Master's Thesis of Landscape Architecture

Evidence-based Planning for Urban Flood Mitigation in Seoul Metropolitan Government

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Under the Direction of Advisor, Prof. Junsuk Kang

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Abstract

Evidence-based Planning for Urban Flood Mitigation in Seoul Metropolitan Government

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Master's Course in Landscape Architecture
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The social and economic damage caused by climate change has increased rapidly over the last several decades, with increasing instances of heat waves, floods, and extreme rainfall. Of these, the damage caused by extreme rainfall is still ongoing, and more extreme rainfall is expected in Korean Peninsula in the future. There was up to 110.5 mm/hr of rainfall in Seoul, which caused 69 casualties and approximately USD 27.6 million in economic damage.

Most of the causes of flooding in modern cities include a sharp increase in non-permeable packaging surfaces and a lack of water circulation facilities. According to climate change scenarios provided by the Korea Meteorological Administration, the average rainfall in cities over the next 100 years is expected to decrease. However, it is predicted that future instances of heavy rain will occur in the future, causing large amounts of local damage. If the current state of infrastructure is not equipped with repair or mitigating technologies, the damage will be significant.

This study was conducted based on the following three objectives. First, to quantitatively analyze urban flood damage over the next 80 years (2020-2100) that could be caused by the climate change scenario provided by the Korea Meteorological Administration. Second, this study was selected disaster mitigation facilities and analyzed their impact on disaster mitigation. It also arranges and designs facilities based on an evidence-based planning. Sustainable facilities were selected by introducing eco-friendly facilities for future generations as mitigate technologies. Third, through the development of the HCFD (Hazard Capacity Factor Design) model, the capacity and performance of the facilities that may change in the future were analyzed. HCFD model was used to consider ways to maintain mitigating technologies.

In order to achieve these goals, a total of three mitigating technologies have been installed. This includes water tanks, permeable pavement, and ecological waterways. In the case of water tanks, the capacity was calculated by referring to the statutes designated by the Ministry of Environment. Also, an Arc-GIS ArcHydro Plug-in was used to calculate the scale of each technology and watershed was analyzed. The precipitation provided by the climate change scenario was analyzed on an hourly basis to determine the extent to which watershed affects it, and the Huff dimensionless curve was used for this purpose.

These three mitigating technologies can contribute to flooding by increasing the storage capacity of rainwater. This study suggests that all floods can be reduced by RCP8.5 in 2050, 2060. Although there will be run-off after 2070, it is analyzed that technology will significantly reduce the volume of the flood. It is deemed that a one-year analysis should be conducted in consideration of the maintenance aspects in the future.

Furthermore, removal timing of the non-point source pollutant was calculated. In the case of water tanks, the amount of non-point source pollutant accumulated inside and the removal timing were calculated through MOUSE regression analysis. Internal management of water tank is classified into caution stage, general stage and safe stage. There were nine local governments that corresponded to the caution stage, ten local governments of general stage and five local governments of safe stage.

There are three main conclusions drawn from the results of this study. First is that the possibility of flooding that could occur according to climate change scenarios was analyzed at a 10-year frequency. Both the RCP 8.5 scenario and RCP 4.5 scenario showed frequent flooding after 2070. For the RCP 8.5 scenario, it is predicted that the year 2090 has the highest amount of precipitation. However, for RCP 4.5 scenario 2100, the maximum daily rainfall is approximately 690 mm, with hourly precipitation of 238 mm.

The second is that capacity of each technology was analyzed. According to the installation rules assumed in this study, the volume of water tanks that can be installed throughout the Seoul Metropolitan Government is 776,588 m^3, permeable pavement is 89,049 m^3, ecological waterway is 81,986 m^3. It is siginificant that each local government has suggested an efficient combination of two technologies.

Third, the amount of runoff that can be reduced by each mitigating technology was quantified. This study has identified that flooding at the local level will be more frequent and is meaningful in analyzing the quantitative effects of disaster mitigation technologies. Besides, when each local government installed flood mitigation technology in the future, quantification data would be provided to ensure optimized decision making for each situation.

The limitations of this study can be diagnosed by dividing them into four parts. The first limitation is uncertainty about climate change scenarios. Since changes in carbon emissions or scenarios can significantly change precipitation values, it is believed that future studies will develop into a more significant study if a scenario with fewer errors is used. The second limitation is that the study was conducted at a frequency of 10 years, as both RCP4.5 / RCP8.5 scenarios were analyzed daily. Third, social change factors are not reflected. Fourth is the limitation of verification. In this study, an arithmetic equation and GIS Arc-hydro were used to calculate the run-off in the Seoul Metropolitan Government. The most ideal method to verification is to compare the results with other software. The reliability of this study can be improved by comparing the amount of runoff before applying technologies using programs such as SWMM, STORM, and MUSIC. Future studies, therefore, should be carried out to overcome the above four limitations. In particular, uncertainty problem of the climate change scenario should be solved.

Keywords : Climate Change Scenario, Evidence-based Planning,
Extreme Rainfall, Floods, Green Infrastructure,
Hazard Capacity Factor Design Model,
Hazard Mitigating Technology.

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Publications

Please note that this dissertation was written as stand-alone paper (see below), and therefore there is some repetition in the methods and results.

Article

Jaekyoung Kim and Junsuk Kang. “Analysis of Flood Damage in the Seoul Metropolitan Government Using Climate Change Scenarios and Mitigation Technologies”. *Sustainability*, 13.1(2021): 105. https://doi.org/10.3390/su13010105.

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Chapter 1. Introduction

1.1 Background

The social and economic damage caused by recent climate change has increased rapidly. Data released by NASA showed an increase of about 0.93 ±0.07 °C between the 1880s and 2018 (Fig. 1) (Nasa Goddard Institute for Space Studies 2020, Lenssen et al. 2019). Climate change is more serious because it leads to direct problems such as thawing glaciers, heat waves, extreme rainfall, as well as collateral occurrences such as the destruction of species diversity and a marked increase in climate change refugees (Korea Water Resources Corporation 2010).

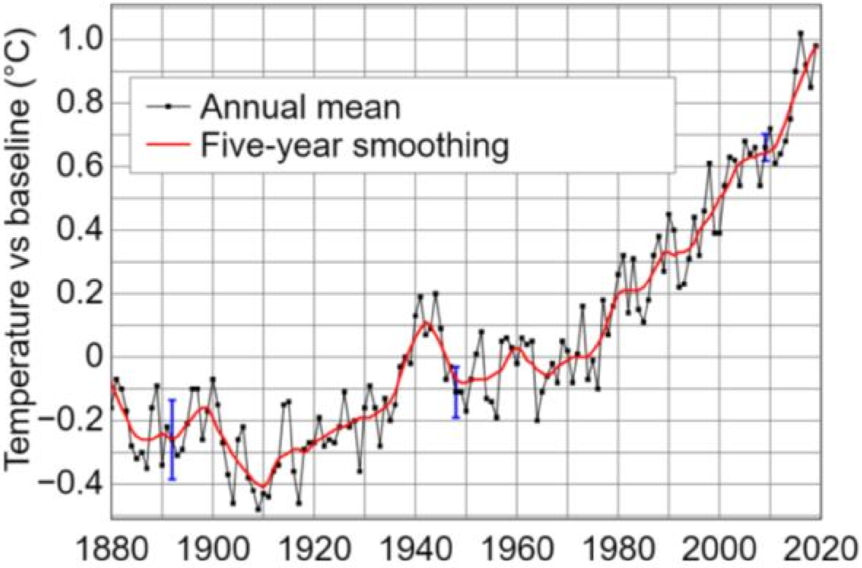


Fig. 1. Global Average Temperature (NASA GSIS 2015)

Thus, the Intergovernmental Panel on Climate Change (IPCC) provides a series of scenarios to minimize damage from climate change. The climate change scenario is divided into four stages, RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, and is used to provide preemptive information that can be used to assess the impact of climate change and minimize damage. (IPCC 2014). The definition of each RCP scenario is shown in Table 1.

Table 1. Description of each RCP scenario (IPCC 2014)

Type	Description	CO_2 Concentration (The Year 2100)
RCP 2.6	Instantaneous greenhouse gas reduction	420 ppm
RCP 4.5	Substantial achievement of greenhouse gas reduction policy	540 ppm
RCP 6.0	Fair achievement of greenhouse gas reduction policy	670 ppm
RCP 8.5	Greenhouse gas emission as current trend	940 ppm

The information produced by applying the model in the climate change scenario includes temperature, precipitation, wind and humidity. Of these, the damage caused by extreme rainfall is still ongoing, and it is predicted that more extreme rainfall will occur in the future.

If greenhouse gases continue to be emitted at the current rate (RCP 8.5), the average temperature is expected to be increased by 6.0 °C, and the precipitation will increase by 20.4% at the end of the 21st century (2070 – 2099). In the case of RCP 4.5, assuming that some efforts to reduce climate change are realized, the temperature and precipitation are expected to be increased by 3.4 °C and 17.3%, respectively (IPCC 2014). As the precipitation increases, it is expected that floods will occur more frequently. In the case of RCP 4.5, the highest rainfall is predicted between the year 2040 and the year 2070, with an average of 1,466 mm in the Seoul Metropolitan Government. On the other hand, from 2071, the trend will be gradually decreasing, and the average precipitation will be decreased to 1,276 mm. However, RCP 8.5 shows a steadily increasing trend. It is estimated that an average rainfall of 1,290 mm will be expected between the year 2040 and the year 2070, and an average rainfall of 1,400 mm will be expected after the year 2070 (Kwon et al. 2020).

The social and economic damages that can be caused by extreme rainfall are landslides and urban floods. For example, heavy rains in central South Korea in July 2011 caused a landslide on Mount Umyeon. Heavy rains of up to 110.5 mm/hr caused 69 casualties and about 27.6 million US dollars economic damage (Fig 2). In addition, peak rainfall of 126.0 mm/hr was recorded in 2001 and 90.0 mm/hr being recorded in 2010, as shown in Fig 2. (Seoul Metropolitan Government 2016). Furthermore, the sharp increase in non-permeable pavement and a lack of water circulation facilities can be named as the main reasons for flooding in cities (Pielke 2000).

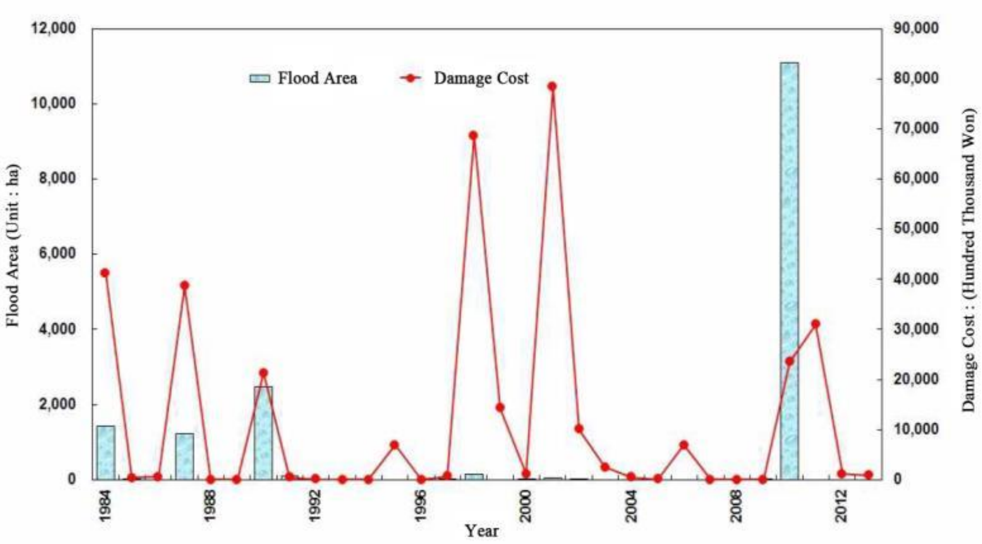


Fig. 2. Seoul Flooding Area and Flood Damage by Year (Seoul Metropolitan Government 2016)

Such disasters occur intermittently not only in the central part but also in the southern part of the country. Heavy rains in 2014 caused a record rainfall of up to 244.5 mm/hr in Geumjeong-gu, Busan, based on statistics by the Korea Meteorological Administration. In 2019, four people were buried in a massive landslide due to the influence of Typhoon Meitak.

The damage caused by extreme downpours is not a uniquely Korean problem. Floods in western Japan in 2018 caused a total of 225 deaths, with economic damage at that time estimated at 19 trillion won.

In 2016, the Seoul Metropolitan Government analyzed the cause of flooding in urban areas. It cited a sharp increase in permeable packaging and a lack of water circulation facilities as the main reasons for this. These causes are the unfortunate result of an increase in unplanned infrastructure (SOC) that failed to take into account water circulation facilities throughout the 1970s and 1980s (Seoul Metropolitan Government 2016).

In the case of Korea, which clearly shows the nature of concentrated summer precipitation, flood damage is expected to increase further as illustrated in the climate change scenario. This study originated from the question of how society may best reduce urban flooding by establishing and using a water circulation system. Therefore, this study was conducted to analyze technologies that can improve water circulation functions in cities and to examine future damage mitigation.

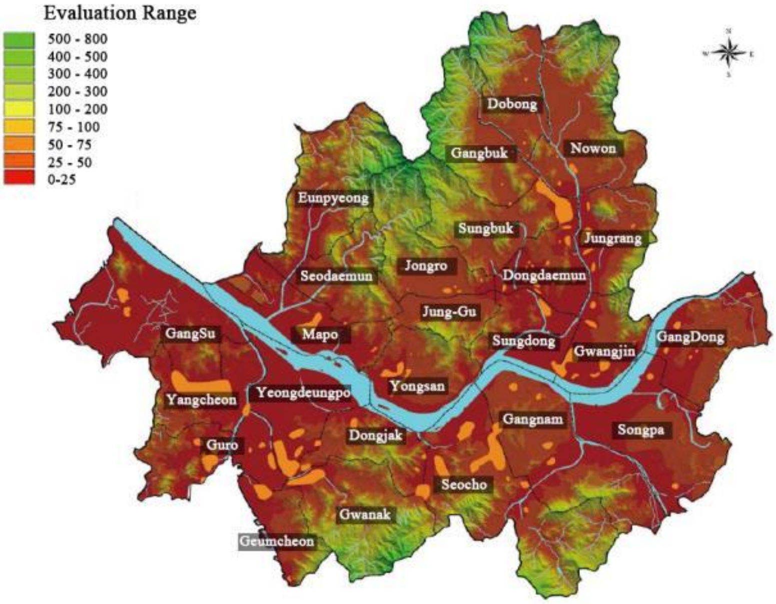


Fig. 3. July 14-15, 2001 Flooded Areas (Seoul Metropolitan Government 2016)

1.2 Objectives

As mentioned, the flood damage caused by climate change and heavy rainfall is growing. However, for once-built SOC facilities, especially for non-permeable packaging such as concrete, there are limitations in improving the facilities (Pielke Jr 2000). This is because roads and buildings made of non-permeable packaging are directly linked to citizens' living rights and safety areas. Therefore, the study was conducted based on the following five purposes:

First, to quantitatively analyze urban flood damage over the next 80 years (2020-2100) that could be caused by the climate change scenario provided by the Korea Meteorological Administration. Second, this study was selected disaster mitigation facilities and analyzed their impact on disaster mitigation. It also arranges and designs facilities based on an evidence-based design. Sustainable facilities were selected by introducing eco-friendly facilities for future generations as mitigate technologies. Third, through the development of the HCFD (Hazard Capacity Factor Design) model, the capacity and performance of the facilities that may change in the future were analyzed. HCFD model was used to consider ways to maintain mitigating technologies.

To meet the above three objectives, a hydrologic analysis of the local government scale was conducted. In addition, an optimized planning in terms of water circulation is presented through landscaping techniques such as ecological waterways.

Furthermore, This study simply evaluate how these technologies can affect the vulnerability of urban area. Vulnerability is widely used concept in climate change. It is very important because it is used as an index to find out the effects of mitigation technologies.

1.3 Scope

The main body of this paper consists of a total of four sections: preemptive research and status survey, methodology, data analysis, and evidence-based planning (Fig 4). Section 1 analyzes and identifies the limitations of the literature review, and deals with urban disaster mitigation technology among the studies related to flooding. In addition, the study examines the government’s current mitigate policy in preparation for urban flooding. The methodology presents three ways to complement the limitations of literature review and to achieve the purpose of the study. It is largely divided into analysis of the historical data of the target site, deriving the data base through simulation, selection of mitigating technology, and assessment of disaster mitigation. In the data analysis, the hydrologic analysis is conducted based on the preceding contents to identify the watershed and the flooded area. In addition, climate change scenarios are analyzed on a daily basis from 2020 to 2100 to see how effective disaster mitigation technologies could be in the future. Finally, when the climate change scenario was occurred, this study analyzed how much damage could be reduced in light of the discussed technologies. It also aims to establish the concept of the HCFD (Hazard Capacity Factor Design) model and to make an evidence-based planning.

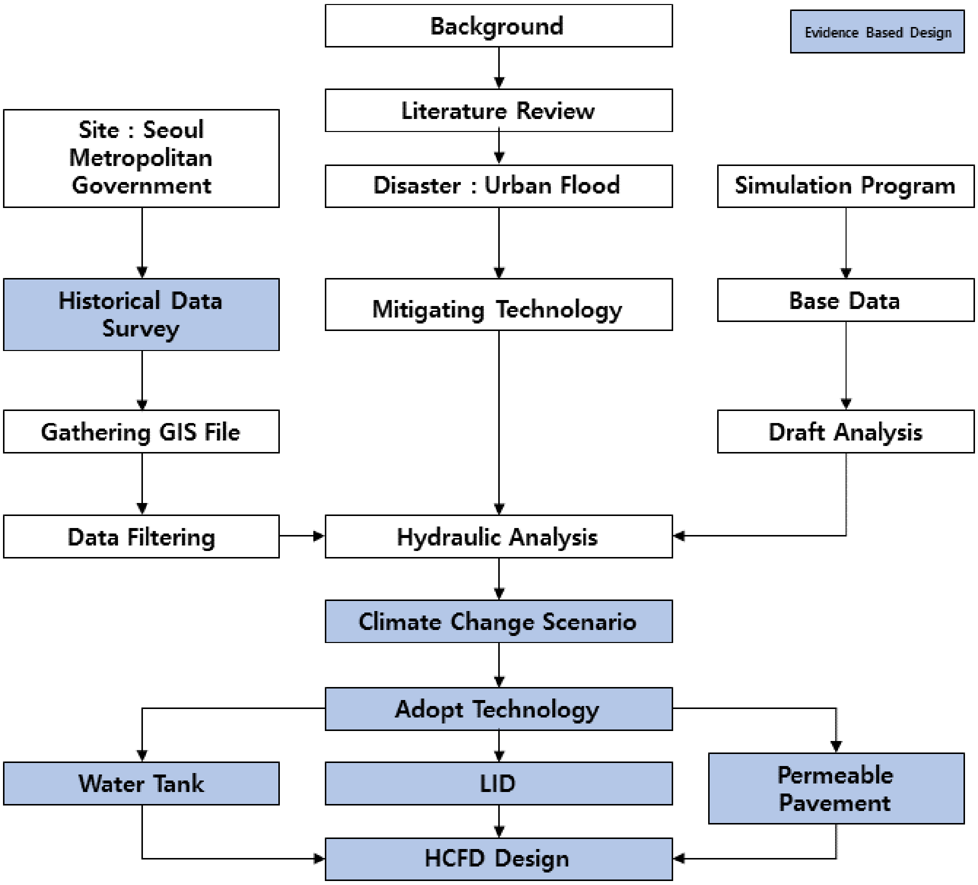


Fig. 4. Schematic Diagram of the HCFD Model and Work Flow

1.4 Definition of Floods

The word flood is commonly used to describe a variety of hydrological phenomena, but the exact meaning is defined differently by each country and study. In the case of Korea, the definition is summarized as "a large volume of water that is expected to be dangerous, including river flooding due to the rise of the river level." as defined by Korea Water Resources Corporation. If look at the definition in more detail, it can be defined as two terms: an occurrence in which a river’s water level has risen higher than usual, or the phenomenon in which the water level of the river rises, causing flooding around the embankment by destroying the bank itself (Korea Water Resources Corporation 2010).

The method of defining the type of flood is also slightly different depending on the institution dealing with the flood. The Floods, a book by Routledge Hazards and Disaster in the U.K., categorizes floods into a total of 11 sections and 22 subdivisions, as shown in table 2 (Parker 2000).

A Swedish study categorized floods into four categories: short-rain flooding, long-rain flooding, snowmelt flooding, and rain-on snowfloods. Short-rain flooding refers to floods caused by short-term rainfall, usually within a day. Long-distance flooding is a disaster caused by rainfall for more than a day, usually with low strength and per hour rainfall rates, but that can cause major run-off through the mass collection of water (Hundecha et al. 2017).

Table 2. Types and Examples of Floods (Parker 2000)

Agent	Details Examples of Floods
Rainfall	Riverine or non-riverine Slow-onset of flash flood Convectional/frontal/orographic Torrential rainfall floods
Snowmelt	Riverine Overland flow
Icemelt	Glacial meltwater (rise in air temperature) Glacial meltwater
Flooding during freeze-up	Riverine
Flooding by ice breakup	Riverine (also called ice-jam floods)
Mudfloods	Floods with high sediment content
Coastal/Sea/Tidal floods	Storm surge (tropical or temperate induced) Ocean swell floods Percolation floods Tsunamis (induced by geological process)
Dam	Dam-break flood Dam overtopping
Sewer/Urban drain flood	Storm discharge to sewers and drains exceeds capacity
Rising water tables (high groundwater levels)	Many casual factors including land subsidence, rising sea levles, temporal reduction in water abstractions from aquifers
Combined events	Example include : river/tidal flooding - rain on snow floods

According to the Meteorological Encyclopedia published by the Korea Meteorological Association, flooding can be divided into two categories. The first is an open flood of water from rivers and streams, and the second is a flood of domestic origin where rainwater such as sewage and drainage cannot drain into the river, causing flooding of residential areas (Shin 2006).

Korea Water Resources Corporation defined a total of four types of floods: coastal, river, flash and urban flooding. Coastal flooding refers to floods that occur in coastal areas, while sudden flooding refers to floods that occur in areas where there is a steep slope. River floods refer to cases in which there is overflow along a river, and urban flooding occurs within cities. The characteristics of floods classified by the Korea Water Resources Corporation are as shown in Table 3.

Table 3. Cause and Characteristic of Floods

Type	Cause	Characteristics
River flood	flooding of rivers caused by typhoons or torrential rains	Long-term (daily) damage occur in a wide area, and damage caused by overflow and collapses is dominant
Urban flood	An increase in the number of non-permeable areas such as parking lots, buildings, roads, etc. in the city	Damage caused by the increase in peak flooding and the reduction of time to reach due to the increase in permeable areas. The flooding of residential areas and commercial factory sites
Flash flood	Heavy rain in the mountainous areas where there is a steep terrain	Occurring for a short period of time (minutely) in a narrow area, dominant in the damage of rapid increases in upstream river flow, landslides, and collapse of upstream small dams
Coastal flood	Rising sea levels and forming high waves due to low pressure formation during heavy rains	Damage caused by sea water flooding in coastal areas due to elevated sea levels and waves, and damage caused by flooding of rivers due to inflow of seawater

Although different concepts define the type of flood, the type of flood that this study deals with is close to the short-lane flooding and urban flooding forms. When torrential rain exceeds the capacity of the city's drainage and residence systems, excess water escapes into the runoff, causing flooding damage to buildings or streets in the city center. The two types of flooding have many similarities in the nature of rainfall, causing large-scale flooding damage to the city. One characteristic of urban flooding is that most of the casualties caused by it tend to occur in low-lying areas or in certain areas of the city. Through this, it was possible to see that there was a section inside the downtown area that was habitually flooded.

The effects of flooding are largely divided into three categories: primary effects (physical risks), secondary effects, and long-term effects. Primary effects can pose risks to structures such as bridges, buildings, roads, and canals. People and livestock often drown to death, which can lead to secondary effects such as infectious diseases. Secondary effects are caused by water pollution, resulting in a scarcity of clean water and waterborne diseases under unsanitary conditions. The long-term effects are social/economic impacts on the local governments, including a temporary drop in the number of tourists, reconstruction costs, and economic hardships caused by food shortages. Long-term effects can have a more fatal impact, especially on vulnerable populations such as children, the elderly, and those in lower economic classes, among others.

1.5 Vulnerability

Using the concept of vulnerability used in the IPCC report, this study try to understand what kind of changes can be made to urban area. Vulnerability and main concepts defined in IPCC are as follows.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. Climate-related stimuli encompass all the elements of climate change. Adaptive capacity is the ability of a system to adjust to climate change. Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change (IPCC 2014).

In general, the relationship between vulnerability, sensitivity, exposure, and adaptability is shown as Eq. (1) (Adger 2006).

$$Vulnerability = \frac{Sensitivity\,to\,stress \times Prob.\,of\,exposure\,to\,stress}{State\,relative\,to\,threshold} \tag{1}$$

Concluding this section, the following terms are important to the study or related to flooding as shown in Table 4.

Table 4. Key Words and Definitions Used in this Study

Terminology	Definition of terminology
Mitigating technology	The term refers to the technology that minimizes damage to human life and property by mitigating natural disasters and swiftly responding to changes in the environment
External flood	The phenomenon of flooding of rivers or streams, and flooding mainly with streams. Occurs mainly when having a small catchment area
Internal flood	It is caused by the absence of functions such as sewerage or drainage, and the rainwater can not drain into the river. Mainly flooded residential, commercial areas, etc. and can be submerged in large amounts of water at a time
Overflow	The phenomenon of overflowing water in embankments, breakwaters, lakes, etc. or the amount of water. Overtopping is a phenomenon in which water crosses the floor of a structure by high waves, high elevations.
River stage	An indication of the water surface of a river at a height from a certain plane. Measurement method: reading it as a scale plate placed in a river, or automatic recording the rise and fall of buoys in a connected with river water
Vulnerable district	An area where significant damage is expected or has occurred from disasters such as floods. Areas where many children or senior citizens live and are expected to be severely damaged due to difficulties in dealing with disasters
Water cycle (Hydrolocial cycle)	A phenomenon in which water on earth receives solar energy and circulates constantly between lithosphere hydrosphere and atmosphere, also called hydrologic circulation
Watershed	When a flood occurs, it means the extent to which the water flows into one point affects the area

Chapter 2. Literature Review

2.1 Overview

Flood-related studies in cities is divided into studies that assess vulnerable zones and risks and those that suggest response techniques. This is as shown in Table 5.

Table 5. Classification of Prior Research

A Study on the evaluation of vulnerabilities and risks	Flood mitigative technical proposal study
· Development of Recovery Techniques of Urban Flood Disaster Multilayer Defenses : A Case of Chuncheon City · Inundating Disaster Assessment in Coastal Areas Using Urban Flood Model	· Preventive Design for Flooding on Local Government based on Urban Scale Hydraulic Anaylsis · Flood hazard vulnerabilities and coping strategies of residents of urban poor settlements in Metro Manila, the Philippines

As the most recent study on flood mitigation technology, local governments have designed flood mitigative technologies, focusing on the design of a water tank for the Gangdong-gu district. Only one district was analyzed using ArcGIS. Based on the Gangdong-gu RCP scenario report, the 40-year and 70-year frequency of rainfall were analyzed. It is meaningful that local governments have provided some decision-making guides in calculating the capacity of water tanks. However, despite referring to the climate change scenario based on continental climate simulation, the research was conducted only in Gangdong-gu, which has its limitations. (Choi 2019). The gap between prior research and this study is that this study expanded to cover the entire Seoul Metropolitan Government. Moreover, the full data of climate change scenario RCP 4.5 / RCP 8.5 provided by the Korea

Meteorological Administration were analyzed on a time-by-hour basis to determine the effectiveness of the mitigation technology.

In order to adapt to climate change, including floods, some studies were conducted that quantified technologies referred to as green infrastructure, such as roof gardens, permeable pavements, and ecological waterways (Bae and Lee 2020, Kim et al. 2020). Using a run-off analysis program such as SWMM (StormWater Management Model), it has been revealed that green infrastructure such as roof gardens can not only reduce peak flow and flooding but also have a positive effect on carbon reduction and temperature reduction.

In another paper related to flood mitigation, flood reduction ecosystem services were evaluated, focusing on Shenzhen, a major city in Southern China. Shenzhen's capacity for flood mitigation gradually decreased due to changes in land use, which weakened Shenzhen's resilience. It is argued that the conservation, restoration, and construction of urban ecological spaces should be advanced through the progress of the sponge city plan (Xu et al. 2020). In addition, research on selecting vulnerable areas for urban landslides due to floods and designing mitigation facilities is being actively conducted (Jeon and Kang 2020).

Recently, a flood risk zone analysis was developed that combines the analytical hierarchy process (AHP), geographic information system (GIS), remote sensing (RS), and Google Earth Engine (GEE) platform (Swain et al. 2020). In Russia, three types of data were collected using rain gauge and radar. It was revealed that hydrology model analysis using SWAT (Soil &Water Assessment Tool) could not only improve the rain gauge networks but also help to mitigate urban flooding (Grek and Zhuravlev 2020).

Recently, a framework study was also conducted to evaluate community resilience against urban flooding. The flood resilience framework is expected to be applied to sustaining urban planning and flood evacuations (Zhong et al. 2020).

The book Floods, part of the Route Hazards and Disasters Series published in the United Kingdom, covers many of the papers related to flooding. The book deals with a series of problems, impact measurement, vulnerability, and predictability caused by floods (Zoleta 2000). Papers on disaster mitigation techniques are also introduced in the book. However, most of the mitigating technologies introduced deal with the policy and administrative aspects, and fail to clarify the quantitative effects of introducing technology at the level of local government. Also, since most of the contents target developing countries and the vulnerable, most of them were policies that were difficult to apply in urban areas where the population was overcrowded and packaging had low permeability (Albano et al. 2017).

There was also a paper suggesting that there are "multiple mitigate system restoration techniques" related to the development of disaster mitigation technology. It is meaningful that it proposed a kind of process to quickly recover the damage that could be caused by floods. It has the advantage of utilizing both structural and non-structural techniques to actively utilize ecological cycles and existing facilities (Eo et al. 2018). However, the focus of the study is only on recovery, so there is a lack of discussion of mitigating techniques. This study is differentiated in that it prepares for flooding on a mitigating level and presents a quantitative mitigation for damage.

Among the studies related to the risk of flooding is the analysis of possible flood damage using the SWMM model, which can estimate the levels of urban flooding that will occur. It was connected to the GIS database with anticipation of flooding in the areas of Wolyeong-dong, Masan, where flood damage occurred during Typhoon Maemi. It is meaningful that the target area was divided into small watersheds and

SWMM was used. It is also meaningful to predict the location and depth of flooding, and to predict areas affected by rising sea levels. Simulations conducted on flooded areas using SWMM have produced results that are quite similar to the actual flooded areas, which has helped scientists and disaster analysts to better understand the depth of flooding and to predict the risk of flooding by building purpose. This greatly contributed to the establishment of policies, such as evacuation plans (Yoo, Kim, and Kim 2006).

Seoul National University used Linear Regression and Mann-Kendall techniques to present frequency analysis measures that reflect the increasing trend of flooding caused by climate volatility. Five branches, including Seoul, Incheon and Ulleungdo, were analyzed, and similar increases were demonstrated over time. It is meaningful that the risk of flooding in the future was predicted using statistical-based techniques. However, Andong Dam and Soyang River Dam, which have been selected as the sites for flood prediction, were located at a distance from dense residential areas. It also has a limitation that statistical significance has not been verified in most regions and that data such as climate change scenarios have not been actively utilized (Jeong et al. 2008).

Most of the papers discussed in this chapter were based on hydrology. On the other hand, a paper that approached flood-prone areas in a topographical way can be found. It is mainly calculated using topographical information such as elevation and gradient. Recently, LiDAR measurements have seen an increase in usage. With Munsan and Gokneungcheon stream at the center, TIN (a point model) was used to predict the vulnerability of certain areas to flooding. However, because only topographical information was used, hydrological information was not accumulated. It will be practically used as data on disaster mitigation when handling affairs in national territory information such as land and road plans (Hwang 2006).

Furthermore, studies related to decision making on flood mitigation, flood management and impact of future changes are being proposed. For example, information-theoretic Portfolio Decision model(iPDM) was introduced for the optimization of a systemic ecosystem value at the basin scale by evaluating all potential flood risk mitigation plans. iPDM calculates the ecosystem value predicted by all feasible combinations flood control structures (FCS) considering environmental, social and economical asset criteria (Covertino et al. 2019). In other study, a Multi-Criteria Decision Analysis(MCDA) decision framework for optimal decision making in flood protection design. This framework accounts for climate change, increasing urbanization, and evolving socio-economic features of flood. The MCDA uses as its criteria the annual expected loss, graduality, a newly developed Socio-Economic Vulnerability Index (SEVI) and levee construction cost. It is demonstrated for a central basin of Jakarta, Indonesia (Daksiya and Velautham. 2019). Recently, a real option analysis (ROA) plan used to enable decision-makers to reflect uncertainties in flood policies. This study assesses the capacity of technology to adapt to flooding, different from the uncertainties of decision-making in these preliminary studies (Ryu et al. 2018). Another gap is that this study is not directly involved in disaster decision making. This study quantitatively analyzes the capacity of technologies that can support decision making. This study can be used as data to support decision makers in creating disaster models.

2.2 Policy Review

Policy trends related to flooding can be classified into various categories depending on their size. They can be divided into local government policies such as municipal and provincial governments, national policies, and policy recommendations from international cooperative organizations such as the United Nations (Winchester 2000). This study examined local government policies to determine the magnitude of possible flooding in cities. One domestic case and two overseas case were cited.

The Seoul Metropolitan Government set a goal for short-term flood control by 2021, after two cases of massive urban flood damage in 2011 and 2012. A plan was established to simultaneously consider the system for expanding infrastructure and improving water circulation in Seoul Metropolitan Government. The plan is prepared for up to 100 mm/hr levels of rainfall.

The Seoul Metropolitan Government aims to refurbish facilities that can cope with more than 50 years of rainfall, taking into account the environment throughout local river facilities. The specific facilities include the maintenance of the control area and the installation of flood classification facilities (drainage, bypass flood, and waterfront reservoir). In addition, 34 vulnerable districts designated by the Seoul Metropolitan Government were given priority to expand the capacity of sewage control. It plans to dredge sewage pipes mainly in low-lying vulnerable areas.

It should be noted in the city's policies that short-term policies are carried out more specifically, but long-term goals are set more abstractly.

The U.S. was able to confirm that it introduced a global management plan for flooding earlier than Seoul. After two major floods in 1929 and 1935, the state of Texas established the Harris County Flood Management District in 1937 to respond to floods. The flood control district uses flood control reservoirs along with waterway improvement, waterproofing, bridge improvement, and embankment construction to improve flood capacity as a structural method for mitigating flood damage.

In other words, Harris County is not equipped with flood-mitigating facilities as a specific area or additional facility, but rather utilizes a widespread variety of existing infrastructure to reduce flooding. Currently, about 50 reservoirs are installed, and up to 100 reservoirs are planned to be secured. The reservoir within the White Oak Bayou basin inside Harris Country has a very small reservoir area of 80,000 m^2. Nevertheless, flood control in Texas has been successful because small-scale reservoirs have been installed in riverbeds in distributed forms. In other words, the sum of a number of small-scale reservoirs played a major role in improving the city's overall ability to cope with floods.

Japan is a country that shares the same East Asian climate zone as Korea, and suffers socioeconomic damage from floods every year. In particular, cities along the coast are suffering from floods accompanied by tsunamis. In the case of Japan, where the nature of local governments is independent, it can be seen that local governments are systematically planning to defend the country against flooding. Tokyo targets 324 kilometers of small and medium rivers west of the Sumida River to ensure safety from floods that could occur in 50 mm/hr rainfall. In the control area, 225 rivers including the Shakuji River, Meguro River, and Iri River were refurbished (Yeo 2016).

Relative to Seoul, Texas, and Tokyo are making great efforts to improve sewage facilities to prepare for flooding. However, the policies of these three cities focus only on improving the efficiency of sewage pipe networks, and oversight of water circulation and improving the permeability are not being addressed. It is urgent to introduce complex and sustainable flood mitigating measures / water circulation mitigating technology (Fang et al. 2014).

2.3 Types of Mitigating Technologies

To prepare for flooding and improve the water circulation system, a total of four facilities should be considered. These include collection facilities, treatment facilities, storage facilities, and transmission and drainage facilities, with the composition of each being shown in Table 6 (Kim 2012).

Table 6. Water Circulation System Facility for Flood

Collection facility	Treatment facility
· Water surface (Roof, Pavement etc) · Gutter hanger · Collect pipe	· Precipitation tank · Initial rainwater treatment system · Filter tank (Sand, Crashed stone) · Disinfection facility
Storage facility	**Transmission and drainage facility**
· Water tank (RC, FRP, Pipe plastic Type) · Ecological reservoir · Ecological waterway · Permeable pavement	· Water supply pump · Water supply facility · Water supply pipe · Utilization facility · Measuring and controlling facility

A collection facility is a facility that is used to collect rain effectively. A typical example is a water collector. Treatment facilities are used to maintain the appropriate quality of rainwater, functioning as the filtration and disinfection thereof. Storage facilities store collected rainwater in a capacity suitable for use. The materials and types vary depending on the conditions of the target site, and are divided into those using artificial materials and those using ecological materials. Storage tanks must have structural safety. A transmission and drainage facility refers to those facilities that send stored rainwater to a place of use or that discharge it into rivers and public sewage systems for safety reasons.

This study was focused on the storage facilities among the four technologies to establish flood damage mitigation measures. Permeable pavement is generally classified into a collection facility because rain falls directly on the pavement (Pratt 2003). However, this research was conducted by classifying it as a "storage facility" because it will focus on the permeability and storage functions.

In this study, three technologies are used: permeable pavement, water tanks, and ecological water ways. The permeable pavement is judged by the permeability coefficient of the pavement surface, which can be largely divided into full permeable packaging, partial permeable packaging, and drainage packaging. Generally, it refers to a full permeable packaging (PP), which means that the on-road permeability coefficient is $1.0X10^{-4}$ or less. A water tank is a technology that can store rainwater underground, and PC low-flow tanks and plastic laminated construction methods are mainly used. Ecological waterways are classified by methods such as penetration channels and vegetation channels, and are often installed linearly along roads. The classification and detailed description of each technology is explored in the sub-chapter.

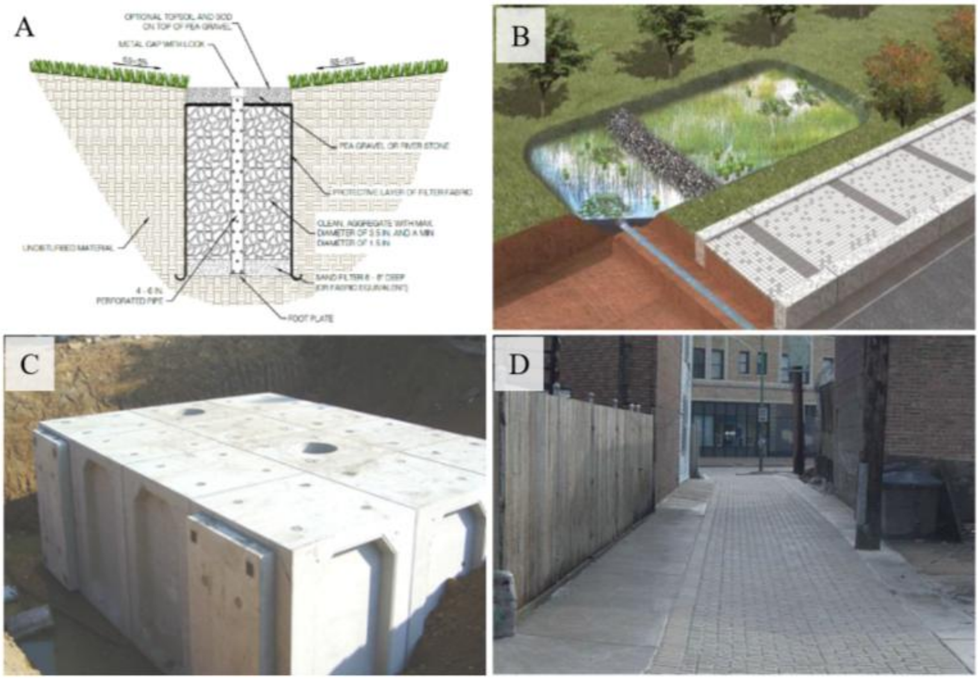


Fig. 5. Type of Mitigating Technology (Kim 2012)
(A : Infiltration Ditch, B : Vegetation Waterway, C : PC Water Tank, D : Permeable Pavement)

2.3.1 Definition and Classification of Water Tanks

Since water tanks use artificial materials such as RC, FRP and steel plastics, they are facilities that can manage high volumes of rainwater at low cost. They are usually installed in buildings, parking lots, and parks to store rainfall. In the past, it was common to transfer water stored in a water tank to a sewage facility, but now it is commonly reused through filtration.

In the case of water tanks, the size and design standards are regulated by a series of policies, which currently fall under the jurisdiction Seoul Metropolitan Government's guidelines around waterworks. Open spaces such as parks are required to have their minimum volume capacity be multiplied by more than 0.05 m in the area of water. In the case of buildings, water tanks are required to be installed in public facilities. The minimum volume capacity in the building area needs to be by 0.05 m or the land area by 0.02 m (Ministry of Environment 2010). Water tanks are classified according to their purpose as shown in Table 7.

Table 7. Water Tank Type According to the Installation Location (Kim 2012)

Install location	Application	Characteristics
Roof installation	· Housing · Small office Building	· Easy to maintain · Load can be considered · No power required for water supply
Ground installation	· Housing · Office	· Easy to maintain · Power is required for water supply
Underground installation (Full space)	· Housing · School · Office	· Ease of introducing large new buildings · Using underground basic structures
Underground installation (Partial space)	· Office	· Ease of planning rainwater use in existing buildings
Off-building space	· Roads · Parking lots · Sports field	· Ease of existing buildings · High utilization of space other than rainwater

The commonly used water tank is an underground installation type, and is usually installed in new buildings. Among the underground installations, it is often used in facilities such as houses, schools, and offices, which can be classified into four categories, according to the construction method, as shown in Table 8.

Table 8. Method of Water Tank Construction (Kim 2012)

Type	Construction sequence	Advantages and disadvantages
Field const.	① Ground excavation ② Installation of formwork ③ Concrete pouring ④ Installation of pipe entrance for waterway ⑤ Re-fill and install top plate	· Free installation of specifications and interior · A number of these have already been installed · Long-term construction period · Civil complaints such as dust · Delay of construction period according to conditions
PC rainwater reservoir	① Ordering ready made tank ② Assemble product ③ Installation of pipe entrance for waterway ④ Re-fill and install top plate	· Short construction period · Low construction impact means lower likelihood of civil complaints · Easy partial repair · Less capacity than on-site placement
Waveform steel water reservoir	① Order based on site and size ② Ground excavation and assemble product ③ Installation of pipe entrance for waterway	· Short construction period · Low construction impact means lower likelihood of civil complaints · Easy partial repair · Need to be prepared for leaks
Plastic water reservoir	① Ground excavation ② Assembling tank ③ Installation of pipe entrance for waterway	· Short construction period · Low construction impact means lower likelihood of civil complaints · Easy partial repair · Factory production allows winter construction · Need to secure the top fill height considering the load · Need to be installed for easy removal of sediments

2.3.2 Definition and Classification of Permeable Pavement

Although river maintenance facilities such as water tanks should be the priority for decreasing the amount of flood runoff, additional alternatives are needed in case of difficulties in installing water tanks. The representative facility of this is permeable pavement. For permeable pavement, the ratio of ground water on the surface is high due to the high permeability rate, and the growth condition of plants is better than ordinary packaging materials. Water-permeable pavement can be classified as shown in Table 9 (Smith 2011).

Table 9. Types of Permeable Pavement According to Seoul (Smith 2011)

Type		Characteristics
Permeable system	Full permeable pavement	· Installation of rainwater so that it penetrates the base layer and the road
	Partial permeable pavement	· Installation if the road cannot absorb all rainwater · Installation of drainage pipes to move to a water tank
	Drainage pavement	· Installed if the road surface is not solid and the permeable function is weak · Store and utilize rainwater by using the upper part of the road as a rainwater storage tank
Permeability of block surface	Surface permeable block pavement	· Pavement that uses a block with a large permeable coefficient to pass rainwater from the top of the block through the inside (Masonry joint : 2~3 mm)
	Masonry joint permeable pavement	· Packaging that passes rainwater between blocks and other blocks (Masonry joint : less than 10 mm)

The permeable pavement is classified by the system, but there are more than 50 categories at the construction site. A total of eight types of water permeable pavement were described in this study, and characteristics were analyzed to select the appropriate form for the study.

Table 10. Types of Water Permeable Pavement Classified in this Study

Type	Characteristics
Permeable concrete pavement	· Using permeable concrete as a way to eliminate hydroplaning in cities · Use net-type materials to allow rainwater to penetrate the ground. · Materials used in permeable concrete are currently being studied a lot and mainly focused on asphalt with good absorption → Care should be taken when mixing, transporting, or laying, as a reduction in temperature-lowering speed may occur.
Permeable block pavement	· A product that replaces existing regular cement blocks is installed around walking paths in urban areas. · Rainwater surface drainage not only contributes to natural ecological restoration, but also has excellent tree protection and mitigation of heat island phenomena. · It is a material that can create a natural texture and give a comfortable and pleasant feeling to urban residents. → Soil and dust significantly reduce the permeability, resulting in management difficulties
Grass pavement	· One of the best alternatives to expanding the area of plants and permeability · Depending on the material, plants can compose between 50 and 90% of the total material · In foreign countries, types of private parking lots and gardens are actively constructed. → Good material for a positive effect on the city's beauty and climate

Type	Characteristics
Wood blocks	· Type of construction can be carried out using actual and artificial wood. · There is not much difference in price between the two types · Psychological effects can be expected and making it excellent for recycling
Cube stone blocks	· Packaging using square-shaped trimming materials · Generally, layers of 50 to 150 mm are formed to pack · Recently, it has been used in various ways, such as roads, landscaping facilities, etc.
Asphalt concrete	· Cement-based packaging materials that can be applied to the surface with resin of acrylic system to reduce peel-off phenomenon · Water spillage, inflow or evaporation between cement · It is flat and installed on bike lanes, parking lots, squares, walking paths, etc.
permeable polymer concrete	· Permeable blocks used by replacing a powdered polymer VAE · Polymer-permeable blocks mixed with artificial water pipes have a higher air gap than the standard for interlock blocks · If polymer is replaced, so the product can be lighter · It has three to five times the strength of ordinary cement concrete
Geo-cell reinforced permeable pavement	· The application of the geo-cell method allows for similar strength to normal permeable water pavement in the event of heavy rain · It appears that rainwater can be quickly drained to the underside of the package, contributing to the improvement of the water circulation system · Noise reduction and slide resistance were obtained compared to normal packaging, and packaging temperature reduction was found due to vaporization heat of water

In this study, geo-grid reinforced permeable pavement is introduced as a mitigating technology. The use of underground reinforced structures such as geo-grids can solve safety areas that have previously been pointed out as problems in water-permeable pavement. It can improve ground safety as well as increase water permeability at the bottom of road pavement.

The sectional drawings of sustainable permeability pavement utilized in this study were announced by the Seoul Metropolitan Government. The permeable pavement shown in Fig. 6. was installed in Gwanak-gu in 2012 and was also used for vehicle driving routes. Compared to asphalt, there was no water flowing or pooling along the surface at the time of the spray test (Seoul Metropolitan Government 2009).

In the road flatness test, the flatness of the asphalt road was 3.7 m/km, while the permeable pavement was 8.8 m/km, indicating that it would be more than twice as flat as the existing asphalt pavement. Thus, the Seoul Metropolitan Government recommended the installation of low-speed roads, such as child protection zones and back roads, but this study assumes that only pedestrian roads should be installed in consideration of damage.

It was analyzed that the amount of rainwater that can be stored in the 1 m section was 0.296 m^2 when the permeable pavement as shown in Fig. 6. was installed at a width of 3 meters (Korea Construction Standards Center 2018).

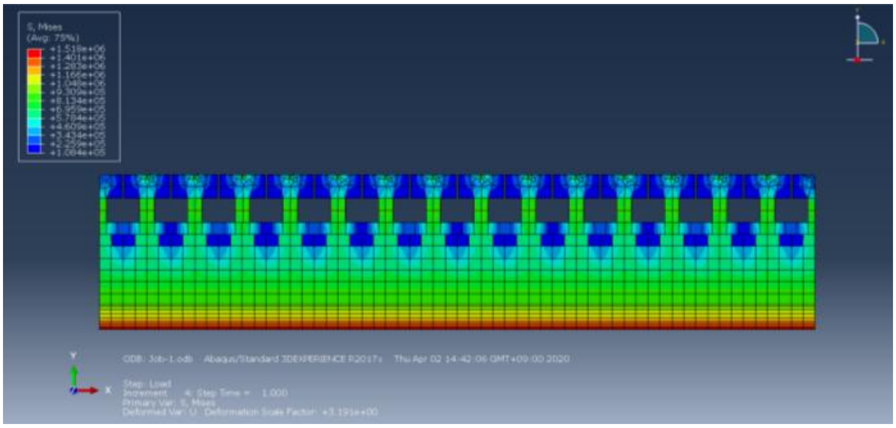


Fig. 6. Finite Element Model of Permeable Pavement

2.3.3 Definition and Classification of Ecological Waterways

Ecological waterways have a high mitigation efficiency in flooding and have an ecologically friendly image. In addition, it is relatively convenient to maintain as it is often installed on the ground. Sometimes the roots cause cracks in the packaging when trees are planted. However, in new cities such as Sejong City, it is legally stipulated that the cross-sectional design of roads should account for the expanding scope of vegetation space to solve problems.

Ecological waterways have the advantage of being able to treat rainwater in large quantities, but they are having difficulty selecting sites because they are formed along the sidewalk. Ecological waterways are named differently depending on the institution, and there is no clear standard for distinguishing each facility. In this study, the ecological waterway was divided into four types used for the design of Asan Tangjeong district (Park, Joh, and Sung 2011).

Table 11. Classification of Ecological Waterway (Park, Joh, and Sung 2011)

Type	Characteristics
Penetration ditch	· Use gravel sand, etc. and use natural construction methods through soil penetration · It can be designed as an eco-friendly facility considering the surrounding natural scenery
Vegetable waterway	· Ecological restoration function · The flow rate of rainfall decreases, thereby facilitating the removal of pollutants from the water.
Lateral penetration facility	· Same role as a lateral ditch · Suitable for small-scale sites and easy to construct · Securing convenience of maintenance
City-type artificial wetland	· Applicable to small-scale urban sites and has ecological restoration function · Provides a pleasant aesthetic view

In this study, infiltration ditches were selected as disaster mitigation techniques among the four facilities. This is because the rainwater capacity of the four facilities was greatest when the scale was constant (W: 1.5 X L: 10.0 X H:1.0). When measuring the capacity of each facility, the infiltration ditches have a volume of 5.4 m^3, plantation waterways have a volume of 2.0 m^3, lateral ditches have a volume of 2.6 m^3, and urban type artificial wetlands have a volume of 3.1 m^3.

In addition, run-off occurred in early rainfall in all facilities except for infiltration ditches. Through this, this study can see that the permeability and rainfall inflow function of the penetration ditch is higher than other facilities. In this study, which defines large amounts of rainfall in a short period of time as a disaster, it is assumed that permeability is the most important disaster mitigation indicator.

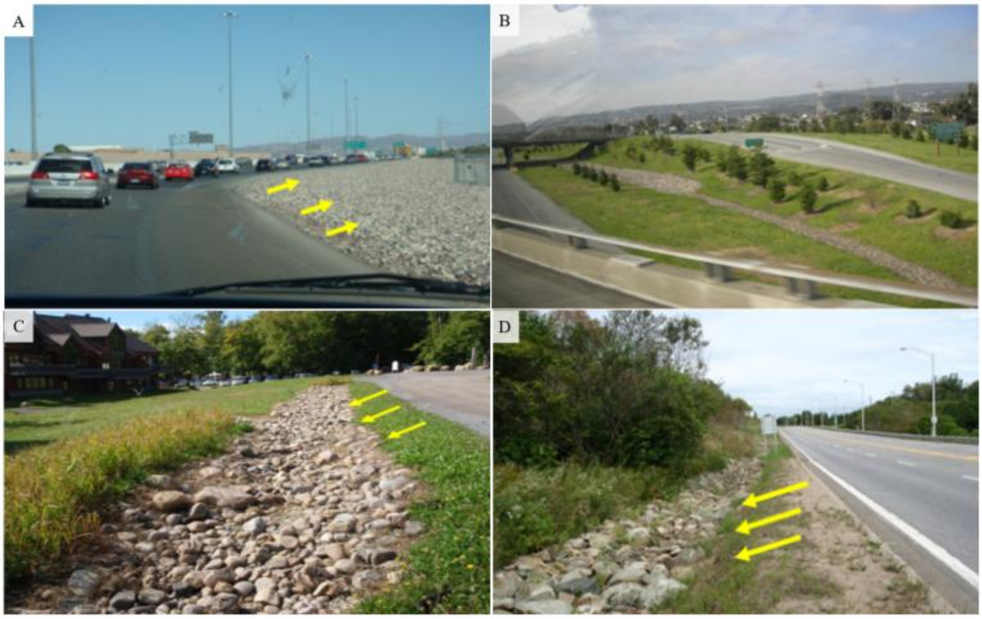


Fig. 7. Examples of Penetration Ditch Installation (Park, Joh, and Sung 2011)
(A : Navada USA, B : California USA, C,D : Quebec Canada)

2.4 Types of Analysis Programs

Planning/design models and programs for rainwater-use facilities shall be able to review the effects of rainwater use facilities before and after installation, and the improvement of water circulation. In addition, water and energy balance can be simulated according to landscaping water and penetration of rainwater in rainwater-use facilities.

The EPA's Storm Water Management Model (SWMM) is one model that can be used in the design of rainwater-use facilities (Tobio et al. 2015). There is also the ARC GIS ArcHydro, Model for Urban Stormwater Implementation Conceptualization (MUSIC) of CRCCH, and STORM of IPS.

Developed domestically, the models include RainStock, a building rainwater-use facility design program developed by the Korea Institute of Construction Technology, and the RainCity model, a decision-making support system for rainwater management facilities in apartments. The advantages and disadvantages of each item are summarized in Table 12 (Ministry of Environment 2010).

Table 12. Features of Rainwater Facilities Planning/Design Program

	Advantages	Disadvantages
Arc hydro	· Geographic information system (GIS) can be used to predict the nature, quantity of available water, and flood mitigation plans · Overall design and visualization of natural environment and water resource management is possible · It can solve water resource problems and provides Raster format	· Only when data on the flood impact area provided by ESRI is established can it be analyzed more easily · Since it is based on geographical information, information on the surface can be easily grasped, but the operation of the drainage (underground) system has limitations

	Advantages	Disadvantages
Rainstock	· Suitable for planning and design of rainwater management facilities in buildings · Simple information such as rainfall, water collection area characteristics, and rainwater usage can be used	· Limited to the current rainwater reservoir
RainCity	· Suitable for design/planning rainwater management facilities in multi-family housing complexes · Consideration of remote control/maintenance measures when operating facilities as well as the effects of individual facilities · Quantity of use can be calculated by usage, day of the week, and hour	· Unable to interpret pollutant leakage and reduction
MUSIC	· Capacity design of various excellent drainage systems, such as wetlands, buffers, ponds, ecological storage facilities, etc., and simulation of water quality improvement effects is possible · Suitable for strategy analysis when introducing rainwater management facilities	· Since the penetration into the basement after the interim outflow is considered a loss, it is difficult to consider the water circulation aspect · Unable to calculate the future amount of evaporation, etc. as the operation is performed mainly on the drainage system

	Advantages	Disadvantages
STORM	· Design and effect analysis of various excellent drainage systems, including rooftop greening, wetlands, water tanks, trenches, and surface penetration facilities can be erformed · Not only short-term simulation due to heavy design but also long-term simulation for more than 10 years at the same time · Facility rough design (Pre-Dimensioning)	· Some theoretical methods, such as the amount of evaporation, utilize the German empirical formula, so domestic data needs to be adjusted · Due to the complicated format of rainfall data, it takes days to build input data
SWMM	· High utilization in various fields, such as determining the size of storage facilities and accessories, analyzing flood sites in natural rivers, and establishing strategies to minimize CSOs · Flood season and long-term simulation possible · Used as a model for pollution control at BMPs facilities in U.S. EPA	· When designing rainwater facilities, it is necessary to convert them into storage units · Difficulty in considering infiltration facilities

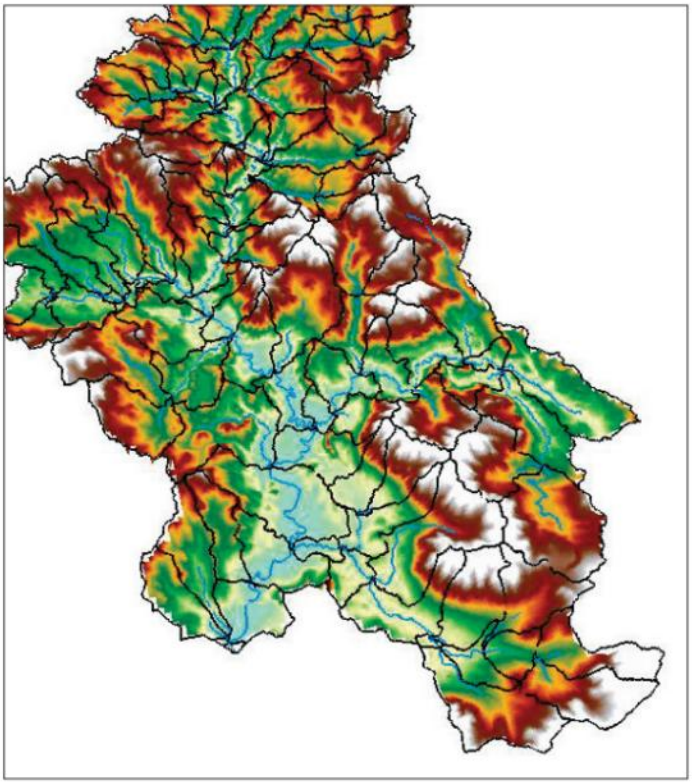


Fig. 8. Visualization of a Watershed Model Created Using Arc Hydro Data Structure and Tools (ESRI 2015)

This study used the Hydro Plug in of ARC GIS. The following are the reasons for deciding on the program (Chen et al. 2009).

1) GIS data can be generated through DEM data, and comprehensive analysis of topographical maps, land use status, and vegetation required for hydrologic analysis is possible.

2) Data linked to the current status of facilities such as sewage pipe network facilities can be created, and other hydrologic analysis program models can be improved.

3) The simulation results can be visualized, and the GIS data, such as traffic analysis, and the comprehensive results can be shown.

2.5 Target Site

The research target site is the Seoul Metropolitan Government. Most of the flood damage is accompanied by typhoons, and the affected areas are different in each examined period of time. In 2011, the affected areas suffered socioeconomic damage worth 31.3 billion won. In particular, Seocho-gu showed 17.2 billion won worth of damage on a nation-wide scale (Korea Water Resources Corporation 2019).

According to the Seoul Metropolitan Government's comprehensive plan for mitigating storm and flood damage, there are a total of 80 sites for river disaster risk zones based on the disaster history, on-site surveys, and opinions of related agencies. It was often caused by a lack of free space for drainage effects or lack of maintenance in the road planning section.

In addition, since the habitual flooding area provided by Esri was established, it was easy to estimate the extent of the damage caused by flooding in the future. When the National Flood Risk Map, which is currently being established by the Ministry of the Interior and Safety, is finalized and disclosed for research purposes, this methodology could be applied and expanded to nationwide analysis.

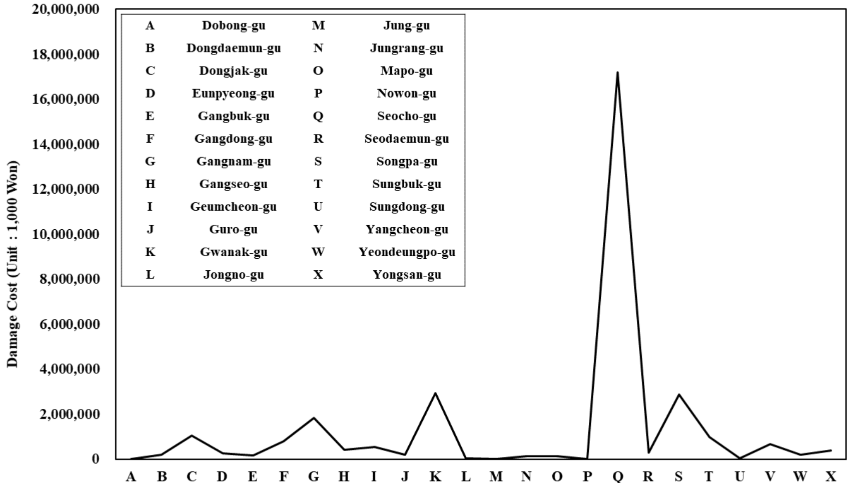


Fig. 9. Flood Damage Status by Administrative District of Seoul in 2011

2.6 Climate Change Scenarios

In this study, flood damage and mitigating technologies were calculated in consideration of climate change scenario RCP 8.5 and RCP 4.5, as provided by the Climate Information Portal (Lee 2008). Prior to the analysis of climate change scenarios, this section will briefly look at the definition of climate change scenarios and look at the forecast trends between the current year and 2100.

The climate change scenario is the future climate forecast information produced by applying changes in radiative forcing caused by artificial causes such as greenhouse gases and aerosols to the global system model. Scenarios are divided into SRES and RCPs (Han 2009). Depending on the type of RCP scenario, it is predicted that future precipitation, temperature, humidity, etc., will vary.

The representative concentration pathway (RCP) is a scenario used in the IPCC 5th assessment report, and the concentration of greenhouse gases is determined by the amount of radiation that human activity emits to the atmosphere. The RCP scenario also carries uncertainty because it is a model that is predicted based on carbon emissions and human activity. However, many studies have been conducted to quantify and reduce the uncertainty of the RCP scenario (Gao et al. 2019).

Therefore, most recent studies, including this study, use RCP scenarios. The climate change scenario is provided by each administrative district or grid. It provides data up to 2100, considering daily units. In this study, daily precipitation forecasts were used as data.

Using RCP 8.5, the average precipitation from 2021 to 2100 is expected to be about 1305.1 mm. This is about 53.4 mm less than the average precipitation from 2001 to 2010. However, annual precipitation of about 2,169.5 mm is expected in 2090, meaning that it will temporarily double that of the other average year.

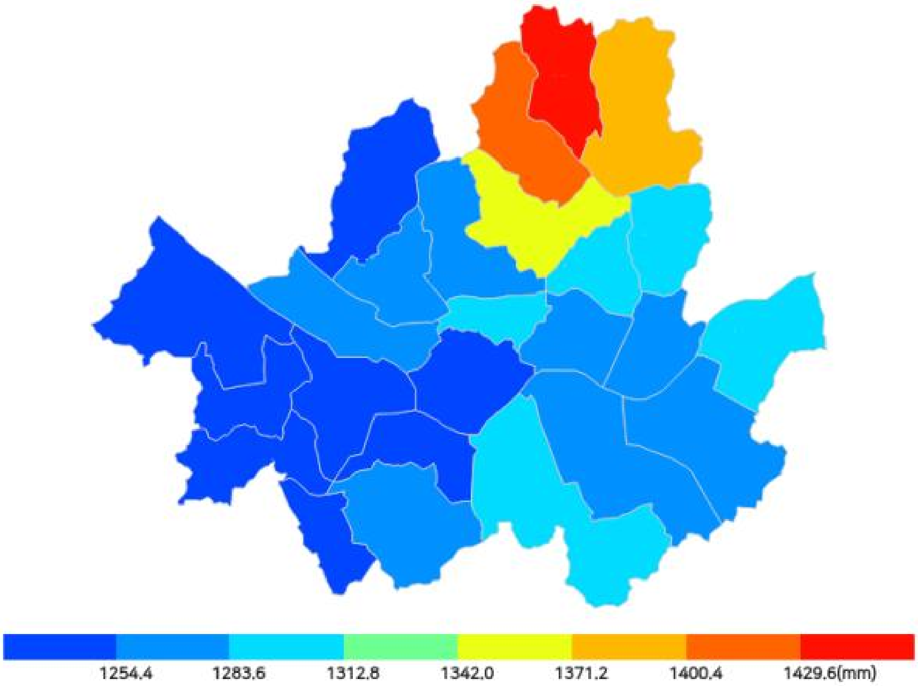


Fig. 10. RCP 8.5 Scenario Precipitation Forecast (Weather Data Portal 2020)

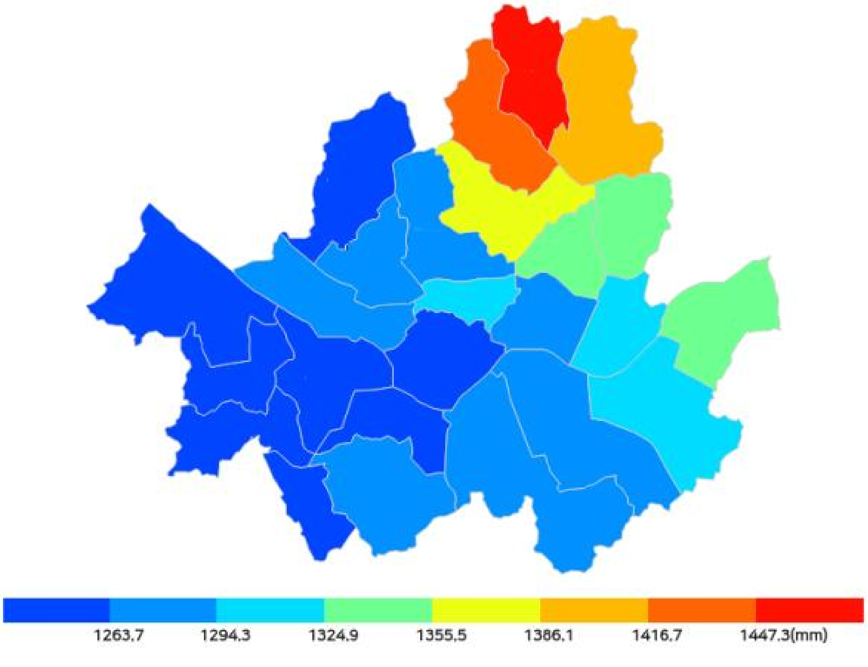


Fig. 11. RCP 4.5 Scenario Precipitation Forecast (Weather Data Portal 2020)

In the RCP 4.5 phase, the average rainfall is forecast to be 1,289.5 mm from 2021 to 2100: about 69.0 mm less than the average precipitation from 2001 to 2010. RCP scenario 4.5 is forecast to have a maximum annual precipitation of 2,894.2 mm in 2055.

The four points that can be seen through this are summarized as follows:

1) At stage 4.5 of the RCP scenario, a larger scale of flooding than RCP scenario 8.5 is expected.

2) In RCP scenario 4.5, a tsunami-class disaster will occur sooner than in RCP scenario 8.5, likely in 2055. Annual precipitation at this time is expected to be about 2,894.2 mm, with most parts of Seoul forecast to be inundated.

3) The RCP scenario shows an increasing trend, drawing a positive trend line in both the 8.5 and 4.5 scenarios. However, the timing of precipitation tends to be very irregular and sporadic.

4) Among the 25 districts, Dobong-gu is expected to have the highest precipitation, with an average increase of 1,454.3 mm. On the other hand, Jung-gu is expected to have the lowest precipitation of 1,243.2 mm.

Chapter 3. Methodology

3.1 Hydrologic Analysis

3.1.1 Base DEM(Digital Elevation Model)

The Digital Elevation Model (DEM) and Digital Surface Model (DSM) are hydroponic models made by means of an elevation (isometric line). While the DSM includes information such as the locations and impact of buildings, trees, and pavement in a given site, the DEM excludes this data. The DSM model has the advantage of having a variety of accurate information, but the disadvantage is that it is not suitable for use on a wide unit because of the large size of the information it contains. Therefore, after the DEM was established, this study chose to add other information.

The DEM files were provided by the National Geographic Information service’s National Territory Information Platform. The DEM data were produced in 2014. In the case of the Seoul Metropolitan Government, there have been no major civil engineering works since large-scale facility maintenance to mitigate floods was carried out in 2012. The reason for using DEM data produced in 2014 is that most watersheds are consistent to the year 2020. In general, large areas such as the Seoul Metropolitan Government use a DEM resolution between 30 and 5 m (Vaze et al. 2010).

To build a DEM, convert the 3D terrain (Tin File) into an Elevation Sharp extension file, and replace this Tinfile with the Raster File to complete the basic DEM. Later, the building's Raster File was created and the two files were Merged. Cell Size in Raster File was based on 2.5 m to build more accurate data. If the area is large according to each distinguishing feature, the resolution of the Cell Size is 10m (Correia, Da Silva, and Ramos 1999).

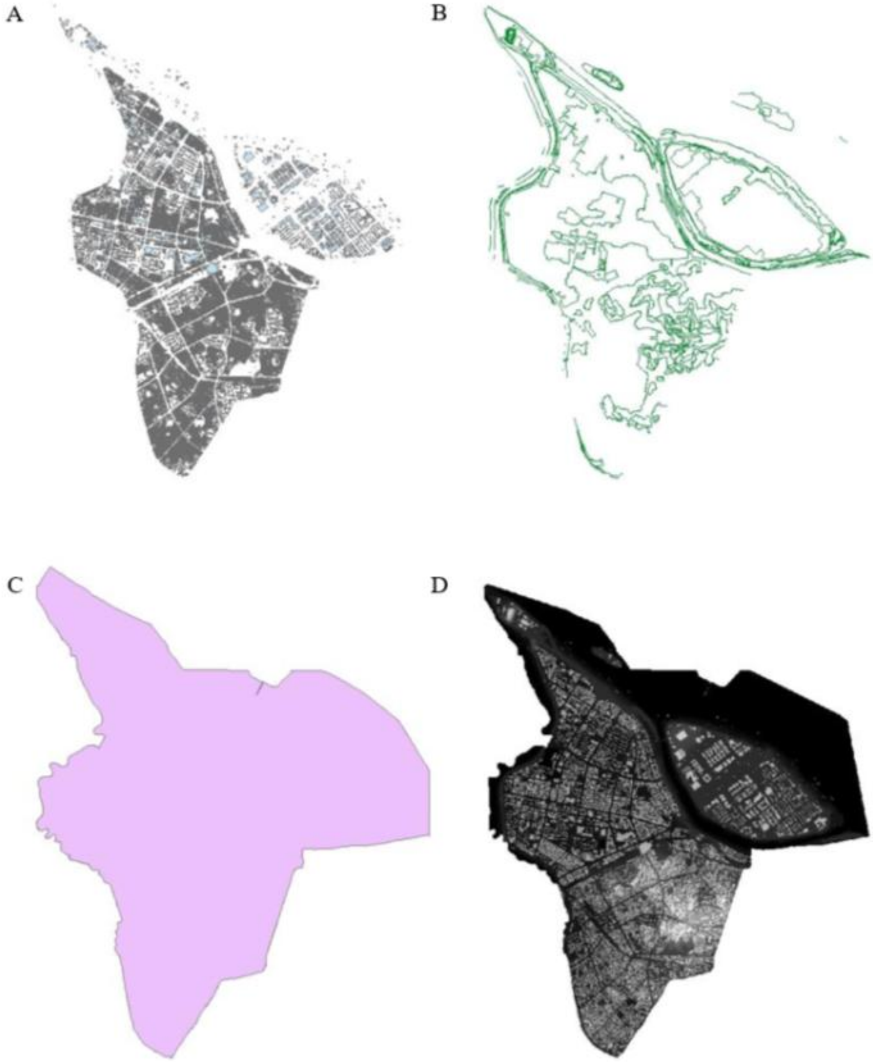


Fig. 12. File Used to Create DEM
(A : Building, B: Level, C : Boundary, D : Topography Raster)

3.1.2 Forming a Watershed Area

The previously selected ArcHydro Plug-in was used for Watershed export. The sequence within the program for building watershed is demonstrated in Fig. 13.

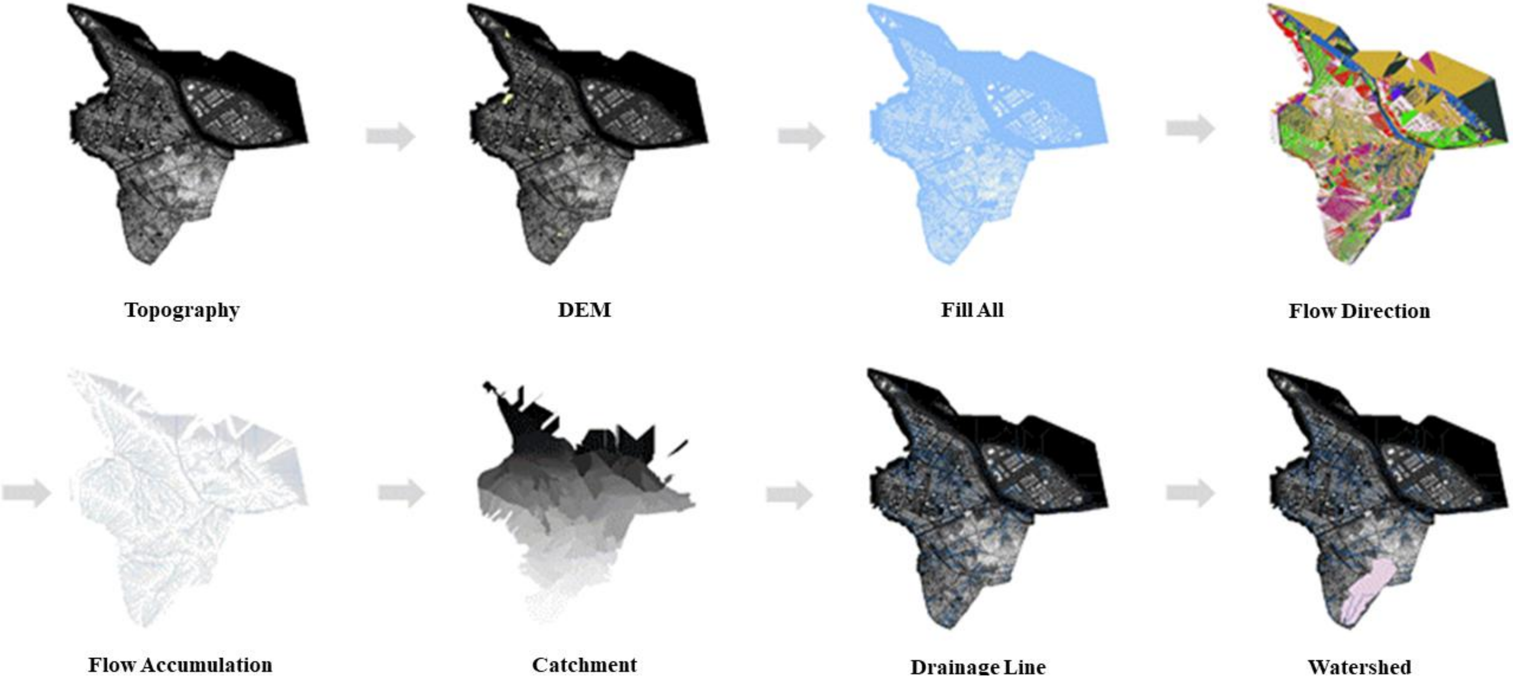
The basic DEM has lost space, so the Prefill DEM, Fill Sink, and FillAll commands were used to fill it. First, use PrefillDEM to fill the lost parts, and the remaining empty spaces use the Fill Sink and FillAll commands.

After the analysis of DEM, the process of analyzing the flow of floods and watersheds is carried out. The first is Flow Direction, which analyzes the height values of the Raster. This determines how water flows between the Raster.

Flow Accumulation produces the rainfall flow based on the data produced in Flow Direction, and specifies the size of the flow. In this study, the minimum size of the flow (Stream Line) was set to 30 m. After the stream line is derived, the work to make a polygon is carried out.

Catchment is the stage of obtaining the basin, and Drainage Line shows how water flows and drains in a set area based on previous analysis. Analysis using Drainage Line is used to classify the area of flooding and influence.

Subsequently, the affected area (Watershed) may be obtained watershed means how much influence the area has when water flows into one point. Fig. 13 shows what has been done in this study until the establishment of an watershed.



Topography

DEM

Fill All

Flow Direction

Flow Accumulation

Catchment

Drainage Line

Watershed

Fig. 13. Hydrological Analysis Method

The D8 algorithm was used to determine the flow of water in the layer that determines flow direction. The D8 algorithm means that the next cell is formed in the steepest direction among the eight cells adjacent to each cell or in diagonal directions.

This algorithm largely forms two grids. The first grid calculates the steepest slope in each grid cell and contains information about which direction it flows in the neighborhood or diagonal direction. The second grid contains the tangent value of the height and distance as the slope is evaluated in the direction of the most severe slope (Zhang et al. 2018).

The flow direction of all grid cells adjacent to the NODATA value of the DEM is recognized by NODATA. The flow direction of D8 is coded in a total of eight directions clockwise from east 1 to southeast 8. The flow direction used in this study is shown in Fig. 14.

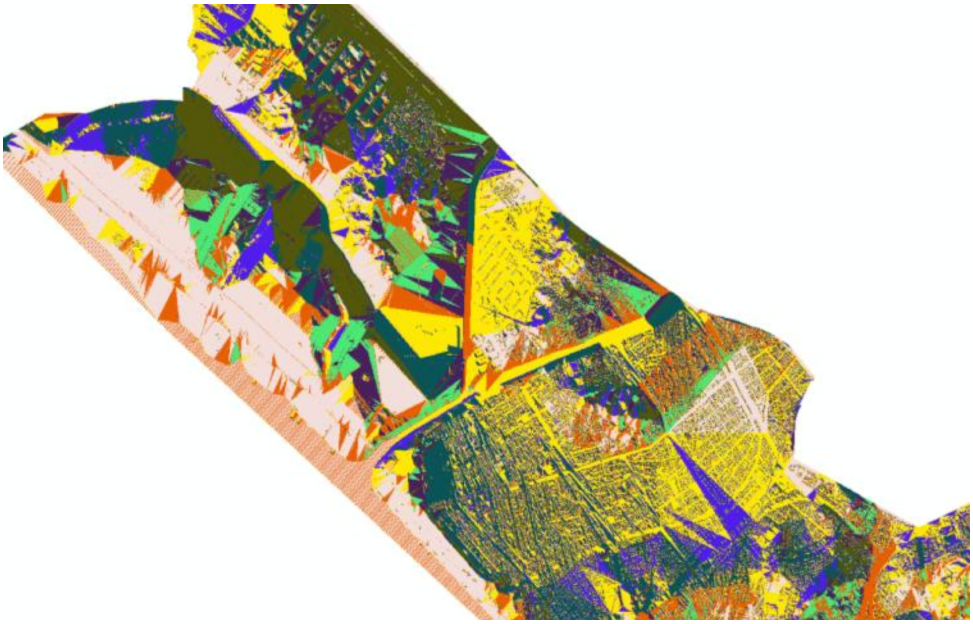
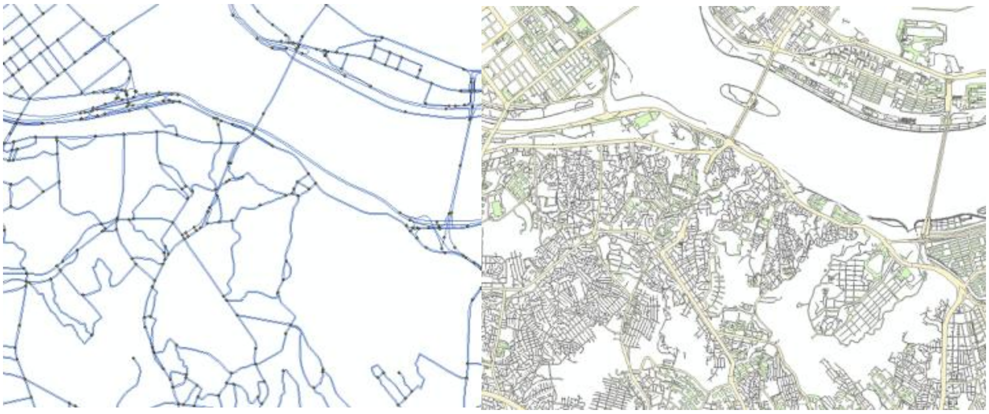


Fig. 14. D8 algorithm Used in This Study (ESRI 2015)

3.1.3 Road Analysis

To calculate the area of the waterways and the permeable pavement at the cross-section of the road, the process of identifying the width of each road category was necessary. To determine the width of each road, the GIS road network file which was built in 2018 and provided by the standard node-link of the Ministry of Land, Infrastructure, and Transport was used. An example of the road network data used is shown in Fig. 15. (Ministry of Land, Infrastructure and transport 2018).



(a) (b)

Fig. 15. GIS files used in research : (a) ; Road link and node information (b) Building information (Ministry of Land Infrastructure and transport 2018)

3.2 Application of mitigation technology and estimation of flood damage

The mitigation technologies take into account all of the abovementioned water tanks, ecological waterways and permeable pavement. The amount of run-off was calculated by dividing the mitigation method into type A to type D. Type A refers to the amount of run-off that can occur in the current facility when the RCP 4.5 and RCP 8.5 climate change scenario is applied. Type B refers to the amount of run-off that can occur when water tank is installed, Type C means when the permeable pavement and water tank were installed, and Type D means when all mitigation technologies have been installed. It is assumed that both permeable pavement and ecological waterways will be installed on sidewalk with more than six lanes, and it is predicted that the only permeable pavement will be installed on the walkway with more than four lanes and less than six lanes. The capacity formula for each mitigation technology is shown in Eq. (2) – Eq. (4)

$$C_w = A_b \cdot 0.05 \tag{2}$$

where C_w is the capacity of water tank (m^3); A_b is the area of building in the watershed (m^2) (Ministry of Environment 2010).

$$C_p = (L_m + L_b) \cdot 0.296 \cdot 2 \tag{3}$$

Where C_p is the capacity of permeable pavement (m^3); L_m is length of roads with more than four lanes, and less than six lanes (m); L_b is length of roads with more than six lanes (m) (Seoul Metropolitan Government 2009).

$$C_e = L_b \cdot 0.5375 \cdot 2 \tag{4}$$

Where C_c is the capacity of ecological waterway (m^3) (Park et al. 2011).

GIS analyzes the space that can be installed in watershed for each technology. The capacity of the mitigation technology per unit area shown in 2.1 Alternative mitigation options is multiplied to calculate the capacity of rainfall by each space of length. Finally, the amount of run-off is calculated by subtracting the capacity that can reduced for each type from the amount of rainfall that can occur.

3.3 Calculation of Current Rainfall Capacity and Run-off

To figure out the effect after mitigation technology installed, the calculation of the capacity of rainfall per hour in the current state is important for the Seoul Metropolitan Government. It is common to use hydrodynamics because floods are calculated by changing precipitation per hour. This requires detailed modeling of currently installed data such as sewer pipes, manholes, etc (Yoo, Kim, and Kim 2006). This interpretation is generally used on a small scale of the unit, and there was a limitation for conducting a dynamic analysis of the entire Seoul Metropolitan Government. Also, local governments are not analyzing clear threshold on flooding. Therefore, each local government must analyze the threshold for flooding. It was assumed that the flood will occur between the minimum precipitation in the year when flooding occurred and the maximum precipitation in the year when flooding did not occur. Thus, using historical data from 2001 to 2019, the historical estimation method was used to calculate the capacity of rainfall in the current state as given in Eq. (5):

$$Q_c = \frac{M_f + M_{nf}}{2} \tag{5}$$

where Q_c the capacity of rainfall per hour for each district (mm/hr); M_f is the minimum amount of rainfall per hour at the time of flooding occurred (mm/hr), and M_{nf} is the maximum hourly rainfall in the case of no flooding (mm/hr) (Choi 2019).

For the establishment of the capacity, disaster observation data provided by the weather data portal was utilized (Weather Data Portal 2020). Since then, flood-damaged districts have been identified for each year, as provided by the Water Information Portal.

During the period of collecting historical data, the Seoul Metropolitan

Government aimed to become a “sustainable city” (Seoul Metropolitan Government 2016). This focused on maintaining existing facilities without major civil engineering or development. Therefore, there were no significant changes in watershed or DEM in the last 20 years. However, since the study analyzed a very large site, some errors in watershed change could exist.

The rainfall capacity for each district is as shown in Table 13. The district with the highest capacity for rainfall per hour is Geumcheon-gu, which is believed to be capable of accommodating up to 82.8 mm per hour, while the Yongsan district with the lowest capacity for rainfall per hour is expected to accommodate up to 38.5 mm per hour (Korea Meteorological Administration Seoul 2019).

Using the Table 13, the amount of run-off for each district capacity can be predicted. Run-off refers to the phenomenon of overflowing water, exceeding the permeation rate and percolation rate that the city can afford. Assuming that up to 100 m/hr of rainfall has fallen in Gangnam-gu, the run-off of 55 m/hr and the resulting damage are expected to occur within the watershed of the city. Eq. (6) provides the formula for calculating the amount of run-off for each district:

$$Q_r = 0.001 \cdot (R - Q_c) A_w T \tag{6}$$

Where Q_r is the amount of run-off (m^3), R is the precipitation per hour (mm/hr), is the area of the influence area (m^2), and A_w is the duration of the rainfall (hour) (Choi 2019).

Table 13. Hourly Rainfall Capacity of Local Government in Seoul

	M_{nf} (mm/hr)	Date	M_f (mm/hr)	Date	Q_c
Gangnam	42.5	2009-07-14	47.5	2014-08-21	45.0
Gangdong	73.0	2003-08-24	79.0	2010-09-21	76.0
Gangbuk	57.5	2003-08-20	67.0	2010-08-15	62.3
Gangseo	49.5	2009-07-02	58.0	2010-08-13	53.8
Gwanak	56.0	2013-07-22	62.5	2012-07-06	59.3
Gwangjin	60.0	2012-08-15	68.5	2002-08-04	64.3
Guro	59.5	2005-06-26	63.5	2003-08-24	61.5
Geumcheon	67.5	2012-08-15	98.0	2010-09-21	82.8
Nowon	71.5	2003-08-20	83.5	2001-07-15	77.5
Dobong	60.5	2010-08-10	72.5	2011-07-26	66.5
Dong daemun	58.0	2012-07-13	65.5	2010-09-21	61.8
Dongjak	47.0	2005-06-26	49.0	2012-07-06	48.0
Mapo	67.0	2005-06-26	69.0	2003-08-24	68.0
Seodaemun	52.0	2005-06-26	53.0	2011-07-27	52.5
Seocho	48.5	2014-08-21	56.5	2012-07-06	52.5
Seongdong	75.0	2010-09-21	84.5	2001-07-15	79.8
Seongbuk	58.5	2004-07-06	59.0	2011-07-26	58.8
Songpa	71.5	2003-08-24	72.0	2011-07-27	71.8
YangChun	66.0	2005-06-26	71.5	2010-09-21	68.8
Yeong deungpo	57.5	2005-06-26	59.0	2010-08-13	58.3
Yongsan	38.0	2014-08-21	39.0	2013-07-22	38.5
Eunpyeong	51.5	2005-06-26	51.5	2005-06-26	51.5
Jongno	50.5	2013-07-12	58.0	2011-07-26	54.3
Jung-gu	59.5	2003-08-24	73.5	2010-09-21	66.5
Jungnang	61.5	2014-08-22	64.5	2011-07-26	63.0

3.4 Estimation of Hourly Precipitation in Climate Change Scenarios (RCP 8.5/RCP 4.5) using the Huff curve

The RCP scenario provided by the Climate Information Portal analyzes daily rainfall up to the year 2100. However, when planning general hydrology and flood mitigation technologies, it is necessary to convert daily precipitation (mm/day) into hourly precipitation(mm/hr) because it is calculated every hour when planning flood mitigation technologies. To calculate rainfall per hour of climate change scenario, Huff dimensionless curves were used (Han 2009, Lee 2008).

In the Huff dimensionless curve, rainfall duration is divided into four quartile. To classify the rainfall into four time-groups, the cumulative duration of the individual rainfall and the resulting cumulative rainfall are expressed in the form of percentages as illustrated in Eqs. (7a) and (7b), respectively (Bonta and Abulbasher 2003).

$$PT(i) = \frac{T(i)}{TO} \times 100\% \tag{7a}$$

$$PR(i) = \frac{R(i)}{RO} \times 100\% \tag{7b}$$

Where PT(i) is the non-dimensional cumulative time of T(i) at a random time, T(i) is cumulative time from the start of rainfall to the Ith time, is the total rainfall duration, i is the unit increment count, PR(i) is the non-dimensional cumulative rainwater at random time (T), R(i) is the cumulative rainfall from precipitation T(i) to random time, and is total rainfall during *TO*.

The Huff dimensionless curve is shown in Figure 16. Korea’s official agencies, including the Ministry of Environment and the Ministry of Land, Infrastructure and Transport, mainly use the rainfall type in the 3rd quartile. This is a regression formula set aside by the Ministry of Construction and Transportation of the Republic of Korea, which is optimized for the Korean Peninsula (The Ministry of Land, Transport and Maritime Affairs, 2012). In this study, the hourly rainfall was analyzed using the rainfall form in 3rd quartile as shown in Eq. (8):

$$\begin{aligned} Y = {} & 0.09646236117 - 0.3061744138 \cdot X + 0.09318964715 \cdot X^2 \\ & - 0.004778465652 \cdot X^3 + 0.0001114314982 \cdot X^4 \\ & - 1.098642534 \cdot 10^{-6} \cdot X^5 + 3.820261438 \cdot 10^{-9} \cdot X^6 \end{aligned} \tag{8}$$

Where X is the dimensionless precipitation time (%), and Y is the dimensionless cumulative rainfall (%). In other words, the X-axis represents the total precipitation time as a percentage, and the Y-axis means the total precipitation as a percentage. For instance, if 100 mm of rainfall fell for 10 hours, the value indicated by 100% of the X-axis is 10 hours and the value indicated by 50% is 5 hours. The value indicated by 100% of the Y-axis is 100 mm rainfall and 50% is 50 mm rainfall. This study covers the analysis of every 10 years until 2100.

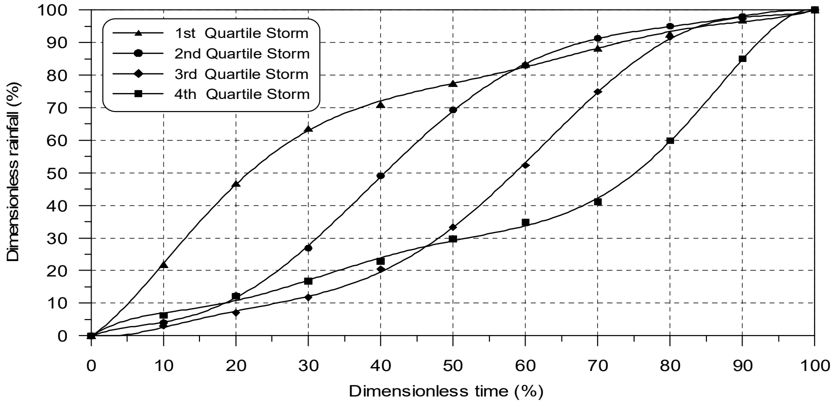
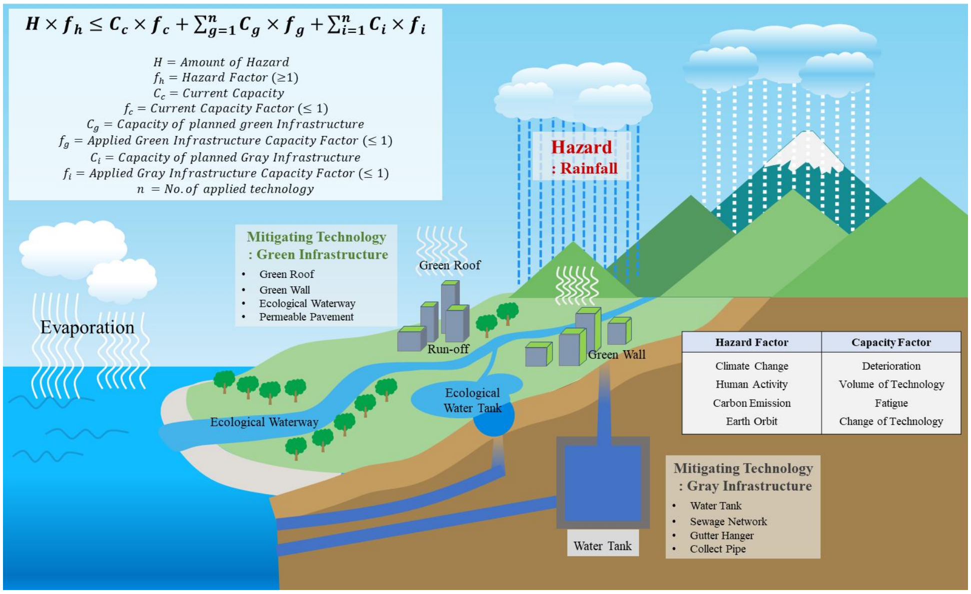


Fig. 16. Huff Curves for Hourly Rainfall Estimation (The Ministry of Land, Transport and Maritime Affairs 2012)

3.5 The Concept of HCFD (Hazard Capacity Factor Design) Model for observing Future Ability Changes of Facilities



$$H \times f_h \leq C_c \times f_c + \sum_{g=1}^{n} C_g \times f_g + \sum_{i=1}^{n} C_i \times f_i$$

H = Amount of Hazard
f_h = Hazard Factor (≥ 1)
C_c = Current Capacity
f_c = Current Capacity Factor (≤ 1)
C_g = Capacity of planned green Infrastructure
f_g = Applied Green Infrastructure Capacity Factor (≤ 1)
C_i = Capacity of planned Gray Infrastructure
f_i = Applied Gray Infrastructure Capacity Factor (≤ 1)
n = No. of applied technology

Hazard Factor	Capacity Factor
Climate Change	Deterioration
Human Activity	Volume of Technology
Carbon Emission	Fatigue
Earth Orbit	Change of Technology

Fig. 17. Concept of HCFD (Hazard Capacity Factor Design) Model

The HCFD model covered in this paper refers to the Hazard Capacity Factor Design Model. This varies for each disaster (hazard), but it can create a common feature in that it uses similar algorithms to find optimized models. It is also meaningful that the technology to mitigate disasters is not just evaluated in terms of efficiency, but also in terms of timing and method for maintenance. The above concept is a complex model with a total of three concepts mixed together.

The first purpose of the model is to determine the amount of damage that can be generated when a disaster occurs in the future. The damage that can occur at this time depends on the disaster. The disasters to be calculated can be fire, precipitation, earthquakes, heavy snow, or typhoons, among others. Damage caused by these phenomena include flooding and structural collapse. This study calculates large-scale precipitation as a hazard, and estimates the amount of damage that may result from the run-off.

The second purpose is to calculate the capacity of a disaster that can be accommodated at this point in time. For capacity of damage, refer to historical data. At this stage of the model, it is necessary to clarify the scale and unit of damage measurement that can occur from a disaster, and to analyze past socio-economic damage caused by a disaster. Data that can be used at this time includes reports and databases.

The third purpose is to aid in the selection of a technology that can mitigate disasters and quantitatively calculate the amount of disasters that can be mitigated. The technologies available at this stage can be divided into two main categories: the first is Gray Infrastructure, and the second is Green Infrastructure. Examples of the first classification include Geo-material, Smart Technology, and Composite New Material Structures, while examples of the second classification include LID techniques and green techniques.

Taking heat waves as an example of a disaster, the damage that can occur include heat island phenomena and heat diseases. Among the technologies for mitigating this, examples of Gray Infrastructure are nano mist spray, and examples of Green Infrastructure include wall/rooftop greening.

The Hazard Capacity Factor Design Model including the above three concepts as shown in Eq. (9):

$$H \times f_h \leq C_c \times f_c + \sum_{g=1}^{n} C_g \times f_g + \sum_{i=1}^{n} C_i \times f_i \tag{9}$$

Where H is amount of hazard, f_h is hazard factor which is more than 1, C_c is capacity of current state, f_c is capacity factor of current state which is less than 1, C_g is capacity of planned green infrastructure, f_g is capacity factor of green infrastructure, C_i is capacity of planned gray infrastructure, f_i is capacity factor of gray infrastructure which is less than 1, and n is number of installed technology.

In this study, the hazard corresponding to H is flood, and the factor corresponding to f_h is climate change scenarios.

In this study, C_c was expressed as shown in eq. (5) using historical data as the capacity of the flood that can be stored in the present state. The specific f_c was not considered, but the state of C_c already includes the safety factor.

There are three disaster-mitigation technologies corresponding to C_g and C_i applied in this study: water tanks, ecological waterways, and permeable pavement. Water tanks correspond to the Gray Infrastructure, and the ecological waterways and water permeable pavement correspond to the Green Infrastructure.

Ultimately, these three technologies are evaluated to determine their capacity to comprehensively reduce disaster impacts. It also estimates the optimal design and maintenance timing. The items of maintenance are defined differently by the researchers according to each technology, and in this study, the non-point source pollutant in the water tank.

Non-point source pollutant inside the water tank correspnds to f_i as it can affect C_i over time. In this study, f_g was not considered, so additional factors and socioeconomic damages that could occur due to climate change scenarios need to be considered in future studies.

To mitigate any disaster, the HCFD model defines the above processes that analyze the quantitative effects of the technology and estimate the timing of maintenance for it.

Chapter 4. Results

4.1 Site Analysis

4.1.1 Watershed

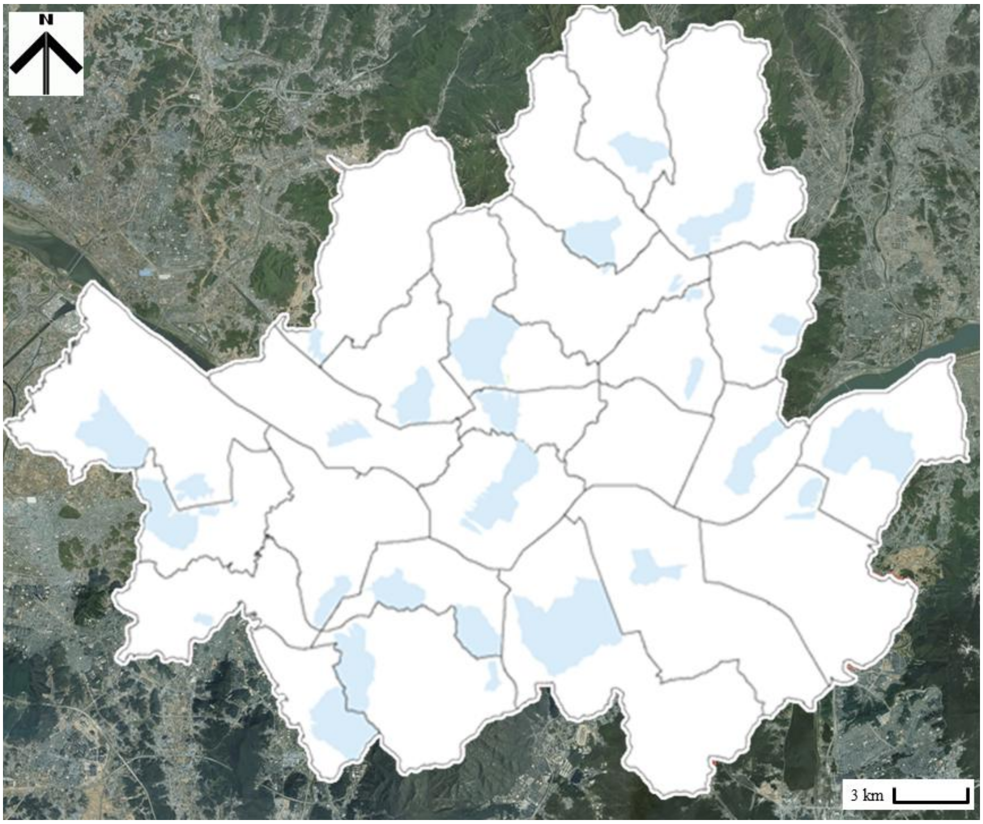


Fig. 18. Watershed in Seoul Metropolitan Government using ArcHydro

Among the 25 districts, Seocho-gu had the largest watershed of 9,385,502 m^2. The watershed area is to 19.9% of the total Seocho-gu of 47,140,000 m^2. On the other hand, Guro-gu had the smallest watershed area, calculated as 265,350 m^2, accounting for 1.31% of the total Guro-gu area of 20,120,000 m^2. There are two main reasons why Guro-gu has a small watershed compared to Seocho-gu and other districts.

The slope of more than 60% of Guro-gu watershed is less than 10%.

Furthermore there are many apartments and buildings compared to other watersheds. This means that there is a wide range of living areas and it is difficult for catchment to form when precipitation occurs. The second reason is that Guro-gu watershed is formed on the boundary of the district. In other words, it is sharing watershed in another neighboring city.

4.1.2 Building and road area in the watershed

The area occupied by buildings and roads throughout the Seoul Metropolitan Government's Watershed area is as shown in Figure 19. Within the watershed of each local government, buildings were shaded, roads with more than six lanes were marked in red, roads with more than four lanes, and less than six lanes are in green.

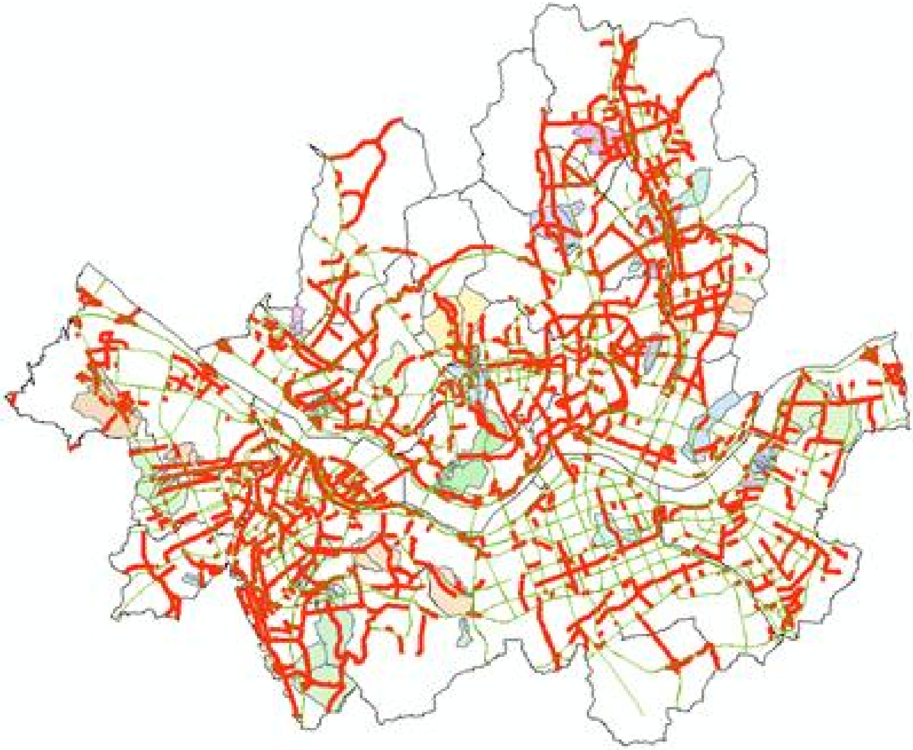


Fig. 19. Building and road area of Seoul Metropolitan Government

The local government with the largest building area was Seocho-gu, which was 2,122,317 m^2, to 22.6% of the total Seocho-gu watershed area of 9,385,502 m^2. This shows that Seocho-gu has the largest building area and watershed area.

In the case of watershed, Guro-gu had the smallest area, while in the case of the building area in watershed, Seongbuk-gu had the smallest area. The watershed of Seongbuk-gu is 26,231 m^2, which is about 8.6% of the Seongbuk-gu watershed area of 304,238 m^2.

In Seongbuk-gu, the Watersheds are divided into two areas and distributed. The first area was an apartment residential complex with relatively large open spaces, while the second area of the watershed was relatively small.

In the case of Seongbuk-gu, it is deemed that additional standards for the introduction of water tanks should be applied considering areas with large areas of natural green parks and open spaces. Watershed, building area, and road length for each district are as shown in Table 14.

Table 14. Area of the watershed, building area in the watershed, road length for each district

District	Watershed (m^2)	Building Area in Watershed (m^2)	Road A Length (m)	Road B Length (m)
Gangnam	1,582,619	494,707	3,355	3,451
Gangdong	6,281,719	1,445,439	4,871	3,837
Gangbuk	2,747,831	887,047	2,528	5,699
Gangseo	5,182,188	1,002,454	7,118	3,342
Gwanak	3,912,091	851,795	1,155	2,086
Gwangjin	2,429,075	657,941	3,356	892
Guro	265,350	66,000	-	1,331
Geumcheon	4,167,619	809,444	1,343	3,605
Nowon	3,012,074	416,299	4,621	4,849
Dobong	208,294	475,941	2,362	1,185
Dongdaemun	915,256	225,245	2,101	6,752
Dongjak	4,698,162	1,443,029	989	-
Mapo	983,377	324,073	1,413	-
Seodaemun	2,178,388	406,042	1,216	1,474
Seocho	9,385,502	2,122,317	18,606	4,858
Seongbuk	304,238	26,231	-	270
Songpa	1,037,149	229,247	455	3,724
YangChun	3,816,062	1,040,309	5,799	441
Yeongdeungpo	1,244,069	405,863	766	1,500
Yongsan	4,103,467	698,914	2,195	96
Eunpyeong	545,487	98,884	579	6,779
Jongno	5,015,240	765,761	2,699	8,983
Jung-gu	1,868,929	530,119	6,305	6,832
Jungnang	965,675	108,649	323	4,280

Road A means a road with at least four lanes and below six lanes, and Road B means at least six lanes.

Using the length of the road and the building area in watershed as suggested in Table 14, capacity for each district and technology is calculated. The capacity of each district and technology is as shown in Table 15. Type A means when no technology has been installed, Type B means when only a water tank is installed, Type C means when the permeable pavement is added to Type B, Type D means when all technologies have been installed.

Table 15. The capacity of each district and technology (Unit: m^3)

	Type B	Permeable Pavement	Ecological waterway	Type C	Type D
Gangnam	24,735	4,029	3,710	30,172	33,882
Gangdong	72,272	5,155	4,125	78,993	83,117
Gangbuk	44,352	4,870	6,126	51,548	57,674
Gangseo	50,123	6,192	3,593	57,679	61,271
Gwanak	42,590	1,919	2,242	45,360	47,602
Gwangjin	32,897	2,515	959	35,776	36,735
Guro	3,300	788	1,431	4,631	6,062
Geumcheon	40,472	2,929	3,875	44,872	48,748
Nowon	20,815	5,606	5,213	28,400	33,612
Dobong	23,797	2,100	1,274	26,380	27,654
Dongdaemun	11,262	5,241	7,258	19,258	26,516
Dongjak	72,151	585	0	72,737	72,737
Mapo	16,204	836	0	17,040	17,040
Seodaemun	20,302	1,592	1,585	22,496	24,081
Seocho	106,116	13,891	5,222	121,989	127,211
Seongbuk	1,312	160	290	1,582	1,872
Songpa	11,462	2,474	4,003	15,456	19,459
YangChun	52,015	3,694	474	55,889	56,364
Yeongdeungpo	20,293	1,341	1,613	22,247	23,859
Yongsan	34,946	1,356	103	36,341	36,444
Eunpyeong	4,944	4,356	7,287	12,066	19,353
Jongno	38,288	6,916	9,657	48,869	58,526
Jung-gu	26,506	7,777	7,344	37,071	44,415
Jungnang	5,432	2,725	4,601	8,157	12,758
Total	776,588	89,049	81,986	865,637	947,623

When permeable pavement and ecological waterways applied for additional capacity, the local government with the largest capacity of technology is Seocho-gu.

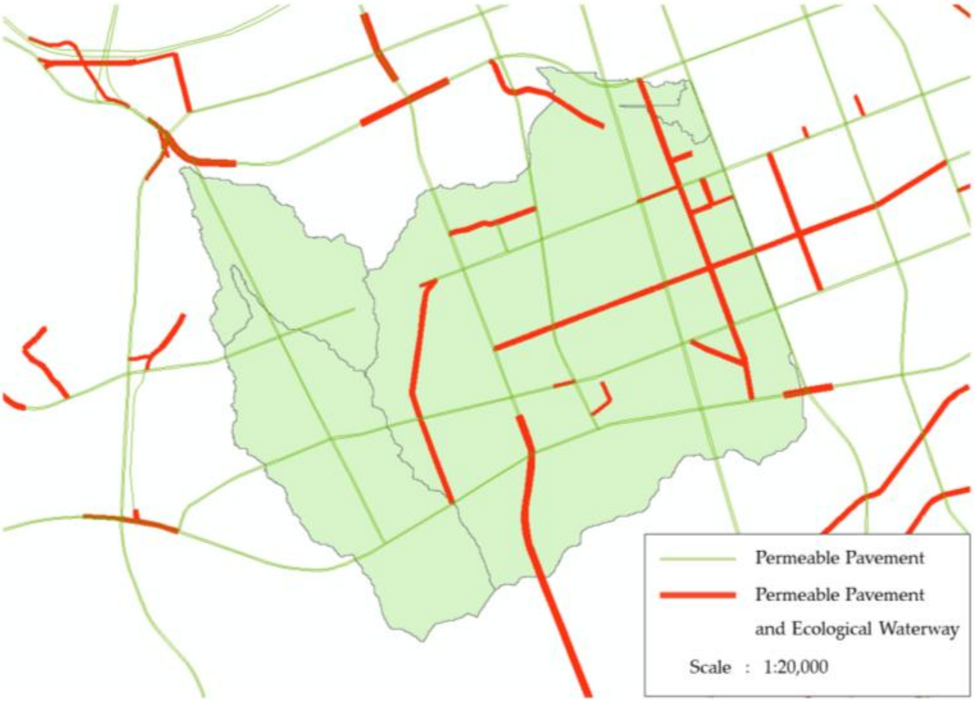


Fig. 20. Seocho-gu permeable pavement and ecological waterway area

In the case of Seocho-gu, the total length of the road, which is more than four lanes and less than six lanes in the watershed, is estimated to be 18,606 m. Besides, a total of 4,858 m were identified for six lanes or wider.

The capacity of the permeable pavement that can be installed in Seocho-gu is 13,891 m^3, which is analyzed to be the most efficient one of the 24 local governments. In the case of ecological waterways, it is estimated that 5,222 m^3 of rainwater can be additionally stored. The additional capacity of the two facilities is 19,113 m^3. This is an effect of

118% compared to when only water tanks are installed.

Assuming that facilities can be installed on a limited basis in consideration of economic feasibility, water tank, and permeable pavement or water tank and ecological waterways may be applied respectively. When water tank and permeable pavement are installed, the effect could be 113.1% and when water tank and ecological waterways are installed, the effect could be 104.9%, compared to the installation of the water tank only.

On the other hand, in Seongbuk-gu, only a few areas were formed for the installation of permeable pavement and ecological waterways within the area of the watershed as illustrated in Figure 21.

Fig. 21. Seongbuk-gu permeable pavement and ecological waterway area

In the case of six or more lanes within the watershed, a total of 270 m could be installed. At this time, it was estimated that the volume of rainwater acceptable in a permeable pavement was 159 m^3 and the volume acceptable in an ecological waterway was 290 m^3.

Besides, the two facilities had an additional capacity of 450 m^3, which resulted in a 134.3% effect compared to the installation of only water tanks. It is estimated that 112% of the water tank and permeable pavement will be installed, and 122% of the water tank and ecological waterway will be used.

Seongbuk-gu is in contrast to Seocho-gu, which has the largest capacity for permeable pavement and ecological waterways. In the case of Seocho-gu, if one of the techniques of ecological waterways and the permeable pavement is installed, it will be efficient to reduce floods by focusing on the construction of permeable pavement. On the other hand, in the case of Seongbuk-gu, it is analyzed that installing an ecological waterway is more efficient. In the same way as above, two efficient mitigation techniques were organized in 24 districts as shown in Table 16.

Table 16. Efficient Case when Two Technologies are installed in consideration of Capacity

Water tank + Permeable Pavement	Gangnam-gu, Gangdong-gu, Gangseo-gu, Gwangjin-gu, Nowon-gu, Dobong-gu, Dongjak-gu, Mapo-gu, Seodaemun-gu, Seocho-gu, Yangcheon-gu, Yongsan-gu, Jung-gu
Water tank + Ecological Waterway	Gangbuk-gu, Gwanak-gu, Guro-gu, Geumcheon-gu, Dongdaemun-gu, Seongbuk-gu, Songpa-gu, Yeongdeungpo-gu, Eunpyeong-gu, Jongno-gu, Jungnang-gu

The combination of technologies shown in Table 16 does not take into account the cost per unit area, and simply shows a more efficient method in terms of capacity.

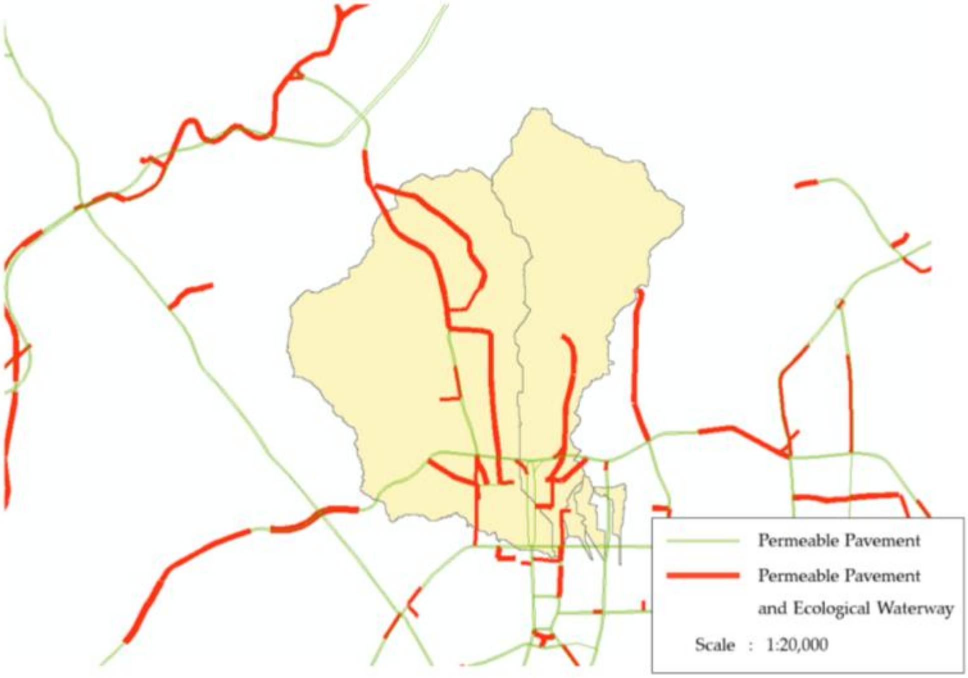


Fig. 22. Jongno-gu permeable pavement and ecological waterway Area

11,682 m of roads with more than four lanes were estimated to be within the entire watershed, of which 76.9% were suitable for installing ecological waterways.

When an ecological waterway is installed in a total of 8,983 m section, 9,656 m^3 of rainwater can be stored. This is considered to be about 39.6% more efficient than when only the permeable pavement was installed in the entire section (6,915.74 m^3).

4.2 The 10-year frequency flood damage analysis for 2021-2100

Huff curves were used to predict maximum precipitation per hour using the daily maximum precipitation provided by the Climate Change Scenario. The formula in the third quartile was used. To estimate rainfall duration, the analysis was conducted in three types: 24-hour distribution, 12-hour distribution, and 6-hour distribution. Fig. 23. shows the cumulative graph of maximum precipitation per hour on July 27, 2090, for a rainfall duration of 24 hours.

It is predicted that the year 2090 has the highest amount of precipitation when analyzing the RCP 8.5 scenario with a frequency of 10 years. The day with the highest daily precipitation in 2090 appears differently for each district from July 16 to 17. The district with the highest daily rainfall was Mapo-gu, which shows a scenario of 373.8 mm of the fall during the day. The average rainfall in Seoul is expected to reach 302.3 mm.

The uppermost curve belongs to cumulative precipitation of Mapo-gu while the lowest one shows that of Geumcheon-gu which has a daily precipitation of 123 mm. This means that there may be a 250 mm difference in rainfall in two different districts in Seoul during a day. In other words, it is expected that there will be a strong local rainfall in the Seoul Metropolitan Government. This is quite different from the current graph.

From the analysis of the historical data, the heavy flood that occurred on September 21, 2010, was due to the shortest time of a rainfall duration of 11 hours from 12 to 23. In other words, it is unlikely that extreme precipitation will fall in six hours under the current conditions. However, the rainfall duration was set to 6 hours as it is common for the analysis considering safety factors and design mitigation techniques for future disaster mitigation.

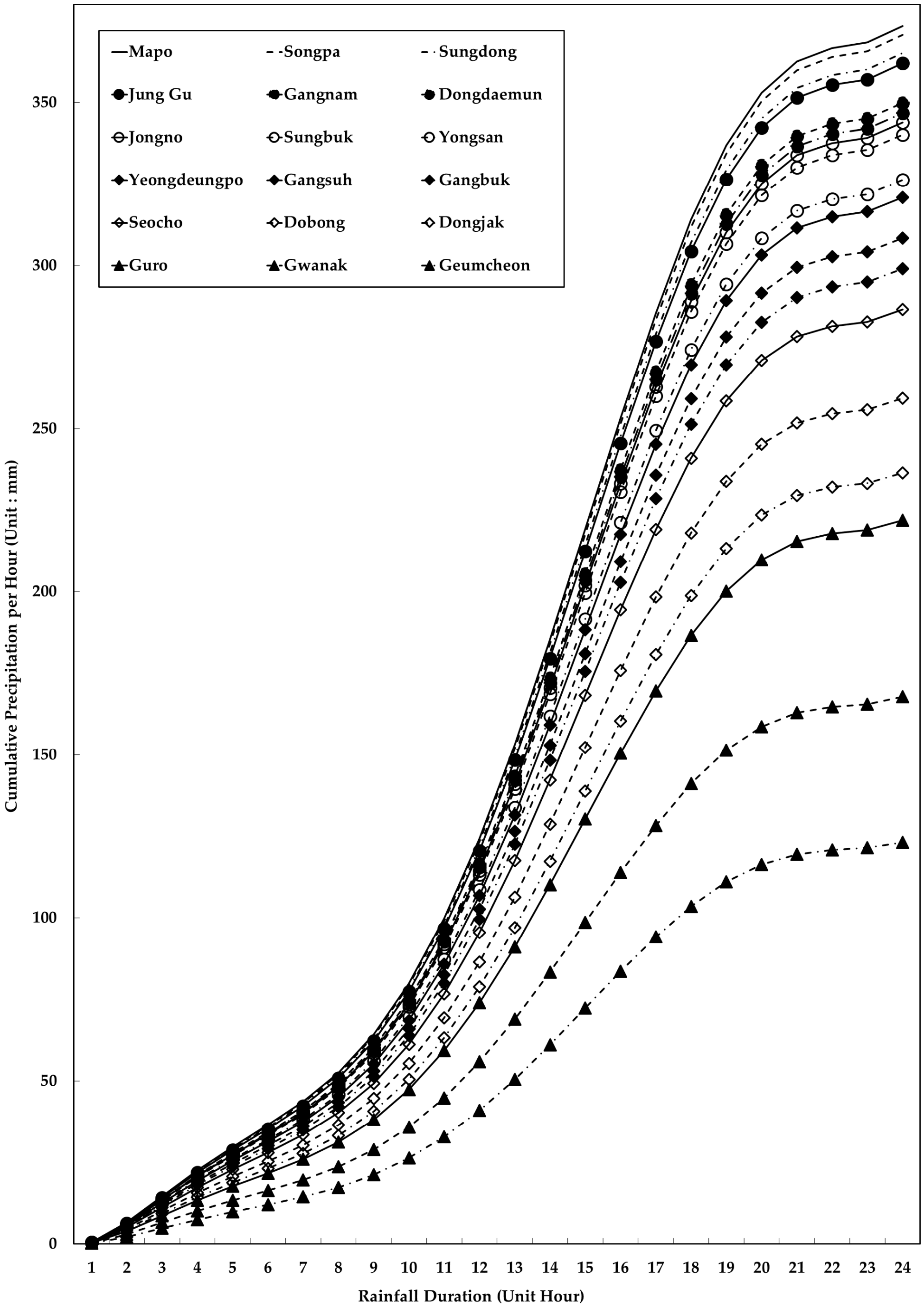


Fig. 23. RCP8.5 – July 7, 2090 precipitation distribution per rainfall duration of 24 hour

RCP 8.5, and 4.5 scenarios were analyzed respectively revealed a precipitation per hour for the frequency of 10 years as shown in Appendix B and Appendix C. The red-colored compartments are difficult to be completely prevented with the current state of mitigation technology, thus, it is expected to cause urban flooding. On the other hand, the green-colored compartments are believed to be able to defend themselves even in the current state.

Referring to Appendix B and Appendix C, 2100 requires preparation for the disaster mitigation technology for the RCP 4.5 scenario. Fig. 24. shows very different forms of RCP 4.5 and 8.5.

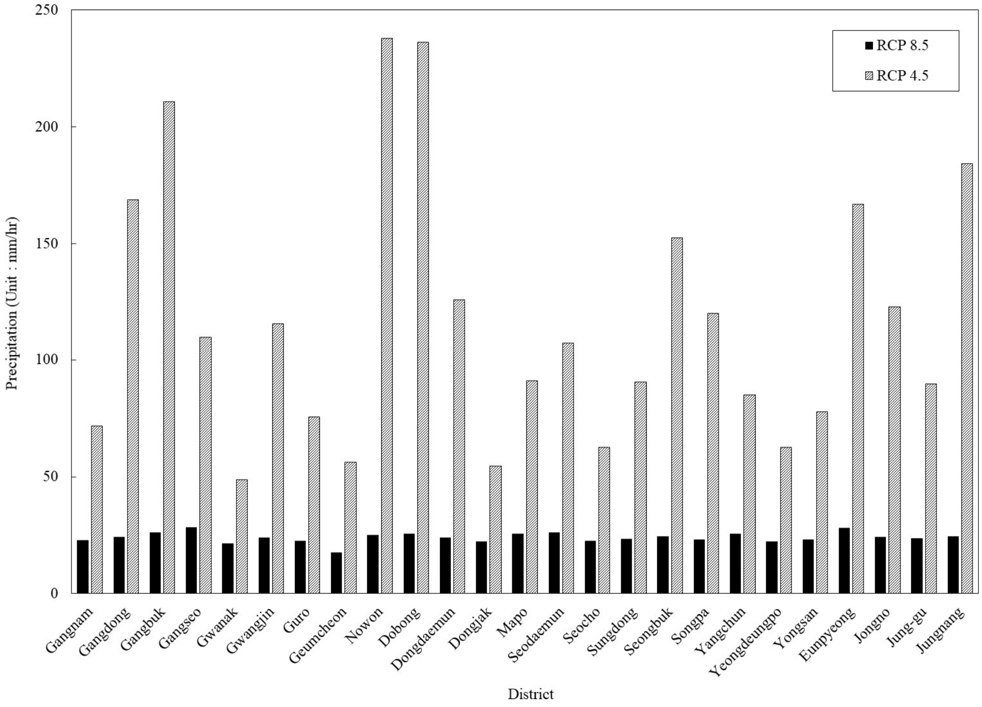


Fig. 24. Comparison of maximum precipitation in 2100 between RCP 8.5 and RCP 4.5

For RCP 4.5 Scenario 2100, the maximum daily rainfall is approximately 690 mm, with maximum hourly precipitation of 238 mm. On the other hand, Gwanak-gu, which has the least precipitation, is expected to have a maximum daily rainfall of 142 mm and maximum hourly precipitation of 48 millimeters. In the RCP 4.5 scenario 2100, the standard deviation of precipitation was 45, showing an uneven distribution for each district.

On the other hand, the RCP 8.5 Scenario of 2100 showed a very even distribution with a standard deviation of 1.58. In the case of Nowon-gu, the hourly precipitation in the two scenarios is expected to be about 213 mm apart.

In general, when statistically processing of climate change scenario forecast information, an arithmetic mean value is used (Korea Meteorological Administration, 2019). This method is specified in the climate statistics guideline presented by the Korea Meteorological Administration, and the equation of average is shown in Eq. (10).

$$\overline{X}=\frac{X_1+X_2+....+X_{n-1}+X_n}{n}=\frac{1}{n}\sum_{i=1}^{n}X_i \qquad (10)$$

where X_i refers to precipitation per day, n refers to the number of data, and $\overline{X}$ refers to the sum of Xi divided by n (Korean Meteorological Administration 2019).

However, the methodology suggested in the statistical guideline is the average for annual precipitation, which differs from the maximum annual daily precipitation used in this study. Therefore, this study compared the average value of the highest precipitation over one decade with the highest value of the frequency of 10 years. A comparison graph of RCP 8.5 / RCP 4.5 scenarios values and average value is shown as Fig. 25. and Fig. 26.

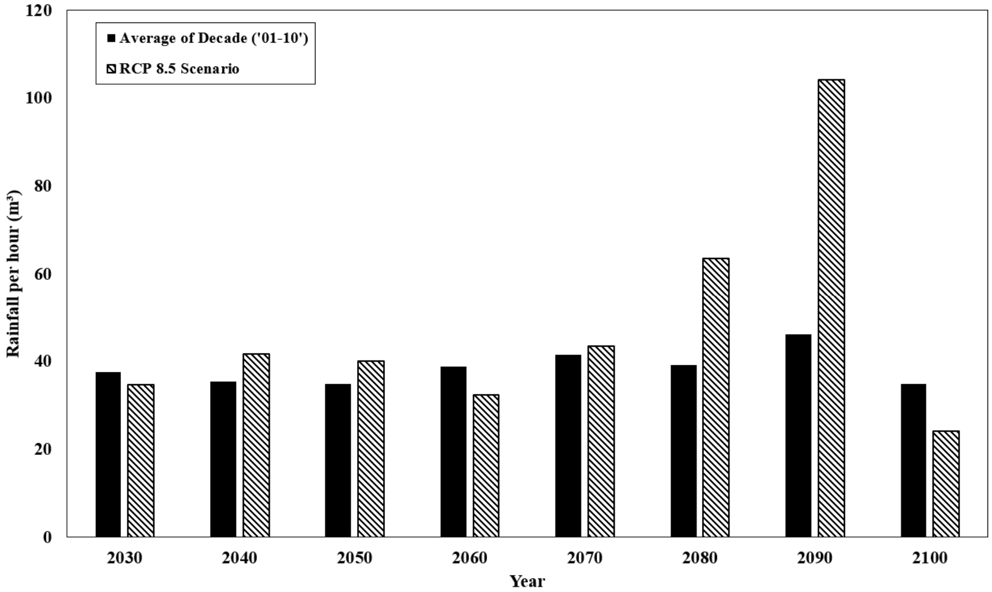


Fig. 25. Comparison graph of RCP 8.5 scenario value and average of decade

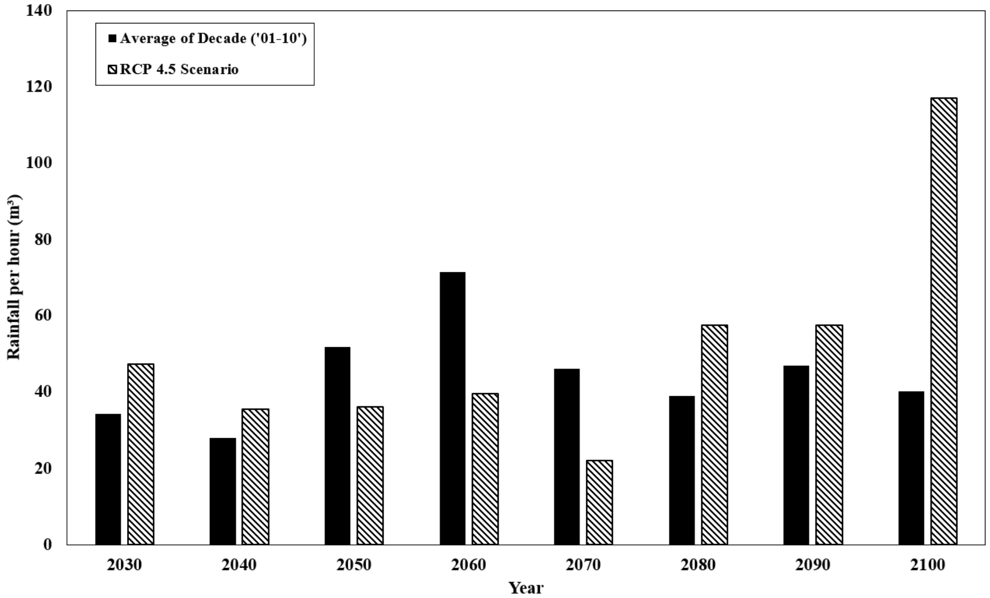


Fig. 26. Comparison graph of RCP 4.5 scenario value and average of decade

Referring to Fig. 25. and Fig. 26., this study uses a general Korean Peninsula climate change scenario. There are two reasons. First, as a flood is an event disaster caused by rain falling in a short moment. It is not appropriate to apply annual average methodology. The average value is considered to be more suitable when analyze the overall trend of precipitation forecast.

The second reason is that the predicted precipitation in the Korean Peninsula climate change scenario is much higher than the average value. Recently, there is much attention on mitigating technology in climate change. The reason is that experts think it is difficult to lower climate change with current carbon emissions. The techniques used in this study are also mitigation techniques. The most important consideration in designing mitigating technology is the safety aspect. If average values of decade are to be used, lower capacity mitigating techniques should be designed because less precipitation is predicted to mitigate design.

From 2050 to 2070 the peak average values are higher than Korean Peninsula climate change scenario RCP 4.5 values, but techniques are considered safe enough because flood mitigation technology was designed based on the value of 2100 RCP 4.5 scenario.

However, unlike this study, the average of one decade will allow to design even more economical mitigation techniques. Future studies will require mitigation technology design using average values of one decade and analysis of run-off. This will help make more efficient climate mitigating policy decisions.

4.3 Variation of the flooded area after application of disaster mitigating technology

In this study, the changing flooded areas were identified when the three mitigation technologies were applied to the watershed. A total of 24 districts in Seoul have been analyzed, and three districts in Gangnam-gu, Dongdaemun-gu, and Jung-gu have been considered. After applying the mitigation technology, the run-off values of the Seoul Metropolitan Government were obtained as provided in Table 17.

Table 17. Total runoff of Seoul Metropolitan Government until 2100 (10-year frequency (m^3))

Scenario	Year	Type A	Type B	Type C	Type D
RCP 8.5	2030	-	-	-	-
	2040	96,694	17,944	12,789	8,664
	2050	6,893	1,949	-	-
	2060	-	-	-	-
	2070	1,721,000	107,178	100,198	95,252
	2080	516,204	199,751	179,181	156,957
	2090	2,842,776	2,149,250	2,065,133	1,990,695
	2100	-	-		-
RCP 4.5	2030	190,332	77,802	66,316	55,683
	2040	-	-	-	-
	2050	-	-	-	-
	2060	-	-	-	-
	2070	-	-	-	-
	2080	733,654	426,587	406,725	397,690
	2090	417,892	84,623	66,141	62,755
	2100	3,492,778	2,866,561	2,798,498	2,730,895

For easier understanding, the run-off of 2090 was organized by the watershed of each district. Several district, including Gwanak-gu and Guro-gu, show that the mitigation technology reduce all run-off. When checking the value of the total in Table 18, it can be seen the same as the value for 2090 in Table 17.

Table 18. The amount of run-off when types of mitigation technology installed in 2090 (RCP 8.5/4.5, (m^3))

Year: 2090	RCP 8.5				RCP 4.5			
	Type A	Type B	Type C	Type D	Type A	Type B	Type C	Type D
Gangnam	119,926	95,191	91,162	87,452	27,385	2,649	-	-
Gangdong	171,598	99,326	94,171	90,046	-	-	-	-
Gangbuk	112,554	68,202	63,331	57,205	-	-	-	-
Gangseo	273,115	222,993	216,800	213,208	41,668	-	-	-
Gwanak	-	-	-	-	31,762	-	-	-
Gwangjin	128,687	95,790	93,275	92,316	-	-	-	-
Guro	4,004	704	-	-	2,032	-	-	-
Geumcheon	-	-	-	-	-	-	-	-
Nowon	35,450	14,635	9,028	3,816	-	-	-	-
Dobong	47,956	24,159	22,059	20,785	-	-	-	-
Dongdaemun	53,026	41,764	36,523	29,265	-	-	-	-
Dongjak	157,933	85,782	85,196	85,196	81,493	9,342	8,757	8,757
Mapo	59,894	43,690	42,854	42,854	-	-	-	-
Seodaemun	127,383	107,081	105,489	103,904	11,419	-	-	-
Seocho	435,832	329,716	315,825	310,603	123,290	17,174	3,283	-
Seongbuk	17,837	16,525	16,365	16,075	-	-	-	-
Songpa	58,304	46,842	44,368	40,365	-	-	-	-
YangChun	169,604	117,589	113,895	113,420	-	-	-	-
Yeongdeungpo	65,301	45,008	43,666	42,054	8,440	-	-	-
Yongsan	304,155	269,209	267,853	267,750	90,403	55,458	54,101	53,998
Eunpyeong	28,396	23,452	19,096	11,808				
Jongno	323,172	284,883	277,968	268,311				
Jung-gu	109,241	82,735	74,958	67,614	-	-	-	-
Jungnang	39,408	33,975	31,250	26,649	-	-	-	-
Total	2,842,776	2,149,250	2,065,133	1,990,695	417,892	84,623	66,141	62,755

In the case of Gangnam-gu, for the RCP 8.5 scenario, floods will occur in 2080 and 2090, with the RCP 4.5 expected to have a total of three floods in 2080, 2090, and 2100.

The watershed area of Gangnam-gu was 1,582,619 m^2, and the building area of the watershed was 494,706.7 m^2. The total capacity of the rainwater water tank that can be installed was 24.735.3 m^3. The length of roads with four to six lanes was 3,355 m, while those with six lanes or more were 3,451 m. The total rainwater acceptable volume of the permeable pavement was 4,029.2 m^3 and 3,709.8 m^3 for the ecological waterway.

RCP 8.5 estimated that there will be 50.9 mm of rainfall per hour in 2080, with about 9,255.5 m^3 of runoff occurring in the watershed, which may cause flooding. In this case, it is believed that all floods can be reduced by using one technique of water tank.

On the other hand, for RCP 4.5, it is predicted that there will be rainfall of 71.8 mm per hour in 2100, with approximately 42,393 m^3 of runoff occurring in the watershed. Fig. 27 shows the size of the flood area throughout Gangnam-gu in 2100 for RCP 4.5. When only one technology of water tank is applied, only 17,658 m^2 of runoff water can be generated, resulting in an effect of about 58% compared to before the technology installation. In addition, run-off could be further reduced by 9.6% in permeable pavement and 8.8% in ecological waterways. When all mitigation technologies are applied, 77% of flood runoff can be reduced. The area of flooding after technology applied in Gangnam-gu is as shown in Fig. 28.

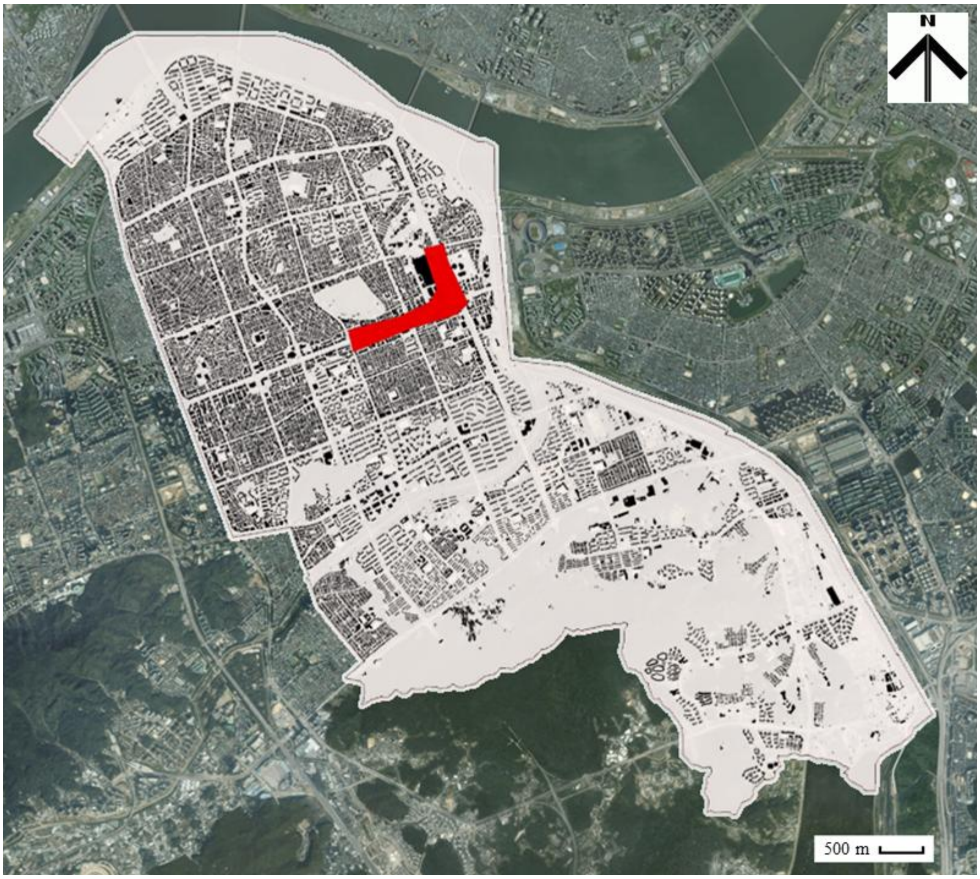
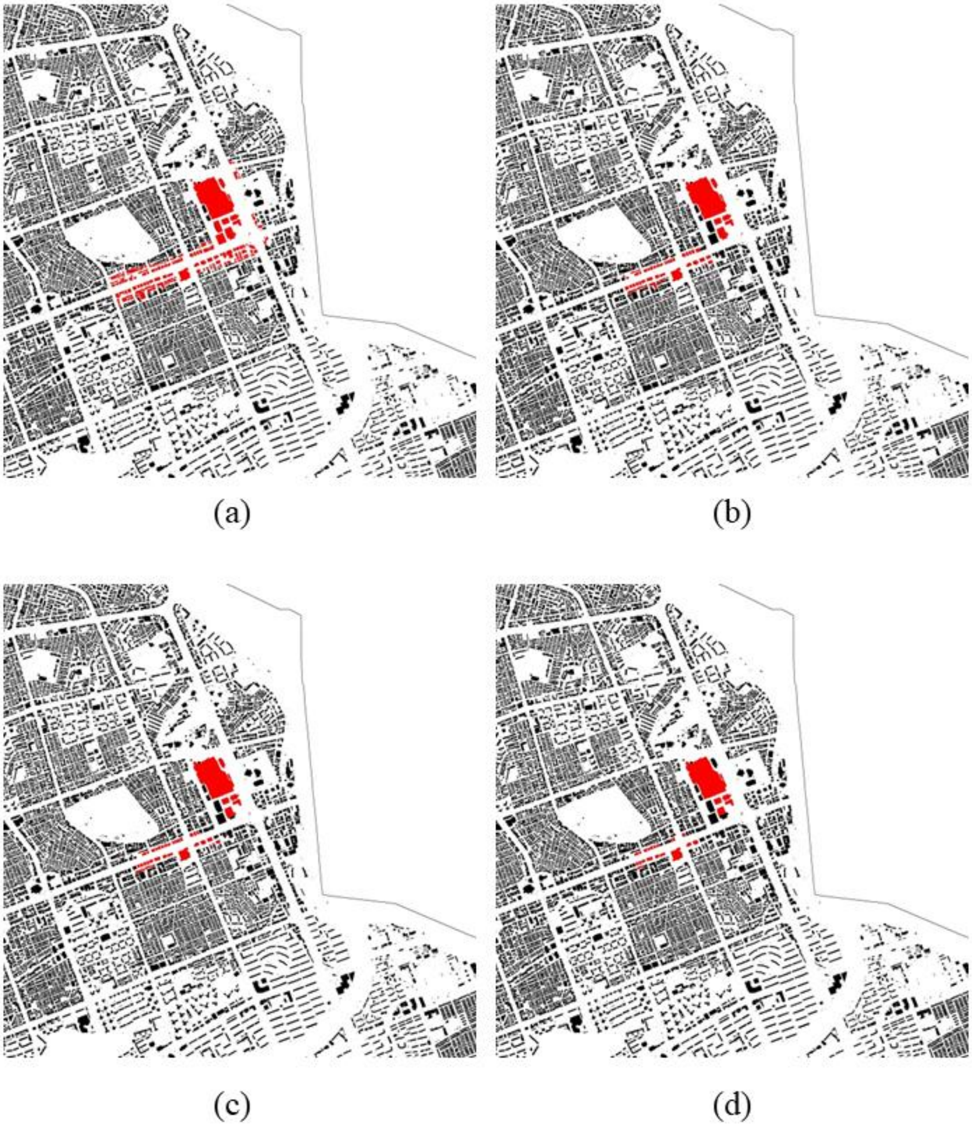


Fig. 27. The size of the flood area throughout Gangnam-gu in 2100 (RCP 4.5)



(a) (b)

(c) (d)

Fig. 28. Gangnam-gu flood area: (a) Before installed technology (b) Installed water tank (c) Installed water tank and Permeable Pavement (d) Installed Water tank, Permeable Pavement, and Ecological Waterway

In the case of Dongdaemun-gu, there are two watersheds, which are located inside and at the end of the district. Dongdaemun-gu will be flooded once in 2090 with RCP 8.5, twice in 2080, and 2100 with RCP 4.5.

Dongdaemun-gu had a relatively small watershed at 915,256 m². The building area that is formed inside the watershed is 225,245 m^2, which is about 24.6%. The total volume of the water tank is 11,262 m^3. The total length of roads between four and six lanes was 2,101 m, while for the roads above six lanes it was 6,752 m. The permeable pavement can store a total of 5,241 m^3 of precipitation, and the ecological water can store 7,258 m^3.

For the RCP 8.5 scenario, there will be 119.69 mm of rainfall per hour in 2090. The total run-off volume is 53,026 m^3, and when all three technologies are installed, the volume of run-off is estimated to decrease to 29,265 m^3. This represents a 44.8% decrease from the time of having no technology installed.

For the RCP 4.5 scenario, it is expected to bring about 65 mm of rainfall per hour in 2080, with 3,022 m^3 of run-off occurring in the watershed, which possibly causes flooding. With one water tank installed, 11,262 m^3 of rainwater can be stored, thus, flooding can be prevented without installing the other two mitigation technologies.

For the RCP 4.5 scenario in 2100, it is predicted that 126.0 mm of rainfall per hour will occur which is the highest hourly precipitation of the two scenarios. Figure 29 shows the size of the flood area throughout Dongdaemun-gu in 2100 for RCP 4.5. This is more than double the 61.8 mm/hr of acceptable precipitation per hour in Dongdaemun-gu. The volume of run-off is estimated to be 58,844 m³.

Under the above circumstances, the flood volume in Dongdaemun-gu is expected to be reduced by about 19.1% when a water tank technology is installed. It is estimated that the additional flood-mitigation effect of 8.9%

for permeable pavement and 12.3% for ecological waterways, with the final run-off volume of 35,082 m^3 when all three mitigation technologies are installed, accounting for 59.6% of the previous volume. The area of flooding after technology applied in Dongdaemun-gu are as shown in Figure 30.

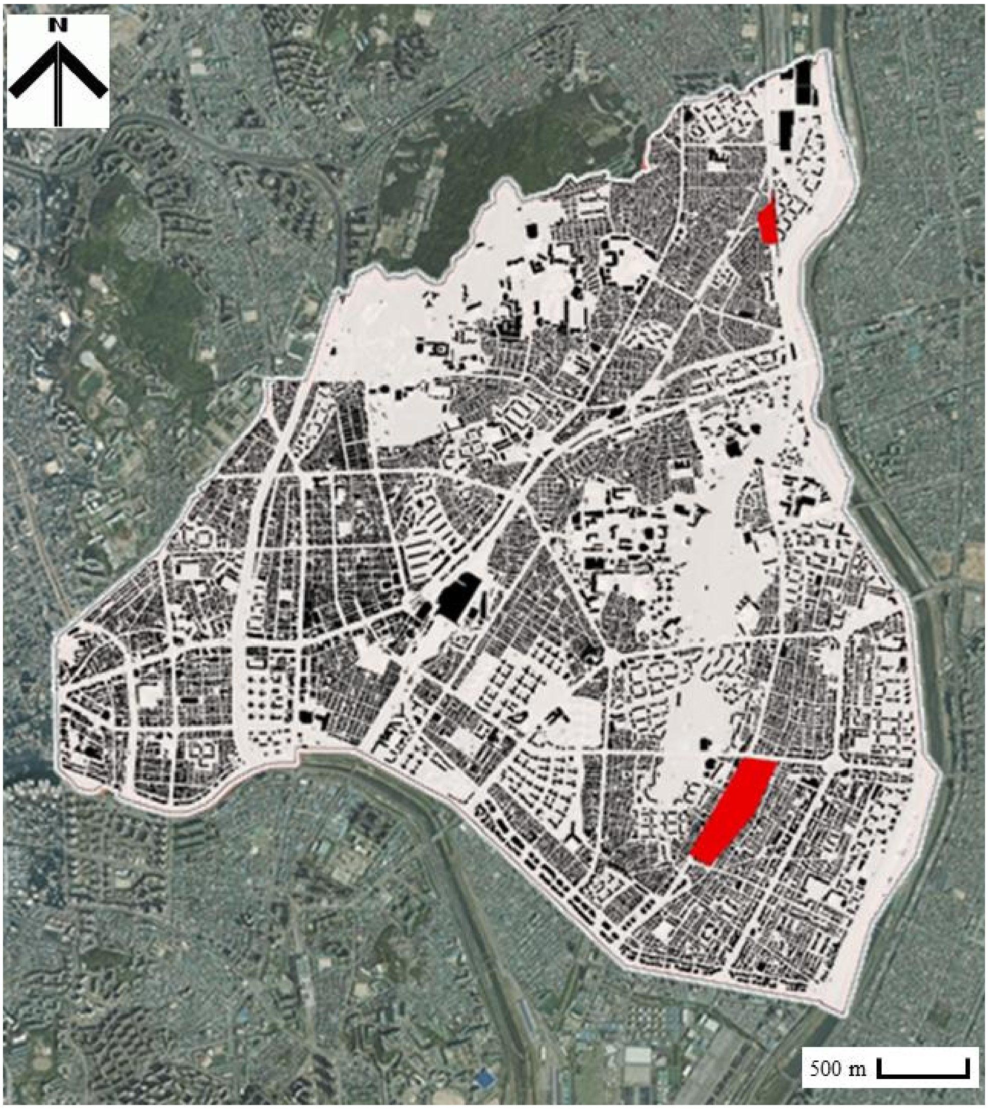


Fig. 29. The size of the flood area throughout Dongdaemun-gu in 2100 (RCP 4.5)

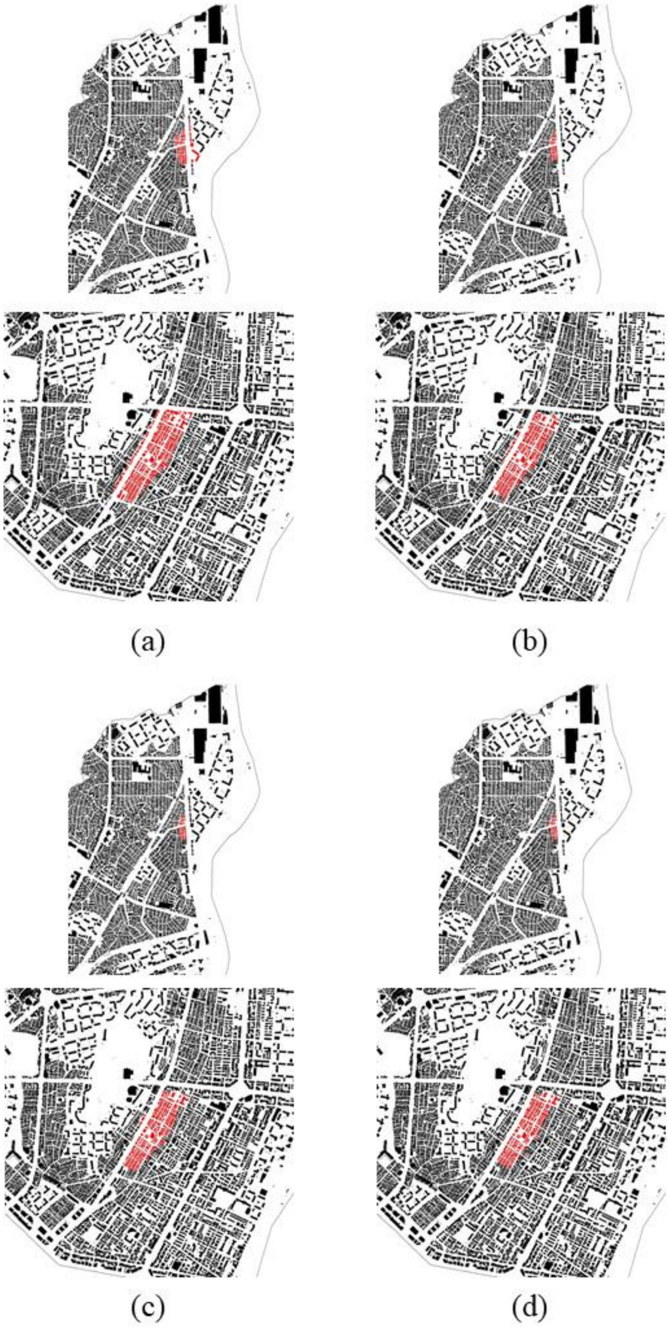


Fig. 30. Dongdaemun-gu Flood area: (a) Before installed technology (b) installed water tank (c) the installed water tank and permeable pavement (d) installed Water tank, permeable pavement, and ecological waterway

Jung-gu, the last district to be considered in this study, can be seen that the area of the watershed is formed at the end of the district compared to Gangnam-gu and Dongdaemun-gu. The total area of the watershed is 1,868,929 m^2 and the building area is 530,119 m^2.

On average, the expected rainfall is not as high as in other districts, so flooding does not occur frequently. However, in the case of RCP 8.5 Scenario 2090, heavy rain of 125mm per hour is expected, requiring preparation.

When the facility is not installed, the volume of run-off is 109,241 m^3. When the water tank is installed, the volume of run-off water is expected to decrease by 82,735 m^3 and 67,613.9 m^3 when two additional mitigation technologies are installed. Although this is a decrease of about 38% of the total run-off, it cannot be a complete countermeasure against flooding, so it is deemed that additional precautions should be taken.

For the RCP 4.5 scenario 2080, a maximum of 75 mm of precipitation per hour is estimated. Watershed area is expected to have 15,880 m^3 of run-off. In this case, the only water tank can serve as a whole disaster mitigation facility.

On the other hand, in the case of 2100, 89.6 mm of rainfall occurred per hour, so it is deemed that all three technologies should be installed. Figure 31 shows the size of the flood area throughout Jung-gu in 2100 (RCP 4.5). The volume of runoff water expected after the technical application is 43,192 m^3, and the amount of rainfall that can be reduced by just one technique of water tank is 26,506 m^3. The amount of run-off can be reduced by 61.4% and additionally by 18% by permeable pavement and 17% by the ecological waterway. Finally, the amount of water that can be reduced is 96%, and the only 1,565 m^3 of water is expected to cause flooding. The area of flooding after technology applied in Jung-gu is as shown in Figure 32.

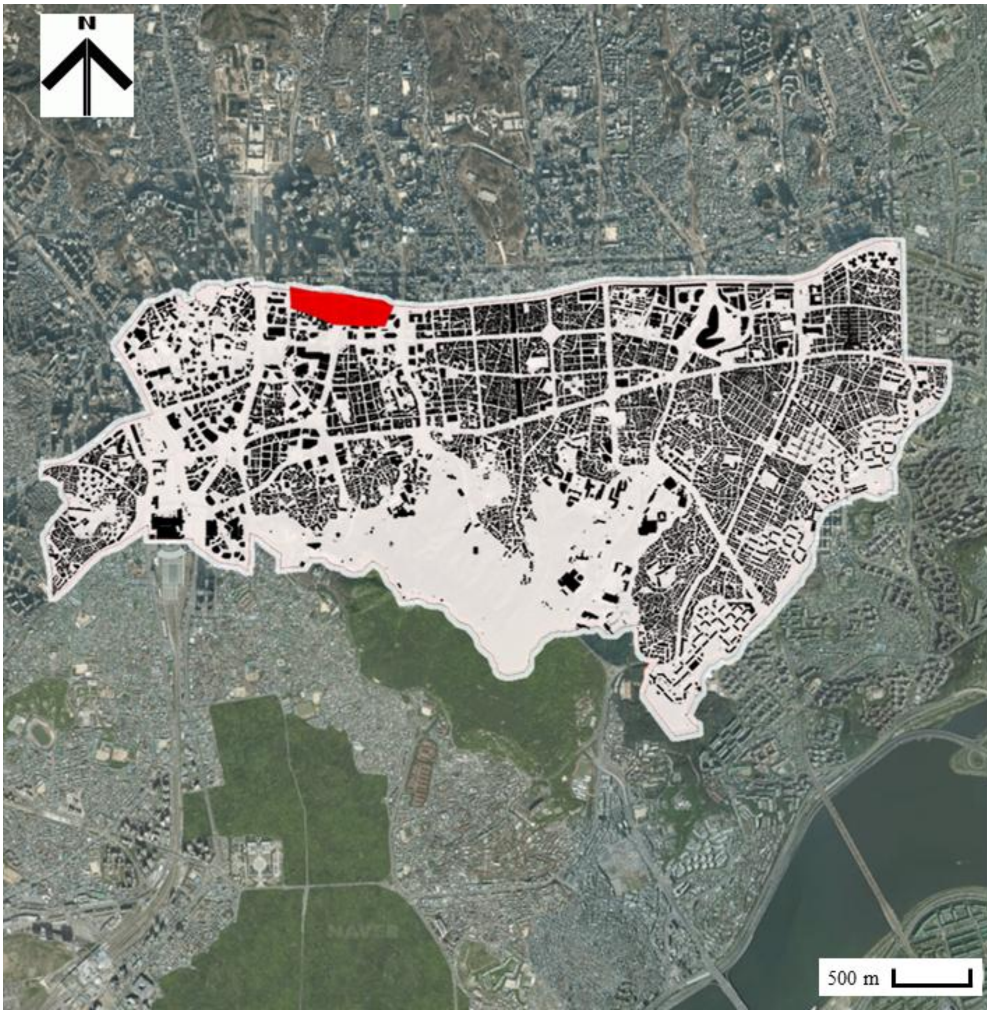
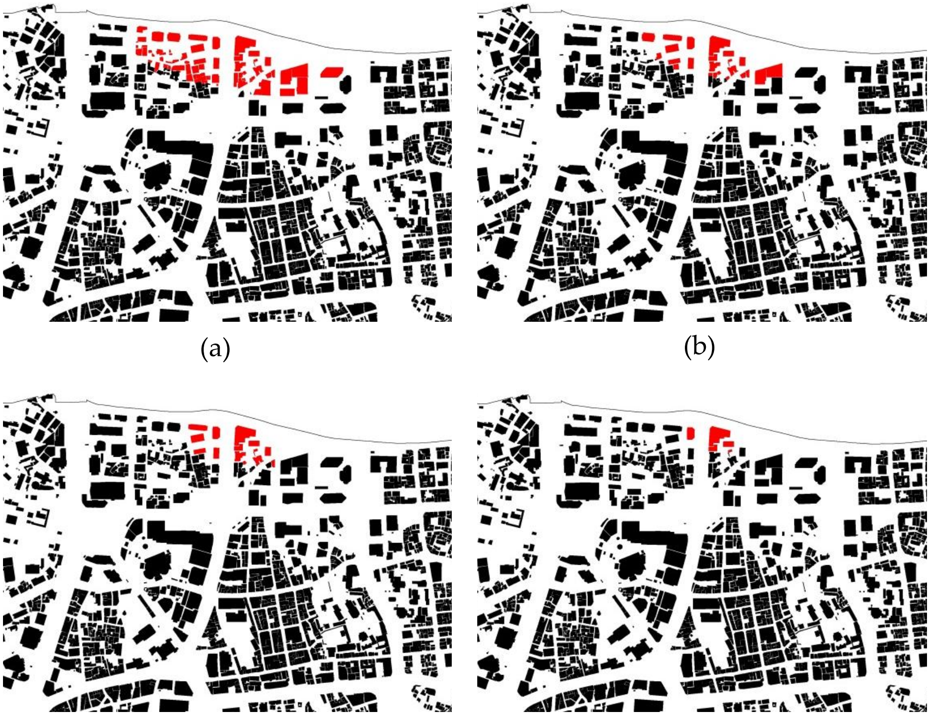


Fig. 31. The size of the flood area throughout Jung-gu in 2100 (RCP 4.5)



(a) (b)

(c) (d)

Fig. 32. Jung-gu Flood area : (a) Before installed technology (b) Installed water tank (c) Installed water tank and Permeable Pavement (d) Installed Water tank, Permeable Pavement, and Ecological Waterway

It is observed that having the mitigation technology installed, Guro-gu is believed to be able to prevent flooding in all cases. Guro-gu has a total of three floodings (years 2070, 2080 and 2090) in the RCP 8.5 scenario, and a total of two floodings (years 2090 and 2100) in the RCP 4.5 scenario.

Guro-gu has a watershed area of 265,350 m^2 and a building area of 66,000 m^2. Watershed in Guro-gu is located at the end of the district. There were no four-lane or six-lane roads, and the total length of the boulevard having more than six lanes was 1,331 m. Therefore, the volume of rainwater that can be installed in the water tank was 3,300 m^3 while the volume of permeable pavement was 788 m^3 and the volume of the ecological waterway was 1,431 m^3. It can be concluded that, compared to other districts, this area is expected to have a greater effect as an ecological waterway against.

In the case of the RCP 8.5 scenario 2080 and RCP 4.5 Scenario 2090, it is believed that the installation of the water tank will prevent urban flooding. A reason for this was that Guro-gu had a much lower hourly precipitation of 10-year frequency compared to other districts. The RCP 4.5 scenario 2100 for Nowon-gu, up to 238 mm/hr, Gangbuk-gu up to 211 mm/hr, and Guro-gu down to 76 mm/hr. For the RCP 8.5 scenario, the maximum precipitation per 10-year frequency per hour is 51 mm/hr, and the maximum precipitation per 10-year frequency for the RCP 4.5 scenario is 43 mm/hr, far below the current state of precipitation acceptable to the district.

In the case of the RCP 8.5 Scenario 2070, 2090, and RCP 4.5 Scenario 2100, it is analyzed that the installation of the water tank cannot prevent flooding across the city. However, it is deemed that the combination of permeable pavement and ecological waterways will prevent domestic flooding occurring in cities in all cases.

In the case of 2070, the installation of only water tank is expected to reduce the overall run-off by about 60.7% of 5,441 m^3, and the effect of the permeable pavement by 14.5% and ecological waterway by 24.9%. The area of flooding after technology applied in Guro-gu is shown in Figure 33.

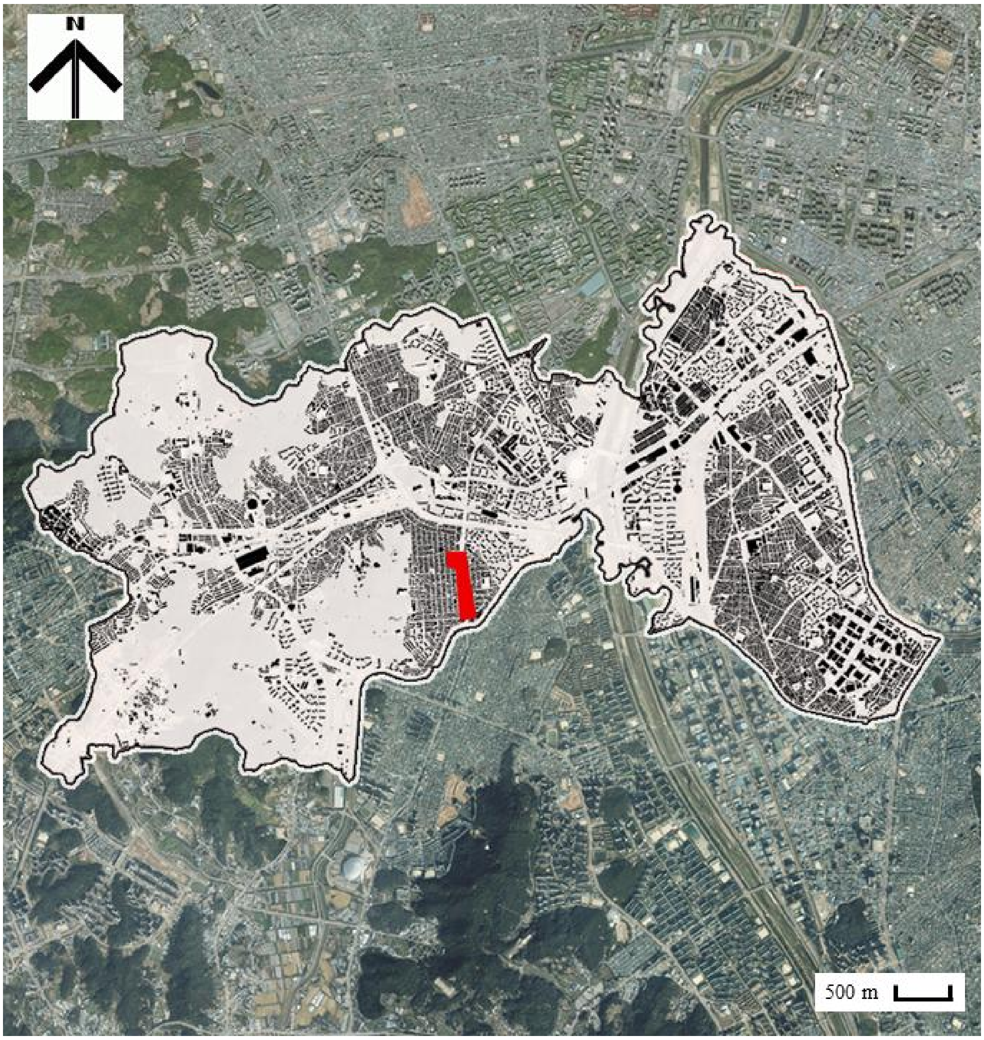


Fig. 33. The size of the flood area throughout Guro-gu in 2070 (RCP 8.5)

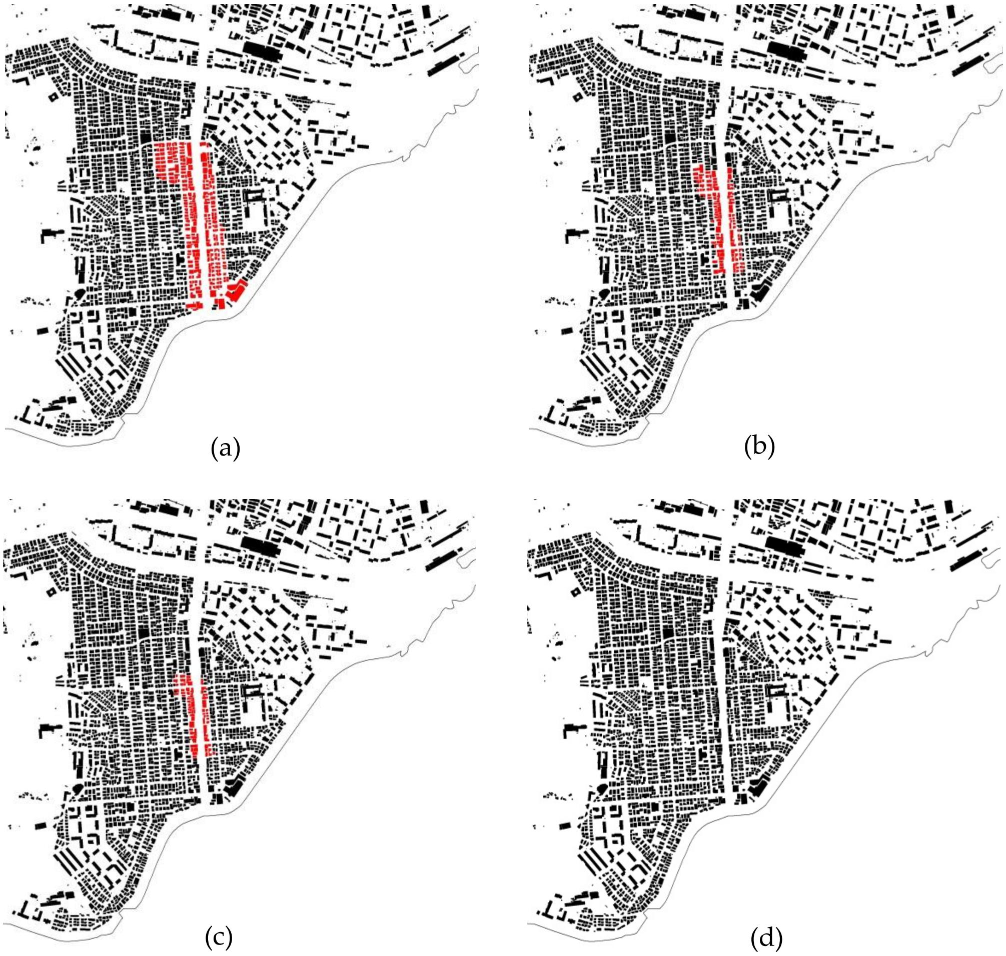

(a) (b) (c) (d)

Fig. 34. Guro-gu Flood area : (a) Before installed technology (b) Installed water tank (c) Installed water tank and Permeable Pavement (d) Installed Water tank, Permeable Pavement and Ecological Waterway

According to this analysis, the mitigating technologies used in this study can lower vulnerability within an urban area. There are two reasons. First, it is possible to increase the adaptive capacity to climate change by applying sustainable technologies such as water tanks, ecological waterways, and permeable pavement. The second is that the number of days of flooding can be reduced, so exposure to climate change could be decreased. However, this study was unable to assess changes in sensitivity, which is the third of the limitations described below. In subsequent studies, it is judged that more quantitative vulnerability reduction should be measured using vulnerability assessment indicators.

This study has identified that flooding at the local level will be more frequent and is meaningful in analyzing the quantitative effects of disaster mitigation technologies. In addition, when each local government installs flood mitigation technology in the future, quantification data should be provided to ensure optimized decision-making for each situation.

The above results can be discussed in some ways compared to other studies related to flood mitigation. In another study, SWMM analysis was conducted in the southern city of Beijing, China. A previous study revealed that a type of permeable pavement called biotention cell and an ecological waterway called vegetated swale were very effective in reducing urban flooding (Mei et al. 2018). Nevertheless, these studies concluded that damage could occur in the case of strong storm water. Another study investigated how much inundation can be reduced by using a combination of water tank and green infrastructure in Melbourne, Australia and determined that the maximum downstream inundation area can be reduced by an average of 91% (Maragno et al. 2018). In a study on the calculation of flood reduction using green infrastructure in Italy, run-off in a total of nine regions was analyzed, and the reduction effect was unevenly distributed in most regions. This is in agreement with this study, which analyzed all 25 districts in the Seoul Metropolitan Government, and the aforementioned study found that the effect of the amount of run-off reduction is different for each district, which is the same result as the current study [46]. The above three studies differ from this study in that they did not use a climate change scenario. However, the previous studies also showed that a water tank and combination of green infrastructure could achieve the greatest reduction effect of run-off.

4.4 Amount of non-point pollutant deposits in the water tank and maintenance time using the MOUSE regression equation

In this study, the accumulation of non-point source pollutants in the water tank was set as a factor for calculating the last stage of the HCFD model, the timing of maintenance. The maintenance timing referred to in this study is timing to clean the non-point source pollutants accumulated in the water tank over time. Depending on the local government's decision, it could be cleaned when the sediment is 10% or 50% of capacity. For the calculation of the amount of deposits of non-point source pollutants in the water tank, all 25 local government located in Seoul Metropolitan Government were analyzed, and the MOUSE regression equation was used for analyzing.

However, the form of the result of the MOUSE regression equation is calculated in units of weight (Unit: kg). In other words, it was necessary to divide the weight by the density of the non-point source pollutant and change it into volume (Unit: m^3). In the case of the specific gravity of non-point source pollutants, it is necessary to assume that it is the case of the safest state, since it can be varied.

For the calculation of the proportion of non-point source pollutants, the attached table of the Ministry of Environment Notice No. 2016-27 of the Neglected Waste Treatment Performance Guarantee Business Treatment Guidelines was referred to the specific gravity for each type of waste. According to the Notice, 0.30 t/m^3 of household waste and 0.40 t/m^3 of garden/park waste are used. 20% of the concept of the safety factor was introduced into the proportion of general garbage and 0.235 t/m^3 was set as the proportion of non-point source pollutants. The MOUSE regression equation accordingly is as shown in Eq (11) (Lee and Lee 2008).

$$V_{TS} = 2.9289A^{0.747}P^{0.009}T^{0.855}/235 \qquad (11)$$

Where V_{TS} is the volume of non-point pollutant by rainfall (m³), P is the hourly rainfall (mm/hr), and T is the duration of rainfall. The maintenance period of the storage tank is marked with the year when 10% of the internal capacity becomes and the year when it becomes 50%. The timing of maintenance suggested in this study is thought to be able to help in policy and administrative decision-making for rainwater circulation management. The maintenance period of the 24 autonomous districts is shown in the table 19.

Table 19. Maintenance period of districts in Seoul Metropolitan Government

		Jongno-gu	Jung-gu	Yongsan-gu	Gwangjin-gu	Dongdaemungu	Jungnang-gu	Seongbuk-gu	Gangbuk-gu
RCP 8.5	10%	2023	2025	2024	2029	2022	2021	2020	2026
	50%	2037	2047	2041	2064	2029	2029	2024	2051
RCP 4.5	10%	2023	2025	2024	2029	2022	2021	2021	2026
	50%	2039	2048	2042	2067	2030	2029	2025	2052
		Dobong-gu	Nowon-gu	Eunpyeong-gu	Seodaemun-gu	Mapo-gu	Yangcheon-gu	Gangseo-gu	Guro-gu
RCP 8.5	10%	2024	2022	2021	2023	2025	2026	2024	2022
	50%	2040	2034	2032	2038	2046	2051	2043	2034
RCP 4.5	10%	2024	2023	2022	2023	2025	2026	2025	2022
	50%	2042	2035	2033	2040	2047	2053	2045	2035
		Geumcheon-gu	Yeongdeungpo-gu	Dongjak-gu	Gwanak-gu	Seocho-gu	Gangnam-gu	Songpa-gu	Gangdong-gu
RCP 8.5	10%	2024	2025	2027	2024	2026	2025	2023	2026
	50%	2041	2048	2057	2042	2050	2048	2038	2050
RCP 4.5	10%	2024	2026	2027	2024	2026	2025	2023	2026
	50%	2042	2050	2059	2043	2051	2049	2040	2051

When analyzing the entire city of Seoul Metropolitan Government, the variation of water tank capacity considering non-point pollutant is shown in Fig. 35. In both the RCP 8.5 and RCP 4.5 scenarios, it is expected that after 2060, maintenance of water tanks in the entire Seoul Metropolitan Government will necessary.

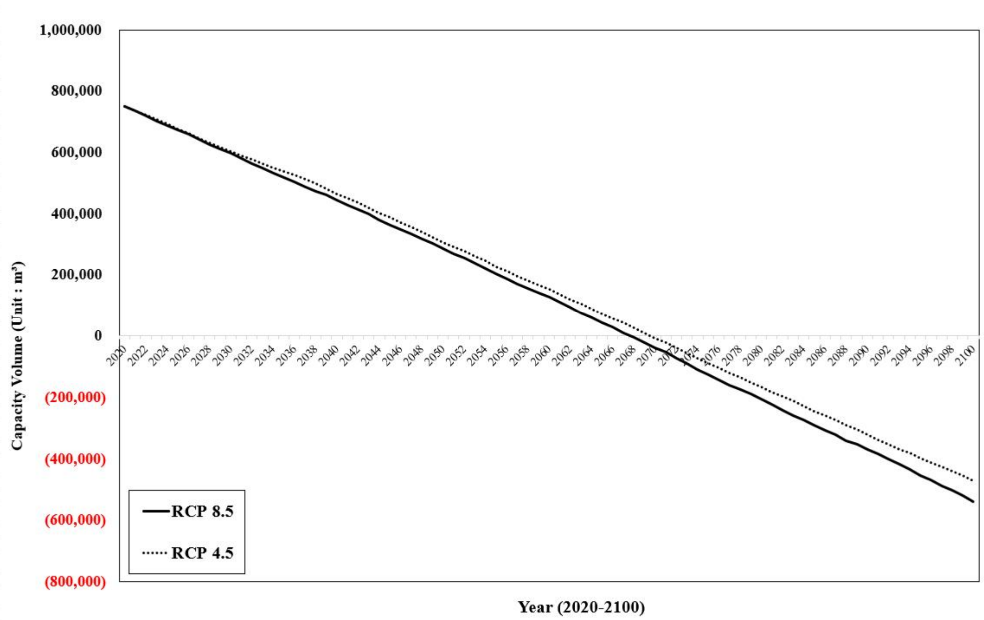


Fig. 35. Variation of water tank capacity considering non-point pollutant in Seoul Metropolitan Government

In this study, using Table 19, the districts of Seoul Metropolitan Government were classified into three in terms of maintenance of non-point pollutant. Rainwater storage tank internal management is classified into caution stage district, general stage district and safe stage district. This type classification is shown in Table 20. The local government with the later year of sediment accumulates, the less socio-economic costs used for cleaning could be reduced. In other words, local governments in the safety stage are more advantageous for maintenance. Local governments, which are in the caution stage, will have more than 50% of non-point pollutants accumulate inside the water tank before the year 2040. Local governments, which are in the general stage, has more than 50% of non-point pollutants accumulate inside the water tank between 2040 and 2050. Local governments, which are in the safe stage, accumulate more than 50% of non-point pollutants after the year 2050.

Table 20. Classification of districts in Seoul Metropolitan Government according to maintenance period

Caution Stage Districts	Jongno-gu, Dongdaemun-gu, Jungnang-gu, Seongbuk-gu, Nowon-gu, Eunpyeong-gu, Seodaemun-gu, Guro-gu, Songpa-gu
General Stage Districts	Jung-gu, Yongsan-gu, Mapo-gu, Gangseo-gu, Geumcheon-gu, Yeondeungpo-gu, Gwanak-gu, Seocho-gu, Gangnam-gu, Dobong-gu
Safe Stage Districts	Gawangjin-gu, Gangbuk-gu, Gangdong-gu, Dongjak-gu, Yangcheon-gu

The first number of districts that need caution in the internal management of water tanks are Jongno-gu, Dongdaemun-gu, Jungnang-gu, Seongbuk-gu, Nowon-gu, Eunpyeong-gu, Seodaemun-gu, Guro-gu, and Songpa-gu. Among them, Seongbuk-gu is predicted to accumulate the fastest non-point source pollutants inside the water tank. In preparation for a large-scale flood, it is estimated that maintenance of non-point source pollutants inside the water tank is required every year. The reason why the maintenance period of the districts under the early precaution is that the capacity of the rainwater storage tank inside the watershed is extremely small compared to other districts.

The graphs of non-point pollutant and maintenance periods in Seongbuk-gu and Jungnang-gu that correspond to caution stage districts are as shown in Fig. 36. and Fig. 37.

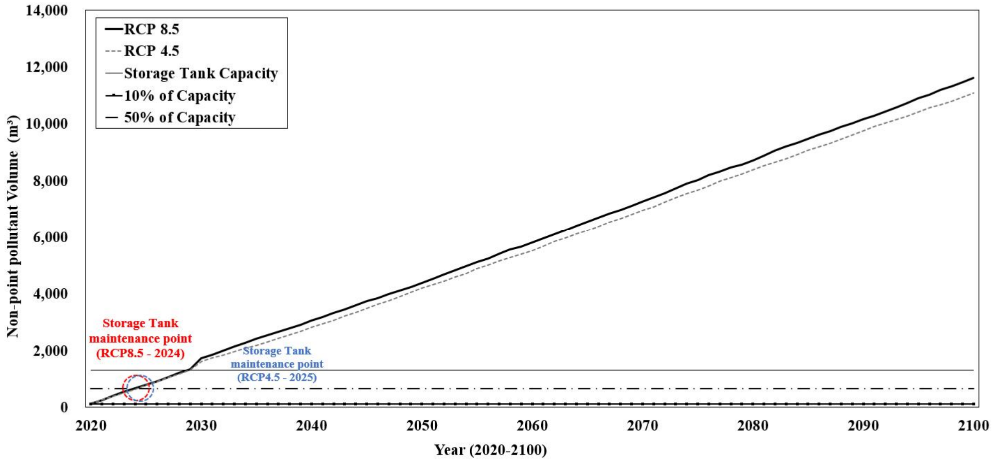


Fig. 36. Non-point pollutant volume increasing graph in Seongbuk-gu

In the case of Seongbuk-gu, when maintenance is not performed, a maximum of 11,626.9 m³ is expected to be filled in the water tank within the watershed by 2100 for the RCP 8.5 scenario. For the RCP 4.5 scenario, 11,081 m³ is expected to be deposited. Assuming that maintenance is required when 50% of capacity is filled as non-point pollutants, for the RCP 8.5 scenario, the water tank should be cleaned in the year 2024. In case of RCP 4.5 scenario, the water tank should be cleaned in the year 2025.

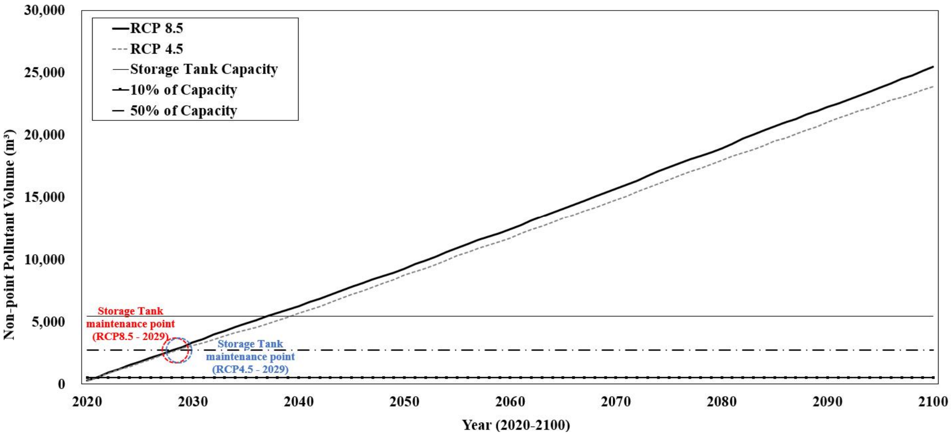


Fig. 37. Non-point pollutant volume increasing graph in Jungnang-gu

Second, there are 12 districts in which the management period of the water tank is general stage : Jung-gu, Yongsan-gu, Mapo-gu, Gangseo-gu, Geumcheon-gu, Yeongdeungpo-gu, Gwanak-gu, Seocho-gu, Gangnam-gu, and Dobong-gu. The graphs of sediment and maintenance period in Jung-gu and Yongsan-gu are shown as Fig. 38. and Fig. 39.

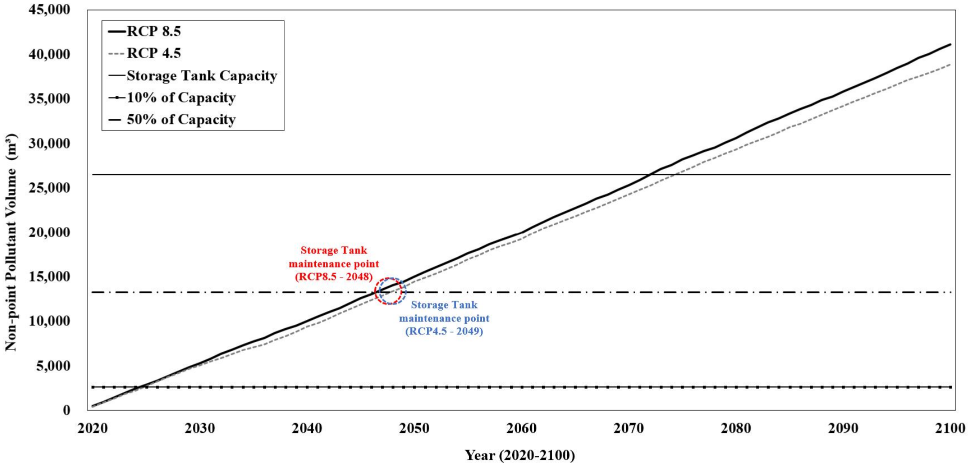


Fig. 38. Non-point pollutant volume increasing graph in Jung-gu

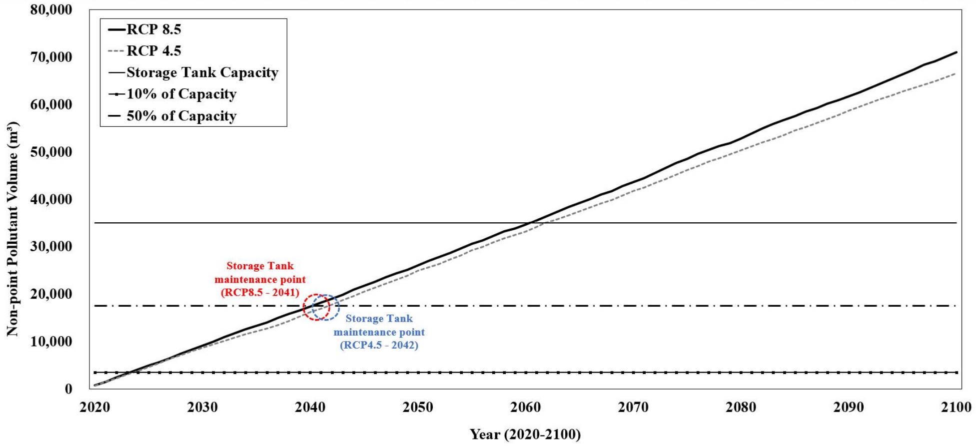


Fig. 39. Non-point pollutant volume increasing graph in Yongsan-gu

In the case of Jung-gu, when maintenance is not performed, a maximum of 41,134.6 m³ of non-point pollutant is expected to be deposited in the water tank within the entire watershed by 2100 for the RCP 8.5 scenario. In case of the RCP 4.5 scenario, it is estimated that 38,885.25 m³ of non-point source pollutants will be deposited. This is about 150% of the water tank capacity.

Lastly, Gwangjin-gu, Gangbuk-gu, Gangdong-gu, Dongjak-gu and Yangcheon-gu are safe stage districts in terms of maintenance of water tank. Among these, Gwangjin-gu is expected to be more convenient for maintenance than the other two districts. The graph that calculated the sediment and maintenance period of Gwangjin-gu and Dongjak-gu are shown as Fig. 40 and Fig. 41.

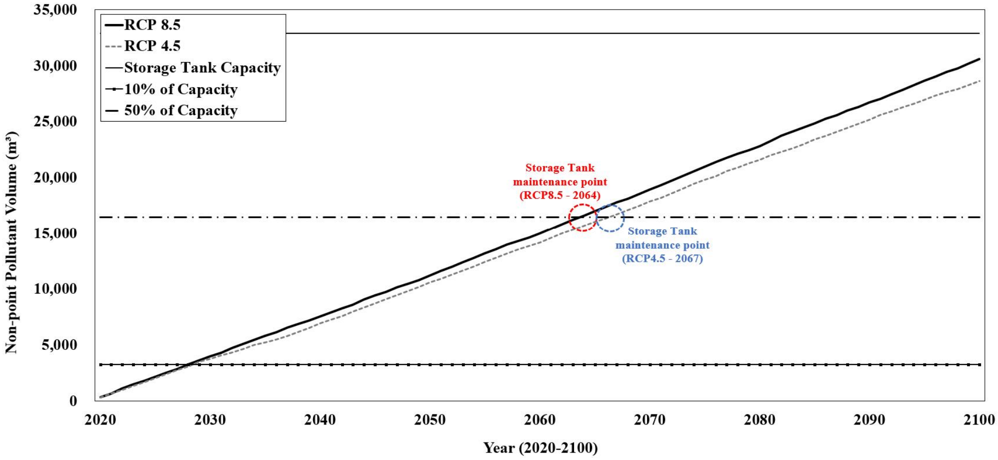


Fig. 40. Non-point pollutant volume increasing graph in Gwangjin-gu

In the case of Gwangjin-gu RCP 8.5 scenario, without maintenance, 30,616.0 m³ of non-point pollutants will be deposited in the water tank within the watershed. For RCP 4.5 scenario, 28,658.2 m³ of non-point pollutants will be deposited.

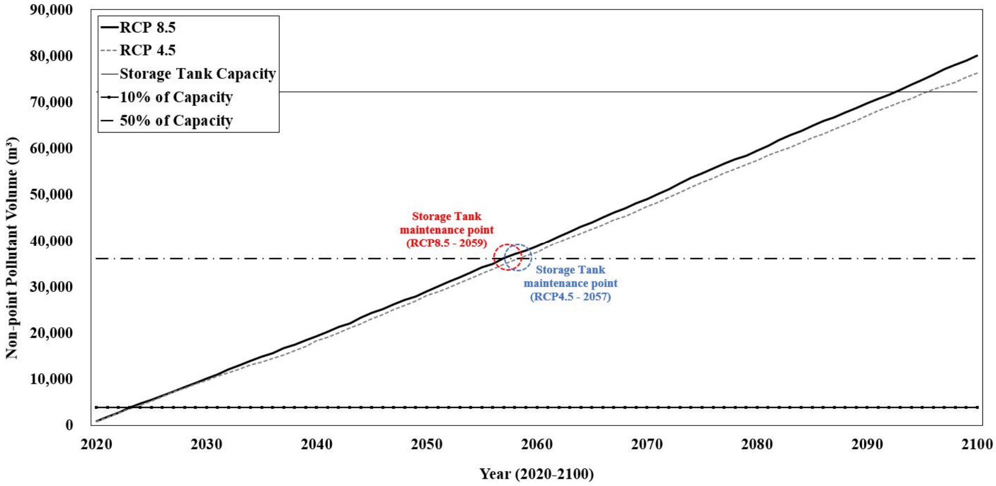


Fig. 41. Non-point pollutant volume increasing graph in Dongjak-gu

In the case of Dongjak-gu, when maintenance is not performed, a maximum of 80,010.8 m³ is expected to be deposited in the water tank which located in watershed by 2100 for the RCP 8.5 scenario. In the case of the RCP 4.5 scenario, 76,354.8 m³ is expected to be deposited.

Through this analysis, it was found that in the case of Gwangjin-gu, there would be no case of overflowing to the ground even if the sediment was not maintained and managed until 2100.

Chapter 5. Summary and Conclusions

The objectives of this study was analyze urban flood damage over the next 80 years (2020-2100) that could be caused by the climate change scenario. The study selected disaster mitigating facilities and analyzed their impact on disaster mitigation. Furthermore, through the development of the HCFD model, the capacity and performance of the facilities that may change in the future were analyzed.

Using the climate change scenario on the Korean Peninsula, this study identified the amount of flood damage that could occur until 2100 and analyzed the effects of mitigation technologies. Huff dimensionless curves were used for hourly precipitation analysis, and GIS ARC Hydro plug-in was used for hydrology. The target site is Seoul Metropolitan Government, and it has a gap from other studies in that analyzed a wide area.

There are three main conclusions drawn from the results of this study. The first is that the possibility of flooding that could occur according to climate change scenarios was analyzed at a 10-year frequency. Both the RCP 8.5 scenario and RCP 4.5 scenario showed frequent flooding after 2070. For the RCP 8.5 scenario, it is predicted that the year 2090 has the highest amount of precipitation. However, for RCP 4.5 scenario 2100, the maximum daily rainfall is approximately 690 mm, with hourly precipitation of 238 mm.

The second is that the capacity of each technology was analyzed. According to the installation rules assumed in this study, the volume of water tanks that can be installed throughout the Seoul Metropolitan Government is 776,588 m^3, the volume of permeable pavement is 89,049 m^3, and the volume of the ecological waterway is 81,986 m^3. When all technologies are installed, the capacity secured by the Seoul Metropolitan Government is 947,623.7 m^3, and if only two technologies are applied, the water tanks and permeable pavement will be the most efficient cases. It is siginificant that each local government has suggested an efficient combination of two technologies.

When all technologies are installed, the RCP 8.5 Scenario in 2050 and 2060 are expected to reduce the run-off by 100 percent in all areas of the Seoul Metropolitan Government. RCP 8.5 scenarios in 2020, 2040, 2070, 2080, 2090, and RCP 4.5 scenarios in 2030, 2080, 2090, 2100 are expected to have significant hazard mitigations. After 2070, there may be large-scale flooding, so the additional mitigation technology is necessary.

Third, the amount of runoff that can be reduced by each mitigating technology was quantified. In the case of the RCP 8.5 scenario, it could be reduced by 70% of runoff in year 2080 and 30% in year 2090. However, with RCP 4.5 scenario, runoff will be reduced by 85% in 2090 and 22% in 2100. In RCP 4.5 scenario in year 2100, additional mitigating technology is required as about 200 mm of rain is predicted.

Furthermore the non-point source removal timing of water tank was calculated. Water tank internal management is classified into caution stage district, general stage district and safe stage district. There were nine local governments that corresponded to the caution stage, twelve local governments of general stage and three local governments of safe stage.

This study has identified that flooding at the local level will be more frequent and is meaningful in analyzing the quantitative effects of disaster mitigation technologies. Besides, when each local government installed flood mitigation technology in the future, quantification data would be provided to ensure optimized decision making for each situation.

For further consideration, this paper can lower vulnerability within urban area. There are two reasons. First, it is possible to increase the mitigating capacity to climate change by applying sustainable technologies such as water tanks, ecological waterways, and permeable pavement. The second is that the number of days of flooding can be reduced, so exposure of climate change could be decreased. However, this study was unable to assess changes in sensitivity, which is the third of the limitations described below. In subsequent studies, it is judged that more quantitative vulnerability reduction should be measured using vulnerability assessment indicators.

The limitations of this study can be diagnosed by dividing them into four parts, and later studies suggest that the following limitations should be resolved. The first limitation is uncertainty about climate change scenarios. Since changes in carbon emissions or scenarios can significantly change precipitation values, it is believed that future studies will develop into a more significant study if a scenario with fewer errors is used. It is deemed that further economic analysis should be studied when the technology is installed in the current condition and maintained in the future.

The second limitation is that the study was conducted at a frequency of 10 years, as both RCP4.5 / RCP8.5 scenarios were analyzed daily. Subsequent studies suggest that more detail and broader analysis should be conducted yearly.

Third, social change factors are not reflected. Cities can be urbanized, depending of policy of decision-makers. For example, a building may be re-built, and the length or size of road may vary. Since this paper is based on the current state of facilities and environment of society, decision makers will have to consider these limitations when setting up flood measures.

Fourth is the limitation of verification. In this study, an arithmetic equation and GIS Arc-hydro were used to calculate the run-off in the Seoul Metropolitan Government. There was an opinion of experts that this study is different from the methodology of previous study and that verification is necessary. However, due to the scope of this study, it is difficult to perform verification. Therefore, only verifiable methodologies are suggested in this summary. The most ideal method to verification is to compare the results with other software. The reliability of this study can be improved by comparing the amount of runoff before applying the technology using programs such as SWMM, STORM, and MUSIC. SWMM is considered to be the most efficient verification method since it can put pipe network facilities such as orifices plate. Additionally, LID facilities such as ecological waterway can be quantified and interpreted. It is judged that future studies of this study should be verified the amount of run-off in a number of districts in Seoul metropolitan districts.

Future studies, therefore, should be carried out to overcome the above four limitations. In particular, uncertainty problem of the climate change scenario should be solved. The reason is that the second and third limitations are due to uncertainty of the climate change scenario. Recently, many study has been conducted to reduce errors in scenario models using AI. If these AI studies are verified, it will be useful for future research.

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초록

도시홍수 저감을 위한 근거기반 계획
- 서울시를 중심으로 -

김재경
생태조경·지역시스템공학부
서울대학교 대학원

최근 기후변화로 인해 발생되고 있는 사회/경제적 피해는 급속히 증가하고 있다. 기후변화로 인한 2차적 피해로는 폭염, 홍수 등이 있다. 그 중에서 극한 강우는 도심지역에 큰 피해를 발생시키고 있다. 대표적으로는 2011년 발생한 집중호우 등이 있는데, 당시에는 최대 110.5 mm/hr의 기록적인 강수가 내렸다.

현대 도시에서 발생하는 홍수의 대부분 원인은 불투수성 포장면의 급격한 증가와 내수배제 불능, 물순환 시설 부재 등의 원인이 있다. 기상청에서 제공하는 기후변화 시나리오에 따르면, 향후 100년간 도시의 평균 강수량은 줄어들 것으로 파악된다. 하지만, 일시에 폭우가 내리는 빈도가 증가하고 국지성 피해가 뚜렷하게 발생할 것으로 판단된다. 현재 상태의 기반시설들에 보수나 방어기술이 수립되지 않으면, 그 피해는 상당할 것으로 판단된다.

이에 본 연구는 총 세 가지 연구 목표를 수립하여 수행하였다. 첫 번째, 기상청에서 제공하는 기후변화 시나리오(RCP 4.5/RCP 8.5)로 인해 발생할 수 있는 향후 80년(2020년-2100년)의 도시 홍수 피해량을 정량적으로 분석한다. 두 번째, 정량적으로 분석된 피해량에 기반한 재해 저감 시설을 선정하고, 재해의 저감량을 분석한다. 이를 통해 근거 기반

(Evidence-Based Planning)의 시설배치 및 설계한다. 재해 저감 시설은 미래 세대가 지속적으로 사용할 수 있는 친환경(Eco-Friendly) 시설물을 선정하였다. 세 번째, HCFD (Hazard Capacity Factor Design) 모델의 개발을 통해, 향후 변화할 수 있는 시설물들의 용량과 성능에 대해 정량적으로 분석한다. HCFD 모델은 저감 기술을 유지하는 방법을 고려하는데 사용된다.

이러한 목표를 달성하기 위해서 방어 기술로 총 세 가지를 도입하였다. 저류조, 투수성 포장 그리고 생태수로가 이에 해당한다. 저류조의 경우, 환경부에서 지정하고 있는 법령을 참고하여 도입 가능한 용량을 파악하였다. 투수성포장과 생태수로는 법령으로 명확히 규정하는 설계 지침이 없기에, 타 연구 보고서를 참고하였다. 각 기술들의 도입 규모를 산정하기 위해서 Arc-GIS ArcHydro Plug in을 사용하였고 Watershed를 분석하였다. Watershed에 영향을 미치는 범위를 파악하기 위해서 기후변화시나리오에서 제공하는 강수량을 시간 단위로 분석하였고, 이를 위해 Huff Curve 공식을 사용하였다.

위에서 언급된 세 가지 기술은 빗물의 저장 용량을 증가시켜 홍수 완화에 기여할 것으로 판단된다. 세 가지 기술을 모두 도입하였을 때 2050년과 2060년에는 RCP 8.5 시나리오의 모든 홍수피해를 저감할 수 있을 것으로 판단된다. 2070년 이후에는 유출이 발생할 것으로 분석되지만, 적응 기술을 통해 홍수를 크게 줄일 수 있을 것으로 예측된다. 본 연구 논문에서는 10년 단위의 홍수와 적응량을 산정하였지만, 추후 후속 연구에서는 1년 단위의 분석이 실시되어야 할 것으로 판단된다.

또한 저류조 내부에 퇴적되는 비점오염원의 청소 시기가 산정되었습니다. 저류조의 경우 MOUSE 회귀 분석을 통해 내부에 축적된 비점오염원 제거 시기를 산정하였다. 빗물 저류조 내부 관리는 크게 주의단계, 일반단계, 안전단계로 지방자치단체를 구분하였다. 주의단계에 해당하는 지방자치단체는 9개, 일반단계에 해당하는 지방자치단체는 10개, 안전단계에 해당하는 지방자치단계는 5개가 해당한다.

이 연구의 결과를 통해 도출된 결론 및 의의는 세 가지로 요약된다. 첫째, 본 연구는 기후변화 시나리오에 따라 발생할 수있는 홍수 가능성을 10년 주기로 분석했다.RCP 8.5 시나리오와 RCP 4.5 시나리오 모두 2070년 이후에 빈번한 홍수의 추이를 볼 수 있었다. RCP 8.5 시나리오의 2090년에 강수량이 가장 많을 것으로 예상된다. RCP 4.5 시나리오 2100년의 경우, 최대 690 mm, 시간당 강수량은 238 mm까지 내릴 것으로 판단된다.

두 번째, 본 연구 논문은 각 기술의 용량을 자치구별로 분석하였다. 본 연구에서 가정한 설치 규정에 따르면 서울시 전역에 설치할 수 있는 빗물 저류조의 부피는 776,588 m^3, 투수성 포장은 89,049 m^3, 생태수로는 81,986 m^{3}이다. 각 지방자치단체가 두 가지 기술만을 적용하였을 때 효율적인 조합을 제안한 것은 본 연구가 가지는 중요한 의의입니다.

셋째, 각 재해저감 기술로 저감할 수 있는 유출량을 정량화했습니다. 이 연구는 지역 차원의 분산적 형태의 홍수가 더 자주 발생하고, 재난저감 기술의 정량적 효과를 분석하였다는데 의의가 있다.

본 연구의 한계는 네 부분으로 나눌 수 있다. 첫 번째 한계는 기후변화 시나리오에 대한 불확실성이다. 탄소 배출량이나 시나리오의 변화는 강수량 값을 크게 변경할 수 있기 때문에 오류가 적은 시나리오를 사용하면 향후 연구가 더 중요한 연구로 발전할 것으로 판단된다. 최근 기후변화 시나리오의 불확실성을 줄일 수 있는 연구가 활발히 진행 중이기 때문에, 첫 번째 한계점을 보완한 후속연구가 진행될 것이라 판단된다. 두 번째 한계는 RCP 4.5 / RCP 8.5 시나리오가 10년의 빈도로 수행되었다는 것이다. 세 번째 한계점은 사회 변화 요인이 반영되지 않았다는 것입니다. 네 번째는 검증의 한계입니다. 본 연구에서는 서울시의 유출수를 계산하기 위해 산술 방정식과 GIS Arc-hydro를 사용하였다.추후 SWMM 등의 홍수 해석 프로그램을 활용하여 추가적인 검증이 되어야 한다. 따라서, 위의 네 가지 한계를 극복하기 위해 후속 연구가 수행되어야 할 것으로 판단된다. 특히 첫 번째 문제점인 기후변화 시나리오의 불

확실성 한계점은 후속되는 세 가지 한계점을 발생시키기에, 필수적으로 해결되어야 한다.

주요어 : 그린인프라, 극한강우, 근거기반계획, 기후변화 시나리오,
재해 완화기술, 홍수, HCFD 모델
학 번 : 2019-20317

Appendix

Appendix A. Historical data of district that was damaged by the flood

년도	District
2014	Sungdong-gu, Gangnam-gu, Yongsan-gu
2013	Seodaemun-gu, Seocho-gu, Gangnam-gu, Yongsan-gu, Gangseo-gu, Eunpyeong-gu, Dongdaemun-gu, Dobong-gu
2012	Gwanak-gu, Yeongdeungpo-gu, Guro-gu, Mapo-gu, Sungdong-gu, Yangcheon-gu, Gangnam-gu, Seocho-gu, Gangdong-gu, Yongsan-gu, Gangseo-gu, Jung-gu, Seodaemun-gu, Dongjak-gu
2011	Seocho-gu, Gwanak-gu, Songpa-gu, Gangnam-gu, Dongjak-gu, Sungbuk-gu, Gangdong-gu, Yangcheon-gu, Geumcheon-gu, Gangseo-gu, Yongsan-gu, Seodaemun-gu, Eunpyeong-gu, Guro-gu, Dongdaemun-gu, Yeongdeungpo-gu, Gangbuk-gu, Mapo-gu, Jungrang-gu, Sungdong-gu, Jongno-gu, Nowon-gu, Dobong-gu, Jung-gu
2010	Yangcheon-gu, Gwanak-gu, Seocho-gu, Gangseo-gu, Seodaemun-gu, Yongsan-gu, Gwangjin-gu, Gangdong-gu, Guro-gu, Dongjak-gu, Yeongdeungpo-gu, Songpa-gu, Geumcheon-gu, Mapo-gu, Gangnam-gu, Jungrang-gu, Jongno-gu, Eunpyeong-gu, Gangbuk-gu, Dongdaemun-gu, Sungbuk-gu, Jung-gu
2009	Yeongdeungpo-gu, Jung-gu, Seocho-gu, Eunpyeong-gu
2008	Sungbuk-gu
2006	Yangcheon-gu, Eunpyeong-gu, Gangbuk-gu, Jongno-gu, Yongsan-gu, Sungbuk-gu, Jungrang-gu, Guro-gu, Mapo-gu, Sungdong-gu, Nowon-gu, Gangdong-gu, Gwanak-gu, Seocho-gu, Gangseo-gu
2005	Gangseo-gu, Jungrang-gu, Yongsan-gu
2004	Gangdong-gu, Gangnam-gu, Songpa-gu, Mapo-gu, Seodaemun-gu, Nowon-gu, Gwanak-gu
2003	Gwanak-gu, Jungrang-gu, Dongdaemun-gu, Dongjak-gu, Yangcheon-gu, Seocho-gu, Seodaemun-gu, Guro-gu, Gangnam-gu, Yongsan-gu, Gangseo-gu, Yeongdeungpo-gu, Mapo-gu, Gwangjin-gu
2002	Gwanak-gu, Nowon-gu, Seocho-gu, Sungdong-gu, Seodaemun-gu, Yeongdeungpo-gu, Dongjak-gu, Gangnam-gu, Sungbuk-gu, Guro-gu, Dobong-gu, Songpa-gu, Jongno-gu, Gangbuk-gu, Eunpyeong-gu, Gangdong-gu, Dongdaemun-gu, Mapo-gu, Gwangjin-gu, Yangcheon-gu, Yongsan-gu, Gangseo-gu
2001	Gwanak-gu, Yeongdeungpo-gu, Jungrang-gu, Sungbuk-gu, Seocho-gu, Songpa-gu, Gangdong-gu, Nowon-gu, Sungdong-gu, Gangnam-gu, Yongsan-gu, Gwangjin-gu, Guro-gu, Seodaemun-gu, Eunpyeong-gu, Dobong-gu, Yangcheon-gu, Gangseo-gu, Dongdaemun-gu, Gangbuk-gu, Jung-gu, Jongno-gu, Mapo-gu, Dongjak-gu, Geumcheon-gu

Appendix B. RCP Scenario 8.5 - Flood-prone year (10-years frequency / precipitation (mm/hr))

District	Flood Threshold	2030	2040	2050	2060	2070	2080	2090	2100
Gangnam	45	34.1	41.7	36.5	33.8	34.5	50.8	120.8	23.0
Gangdong	76	34.9	90.4	36.6	32.2	36.4	51.0	103.3	24.2
Gangbuk	62.3	35.9	42.0	58.2	30.8	38.4	69.9	103.2	26.3
Gangseo	53.8	37.5	38.2	35.7	34.0	83.7	76.3	106.5	28.5
Gwanak	59.3	33.6	34.3	36.3	35.5	39.6	58.1	57.9	21.4
Gwangjin	64.3	34.7	66.7	36.0	31.9	36.0	50.9	117.2	23.9
Guro	61.5	34.2	36.8	35.9	33.2	82.0	68.9	76.6	22.5
Geumcheon	82.8	33.4	32.2	36.1	33.4	52.9	60.5	42.5	17.6
Nowon	77.5	36.1	42.1	53.9	29.5	38.2	63.0	89.3	25.0
Dobong	66.5	36.3	43.2	56.8	32.0	38.2	69.8	89.5	25.7
Dongdaemun	61.8	35.1	47.8	35.5	31.3	36.9	56.0	119.7	24.1
Dongjak	48.0	33.9	34.3	36.1	33.5	38.0	62.1	81.6	22.4
Mapo	68.0	34.5	37.4	35.6	33.7	43.6	79.9	128.9	25.6
Seodaemun	52.5	34.5	38.0	35.5	31.7	38.8	76.5	111.0	26.1
Seocho	52.5	33.9	32.9	36.6	34.9	34.6	52.0	98.9	22.6
Sungdong	79.8	34.7	42.6	35.5	31.1	35.9	53.5	126.0	23.4
Seongbuk	58.8	35.3	40.3	44.3	30.7	37.8	63.6	117.4	24.6
Songpa	71.8	34.2	63.9	37.3	33.6	34.5	49.9	128.0	23.2
Yangchun	68.8	34.9	37.4	35.9	34.1	71.8	76.6	113.2	25.8
Yeongdeungpo	58.3	34.0	36.4	35.9	33.9	45.1	73.8	110.7	22.4
Yongsan	38.5	34.3	33.4	35.6	32.1	36.6	60.5	112.6	23.2
Eunpyeong	51.5	35.0	39.7	64.1	31.6	41.5	82.2	103.6	28.2
Jongno	54.3	34.8	38.5	43.0	31.4	37.8	68.6	118.7	24.4
Jung-gu	66.5	34.5	35.5	35.3	30.7	36.6	59.8	125.0	23.8
Jungnang	63.0	35.3	63.7	35.8	30.8	37.5	55.6	103.8	24.6

Note: Red box means that a flooding may occur, and green box means a year that is safe from flooding

Appendix C. RCP Scenario 4.5 - Flood-prone year (10-years frequency / precipitation (mm/hr))

District	Flood Threshold	2030	2040	2050	2060	2070	2080	2090	2100
Gangnam	45.0	32.7	37.0	29.6	31.5	23.5	80.7	62.3	71.8
Gangdong	76.0	38.1	39.9	30.1	34.3	24.8	44.2	50.9	168.7
Gangbuk	62.3	89.8	33.7	40.3	40.9	21.1	45.6	46.3	210.9
Gangseo	53.8	43.2	33.6	42.9	53.0	20.9	45.2	61.8	110.0
Gwanak	59.3	31.5	37.2	32.2	44.7	20.9	65.4	67.4	48.9
Gwangjin	64.3	38.0	36.4	32.2	35.0	23.6	65.9	53.8	115.8
Guro	61.5	31.7	36.0	37.9	53.1	20.8	42.7	69.2	75.7
Geumcheon	82.8	32.2	37.2	33.6	54.6	20.5	40.3	68.5	56.2
Nowon	77.5	77.9	34.4	38.7	41.7	21.5	44.4	43.7	238.0
Dobong	66.5	96.1	33.5	40.7	42.1	20.8	45.7	43.0	236.4
Dong daemun	61.8	49.8	35.4	35.7	37.6	22.1	65.1	51.7	126.0
Dongjak	48.0	30.9	36.4	34.1	35.3	21.4	68.9	65.3	54.6
Mapo	68.0	40.4	34.4	39.5	36.7	21.5	46.3	61.3	91.2
Seodaemun	52.5	49.5	34.3	39.3	37.2	21.6	53.4	57.7	107.5
Seocho	52.5	31.7	37.2	29.1	30.7	23.0	89.7	65.6	62.6
Sungdong	79.8	38.8	35.8	34.3	35.7	22.3	77.9	55.8	90.4
Seongbuk	58.8	67.3	34.5	38.2	39.2	21.6	55.8	50.7	152.4
Songpa	71.8	34.3	37.2	28.2	31.2	24.9	58.2	58.9	120.2
Yangchun	68.8	32.6	35.0	39.7	45.5	21.1	43.6	66.6	85.0
Yeong deungpo	58.3	32.6	35.4	37.4	35.3	21.4	45.9	65.0	62.6
Yongsan	38.5	34.0	35.7	35.3	35.2	21.8	77.7	60.5	77.7
Eunpyeong	51.5	73.9	33.1	41.9	38.4	20.9	46.2	50.0	166.9
Jongno	54.3	61.6	34.3	38.9	38.3	21.5	58.3	52.9	122.9
Jung-gu	66.5	41.6	35.2	36.5	36.6	21.9	75.0	56.5	89.6
Jungnang	63.0	49.9	35.7	35.1	38.4	23.1	51.4	47.7	184.4

Note: Red box means that a flooding may occur, and green box means a year that is flooding