSP1-2.6, Sustainable Growth; SSP2-4.5, Moderate Growth; SSP3-7.0, Unequal Growth – Continuing Current Trends; SSP5-8.5, High Growth) as shown in [Figure 44]. In this study, flood risk areas for 2030 were predicted based on changes in maximum temperature, average temperature, and cumulative precipitation according to these scenarios.

종류	의미	인도네시아 평균 기온(2030)	인도네시아 강수량(2030)
SSP1-2.6	✓ 사회 불균형 감소와 친환경 기술의 빠른 발달로 기후변화 완화 ✓ 적응능력이 좋은 지속성장가능 사회경제 구조의 저탄소 시나리오	+ 0.4°C	- 80.6 mm
SSP2-4.5	✓ 중도성장의 사회경제 시나리오로 기후변화 완화 ✓ 사회경제 발전 정도가 중간단계 가정	+ 0.38°C	-84.1 mm
SSP3-7.0	✓ 사회경제 발전의 불균형과 제도적 제한으로 인해 기후변화에 취약한 상태에 놓이는 사회경제 구조의 시나리오*(Baseline)*	+ 0.4°C	- 122.2 mm
SSP5-8.5	✓ 기후정책 부재, 화석연료 기반 성장과 높은 인적투자로 기후변화 적응능력은 좋지만, 완화능력이 낮은 사회경제 구조의 고탄소 시나리오	+ 0.52°C	- 39.1 mm

* 2014년 대비 2030년 변화량

[Figure 44] Climate change scenarios

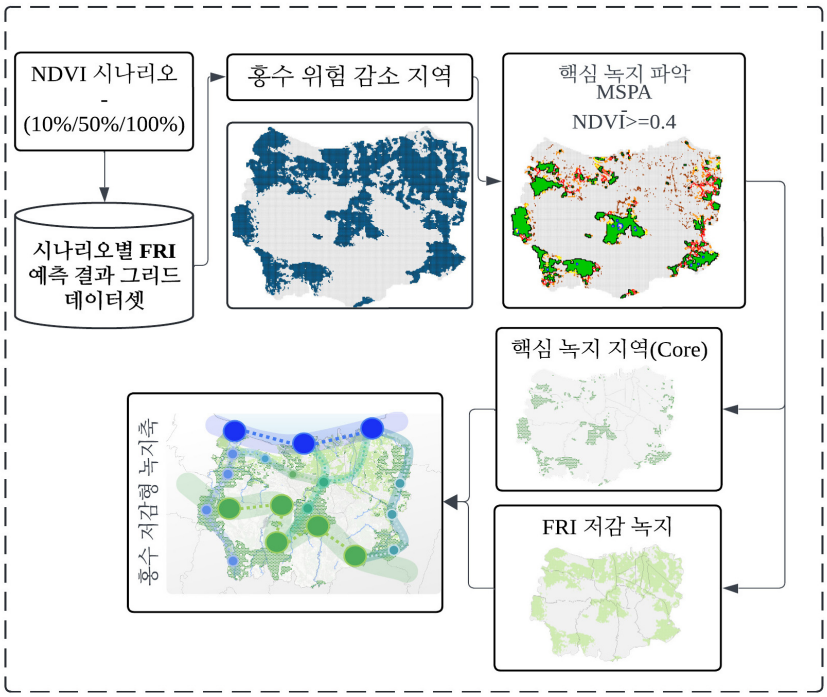
Using the SSP-RCP scenarios, climate change predictions were made for each RW (village) in Indonesia (Jakarta RW = 264, Semarang RW = 177). In addition, to account for extreme weather events such as localized heavy rainfall due to climate change, the number of days with rainfall over 50mm and the average maximum daily rainfall were considered. Using the previously established model, FRI predictions were made according to the scenarios, and based on this, k-means clustering was applied to group the flood risk indices by scenario, identifying areas with very high flood risk. The prediction results showed that in Jakarta, areas such as Danau Sunter Dll, Kampung Melayu, Bungur, and Rawa Buaya were identified as high flood risk areas. All four areas currently have inadequate green connectivity, highlighting the need for the proposal of flood mitigation green corridors. In Semarang, coastal areas such as Tambakrejo and Kemijen were predicted as flood risk zones. Except for mangrove conservation areas, there is a lack of green infrastructure in these regions, emphasizing the need for green corridors that reflect this situation (see Figure 45).



[Figure 45] Flood Risk Areas by Climate Change Scenario

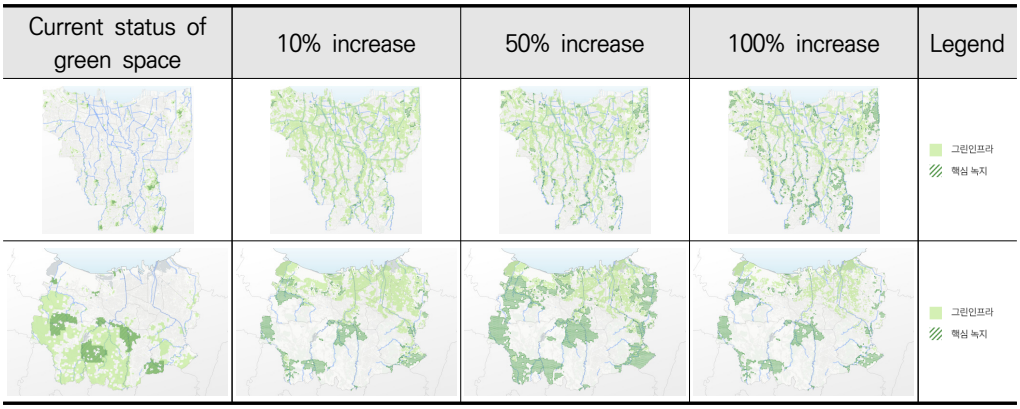
③ Step 3: Deriving Flood Mitigation Green Axis

[Flood Mitigation Green Axes]



[Figure 46] A framework for deriving the flood-reduction type green axis

In step 3, the analysis was divided into three detailed steps to derive the long-term flood reduction green axis through NDVI scenarios. For the detailed research phase, 1) NDVI scenario analysis (10%, 50%, 100% increase) was conducted to derive the green axis in the target area considering the flood risk index. 2) Random Forest, a machine learning model, was utilized to determine the areas where the FRI decreases as the NDVI increases according to the scenario, and the core green areas that should be reflected in the green axis were identified and a grid dataset was built. 3) To reduce FRI, we proposed a long-term green axis that reflects regional characteristics (see Figure 46).



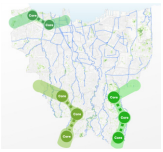
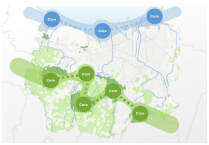
[Figure 47] Flood Risk Reduction Area by Vegetation Index Improvement Scenario

After conducting the scenario analysis in step 1, the results of identifying the core green area and the FRI-reduced green area in step 2 were shown in [Figure 47]. FRI-reduced green areas were defined as areas where FRI decreased when the NDVI value increased, and the core green area (Core) was defined as an area where the NDVI value was 0.4 or more among the FRI-reduced green areas, which should be considered first when constructing a green area axis for flood reduction. As a result of the analysis, in the case of Jakarta, as the vegetation index improved, the area where the FRI decreased increased, and it was confirmed that the core green area was expanded mainly around the Suka Pura area located in East Jakarta. In particular, the FRI reduction area due to the improvement of NDVI increased centering on the riverside space, which means that it is necessary to present a green axis using the riverside area. On the other hand, in the case of Semarang, when NDVI increased by 50%, FRI was reduced in the most areas, and the core green area was derived mainly from the mountains located in the southwest. This means that in Semarang, where there is already an abundant green space in the southwestern part, it is necessary to present a green space axis that preserves existing core green areas rather than unconditionally increasing the amount of green space, but improves green connectivity with the urban center. Putting the analysis results together, in Jakarta, where most of the region is developed and the proportion of impermeable people is high, the FRI decreases when the green space centered on the green space, especially the riverside space, increases, and in

Semarang, when the green space in the urban area is presented along with the preservation of the mountainous area, the FRI is reduced, indicating that it is necessary to present a green space according to regional characteristics. Based on this, in step 3, a green space axis that can reduce FRI was derived by organically connecting the green space in the city, and the results are shown in Figure 48 below. In the case of Jakarta, a U-shaped green axis connecting the outskirts of the city appeared, and in the case of Semarang, a spider web-shaped green axis connecting the conservation mountain, downtown, and coastal mangrove area appeared.

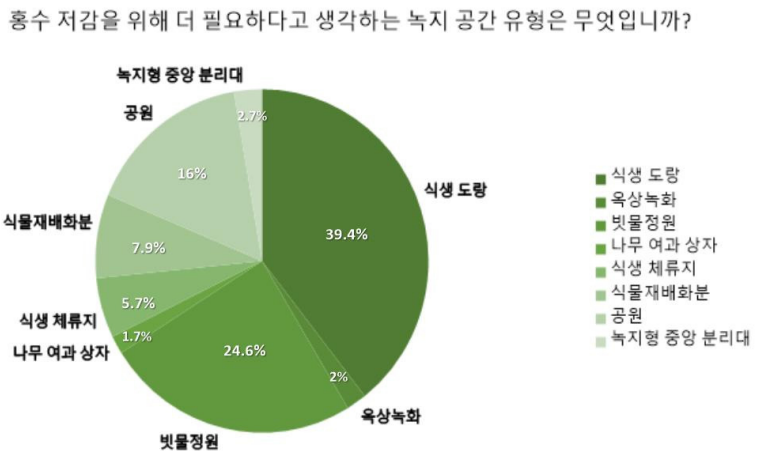
After conducting scenario analysis in Step 1, the results of identifying key green areas and flood risk index (FRI) reduction zones in Step 2 are shown in [Figure 41]. The FRI reduction zones were defined as areas where FRI decreases when the NDVI value increases, and key green areas (Core) were defined as the FRI reduction zones with an NDVI value greater than 0.4, which should be prioritized when constructing green axes for flood mitigation. The analysis revealed that in Jakarta, as NDVI improved, the regions where FRI decreased increased, with the core green areas expanding primarily in East Jakarta, particularly around the Suka Pura area. Notably, FRI reduction zones increased along riverbank spaces, suggesting the need for green axes along riverbanks. Semarang, in contrast, the largest reduction in FRI was observed when NDVI increased by 50%, with the core green areas primarily located in the southwestern mountainous region. This suggests that in Semarang, where abundant green space already exists in the southwest, the focus should not be solely on increasing green space but on preserving existing core green areas while enhancing green connectivity with urban areas. In summary, in Jakarta, where most areas are developed with a high percentage of impervious surfaces, FRI decreases when green spaces, especially along riverbanks, are increased. In Semarang, FRI is reduced when the preservation of mountainous areas is coupled with the introduction of green axes in urban areas, indicating that green axes need to be proposed according to regional characteristics. Based on this, in Step 3, green axes that can organically connect green spaces within the city to reduce FRI

were derived, which are shown in [Figure 42]. In Jakarta, a U-shaped green axis connecting the outskirts of the city was identified, while in Semarang, a spiderweb-shaped green axis connecting the conservation mountains, urban areas, and coastal mangrove regions was identified.

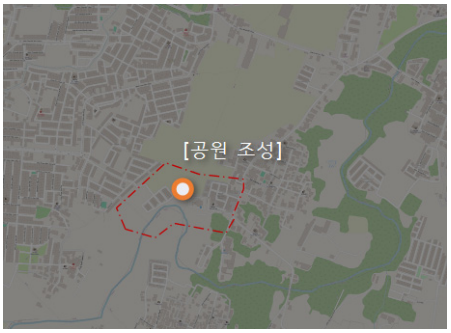
Current status of green space	10% increase	50% increase	100% increase	Legend
				
				

[Figure 48] A Proposition of Greenbelt by Vegetation Index Scenario

To propose practical green axes for flood mitigation, a survey was conducted to assess the preferences of residents in flood-prone areas regarding Low Impact Development (LID) methods. Based on the survey results, a plan for introducing green infrastructure in these areas to create green axes was proposed. The survey was conducted in Semarang's Tambakrejo and Meteseh areas, and the results showed high preferences for vegetated swales (39.4%), rain gardens (24.6%), and parks (16%) (see Figure 49). The most preferred LID types, such as rain gardens, not only help reduce flood risks by storing rainwater but can also serve as leisure spaces, enhance the local aesthetics, and address drainage issues such as trash in canals. Thus, the green axes were developed by incorporating these elements into areas that met the following conditions: 1) regions with lower elevation that require stormwater retention facilities, 2) idle or vacant land, and 3) areas with existing drainage systems. The results of the green infrastructure integration for creating green axes are shown in [Figure 44].



[Figure 49] LID Preference Survey Results

Tambakrejo	Meteseh
	

[Figure 50] Example of LID Application for the Development of Green Axis in Flood Hazardous Areas

Section5. Synthesis

1. Key Findings for each disasters

In this chapter, in order to 'explore the influencing factors by field according to climate change', the current status of disasters in Indonesia's coastal cities centered on Jakarta and Semarang was diagnosed, and then the influencing factors were derived by analyzing the characteristics of coastal city areas that affect the occurrence of disasters. The risk index for each disaster was developed based on the influencing factors, the scenario analysis was conducted based on the results of the fieldwork and a solution was proposed.

1) Disease

In the area of disease impact, the interaction between coastal urban structure, climate change, and endemicity was analyzed through two stages. In the first step, the status of endemic diseases according to past and present climate change in Indonesia was confirmed through reports and policy reviews, and the relationship between endemic diseases and climate change factors was confirmed based on the five areas of UNSD climate change statistics, and research variables were derived. Subsequently, in the second step, hot spots were derived by diagnosing the status of endemic diseases by city, and the interaction between endemic diseases and coastal urban structures was confirmed using K-means clustering and decision tree model, and the possibility of spreading endemic diseases was confirmed.

Through a macro-environmental analysis (PESTEL) by reviewing Indonesian government reports and international organization reports to diagnose the status of endemic diseases caused by climate change in Indonesia in the past and present, the vulnerability to endemic diseases including dengue was reaffirmed overall. In particular, for systematic response to endemic diseases, the cooperation system between government ministries and local-central governments was insufficient, and the need for improvement was confirmed. In addition, various systems and policies

related to the response to endemic diseases have been prepared, but there was also a problem in application due to the limitation of response capabilities. In particular, the need to prepare for the vulnerability of women and children to endemic diseases, and the need to expand health infrastructure and improve the information provision system was confirmed.

Subsequently, academic papers and research reports were reviewed to confirm the relationship between climate change and endemic diseases in Indonesia. In climate conditions, temperature, humidity, precipitation, wind speed, geographic conditions, land cover, altitude, vegetation index, and urbanization, wastewater treatment ratio, and sewage systems were derived as social variables, including population density, age, labor population, and environmental factors.

Following the diagnosis of the status of endemic diseases by city, dengue hot spots were formed in Jakarta in the center of the city where residential areas were concentrated, and these areas had high population density regional characteristics such as low-density residential areas and industrial areas. Meanwhile, in Semarang, dengue hot spots were mainly formed in the southeastern part of the city with many mountainous areas, which was expected to be due to environmental factors favorable to mosquito habitat.

To analyze the interaction between endemic diseases and coastal urban structures, K-means clustering was conducted by constructing a sample from 11 coastal cities (large urban areas) on Java Island with similar geographic and climatic characteristics. Variables that greatly contribute to the difference in characteristics between clusters were the water supply method, endemic outbreak, water pollution, flood occurrence, presence or absence of slum areas, access to medical facilities, number of cases of malnutrition, and the proportion of low-income families. As a result of K-means clustering, the outbreak area by climate among 15 clusters was mainly concentrated in cluster 2, and the occurrence of endemic diseases in Semarang and Jakarta was also concentrated in that cluster. Four characteristics were largely derived as the main characteristics of cluster 2. First,

the importance of water management was emphasized as the ratio of water supply through means other than open tap water such as well and spring water was high. In addition, as the incidence rate of water pollution was higher than that of other clusters, the need for comprehensive water management for water management emerged at the public health level. On the other hand, cluster 2 was found to be vulnerable to flood occurrence, and the effects of complex disasters were confirmed, and it can be said to be a result showing the relationship between the outbreak of endemic diseases and comprehensive water management. Finally, Cluster 2 shows a relatively high proportion of slum areas and low-income families, so it is necessary to consider the effects of socioeconomic factors.

According to the decision tree analysis on the interaction between coastal urban structures and endemic diseases, access to medical facilities, low-income households, and low-income household drinking supply were the most important factors in the number of outbreaks, and access to medical facilities and household drinking water supply were also the main factors.

Based on these results, the need for low access to medical facilities, low-income residents, poor water supply and sanitation facilities, and green area management was raised in major endemic-affected areas within the actual target site.

In sum, the correlation between endemic diseases and coastal city structure was confirmed, and the management of water space, water resources, and socioeconomic factors was particularly important. This is a result in line with the heat and water disasters and their effects, and suggests that endemic management is necessary in terms of complex disasters.

2) Heat

In the heat impact part, the heat island potential, an indicator of heat impact, was used to derive areas with high heat risk in the past and present, and based on this, a machine learning model was used to predict future heat risk areas. After that, through Envi-met simulation analysis, an appropriate heat mitigation strategy was

derived according to the physical environmental conditions of the target site, and a plan to improve the thermal environment was suggested.

The heat island potential analysis in Jakarta and Semarang shows that artificial heat sources such as industrial complexes were identified as a major factor in increasing the heat island potential, and this effect tended to spread to nearby residential areas. In Jakarta, the Kalideres and Kota Jakarta Barat areas showed high heat island potential due to the concentration of small industrial complexes and warehouses, which affected the residential area in the southwest. The Cilining area recorded a very high heat island potential locally due to the heat released from the medium and large industrial complexes. In Semarang, airports and factories were found to be the main causes of increasing the heat island potential. In particular, in the Bongsari area, textile manufacturing plants caused heat island, and in the Tambakharjo area, airports and plastic processing plants acted as the cause, affecting the surrounding residential areas. This shows that the heat released from industrial facilities has a decisive effect on the heat island phenomenon. Tambakrejo and Meteseh were selected as the study area in consideration of the complex disaster area. Tambakrejo is an area where industrial complexes are adjacent and factories are located, and is affected by heat island. Meteseh is a residential dense area located in the basin topography, and it was found to be an area with a high risk of heat.

Based on previous studies and Living Lab results, Cool Roof, rooftop greening, and street tree planting were derived as thermal mitigation measures that can be easily applied to the study site. The most suitable thermal mitigation plan for each environmental condition was analyzed by performing simulation under the same condition, and based on this, guidelines for effective thermal environment improvement were presented.

The effect of the thermal mitigation plan was different according to the physical environmental conditions. It was analyzed that the rooftop greening was the most effective in the residential dense area of the atypical block, and the planting of

street trees and the creation of wind roads were additionally required. On the other hand, in the residential dense area of the stereotyped block where green areas are insufficient, the cool loop showed the greatest thermal mitigation effect, and the improvement of the reflectance of buildings was more effective than the green area composition. In a low-density decentralized residential environment, rooftop greening and dense external green space creation greatly contributed to the improvement of the thermal environment. In the stereotyped block area where green areas exist, a slight temperature reduction effect was confirmed through additional rooftop greening and external green area creation. It is important to design a customized thermal environment response plan according to physical environmental conditions, and in addition, a thermal mitigation policy that comprehensively considers factors such as vegetation and green area should be established.

3) Water

In the water impact part, after deriving the flood-affected factors, a flood risk index was developed based on this, and a greenhouse axis for flood risk reduction was suggested. To this end, NDVI was first used to understand the current status of green infrastructure and greenhouse axes in Jakarta and Semarang, which are target sites, and then a flood vulnerable area was derived by constructing an FRI for evaluating the flood risk of a machine learning-based target site by using climatic and geographic factors and flood information. In the case of Jakarta, Penjaringan (park and artificial fishing grounds) and Kakung Timur (lake and townhouse sites) were derived as flood risk areas, and Penjaringan is an area located along the coast and has a lower altitude than other areas, so it was inferred that it was derived as a flood risk area due to the occurrence of sea level rise and ground subsidence. Kakung Timur is an area where flooding is judged to occur due to river flooding because the distance to the Kakung River, where river flooding, especially during the rainy season, occurs frequently, is close. In the case of Semarang, it was found that Tambakharjo (airport and artificial fishing grounds)

and Tambakrejo (low-rise residential densely populated areas), both areas are located along the coast and have lower altitudes than other areas. In other words, the elevation is lower than that of other areas and the lack of green space does not facilitate excellent storage, and tidal flooding occurs due to ground subsidence, which is classified as a flood risk area. In particular, in the case of Tambakrejo, there was a characteristic that floods occurred because of insufficient management of the drainage system in the area due to physical factors and garbage dumping. In order to reduce flooding, flood risk areas according to the climate change scenario were also predicted, and there was a common point that there was a lack of green space to reduce the flood risk in the areas that appeared as flood risk areas, suggesting the need for green infrastructure for flood reduction.

Based on the previously derived results, based on the NDVI increase scenario, a green axis customized for regional characteristics based on the core green area was presented to be considered in the creation of the green axis, and it was derived that it was necessary to consider this in urban planning and the basic plan of park green areas. Furthermore, in order to establish a green axis for flood reduction, the LID factor preference was investigated to suggest a green area development plan for flood risk reduction. As a result, it was confirmed that the application of a vegetation ditch that can solve the problem of the drainage system and flood occurrence caused by waste dumping in the area can be used first to build a green axis for flood reduction. Furthermore, in terms of resident participation, it is necessary to systematically manage flood factors through the establishment of an efficient flood reduction system, such as applying a resident-reported unauthorized dumping waste reporting system and using an automatic garbage collection drone for local environmental management for flood reduction along with vegetation ditch.

2. Coastal cities and Complex Disasters

Disease-heat-water disasters occurring in coastal cities are complex disasters, where causes and influencing factors interact, and the results or damage of each disaster may lead to other disasters.

Flooding, a representative case in terms of complex disasters, is not limited to primary damage such as property damage caused by flood occurrence, so it is necessary to consider this in a complex dimension. First, the occurrence of floods due to river flooding and drainage system problems pollutes the inundation and intake water of residential areas, causing water problems in terms of drinking water hygiene as well as intensifying the infectious disease problem. In addition to the inflow of contaminated water due to flood residual water (Stagnant Floodwater), it also increases the possibility of infectious diseases including waterborne diseases due to the increase in the number of mosquitoes, which are causes of malaria and dengue infections due to the expansion of mosquito habitats. In particular, the chain and simultaneous nature of disasters are occurring, such as secondary damage caused by confusion between skin rash and waterborne skin disease, one of the symptoms of dengue. In other words, natural disasters caused by climate change show a pattern of transformation as a starting point of social disasters and are developing into complex disasters.

The Urban Heat Island phenomenon is a phenomenon in which the temperature in the city center is higher than that in the surrounding rural areas, and this phenomenon has a direct or indirect effect on the occurrence of floods. Temperature increases due to heat islands can change atmospheric circulation, changing precipitation patterns, and leading to abnormal climates such as floods due to increased precipitation. In particular, urban areas tend to experience more extreme rainfall events and have a higher flood risk than rural areas (Lowry, 1998), which can be linked to situations in which Jakarta and Semarang are experiencing serious problems due to heat waves and floods. This can be interpreted as the result of the excessive distribution of impermeable layers such as asphalt and

concrete in the heat island areas of Jakarta and Semarang city centers, and this physical environment acts as a factor that further increases the risk of urban flooding by lowering the drainage capacity during rainfall.

In addition, the heat island phenomenon is closely related to the occurrence of dengue, a mosquito-borne disease. Rising temperatures accelerate the ecological properties of mosquitoes, especially their reproduction and growth, thereby increasing the rate of disease transmission. In addition, heat waves can increase the temperature of water reservoirs and water holes, strengthening the habitat environment of mosquito larvae, and lowering hygiene. This is in line with the results of the survey conducted, and is consistent with previous studies showing that dengue cases are concentrated in areas where the surface temperature is higher than 32°C rather than in areas such as low socioeconomic areas, high population density areas, or slums (Araujo et al., 2015).

Therefore, heat island phenomena (heatwaves), floods, and infectious diseases are easy to be recognized as individual climate disasters, but they actually interact and can affect urban environments in the form of complex disasters. Heatwaves change air circulation and precipitation patterns through temperature rise, increasing the risk of increased precipitation and flooding. At the same time, stagnant waterholes formed by the floods provide a habitat for mosquitoes, thereby promoting the spread of infectious diseases, especially dengue. At the same time, heatwaves and high humidity environments in tropical cities worsen sanitary conditions and weaken people's immunity, increasing their vulnerability to diseases.

In the case of such complex disasters, especially social disasters caused by natural disasters, it is difficult to immediately respond because the responsibility is unclear, so there is a possibility that the disaster can be intensified. In addition, disease, heat, and water have interdependence rather than individual problems, and therefore, it is judged that understanding the interactions between them in an integrated manner can reduce the risk of complex disasters and improve resilience by preparing solutions, and that the results of this chapter can be used as basic data for complex disaster response.

III. [Phase 2] Living Lab Prototype Development for Climate Change Adaptation

Summary in Local Language (Sekilas tentang Bahasa Indonesia)

Fase 2 secara intensif memanfaatkan pendekatan living labuntuk mengatasi dampak bencana kompleks—penyakit, panas, dan pengelolaan air—akibat perubahan iklim di Jakarta dan Semarang, Indonesia. Living labdirancang sebagai platform partisipatif berbasis masyarakat sehingga secara kolaboratif mengidentifikasi kerentanan, permasalahan lokal setempat, dan solusi-solusi berkelanjutan. Proses ini dilakukan dalam tiga tahap. Pada tahap pertama, identifikasi titik panas (hotspot) di Jakarta dan Semarang yang memiliki kemungkinan tinggi terjadinya bencana kompleks dilakukan dengan memfokuskan pada kerentanan geografis, iklim, dan sosial ekonomi menggunakan pembelajaran mesin dan AI. Pada tahap kedua, peneliti merancang awal bentuk living lab dengan membangun kemitraan bersama pemangku kepentingan lokal, termasuk Masyarakat setempat, pejabat pemerintah, perwakilan sektor swasta, dan akademisi. Melalui lokakarya awal dan konsultasi, peneliti mendiskusikan risiko-risiko bencana, dampak-dampaknya, serta rencana adaptasi untuk mengembangkan kerangka kerja living lab. Pada tahap ketiga, living labdioperasikan sepenuhnya di titik panas (hotspot) yang telah diidentifikasi, dengan mewadahi diskusi partisipatif, wawancara, dan kegiatan pemecahan masalah secara kolaboratif bersama komunitas masyarakat dan para pemangku kepentingan utama.

Living labmenekankan pelibatan aktor lokal dengan menyelenggarakan berbagai kegiatan yang disesuaikan dengan masing-masing kelompok pemangku kepentingan. Misalnya, kegiatan ini meliputi sesi konsultasi untuk warga, pertemuan dengan pakar dan sektor swasta, serta diskusi meja bundar bersama aktivis lokal. Kegiatan-kegiatan tersebut bertujuan untuk memahami persepsi lokal terhadap bencana, akar penyebabnya, dan dampaknya, sambil mengeksplorasi

solusi-solusi adaptif. Wawancara tambahan dengan lembaga pemerintah (misalnya, Badan Penanggulangan Bencana Daerah Kota Semarang, Dinas Tata Ruang, dan Dinas Kesehatan) mampu lebih lanjut menjelaskan efektivitas kebijakan-kebijakan yang sudah ada serta mengidentifikasi kesenjangan dalam pengelolaan bencana kompleks. Dengan membandingkan temuan lapangan dengan strategi-strategi pada program dan kebijakan pemerintah, penelitian ini memastikan bahwa solusi-solusi yang diusulkan sesuai dengan realitas lokal setempat dan kerangka kebijakan yang ada.

Melalui proses living lab, permasalahan utama di wilayah-wilayah target, yakni Meteseh dan Tambakrejo, berhasil diidentifikasi. Di Meteseh, pesatnya urbanisasi, berkurangnya ruang hijau, dan pasokan sumber daya air yang tidak stabil memperburuk masalah seperti kekeringan, pulau panas (heat island), banjir, dan wabah demam berdarah. Sedangkan di Tambakrejo yang merupakan desa pesisir dataran rendah, permasalahannya meliputi banjir yang sering terjadi akibat penurunan tanah dan gelombang pasang, sistem drainase yang tidak memadai, lemahnya pengelolaan sampah, serta kurangnya ruang hijau. Masalah-masalah ini diperparah oleh sifat bencana-bencana tersebut yang saling terkait satu sama lain sehingga tidak mudah untuk diselesaikan secara terpisah.

Berikut Tiga Solusi yang Diusulkan Berdasarkan Temuan Living Lab:

Sistem Informasi Kesiapsiagaan Bencana Berbasis Masyarakat: Sistem ini bertujuan meningkatkan akses terhadap informasi terkait bencana di tingkat masyarakat. Komponen utamanya meliputi sistem peringatan dini bertenaga surya (Solar Early Warning System/EWS) serta sarana berbasis teknologi seperti aplikasi seluler untuk menyebarkan peringatan langsung (waktu nyata) dan menyajikan panduan selama keadaan darurat.

Mitigasi Bencana Kompleks di Lingkungan melalui Penghijauan: Pendekatan ini berfokus pada peningkatan infrastruktur fisik untuk mengatasi risiko bencana-bencana yang saling berkaitan. Solusi-solusi yang diusulkan mencakup

restorasi ruang hijau, penghijauan atap (rooftop greening), serta pengembangan sistem drainase yang mengintegrasikan parit bervegetasi untuk mengelola banjir dan mengurangi dampak panas. Integrasi ruang hijau perkotaan mampu meningkatkan penyerapan air dan pelepasan panas.

Sistem Pengelolaan Sampah Terpadu: Sistem ini menangani masalah pengelolaan sampah yang berkontribusi pada banjir dan wabah penyakit. Alat yang diusulkan mencakup robot penghisap sampah Wasteshark, sistem pengumpulan sampah pintar yang menggunakan drone untuk pengelolaan sampah otomatis, serta sistem pelaporan oleh warga untuk mengidentifikasi pembuangan sampah ilegal. Solusi-solusi ini bertujuan meningkatkan efisiensi drainase dan mengurangi habitat nyamuk.

Solusi-solusi tersebut menekankan pada implementasi yang berkelanjutan dan mandiri dengan menyediakan teknologi yang didukung bantuan internasional, sekaligus membangun kerangka operasional yang memberdayakan komunitas lokal untuk mengelola dan memelihara sistem tersebut. Survei yang dilakukan terhadap 406 warga di kedua wilayah target tersebut mengonfirmasi kelayakan dan efektivitas solusi-solusi ini, dengan evaluasi positif yang menunjukkan potensi besar dalam meningkatkan respon dan ketahanan terhadap bencana.

Proses-proses living labterbukti efektif dalam menghasilkan strategi penanganan bencana kompleks melalui pelibatan masyarakat, mendukung kearifan lokal, dan memanfaatkan metode pemecahan masalah secara partisipatif. Dengan melibatkan masyarakat dan para pemangku kepentingan dalam mengenali kerentanan dan mengembangkan solusi bersama, pendekatan ini mampu meningkatkan kapasitas adaptif masyarakat secara berkelanjutan dan mandiri. Penelitian ini membuktikan bahwa living labdapat menjadi platform yang berharga untuk mengatasi tantangan iklim yang saling berkaitan, memberikan wawasan sekaligus kerangka kerja yang penting bagi kebijakan dan implementasi ketahanan serta adaptasi bencana di masa depan.

Section1. Living Lab Contents and Objectives

1. Living Lab Objectives

This study aims to identify communities in Indonesia that are expected to experience significant impacts from climate change-related diseases, heat, water management, and compound disasters and to develop climate change adaptation strategies. Additionally, it seeks to design a living lab prototype that can effectively respond to climate change by conducting living lab studies based on micro-level participatory observation in local communities in Jakarta and Semarang, addressing the causes and impact factors of compound disasters.

2. Living Lab Procedures

In the first stage, communities in climate crisis hotspots with a high likelihood of compound disaster occurrences will be selected based on the results of research on diseases, heat, and water management. At the same time, the impact factors such as diseases, heat, and water will be diagnosed, and a preliminary design for the living lab will be developed while building local partnerships to execute the plan.

To develop and operate the living lab prototype and its manual, workshops will be held in collaboration with local living lab partners and participants to define key climate change issues in the selected areas, discuss the cognitive impacts across various groups, and derive considerations and solutions for climate change adaptation. This process will include performance verification for participants, sustainability evaluation of the prototype, and the establishment of local support mechanisms. Ultimately, the results of the prototype operation will be used to develop a handbook, manual, and guidelines, maximizing their applicability for stakeholders and enabling the expansion of the outcomes.

3. Expected Outcomes

This research aims to establish an integrated climate change adaptation platform through community-based living labs and to provide a foundation for effective climate change adaptation measures for Indonesia and other countries, based on intensive participatory observation and long-term empirical data collection. Furthermore, by actively involving Indonesia in the design and operation of the living lab, the study is expected to enhance the country's capacity to develop autonomous climate change response measures.

Section2. Living Lab area

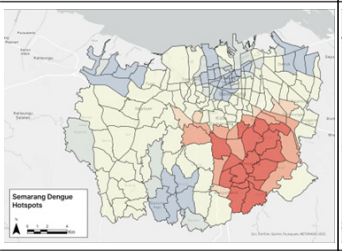
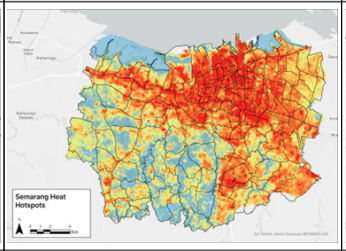
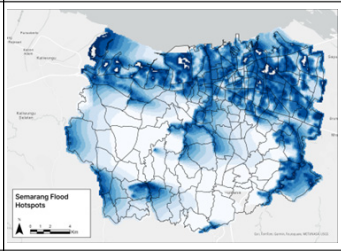
1. Target City

Semarang, Indonesia, is a major city with a population of 1.5 million and the capital of Central Java Province. Located in the lowlands along the northern coast of Java Island, it is vulnerable to infectious diseases like dengue, heat-related illnesses caused by the urban heat island effect, and water-related disasters such as droughts, floods, and land subsidence. The Indonesian government is currently making efforts to address disease, heat, and water management in Semarang, including releasing Wolbachia bacteria-infected mosquitoes to curb the spread of dengue and constructing protective embankments.

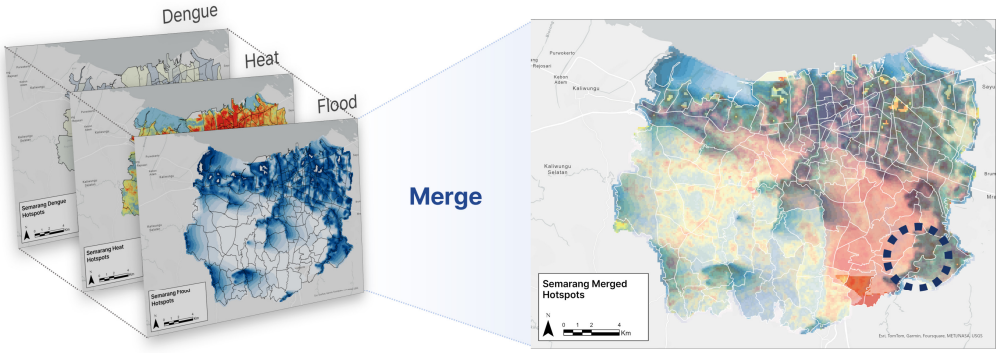
Meanwhile, Jakarta, located in a wetland area facing the Java Sea and traversed by 13 rivers, is experiencing challenges such as sea level rise and inadequate infrastructure due to climate change. Land subsidence caused by groundwater use is also evident, with North Jakarta sinking by 25 cm annually, and predictions suggest that 95% of the area could be submerged by 2050 (BBC, 2018/08/15). The climate crisis exacerbates Jakarta's environmental vulnerabilities, with expected increases in surface temperature, rainfall, and extreme weather patterns, making disease, heat, and water management increasingly difficult.

2. Target Village

To consider the disaster impacts of climate change, this study selected Semarang as a living lab site in the Jakarta-Semarang coastal urban belt due to its easy access to data and favorable local partnerships. During the first phase of the empirical study, we identified hotspots where disease, heat, and water (flooding) management needs were intensified and overlapped to present compound disaster hotspots. The analysis revealed that disease, heat, and water are all common to the southeastern region of Semarang, and the individual characteristics of each disaster hotspot are as follows.

Diseases	Heat	Water
		
Residential areas adjacent to forests	City centers and residential areas	Waterfronts (coastal and riverine) and lowlands

[Figure 51] Hotspot analysis results by disaster

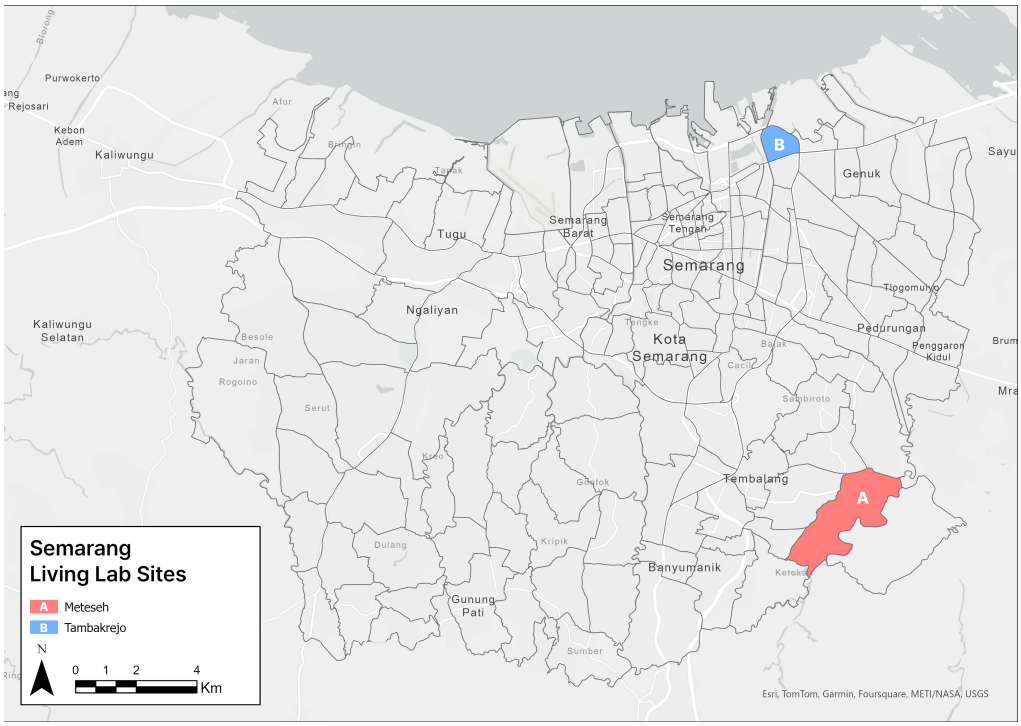


[Figure 52] Living Lab destination hotspot identification process

Based on these various disaster hotspots, we aim to derive comprehensive and diverse types of living lab prototypes. We plan to implement living labs in multiple locations, not just one, Meteseh, where three disasters overlap was selected as the first living lab site.

Meteseh is a Kelurahan (village) located in the southeastern part of Semarang, with a low-density residential neighborhood adjacent to forests and a topographical feature of hills bordering a river. It is one of the most populous districts in Semarang, ranking 9th in population among Semarang's 177 villages as of 2020, with a projected population of 24,134 in 2023. Metese is currently a fast-growing area within Semarang and is a relatively new development.

Also, Tambakrejo, a common hotspot of heat and water with Metese was selected as the second living lab site. Tambakrejo is located on the northeastern coast of Semarang.KelurahanIt is a mixed-use area located in a low-lying area. There are concerns about ground subsidence as the area is not only a residential area but also has factories, and groundwater usage is high. Through data from the Indonesian Disaster Management Agency and quantitative analysis results, it was confirmed that this is an area prone to flooding. Especially here, there are many low-income and vulnerable people living there, and slum housing has been formed. The disaster-prone nature of the area made it a suitable location for a living lab. The suitability of the target site was reviewed by key stakeholders in Semarang through preliminary workshops as well as local Indonesian partners.

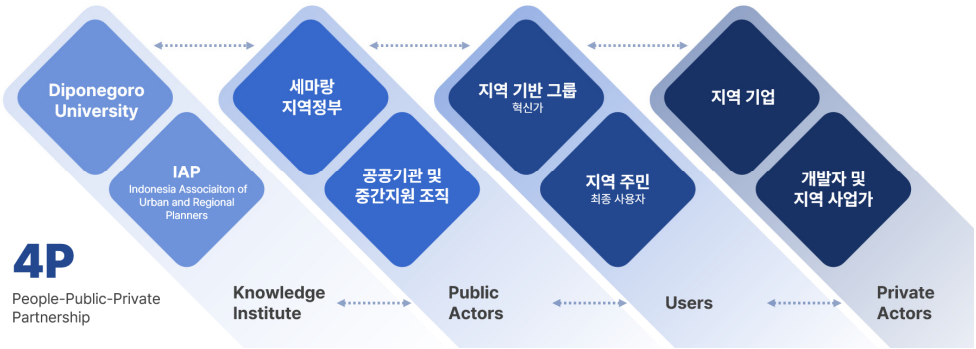


[Figure 53] Semarang Living Lab Target Areas

Section3. Living Lab Pre-design and Partnership Building

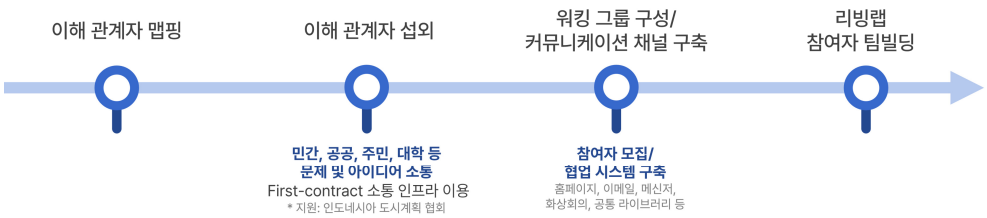
1. Partnership Building

A local multi-channel (4P) partnership was established to build the Living Lab, which included the public sector, private sector, academia and research, and user groups. Key stakeholders in the multi-channel partnership include Semarang (community), Diponegoro University (academia), Semarang City Hall (public), and Environmental Resource Management (private).



[Figure 54] Establishing local multi-channel (4P) partnerships to build a living lab

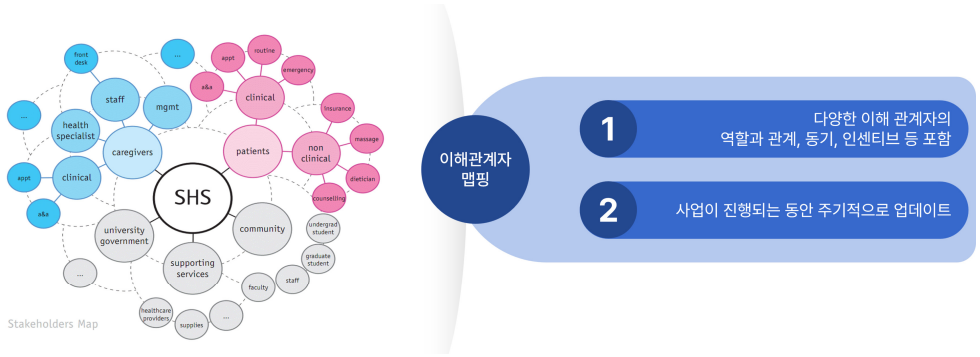
In addition, we conducted stakeholder mapping, stakeholder recruitment, working group organization and communication channel establishment, and team building of living lab participants to build local multi-channel (4P) partnerships.



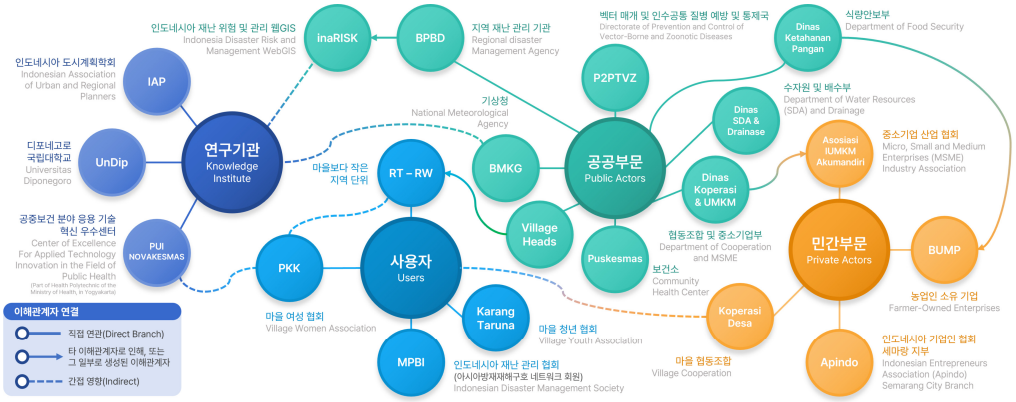
[Figure 55] The process of building local multi-channel (4P) partnerships

Participants in the living lab project were recruited through local partnerships, and the researchers and their research partners from the other country, Prof. Iwan

Rudiarto and Prof. Wiwandari Handayani, participated as co-facilitators. Through consultation meetings with these local partnerships, the preliminary design of the living lab was validated and adapted to the local context, and a prototype was co-developed. Stakeholder mapping was also conducted to establish a local multi-channel partnership (4P) of research institutions, users, public and private sectors.



[Figure 56] Example of stakeholder mapping



[Figure 57] Partnership primary mapping

2. Living Lab Pre-design and Implementation Process

The pre-design and implementation process of the Living Lab went through the following steps.

First, an open platform was built through stakeholder mapping and recruitment from January to April, and the Korean and Indonesian teams held regular meetings and built partnerships step by step through mutual feedback. At the same time, from March to April, the Korean and Indonesian teams identified hot spots based on the diagnosis results of diseases, heat, and water, which are the causal factors of the climate crisis, and prepared for fieldwork.

Then, on June 3, we held an online preliminary workshop with the Korean and Indonesian teams and key stakeholders in Indonesia to define key climate change issues in the target areas based on the research and discuss the perceived impacts of each group of residents. We also discussed considerations and solutions for climate change adaptation, and finally shortlisted the target areas for the Living Lab.

In the preliminary living lab design process, which began in June, one living lab topic for each destination was identified based on workshops and research, and the Korean and Indonesian teams conducted the first internal evaluation to check for feasibility and consistency. Based on this, we conducted stakeholder consultations in July, conducting focus group interviews with residents, researchers, academics, industry experts, and government officials to develop and review preliminary Living Lab designs. Ultimately, we co-developed a prototype with local partnerships around the preliminary design, and iteratively tested it in the real world, reflecting feedback and optimizing it.



[Figure 58] Living Lab pre-design and process

Section4. Pre-workshops and Seminars

1. Preliminary Workshops

1) Overview of the Preliminary Workshop

Based on the Phase 1 research, a preliminary workshop was held to ensure the local relevance of the findings and to discuss the perceived impacts of climate change on different groups along with key local climate change issues. It was held on June 3, 2024, from 12:00 to 13:30, and was attended by 15 Korean and Indonesian researchers and 16 Indonesian key stakeholders. In particular, the Indonesian key stakeholders included experts from various fields such as public, private, and academic sectors, as shown in 〈Table 36〉.

〈Table 36〉 Key Indonesian Stakeholders Attending the Preliminary Workshop

연번	성명	소속	직책
1	Ahmad Muhajirin	Regional Planning and Development Agency of Semarang City (Bappeda)	Representative
2	Nur Wachid	Public Works Department of Semarang City (DPU)	Representative
3	Fauziah RA	Public Works Department of Semarang City (DPU)	Representative
4	Arum N.A.	Public Works Department of Semarang City (DPU)	Representative
5	Abdul Hakam	Health Department of Semarang City (Dinkes)	Head of Dept.
6	Sidiq Disperkim	Housing and Settlement Areas Department of Semarang City	Representative
7	Fetri	Environmental Agency of Semarang City (DLH)	Representative
8	Safrinal Sofianidi	Environmental Agency of Semarang City (DLH)	Representative
9	Herlina Nia	Regional Research and Innovation Agency of Central Java Province (Brida Jateng)	Representative
10	Ardian Bakhtiar	Regional Research and Innovation Agency of Semarang City (Brida Semarang)	Chair
11	Dr. Muhammad Helmi S.Si. M.Si.	Center for Coastal Rehabilitation and Disaster Mitigation Studies (CoREM)	Chair
12	Arif Ganda Purnama S.T. M.T.	Association of Urban and Regional Planners of Central Java Province (IAP)	Chair

연번	성명	소속	직책
13	Mega Anggraeni S.T. M.Si.	Initiative Foundation for Climate Change (IKUPI)	Manager
14	Gregorius Jasson	Kota Kita	Director
15	Rizqa Hidayani	Kota Kita	Director
16	Silvania Utami	Kota Kita	Director
17	Raka Whisnu Suryandaru S.T. M.Sc.	PT Krida Karya Advisory	Director

2) Key Discussion Points

In the pre-workshop, each research team presented their Phase 1 findings, along with an overall introduction to the study to key stakeholders in Indonesia. In the first half of the pre-seminar, the teams discussed the practicalities and gaps in the research based on their findings.

In terms of diseases, the other endemic disease, leptospirosis, which is currently endemic in Semarang, was also considered as it is closely related to sanitation and has caused 18 deaths in northern Semarang from January to March 2023. We also analyzed the pattern of dengue hemorrhagic fever outbreaks in Semarang from 2016 to 2023 and found that increased humidity in the first rainy season, March-May, paralleled the pattern of increased dengue cases, which is relevant to this study, which examines the relationship between climate change and disease.

In the case of heat, it was suggested that the impacts of the most heat-affected communities be identified, and that consideration be given to how living labs can contribute to minimizing impacts. In the case of water, Mercy Corp, a non-profit humanitarian aid organization, through its Asian Cities Climate Change Resilience Network (ACCCRN), is building evidence and conducting a follow-up program in Semarang, and discussed that climate resilience in Semarang and along the northern coast of Java is very local and depends on specific circumstances, noting that the flooding in Semarang is not only due to climate change, but also to complex and permanent inundation caused by land subsidence, urban dynamics, and infrastructure.

In the second half of the pre-seminar, we proposed Meteseh, Rowosari (a village with similar conditions adjacent to Meteseh), and Tambakrejo as potential sites for the Living Lab, and reviewed their suitability and feasibility with key Indonesian stakeholders. As a result, all three sites were considered suitable by most participants, and the idea of running multiple Living Lab prototypes was welcomed. In particular, Mercy Corps will be running Living Labs in certain areas of Babon and Tuntang in Semarang, and suggested future collaborations.

3) Additional written feedback

To overcome the time and physical limitations of the online pre-seminar, written feedback was solicited from each participant to share their knowledge of complex disasters in Semarang, validate the research findings and the suitability of the selected Living Lab sites for the region, and generate Living Lab ideas.

Through written feedback, all participants reaffirmed the relevance of the research findings and offered suggestions that could be applied in the finalization phase of the Phase 1 study. They also reaffirmed that all of the proposed Living Lab sites are hotspots for multiple disasters, and recommended Meteseh and Tambakrejo as possible sites. In particular, Meteseh is a newly developed and previously unstudied site, despite its frequent disasters. On the other hand, it was pointed out that Tembalang, which includes Meteseh, is less prone to flooding than the coastal areas, and therefore has less local attachment than Tambakrejo due to the large influx of new people due to ongoing urbanization, and therefore less understanding of the core of the problem.

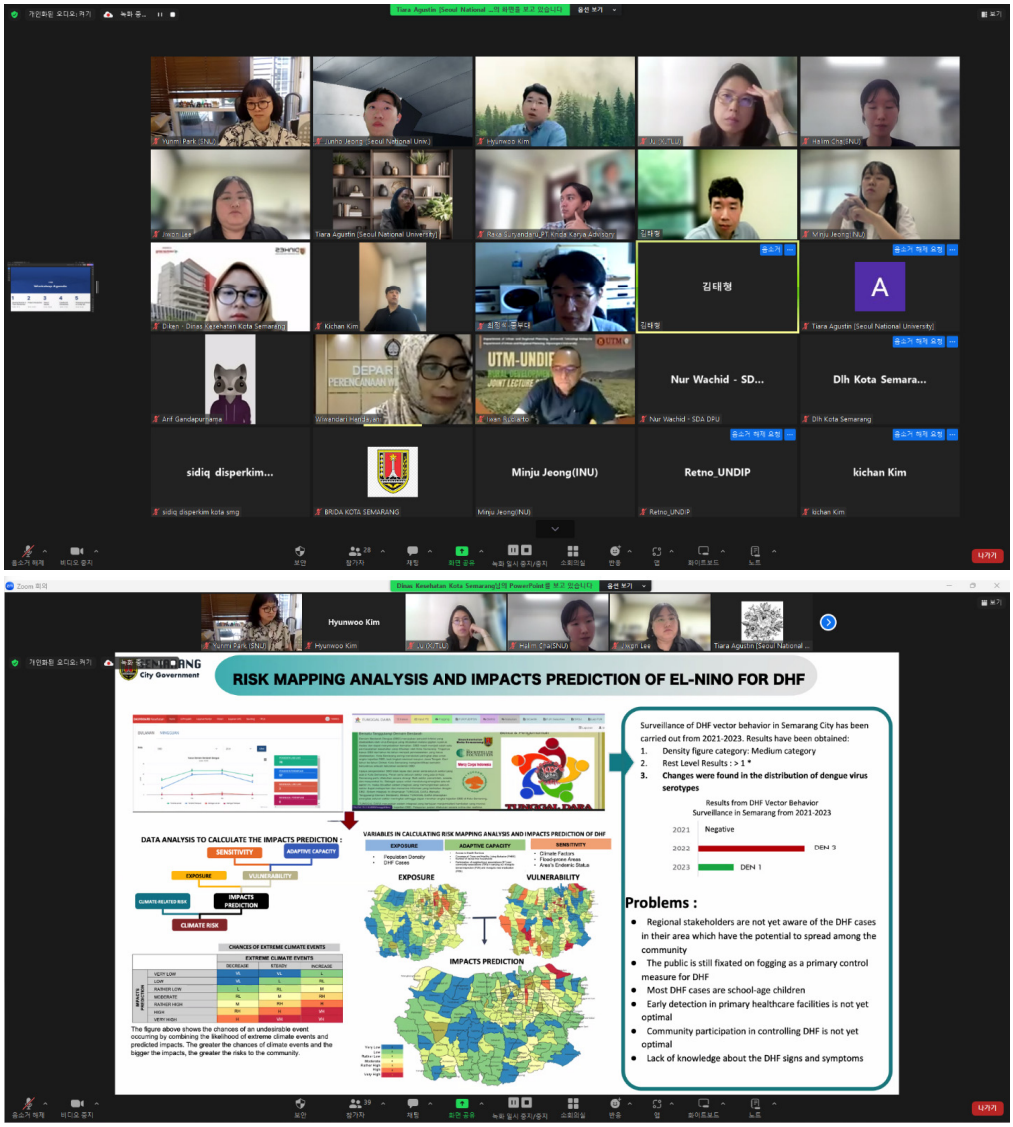
A variety of other living lab ideas were presented, with Pedurungan District, Genuk District, and Kaligawe being suggested as possible living lab destinations. Most of these are community-based living labs that respond to the climate crisis through the spirit of Gotong Rojong, a collaborative effort where members work together to achieve a common goal. Specifically, community-level responses were proposed to combat the effects of climate change and reduce carbon emissions through

drainage pipe installation and cleaning, and waste management based on recycling. In addition, it is proposed to consider non-structural solutions simultaneously with structural solutions, and to coordinate with Semarang urban planning and infrastructure.

4) Outcomes

The preliminary seminar allowed us to review the local relevance of the Phase 1 study and confirm that the individual disaster hotspots identified in the Phase 1 study reflected the actual situation. This ensured the credibility of the study and organized the direction of the remaining quantitative analysis. We confirmed the suitability and feasibility of the candidate sites for the Living Lab, and based on this, we finalized the target sites. The significance of the site selection process is that it reflected local perspectives and enabled the development of a more localized and feasible living lab prototype.

By establishing and developing relationships with key Indonesian stakeholders involved in this study, we were able to lay the foundation for building relationships with stakeholders that could lead to further development of the living lab prototype and subsequent research. In addition to complementing the results of the quantitative analysis, it was a major achievement to solicit and secure the provision of data that was needed for the development of the living lab prototype but was not readily available online.



[Figure 59] Pre-Seminar Online Meeting

2. SNU EPI & KOICA Invitational Seminar with Semarang City Mayor on Urban Disaster Responses

1) Overview of Seminar

Among the participants of the preliminary seminar, Dr. Abdul Hakam, the Director of Health of Semarang, and a group of government officials visited the country to attend an international event, and it was suggested that further discussions be held, so a visit seminar was organized on June 25, 2024, from 20:00-22:00 at the Graduate School of Environmental Study, Seoul National University, in a hybrid of a global hall and online. This allowed for follow-up in-depth discussions related to the preliminary workshop.

2) Key Discussion Points

The discussion began with an introduction to the various climate change-related programs being implemented by the Semarang Ministry of Health. One of them is a program to develop vulnerability maps using smartPLS based on the WHO's 12 categories, and 15 climate-related disease impact risk assessments have been conducted in the past two years. In this regard, there are examples of analyzing the association of TBC diseases with climate variables to create vulnerability and exposure maps for each village, and analyzing the causes of diseases such as diarrhea at the village level using the "Papandayan" initiative for food, water, and air quality sampling and testing.

This, coupled with regular data collection through 39 health centers (Puskesmas), updated and validated on a monthly basis, provided the rationale for using dengue as a proxy measure of climate-impacted diseases, especially in the context of the climate change. Data over the past decade has shown that dengue incidence increases with decreasing temperatures, while warmer temperatures have a 2-3 month delayed impact. This means that dengue can be used as a good proxy for climate-impacted diseases. In addition, social survey data and micro-level data are

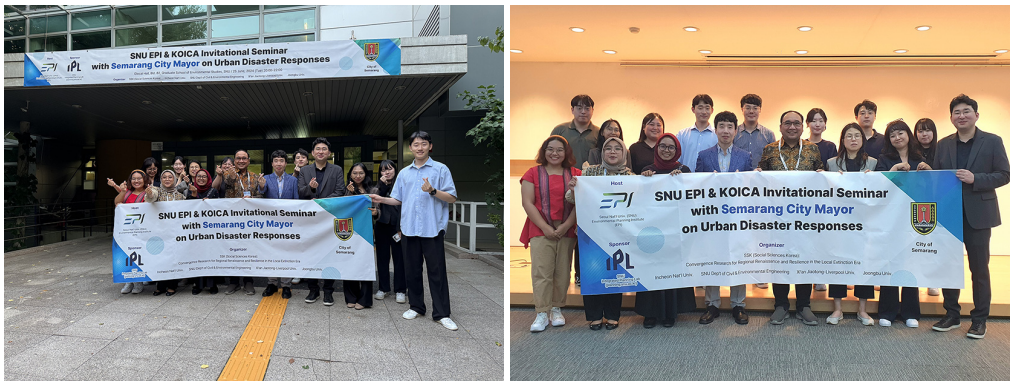
partially available, and data coverage for sanitation and hygiene (PHBS and STBM) is currently at 30%, with plans to continue and expand this coverage.

The discussion also included further discussion on the issue of land subsidence in Semarang and whether and how to plan for future development. Currently, the rate of land subsidence in Semarang is 5-7 cm per year, and innovative programs such as the bangerfolder system and embankments are being implemented to address flooding. The development plan focuses on the northern part of Semarang, where residents have low economic capacity and are vulnerable to disasters, and aims to strengthen economic activities and social interventions to improve adaptive capacity. In addition, a mangrove protected area is located in the northwest of the district, which was also discussed.

Finally, in relation to the Semarang Living Lab site, additional notes were made that both neighborhoods (Meteseh and Tambakrejo) are prone to frequent flooding, have a high rate of thieves, are densely populated, and have poor sanitation. This suggests that a broader approach is needed to improve sanitation and change habits and lifestyles in the region.

3) Outcomes and meaning

The discussions covered issues related to climate change, urban development, and health in Semarang in depth, adding to the discussions that were not covered in the pre-seminar. We were able to gain new insights on health and wellness in Semarang, including specifics on dengue and leptospirosis. We also learned about urban development and water management policies in Semarang, which helped us understand the context of Semarang and the Living Lab site, and strengthened our collaboration in providing data and developing the Living Lab prototype.



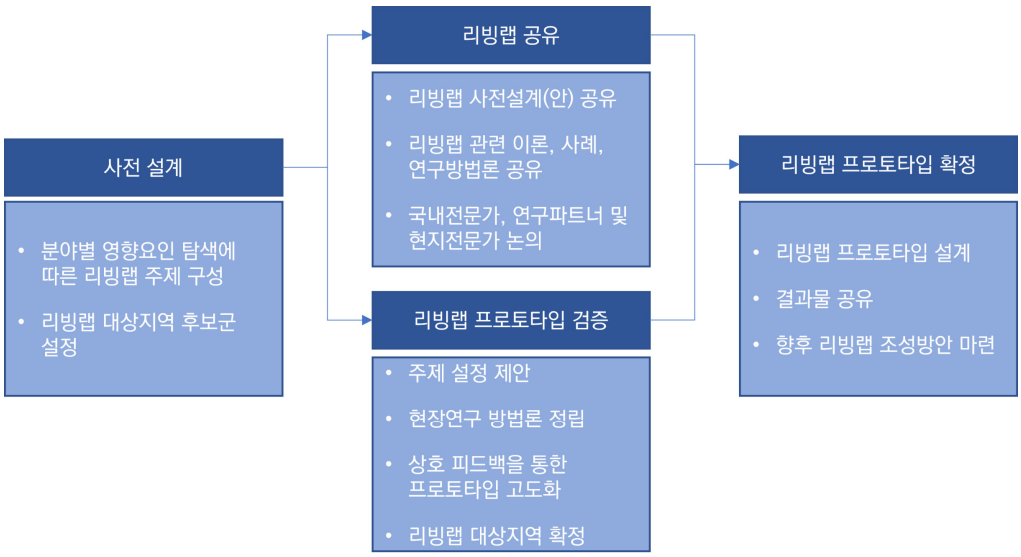
[Figure 60] Pictures of Seminar

Section5. Fieldwork for Living Lab Prototype Operation

1. Overview

In order to develop the living lab prototype, joint workshops were held with local partnerships and participants to define the key climate change issues in the selected regions. After discussing the perceived impacts of different groups, adaptation considerations and solutions were identified, focusing on the establishment of ICT-based climate change disaster notification systems and shelter selection. The main purpose of developing the Living Lab prototype is to iteratively test the ideas generated from this process in a real-world environment and improve them based on feedback from various users.

After the end of the study, the living lab prototype will be expanded and operated as a real living lab by Indonesian research partners or through follow-up research, and will be utilized for various policy and planning experiments and empirical data to prepare climate change adaptation measures at the community level.



[Figure 61] Living Lab Prototype Development Procedure

2. Plan and Preparation

1) Overview and Schedule

To develop the Living Lab prototype, six researchers and two external experts traveled to Semarang and Jakarta, Indonesia from July 13 to July 25, 2024 to conduct fieldwork. In Semarang, we developed and validated the Living Lab solution with key stakeholders and the community in three phases, and planned a timeline for sharing and evolving the solution with key organizations.

In Jakarta, the Living Lab solution was developed and additional fieldwork were conducted to identify vulnerabilities and solutions to multi-hazard disasters in the context of Indonesia's coastal cities. Through fieldwork, we developed a locally optimized Living Lab prototype and shared our findings to improve and refine the prototype.

〈Table 37〉 Fieldwork schedule

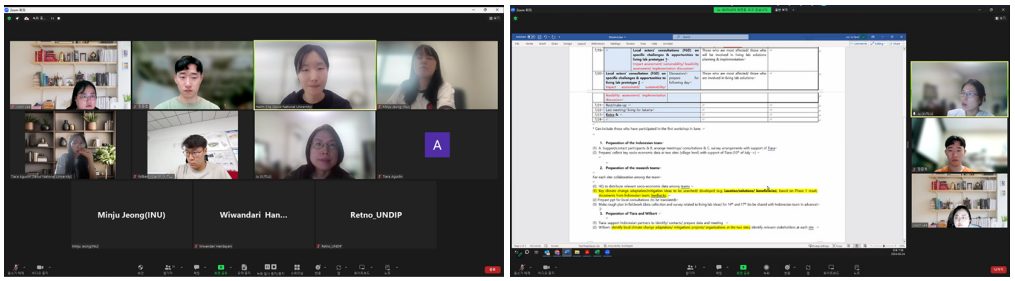
Date	Main schedule	Contents and Notes
7/13 (Sat)	Transit (Incheon → Jakarta → Semarang)	Early departure of one member of the research team (10th to 13th)
7/14 (Sun)	Living Lab site visit 1 (Meteseh) Living Lab Preparation Meeting	
7/15 (Mon)	Meeting 1: Local resident consultation 1(Meteseh)	Holding meetings to develop and develop living lab ideas with local partners (Diponegoro University) and local stakeholder representatives (village women's groups, etc.)
7/16 (Tue)	Living Lab site visit 2 (Tambakrejo) Meeting 1: Local resident consultation 2 (Tambakrejo)	
7/17 (Wed)	Interviews with major organizations and experts	Visit major living lab-related institutions to share research results and confirm issues identified in Meeting 1
7/18(Thu)	Meeting 2: Meetings for experts and organizations (Living Lab Development)	Discussion for co-development of living lab prototype
7/19 (Fri)	Meeting 3: Local Activist Focus Group Discussion (FGD) (Living Lab Application)	Discussion of impact assessment, sustainability and feasibility assessment, and application among the most affected people and local actors who will participate in planning and application of living lab solutions.

Date	Main schedule	Contents and Notes
7/20 (Sat)	Workshop 1: Summary and discussion of results	
7/21 (Sun)	Workshop 2: Writing the draft of Living Lab solutions	
7/22 (Mon)	Meeting with key organizations (Semarang City Health Department, DINKES) Transit (Jakarta → Semarang)	
7/23 (Tue)	Workshop 3: Development of Living Lab Solutions and Site visit	
7/24 (Wed)	Transit (Jakarta → Incheon)	Arrival at 25th

2) Pre-inspection

① Identifying Living Lab Ideas and Engaging Local Stakeholders through Mutual Feedback

In order to prepare for the project, we held frequent meetings with local researchers and local partners to discuss ideas with specific living lab target communities. In particular, we went through a process of deriving and developing joint living lab ideas to integrate and organically reflect each team's findings, and reviewed previous studies and cases to identify innovative and localized living lab ideas. Then, based on the research results of each team, a list of local stakeholders was jointly compiled and recruited to participate in the living lab prototype development process.



[Figure 62] Preparation Meeting for Fieldwork

② Site inspection and preparation

To ensure a smooth fieldwork, one of the researchers departed the country early to conduct pre-inspection and preparation work. In the site inspection, we checked the meeting venue in the Living Lab destination and checked the preparation status of the local partner, Diponegoro University. In addition, physical invitations were sent to participants, including local residents and experts, and preliminary facilitator training was conducted with the local partner.



[Figure 63] Local partner review meeting



[Figure 64] Meeting venue review

3. Main Results

1) Site Visit

The fieldwork were conducted to verify the consistency of the hotspot findings for each disaster in the study area from the quantitative research in Phase 1 and to gain a better understanding of the study area. The fieldwork were centered on hotspots and were accompanied by local partners to conduct on-site interviews with local residents about the destination and hotspots.

① Meteseh (July 14th, 2024.)

In Meteseh, we confirmed the consistency of the quantitative findings by visiting RT08/RW22[3)] which was identified as a common hotspot for all three disasters, and

RT03/RW10, which was identified as a disease hotspot, and found that the hotspots were indeed vulnerable to frequent flooding and dengue. Interviews and participatory observations with local residents revealed that the lack of disaster prevention infrastructure in the area caused flood damage, but public support was lacking. We also identified frequent garbage dumping as a new problem, and visited a community with excellent planting activities to solve the heat island phenomenon as a case study, and confirmed that it is difficult to use water and sewage due to topographical factors.



[Figure 65] Meteseh site visit



[Figure 66] A levee that collapsed due to flooding and was repaired by local residents

② Tambakrejo (July 16th, 2024)

In Tambakrejo, we visited PT Javaprima Abadi (a coffee factory), Jl. Kali Tenggang, and Jl. Purwosari, which were identified as heat island hotspots, to confirm the consistency of the quantitative findings, and confirmed the heat island factors in the identified hotspots. In addition, through on-site interviews and participatory observation with local residents, we identified flooding and garbage as major problems in the area. In particular, we found that many households use groundwater instead of using public water due to frequent flooding of roads and low price accessibility.

3) RW (Rukun Warga), RT (Rukun Tetangga): A unit of administrative authority in Indonesia, but the smallest village unit. RT is a sub-unit of RW.



[Figure 67] Tambakrejo site visit



[Figure 68] Garbage flowing into the drain



[Figure 69]
Roads prone to frequent flooding



[Figure 70]
House with raised door height due to flooding

2) Meeting 1: Local residents consultation

① Overview and Process

In Meeting 1, we invited representatives of the village, including the village mayor, the president of the women's organization (PKK), and the president of the youth organization, to identify the causes and impacts of the climate crisis and discuss the Living Lab solution ideas that they believe are needed. Led by a facilitator, residents used maps to map the areas affected by the disasters and where they would like to see solution ideas applied, and the results were used to identify local Wicked Problems and develop solutions.

The meetings lasted 1 hour and 45 minutes in each region, and went like this First,

after a brief introduction to the purpose of the meeting and the project, the research team presented the impacts and causes of the village's complex disasters and potential living lab ideas based on quantitative analysis and site visits. Participants were then randomly divided into two groups and led a group activity based on community mapping.

In the group activity, participants mapped their perceptions of disaster impacts, experiences, and living lab ideas on a map of their village. Different colored post-it notes were used to symbolize each disaster (endemic: yellow, heat island: red, flood: green) (Figures 71 and 72). First, in terms of impacts, participants were asked to qualitatively assess how the flood, heat island, and disease had changed their daily routines and overall quality of life, including economic activities and social gatherings, and to quantitatively assess the extent to which it had. At the level of experience and current practices, we identified different ways or local practices that communities have adapted to complex disasters (qualitatively) and what works best (quantitatively). Finally, we assessed the relevance of the proposed living lab idea and how it could be linked to existing practices.



[Figure 71]
Meeting 1 Group activity (Meteseh)



[Figure 72]
Example of Meeting 1 results (Tambakrejo)

Finally, each group shared their discussions with the group as a whole, and a discussion was held on the relevant content. A tabular representation of this process was operated as 〈Table 38〉.

〈Table 38〉 Meeting 1 Process

Schedule	Detail	Contents	Time
Introduction	-	- Introduction of the purpose of the meeting and participants - Brief introduction of the project	10mins
Presentation	-	- Sharing the impact and causes of complex disasters in villages based on quantitative analysis - Presenting potential living lab ideas derived from site visits	20mins
Discussion on "Problem - Solving Suitability"	Explanation of the Process	- Divide participants into two groups - Explain the discussion process and methods	5mins
	Group Activity	Participants mapped the problem (complex disaster), impact, experience, and perception of the Living Lab idea using post-it notes - (i) Impact : What changes have there been in daily life (economic activities, social gatherings) and overall quality of life due to floods, heat islands, and diseases (qualitative) and how severe are they (quantitative)? - (ii) Experience/Current Practice: What are the various ways or local practices (qualitative) that the community has adapted to the challenge? What is most effective (quantitative)? - (iii) Perception of the Living Lab idea: Whether the idea presented is appropriate, how can it be related to current practices?	40mins
	Discussion	- Share and interact with each group's results	20mins
	Final proposal and Conclusion	- Summarize and conclude the discussion	10mins

② Main Outcomes in Meteseh

[Climate Change and Impacts]

According to Metetseh residents, the Meteseh neighborhood has become increasingly hotter since 1993, which has caused discomfort in the living conditions. There have been attempts to reduce the temperature, especially through tree planting, and many households have seen a reduction in temperature. However, it was also found that there is still a problem of rising temperatures in the area.

[Water Quality]

In Meteseh, wells were mainly used in the past, but the lack of proper drainage has led to water stagnation and made the wells unsuitable for drinking, mainly in the Dinar area. Meanwhile, residents in most neighborhoods, not just Dinar, are experiencing deteriorating water quality, which is likely to lead to health problems.

[Flooding]

Residents of Meteseh assessed that flooding limits their activities and causes economic losses. However, since 2014, no action has been taken to address the flooding problem, particularly the lack of improvements to the drainage system.

[Health]

In terms of health, residents of Meteseh reported that heat-related illnesses (fever, flu) are occurring and that preventive measures are inadequate. In particular, they noted that although health education is available in the community to prevent diseases, it lacks effective distribution and implementation.

③ Main Outcomes in Tambakrejo

[Climate Change and Heat]

Residents of Tambakrejo reported an increase in dehydration and a decrease in outdoor activities due to rising temperatures. They also reported increased electricity consumption and health problems, including coughs and colds, due to the heat. Attempts have been made to reduce the heat in the homes that contribute to these problems through urban agriculture and greening, but these have been limited by the difficulty of growing plants due to the effects of seawater.

[Flooding]

Flooding was still a serious problem for residents, even though the government was able to respond quickly to floods. In particular, floods frequently caused flooding of residences and interruption of power and water supply, which caused

inconvenience to residents. However, residents pointed out that despite various efforts by the government, such as raising roads and installing drainage pumps, the flood problem has not been completely solved.

[Disease and Helalthcare]

Diseases such as dengue remain a problem in Tambakrejo, which residents try to prevent through mosquito larvae surveillance and health checks. However, mitigation measures such as fogging proved to be less effective.

[Community and government responses]

While the government has undertaken various efforts to address the flooding and heat, communities have expressed that they still need more support and resources, and that they need to be empowered through economic support and education.

3) Meeting 2: Meetings with experts

① Overview and Progression

Meeting 2 was organized to invite industry and expert groups, such as local companies or experts, engineering firms, or consulting firms involved in climate change adaptation and mitigation solutions or working on related living lab projects, to examine and discuss the feasibility, feasibility, and innovation of living lab solution ideas. In Meeting 2, two people from Mercy Corps and one person from IKUPI, who have a lot of experience in related projects among non-profit organizations, discussed the feasibility and feasibility of the living lab solution ideas developed based on the results of Meeting 1.

The meeting lasted for a total of 1 hour and 5 minutes. After a brief introduction to the purpose of the meeting, the participants, and the project, the research team shared the results of the 'exploration' of the key issues in the target locations and the current practices of the end users (communities). The expert group shared institutional experiences based on past project evaluations to learn from each

other. Finally, the group focused on transforming the living lab solution idea into a functional prototype, examining process innovation, key features, optimal environment, and market feasibility.

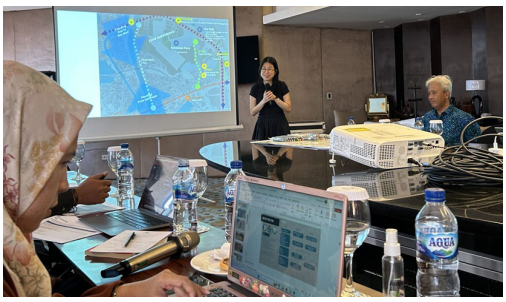
A tabular representation of this process is shown in 〈Table 39〉 below.

〈Table 39〉 Meeting 2 process

Schedule	Contents	Time
Introduction	- Introduction of the purpose of the meeting and participants - Brief introduction of the project	10mins
Sharing Living Lab Ideas	- Sharing the results of 'exploration' of the main issues in the target area and current practices of end users(community) (research team) - Sharing the experience of the institution (experts - e.g. based on evaluation of past projects)	15mins
Discussion on "Problem - Solving Suitability"	* Focus on turning concepts into functional prototypes - process innovation, key features, optimal environment, market feasibility	40mins



[Figure 73] Meeting 2



[Figure 74] Meeting 2

② Main Results

[Responding to local issues and complex disasters]

In the case of Tambakrejo, both organizations identified that the area has a high concentration of government projects, and that malnutrition and stunting associated with flooding are significant. In particular, they found that flooding increases the amount of money households have to spend, which adversely affects health and food. Flooding exacerbates stunting and immune compromise in pregnant women and children, and requires sustainable interventions at the

household and community level.

Ecological, social, and economic changes are expected after the construction of seawalls to prevent flooding, and the issue of land loss (changes in flooded and dry areas) due to the changing topography of the region is also important to address.

[Solutions]

Seawater desalination: Saltwater intrusion in the Tambakrejo area has increased the salinity of the soil, and the team proposed seawater desalination as a solution. Experts confirmed that desalination can act as a filter for contaminated areas and is suitable for industrial areas such as Tambakrejo, but there are concerns about whether the technology can be understood and practically used by the community, with economic sustainability being a key issue.

Automated trash collection drones: Experts noted that drones are effective at collecting trash, but there are concerns that the complexity of the technology could make it difficult for communities to understand and maintain.

Disinfection and quarantine: Low-cost disinfection programs can be cost-effective, but questions were raised about the ability of communities to understand and sustain them.

Rainwater harvesting systems: emphasized the need to find ways for residents to understand and build them themselves.

4) Meeting 3: Local Activists Focus Group Discussion (FGD)

① Overview and progress

Meeting 3 was organized to deepen the understanding of the impact of multiple disasters in the village as perceived by the community, focusing on the hotspots identified in the quantitative research through Focus Group Discussion (FGD). The purpose of this meeting was to check the feasibility, scalability, usability, and

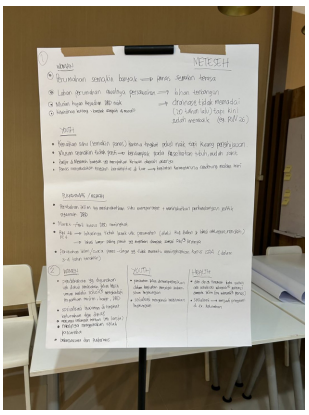
sustainability of the Living Lab solution ideas from a local perspective and to identify strategies for implementation.

Unlike the previous meetings 1 and 2, Meeting 3 was held in the same space, separating the two destinations, and under the leadership of the facilitator, maps were used to map the affected areas and the areas where solution ideas could be applied. In Meteseh and Tambakrejo, 3 representatives from women's organizations, 3 representatives from local health centers (Puskesmas), 3 representatives from youth organizations, and 18 participants in total participated in 4 rounds of FGDs on the impact of the complex disaster on hotspots in the target areas and Living Lab solution ideas.

Meeting 3 was divided into four rounds: Rounds 1 and 2, Round 3, and Round 4. Rounds 1 and 2 were plenary discussions where participants were divided into groups by destination to identify perceptions of changes and impacts. In terms of disaster experience, Round 1 assessed the changes in flooding, heat islands, and diseases experienced by participants and the region over the past few years and the impact these changes have had on daily life and livelihoods, while Round 2 looked at climate change perceptions, identifying discussions within participants and the region about the causes and impacts of climate change.



[Figure 75]
Meeting 3 Round 1, 2



[Figure 76]
Meeting 3 Results of Meeting 3 Round 1, 2

Rounds 3 and 4 consisted of FGDs, where participants shared their specific perceptions of hotspots and their ideas for living lab destinations and solutions. In Round 3, participants were divided into three groups (public health workers, women's organizations, and youth organizations) in separate rooms for each destination and provided with a map. On the maps provided, each group mapped what they considered to be hotspots within the destination, identifying and mapping how communities have adapted to flooding, heat islands, and disease, and whether there are traditional practices or knowledge that have helped them cope. Each group's mapping results were shared with other groups in the destination for mutual learning.

Finally, in Round 4, all participants were gathered in one room again to discuss the Living Lab destination and solution ideas. In particular, they suggested areas and directions for solution application, evaluated whether they would like to use the solution when it is introduced, and identified challenges in specific implementation.

〈Table 40〉 Meeting 3 process

Schedule	Contents	Time
Introduction	- Introduction of the purpose, method and participants of the meeting	10mins
Round 1	**Complex disaster experience** - Changes in floods, heat islands, and diseases experienced by participants and the region over the past few years - Identify the impacts of these changes on daily life and livelihoods	25mins
Round 2	**Climate change awareness** - Identify discussions within participants and the region on the causes and effects of climate change	
Round 3	**Hotspot awareness** [3-1] Identify hotspot locations [3-2] Community adaptation to floods, heat islands, and diseases	20mins
Round 4	**Living Lab target areas and solution ideas** - Application areas and directions of solutions - Desire to use the solutions - Specific implementation tasks	20mins



[Figure 77] Meeting 3 Round 3(Meteseh)



[Figure 78] Meeting 3 Round 4

5) Interview with key organizations and experts

① Overview and progress

In order to identify and understand the causes, relationships, impacts, and policies of various complex disasters caused by the climate crisis, we visited key organizations and conducted interviews. The interviews focused on identifying government policies that consider community disaster prevention and disaster vulnerability due to climate change, and the results of each meeting were used to compare the effectiveness of government policies.

A total of six organizations were visited, and the specific names and schedules are shown in 〈Table 41〉.

〈Table 41〉 Meeting 3 process

Timeline	Departments
July 17th 08:00	Disaster Management Department of Semarang (BPBD Kota Semarang, Badan Penanggulangan Bencana Daerah)
July 17th 10:00	Spatial Planning Department of Semarang (Distaru Kota Semarang, Dinas Penataan Ruang)
July 17th 11:00	Public Affairs Department of Semarang (DPU Kota Semarang, Dinas Pekerjaan Umum)
July 17th 13:30	Lasker Besti (Regional Research Institute)
July 17th 14:30	Ministry of Environment of Semarang (DLH Kota Semarang, Dinas Lingkungan Hidup)
7July 22nd 10:00	Ministry of Health of Semarang (DINKES Kota Semarang, Dinas Kesehatan)

② Main Results

[Disaster Management Department of Semarang]

The local context of the Tambakrejo area was identified as a former pond (Tambak) area, and it was confirmed that dykes and reservoirs are part of the local natural elements and that local people are accustomed to flooding, recognizing that they live in an area that used to be a reservoir. In relation to flood impacts in Tambakrejo, we also learned that during the most severe floods, the water was chest high and residents primarily traveled by boat.

In terms of physical infrastructure, it was noted that SIPEL seawalls were constructed to reduce tidal flooding in the Tanjungmas area, that Tambakrejo used to be part of the Tanjungmas area, and that these SIPELs were constructed as part of the Semarang-Demak Coastal Seawall National Strategic Project, similar to the seawall in Tambaklorok.

The Disaster Management Agency confirmed that the Semarang government has a contingency plan (Rencana kontigensi) for flooding and other diseases that involves multiple stakeholders, including the community and government officials, and that the contingency plan provides comprehensive guidance to all departments, including the Ministry of Health and the National Disaster Management Agency, on relevant response plans. These contingency plans are led by the Disaster Management Agency (BPBD), and examples of disaster management where these contingency plans have been utilized include the 2023 Meteseh floods and frequent flooding in Tambakrejo, confirming that flooding is indeed frequent in the destination and that government-level planning is in place.

The cause of the Meteseh flood in 2023 was identified as strong heavy rainfall in the Babon watershed at the time, and the government opened the upstream dam to prevent further damage, but the downstream flow overflowed, causing flooding. The government sent WMT upstream in response, but residents suffered from skin rashes afterward due to lactic acidosis, confirming a case of compound disaster.

[Spatial Planning Department of Semarang]

Semarang has a diverse terrain ranging from lowland to highland, and as a city that is more than 400 years old, the team identified the natural geographical cause of land subsidence as sedimentary soils. To compensate for this natural geography, Gunung Pati and surrounding areas have been designated as a kawasan penyangga (buffer zone), recognizing the importance of green infrastructure by finding that 20% of the city's area is green space.

A 200-250 ha retention pond with seawalls is being built as part of a toll road project, but disaster management infrastructure projects require significant funding, with little direct return. The Ministry of Spatial Planning recognized that combining these disaster-related projects with highway tolls would provide an economic return, increasing the likelihood of attracting investment in disaster prevention projects.

A WebGIS called Onemap Semarang was being used for urban planning, with hazard maps in PERDA TATARUANG No5/2021, a city planning and zoning regulation valid until 2031, which includes data on soil capacity levels, topography, slope, faults, soil types, and flood analysis.

In terms of green space and environmental planning, the Spatial Planning Department confirmed that the city has a target of 30% green space to combat rising temperatures. In particular, it advocated for rainwater harvesting, policies to encourage green building, and community education to improve infrastructure and sanitation.

[Public Affairs Department of Semarang]

For flood management, we found that the upper basin is being managed with reforestation, increased vegetation, and the use of horizontal IPALs to slow down the flow of water downstream, while the lower basin is being improved with physical infrastructure, including the installation of pumps and increased pumping capacity in low-lying areas. Tree planting is being done in collaboration with DLH

and BBWS, as well as efforts to clean 35 waterways daily to remove sediment and debris.

In terms of climate change adaptation, the Public Works Department confirmed that climate change is an important consideration and that tree planting activities and watershed-related programs will be implemented in Kali Gara in August with the support of DLH's vegetation. In addition, events are being organized to promote regular river cleaning, a river meeting is scheduled for July 27, and a coastal clean-up exercise will be held on August 2 in collaboration with the Fisheries Department.

Topographically, the Kali Babon River flows through two areas in Semarang, upstream and downstream, with the upstream area still in need of more natural management. In particular, it was decided to plant trees in Meteseh to preserve green space and protect residential areas from urbanization, which is in the same vein as the team's plan to propose planting as a living lab solution.

Although the role of the public works department is less directly related to disaster prevention, it was recognized that cleaning urban waterways contributes to a reduction in the number of mosquito breeding sites, and clean waterways have a positive impact on public health. This was especially true in Tambakrejo, where the fieldwork identified a post-flood outbreak of skin diseases and fever, indicating the need for such efforts to mitigate the effects of multiple disasters.

All flood events are managed directly by the mayor, which includes not only a physical response but also a social response, and we found that Tambakrejo has a good disaster response infrastructure, with public kitchens and health posts that include the police, military, and central government.

[Lasker Besti]

Diseases are broadly categorized into vector-borne diseases such as dengue and non-communicable diseases, and research has shown that vector-borne diseases are closely linked to climate, with rising temperatures lengthening the life cycle of

mosquitoes, making them more viable at higher elevations.

In Semarang, the Climate Smart Village project involves the Ministry of Urban Development, the Environment Agency, the Meteorological Department, and other departments as stakeholders, and has agreed to expand the analysis and early warning system for climate-related diseases conducted in collaboration with the Meteorological Department to the village level.

The pilot project focused on dengue and leptospirosis in Kemejen village, which is known to be vulnerable to climate change and related diseases, and leptospirosis is a disease that is highly affected by climate and environmental change and needs more awareness and attention as a climate-related disease.

The role of programs and communities in climate change-related disasters includes

- 1 House 1 Supervisor: Monitoring for mosquito larvae in each home
- Laskar Besti : Monitor and report on mosquito larvae in public areas such as schools, markets, and mosques through the Sijentik program.
- Sijentik program: Educate the public to identify mosquito larvae and prevent mosquito bites.
- Tunggaldara System : Real-time reporting and monitoring via a website, with participation from the government's community health clinics, Puskesmas.

Meteseh district has been working with health centers to manage the disease, but these efforts require community action, and leptospirosis disease is common in reservoir terrain such as Tambakrejo in addition to Meteseh.

[Ministry of Environment of Semarang]

Confirmed that a permit is required to cut down a tree and a retribution fee is charged, and explained that the PERDA 8 No. 2018 ordinance requires that if a tree is cut down, it must be replaced with another tree. He also confirmed the Ministry of Environment's efforts to distribute trees for free to increase vegetation.

Meteseh noted that different housing estates and neighborhoods have different levels of trees and green spaces and interest in them, and that community efforts are needed to create green spaces, especially for PROKLIM, which is a mitigation measure by increasing vegetation. Mr. Meteseh reaffirmed that there are problems such as drought and water scarcity, waste burning, open burning, and unregulated burning, which leads to land drying.

With the Living Lab idea, the Ministry of Environment proposed ways to utilize renewable energy, including the use of wind and solar energy, the use of electricity to power pumping machines, Early Warning Systems (EWS), biogas purification tanks, and the purification of brackish water for drinking.

Finally, the ministry emphasized green building, encouraging the maintenance of vegetative cover on houses and high-rise buildings, the use of wastewater from sewage treatment plants for vegetation, and the introduction of vertical gardens.

[Ministry of Health of Semarang]

To identify and understand the causes, relationships, impacts, and policies of health problems in Semarang, including diseases caused by the climate crisis, we visited and interviewed the Semarang City Health Department, a key institution involved. Focusing on identifying policies that take into account the community's vulnerability to disaster prevention and climate change-induced diseases, we compared and confirmed the effectiveness of the policies based on the findings from Meeting 1, and exchanged the results of the research conducted since the MOH's visit in June.

The MOH analyzed data from March to June 2024 using recent hospital (ICD) data and found that a heat wave occurred during this period, and initial results suggest that high temperatures contributed to an increase in pneumonia cases. This is an important indicator of the health impacts of climate change, and suggests the need for further research and response.

Meteseh is experiencing increased health risks due to the increase in developed

housing areas and the heat island effect caused by lack of vegetation, while Tambakrejo is experiencing severe environmental and health challenges due to flooding from upstream and difficulties with wastewater treatment. The Ministry of Health is taking preventive and response measures to address these issues, but faces many challenges, including staff shortages and resistance from residents.

In Tambakerjo, residents initially did not recognize dehydration as a health issue, but through education and treatment at health centers (Puskesmas), awareness has improved to some extent. However, it is still not complete, suggesting the need for continued education and outreach to raise health awareness among residents.

Direct outreach and education to vulnerable groups of residents, particularly the elderly, pregnant women, children, and people with disabilities, was emphasized, and the importance of interdepartmental cooperation and community engagement to ensure their health and safety was highlighted. Efforts to control diseases such as dengue through innovative approaches such as the Volvakia project are underway, but are hampered by misinformation and resistance from residents, and require continued education and outreach to improve awareness.

Meanwhile, to improve the environment, urban greening programs are underway, and efforts are being made to address the lack of vegetation through technical modifications and artificial interventions. Ideas such as applying the idea of a living lab for wastewater intake in the Tenggang River were discussed.

Going forward, the Ministry of Health aims to strengthen its response through data sharing and further research, and to collaborate with academia to incorporate research findings into policy, with particular attention to the findings of this study.

③ Picture of visit and interviews



[Figure 79] Visit and interview with key institutions (BPBD)



[Figure 80] Visit and interview with key institutions (Distaru)



[Figure 81] Visit and interview with key institutions (DPU)



[Figure 82] Visit and interview with key institutions (Lasker Besti)



[Figure 83] Visit and interview with key institutions (DLH)



[Figure 84] Visit and interview with key institutions (DINKES)

6) Living Lab Idea Workshop

① Overview and process

Based on the results of each meeting and the interviews with key organizations, the research team conducted workshops to generate and develop living lab solution ideas. Three workshops were held in total, each consisting of 1) summarizing and discussing the results, 2) drafting the living lab solution, and 3) developing the living lab solution.

In Workshop 1, we summarized and discussed the main results from Meetings 1-3. In particular, community maps were computerized and translated to identify the impacts and responses to complex disasters, solution ideas, and desired areas as perceived by local residents.

In Workshop 2, we identified local challenges based on the results of Workshop 1 and drafted Living Lab solutions based on various cases. As local challenges are complex, solutions were brainstormed to respond to various challenges in an integrated and organic manner.

Finally, in Workshop 3, the solution ideas generated in Workshop 2 were refined. We reviewed the feasibility, appropriateness, effectiveness, and novelty of the solution ideas and worked to refine the ideas. This resulted in a total of three final Living Lab solution ideas.



[Figure 85]
Workshop 1: Organize and discuss results



[Figure 86]
Workshop 2: Drafting a Living Lab Solution



[Figure 87] Workshop 3: Refine solution ideas

7) Jakarta field visit

① Overview and main results

To identify additional sites in Jakarta that are threatened by multiple disasters and compare them to Semarang, as well as to visit green infrastructure case studies to understand the impact of green infrastructure in urban planning, we traveled to Jakarta.

We first visited Muara Angke, a coastal neighborhood threatened by sea level rise, land subsidence, and identified as a flooding and heat hotspot, to review living conditions, sanitation conditions (including exposure to open drainage), and disease vulnerability. The visit revealed that Muara Angke is a fishing port similar to Semarang, sharing the same issues of poor drainage, poorly pitched roads, and litter, which led us to explore the potential for scaling up the solution.

Next, the team visited the Green Belt PIK2, a case study of green infrastructure development in response to the climate crisis and multiple disasters, to review best practices. Green Belt PIK2 is a 2-kilometer-long linear park in a new city that creates a green axis centered on a drainage canal and connects residential, commercial, and business areas. The case study demonstrated the effectiveness and application of green infrastructure.



[Figure 88] Jakarta field visit (Muara Angke)



[Figure 89] Jakarta field visit (Muara Angke)

4. Living Lab Solution Idea Development

1) Wicked Problem Identification and Solution Matching

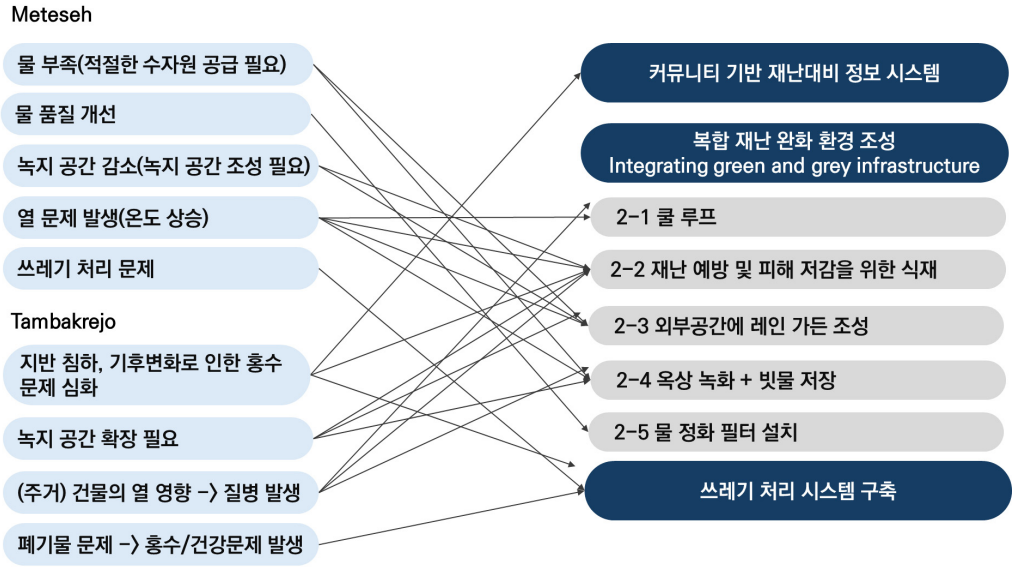
Through the process of Meetings 1 through 3, site visits, and interviews with key organizations and experts, we identified a number of issues in the target areas. From these issues, Wicked Problems were identified as those that have been consistently challenging to solve, are highly interconnected and difficult to solve in isolation, and are related to complex disaster impacts and responses.

The Wicked Problems identified by Meteseh and Tambakrejo include

〈Table 42〉 Main Wicked Problems from target areas

Areas	Wicked Problems	Contents
Meteseh	No access to adequate water resources (domestic water)	- Lack of water purification and water and wastewater infrastructure leads to quality issues - Water shortages
	Reduced green space due to sprawl	- Rapidly developing areas, resulting in sprawl and reduced green space - Increased speed of flooding due to reduced green space
Tambakrejo	Increased thermal impact on residential buildings	- Increased thermal impact of residential buildings due to poor materials, insulation, and climate
	Drainage problems due to low-lying areas and land subsidence	Low ground levels due to coastal location and excessive use of groundwater, resulting in constant ground subsidence, causing recurrent flooding - Poor drainage and pavements with low water permeability
Meteseh & Tambakrejo	Lack of planting to reduce flooding and heat damage	- Lack of green space and lack of trees and other vegetation, especially in residential areas, making them more susceptible to flooding and heat damage
	Lack of late disaster warning systems and information	- Disaster warning systems exist, but notifications are too late to evacuate in advance - Notifications from disaster warning systems are not well communicated - Government agencies already provide disaster and disease-related information, but the digitally excluded have limited access to it
	Garbage disposal problems	- Waste collection is poorly enforced, and much trash is dumped or burned

Based on the identified local challenges, the research team developed three living lab solution ideas that are feasible and can be implemented at the community level: 1) a community-based disaster preparedness information system, 2) the creation of a multi-hazard mitigation environment, and 3) integrated waste management, and matched each of them with the following [Figure 90] to confirm the alignment of the solutions.



[Figure 90] Identify local Wicked Problems and match solutions

2) Solution Idea 1: Community-based disaster preparedness information system

① Main Wicked Problems to address

In the existing target areas, Early Warning Systems (EWS) have been installed to respond to disasters, but the notifications are late and poorly communicated, which limits the response to disasters. In terms of disaster information, government agencies already provide information on disasters and diseases, but the digitally disadvantaged have limited access to information.



[Figure 91]
EWS in local town(Tambakrejo)



[Figure 92]
Evacuation signs in local town (Tambakrejo)

② Overview of idea

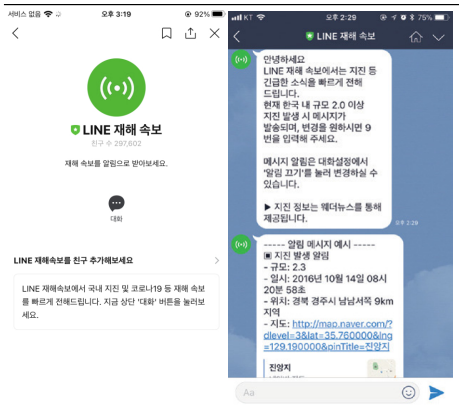
To overcome the limitations of the existing EWS and to improve access to disaster information at all levels, we propose a community-based disaster preparedness information system that organically connects the community, the public, and technology, which is installed and operated in four phases.

In the first phase, a solar-powered Solar EWS will be installed at locations mapped by the residents as necessary. The system will be jointly developed and installed by universities in Semarang, a company with relevant technology, and the Semarang Disaster Management Agency (BPBD). The Solar EWS is maintained periodically by the village youth organization with the help of the BPBD.

Next, community-specific disaster response organizations are established to share roles in the event of a disaster. In collaboration with the health center (Puskesmas), which is already in charge of village health activities such as responding to the injured and contagion control, and the fire and police departments, which are in charge of disaster rescue and recovery activities, youth organizations disseminate information to the vulnerable in the village and assist in the evacuation of vulnerable people. Women's organizations can help prepare and distribute emergency food during floods, disseminate information to the less informed in the village during heat islands and disease outbreaks, and assist in the return and

evacuation of vulnerable people. Disaster response organizations communicate with each other via Whatsapp (or dedicated app) based chat.

Once the solar EWS and community disaster response organization are in place, establish a system to automatically send notifications to the disaster response organization and residents when the solar EWS detects signs of disaster. To do this, the existing EWS is upgraded and the newly installed EWS is integrated and operated. The upgraded EWS warns villages of disasters with sirens as before, while automatically sending response instructions to disaster response organizations via Whatsapp and evacuation messages to villagers. When there is a change in the disaster forecast or situation, it is updated in real time through Whatsapp.

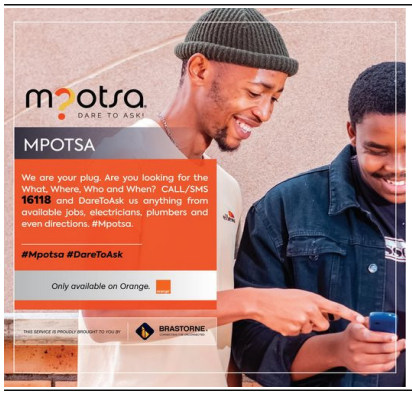


Adding disaster news to your friends on Line, a messenger app, allows you to receive notifications when disasters such as earthquakes occur.

Source: Korea Meteorological Administration Online Earthquake Science Center (https://www.kma.go.kr/eqk_pub/bbs/board.do?tableType=online_news&wrId=181

[Figure 93] Similar Example: Line Disaster (Earthquake) Breaking News Notification Service

Finally, we provide disaster response education during peacetime. In preparation for a disaster, a Whatsapp chatbot is opened and operated so that residents can easily understand disaster response tips in everyday life. For the information disadvantaged who have difficulty using Whatsapp, the ARS-based Disaster Help Center is operated to answer questions about disaster response tips in everyday life, and to request rescue in case of emergency and report disaster damage (see [Figure 94]).

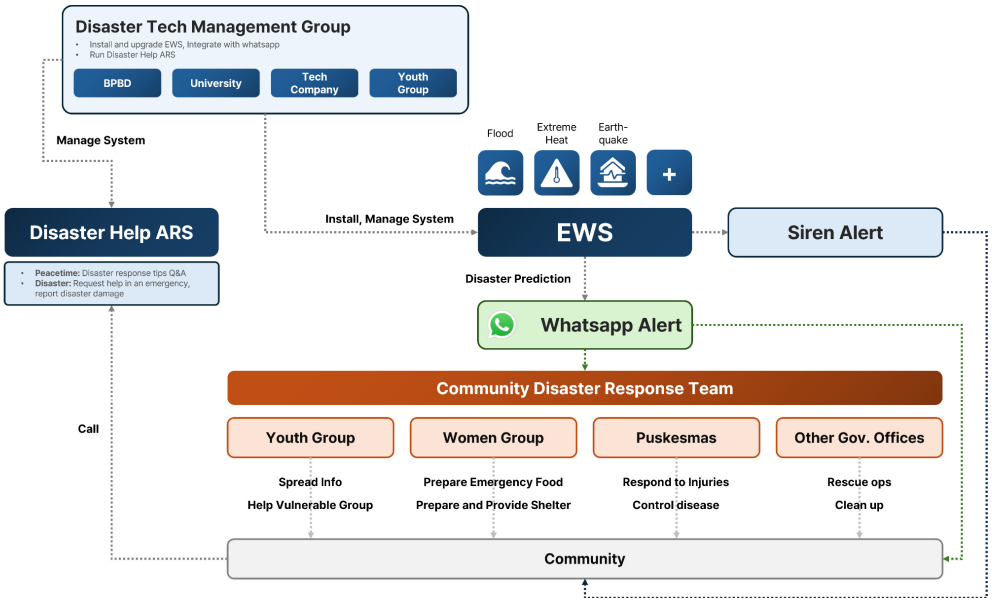


A two-way, phone-based question-and-answer platform designed for underserved populations with limited access to data and technology that can provide almost any information, especially health-related information.

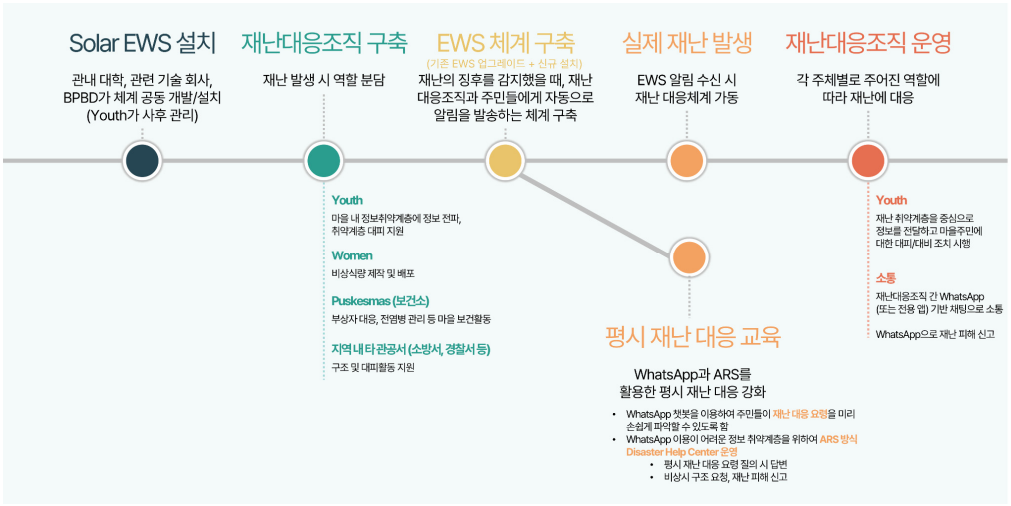
Source: Mpotsa (https://brastorne.com/wp-content/uploads/2024/03/Mpotsa-Brochure.pdf)

[Figure 94] Similar Example: Mpotsa

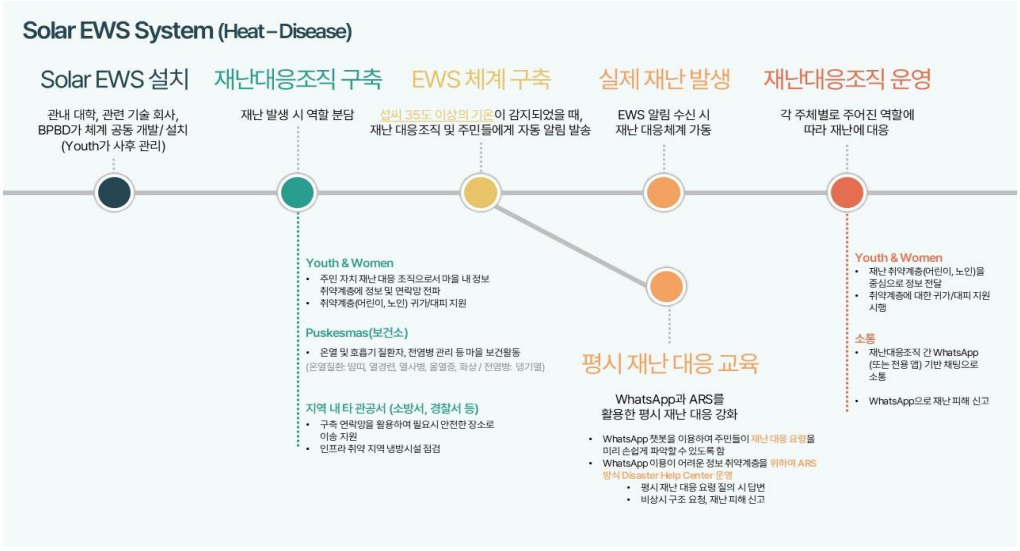
The structure of the solution is shown in [Figure 95] and is built with the timeline shown in [Figure 96] and [Figure 97]. The proposed solution is expected to reduce the information gap, enable the community to be more proactive in responding to disasters, and ultimately improve the community's disaster response capabilities.



[Figure 95] Community-based disaster preparedness information system structure



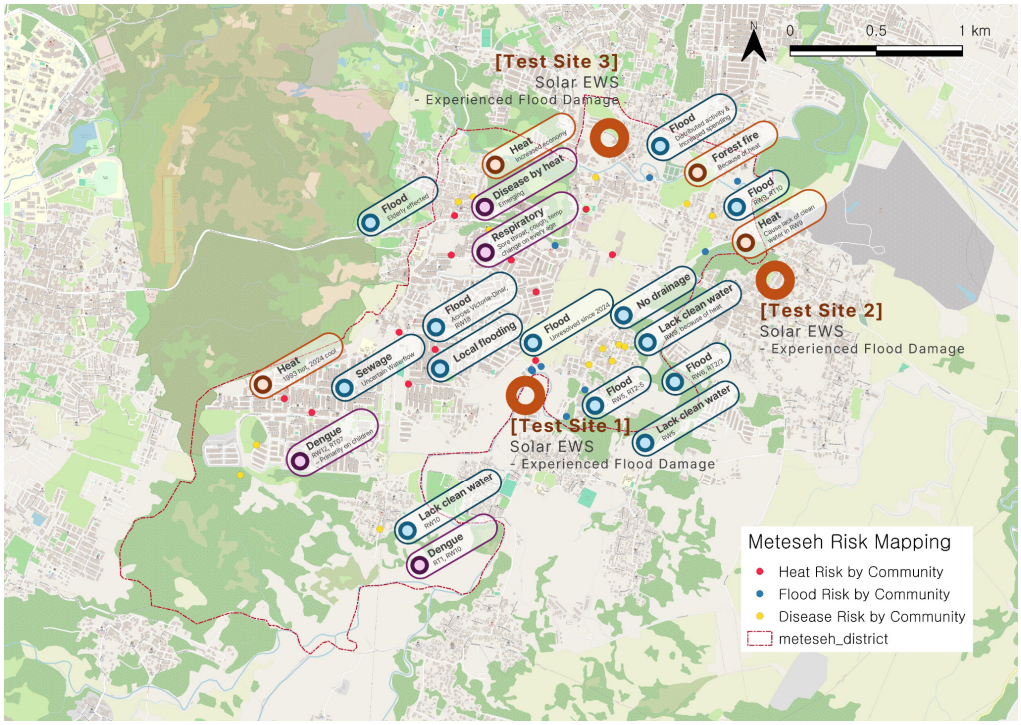
[Figure 96] Timeline for building a community-based disaster preparedness information system (flooding)



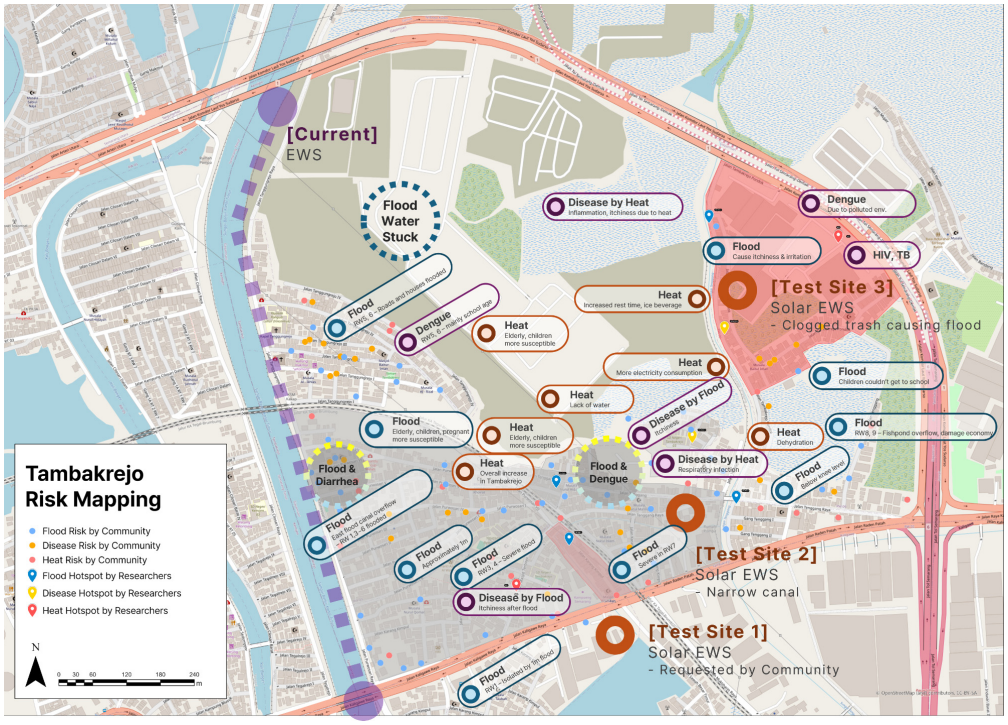
[Figure 97] Timeline for building community-based disaster preparedness information systems (heat islands, disease)

③ Mapping the solution of target areas

Based on the Phase 1 research and fieldwork, we identified and refined hotspots and places where residents mapped a need for a solution, and prioritized points to introduce the solution in the target area, as shown in [Figure 98] and [Figure 99].



[Figure 98] Mapping community-based disaster preparedness information system solutions (Meteseh)



[Figure 99] Mapping community-based disaster preparedness information system solutions (Tambakrejo)

3) Solution Idea 2: Complex disaster mitigation environment by planting

① Main Wicked Problems to address

The target sites have in common a lack of green space, which makes it difficult to respond to disasters, including heat impacts and flooding. In particular, in Tambakrejo, the thermal impact of residential buildings is increasing, and in Meteseh, there is a lack of adequate water supply (domestic water), while at the same time, green space is decreasing due to sprawl.

② Overview of the Idea

The multi-hazard mitigation environment aims to integrate water and heat management through planting and roof improvement solutions. The solution consists of four main components, which are customized for each destination.

Through comprehensive and locally tailored planting solutions for disaster prevention and damage reduction, it is expected to improve local water and heat management, respond effectively to complex disasters, and ultimately strengthen community functioning.

[Solution 2-1] Cool roof (Tambakrejo)

In Tambakrejo, the thermal impact of residential buildings is increasing due to poor materials, insulation, and climate, and residents are experiencing heat-related illnesses, but fundamental improvements are difficult due to the lack of available green space. Therefore, the project aims to reduce the indoor temperature by 4℃ and reduce cooling energy by an average of 20% in an economical way through the Cool Roof, which applies white thermoplastic film material paint to the roof.

The introduction of Cool Roof consists of the following steps: implementing support projects at the community level, providing education on the application of Cool Roof, implementing support projects, and identifying and prioritizing energy marginalized groups. First, individuals receive education on the application of cool roofs to understand the necessity and benefits of cool roofs, as well as management measures such as rooftop and roof cleaning to enhance their effectiveness. Then, each home will be phased into the Cool Roof program. In the first phase, active participants replace roofing materials such as iron sleeves, which are highly affected by heat and increase indoor temperature, with bricks, etc. For passive participation groups that have difficulty replacing materials, the roof color is changed to white.

At the community level, youth, women's groups, and health centers will work to identify energy disadvantaged groups in their communities so that they can be prioritized for public cool roof support. This includes the elderly living alone. In addition, local painters and building contractors and the public will work together to speed up the construction of cool loops, and youth organizations will help the internet poor apply for cool loop support projects to connect individuals and public projects.

Finally, the public provides subsidies for cool roof construction through household-level support projects. For example, in Korea, there is a program that provides 15,000 won (up to 1.5 million won) per unit area, with priority support for vulnerable groups. In addition to households, at the community level, cool roofs can be applied to facilities and gathering places (such as daycare centers, schools, senior centers, etc.) where residents can gather to escape the heat to create heat shelters.



[Figure 100] Example of Cool roof

[Solution 2-2] Planting for disaster prevention and mitigation (Meteseh, Tambakrejo)

Both Meteseh and Tambakrejo suffer from poor vegetation and a lack of green space, making it difficult to cope with heat islands and flooding. Furthermore, even when they are planted, they often fail to withstand disasters. Therefore, we aim to prevent disasters and reduce damage by planting water (drought, flood) tolerant tropical plants that can survive the prolonged dry season and flood-resistant herbaceous plants by region. The plantings will target plants that (1) can be applied to rooftop greening and rain gardens, (2) are salt tolerant and can be planted near rivers to absorb water and act as a barrier, and (3) can survive in areas with long dry seasons or water shortages.

Each actor will engage in the following activities First, individuals will receive training to better understand their local environment (where saltwater meets freshwater), while also learning about flood-resistant plants and saline plants. The community forms a group to manage green spaces (fruit gardens, rain gardens) in

public spaces/empty lots and conducts planting activities. Finally, the local government supports the initial installation costs by providing plants and fertilizer to residents, and provides a minimal manual for ongoing management so that residents can create their own green spaces. In the long term, the green spaces are monitored to ensure that the system is established.

The planting timeline and recommended tropical plants for disaster prevention and mitigation are as follows.



레인가든/옥상녹화 식재 타임라인

식재 역할: 배수, 토양 정화, 토양 침식 방지, 잡초 억제, 미관

적용 지역	식물 종류	유형	식재 시기	정착 기간	적용 방식	주요 역할	세부 역할	특징
Meteseh	Brachiaria decumbens	초본	11월	11월~2월	옥상녹화	홍수 저감, 열섬 완화	배수, 침식 방지, 잡초 억제, 토양 정화	• 오염된 토양에 내성 • 심한 홍수에는 약함
	Panicum maximum	초본	11월	11월~2월	레인가든, 옥상녹화	홍수 방지, 열섬 완화	배수, 침식 방지	• 척박한 환경에 적응 • 장기간의 건기에 내성
Tambakrejo	Paspalum vaginatum (seashore paspalum)	초본	11월	11월~2월	레인가든	홍수 방지, 홍수 저감, 열섬 완화	배수, 침식 방지	• 수변(염수 해안)에서 생장 • Paspalum distichum는담수해안에서자라는유사종
	Axonopus compressus (Broadleaf carpet grass)	초본	11월	11월~2월	옥상녹화	열섬 완화	토양 정화, 미관	• 습도가 높은 곳에서 생장 • 그늘진 환경 선호 • 농장의 토양 덮개로 사용 • 염도 내성 낮음
	Axonopus compressus (Broadleaf carpet grass)	초본	11월	11월~2월	옥상녹화	홍수 저감, 열섬 완화	침식 방지, 미관	• 습도가 높은 곳에서 생장 • 그늘진 환경 선호 • 농장의 토양 덮개로 사용 • 염도 내성 낮음
Both	Gamba Grass (Andropogon gayanus)	초본	11월	11월~2월	레인가든, 옥상녹화	홍수 저감, 열섬 완화	침식 방지	• 다양한 토양환경에 적응 • 계절성 습지에서 발생 • 침수토양에 잘 적응

[Figure 101] Timeline for Planting for disaster prevention and mitigation

〈Table 43〉 Suggestions for Planting for disaster prevention and mitigation

Target Areas	Classification	Name	Purpose and Characteristics	Photo
Meteseh & Tambakrejo	Herbaceous Plants	Gamba Grass (Andropogon gayanus)	- Various soil adaptations (sand-clay, alkaline-acidic) - Tolerance to temporary flooding - Var. gayanus occurs in seasonal wetlands and adapts well to flooded soils - Planted around rivers (especially Meteseh)	
		Axonopus compressus (Broadleaf carpet grass)	- Various soil adaptations (sand-clay, alkaline-acidic) - Tolerance to temporary flooding - Var. gayanus occurs in seasonal wetlands and adapts well to flooded soils - Planted around rivers (especially Meteseh)	
		Brachiaria decumbens	- Tolerant to contaminated soils - Used for green roofs and rain gardens	
		Panicum maximum	- Tolerant to harsh environments, such as when cultivating barren land	
Tambakrejo		Paspalum vaginatum (seashore paspalum)	- Grows easily near water - Deep roots	
	Woody Plants	Mangrove	- Effective in preserving ecosystem diversity and preventing floods, sea level rise, and typhoons	
		Passion Fruit	- Among the passion fruit varieties, Passiflora gibertii and Passiflora edulis are tolerant to salt	

[Solution 2-3] Apply an exterior space region (Meteseh)

Rain gardens store rainwater in outdoor areas to reuse water and affect the reduction of ground temperature. Accordingly, Solution 2-3 aims to strengthen the disaster resilience of community spaces by creating rain gardens using the leftover space between houses.

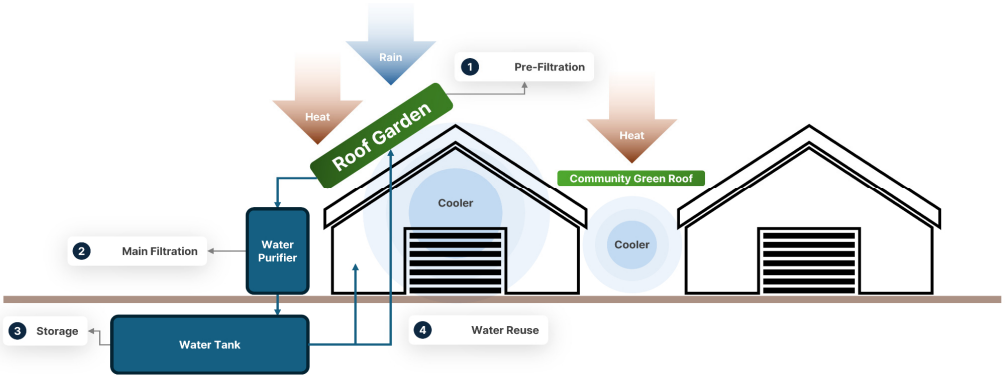
The following activities are carried out by each subject. First, individuals receive education on the necessity of rain gardens for using the leftover space between educational houses, active participation, and land use, and install rain gardens on land that can be used as leftover space within a village or household. These rain gardens can be used as urban farms, and when used in yards or gardens within households, crops that can be consumed at home can be grown. After creating a rain garden, the environment is maintained through continuous management. In particular, the efficiency of rainwater storage is increased by managing plants without leaving waste.

The community identifies leftover spaces (idle lots) within the community where water often collects and waste is frequently dumped, and derives candidate sites for installing rain gardens. They manage the plants and waste in the rain gardens in the village, and manage the rainwater collected through the pipes under the rain gardens. In addition, youth and women's groups collect the rainwater collected in tanks such as rainwater storage tanks, purify it, turn it into drinking water, store it, and distribute it. It is also used as living water for washing hands or doing laundry at mosques, and religious and youth groups manage and distribute water pollution conditions. Women's groups use crops grown in idle land in public kitchens (in case of disasters) and in free meal centers visited by low-income families during normal times. Finally, the public sector implements a rain garden support project to distribute subsidies that can ease the financial burden and actively promote the installation of rain gardens in idle land. In addition, they distribute crops and other plants that can be planted in rain gardens and install pipes and other irrigation facilities, and use the puddle data utilized by the

Semarang Department of Public Works (DPU) to identify where rainwater collects. Finally, pipes and other plumbing facilities are managed in cooperation with the DPU.

[Solution 2-4] Multi-purpose rooftop greening and water filtration system (Meteseh)

Meteseh is a high-altitude, newly developed area with insufficient water supply and sewage infrastructure, which makes it difficult to smoothly supply adequate water resources (domestic water). At the same time, indiscriminate development is reducing green space. Therefore, a multi-purpose rooftop greening and water purification system that can secure water resources and green space at the same time is introduced to build a water cycle system that goes from rainwater 〉 rooftop garden 〉 storage 〉 water purifier 〉 domestic water. In particular, the rooftop greening and water purifier will be introduced in stages, and they will be integrated and linked to enable a single solution to respond to complex disasters, and a universal solution that can be applied at both the individual and community levels will be presented.



[Figure 102] Multi-purpose rooftop greening and water filtration system schematic

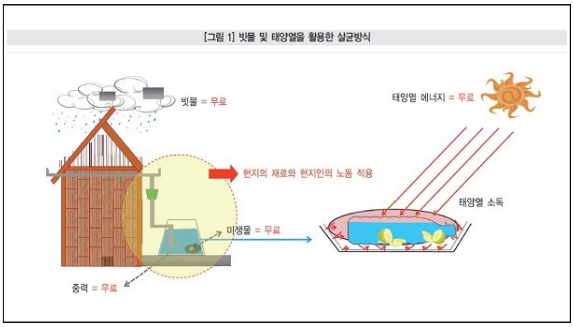
First, in the short term, we will introduce and demonstrate community-use water purification and storage facilities using solar energy, microorganisms, or biosand. In addition, we will create green roofs using light materials and vines between public spaces and houses, on streets, etc., and when food crops are grown, the villagers can harvest or sell them for public use. In the mid- to long-term, we will

install and demonstrate small-scale water purification and storage facilities in some households, and install rooftop gardens in those households. The installed rooftop gardens will be connected to household water purification and storage facilities, demonstrated, and expanded to the village level.



[Figure 103]
Community greenloop example

Source: https://www.diakonia.se/en/where-we-work/asia/bangladesh/transforming-endless-poverty-in-balurmath-slum/



[Figure 104]
Example water storage and purification system

Source: https://www.jejunews.com/news/articleView.html?idxno=2206286

To achieve this, community-level education and support should be provided to encourage each household to install rooftop gardens. Specifically, training on planting and installation methods should be provided, along with financial support for installation costs or materials and plants. The rooftop gardens should be planted with pest- and drought-resistant plants that are locally available, and the design should be lightweight and easy to install to minimize the load on existing homes. For this, collaboration with local universities is needed to develop and verify a standard rooftop garden model.

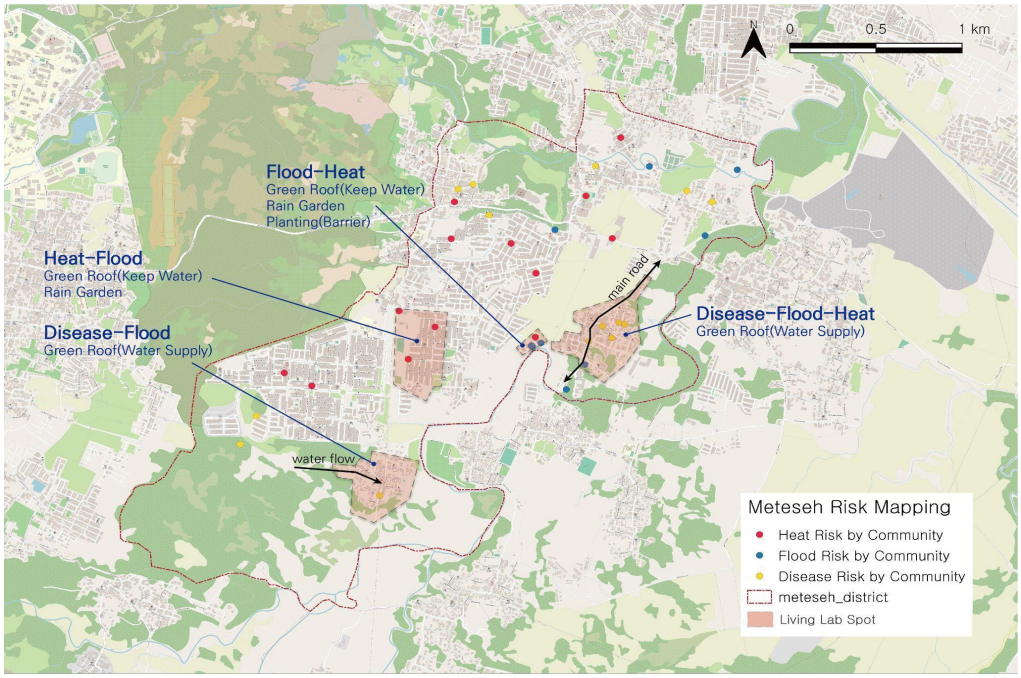
At the individual level, rooftop gardens can be used to first purify and store rainwater during the rainy season. During the dry season, the stored rainwater, combined with groundwater, can be purified using solar energy, microorganisms, or bio-sand filters before use.

At the community level, green roofs should be created using lightweight materials

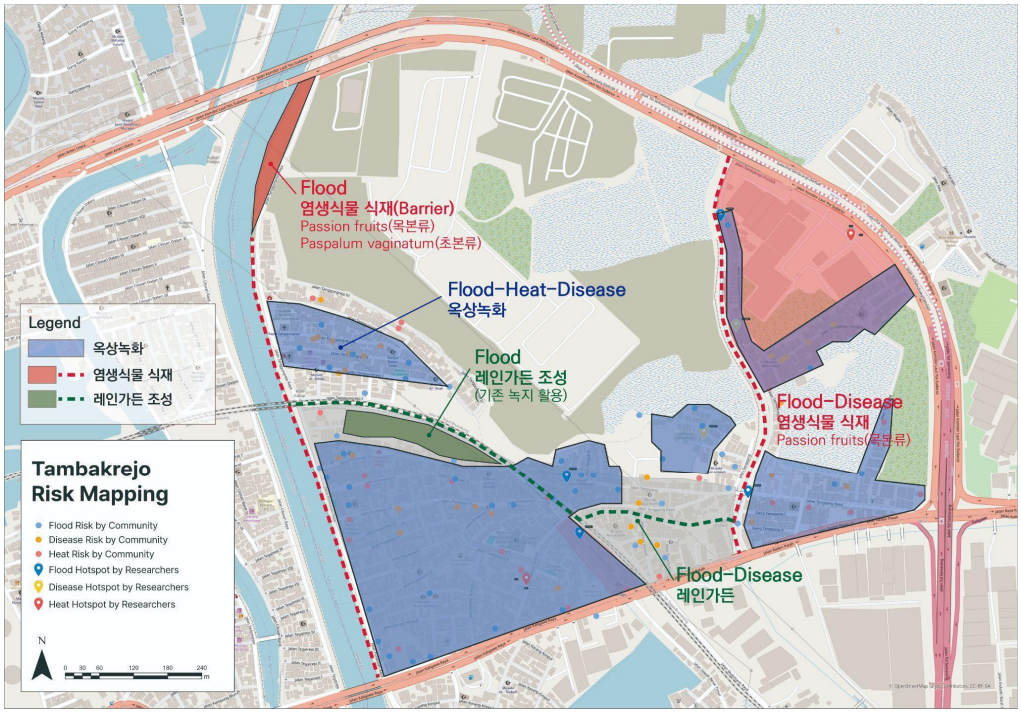
and climbing plants between houses and along streets, with the community managing them collectively. Through gardening education, residents can learn how to effectively manage the rooftop gardens and improve them over time. Youth and women's groups should jointly manage community water purification facilities, with regular inspections conducted by the local health center.

③ Mapping solution target areas

Based on the Phase 1 research and local investigation, the priority introduction points for solutions within the target area, centered on hotspots derived and supplemented and places mapped by residents as needing solutions, are as follows.



[Figure 105] Mapping planting solutions for disaster prevention and mitigation (Meteseh)



[Figure 106] Mapping planting solutions for disaster prevention and mitigation (Tambakrejo)

4) Solution Idea 3: Integrated Waste Management

① Main Wicked Problems to address

The target area is commonly not properly managed, such as by dumping or incinerating garbage, which is affecting the response to complex disasters. Garbage flows into drains and rivers, preventing smooth drainage, polluting the soil, and reducing the permeable area.

② Overview of idea

A system is established to automatically collect waste within the target area and for the community to participate in management, and it consists of the following steps:

〈Table 44〉 Step-by-step implementation plan for integrated waste management

Phases	Conetens	Detailed
Step 1	Illegal Dumping Reporting Application and Designation of Waste Collection Personnel	1-1: Designation of waste collection personnel and waste collection education 1-2: Distribution of illegal dumping reporting application 1-3: Distribution of waste reporting manual (focused on youth and women's groups) 1-4: Implementation of waste collection project based on application timeline
Setp 2	Distribution of Automatic Waste Collection Drones	2-1: Proactive distribution of automatic waste collection drones in testing areas 2-2: Maintenance and management of waste collection personnel and public services 2-3: Identification of habitual illegal dumping sites through the illegal dumping reporting application and selection of drone operation areas
Setp 3	Household Education and Management	3-1: Household education on waste disposal based on application operation results and drone collection outcomes 3-2: Supervision of the processes in phases 1 and 2

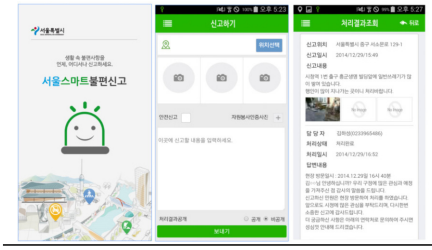
The implementation plan and effects by subject are as follows. First, at the individual level, the illegal dumping reporting application is utilized to raise awareness of illegal dumping of general waste. Not only can immediate response to illegal dumping of waste be made possible through the application, but awareness of waste disposal can be raised through the use of a resident participation system. In addition, in the process of designating a general waste collection manager and establishing a waste collection system in the region, basic livelihood recipients can be designated as collection managers and then waste collection costs can be paid to use as a means of supplementing living expenses. A systematic collection system such as waste patrols can be established in connection with the waste collection activities currently being carried out by women's groups in Tambakrejo. Finally, education on general waste disposal (illegal dumping) by household can be provided so that waste generation itself can be reduced.



- Powered by rechargeable batteries, capable of traveling approximately 5 km on a single charge, and can collect 500 kg of water debris (equivalent to 21,000 plastic bottles) through 8-10 hours of water cleaning work on a single charge.
- Equipped with sensors, eliminating the need for an operator during operation, and models with sensors capable of detecting water quality are also available.

Source: https://dronesolutionservices.com/wasteshark

[Figure 107] Similar Example : Wasteshark

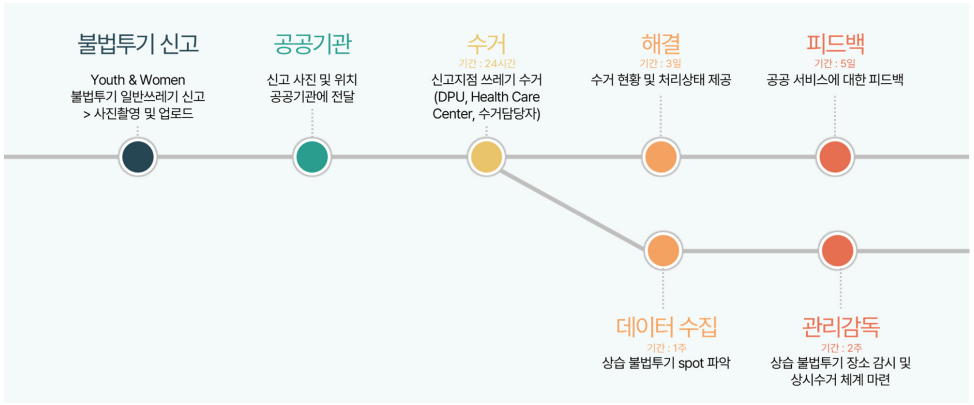


- An application that allows easy reporting of illegal waste dumping, with immediate access to the processing results.

Source: https://smartreport.seoul.go.kr/w100/index.do

[Figure 108] Similar Example: Seoul Smart Inconvenience Reporting

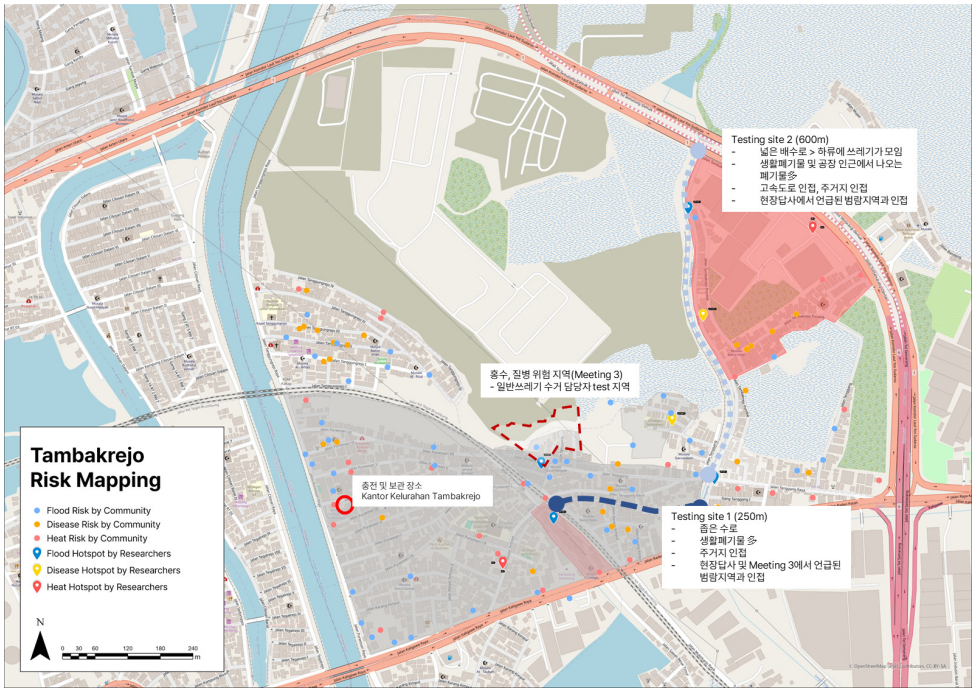
At the community level, youth groups, women's groups, and other residents who are familiar with using applications and smartphones actively report illegal dumping by distributing applications to village residents. In addition, automatic garbage collection drones (see [Figure 107]) are operated, and general garbage collection personnel in the region are designated and paid for garbage collection. Garbage collection personnel collect garbage collected at designated times and charge the drones (stored and charged at the Village Center), and the DPU, women's groups, and Community Center work together to monitor and monitor the status of activities. Finally, in the public sector, an immediate feedback response system is established based on the identification and reporting of illegal dumping sites through an illegal dumping reporting application, and a charging and storage location for automatic garbage collection drones is established. The timeline for this content is as follows:



[Figure 109] Integrated waste management adoption timeline

③ Mapping solution target areas

Based on the Phase 1 research and local investigation, the hotspots and places where residents have mapped out where solutions are needed were identified and supplemented, and points where solutions should be introduced first within Tambakrejo were identified as shown in the figure below.

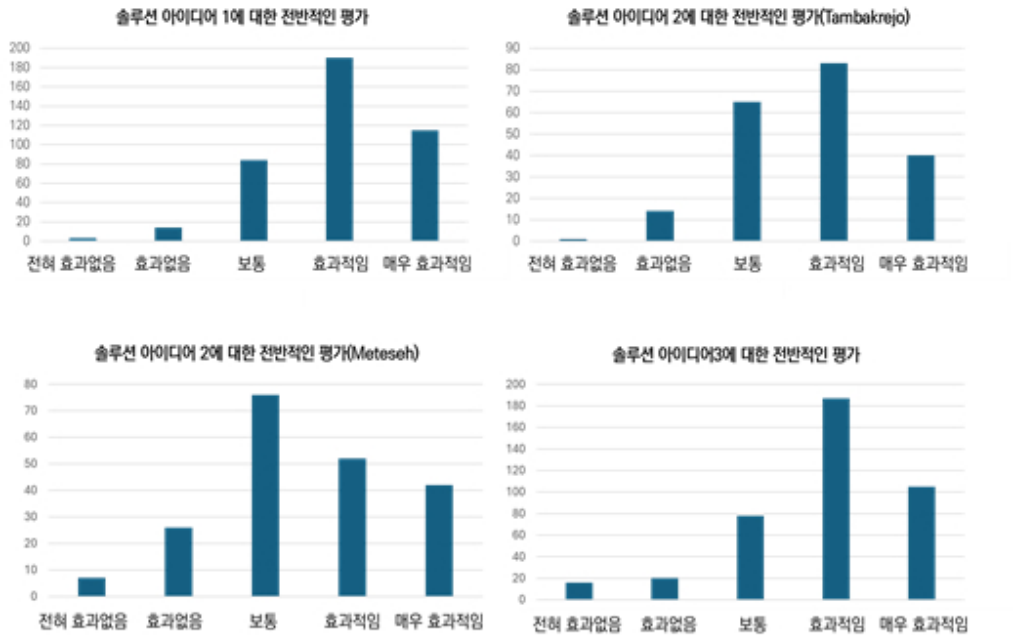


[Figure 110] Mapping an integrated waste management solution (Tambakrejo)

5) Validation of Solution Ideas and Awareness of Complex Disasters

In order to review the feasibility and effectiveness of the solutions derived based on the results of the Living Lab, and to finalize the solutions by checking the awareness of complex disasters, a survey was conducted among the residents of the target area.

The survey was conducted during the month of October 2024 and consisted of questions on experiences and perceptions of complex disasters, disaster vulnerability and response, and evaluation of the solution ideas proposed by the researchers. The survey was conducted in Meteseh and Tambakrejo districts, where the fieldwork was conducted, with a total of 406 respondents, 203 per village. Among the survey results, we found that the effectiveness of Solution Idea 1 was generally rated as “Effective” and “Very Effective,” indicating a high degree of feasibility. As a result of evaluating the effectiveness of each solution, we found that solutions that help people to respond immediately in disaster situations, such as 'early warning system', 'community-based disaster preparedness information system', 'early warning system and disaster text service', and 'early warning system and disaster text service', would be helpful, and that people also positively evaluate disaster education and information delivery systems, such as 'community-based disaster information system (information delivery and support for disaster vulnerable groups)' and 'regular disaster response education' [see Figure 111].



[Figure 111] Evaluation for the effectiveness of solution idea 1

Section6. Synthesis

This study aimed to detect the effects of complex disasters (disease, heat, and water management) due to climate change in Jakarta and Semarang, Indonesia, and to design, operate, and develop a Living Lab prototype that allows local communities to effectively adapt to climate change. The researchers used machine learning and AI to identify climate, geographic, environmental, and socioeconomic factors in the region that affect the occurrence of disasters, and derived hot spots with a high probability of complex disasters. After that, a local partnership and cooperation system were established to design a Living Lab prototype, and Living Lab was operated during the fieldwork to identify the vulnerability of complex disasters in the region, discover major problems, derive local problems, and seek solutions together.

The detailed procedure of Living Lab consists of selecting hot spots for areas of interest in the climate crisis in the first stage, pre-designing and local partnership establishment in the second stage, and the third stage of Living Lab prototype operation. Through local partnerships, the researchers conducted preliminary workshops, interviews, and participatory observations for various stakeholders (residents, public, private, and academic circles), discussed perceptions, impacts, and adaptation plans for disasters, and derived solutions.

This study suggests that it can contribute to establishing a solution system for climate change adaptation through community-based living lab and suggesting an efficient climate change adaptation plan in Indonesian coastal cities based on empirical data obtained through participatory observation. In particular, in the Semarang region, after deriving hotspot areas for complex disasters centering on problems such as dengue, heat island phenomenon, and flood, fieldwork and living labs were conducted on Meteseh and Tambakrejo, which are highly likely to occur in complex disasters. Living Lab was conducted as a consultation for local residents, a meeting for experts and private companies, and a roundtable meeting for local activists. In addition, interviews were conducted by visiting major

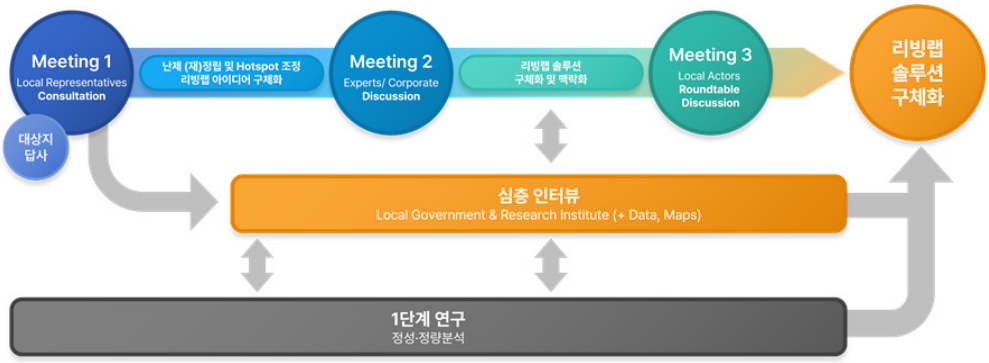
institutions (Semarang Disaster Management Bureau, Space Planning Department, Environment Ministry, Ministry of Health, and Regional Research Institute within universities) to understand the causes, relationships, impacts, and policies of various complex disasters caused by the climate crisis. This interview focused on identifying government policies that take into account the prevention of complex disasters in the local community and the vulnerability of disasters due to climate change, and compared and confirmed the effectiveness of government policies based on the results derived through each meeting.

Based on the results derived from each meeting and interviews with major organizations, the researchers organized the results through a number of workshops and drafted a Living Lab solution, and based on this, the Living Lab solution was embodied. The main challenges that appeared in the target areas, Meteseh and Tambakrejo, were found to be drought and intensifying water shortages due to climate change, floods, dengue, and thermal diseases caused by abnormal climate phenomena, confirming the impact of climate change and the possibility of complex disasters. Along with this, Meteseh is a newly developed residential area, and the problem of reducing green space due to instability in the supply of water resources and indiscriminate development is occurring, and as a result, problems such as endemic diseases (dengue), heat (heat island and thermal disease), and water management (water resource supply and management, flood) appeared in combination. Meanwhile, Tambakrejo, located in a coastal area, had problems such as heat (heat island), drainage problems due to low-lying and ground subsidence, garbage disposal problems, and difficulties in planting. Tambakrejo, in particular, is a coastal village where floods occur frequently, showing a high building and population density, and impermeable area ratio, and continuous flooding occurs due to ground subsidence due to indiscriminate groundwater use. Therefore, despite the efforts of the city government and international organizations to solve the problems occurring in the target area, it has been difficult to solve, and it can be seen as a difficult problem in that the interconnection between the problems is strong and as a result, it causes complex

disasters, making it difficult to solve them alone.

As above, in order to solve the major problems occurring in the region, the researchers proposed three solution ideas: 1) community-based disaster preparedness information system that can be introduced at the community level and is highly feasible; 2) creation of complex disaster mitigation environment; and 3) integrated garbage management. The solution proposed in the study is expected to improve disaster response ability by improving disaster information accessibility and supporting disaster response centered on the local community. In particular, it is significant in that after providing technology that can be supported through international aid (Solar EWS, Wastehark for garbage collection), it focuses on establishing an operating system so that the effect can be sustained by utilizing and maintaining the technology in the community. In addition, the researchers conducted a survey of residents of the target area (406 people in total) to verify the feasibility and effectiveness of the solution's introduction effect, and overall, it was confirmed that the feasibility and effectiveness of the solution were positively evaluated.

In addition, through this study, it was confirmed that Living Lab is an effective way to seek solutions led by local communities in the situation of complex disasters caused by climate change. In particular, in the process of recognizing and solving problems by cooperating with various stakeholders of the target country, the self-sustaining capacity for climate change adaptation has improved, and it is expected to be used as important basic data for future policy establishment.



[Figure 112] Fieldwork Methodology

IV. [Phase 3] Proposal of Guidelines for Climate Change Mitigation

Summary in Local Language (Sekilas tentang Bahasa Indonesia)

1. Pengembangan Indeks C4V

Indeks C4V dirancang untuk mengukur dan mengurangi kerentanan di wilayah perkotaan pesisir dengan berfokus pada tiga domain utama: penyakit, panas, dan pengelolaan air. Indeks ini dikembangkan dari data multidimensi yang mencakup faktor populasi, lingkungan, sosial, dan kebijakan. Indeks ini menyediakan indikator spasial dalam menilai risiko perubahan iklim di tingkat masyarakat.

Indeks ini bersifat interaktif, memungkinkan pengguna menerapkan bobot yang disesuaikan pada setiap domain, sehingga dapat disesuaikan dengan masing-masing tujuan perencanaan dan kebijakan. Untuk itu, sebuah situs web khusus (https://c4v.app) telah dikembangkan untuk memvisualisasikan peta kerentanan dan menyediakan sarana yang mudah diakses untuk perencanaan pengelolaan bencana.

2. Panduan Rencana Mitigasi Perubahan Iklim

Panduan ini dirancang untuk menghasilkan strategi yang dapat diterapkan dalam mengelola dampak perubahan iklim di tiga domain utama: penyakit, panas, dan pengelolaan air. Panduan ini menekankan solusi berbasis masyarakat, perencanaan kota, manajemen administratif, serta sistem tata kelola terpadu.

[Sektor Penyakit]

Panduan ini merekomendasikan perluasan akses layanan kesehatan, terutama bagi masyarakat berpenghasilan rendah, melalui pengembangan infrastruktur, unit kesehatan keliling, dan pusat kesehatan lokal. Disarankan untuk menerapkan

sistem peringatan dini untuk penyakit seperti demam berdarah, meningkatkan kondisi lingkungan perumahan dan sanitasi di area-area rentan, serta mengintegrasikan manajemen kesehatan ke dalam perencanaan kota. Kemitraan publik-swasta diusulkan untuk meningkatkan kapasitas layanan kesehatan, kemudian kampanye edukasi yang bertujuan meningkatkan kesadaran masyarakat tentang pencegahan penyakit.

[Sektor Panas]

Untuk mengatasi pulau panas perkotaan (urban heat island), panduan ini merekomendasikan perluasan ruang hijau, pengembangan atap dingin (cool roofs), dan penggunaan bahan reflektif dalam desain bangunan serta infrastruktur. Panduan ini menekankan integrasi infrastruktur biru-hijau seperti lanskap perkotaan yang mampu menyerap air serta mendukung penggunaan energi terbarukan. Strategi perencanaan perkotaan seperti Transit-Oriented Development (TOD) dan peningkatan sistem transportasi publik direkomendasikan untuk mengurangi emisi gas rumah kaca. Partisipasi masyarakat dalam penanaman pohon dan pengelolaan ruang hijau didorong untuk meningkatkan ketahanan masyarakat.

[Sektor Air]

Strategi pengelolaan air mencakup peningkatan sistem drainase, pembangunan fasilitas pemanenan air hujan, serta restorasi lahan basah dan hutan untuk mengurangi risiko banjir dan kekeringan. Panduan ini menekankan penggunaan teknologi air adaptif, seperti desalinasi osmosis balik (reverse osmosis/RO), dan penerapan sistem manajemen banjir dan kekeringan yang terintegrasi. Edukasi masyarakat tentang konservasi air dan pertanian kota disarankan dalam keterlibatan warga untuk penggunaan air yang berkelanjutan.

[Manajemen dan Tata Kelola Terpadu]

Panduan ini menyoroti pentingnya kolaborasi lintas sektor dan antar pemangku kepentingan. Rekomendasi mencakup pembentukan platform manajemen bencana

terpadu, sistem pemantauan waktu nyata, dan kerangka kerja layanan data terbuka. Peningkatan tata kelola mencakup penguatan kemitraan publik-swasta, pengembangan panduan respon bencana yang komprehensif, dan memastikan partisipasi aktif masyarakat dalam perencanaan kebencanaan. Integrasi infrastruktur hijau dan abu-abu diutamakan untuk menangani risiko langsung sekaligus mendorong ketahanan lingkungan pada jangka panjang.

[Rekomendasi-Rekomendasi Utama]

- Integrasi Kebijakan: Mengembangkan strategi perencanaan kota dan tanggap bencana yang mempertimbangkan kesalingterkaitan antara bencana-bencana penyakit, panas, dan air.
- Pemberdayaan Masyarakat: Melibatkan komunitas lokal dalam mengidentifikasi kerentanan dan mengimplementasikan solusi melalui metode-metode partisipatif seperti living lab.
- Inovasi dan Teknologi: Memanfaatkan sistem peringatan dini berbasis AI, teknologi pengelolaan air pintar, dan material bangunan berkelanjutan untuk meningkatkan ketahanan terhadap bencana.
- Pembangunan Kapasitas: Memberikan pelatihan bagi personel tanggap bencana dan anggota komunitas untuk memastikan pengetahuan dan kesiapan yang merata.
- Pembangunan Berkelanjutan: Mengintegrasikan infrastruktur tahan iklim dan energi terbarukan ke dalam pembangunan perkotaan untuk mengurangi risiko jangka panjang.

Secara keseluruhan, penelitian ini menyuguhkan kerangka kerja yang kokoh untuk mengurangi dampak perubahan iklim di kota-kota pesisir Indonesia. Melalui integrasi antara sarana inovatif seperti Indeks C4V dengan strategi-strategi partisipatif dan berbasis teknologi, panduan ini bertujuan untuk mengurangi kerentanan, meningkatkan ketahanan masyarakat, dan menjadi preseden dalam adaptasi perubahan iklim pada konteks perkotaan-perkotaan serupa.

Section1. Development of the C4V Index for Climate Change Mitigation

1. Research objectives

The C4V Index for Climate Change Mitigation aims to propose a vulnerability indicator to mitigate the impacts of climate change at the community level, specifically focusing on disease, heat, and water management.

- This research identified indicators to diagnose capacity factors for climate change mitigation by utilizing the impact factors related to disease, heat, and water management derived in Phase 1 and the core regional management capacity factors for climate adaptation and mitigation confirmed in Phase 2. To maximize the long-term mitigation of climate change impacts and enhance effectiveness, the research proposed short-term plans for water management, short- to medium-term plans for heat, and long-term plans for disease, thereby establishing a framework that ensures sustainable effects and continuous progress in climate change mitigation strategies.

2. Overview of the C4V Index

Through Phases 1 and 2, multidimensional data on population, social, environmental, and policy factors related to heat, disease, and water management were constructed, and the C4V (Coastal City Climate Change Vulnerability) Index was developed by comprehensively considering these factors.

- In this research, a website was developed to visualize and quantify vulnerability maps in three domains based on the detailed research results. These maps provide spatial indicators for assessing climate change vulnerability at the grid level. The C4V Index represents risk indicators for the three domains—disease, heat, and water management—as well as a comprehensive vulnerability

indicator. Rather than fixing weights for specific domains, the website allows users to apply weights according to their purposes and directly derive the C4V Index. Prior to deriving the C4V Index, the indices obtained through Phases 1 and 2 were normalized to a 10-point scale, as shown in [Figure 112], to ensure consistency, and the user-defined weights were applied through the website.



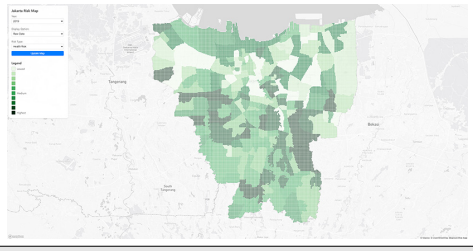
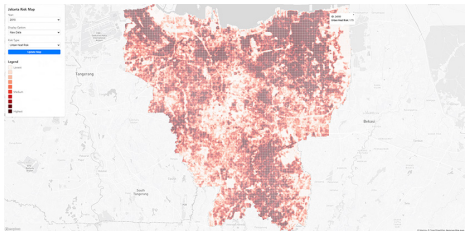
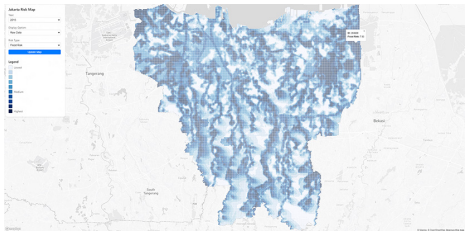
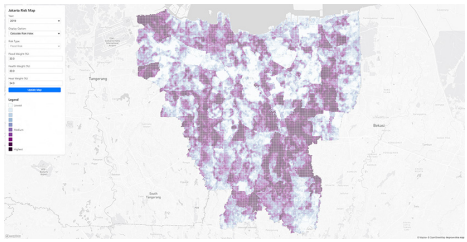
[Figure 113] C4V exponential normalization process

- For the composite disaster index, C4V, the system was designed to help users understand the disaster index more easily by normalizing the total score of 30 points, which is the sum of the indices for the three domains, to a 10-point scale. The formula for calculating the composite disaster index, based on user-defined weights, is shown in [Figure 114]. The weights were configured to ensure that the sum of the three weights does not exceed 100 (see Figure 112: Disease Weight + Flood Weight + Heat Weight = 100). The results of constructing the C4V Index at the spatial unit level are presented in 〈Table 45].
- C4V website address is as follows: https://c4v.app



[Figure 114] C4V exponential normalization process

〈Table 45〉 C4V index

Disease risk indicator	Heat island risk indicator
	
Flood Risk Indicators	**Comprehensive Vulnerability Indicators**
	

Section2. Overview of Guideline Establishment

1. Conceptual Definitions and Guideline Establishment Methods

1) Overview of Guidelines

According to the Cambridge Dictionary, a guideline is defined as “information intended to advise people on how something should be done or what something should be.” In Korea, while not legally binding, the term is used interchangeably with "guideline," "operational regulation," or "administrative rule," often carrying legal effect. However, the term "guideline" is generally used in a non-statutory context. Therefore, in Korea, although both legally effective guidelines and non-binding guidelines are referred to using the same English term, “guideline,” it is important to distinguish between them based on their legal implications. The guidelines proposed in this research align more closely with non-binding guidelines rather than those with legal effects under the Korean legal framework. Both laws and guidelines fall under the broader mechanism of regulation. However, they differ significantly in their status, nature, enforceability, enactment process, and scope of application. The distinctions between legally effective guidelines and non-binding guidelines can be summarized in 〈Table 46〉.

〈Table 46〉 Distinguishing the characteristics of laws and guidelines

Division	Laws	Guidelines
status	A law is a formal written rule established by a government or governing body that is enforceable and binding on individuals and organizations within a particular jurisdiction	Guidelines are often issued by government agencies, professional organizations, or agencies to provide advice, best practices, or recommendations on specific activities, industries, or situations
Enforceability	Violation of the law is likely to result in legal penalties such as fines, fines or imprisonment, depending on the severity of the violation	The guidelines are not legally binding and generally have no effect on the law. However, they are adopted in certain laws or regulations, referred to, or complementary roles to those laws
		Guidelines are intended to provide directions, criteria, or proposals for achieving a particular goal or standard, but they are generally self-contained unless explicitly included in a law or regulation

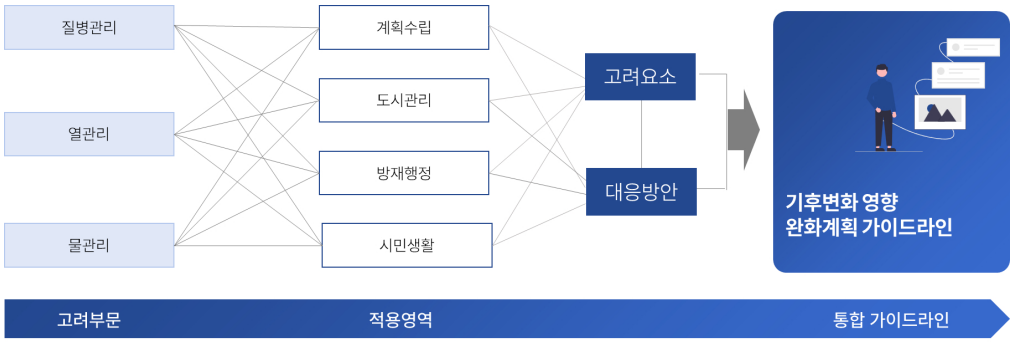
Division	Laws	Guidelines
Creation	Laws are generally enacted through voting and formal legislative procedures by legislative bodies	In addition to administrative authorities and public institutions, the private sector establishes it autonomously for specific purposes or for specific projects
Scope	The law focuses on regulation of a wide range of matters, including criminal, civil, administrative and regulatory issues	Allowing more flexibility and interpretation compared to the law, as it is not generally legally enforced

2) Establishing the Characteristics of the Guideline

By providing mitigation plan guidelines that consider the policy application and impact duration for heat (long-term), disease (short- to medium-term), and water (short-term), tailored climate change response strategies for Indonesian communities are established. The guidelines are developed in collaboration with two research partners from Diponegoro University, stakeholders (Korean-Indonesian advisory group and local residents), and international cooperation expert Professor Juhyun Lee. The guidelines are designed based on the phased results of the research. Through this research, the C4V (Coastal City Climate Change Vulnerability) Index was derived to mitigate the impacts of climate change on communities in terms of disease, heat, and water management. Based on solutions derived from the Living Lab, a "Climate Change Impact Mitigation Plan Guideline" is proposed. Unlike official guidelines used by the Indonesian central or local governments, this guideline draft is based on research into specific themes, reflecting the results of the analysis and solutions drawn from the local Living Lab. The guideline aims to be comprehensive, taking into account governance aspects in planning processes limited to heat, disease, and flooding, as well as urban management, disaster prevention administration, and citizen life. The nature of the proposed planning guideline is to serve as a "Climate Change Impact Mitigation Plan Guideline (draft)" to reduce or mitigate the effects of compound disasters (disease-heat-water) at the urban level in coastal areas of Indonesia. It consists of identifying health impact factors related to climate change in the fields of disease,

heat, and water management, proposing policies and plans to mitigate these factors, suggesting implementation plans for various stakeholders, and securing strategies for collaboration to continuously explore mitigation alternatives. Through continuous feedback with local research partnerships, the research aims to present policy directions, community strategies, and implementation plans to mitigate impacts in each field and to suggest the guideline as a community-based climate change mitigation measure in Indonesia. Ultimately, the purpose of the guideline developed in this research is to provide a frame of reference for drafting official manuals or guidelines aligned with laws, policies, and systems to respond to complex disasters involving heat, disease, and flooding in the Jakarta-Semarang coastal urban belt of Indonesia.

3) Method and Procedure for Guideline Establishment



[Figure 115] Method and procedure for setting up guidelines for responding to complex disasters

※ Coastal City Climate Change Vulability (C4V) is an indicator developed in this research and consists of disease risk indicators, heat island risk indicators, water resource list indicators, and comprehensive vulnerability indicators

Section3. Considerations for Guideline Establishment

1. Similar Guidelines of Korea

In accordance with Article 34-5 of Korea's Framework Act on the Management of Disasters and Safety, the approved crisis management manual is structured as follows.

〈Table 47〉 Composition of Korea's Crisis Management Manual

Division	Drafting Institution	Approving Institution
Crisis Management Standard Manual	Head of disaster management agency	Minister of Public Administration and Security
Working-level manual for crisis response	The head of a disaster management agency and the head of a related agency	A disaster management agency
Field Action Manual	The head of an institution designated by the head of an institution that prepares a working-level manual for crisis response	Head of disaster management agency (The on-site action manual prepared by the head of the mayor/gun/gu is approved by the mayor/governor)

Source: Ministry of Public Administration and Security, 2024, Natural Disaster Office Crisis Management Manual https://www.mois.go.kr/frt/sub/a06/b11/crisisManual/screen.do

As of December 31, 2022, Korea's crisis management manuals for disaster types are composed of 41 standard manuals, of which 8 are related to water, heat, and disease, as specified below.

〈Table 48〉 Korea's Crisis Management Manual on Water, Heat, and Disease

Division	Governing Institution	Standard manual
water-related	Ministry of Oceans and Fisheries	(4) Red tide, green tide, tide, storm and flood damage
	Ministry of Public Administration and Security	(1) Drought
	Ministry of Land, Infrastructure and Transport	(1) Dam (Ministry of Environment)
heat-related	Ministry of Public Administration and Security	(1) Heatwave
Disease-related	Ministry of Health and Welfare	(1) Infectious disease

Source: Ministry of Public Administration and Security, 2024, Natural Disaster Office Crisis Management Manual https://www.mois.go.kr/frt/sub/a06/b11/crisisManual/screen.do

2. Indonesia's Climate Disaster Related Policies and Plans

1) Review of Indonesia's Relevant Key Plans and Derivation of Guideline Considerations

① National Adaptation Plans (NAPs) (2019)

The NAPs identify four priority sectors impacted by climate change: marine and coastal areas, water, agriculture, and health. However, urban areas themselves are not considered a key sector. This omission reflects Indonesia's unique characteristics as a tropical country with an extensive coastline, high population density in coastal regions, a significant dependence on agricultural production and natural resources, relatively low adaptive capacity, and high climatic vulnerability.

The NAPs outline nine detailed climate hazard factors for the four sectors, including floods, water usage, droughts, reduced fisheries and agricultural production, coastal flooding affecting coastal slopes, marine (navigation) safety, sediment changes, reduced navigation range for small fishing vessels, and increased vector-borne diseases and heat stress in urban areas.[4)]

② The National Action Plan (RAN API) under the National Climate Change Adaptation Plan

The National Adaptation Plan (NAPs) proposes the RAN API (Approach in Development Planning) for climate change adaptation. This plan introduces four climate change adaptation clusters and proposes considerations for adaptation strategies across the four nationally significant priority sectors (refer to Table 49).

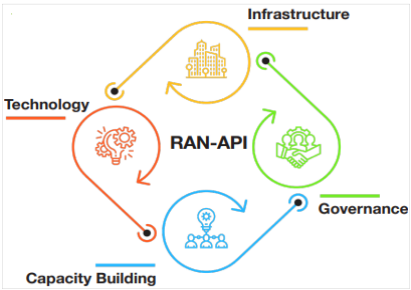
The RAN API serves as a reference for related agencies and local governments to establish action plans or strategies aligned with the central government's direction to address climate change impacts.[5)]

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4) Kementerian PPB/Bappenas, 2019, National Adaptation Plan, Executive Summary, p.7)
5) Kementerian PPB/Bappenas, 2019, National Adaptation Plan, Executive Summary, p.13)

〈Table 49〉 National Action Plan (RAN API) by National Climate Change Adaptation Plan

Preferred sector	Strategic Division	(Common) Considerations
Oceans and coasts	infrastructure, technology, capacity building, governance	Gender Sensitivity, Vulnerable Groups, Ecological Base, Landscape Base, Spatial Base, Financial Innovation, (Information Sharing)
Water		
agriculture		
health		
Policy Direction and Power Promotion of the National Action Plan		



Source: Kementerian PPB/Bappenas, 2019, NATIONAL ADAPTATION PLAN, EXECUTIVE SUMMARY

Meanwhile, the main contents of the climate change adaptation sector are as follows (Table 50).

〈Table 50〉 Climate change adaptation sector (package)

Strategic Division	Key Presentations
Infrastructure	- Resilience to climate impacts, ecosystem foundation, and improvement (improvement) are possible - Green infrastructure in harmony with landscape and nature or using environmentally friendly and affordable technology - Consider climate variability and climate change impacts and help reduce complex risks - Consideration of the low-income and vulnerable groups
Technology	- Development and application of technology as a scientific method to address the potential impact on humans and the environment Adaptation technology can respond to the potential impact of climate change - Meet the development objectives - cost-effective - environmentally friendly - culturally compatible - socially acceptable

Strategic Division	Key Presentations
Capacity building	- Stakeholders design different actions to reduce climate change - Reliable measures to overcome and monitor climate change impacts, adaptations, losses and damages - Monitor climate-related parameters and present new technologies and methods - Raising awareness of climate change
Governance	- Regulatory system and coordination for the adaptation efforts of development entities such as the government, private sector, and local communities - Governance includes regulatory systems and coordination for the adaptation of development entities such as government, private sector, and local communities - Apply principles of inclusivity, transparency, easy access to information, and accountability to implement through coordination of development factors

Source: Kementerian PPB/Bappenas, 2019, NATIONAL ADAPTATION PLAN, EXECUTIVE SUMMARY, p.16

③ Implementation of the Promotion Strategy of the Four Priority Sector for Adaptation to Climate Change

〈Table 51〉 Marine·Ocean sector

Cluster	Delivery Strategy	Indicative Intervention
Infrastructure	- Infrastructure that takes into account the characteristics of coastal terrain in areas with high vulnerability to climate change impacts - Combining ecosystem-based adaptation (EbA) and community-based adaptation (CbA) approaches - Reducing erosion risk in coastal areas	- Ocean Belt (Geotextile Bag/KGM) Construction - Construction of rigid structures: beach belts, hybrid structures, concrete structures - Construction of soft structures: mangrove planting or coastal vegetation), green belts - Composite sluice gates: Installation of automatic sluice gates for drainage in urban flood channels by utilizing water level differences in flood channels.
Technology	- Applying ocean survey technology to detect fish stocks and prevent climate change-induced catch declines	- Remotely Operated Vehicle (ROV) Ocean Survey Technology
	- Technology to detect extreme waves to reduce shipping accidents	- Automatic Identification System (AIS) Technical Use - VTS Technical: Automated tracking of vessels and vessel traffic

Cluster	Delivery Strategy	Indicative Intervention
	- Adaptation to shoreline change due to climate change impacts: applying innovative coastal monitoring systems in areas where spatial planning for sea level rise and climate extremes is needed	- Application of phyto-sandbar artificial technology
	- Increase fishing time certainty and reduce navigation risks from extreme waves for fishermen	- Innovative, adaptable, fiberglass small fishing boat
Capacity building	- Support fishing with standardization of 10+ GT fishing boats	- Manufacturing ToT fishing boats with fiberglass raw materials
	- Providing livelihoods to small-scale fishermen who are unable to go to sea due to extreme weather.	- Empowering cooperatives and fishermen's organizations - Weather index insuarance
	- Strengthening disaster response capacity in coastal areas	- Support for fisherfolk organizations, communities, and local governments
	- Engaging social organizations in coastal areas to apply ecosystem-based adaptation concepts	- Community-based coastal ecosystem management
Governance	- Increasing capacity and access to ocean climate information for small-scale fishers	- Making fisheries information easily accessible - Early warning systems - Education, counseling and public awareness
	- Regulatory mechanisms and information on high wave risk, fishing vessel types, and vessel capacities.	- Technical inputs on climate risk for disaster-related regulations in coastal areas and small island states - Technical inputs on climate risk for marine and coastal regulation - Disaster risk mapping in coastal areas - Regulating fisheries management in regulated areas or marine protected areas

Source: Kementerian PPB/Bappenas, 2019, NATIONAL ADAPTATION PLAN, EXECUTIVE SUMMARY, p.24

〈Table 52〉 Water sector

Cluster	Delivery Strategy	Indicative Intervention
Infrastructure	- Considering areas threatened by drought and flooding - Calculation of capacity based on number of households affected, size of agricultural land, and industry - Considering the number and location of areas with increasing rainfall intensity	- construction of a dam - Installation of the reservoir - Vegetation management in the upper regions - Prepare alternative sources of clean water, improve construction and structure for rainwater storage
	- Adjusting technical capabilities based on rainfall forecasting	- The adjustment of the city's drains
	- Adjusting freshwater management in coastal areas to account for the threat of rising sea levels	- Soil penetration facilities and control
Technology	- Development of superior climate-resistant varieties utilizing biotechnology	- Weather Control Technology (Rain Reduction)
	- Store water in reservoirs to meet freshwater needs	- Weather control technology (reduction of precipitation)
	- Water replenishment with aquifers	- Water injection technology
	- real-time water rationing in drought areas	- Technology to detect leaks and determine water consumption
Capacity building	- Increasing public awareness to use and manage water resources during drought periods	- an increase in public awareness - Increase in community capacity through training, public relations, etc
Governance	- Development or improvement of adaptive engineering design, technical standards, infrastructure	- Technical input to revision of national buildings and operating standards
	- Determination of underground water protection zones (KLA) in the basin, reforestation of forests in the basin, and restrictions on forest use	- Putting technology into policies on groundwater protection zone (KLA) regulations
	- Water resource management to increase water availability to meet household, agricultural and industrial water needs	- Publishing of master plan development norms, standards, procedures and standards for climate change adaptive drinking water supply systems
	- Resource management to improve environmental quality	- Securing Environmentally Safe Water

Source: Kementerian PPB/Bappenas, 2019, NATIONAL ADAPTATION PLAN, EXECUTIVE SUMMARY, p.21

〈Table 53〉 Agricultural sector

Cluster	Delivery Strategy	Indicative Intervention
Infrastructure	- Meeting agricultural water requirements in agricultural centers with frequent droughts and crop failures	- construction of dams, reservoirs, and reservoirs for irrigation - Construction and maintenance of irrigation networks - normalization of rivers, dams and other reservoirs - Piping and shallow wells, drip irrigation and sprinkler irrigation systems
	- Water and soil conservation improve soil characteristics of dry and important land to better preserve water	- Extension of sowing time in drought conditions through rainwater harvesting (integrated small storage facilities) - Increase the use of organic fertilizers and reduce the use of chemical fertilizers - Use of cocopit for seedbeds in abandoned mine areas and important land
Technology	- Development of superior varieties that are strong in the future using biotechnology technology	- Development of superior varieties of plants resistant to climate stress and insect pests. - Development of rice varieties resistant to floods, droughts, salts and pests. - Development of high-salt-resistant rice varieties using specific microorganisms. - a high-nutrient tuber that endures extreme climates
	- Agricultural innovation and technology enhancement considering climate impact and food security	- Utilizing technology for precision agriculture and smart agriculture. - Use sensors (such as video/drone/CCTV) that can determine the moisture content and soil chemistry of agricultural land. - Development of a geographic information system for nutrient and water scarcity points, modeling the water balance and plant nutrients on land - Automation of water supply and fertilizer tools based on land characteristics
	- Adoption and modification of technology to identify plant growth and record water and nutrient usage	- Monitor discussion using Modis and Sentinel-2 images
	- Adjust planting times according to seasonal forecasts to avoid drought	- Integrated planning calendar information system - Determine if the season and region is right for the right crop product - Climate Prediction for Agriculture

Cluster	Delivery Strategy	Indicative Intervention
	- Strengthen agricultural innovation to increase food production in addition to major commodities (rice) considering climate impact	- Development of saline tilapia with high salt tolerance - Development of a nutritious pool that is resistant to climate stress - Improving the Quality of Livestock Feed to Overcome Heat Stress - Development of Livestock Vaccines to Respond to Heat Stress - Development of blue-chip livestock genes resistant to climate stress
	- Use technology to increase rice production by supplying irrigation water to agricultural land during the dry season	- Weather Adjustment Technology to Supplement Agricultural Reservoirs and Forecast Drought in Food Production Centres - a solar water pump.
Capacity building	- Promote farmers' understanding of climate information useful for determining when to plant crops and agricultural practices	- Climate Field School
	- Educate farmers to take advantage of innovation and agricultural technologies (climate-resistant superior varieties, precision farming methods, cultivation calendars, agricultural information systems)	- Support and promotion of farmers' organizations, etc
	- Understanding the agriculture business related to climate smart farming strategies	- Support and promotion of agricultural enterprises
	- Improve institutional capacity and agricultural human resources	- Training of executives and members of agricultural institutions (occupations) related to the implementation of agricultural climate information systems, database management, and precision farming methods
Governance	- Improve the effectiveness of water and fertilizer use to increase crop productivity, cost-effectiveness, and reduce greenhouse gas emissions	- Apply precision farming methods to strategic agricultural land - intermittent irrigation application to rice paddies - Use agricultural waste (household manure) in plants - Integrated cultivation of several types of plants on one farmland.

Cluster	Delivery Strategy	Indicative Intervention
	- Development of Integrated Agricultural Database as part of Climate Smart Agricultural Strategy	- Map of the location and characteristics of farmland development (both the negative and positive effects of climate change) - Map data and information resources - Strengthening cooperation among agricultural sector organizations
	- Provide alternative financing for farmland in the event of climate failure	- climate-based agricultural insurance - Encourage financial and manufacturing utilization of agricultural investment products
	- Strengthen distribution and agricultural markets in accordance with climate smart agricultural strategies	- Review and strengthen regulations related to agricultural business chains - Create new agricultural markets (trade in agricultural innovation technologies between researchers and companies and other agricultural entrepreneurs). - cooperation with telecommunications operators. - Strengthen small and medium-sized enterprises (BUMDs) and agricultural enterprises - Application of environmental and climate -considered operating standards (ISOs)

Source: Kementerian PPB/Bappenas, 2019, NATIONAL ADAPTATION PLAN, EXECUTIVE SUMMARY, 22~23

〈Table 54〉 Health sector

Cluster	Delivery Strategy	Indicative Intervention
infrastructure	- Build the right infrastructure in a location where DHF is highly vulnerable	- Housing and buildings in compliance with building health standards
	- When calculating the capacity of a health facility, consider the potential location of DHF occurrence	- Increasing the capacity of health facilities
	- Strengthen environmental health based on the characteristics of the outbreak area	- Implementation of Community-Based Hygiene (STBM) - Providing clean water and minimal means of livelihood - Fogging (Dengue heat medium eradication) - Additional Open Space (RTH)

Cluster	Delivery Strategy	Indicative Intervention
technology	- availability of DHF occurrence information and early warning systems	- Development of DBD-Klim Early Warning and Information System for Prevention of Occurrence (Daily Reporting System). - Complete data and information
	- Modeling potential vector-borne disease outbreaks (number and duration of infection)	- Health Biological Monitoring of Climate Change Diseases
capacity building	- Promote understanding of communities, especially vulnerable groups, on climate change diseases	- early education on the effects of climate change - Add Public Health and Climate Curriculum to Beginner Curriculum (Natural Science) - Improve climate risk knowledge for health promoters and wiggler surveillance - Spread awareness and raise awareness of prevention and disease control in potential outbreak areas
governance	- Activation of laws and programs for prevention and transmission control based on expected signs of DHF occurrence	- revised disease prevention guidelines - On-site inspection of disease prevention programs - Adjustment of Health Building Standardization
	- Maximize community-based adaptation in preventing/response to DHF outbreaks	- Use of simple technology to prevent dengue transmission and supply clean water (DBD cap)
	- Home-based adaptation (active community involvement to reduce vulnerability at home scale).	Adaptation to climate change in the health sector at the household level: - Women in family welfare (home and neighborhood) - a local youth community - Other village-level communities

Source: Kementerian PPB/Bappenas, 2019, NATIONAL ADAPTATION PLAN, EXECUTIVE SUMMARY, p.25

2) Indonesia's Disaster Management Authority: National Disaster Management Agency (BNPB)[6)]

Indonesia's national disaster management authority is the Indonesian National Board for Disaster Management (BNPB; Badan Nasional Penanggulangan Bencana). Established under Indonesia's Law Number 24 of 2007, its roles and responsibilities are defined across three stages: before, during, and after disaster events. Disaster management at the local level is handled by the Regional Disaster Management Agencies (BPBD; Badan Penanggulangan Bencana Daerah) of each province and regency. The BPBD operates as a subordinate body to the BNPB, carrying out equivalent roles and responsibilities.

Under Indonesian law, flood forecasting and warning systems are closely linked to disaster preparedness measures before disaster events and involve close collaboration with both BNPB and BPBD. However, due to the need for specialized knowledge in water resources and integrated watershed management, BNPB alone faces limitations in fully implementing these systems.

Separately, the River Basin Management Agency (BBWS) is responsible for tasks such as watershed and river monitoring, flood analysis, and integrated watershed management. This has resulted in a dual structure for operating the flood forecasting and warning systems, involving both the River Basin Management Agency and BPBD.

Currently, the collection of hydrological data, flood analysis, and forecasting fall under the jurisdiction of the River Basin Management Agency. In contrast, BPBD oversees issuing warnings to the public, conducting damage assessments, and managing recovery efforts based on the hydrological data and analysis results. This division reflects Indonesia's current reality, where there is no established track record of flood forecasting and warning system operations.

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6) KOICA Indonesia Office (Southeast Asia Division 2), 2019, "Master Plan for the Second Phase of the Flood Forecasting and Warning System in the Citarum River Basin (2020–2023)," p.34)

3) Establishment of 'Low Carbon Development Plan' in Jakarta[7)]

① Overview of Planning

In Indonesia, Jakarta became the first province to establish a comprehensive regulatory policy at the regional level that integrates climate change mitigation and adaptation activities to help achieve the nation's greenhouse gas reduction targets. This initiative, known as the "Regional Low Carbon Development Plan," links climate change agendas with regional development. Additionally, Indonesia, under the Paris Climate Agreement, has set a national greenhouse gas reduction target of reducing emissions by at least 29% by 2030, with a maximum reduction of 41% achievable through international support.

However, despite efforts by the central government and the international community, local governments have struggled to establish procedures that include and engage diverse stakeholders. Particularly, integrating and synchronizing climate change-related activities vertically between the central and local governments has been identified as the most critical factor in achieving the national greenhouse gas reduction target. To address this, the central government has encouraged local governments to voluntarily develop low-carbon development plans that include their own greenhouse gas reduction targets.

In Jakarta, Governor Regulation No. 90 of 2021, titled "Climate Resilient Regional Low Carbon Development Plan," was established, including detailed plans. This regulation represents a comprehensive regional policy that integrates Jakarta's climate change mitigation and adaptation efforts. According to Jakarta Governor Anies Baswedan, Jakarta is the first province in Indonesia to develop a low-carbon development plan in response to the "2020-2024 National Medium-Term Development Plan," and this makes Jakarta the first region to legally regulate climate change-related activities.

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7) Seoul Institute, 2022, World Urban Trends, No. 526 (https://www.si.re.kr/node/66100)

Jakarta's "Regional Low Carbon Development Plan" is an ambitious policy aimed at contributing to the Paris Climate Agreement and Indonesia's national greenhouse gas reduction targets. It emphasizes climate change adaptation activities, which are often undervalued, and incorporates climate change-linked regional development as a core policy. The plan focuses on reducing the vulnerability of disaster-prone areas caused by climate change and enhancing the resilience of local communities.

② Key Contents of the Plan

The Jakarta provincial government aims to transform Jakarta into a climate-resilient city, setting a target to reduce greenhouse gas emissions by a minimum of 30% to a maximum of 50% by 2030 and achieve net-zero emissions by 2050. Major direct and indirect sources of greenhouse gas emissions in Jakarta include energy, waste management, and agriculture, forestry, and fisheries. In 2020, Jakarta's annual greenhouse gas emissions reached approximately 50 million tons of CO2 equivalent (CO2eq). Notably, the energy sector, including the use of fossil fuels in power generation, residential and industrial electricity consumption, and the transportation sector, accounts for a significant share of greenhouse gas emissions.

Climate change mitigation activities in Jakarta are organized into 11 actions across four sectors: energy, agriculture, forestry, and fisheries; waste management; and industrial processes. The details of these activities are presented in 〈Table 54〉.

〈Table 55〉 Climate Change Mitigation Activities in Jakarta

Sector	Activities	Details
Energy	Increase energy efficiency	- Applying green building principles to government buildings and private buildings, efficient use and preservation of energy - Installation of energy-saving streetlights - Provide incentives to green building owners - Transforming the existing Government House to Green Architecture - Government buildings hold lighting-off events three times a year

Sector	Activities	Details
	Expanding the use of renewable energy	- Installing rooftop solar panels - Establishment of Roadmap for Expansion of Renewable Energy Use through Regional Energy General Plan
	Replace with greener fuels	- Introduction of Electric Vehicles on Express Buses - Encourage the use of electric vehicles as government vehicles - Development of Electric Vehicle Support Infrastructure
	Expansion of public transportation	- Optimization of station integration between public transportation - Subway and Light Rail Construction Completed - Promotion of public transportation-oriented development (TOD) - Establishment of regulatory policies for the imposition/implementation of congestion charges and high parking charges in urban areas
	Integration of Walking and Bicycle Use with Existing Public Transportation	- Establishment of routes and facilities for cyclists - Optimization of pedestrian paths and the creation of pedestrian support facilities - Creating a Low Carbon Zone
Agriculture, Forestry and Fisheries	Increased absorption of greenhouse gases	- Planting Conservation Monitoring System - Create open parks and green spaces - Encourage the creation of a rooftop garden in the community - Create a green open space for announcements - Development and Optimization of Urban Agriculture Programs
Waste	Reduce waste emissions by source	- Expanding the installation of waste recycling centers - Optimized 3R (reduction, reuse, recycling) activities - Periodic waste collection and transportation implementation
	Optimization of wastewater treatment	- Optimizing the use of septic tanks, eradicating on-road excreta - Optimization of wastewater treatment facilities
	Improve the waste disposal process	- the construction of a waste incineration power plant - Gathering data to secure investment resources
Industry process	Environmentally Friendly Energy Utilization	- Replace with fuel and gas that meet Euro 4 standards
ETC	Climate change diplomacy	- Encourage other Indonesian cities to join in developing low-carbon development plans - Create an atmosphere of private participation in development projects that support low-carbon development - Optimizing the role of the Climate Change Mitigation and Adaptation Activities Department

In the case of climate change adaptation activities, these are organized into 11 actions across 7 sectors—healthcare, water resources, coastal and island areas, energy, food security, residential areas, and infrastructure—to enhance the resilience of communities vulnerable to disasters caused by climate change. The details are presented in 〈Table 55〉.

〈Table 56〉 Jakarta Climate Change Adaptation Activities

Sector	Activities	Details
Health	Supply and improvement of health service facilities	- Agile ambulance delivery for patient response - Provide an oxygen respirator for disaster management - Expand access to quality health services in times of public health crisis - Expanding the scope of health services and strengthening the capacity of local communities - Equipment support for disabled people with physical disabilities
	Health Service Management	- Achieving 100% Basic Immunity in Infants and Young Adults - Standard health service management for infants, school children, and the elderly - Investigation and management of potential specific diseases and specific events - Emergency service management before hospital transfer through integrated emergency management system
Water resources	Education and awareness of health programs in the community	- Encouraging Healthy Community Health Activities - Social support for orphans, the homeless, the elderly living alone, and the disabled
	domestic sewage management	- Construction and Improvement of Living Sewage Management System
Coast and Islands Area	Infiltration management	- Construction of a penetrating well that quickly penetrates rainwater into the ground
	flood control activities	- Construction of reservoirs, dams, connection channels, bridges, floodgates, etc - Installation of flood control pump - the purchase of land for river water management
	Coastal and island management	- Planting tree species on the beach, such as mangrove trees - Establishment of fishing centers and villages to adapt to climate change - Establishment of regulations on incentives and reverse (逆) incentives for coastal/island area management

Sector	Activities	Details
Energy	Environmentally Friendly Energy Utilization	- Replace with fuel and gas that meet Euro 4 standards
Food Security	Food security enhancement	- The supply of farmable fish seeds - The introduction of hydroponics to vegetable cultivation - Supply of aquaculture facilities and infrastructure - Maintenance of mother trees and tree seeds
residence Area	Maintenance of residential areas	- Apartment construction - Improves access to affordable housing for people who cannot afford their own homes - Improvement of infrastructure in residential areas - redevelopment of old apartments
Infrastructure	Resilient to climate change Infrastructure creation	- Infrastructure Recovery and Reconstruction in the event of a disaster/disaster - Maintenance of roads, bridges, intersections, walkways, etc. from time to time - Encouraging Green Architecture

4) Jakarta's "100 Most Resilient Cities for Recovery" Program[8)]

Jakarta, Indonesia, which participated in the Rockefeller Foundation's "100 Resilient Cities for Resilience" program to prevent various urban problems from a long-term and sustainable perspective and increase response capabilities, recently announced the Jakarta Resilience Strategy, which consists of three main concepts of "prepared, healthy, connected" and detailed strategies. In particular, Jakarta has been participating in the "Top 100 Resilient Cities" program since May 2016, and the Rockefeller Foundation program (2013-2019) has decided to provide a total of $8 million (W9.7 billion) for the continuous resilience activities of member cities

is an international network between cities and a program that supports the improvement of resilience in many cities around the world in response to increasingly frequent physical, social, and economic challenges in the 21st century.

Jakarta's urban resilience strategy is largely composed of three main concepts. They are 'Ready Jakarta', 'Healthy Jakarta', and 'Connected Jakarta'.

8) Seoul Institute, 2019, World Urban Trends, No. 465 (https://www.si.re.kr/node/62524)

〈Table 57〉 Jakarta Urban Resilience Strategy

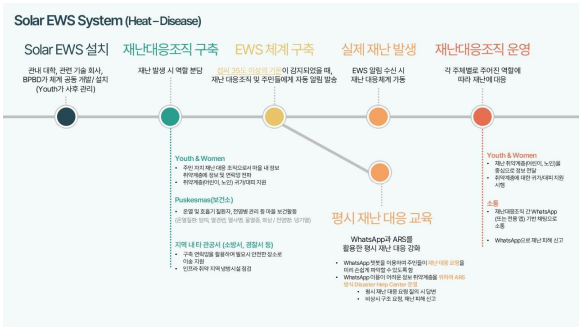
Division	Details
Prepared Jakarta	- A city capable of mitigating and adapting various pressures and shocks, such as the effects of climate change and the risk of disasters - Lower vulnerability levels across Jakarta to 'low' 80% and 'moderate' 20% by 2030
Healthy Jakarta	- Cities that ensure clean drinking water, sewage and access to sustainable waste management services - 100% provision of clean drinking water by 2030, 100% management of sewage by 2050, eradication of street defecation by 2024, and 100% environmentally friendly waste discharge management by 2025
connected Jakarta	- A city that improves connectivity and mobility by providing affordable public transportation available to all citizens and a network to communicate with each other - 60% of public transport utilization in Jakarta's metropolitan area by 2030 and 100% of citizens' access to the public information system by 2030

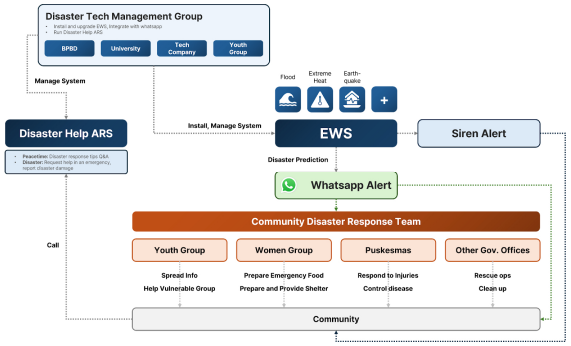
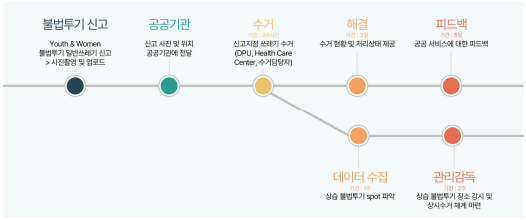
• Jakarta's urban resilience strategy is being developed and implemented over the long term, consisting of 12 directions and 32 strategies under three main concepts. The vision of resilience is defined as providing all citizens with equal opportunities to live safely, healthily, prosperously, and happily through public services and innovation. Additionally, the cities in the network appoint a "Chief Resilience Officer" (CRO) to support the development of resilience strategies and network activities.

3. Consideration of the Guidelines Based on the Results of the Local Living Lab

As a result of conducting Living Labs in two locations in Indonesia (Meteseh and Tambakrejo), key issues to be considered in response to compound disasters were identified, and solutions were proposed as follows (Table 57).

〈Table 58〉 Derivation of problems and search for alternatives through local living labs

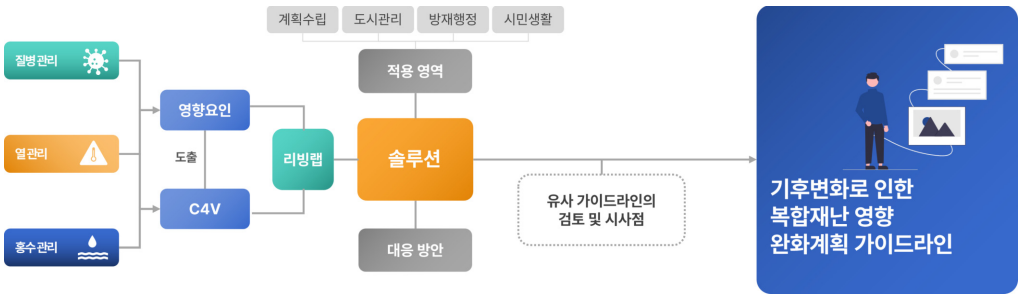
Key problems	Solution alternatives
(M) Inability to provide adequate water resources (household water) - Quality issues, water shortages, etc. due to lack of infrastructure	- Installation of water purification filters - Installing Rooftop Greening and Water Purification Unit - Rainwater 〉 Roof Garden 〉 Storage 〉 Purification Filter 〉 Use as Living Water
(M, T) Late Disaster Alert System (M, T) Lack of information (already government agencies provide information on disasters/diseases, but limited access to information for the digital underprivileged)	- Need to close digital gaps related to disasters and health and expand access to information - Building a Community-Based Disaster Preparedness Information System (1) Installing solar EWS using solar power, (2) establishing a community-specific disaster response organization for disaster response, (3) establishing an automatic notification sending system after detecting the Solar EWS (alert in the village with sirens, sending messages to disaster response organizations and evacuation messages to villagers through Whatsapp), (4) training and operation of disaster response organizations (oriented by Youth groups in the village), and training in normal disaster response (created a Whatsapp chatbot) - Example (thermal disaster) 

Key problems	Solution alternatives
	- System Algorithms 
(M, T) Waste disposal and incineration	- Waste Bank for Waste Disposal Targets Recycled Collection - The collection rate for general waste is low, so it needs to be managed - In particular, waste shock, etc., which automatically collects waste due to the need for unauthorized disposal of waste in rivers/sea/reserves, was introduced - General waste collection officer (low-income class) in the area and waste collection costs are paid and managed - Report on illegal speculation led by residents by developing an application for reporting illegal speculation (case: report of smart inconvenience in Seoul)Linkage with local community activities - ** Order (1) Distribution of applications for reporting illegal dumping (simultaneous manual and training) and designation of a person in charge of garbage collection (2) Supply of automated garbage collection drones (3) Family education and management 
(T) Drainage problems due to low-lying and ground subsidence	
(M) Reduced green space due to reckless development (increased flood speed)	- Rainwater gardens affect the storage of rainwater in the outside area to reuse water and reduce surface temperature - Creating a Rainwater Garden by Utilizing Spaces Between Houses - The community establishes rainwater gardens by identifying scraps in the village (in areas where water is frequently collected and garbage is frequently dumped)

Key problems	Solution alternatives
	- The public will implement rainwater garden support projects and use DPU's puddle data to identify the point where rainwater is collected and communicate information to local residents, install and maintain irrigation facilities
(M, T) Lack of planting to reduce flood and heat damage	- Planting for disaster prevention and damage reduction - Planting tropical plants that are mainly resistant to water (drought, flood) so that they can withstand long-term dry seasons and plants that are resistant to flood - Planting is classified based on the following criteria (1) Applicable to rooftop greening and rain garden (2) Planting around the river that can act as a water absorption and barrier (+salt-resistant planting) (3) Planting that can withstand long dry seasons or areas where water is scarce - Conducting education to enhance understanding of the local environment for local planting for residents - Formation of organizations and planting activities to manage green areas (urban agriculture, rain gardens) in public land and idle land for communities - Public: (1) Short term: Provide plants and fertilizers to residents to support initial installation costs, (2) provide minimal manuals for continuous management so that residents can create their own green spaces, (3) manage whether the system is settled through long term green space monitoring  **레인가든/옥상녹화 식재 타임라인** 식재 역할: 배수, 토양 정화, 토양 침식 방지, 갈초 억제, 미관 적용 지역 / 식물 종류 / 유형 / 식재 시기 / 정착 기간 / 적용 방식 / 주요 역할 / 세부 역할 / 특징 Meteseh / Bachiteta accumbons / 초본 / 11월 / 11월 ~ 2월 / 옥상녹화 / 홍수 저감, 열섬 완화 / 배수, 침식 방지, 갈초 억제, 토양 정화 / • 오염된 토양에 내성 • 심한 홍수에는 약함 Panicum maximum / 초본 / 11월 / 11월 ~ 2월 / 레인가든, 옥상녹화 / 홍수 방지, 열섬 완화 / 배수, 침식 방지 / • 척박한 환경에 적응 • 장기간의 건기에 내성 Paspalum vaginatum (seashore paspalum) / 초본 / 11월 / 11월 ~ 2월 / 레인가든 / 홍수 방지, 홍수 저감, 열섬 완화 / 배수, 침식 방지 / • 수변(염수 해안)에서 성장 • Paspalum distichum는 담수에 안착(자라는 듯함) Tambalekip / Axonopus compressus (Broadleaf carpet grass) / 초본 / 11월 / 11월 ~ 2월 / 옥상녹화 / 열섬 완화 / 토양 정화, 미관 / • 습도가 높은 곳에서 생장 • 그늘진 환경 선호 • 농장적 토양 덮개로 사용 • 염도 내성 낮음 Axonopus compressus (Broadleaf carpet grass) / 초본 / 11월 / 11월 ~ 2월 / 옥상녹화 / 홍수 저감, 열섬 완화 / 침식 방지, 미관 / • 습도가 높은 곳에서 생장 • 그늘진 환경 선호 • 농장적 토양 덮개로 사용 • 염도 내성 낮음 Both / Gamba Grass (Andropogon gayanus) / 초본 / 11월 / 11월 ~ 2월 / 레인가든, 옥상녹화 / 홍수 저감, 열섬 완화 / 침식 방지 / • 다양한 토양환경에 적응 • 계절성 습지에서 발생 • 침수토양에 잘 적응
(T) Increasing the Heat Impact of Residential Buildings	- White Cool Roof: Using white thermoplastic film paint on the roof reduces indoor temperature by 4 degrees, cooling energy by 20% on average - Implementation of Community Support Projects 〉 Cool Roof Adaptation Education 〉 Implementation of Support Projects 〉 Identify and Priority Support for the Energy Underprivileged (When implementing support projects in the public, women/youth communities in the region provide priority to the energy underprivileged)

Section4. Guideline Organization

1. Climate Change Impact Mitigation Plan Guideline Framework



[Figure 116] Method and procedure for setting up guidelines for responding to complex disasters

1) Purpose of the Guidelines

The purpose of this guideline is to support local government authorities in setting policy priorities for climate change impact mitigation, as well as to establish citizen action protocols for disaster response in order to protect citizens from disasters. To achieve this, the findings derived from the research analysis are allocated to applicable domains (planning, management, administration, and daily life), and guidelines are provided for the corresponding considerations and response strategies.

2. Key Considerations by Research Sector

1) The disease sector

In Indonesia, cities expected to have very high cases of Dengue Hemorrhagic Fever (DHF) by 2045 include Pekanbaru, Palembang, Banjarbaru, Banjarmasin, Samarinda, Tarakan, Kolaka, Ambon, Semarang, Bali, and Kupang. Additionally, the possibility of malaria and pneumonia is expected to increase due to changes in rainfall and temperature.[9)]

In the health and medical sector, the following actions are deemed necessary for climate resilience.

〈Table 59〉 Response activities in the health and medical sectors for climate restoration in Indonesia

an action group	the contents of an act
Expansion of health and medical facilities	- Expanding the capacity of hospitals, community health centers and public health facilities - Set up a small health service center in residential areas
the promotion of environmental health in the region	- Form integrated residential areas that are harmonized with nature and take into account climate change - Construction of Sanitary Facilities and Infrastructure in Residential Areas - Construction of water supply facilities and infrastructure - Application of Simple Technology to Prevent Mosquito Infestation

Source: Kementerian PPN/ Bappenas, List of Priority Locations and Climate Resilence Actions, 2021, 64-65

2) Heat Sector

Indonesia, with its rapidly urbanizing process, high population density, tropical climate, and coastal city characteristics, requires essential measures for mitigating and adapting to the urban heat island effect. Some of the measures considered to address the heat island effect include the expansion of urban green spaces and mangrove restoration, with coastal cities like Jakarta and Semarang expected to benefit significantly from mangrove restoration. Additionally, there is a need to introduce various methods and technologies, such as the use of cool roofs and reflective building materials, combining blue-green infrastructure, and systems that capture and store rainwater for use in cooling green spaces or roads.

3) Flood Sector

According to Indonesia's National Long-Term Development Plan (RPJPN, 2005-2025), the third National Medium-Term Development Plan (RPJMN,

9) Kementerian PPN/Bappenas, List of Priority Locations and Climate Resilience Actions, 2021, p.6

2015-2019) emphasizes key water management areas, including flood management, strengthening government policy implementation capabilities for improving water supply and utilization, promoting integrated water management systems, supporting the development of water-related infrastructure, and providing water supply and drainage systems for underserved areas to support inclusive development. [10)]

In response to water-related disasters in Indonesia, the central government's Indonesian National Board for Disaster Management (BNPB; Badan Nasional Penanggulangan Bencana) and local government disaster management agencies (BPBD; Badan Penanggulangan Bencana Daerah) are responsible for managing these issues. [11)]

Additionally, through KOICA's projects, the first phase of the "Flood Forecasting and Warning System Development in the Citarum River Basin" was carried out from 2014 to 2017 (with a $5 million budget), focusing on the upper Citarum River Basin (Bandung region). The project successfully introduced Indonesia's first "real-time" flood forecasting and warning system. The second phase of the project, aimed at expanding this system into a standardized landmark system that can be applied nationwide, is currently underway. [12)]

It is also important to consider the expected reduction in available water. By 2024, a decrease in available water is expected in Java and Nusa Tenggara regions (Java: 439.21 m^3/capita/year, Nusa Tenggara: 1,654.82 m^3[13)]/capita/year). To build climate resilience in the water sector, the following actions are necessary.

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10) KOICA Indonesia Office (Southeast Asia Division 2), 2019, "Master Plan for the Second Phase of the Flood Forecasting and Warning System in the Citarum River Basin (2020-2023)," p.7
11) KOICA Indonesia Office (Southeast Asia Division 2), 2019, "Master Plan for the Second Phase of the Flood Forecasting and Warning System in the Citarum River Basin (2020-2023)," p.35
12) KOICA Indonesia Office (Southeast Asia Division 2), 2019, "Master Plan for the Second Phase of the Flood Forecasting and Warning System in the Citarum River Basin (2020-2023)," p.44
13) Kementerian PPN/Bappenas, List of Priority Locations and Climate Resilience Actions, 2021, p.6

〈Table 60〉 Response activities in the water sector for climate restoration in Indonesia

an action group	the contents of an act
the supply of water storage facilities	- construction of a dam - the construction of a reservoir - Development and coordination of rainwater storage facilities for drought response - Construction of water tanks and reservoirs in coastal and island areas affected by fresh water due to drought and inflow of seawater
rearrangement of catchment areas	- Protection and Restoration of Wetland Ecosystems - Restoration of forests and land by vegetation - the supply of high-quality productive forest vegetation
application of technology	- Application of climate mitigation technology to prevent droughts and replenish water systems - Application of Water Injection Technology from Floods - Construction of permeable and absorbent asphalt against excessive surface runoff
Water recycling and Application of landfill technology	- Application of reverse osmosis desalination (SWRO) technology in the archipelago region - Application of water recycling technology to purify wastewater
Prevention of water loss	- Construction, maintenance, and repair of water supply and drainage pipes - Application of Pipeline Leak Detection Technology
flood mitigation	- Development and Coordination of Water Resources Infrastructure Required for Flood Disaster Resilience - Development of Climate Change Adaptive Drainage System - Construction of river control protection facilities (using concrete or wood) - dredging of reservoirs, lakes, and waterways

Source : Kementerian PPN/ Bappenas, List of Priority Locations and Climate Resilence Actions, 2021, 37-39

4) Integrated Management Division

In terms of integrated management, it is essential to consider the establishment of a collaborative system between public institutions for effective disaster response. Specifically, it is necessary to create a dedicated liaison system for public organizations during disaster response, integrate and streamline disaster response manuals, and enhance their field applicability through digitalization.

Additionally, strengthening guidelines on specific collaboration methods in the disaster response manuals is required. Prior consultation and coordination should

be conducted to clarify the scope of work and roles between relevant organizations, and the effective sharing of resources between public organizations must be improved through the enhancement of the shared disaster management resources system. Finally, strengthening the coordination power between public organizations should be considered by expanding disaster safety management professionals and enhancing the status of local government disaster departments as central agencies in local disaster response.

Furthermore, for effective disaster response, the collaborative system between public institutions and private organizations should also be considered in the integrated management aspect. This could include institutionalizing the participation of private professionals with representation when forming central and regional disaster safety response headquarters, and improving the effectiveness of the integrated volunteer support system to facilitate collaboration with effective volunteer personnel. In addition, a consultative body for coordinating the distribution of emergency relief resources could be operated between the central government, local governments, and private organizations, and public-private cooperation could be activated through the establishment of committees by disaster type in organizations such as central and regional disaster management committees. Other considerations include activating disaster situation and information sharing using portal sites, strengthening pre-disaster response education and training programs for volunteers, and introducing sustainable collaboration incentives to strengthen collaboration with private sectors, such as hospitals, during outbreaks of new infectious diseases.

Ultimately, strengthening community-based disaster response capacity requires enhancing education and exchanges for local residents and vulnerable groups, along with building an information-sharing system between public institutions and private organizations.

3. Key Considerations by Application Sector

1) Planning Sector

In terms of building disaster response urban infrastructure through urban planning, it is necessary to consider the introduction of urban planning tools that support environmental development, taking into account compound disasters, along with the correction of zoning regulations and the reinforcement of key infrastructure. First, it is essential to modify zoning regulations to restrict construction in high-risk areas such as floodplains and coastal regions and encourage sustainable urban growth. Furthermore, essential systems such as power grids, water supply systems, and transportation networks should be reinforced to withstand extreme weather conditions like floods and heatwaves. From an environmental development perspective, the introduction of low-impact development plans and climate-ecology-based infrastructure installation plans is necessary.

〈Table 61〉 Composition of Land Use Plan for Complex Disaster Response

planning area	Contents of the Plan	Details of the plan
land use	Spatial Structure and Application Arrangement	□ Space layout considering natural spill path □ Application arrangement considering the vulnerability of heavy rain □ Principles of conversion or maintenance of conservation areas for disaster-prone areas (e.g., green areas and non-urban areas) □ (Regional designation) Designation and adjustment of zones, including disaster-prone areas, to establish disaster reduction measures □ (Joint Development) Designation of disaster-prone areas and establishment of disaster reduction measures □ (Special Plan Area) When planning a special plan area, donation of disaster prevention facilities and review of excellent outflow reduction facilities □ Purchase of land and migration of residents (purchase of public land, purchase of development rights, review of relocation of small-scale settlement districts in established cities, preparation of alternative land, etc.) □ Review of designation of disaster prevention zones

planning area	Contents of the Plan	Details of the plan
	Avoidance and separation	□ Suppression and conservation of new development in areas vulnerable to heavy rains in areas where residents live less □ Preserve the original form as much as possible and plan open space in conjunction with the water system □ Creating a Low-Flying Super Embankment by the River □ Setback and buffer zone construction with river, coastal, steep slopes, etc
	Restrictions on location and facilities	□ Restrictions on the installation of transportation facilities such as roads, underground roads, railroads, and airports in areas vulnerable to heavy rains □ Restrictions on the installation of schools, public buildings, and general medical facilities in areas vulnerable to heavy rains □ Restrictions on the installation of campgrounds, lodging facilities, semi-underground houses, and evacuation facilities in amusement parks in areas vulnerable to heavy rains □ Where a facility for storage is installed in a park, it is installed directly upstream of the area vulnerable to heavy rain to be protected as much as possible □ Cremation facilities, cemeteries, cave facilities, and natural burial sites shall be installed in places where the topography is well drained and there is no risk of collapse or flooding □ Minimize the development of highly water-permeable and erosive soil □ Electricity supply facilities, gas supply facilities, oil storage, and oil supply facilities are installed in areas where disasters are unlikely to occur, such as flooding and landslides

〈Table 62〉 Composition of infrastructure for complex disaster response

planning area	Contents of the Plan	Details of the plan
infrastructure	Common Matters	□ Expansion of disaster prevention facilities (e.g., strengthening capacity of waterproofing facilities, storage of surface, installation of underground reservoirs, etc.) □ A Study on the Possible Use of Disaster Prevention in Public Facilities □ Improvement of drainage facilities (river maintenance, improvement of drainage system, enhancement of drainage capacity, etc.) □ Establishment of a facility maintenance plan (inspection, maintenance, repair, reinforcement, etc.) □ Strengthen the slope drainage system (improvement of surface water and groundwater drainage system) □ Securing public land, such as playgrounds, parks, etc., as much as possible in flood-prone areas

planning area	Contents of the Plan	Details of the plan
		□ Use water-permeable materials and grass blocks to pack the surface of the parking lot
	Road	□ Installation of Landslide Prevention Facilities Directly Downstream Road Storage Facilities □ Installation of ecological waterways along wide-area roads (more than four lanes) □ Removal of Boundary Jaw for Excellent Inflow to Horizontal Variation Stage □ Strengthening of drainage treatment of road section □ Installation of Transverse Drainage and Underground Reservoir to Prevent Inundation in Adjacent Urban Areas □ Use water-permeable materials that permeate rainwater (walking and cycling paths) and install cross-ditch and underground reservoirs to prevent flooding in adjacent urban areas
	public facilities	□ (School) In the case of high-altitude schools, installation of cross-passage drainage channels and underground reservoirs to prevent flooding in downstream urban areas, and installation of facilities for temporary stays of residents in the event of a disaster □ (Playground) In the case of an outdoor playground in an area vulnerable to heavy rain, installation of facilities for excellent retention in the surrounding area and temporary stay of residents in the event of a disaster □ Installation of storage facilities in areas vulnerable to heavy rains and surrounding areas, installation of facilities for temporary stays of residents in the event of a disaster, and installation of core public buildings in an area safe from disasters, taking into account the overall spatial structure
	parking lot	□ Installation of underground storage facilities in parking lots in areas vulnerable to heavy rain □ Use water-permeable materials, such as grass blocks, to pack the surface of a parking lot □ Installation of ecological waterways around parking lots in areas vulnerable to heavy rain
	Park	□ Installation of retention facilities in the park □ Preservation of the surface of the square, sports facility space, etc. in the park

Source: Korea Research Institute of Land, Infrastructure and Transport, 2019, "Study on Urban Complex Disaster Management in preparation for large-scale disasters", p.105-109 amended

2) Urban Management Sector

In the field of urban management, there are three main areas to consider: nature-based urban management, integrated disaster management, and post-disaster recovery capacity.

First, nature-based urban management involves planning, developing, and managing cities by connecting the natural environment within and around urban areas or integrating ecosystems and green infrastructure into urban regions. This approach aims to solve local environmental issues, improve residents' quality of life, increase resilience to disasters, reduce environmental impacts, and provide various social, economic, and ecological benefits to the community.

For integrated disaster management, it is necessary to establish a management system that enables the rapid implementation of disaster management resources and disaster response services between the government, NGOs, and the private sector.

In terms of post-disaster recovery capacity, it is important to consider setting principles that allow for upgrading disaster-affected infrastructure to a state with higher climate resilience.

3) Administrative management area

In terms of administrative management, it is necessary to consider the regulation of administrative implementation matters in stages to respond to disasters. Disasters are often addressed in stages, and Korea uses the standard model of the four stages of disaster management—mitigation, preparation, response, and recovery—developed by the National Governors' Association (NGA) in the 1970s as part of "comprehensive emergency management."

This cycle, known as the prevention-preparation-response-recovery cycle, has been established as the official process for disaster safety management since the

enactment of the Disaster and Safety Management Basic Act in 2004. [14)]

In contrast, the United Kingdom officially uses the six-stage process of **Integrated Emergency Management (IEM)**, which is divided into the following stages: Anticipation, Assessment, Prevention, Preparation, Response, and Recovery.

In addition, to build disaster resilience against compound disasters caused by climate change, it is necessary to establish the following administrative management system. First, risk assessment and planning must be developed to identify and assess potential risks and vulnerabilities, as well as to create a comprehensive emergency plan outlining protocols, procedures, and responsibilities.

Furthermore, an early warning system should be established, implementing technologies to predict and monitor climate-related risks, and ensuring that timely warnings are disseminated to both the community and authorities to enable early action.

Community participation and education are also crucial components. Education and training on disaster preparedness and response should be provided to communities, and exercises and simulations should be conducted to verify preparedness levels.

Regarding financial support mechanisms, the government can lead the creation of disaster relief funds and climate insurance programs, with participation from local governments, to help local residents and businesses reduce the economic impact of disasters. Additionally, an infrastructure and resource management administrative system should be established to enhance disaster response infrastructure and ensure the availability and efficient supply of disaster management resources, such as food, water, medical supplies, and shelters.

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14) Korea Institute of Public Administration, 2016, "Research on the Strategy for National Disaster Safety Management," p.132)

〈Table 63〉 Classification of disaster management resources in Korea

Large classification	
Materials	Basic materials that can be mobilized for first aid and recovery
Equipment	Equipment mobilized for emergency measures and recovery, etc
Manpower	Human resources with professional skills and skills
Intermediate classification	
Rescue, medical quarantine, emergency living stability support, energy function restoration, facility emergency recovery, emergency communication support, disaster site environment maintenance, transportation measures, maintenance of social order, volunteering, other functions	
Sub-classification	
Materials	38 kinds of heat dissipation clothing, calcium chloride, oil fence, emergency relief set, etc
Equipment	124 types of excavators, dump trucks, pumps, height work vehicles, cranes, etc
Manpower	19 teams including the Korea Maritime Rescue Association, Volunteer Fire Brigade, and Autonomous Disaster Prevention Team

Source: Ministry of Public Administration and Security, 2017, 「DRSS Guidebook」 p.3

4) Civil Life Sector

In the area of citizen life, it is crucial to promote awareness of climate change and climate-related disasters, fostering a climate-friendly mindset. First, in terms of political participation, local politicians and businesses should be encouraged to implement climate-friendly policies and businesses to activate this process. Additionally, climate-friendly awareness should be cultivated to promote environmentally sustainable behaviors such as banning littering, conserving water and energy, and using public transportation or cycling. Ultimately, to ensure that communities can establish and effectively implement response strategies to climate disasters, it is necessary to foster a mindset of active participation in community-based, participatory disaster response and the practice of response actions.

Section5. Key Contents of Guidelines

1. Overview

1) General Rules

① Overview of Guidelines

This guideline aims to establish plans and response strategies for addressing compound disasters in the Jakarta and Semarang coastal urban belt of Indonesia. Additionally, the content of the guideline is based on research findings rather than Indonesian laws and regulations, and it is designed to be revised and supplemented in accordance with future legal and institutional developments by the authorities.

2) Characteristics of Guidelines

① Scope of Guidelines

The spatial scope of this guideline covers the coastal urban belt connecting Jakarta and Semarang, while the content scope is limited to the roles and actions of relevant groups in response to compound disasters caused by diseases, heat, and flooding. The guideline is structured into an introduction, detailed sections, and integrated management. The detailed sections are divided into disease, heat, and flooding based on the research content. In the integrated management section, the guideline presents plans for effective implementation of the response strategies from the detailed sections and the composition of governance for management and administration.

② Securing the ability to implement the guidelines

Public institutions in Indonesia can modify, add, or change this guideline when establishing response strategies for compound disasters in the coastal urban belt. However, considering the uncertainty of compound disasters, the guideline should be applied flexibly through monitoring and management.

2. Disease

1) Management Guidelines for Influencing Factors

① Access to healthcare

To respond to climate change-related diseases, the supply side should ensure the provision of adequate public services, while the demand side should consider the accessibility of healthcare facilities. In this context, healthcare accessibility should be managed in terms of economic and physical accessibility.

To improve healthcare accessibility, it is necessary to expand climate-related public healthcare facilities and explore financial support options for vulnerable groups. Public clinics in rural areas should be expanded, and specialized personnel for climate-related diseases should be increased. When establishing new healthcare institutions, the disaster impact based on location should be assessed, and disaster resilience facilities in existing healthcare institutions should be strengthened.

Climate impact assessments should include health and medical evaluations and the establishment of pre-disaster response systems. Local health centers should use social media as a platform to establish a rapid information delivery system to prevent the spread of diseases like dengue.

② Housing and Living Water Management for Low-Income Classes

Disease management will be strengthened in low-income intensive residential areas, and environmental improvement projects will be prioritized in areas adjacent to waterfront and grassland. In addition, the water supply business is expanded to reduce the use of drinking water for groundwater, and if water supply is not possible, purified groundwater is supplied by supplying a water purification filter.

2) Management Guidelines for Applicable Areas

① Planning Division

A climate and environmental health plan should be established considering the local environmental conditions, and it should be integrated and reflected in disaster response-related urban planning. Through the climate and environmental health plan, health and environmental hazards that need to be considered during compound disaster events should be identified, and emergency service provision strategies for vulnerable groups should be proposed.

② Urban Management Division

In areas with high vulnerability to diseases, construction and development should be encouraged to comply with building health standards. Additionally, the capacity of public healthcare facilities to accommodate patients should be expanded, and in regions lacking advanced medical institutions, health centers should be increased. Policies for improving local healthcare facilities should be prioritized, and the distribution of ambulances should be expanded for rapid patient response.

To maintain access to health services during medical crises, it is essential to secure facilities and personnel, and to support the provision of equipment and resources for disaster-vulnerable groups. To prevent public health issues, facilities should be improved to manage waste in drainage systems, suppress mosquitoes, and eliminate unpleasant odors. Furthermore, an information system should be established for early warning and detection of disease outbreaks in the initial stages.

③ Disaster Prevention Administration Division

Environmental management and health management should be integrated at the regional level, with the promotion of local environmental health as a core goal of disease management. Additionally, an inter-agency administrative management

system should be established for infectious diseases, with continuous education provided to relevant stakeholders.

To support disease management, the installation of water supply, wastewater treatment, and waste disposal facilities should be expanded. Low-cost pest control technologies and supplies should be distributed to control vectors like mosquito larvae. Furthermore, isolation facilities should be designated and newly established to prevent further infections, and primary support measures at the local government level should be defined.

A management system for disaster response should be established, and detailed plans for health and environmental management, as well as patient care, should be prepared for medium- and large-sized hospitals in the event of a disaster. Regional public health administration should include processes for cleaning, disinfection, and sterilization.

④ Civil Life Sector

Efforts should be made to enhance the understanding of vulnerable groups regarding the climate crisis, and climate change-related content should be added to early education curricula starting from basic education. Residents should familiarize themselves with the action guidelines provided by relevant authorities during a disaster and take appropriate actions accordingly.

For areas with potential disease outbreaks, joint public-private programs should be developed and implemented to raise awareness about prevention and control. Additionally, the distribution of simple technologies to prevent the spread of dengue vectors and ensure clean water supply should be expanded. Alternatives to waste dumping and illegal burning should be proposed, and improvements to living environments should be promoted to prevent waterborne diseases.

3. Heat

1) Management Guidelines for Influencing Factors

① Analysis of heat island phenomenon

The physical and meteorological factors of the urban heat island effect should be identified by region and applied to disaster management. In the physical aspect, factors such as building materials, normalized difference vegetation index (NDVI), and land cover should be examined. In the meteorological aspect, factors such as precipitation, sunshine duration, and surface temperature should be reviewed.

2) Management Guidelines for Applicable Areas

① Planning Division

To respond to heat-related diseases caused by climate change, the environmental and health planning should include measures for the prevention and management of heat-related illnesses. Additionally, at the urban level, plans should be developed for climate change adaptation, and in terms of architecture, buildings with high climate resilience should be encouraged.

To promote the transition to eco-friendly energy at the urban level, plans such as Transit-Oriented Development (TOD) and the integration of public transportation stations should be implemented. Furthermore, to reduce the use of private cars, regulations such as congestion charges should be introduced, and the integration of green transportation and public transit should be promoted. Additionally, a roadmap for expanding the use of renewable energy should be established, and heat island mitigation plans that consider wind corridors between buildings should be developed.

② Urban Management Division

To protect and restore wetlands and forests, which serve as a shield against floods

and heatwaves, it is important to enhance natural heat island buffering through the expansion of green corridors and urban forests.

At the architectural level, the installation of cool roofs using highly reflective materials should be encouraged. Additionally, the use of reflective paint and cool pavements on roads, parking lots, and other surfaces can help reduce heat absorption. Furthermore, not only government buildings but also private buildings should be encouraged to adopt and transition to green building practices through incentives.

By integrating blue-green infrastructure, heat island mitigation and water resource management can be effectively combined. The promotion of eco-friendly vehicles can support urban energy transition. For this, the introduction of electric vehicles for bus rapid transit (BRT) and public vehicles should be expanded, and the development of electric vehicle infrastructure should be accelerated. Moreover, expanding Jakarta's MRT and BRT networks will help reduce fossil fuel use and make green transportation more accessible.

Buffer green spaces should be created around roads to mitigate the transfer of heat to residential areas, and the expansion of water facilities in densely populated areas and major pedestrian routes will provide cooling effects. Additionally, shading structures, cooling parks, and other heat-avoidance facilities should be installed in areas with high pedestrian traffic and population density. Multi-functional facilities, such as e-street tree benches, should be installed to reduce seasonal fluctuations in usage and enhance the economic efficiency and effectiveness of facility management.

③ Disaster Prevention Administration Division

Continuous monitoring of heat management should be conducted, and building regulations and design standards aimed at reducing heat absorption should be implemented to readjust land use regulations. The incidence of heat-related diseases and deaths should be monitored regularly, and an emergency response

plan should be developed to prioritize the protection of vulnerable groups in the event of health risks related to heat.

During heatwave periods, a power demand response program should be implemented to reduce the load on the power grid and minimize power outages. Additionally, an integrated administrative system should be established that considers both water and heat islands to prevent heat island effects in areas facing water shortages during droughts.

④ Civil Life Sector

Housing policies should be implemented to improve access to energy-efficient housing for low-income groups, minimizing their exposure to heat, and promoting housing improvements with a focus on insulation. Additionally, community participation in heat mitigation efforts such as tree planting, cooling center management, and green roof projects should be encouraged.

Citizens should familiarize themselves with heatwave preparedness guidelines and avoid prolonged activities near paved roads during extreme heat. Furthermore, during heatwaves, they should follow the action guidelines provided by relevant authorities and check public media for safety measures.

4. Flood

1) Management Guidelines for Influencing Factors

① Analysis of flood factors

Physical and meteorological factors related to flood damage in each region should be identified and applied to disaster management. In the physical aspect, factors such as impervious surface area, flow rate, and the distance to rivers, streams, and roads should be examined. In the meteorological aspect, factors such as saturation vapor pressure, climate moisture deficit, and topographic wetness index should be reviewed.

2) Management Guidelines for Applicable Areas

① Planning Division

When developing plans, planning measures aimed at creating a **Water Wise City** should be applied, and a comprehensive water management plan at the regional level should be established, promoting programs such as Low Impact Development (LID) and expanded wastewater reuse. The water management plan should integrate supply management, utilization management, and surrounding area management to support water resources through an integrated plan. Plans should be developed to mitigate stormwater runoff problems, and guidelines for water-friendly facilities should be established for installations in waterway impact areas. Additionally, environmental assessments of river basins should be strengthened when specific facilities are installed in major watersheds.

② Urban Management Division

To address the issue of impervious surfaces in urban areas, water flow and storage spaces should be created near densely populated residential areas, and ground subsidence in low-lying areas should be prioritized in policy. Flood-prone areas

should be identified, and capacity for drainage pump stations should be secured, with periodic river cleaning to prevent blockages. Flood control pumps should be installed in these vulnerable areas, and land acquisition should be expanded for efficient river management. Additionally, the adjustment and supply of water storage facilities and rainwater storage systems should be increased, and water tanks and reservoirs should be constructed in coastal and island areas.

To consider both water shortages in dry seasons and water pollution during wet seasons, drought- and flood-resistant native plants should be planted. Adaptive water management policies at the regional level should be implemented to establish buffer zone management systems. Plans should be developed by comprehensively considering land use, sewage management, and other factors affecting rivers at the watershed level, and urban areas should expand water supply, sewage systems, and river management infrastructure to prepare for floods and droughts.

To prepare for small river flooding, the design frequency should be increased, and related infrastructure should be expanded to enhance flood defense capacity. Dams, weirs, and tidal gates should be operated in an integrated manner, reinforcing flood control capacity not only for large but also for medium- and small-scale reservoirs. An integrated water management system covering the coast, rivers, and cities should be established, including the creation and management of buffer zones.

In coastal and adjacent areas, infiltration wells should be constructed to allow rainwater to quickly seep into the ground. Water-related infrastructure should be strengthened in climate-vulnerable areas. Moreover, an approach combining ecosystem-based and community-based methods should be used to install various water management structures, conducting dam, reservoir, and vegetation management to address areas and households vulnerable to drought and flood threats.

Alternative water resources should be developed, and structures for rainwater

storage should be improved. Additionally, freshwater management in coastal areas should be adjusted, and the construction of reservoirs, dams, and other facilities should be expanded to strengthen flood and drought control at the regional level. Furthermore, flood-drought integrated management technologies should be developed and applied to prevent droughts, supplement water systems, and introduce water injection technologies for flood protection, along with the application of climate mitigation technologies.

Watersheds should be reorganized to enhance the protection and restoration of wetland ecosystems and strengthen forest vegetation supply. Measures for reverse osmosis desalination technology and water recycling technologies should be developed, and technologies to prevent water loss, as well as pipeline leakage detection, should be expanded.

③ Disaster Prevention Administration Division

In water management administration, the concept of the water footprint should be considered, and an administrative system should be established to enable real-time water distribution in drought-prone areas. Additionally, early warning scenarios should be developed, incorporating analysis of past flooding and drought data, as well as setting risk thresholds, which can be utilized in urban flood and drought response scenarios.

④ Civil Life Sector

During drought periods, water resources should be conserved, and citizens' awareness of disaster prevention issues caused by illegal dumping should be raised through education and training. Additionally, urban agriculture, which can also be used as basic living infrastructure at the community level, should be introduced and residents should be encouraged to participate, contributing to solving water issues.

Citizens should avoid accessing flood-prone areas during floods and be cautious when using vehicles. They should also check weather conditions through public media and follow the action guidelines provided by relevant authorities.

5. Integrated Management of Complex Disasters

1) Integrated Plan

① Linkage and integrated management of disaster plans

To enable integrated planning between the environment, urban areas, and disaster response, alternative urban planning approaches should be developed, and these should be institutionalized through laws and administrative regulations to link environmental, urban, and disaster prevention plans. Furthermore, preventive urban planning measures should be established by integrating disaster vulnerability analysis, compound disaster management maps, and disaster prevention plans for each city. Response plans for heat, disease, and flooding should be cross-examined to minimize negative feedback.

A feedback mechanism should be introduced to assess the appropriateness of understanding disaster response plans and related legal plans, and the implementation of disaster-related plans and performance evaluations should be differentiated between frontline agencies and coordinating agencies, clarifying the roles and responsibilities of the relevant institutions. For disaster monitoring, an open monitoring system should be developed to allow direct community participation.

Infrastructure and urban facilities should be reorganized to enhance their functionality in responding to compound disasters, with urban, environmental, and climate experts identifying effective urban facilities for compound disaster response. In the short term, a suitable mix of green infrastructure (green infra) and gray infrastructure (gray infra) should be used, and in the long term, urban facilities should be restructured with a focus on green infrastructure. The expansion of urban green spaces and the identification of alternative green spaces considering spatial characteristics should be promoted.

② City Management

A community-based disaster response information system should be established to create a proactive response framework at the regional level. Additionally, flood forecasting systems using AI should be developed and applied to extend early warning times for compound disasters and reduce prediction intervals.

A disaster management manual tailored to the region should be created, with roles and organizational structures assigned accordingly. A continuous management system for personnel, technology, and equipment from private organizations that can be utilized during disasters should be maintained. Furthermore, a disaster prevention and management integrated platform should be developed to integrate the compound disaster management map and urban disaster prevention plans.

Through the establishment of this open platform, related private organizations should be able to participate in the integrated platform, allowing them to actively engage in disaster response operations.

Compound disasters should be managed in stages, with separate management measures for prevention, preparation, response, and recovery.

Prevention Phase: This phase includes the establishment and maintenance of disaster response organizations, the creation of predictive information, promotion of education and training, and specific measures for targeted management areas. It corresponds to the phase of strengthening the management of essential service facilities to prevent the compound disasterization of natural disasters.

Preparation Phase: This phase involves the establishment of emergency communication systems, the development and utilization of disaster response action plans by function, and the stockpiling of disaster management resources. Regular training is conducted for efficient resource allocation.

Response Phase: The response phase is divided into three stages: response, emergency measures, and emergency rescue. In the response stage, urgent rescue

operations and the establishment of rapid response facilities must be conducted within one day of the disaster occurrence. The emergency measures stage includes issuing disaster warnings, evacuation recommendations and instructions, setting up danger zones, emergency calls for local government employees, securing water supplies and shelters, and requesting work suspensions and school closures. Finally, the emergency rescue stage is centered on the Fire Department and focuses on preventing the spread of damage.

Recovery Phase: This phase is divided into short-term recovery (within one week) and long-term recovery stages. It includes the reporting, investigation, and documentation of disaster damages, as well as the establishment and implementation of disaster recovery plans. In the short-term recovery phase, basic needs for food, shelter, and essential services are supported, while the long-term recovery phase focuses on restoring economic and social activities and managing regional recovery efforts related to economic activities.

③ Administrative management

A Crisis Management Response Manual should be developed and updated to enhance the capacity for responding to compound disasters. These response manuals should be created and operated at the local government level, divided into practical manuals and action manuals. Additionally, local governments should increase the number of public officials in disaster-related fields, and promote the enhancement of their expertise through training programs.

The importance of key vulnerable and supporting facilities should be identified to create a compound disaster management map. Essential support facilities required for disaster response should be categorized into essential service supply facilities, economic activity infrastructure, transportation infrastructure, and relief and response facilities, which will be managed by local governments.

A field-based disaster safety communication network should be established, centered around local public institutions, and regular disaster preparedness drills

should be conducted in densely populated areas to enhance response capabilities. Furthermore, Disaster Response Action Guidelines should be created for the administrative, support, and resident sectors, and field exercises should be carried out. A **public-private integrated disaster management resource co-management system** should be established to ensure immediate mobilization in the event of a disaster.

④ Governance

A disaster response governance system should be established considering the highest level of community participation, an efficient collaboration structure, and the maximum utilization of local resources. Additionally, efforts should be made to minimize the digital divide among disaster-vulnerable groups to maximize their access to disaster information. Motivation for residents to participate in disaster response education should be provided, and citizens should be actively engaged in creating safe areas from climate change.

A disaster response system and continuous management framework that allow for cooperation between local governments and private institutions should be established. Private companies with necessary personnel and facilities for disaster response should be designated as disaster response support agencies and managed continuously. Furthermore, cooperation plans between public and private institutions (corporations) and between public institutions and local residents should be developed and institutionalized as a practice for disaster response.

From a disaster response perspective, a local-level circular resource utilization program for waste management should be identified, and an inventory of disaster preparedness equipment and supplies that can be procured locally should be compiled and shared with relevant institutions and residents.

V. Conclusion

Summary in Local Language (Sekilas tentang Bahasa Indonesia)

Penelitian ini menyoroti ancaman yang meningkat dari bencana kompleks akibat perubahan iklim, khususnya di kota-kota pesisir Indonesia seperti Jakarta dan Semarang. Perubahan iklim memperparah bencana-bencana yang terkait dengan penyakit, panas, dan pengelolaan air. Bencana-bencana ini—yang sering kali saling terkait—mengancam keselamatan, keberlanjutan, dan ketahanan masyarakat setempat. Kenaikan permukaan laut, frekuensi badai yang lebih sering, pulau panas (heat islands), dan penyakit terkait air seperti demam berdarah adalah contoh nyata dari krisis-krisis yang saling berkaitan. Studi ini menekankan pentingnya pendekatan terpadu berbasis sains dan kerja sama internasional untuk menurunkan ancaman-ancaman tersebut.

Sebagai upaya mengatasinya, penelitian ini mengadopsi pendekatan living labyang partisipatif dengan melibatkan komunitas masyarakat lokal, lembaga pemerintah, dan pakar akademis. Proses living labmemungkinkan para pemangku kepentingan mengidentifikasi kerentanan, mengembangkan solusi, dan mengintegrasikan pengetahuan lokal. Tantangan-tantangan utama yang diidentifikasi di Jakarta dan Semarang meliputi:

- Banjir: Diperparah oleh penurunan tanah, buruknya drainase, dan kenaikan permukaan laut..
- Panas: Diperparah oleh efek pulau panas perkotaan dan kurangnya ruang hijau.
- Penyakit: Meningkatnya risiko penyakit vektor seperti demam berdarah akibat sanitasi buruk dan genangan air.

Proses living labmengungkapkan bahwa bencana-bencana ini tidak terjadi secara terpisah, tetapi saling berinteraksi sehingga menciptakan efek berantai. Oleh

karena itu, tim peneliti merekomendasikan tiga solusi untuk menghadapi bencana kompleks berdasarkan hasil temuan dari living lab.

[1. Sistem Informasi Kesiapsiagaan Bencana Berbasis Masyarakat]

- Memanfaatkan sistem peringatan dini (Early Warning System, EWS) bertenaga surya untuk banjir dan gelombang panas.
- Membentuk tim respon bencana yang spesifik pada setiap komunitas.
- Menggunakan sarana digital seperti WhatsApp untuk penyebaran peringatan secara waktu nyata.

[2. Mitigasi Bencana Kompleks di Lingkungan melalui Penanaman]

- Memperkuat infrastruktur hijau, seperti taman atap (rooftop garden) dan penyimpanan air hujan.
- Menerapkan desain perkotaan yang sensitif terhadap air untuk mengatasi banjir dan panas.

[3. Sistem Pengelolaan Sampah Terpadu]

- Memperkenalkan teknologi pintar untuk pengumpulan sampah.
- Memberikan edukasi kepada warga masyarakat terkait pengelolaan dan pembuangan sampah.
- Solusi ini menekankan keberlanjutan dan implementasi yang dipimpin dan diimplementasi oleh komunitas masyarakat, dan didukung oleh kerja sama internasional dalam pertukaran teknologi dan pembangunan kapasitas.

Tim peneliti juga mengembangkan Indeks Kerentanan Perubahan Iklim Kota Pesisir (Coastal City Climate Change Vulnerability/C4V) untuk menguji risiko di bidang penyakit, panas, dan air. Indeks ini menyediakan indikator spasial dan memungkinkan pemangku kepentingan menyesuaikan bobot berdasarkan prioritas lokal. Alat ini mampu membantu mengidentifikasi area target dalam upaya mitigasi dan adaptasi bencana.

Kemudian, panduan untuk mitigasi bencana kompleks juga dirancang, yang mencakup strategi-strategi fleksibel dan adaptif untuk perencanaan perkotaan, manajemen bencana, dan tata kelola.

Panduan untuk masing-masing sektor sebagai berikut:

- Penyakit: Memperluas akses layanan kesehatan, membangun sistem peringatan dini, dan meningkatkan sanitasi.
- Panas: Menambah ruang hijau, menggunakan material reflektif, dan mengembangkan energi terbarukan.
- Air: Mengembangkan sistem pengelolaan banjir dan kekeringan terpadu, rehabilitasi lahan basah, dan memperluas penampungan air hujan.
- Manajemen Terpadu: Memperkuat tata kelola dan kemitraan publik-swasta, menciptakan peta manajemen bencana terpadu, dan meningkatkan partisipasi masyarakat.

Penelitian ini menekankan peran penting kerja sama internasional, seperti proyek-proyek dari Korea International Cooperation Agency (KOICA) dalam menghadapi bencana kompleks.

Contoh implementasi saat ini meliputi:

- Sistem peringatan dini banjir di Filipina.
- Inisiatif penghijauan perkotaan di Uzbekistan.
- Program pengelolaan sampah laut di Filipina.
- Berbagi keahlian, teknologi, dan pendanaan melalui kolaborasi internasional yang dapat meningkatkan ketahanan terhadap bencana di Indonesia.

Penelitian lebih lanjut disarankan tidak hanya berfokus pada komersialisasi solusi-solusi yang telah direkomendasikan melalui kerja sama internasional, tetapi juga memperluas penerapan Indeks C4V, memperbesar skala kerangka living labke wilayah rentan lainnya, dan memperkuat keselarasan kebijakan dengan panduan

yang telah dirancang untuk memastikan ketahanan jangka panjang.

Dengan memanfaatkan penelitian ilmiah, partisipasi komunitas masyarakat, dan kolaborasi global, penelitian ini mampu memberikan landasan untuk mitigasi dampak perubahan iklim dan mendorong pembangunan berkelanjutan di kota-kota pesisir Indonesia.

Section1. Summary and expectations

1. Expected impact of the research in terms of international cooperation

Climate change is causing a surge in disasters related to disease, heat, and water management. This is especially true in Indonesia's coastal cities. Climate change-induced extreme weather events, such as rising sea levels and frequent storms, exacerbate the vulnerability of coastal areas and create a dual risk of flooding and disease outbreaks. Simultaneously, rising temperatures resulting from climate change are leading to issues such as heat islands, heat-related illnesses, and droughts, emphasizing the need for water management in the region. These compound disasters that occur in these situations pose a major threat to the livelihoods and survival of local communities and undermine sustainable development.

Cascading disaster events caused by climate change have a profound impact on the safety and survival of local communities, requiring an understanding of the complex interactions of disasters. Furthermore, effective responses to multiple disasters require tailored actions at the community level to both mitigate and adapt to the impacts of climate change, emphasizing the importance of international cooperation to develop appropriate response strategies. Countries or international organizations with similar climate characteristics or disaster experience can work together to share research data on climate change and strengthen the scientific basis for improving climate resilience in Indonesian coastal cities. As demonstrated in this research, it is necessary to use the latest climate modeling techniques and disaster prediction systems to identify risk areas and develop community-led response strategies based on them.

International cooperation-based technology transfer and financial support can play an important role in helping other countries overcome complex disasters. In

Southeast Asia, including Indonesia, the Korea International Cooperation Agency has built infrastructure to prevent flooding and established efficient water management systems to address water scarcity. Sharing these experiences and technologies and providing the necessary funding can contribute to making communities more climate resilient. This research was conducted as a living lab based on the characteristics and impact factors of complex disasters derived through a science-based approach, and through this, we aimed to interact with various stakeholders related to climate change-induced disasters and derive solutions led by local people.

Moreover, sharing these experiences with local communities and offering education and training programs for local residents and counterparts to build their response capacities. Therefore, using the results of this research and the proposed guidelines synthesized from them to collaborate with counterparts through scientific data sharing, technical and financial support for complex disaster adaptation and mitigation, and capacity-building programs is expected to play an important role in promoting sustainable development and disaster resilience in Indonesian coastal cities.

This research focuses on the Jakarta-Semarang coastal city belt, located on the island of Java, which is one of the coastal cities in Indonesia. Jakarta and Semarang are coastal cities that are located on the coast and are subject to regular flooding due to their lower elevation above sea level, and they face heat problems caused by extreme weather and endemic diseases such as dengue. This research analyzed climate change vulnerability factors based on empirical research (machine learning, AI prediction) and conducted a participatory observation study (living lab) to derive responses for climate change adaptation and mitigation through a microscopic approach from the local community. The research designed and operated a living lab prototype with local residents and public, private, and academic experts in the target countries to analyze disease, heat, and water management issues as compound disasters and identify practical alternatives.

Through the Living Lab, the researchers realized that the interaction between disease, heat, and water management creates a complex disaster, and that the local issues that drive it are difficult to address from a single disaster perspective.

The geographical characteristics of the coastal area (proximity to the coast and land subsidence; Semarang is below sea level) and environmental characteristics (large areas of impervious surface, poor water management, resulting in drainage problems) exacerbate the damage caused by flooding in the region. Additionally, water management issues such as ponding after flooding and poor drainage and sewage treatment contribute to disease outbreaks. Poor social and physical conditions in the region increase the damage caused by heat, which in turn creates a double whammy of heat illness and drought, emphasizing the need for policies to mitigate disaster damage from a multi-hazard perspective.

As international collaboration typically involves a preliminary information gathering, project design, framework development, and model application phase (International Organization for Migration United Kingdom, 2024), this research involved researching the current status of climate change-induced disasters in the target countries and policies addressing their impacts, and identifying relevant stakeholders. In addition, local partnerships were established and government agencies were engaged to understand local problem perceptions and policy trends. Based on the results of the living lab, we then refined the scope, objectives, and research targets for solutions to address local issues. Through this, the researchers aimed to maximize the potential for commercializing the solutions proposed in the research through international development cooperation.

Epidemics, heat islands (heat waves), and floods are often perceived as individual climate disasters, but in reality, interactions between disasters can occur and affect cities in the form of compound disasters. In particular, social disasters caused by natural disasters can be difficult to respond to immediately due to unclear accountability, which has the potential to exacerbate the disaster. Therefore, this research shows that an integrated understanding and resolution of the interactions

between them can be utilized as a basis for responding to complex disasters. Moreover, the C4V indicators derived from the research can be used to predict future disease, heat, and water management disasters in coastal cities in Indonesia, and to select target areas for international cooperation projects.

To mitigate and adapt to the possible occurrence of climate change complex disasters in the Jakarta-Semarang coastal belt of Indonesia, the proposed 'Climate Change Complex Disaster Impact Mitigation Planning Guidelines (Draft)' was proposed based on the overall results of the research and relevant domestic and international guidelines and guidelines, and is mainly designed to apply the solutions derived through the Living Lab to planning, urban management, disaster prevention administration, and civic life. In particular, Indonesia lacks direct guidelines and directives for responding to complex disasters, and there is a need to review climate disaster-related policies and planning practices to identify factors to consider for guideline setting and responses.

For the above reasons, this research developed a draft guideline for climate change multi-hazard disaster impact mitigation planning in coastal belt cities in Indonesia, consisting of a general guideline, sectoral (disease, heat, flood) guidelines, and integrated management guidelines, to define roles and actions for each area of application. In particular, the General Guideline (Chapter 1) provides suggestions that can be utilized in the planning and strategies that need to be formulated to respond to complex disasters in Jakarta and Semarang, Indonesia, and is intended to be flexible enough to be modified and supplemented by public institutions in Indonesia in accordance with laws and regulations. The sectoral guidelines proposed policy directions for each disaster from a multi-hazard perspective. For example, the heat sector (Chapter 3) emphasized the need to develop a health and wellness plan (disease + heat perspective) to respond to heat-related illnesses, and the need to establish a coordinated administrative system for integrated management of heat island mitigation and water resources management, while the flood sector (Chapter 4) suggested the need to establish an integrated water

management system through integrated water management policies and the application of integrated flood and drought management techniques.

The research also suggested directions for linkages with local challenges and solutions identified through the Living Lab. In this regard, the research further reviewed the international cooperation cases of Korea International Cooperation Agency (KICA) and found that KICA can contribute to disaster adaptation and mitigation in coastal cities in the target countries based on its rich experience and expertise 〈Table 63〉. For example, KIDS has established flood early warning systems in the Philippines and Mozambique. In the Philippines, the early warning system was established in the basin of a major river in Manila, along with workshops for disaster prevention organizations and evacuation drills for residents. Other projects include disaster prevention and greening projects based on the natural environment, such as Solution Idea 2; community-based response systems and regular trainings to strengthen local capacity to respond to infectious diseases; and a monitoring system for marine debris disposal. As such, the experience and financial support of the Korea International Cooperation Agency for the solutions proposed to solve the problems of the research area is expected to help Indonesia respond to the complex disasters caused by climate change in coastal areas and solve the problems through effective projects.

〈Table 64〉 Living Lab Solution Ideas and KOICA projects

Solution ideas	KOICA projects		
	Title	Target areas	Contents
Solution Idea 1: Community-based disaster preparedness information system (flooding)	Establishing a flood early warning and monitoring system	Philippines	Established real-time observation and early warning system for major river basins in Manila Conducted workshops for disaster prevention agencies and evacuation drills for residents
Solution Idea 1: Community-based disaster preparedness information system (flooding)	Licungo river River Basin Flood Example - Warning System Construction Project	Mozambique	Established a flood warning system Developed a hydrological model for flood prediction Conducted flood response drills involving relevant agencies and local residents
Solution Idea 1: Community-based disaster preparedness information system (heat island, disease)	Strengthening the Infectious Disease Prevention and Response System	Cambodia	Public Health Management Capacity Building Program Establishment of emergency response system and national public health response plan
Solution Idea 1: Community-based disaster preparedness information system (heat island, disease)	Pandemic Disease Management Capacity Building Project	Uzbekistan	Identifying the causes of waterborne foodborne infectious diseases Established a master plan for mid- to long-term epidemiologic investigator training courses Conducted invited domestic (Korea) training to strengthen capacities
Solution Idea 2: Creating a complex disaster mitigation environment	Smart Technology-based Forest and Urban Greening Capacity Building Project	Uzbekistan	Training on selection of planting sites, planting methods, and post-planting management Supplying trees for urban greening
Solution Idea 3: Integrated Waste Management	Marine Waste Management Capacity Building Project	Philippines	Marine waste monitoring project (identifying trends in marine garbage generation and supporting collection and treatment in source countries) Design, supervision, construction, and deployment of clean harbor vessels

2. Future Research Suggestions

Based on scientific evidence, the study analyzed the areas where multiple disasters occurred and the relationship between disasters and coastal urban structures, and specified the detailed scope, objectives, and targets of solutions to address local issues identified through the living lab. The study also gradually implemented each solution with the aim of solving sustainable problems and mitigating climate change impacts through a phased approach, and proposed guidelines to maximize the potential for commercialization through future international development cooperation. Then, we reviewed the past and current support projects of Korea International Cooperation Agency for commercialization of the solutions to identify similar cooperation cases.

Future research should focus on commercialization to substantially mitigate the impacts of climate change-induced disasters. Based on the local partnerships established in this study, a specific action plan should be established to be promoted as an international cooperation project, and the overall characteristics of complex disasters in coastal cities in Indonesia should be identified for the dissemination of research results.

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Appendix

Appendix 1. Guideline for Climate Change Mitigation Plan Based on Living Lab (Draft)

Chapter 1: General Provisions

1.1 General Rules

1.1.1 The purpose of this guideline is to present directions and factors to consider in formulating plans and response strategies to address diseases, heat, flooding, and related compound disasters in the coastal urban belt of Jakarta and Semarang, Indonesia.

1.1.2 This guideline is not based on the laws and systems of the Indonesian central government and local governments (Jakarta, Semarang) but rather on suggestions derived from research findings. Therefore, it is designed to be used flexibly by the relevant authorities for related planning and policy development, with possible modifications and additions.

1.2 Nature of the Guideline

1.2.1 The spatial scope of this guideline is limited to the coastal urban belt connecting Jakarta and Semarang in Indonesia.

1.2.2 The content scope of this guideline includes suggestions for the roles and actions of related groups in response to compound disasters caused by diseases, heat, and flooding.

1.2.3 The suggestions in this guideline are not based on the regulations of Indonesian laws and systems but are practical implications derived from research findings.

1.3 Structure of the Guideline

1.3.1 This guideline consists of an introduction, detailed sections, and integrated management.

1.3.2 The detailed sections are divided into disease, heat, and flooding, based on the

research content.

1.3.3 The integrated management section provides guidelines on how to establish integrated plans and governance to efficiently implement the response measures proposed in the detailed sections.

1.4 Ensuring the Implementation of the Guideline

1.4.1 When public institutions in Indonesia establish plans or guidelines to address climate crises or compound disasters in the coastal urban belt, the contents of this guideline can be modified, added to, or changed for use.

1.4.2 When public institutions apply this guideline, they must consider the uncertainties of compound disasters caused by climate change. The guideline should be adapted flexibly by revising and improving it through monitoring, implementation performance, and feedback loops.

Chapter 2: Diseases

2.1 Guidelines for Managing Influencing Factors

2.1.1 Medical Accessibility

1) The key strategy for responding to climate-related diseases on the supply side is to provide adequate public services for climate diseases, and on the demand side, it is necessary to consider how easily patients with climate-related diseases can access medical facilities.
2) Medical accessibility is managed by dividing it into the economic accessibility of medical users and the physical accessibility of medical facilities to medical users.
3) To account for disparities in the ability of local residents to pay for medical costs, expand public medical facilities for climate-related diseases and develop cost support measures for vulnerable groups.
4) To reduce the disparity in access to medical institutions between urban and rural areas, expand public clinics and other services in non-urban areas.
5) Increase the number of healthcare professionals specializing in climate-related diseases, such as heat-related illnesses.
6) When establishing new medical institutions, assess the potential disaster impact based on the location of the facility to ensure that it is not affected by disasters. For existing institutions, strengthen disaster prevention facilities.
7) Conduct climate impact assessments that include evaluations of medical and health impacts to establish a proactive response system for climate diseases.
8) Health centers in the region should establish emergency contact networks based on social media to ensure rapid communication and information dissemination to prevent the spread of diseases such as dengue during floods.

2.1.2 Management of Low-Income Residential Areas

1) Given the increase in dengue outbreaks in low-income communal living areas, strengthen disease management in areas with high proportions of low-income residents.
2) Prioritize sanitation and environmental improvement projects in low-income communal living areas that are close to water bodies or grasslands.

2.1.3 Management of Domestic Water

1) To reduce the use of groundwater for drinking water, expand public water supply

projects to provide safe drinking water through municipal water systems.
2) Even in areas where groundwater must be used due to the lack of a water supply, provide water purification filters so that groundwater is not used directly, but rather filtered and purified for consumption.

2.2 Guidelines for Managing the Application Areas

2.2.1 Planning Sector

1) Establish climate and environmental health plans considering regional climate change and environmental conditions, and ensure that the contents are integrated and reflected in disaster response plans, urban planning, and environmental planning.
2) Through climate and environmental health plans, identify the health and environmental hazards that must be considered during compound disaster occurrences, and propose urban planning and disaster response solutions, as well as emergency service provision measures for vulnerable groups.

2.2.2 Urban Management Sector

1) To expand the infrastructure for disease management, encourage the installation of housing, buildings, and infrastructure that comply with health standards in areas with high vulnerability to diseases such as dengue.
2) To expand the services of healthcare facilities, increase the patient capacity of hospitals, health centers, and other public medical facilities. (Kementerian PPN/Bappenas, List of Priority Locations and Climate Resilience Actions, 2021, 64-65)
3) In areas lacking advanced medical institutions such as hospitals, expand health centers to strengthen healthcare and health functions.
4) Expand health service facilities at the regional level and prioritize policies and projects to improve healthcare facilities. (Seoul Institute, 2022, "Jakarta Province's 'Low-Carbon Development Plan' Case," World Cities Trends, Issue 526, Link)
5) Expand the availability of ambulances to ensure a rapid response to patients during disasters.
6) Ensure that basic health services are accessible in low-income or vulnerable areas during public health issues or medical crises by securing facilities and personnel.
7) Support the provision of equipment and tools for disaster-vulnerable groups, such as individuals with physical disabilities, to use in emergencies.
8) Establish an information system to detect early information on disease outbreaks

such as dengue and activate early warning systems.

9) Improve facilities to prevent health and hygiene issues such as blockages in drainage systems caused by waste disposal or the generation of mosquitoes and unpleasant odors from open drains.

2.2.3 Disaster Prevention Administration Sector

1) Set the improvement of the region's environmental health as the core objective of disease management administration, and consider environmental management and health management integrally at the regional level. (Kementerian PPN/Bappenas, List of Priority Locations and Climate Resilience Actions, 2021, 64-65)
2) Expand the installation of essential supply and treatment facilities for disease management, such as water supply, sewage, and waste disposal facilities, in densely populated residential areas.
3) Increase the distribution of low-cost pest control technologies and materials to control disease vectors, such as mosquito larvae.
4) Establish an intergovernmental administrative management system for infectious diseases and provide continuous education and training for public servants and relevant stakeholders.
5) Designate or establish isolation facilities to treat infected individuals and prevent further infections, define the primary support tasks of local governments, and establish measures for citizens' infection prevention and safety. (National Disaster Safety Research Institute, 2020, "Development of Social Disaster Response and Support Guidelines," p. 124, modified)
6) Establish a medical management system for emergency surgeries and other urgent procedures during disasters, and prepare detailed plans for health and environmental management, emergency surgeries, and patient care at regional mid-to-large hospitals in the event of a disaster. (WHO, 2008, "DISASTER MANAGEMENT GUIDELINES: EMERGENCY SURGICAL CARE IN DISASTER SITUATIONS," pp. 4-6)
7) Regional health and environmental administration includes waste disposal, cleaning, disinfection, and sterilization.

2.2.4 Civil Life Sector

1) Enhance the understanding of climate change and climate-related diseases in the community, particularly among vulnerable groups. (Kementerian PPB/Bappenas, 2019, NATIONAL ADAPTATION PLAN, EXECUTIVE SUMMARY, p. 25)

2) Add public health and climate-related content to early education programs to raise awareness of the impacts of climate change.
3) In areas with high potential for disease outbreaks, implement various public-private joint programs to spread awareness and improve understanding of prevention and disease control.
4) Expand the distribution and use of simple technologies (e.g., DBD cap) to prevent the transmission of dengue vectors and ensure the supply of clean water.
5) Residents should familiarize themselves with the necessary actions for disease prevention and infection control provided by the government.
6) During disasters, residents should follow the actions outlined by central or local government agencies and take appropriate measures.
7) Residents should monitor disease response situations through news and public media, while also implementing health and hygiene measures in daily life.
8) Educate citizens on the issues of illegal waste dumping and burning, and develop and propose alternative solutions for waste management.
9) Promote a citizen-driven movement for improving living environments to prevent waterborne diseases caused by floating and accumulated waste in rivers.

Chapter 3: Heat

3.1 Guidelines for Managing Influencing Factors

3.1.1 Scientifically identify the physical and meteorological factors that may influence the intensity of the urban heat island effect and heat-related damage in each region, and apply these findings to regional disaster management.

3.1.2 On the physical side, consider factors such as building materials, building density, normalized vegetation index, population density, vegetation, land cover, and elevation.

3.1.3 On the meteorological side, consider factors such as precipitation, air temperature, humidity, surface temperature, sunlight, and wind speed.

3.2 Guidelines for Managing the Application Areas

3.2.1 Planning Sector

1) In the establishment of climate change-related heat disease management systems, include preventive and management measures for heat-related diseases in regional environmental health plans or health plans.
2) At the urban level, establish and implement plans to respond to climate change, and promote climate-resilient architecture, such as "rumah panggung" (traditional raised houses).
3) Expand planned considerations to support the transition to environmentally friendly energy sources in cities.
4) Optimize the integration of public transportation stops and promote Transit-Oriented Development (TOD), including the construction of subways and light rail, tailored to the characteristics of the city, to encourage the use of public transportation. (Seoul Institute, 2022, “Jakarta Province’s ‘Low-Carbon Development Plan’ Case,” World Cities Trends, Issue 526, Link)
5) Implement regulatory policies, such as congestion charges and high parking fees, to discourage single-occupancy vehicle use in urban areas.
6) Promote the integration of green transport (walking and cycling) and public transportation by developing bike lanes and facilities, optimizing pedestrian pathways, creating pedestrian support facilities, and establishing low-carbon zones.
7) Expand the use of renewable energy by installing rooftop solar panels and establishing and implementing a roadmap for the expanded use of renewable energy through regional

energy plans.

8) Establish heat island mitigation plans by considering wind corridors in the spaces between buildings to address heat retention caused by high building density.

3.2.2 Urban Management Sector

1) From a nature-based urban management perspective, protect and restore wetlands, mangrove forests, and forests that serve as natural barriers against floods, storms, tsunamis, and heat waves.
2) Expand multi-purpose parks, green corridors, and urban forests to activate natural urban heat island buffering and absorb excessive rainfall, thereby mitigating the urban heat island effect.
3) Encourage the installation of cool roofs with reflective materials on residential and commercial buildings, considering the high solar radiation in urban areas.
4) Apply reflective paints and cool paving materials to paved areas such as roads, sidewalks, and parking lots to reduce heat absorption.
5) Apply blue-green infrastructure integration to manage heat island effects and water resources in an integrated manner.
6) Support the urban energy transition by enhancing energy efficiency, expanding the use of renewable energy, and promoting the use of eco-friendly vehicles.
7) Promote the application of green building principles, energy-efficient usage and conservation guidelines, installation of energy-saving streetlights, provision of incentives for green building owners, and conversion of existing public buildings to green architecture, starting with government buildings and key private buildings.
8) Since materials like concrete and asphalt absorb heat, increasing the city's temperature, apply reflective paints and cool roofs to building surfaces to reflect heat.
9) Expand the use of eco-friendly vehicles by increasing the adoption of electric vehicles (EVs) for bus rapid transit (BRT), government and public sector vehicles, and accelerating the development and installation of EV infrastructure to support the wider use of electric vehicles.
10) To mitigate the spread of heat to residential areas, create buffer green spaces around roads to reduce heat movement into residential zones.
11) Expand water features in plazas, crowded transit areas, multi-use facilities, and densely populated residential areas to provide immediate cooling effects and mitigate the heat island effect.
12) Install heat-relief facilities such as shade structures, cooling shelters, cooling pods,

and water fountains in crowded areas, public transportation stops, and major pedestrian routes to reduce heat-related health impacts in urban areas.

13) To reduce fossil fuel use, expand Jakarta's MRT and BRT systems, and facilitate easy access to electric vehicles and green transport (walking and cycling).

14) Install multi-functional urban facilities, such as e-tree benches, to minimize seasonal usage fluctuations and increase the economic efficiency and sustainability of facility management, helping to mitigate heat-related issues.

3.2.3 Disaster Prevention Administration Sector

1) Continuously monitor the urban heat island effect and heat management, and develop corresponding action plans.

2) Implement building regulations and design standards that require cool roofs, reflective pavements, and energy-efficient buildings, and revise land use regulations to reduce heat absorption.

3) When heat waves or heat-related health risks are anticipated, prioritize the establishment and implementation of emergency response plans to protect vulnerable groups.

4) Monitor heat-related diseases and fatalities, track their health impacts, and allocate disaster management resources effectively.

5) During heat waves, implement demand response programs to manage electricity demand, reduce the load on power grids, and minimize power outages.

6) During droughts, consider the potential for worsening heat island effects in water-scarce areas, and establish an integrated administrative system that addresses both water and heat island effects.

3.2.4 Civil Life Sector

1) Since socioeconomically vulnerable groups are more susceptible to heat island effects, promote housing policies that enable low-income groups to access energy-efficient housing to minimize heat exposure.

2) Raise awareness of heat-related health issues, and ensure that citizens are familiar with recommended actions to take in preparation for heat waves.

3) Avoid prolonged activity near paved roads to prevent health damage caused by heat increases around roadways.

4) If housing materials and structures are vulnerable to heat effects, carry out home improvements that consider insulation to reduce heat impact.

5) During heat waves, take necessary actions in accordance with the guidelines provided

by the government and relevant authorities.

6) Monitor weather conditions through news and public media and take appropriate safety measures in daily life.
7) Encourage community participation in heat mitigation efforts, such as tree planting, cooling center management, and green roof projects.

Chapter 4: Floods

4.1 Guidelines for Managing Influencing Factors

4.1.1 Scientifically identify the physical and meteorological factors that could affect the severity of flood damage in each region, and apply these findings to regional disaster management.

4.1.2 On the physical side, consider factors such as impermeable areas, vegetation, humidity, land cover, flow rate, slope, and distance from rivers, streams, and roads.

4.1.3 On the meteorological side, consider factors such as the amount of rainfall that flows into rivers, vapor pressure, evaporation, climate moisture deficit, soil moisture, cumulative rainfall, cumulative flow, drought index, maximum temperature, and topographic moisture index.

4.2 Guidelines for Managing the Application Areas

4.2.1 Planning Sector

1) Apply planning tools that aim for a Water Wise City. (Kim, 2017, "Integrated Water Management and Climate Change Adaptation," Seminar Proceedings on Climate Change and Integrated Water Management, p. 27)
2) Establish comprehensive regional water management plans, promoting Low Impact Development (LID), climate and ecology-based infrastructure (green infrastructure), water conservation, wastewater reuse, and groundwater recharge programs. (KOICA Indonesia Office, 2019, "Basic Plan for the 2nd Flood Warning System Project in the Citarum River Basin, Indonesia," p. 6, revised)
3) Develop plans to alleviate the issue of stormwater runoff to manage floods effectively.
4) In flood-prone areas, establish and implement regulations for water-friendly facilities when installing structures. (KEI, 2020, "Environmental Impact Assessment Guidelines for Water-Friendly Structures in River Areas," pp. 32-36, revised)
5) When installing specific facilities of a certain scale in major river basins, strengthen environmental assessments of river basins to consider disaster impacts.
6) Water management plans should be integrated to support comprehensive management, including water supply management (flood control), water usage management (water use), and surrounding area management (riparian management).

4.2.2 Urban Management Sector

1) As an alternative to urban impermeability issues, create water and retention spaces, such as rain gardens and multipurpose lakes, near residential areas.
2) To address drainage issues in low-lying areas, prioritize addressing ground subsidence that hinders drainage.
3) Identify flood-prone areas and ensure the capacity of drainage pump stations to accommodate them.
4) To minimize drainage obstruction caused by floating and accumulated waste in rivers, regularly conduct river cleaning.
5) As a strategy to address both water scarcity in the dry season and water contamination in the wet season, select and plant drought- and flood-resistant indigenous plants to prevent disasters and reduce damage.
6) Through region-specific adaptive water management policies (Kim Young-oh, 2017, "Climate Change and Prospects for Adaptive Water Management," Seminar Proceedings on Climate Change and Integrated Water Management, p. 13-18), create buffer zones around major river basins to prepare for disasters and establish management systems.
7) Develop and implement plans that consider all factors affecting rivers at the watershed level, including land use, point-source and non-point-source pollution control, sewer management, water circulation, housing and transportation planning.
8) In urban areas, expand and strengthen the infrastructure and management required for water supply, sewage, and river management to prepare for floods and droughts.
9) To enhance flood defense capacity, increase the design frequency for small river flooding and continuously expand related infrastructure, such as deep tunnels, underground drainage systems, and riverbank retention areas.
10) To effectively respond to droughts, scientifically coordinate the operation of dams, weirs, and tidal gates, and strengthen flood control capacity not only for large reservoirs (e.g., 5 million m^2) but also for medium and small reservoirs (e.g., 300,000 m^2). (Ministry of Environment, 2023, "Third National Climate Change Adaptation Strategy," Press Release, p. 2)
11) To establish an integrated water management system covering coasts, rivers, and cities, create buffer zones around major river basins for disaster preparedness and set up management systems.
12) In coastal and adjacent areas, construct infiltration wells to rapidly allow rainwater to infiltrate the ground for groundwater management. (Seoul Institute, 2022, "Jakarta Province's 'Low-Carbon Development Plan' Case," World Cities Trends, Issue 526,

Link)

13) Prioritize strengthening water-related infrastructure in areas highly vulnerable to climate change impacts. (Kementerian PPB/Bappenas, 2019, NATIONAL ADAPTATION PLAN, EXECUTIVE SUMMARY, p. 24)
14) Combine ecological and community-based approaches to install various water management structures, such as flexible, rigid, and hybrid structures.
15) Carry out dam, reservoir, and vegetation management based on the area and number of households, agricultural land, and industries threatened by drought and floods.
16) Establish alternative clean water sources and improve structures for rainwater storage and distribution.
17) Adjust freshwater management in coastal areas to address the threat of rising sea levels.
18) To strengthen flood and drought control facilities at the regional level, expand the creation of reservoirs, dams, connecting canals, bridges, and sluices.
19) Expand the installation of flood control pumps in flood-prone areas and, in the long term, increase land acquisition to achieve integrated river management.
20) To increase the supply of water storage facilities, build dams, construct reservoirs, develop and regulate rainwater storage facilities for drought response, and build water tanks and reservoirs in coastal and island areas affected by drought and seawater intrusion.
21) Through the reorganization of catchment areas, protect and restore wetland ecosystems, utilize vegetation for forest and land restoration, and enhance the supply of high-quality, productive forest vegetation.
22) Expand the application of water recycling technologies by developing and applying reverse osmosis desalination techniques and expanding the use of wastewater purification technologies.
23) Expand the development and application of technologies to prevent water loss, construction, maintenance, and repair of supply and drainage pipelines, and the application of pipeline leakage detection technologies. (Seoul Institute, 2022, "Jakarta Province's 'Low-Carbon Development Plan' Case," World Cities Trends, Issue 526, Link)
24) Expand the development and application of integrated flood-drought management technologies to prevent droughts, supplement water resources, apply climate mitigation technologies, introduce water injection techniques for flood recovery, and use permeable and absorptive asphalt to respond to excessive surface runoff.

4.2.3 Disaster Prevention Administration Sector

1) Transition to water management administration that considers the water footprint.
2) Develop and use forecasting and warning scenarios for urban floods and urban droughts.
3) In the forecasting and warning scenarios, analyze past flood and drought data, set flood and drought risk standards, and use these as response scenarios for urban floods and urban droughts at the local government level. (National Disaster Safety Research Institute, 2014, “Development of Major Disaster Response Scenarios and Standards by Region (1) - Focusing on Urban Floods and Droughts,” pp. 52-53)
4) Establish an administrative system to distribute water in real-time to drought-affected areas during disaster occurrences.

4.2.4 Civil Life Sector

1) Promote awareness improvement among citizens through education, training, and public campaigns to conserve and efficiently use and manage water resources during drought periods.
2) Formulate citizen awareness regarding environmental issues caused by littering in rivers or clogging drainage systems, and flood prevention problems.
3) Contribute to water issues and use them as basic living facilities by introducing urban agriculture in housing, buildings, and communities at various scales and methods, and encourage participation in these activities.
4) Familiarize residents with recommended actions in case of flood-related disasters, and avoid access to flood-prone areas such as low-lying areas near rivers and coasts, underground spaces, and construction sites during flood warnings or forecasts. Exercise caution when using vehicles. (Ministry of the Interior and Safety, "National Flood Preparedness Action Guidelines," "Typhoon and Heavy Rain Preparedness Action Guidelines")
5) Residents should monitor weather conditions through news and public media, and when flood risks are high, follow the flood-related safety measures outlined by the government and relevant authorities to ensure safety in daily life.

Chapter 5: Integrated Management of Complex Disasters

5.1 Integrated Planning

5.1.1 Develop and implement disaster prevention-based, region-specific urban planning alternatives that consider compound disasters, making possible the integration of environment, urban, and disaster planning.

5.1.2 To address the reduction of urban green spaces, systematically expand green spaces and, considering spatial characteristics, explore and utilize alternative green spaces such as ecological area ratios, green buildings, linear green spaces, and vertical green spaces.

5.1.3 Establish preventive urban planning measures linked to disaster vulnerability analysis, compound disaster management maps, and city-specific disaster prevention plans.

5.1.4 Institutionalize connected plans between environmental, urban, and disaster plans through laws or administrative regulations to ensure proper linkage.

5.1.5 Restructure infrastructure and urban facilities to activate city functions capable of responding to compound disasters.

5.1.6 Urban, environmental, and climate experts in local communities should identify effective urban facilities for compound disaster response caused by climate change and propose installation strategies.

5.1.7 In the short term, appropriately mix green infrastructure (green infra) and gray infrastructure (gray infra) to respond to compound disasters, while in the long term, restructure urban facilities around green infrastructure.

5.1.8 Actively conduct cross-reviews between response plans for heat, disease, and flooding to minimize negative feedback or negative synergy.

5.1.9 Develop and utilize an open monitoring system, such as smartphone apps, so that residents can participate directly in disaster-related monitoring during daily activities and in their livelihoods.

5.1.10. Introduce a feedback mechanism to assess the appropriateness of disaster response plans and environmental and urban plans, guiding systematic plan implementation.

5.1.11 Conduct performance evaluations for disaster-related plans and projects by dividing responsibilities between frontline agencies and coordinating agencies. (Korean Institute of Public Administration, 2022, "Research on Improving Sector-Specific Performance Indicators: Focus on Disaster Safety," p. 223) Clearly manage the roles and responsibilities of disaster-related agencies.

5.2 Urban Management

5.2.1 Establish a "Community-based Disaster Response Information System" to create a system where local units can quickly carry out basic response measures before the central government intervenes.

5.2.2 Strengthen early forecasting and warning systems for compound disasters due to climate change by developing and applying AI-based flood forecasting systems to extend forecast times and shorten prediction cycles. (Ministry of Environment, 2023, "Third National Climate Change Adaptation Strategy," Press Release, p. 2)

5.2.3 Manage compound disasters in four stages: prevention, preparedness, response, and recovery.

1) Prevention Stage

① Organize and maintain disaster response teams, establish systems for disaster prediction and forecast information, provide training, education, and public awareness campaigns for disaster preparedness, establish safety management systems and regulations, manage national critical infrastructure, take action for specific areas of concern, inspect and maintain disaster prevention facilities, and designate resources such as equipment, facilities, and personnel for disaster management.

② Strengthen the management of essential service facilities in densely populated areas to prevent natural disasters from escalating into compound disasters.

2) Preparedness Stage

① Prepare emergency communication systems, develop and apply disaster response activity plans by function, establish and operate crisis management manuals, and conduct disaster preparedness training.

② Stockpile disaster management resources, establish an integrated disaster management system, and regularly conduct training for efficient resource deployment.

3) Response Stage

① Within the first 24 hours of a disaster, implement emergency measures and emergency rescue operations, followed by quickly setting up relief and response facilities to prevent further disaster expansion and reduce damage.

② Emergency Measures: Issue disaster warnings, recommend and direct evacuations, mobilize personnel, equipment, and supplies, establish danger zones, issue evacuation orders, provide emergency support, secure transport and rescue means, summon local government staff for emergencies, carry out emergency repairs of damaged facilities, maintain order through security, establish water supply, shelter, and relief

supplies, ensure communication and command systems at the scene, recommend travel restrictions, request suspensions of business and educational institutions, and take all other necessary disaster prevention actions.

③ Emergency Rescue: Emergency rescue operations, led by fire departments or fire stations, are critical for swift rescue and minimizing the spread of damage.

4) Recovery Stage

① The recovery stage is divided into short-term recovery (within one week) and long-term recovery stages. It includes reporting, investigation, and assessment of disaster damage, the development and implementation of disaster recovery plans, and project management according to self-recovery plans or special disaster area recovery plans. (National Land Research Institute, 2020, "National Policy Brief," No. 754, p. 4)

② In the short-term recovery stage, it is crucial to support the basic needs of affected residents, including food, shelter, and clothing. Additionally, continue support for essential service facilities during the recovery phase after compound disasters.

③ In the long-term recovery stage, the focus is on helping residents return to normal economic and social life. Given the importance of economic infrastructure, the management of not only general public facilities but also private facilities related to economic activities and regional management is also carried out.

5.2.4 Create disaster management manuals tailored to specific regions and assign roles and responsibilities accordingly, while establishing the responsible organizations for disaster response in each region.

5.2.5 Maintain a continuous management system for personnel, technology, and equipment available for disaster response from private enterprises and organizations.

5.2.6 Develop a "Disaster Prevention and Management Integrated Platform" for the integrated operation of water-heat-disease compound disaster management maps and urban disaster prevention plans.

5.2.7 Build an open, integrated platform that allows relevant private organizations to participate and engage in actual disaster response activities.

5.3 Administrative Management

5.3.1 Develop and maintain an up-to-date "Crisis Management Response Manual" to strengthen response capabilities for managing the crises of compound disasters.

5.3.2 In addition to the national standard manual for compound disaster crisis management, create practical manuals for local governments and action manuals for disaster

response personnel, and operate them. (Chungnam Research Institute, 2019, "Updating Disaster Management Manuals and Creating Initial Action Manuals," pp. 6-9)

5.3.4 Since the roles and capabilities of disaster-related public servants at the local government level are key to improving disaster response capacity, expand and strengthen training programs for disaster-related public servants. (Korean Institute of Public Administration, 2021, "Research on Enhancing Disaster Safety Management Capacity," p. 301)

5.3.5 In addition to public servants, prepare and provide "Disaster Response Training Guidebooks" for officials from the public sector and private companies involved in disaster management, and ensure continuous and systematic training.

5.3.6 Identify the importance of key vulnerable and support facilities to create a compound disaster management map.

5.3.7 Classify essential support facilities for compound disaster response into essential service facilities, economic activity infrastructure, transportation infrastructure, and relief and response facilities, with local governments managing them in detail.

5.3.8 Establish a field-based disaster safety communication network focused on local public offices and schools, among other public institutions.

5.3.9 Regularly conduct disaster preparedness drills in densely populated residential areas and multi-use facilities to develop practical response capabilities.

5.3.10 Develop and distribute "Disaster Response Action Guidelines" for each administrative domain, support domain, and resident domain, and conduct field training based on those guidelines. (Ministry of the Interior and Safety, 2017, "Disaster Management Shared Use System (DRSS) Guidebook," p. 8, 11)

5.3.11 Establish a public-private integrated disaster management resource management system to routinely manage resources necessary for disaster management and ensure they can be quickly mobilized and used during disasters.

5.4 Governance

5.4.1 Citizens actively participate in creating cities and regions that are safe from climate crises.

5.4.2 Governance for disaster response is structured to maximize citizen participation, create efficient collaboration frameworks, and fully utilize local resources.

5.4.3 Minimize the digital divide for disaster-vulnerable groups to maximize access to

disaster-related information for all residents.

5.4.4 Expand disaster response education for residents and provide appropriate incentives to encourage active participation in the training programs.

5.4.5 Build a system that allows local governments and private organizations, such as local businesses, to collaborate efficiently, and establish a permanent management system for this cooperation. For example, Doosan Infracore supported recovery operations during the 2008 Sichuan earthquake and the 2010 Qinghai earthquake by deploying heavy machinery like excavators, and Samsung S1's 3119 Rescue Team became the first private emergency rescue institution in Korea, working with local fire stations during national disasters or large-scale accidents. (Korean Institute of Public Administration, 2022, "Research on Strengthening Collaborative Systems in Disaster Response," p. 53-54)

5.4.6 Designate and manage private companies with appropriate personnel and facilities as disaster response support agencies by local governments.

5.4.7 Based on the collaboration structure between public institutions, establish cooperation mechanisms between public-private organizations (businesses) and between public institutions and local residents, and integrate these collaborations into standard practices for disaster response.

5.4.8 Continuously develop local recycling resource utilization programs that can address waste management from both disaster response and resource management perspectives.

5.4.9 Regularly survey the equipment and materials that can be obtained or procured in the region for disaster preparedness, and share the list with relevant agencies and local residents.

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