A Study on the Urban Flood Response System: Focusing on the case of Korea's abnormal precipitation in the summer of 2020

By

KIM, Hyo-Sung

CAPSTONE PROJECT

Submitted to

KDI School of Public Policy and Management

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ABSTRACT

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By

Hyo Sung, Kim

Climate change and urbanization are accelerating the seriousness of urban flooding. Urban flooding is caused by a combination of urban characteristics, drainage systems, and land-use status. Preventive measures are important in terms of the fact that disasters in urban areas cause enormous human and property damages, and that the cost of restoration exceeds the amount of damage.

This paper aims to contribute to improving city's responsiveness to urban floods by investigating major causes of and suggesting improvement measures to urban flooding. It discusses a framework that highlights the three stages of disaster management (i.e., pre-, during, and post-disaster), including each stage's main activities required and the importance of feedback systems across the stages. Using this framework, a case of urban flooding that took place in the summer of 2020 in Korea, which was recorded the longest rainy season in the country, was analyzed. Through the analysis, two main problems were identified:

First, the capacity of urban flood defense facilities may be fundamentally insufficient due to abnormal precipitation exceeding expectations. Each time a rainfall record is updated, a flexible design standard should be prepared that comprehensively considers the climate, topography, and land-use status rather than unconditionally raising the design standard. Second, the response system to urban floods that occur repeatedly every year is unsatisfactory. Starting with the linkage of information distributed among each institution, the information system should be used as a means, not a purpose.

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1. Introduction

1.1 The background of the study

Korea's urbanization has progressed amid its rapid economic development and industrialization, and the impermeability rate of urban land area increased, making its cities vulnerable to sudden flooding. Cities with a high population density—such as Seoul and other metropolitan cities—particularly face exacerbated flood damages (Kim, 2015). In addition, the global warming is accelerating the seriousness of urban flooding, leading to changes in rainfall patterns (Lee et al., 2015).

The types of urban flooding can be divided into external and internal water-level inundation. External water-level flooding refers to a phenomenon that occurs when the water level of an urban river flowing adjacent to (or through) the city rises and crosses an embankment or collapses, causing the water to flow into an urban area. Internal water-level flooding refers to a phenomenon caused by the backflow of water that was supposed to be let out into the river, caused by torrential rain and insufficient capacity of sewage pipes. In the past, external flooding due to the lack of water control infrastructures such as river levees, waterproofing channels, and floodgates were the main cause of urban flooding. In recent years, internal flooding due to the distortion of the water circulation system caused by reckless urban development has become more pronounced. Internal flooding is closely related to the local characteristics of a city, such as its drainage system and the land-use status. (Moon, 2015; Choi, 2020).

Countermeasures for urban flooding defense can be divided into structural and unstructured countermeasures. Structural measures are to minimize damage through functions such as flood reduction, outflow delay, and storage by installing tangible facilities.

Non-structural measures are to minimize damage through intangible measures such as revision of regulations and improvement of systems. It helps with the difficulty of solving only with structural measures.

Recently, interest in non-structural reduction measures through urban planning is increasing in parallel with structural measures. However, empirical analysis of its effectiveness is quite insufficient. In response, the Ministry of Environment has made efforts to mitigate the problems of urban floods by expanding river forecast points, shortening observation cycles, and providing flood information along the river. However, the current flood forecast system is focused on large rivers, making it difficult to comprehensively consider water circulation in watersheds such as rivers and cities, and the flood control measures focused on structural measures (such as installation of flood control facilities, construction of pump stations, embankments, etc.) also have limitations in eliminating complete flood risk (Lim et al., 2020).

This paper aims to contribute to improving responsiveness to urban flooding by investigating its major causes and deriving improvement measures. It reviews and analyzes data from the central ministries and public institutions (such as Ministry of Public Administration and Security, Ministry of Environment, Meteorological Administration, Ministry of Land, Infrastructure and Transport, etc.) and examines Korea's recent urban flooding case that took place over multiple regions in the summer of 2020, in order to identify the problems of the existing flood response management system. Based on the analysis, the paper suggests ways to improve Korea's urban flood response system.

2. Current status and the causes of urban flooding

2.1 Increased impermeable surfaces and urban flooding

The current law does not separately define the term 'urban flood', but the National Land Planning and Utilization Act defines the 'urban area' among the intended areas. According to this, an urban area refers to an area that requires systematic development, maintenance, management, and preservation of the area due to the concentration or expected concentration of population and industry.

The term "flood" is also used in many laws without a specific legal definition. The River Act, the Act on the Investigation, Planning and Management of Water Resources, and the Natural Disaster Countermeasure Act stipulate the occurrence of floods based on the quantity and water level of rivers. Therefore, in this study, the range of 'urban floods' is defined as floods occurring in urban areas due to flooding of rivers and outflow of rainwater.

In Korea, most of the damage caused by natural disasters is due to water-related disasters such as heavy rain, typhoons, and wind storms. In the past 10 years, an average of 18 people has died or disappeared annually due to typhoons and heavy rains, and property damage of 441.9 billion won has occurred annually. Over the past decade, the amount of damage caused by floods such as typhoons and heavy rains has been 4.1 trillion won, accounting for about 93% of the total damage from natural disasters of 4.4 trillion won.

Table 1. Cases of flood damage in major cities in Korea over the past 10 years.

Date	Region	Precipitation (mm) / day	Damage
July 2020	Daejeon	102(/hour)	Apartment flooded. One person died.
July 2020	Gijang, Busan	205.0	The underground road was flooded to a height of 2.5m, causing three deaths
August 2018	Gwangju	136.5	Dozens of roads and shopping malls, including overpasses and boulevard, are flooded.
September 2017	Yeongdo, Busan	358.5	Building flooding and road traffic control near rivers.
July 2017	Cheongju	290.2	Building flooding, water supply, power outage.
October 2016	Maegok, Ulsan	382.5	Rain damage caused by typhoon "Chaba" and suspension of KTX and aircraft operations.

August 2014	Geumjeong, Busan	244.5	Two people died as Busan subway flooded and Ujangchun-ro underground roads were submerged
July 2011	Gangnam, Seoul	320.0	Sadang Station, Gangnam Station flooded, and a landslide occurred in Umyeonsan Mountain
September 2010	Gangnam, Seoul	293.0	Flood in the lowlands in Gangseo, Seoul, and backflow in the drainage area

Source: Reconfiguration based on Disaster Yearbook 2019

In 2020, the amount of damage caused by floods accounts for a greater proportion. The amount of property damage caused by natural disasters was estimated at KRW 1.3181 trillion. Among them, property damage caused by floods such as typhoons and heavy rains was 1.3177 trillion won. The amount of property damage caused by floods account for most of the total amount of property damage from natural disasters (Ministry of Public Administration and Security, 2020).

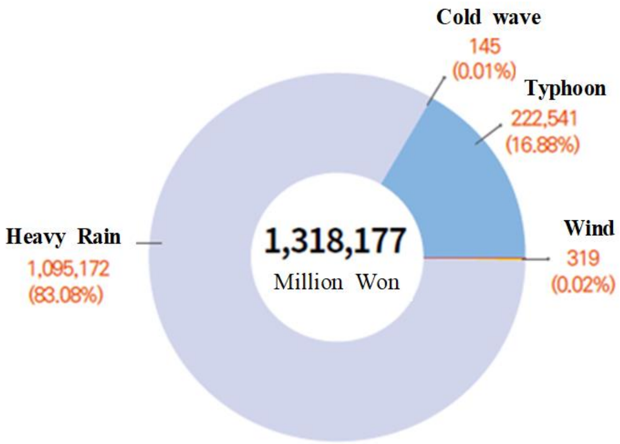

Figure 1. Status of property damage by cause in 2020

Source: Ministry of Public Administration and Security Disaster Yearbook 2020

Table 2. Status of property damage by cause in 2020

Item	Total	Heavy rain	Typhoon	Wind	Cold wave
Amount (M won)	1,318,177	1,095,172	222,541	319	145
Ratio (%)	100	83.06	16.88	0.02	0.01

Source: Ministry of Public Administration and Security Disaster Yearbook 2020

In the past 10 years, the total amount of property damage caused by natural disasters has been 44 trillion won, while the total budget spent on natural disaster damage recovery projects has been 116 trillion won. In responding to natural disasters, much more effort should be put into proactive prevention than follow-up measures, given that the cost of recovery far exceeds the cost of damage.

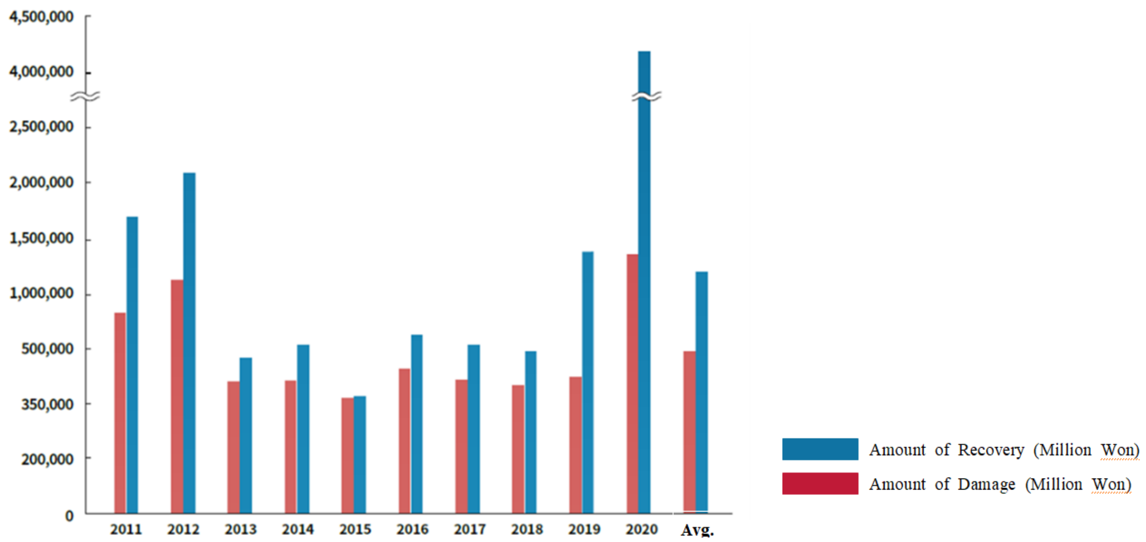

Figure 2. Status of damage and recovery costs over the past 10 years

Source: Ministry of Public Administration and Security Disaster Yearbook 2020

Table 3. Status of damage and recovery costs over the past 10 years

Item	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total	Avg.
Damage (MM won)	794	1,089	172	180	32	289	187	142	216	1,318	4,419	442
Recover (MM won)	1,654	2,053	387	507	38	591	499	443	1,349	4,162	11,683	1168

Source: Ministry of Public Administration and Security Disaster Yearbook 2020

Although human casualties are decreasing due to the government's continuous investment and efforts, the amount of qualitative property damage is soaring from about 700 billion won in 2011 to about 1.3 trillion won in 2020. This is believed to be due to the increase in the intensity of floods and the advancement of land around rivers due to climate changes and urbanization (Ministry of Public Administration and Security, 2020).

The establishment and implementation of national policies centered on economic development have greatly improved people's living conditions, but rapid urbanization has greatly distorted the water circulation system in urban areas, acting as the cause of urban flooding (Yoo et al., 2018). According to the National Statistical Portal KOSIS, 47,597 thousand (91.8%) out of 51,850 thousand people in Korea are concentrated and living in urban areas, and accordingly, green spaces in urban areas have decreased and the impermeable area has increased significantly.

The impermeable area ratio in urban areas more than doubled from 3.0% in 1970 to 7.5% in 2018. In particular, in the case of Seoul, the impermeable area accounts for more than half of the total administrative district area. In rural areas with a small impermeable area, about 45% of precipitation penetrates underground, while in urban areas, only less than 25% of precipitation penetrates underground. As precipitation generated in the city center fails to penetrate underground and flows along the impermeable surface, flooding occurs in urban facilities such as semi-basement houses, underground roads, tunnels, subways, and parking lots, leading to casualties and property damage (Lee et al., 2021).

2.2. Climate Change and Urban Flooding

The summer of 2020 was very long. In June, when it is hotter than July, typhoons hit every week, and rain that falls for as long as 54 days made the already exhausted daily life even more exhausting with COVID-19. As rain and typhoons constantly threatened daily life, the floodgates of the dam were opened at the same time, roads were flooded, landslides, and strong wind damage occurred. We are living in an era where we have to accept this as a daily life while meeting a season that we have never experienced before. In 2019, the Guardian, a British media outlet, began to change its terms to "climate emergency", "climate crisis", and "climate breakdown" instead of "climate change" in discussing climate change (Viner, 2019).

It is expected that both the frequency and intensity of heat waves and extreme precipitation will increase in the future. In addition, according to the National Institute of Meteorological Sciences, the 6th IPCC evaluation report will herald a greater range of climate change than previous predictions (National Institute of Meteorological Sciences, 2019).

Table 4. Comparison with the existing outlook

Item	The existing outlook. (5th IPCC Report, 2014)	New outlook. (IPCC 6th Report, scheduled for 2022)
Target period	Compared to 1971 ～ 2000, 2071 ～ 2100	Compared to 1995～2014, 2081～2100
Temperature	1.3~3.7℃ increase	1.9～5.2℃ increase
Precipitation	3～6% increase	5～10% increase

Source: IPCC 6th Evaluation Report Response Global Climate Change Outlook Report

According to the Korea Climate Change Evaluation Report (2020) jointly published by the Ministry of Environment and the Meteorological Administration, precipitation in summer is 11.6mm every 10 years between 1912 and 2017, and torrential rains in summer (more than 80mm per day) are increasing 7.54mm and 0.07 days every 10 years.

According to the National Institute of Meteorology, in the case of Korea, the impact of climate change is leading to flood damage due to the increase in torrential rain. The frequency and intensity of torrential rain tend to increase since the mid-1990s. In particular, there is a clear increase in the frequency of rainfall with a daily precipitation of 80mm or more. Due to the seasonal characteristics of most precipitation concentrated in a short period of summer, abnormal rainfall exceeding flood defense capabilities that water resource facilities such as dams, levees, estuary banks, and flood control areas cannot handle is increasing. In the summer of June-August, 638mm of rainfall occurs for an average of 29 days, accounting for more than half (51.6%) of the annual average precipitation of 1,237mm. In addition, in order to reduce spring drought damage that occurs repeatedly due to seasonal variations in precipitation, the risk of flooding is increasing because water is secured in dams and reservoirs in case of rainfall in summer.

3. Research design

In this study, in order to analyze the problems of the urban flood response system, a case analysis will be conducted focusing on the main factors derived through literature research. Price & Vojinovic (2008) classified flood response activities according to three main steps and emphasized the importance of activity elements at each stage.

(1) pre-disaster (preparation stage)

(2) during disaster (supportive stage)

(3) post-disaster (restoration stage)

At the pre-disaster stage, all major actors must prepare and review detailed response plans. Disaster management teams need sufficient resources and training in advance, and they need to continuously upgrade their individual skills. At the disaster response stage, activities such as warning, evacuation of residents in affected areas, traffic control, stockpiling sandbags, supply of emergency food and water supplies, and evacuation of high value-added goods in flooded areas should be carried out. At the post-disaster stage, purification, recovery, and resettlement activities continue. It is necessary to evaluate the causes and effects of flooding, improve countermeasures for the following events, and provide recommendations to reduce future losses (Price & Vojinovic(2008). The results of summarizing the main response activities emphasized by Price & Vojinovic (2008) by flood stage are as follows. (Table 5)

Table 5. Reconfiguration of Disaster Management Activities (Price & Vojinovic, 2008)

Stage	Pre-disaster	During disaster	Post-disaster
Activities	Risk Analysis	Flood Warning	Damage assessment
	Actions	Evacuation	Re-construction
	Awareness	Services	Mitigation

Tingsanchali (2012) mentioned the importance of flood management because flood risk cannot be completely avoided. Flood management is not trying to eliminate flood risk, but to mitigate them to an acceptable level. In order to consider the consequences of future changes to urban floods, various scenarios should be modeled for the expected frequency and scale of floods in advance and then countermeasures should be prepared. Accordingly, it is important to evaluate the performance of the implemented measures after the flood occurrence and reevaluate the residual risk, so that the evaluation results are returned to the flood response prevention stage. In addition, as a major cause of urban flooding, the basic problem of reducing the reliability of facility operation by blocking waste from drainage facilities was pointed out, and the importance of cleaning and maintenance of drainage facilities was emphasized. The results of summarizing the main activity factors and feedback systems for each response stage emphasized by Tingsanchali (2012) are as follows.

Table 6. Reconfiguration of Disaster Mgt. Activities & Process (Tingsanchali, 2012)

Stage	Plan	Implement	Evaluate
		Feed Back (REassess)	
Activities	Simulations	Warning	Damage assessment
	Preventions	Evacuation	Recovery
	Facility maintenance	Services	Reduction

Price & Vojinovic (2008) emphasized the factors of activity for each stage of flood response, and Tingsanchali (2012) emphasized the importance of establishing a feedback system for Assess Risk - Implementation Measure - Evaluate Risk flow along with the main factors for each stage. In responding to disasters, factors of activity at each stage are important, but in responding to flood disasters caused by abnormal rainfalls, it is also important to analyze the damage results and take preemptive measures to prepare for the next event. Therefore, in this study, the response activities commonly emphasized by Price & Vojinovic (2008) and Tingsanchali (2012) were derived as follows (Table 7), and the following framework was derived based on the importance of the feedback system (Figure 3). Using this framework, recent flood cases will be analyzed in the pre-disaster, mid-to-late stages, and the causes and problems of damage will be derived.

Table 7. Major activities for disaster response stages

Stage	Pre-disaster	During disaster	Post-disaster
Activities	Risk Analysis	Flood Warning	Damage assessment
	Preventions	Evacuation	Recovery
	Facility maintenance	Services	Mitigation

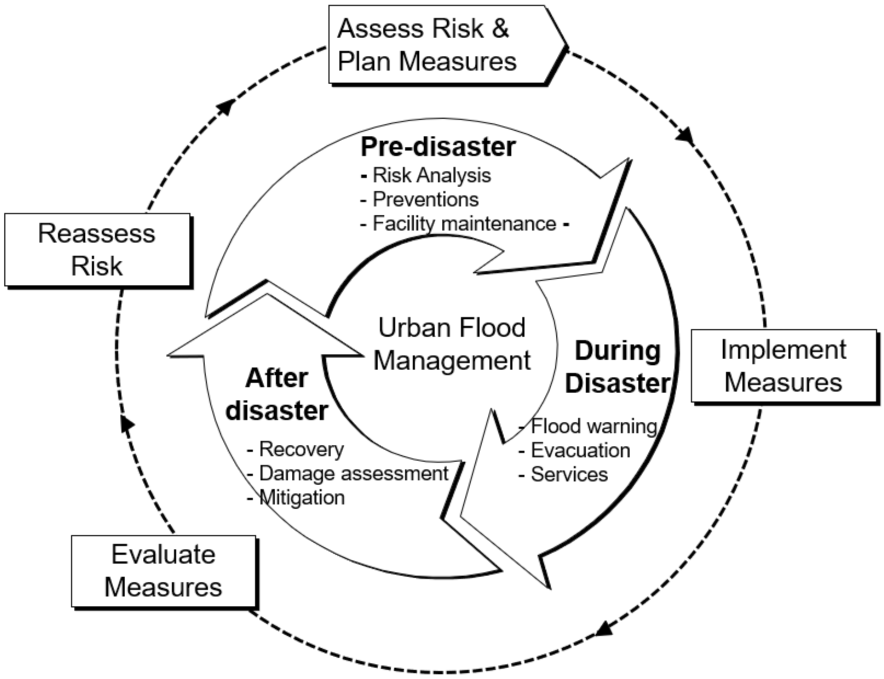

Figure 3. Framework for 2020 Flood Case Analysis

4. The case of urban flooding in the summer of 2020 in Korea

Due to climate change, the frequency and intensity of extreme rainfall phenomena are continuously increasing, and are expected to increase further in the future. Therefore, rather than the past flood cases, the longest-running rainy season case in 2020 was selected as the subject of the study.

Starting from Jeju on June 10, 2020, the longest rainy season and frequent torrential rains occurred in the central region on August 16. The rainy season lasted 54 and 49 days in central and Jeju, respectively, marking the longest rainy season since 1973 when weather observation expanded nationwide. The national precipitation during the rainy season recorded 686.9mm, ranking second in history since 699mm occurred in 2006, and the central region's precipitation was 851.7mm, a record high of about 69% compared to the average annual precipitation of about 1,237mm in Korea (Kim et al., 2020).

Table 8. Comparing the average year and 2020 precipitation

Item	The year of 2020		The common year	
	Duration(day)	Average precipitation(mm)	Duration(day)	Average precipitation(mm)
Central region	54	852	32	366
Southern region	38	567	32	348
Jeju area	49	562	32	399

Source: 2020 Monsoon Statistical Reference (Korea Meteorological Administration, 2020)

A total of 38 cities, counties, districts, and 36 towns were declared special disaster areas due to torrential rains that occurred during the rainy season in 2020. Flood damage also occurred in many urban areas, especially in Busan and Daejeon (Ministry of Public Administration and Security, 2020). In particular, on July 23th, torrential rains of 81.6mm per hour flooded Choryang 1st underground road up to 2.5m in Gijang-gun, Busan, caused three deaths. On July 30th, a record heavy rain of 102.5mm occurred in Daejeon Metropolitan City for an hour, flooding KTX tracks, 28 households on the first floor of an apartment located in Jeongnim-dong, Seo-gu, and 100 cars were flooded, and one person died (Ministry of Public Administration and Security, 2020).

4.1 Pre-disaster stage

In the preliminary preparation stage before a disaster, the intensity of the risk should be identified in advance through risk analysis for expected rainfall and risk related to infrastructure should be evaluated and prevention measures such as strengthening flood defense capabilities should be taken preemptively. Price & Vojinovic (2008) cited risk analysis as the first activity in the pre-disaster stage. Risk should be evaluated in advance and the degree of flood damage should be quantified to prepare for appropriate preemptive measures such as strengthening flood defense. Average recurrence interval (ARI) flood events should be simulated by frequency of 5, 10, 20, 50, 100 and 200 years, and the risks and damages should be calculated. And for each rainfall scenario, dangerous areas should be identified, the flood damage should be calculated, and then Hazards and Risks related to road infrastructure should be evaluated. Tingsanchali (2012) emphasized the importance of regularly checking the performance and function of drainage facilities so that drainage facilities can function properly in the event of a flood, and various scenarios should be modeled in advance.

However, various urban flood prevention facilities installed and operated according to urban flood prevention measures differ in design frequency, which is the standard for determining the capacity of the facility, so there is a limit to respond efficiently to climate change. Design frequency is a criterion for determining the capacity of flood defense facilities, and a 100-year design frequency facility means that it has the ability to defend against floods that occur once every 100 years. In the case of sewage pipes for rainwater drainage, urban main sewage pipes are designed at a 30-year frequency, but branch sewage pipes are designed at a 10-year frequency, so there is a possibility that urban flooding may occur due to internal water flooding due to insufficient capacity of branch sewage pipes.

Sewage pipes in Busan are installed based on a 10-year design frequency (77.4mm per hour), but precipitation of more than 80mm per hour has occurred. Flooding occurred even though precipitation slightly exceeded the design frequency. This phenomenon is numerically due to a lack of drainage capacity for sewage pipes, but inappropriate construction of sewage pipes, aging of sewage pipes, and insufficient facility maintenance in pipes are also pointed out as problems. Sewage pipes in Daejeon are installed with a design frequency of 10 years (65mm per hour), but as precipitation of more than 100mm per hour occurred, the drainage capacity was fundamentally insufficient, and the phenomenon of backflow of sewage pipes and blockage of drainage pipes increased the damage.

Table 9. Design frequency and precipitation

Item	Date	Design frequency	Precipitation	Excess
Busan	July 23th, 2020	77.4mm/h	81.6mm/h	106%
Daejeon	July 30th, 2020	65.3mm/h	102.5mm/h	158%

Similarly, in the case of river levees to prevent flooding of urban rivers, national rivers are designed with a frequency of 100 to 200 years, local rivers with a frequency of 50 to 200 years, and small rivers with a frequency of 50 to 100 years. Therefore, in the case of discharging a flood rate of 200 years from a dam upstream of the city, there is a possibility that flood damage may occur in the confluence area where local rivers and small rivers with a design frequency of under 200 years and national rivers meet (Kim et al., 2021).

Table 10. Design frequency for major urban flood prevention facilities

Item		Structure	Design frequency
External water level inundation response facility	Drainage facility	Drainage channel, drainage agent, drainage door, Drainage pump, reservoir.	More than 30 years
	River embankment	Population-intensive areas, asset-intensive areas, industrial complexes, major national facilities, etc. Flood defense grade A, such as	200~500 years
		Commercial facilities, industrial facilities, public facilities, etc. Flood defense grade B	100~200 years
		Farmland, agricultural land, etc. Flood defense grade C	50~80 years
		Wetland, etc. Flood defense grade D	Less than 50 years
		National river	100~200 years
		Local river	50~200 years
		Small river (urban area)	50~100 years
	Flood defense and control	Reservoir	More than 50 years
		Spillway	Probable maximum flood

	facility	River bank	More than 10 years
Internal water level inundation response facility	Sewage facility	Branch pipes	10 years
		Main pipes	30 years
		Rain water pump station	30 years
	Rainwater spill reduction facility	Permanent structure	50 years
		Temporary structure	30 years

Source: Reorganization of river design standards (2019), sewage design standards (2019), and small river design standards (2020)

Urban flood prevention facilities should be installed and operated organically in consideration of climatic and topographic characteristics such as precipitation types and topographic conditions in the urban area. However, most facilities are simply designed and operated according to the structure and importance of the facility. Therefore, there is a problem that the defense capacity of urban flood prevention facilities can be fundamentally insufficient in the event of abnormal rainfall.

4.2 During disaster stage

The disaster response stage is the stage of fighting the impact of flood disasters and providing immediate service to victims and local communities. The response to urban flooding requires an immediate, comprehensive, and very clear command line, so a sequence system of command systems for all responsible personnel is required.

Price & Vojinovic (2008) cited disaster response activities as the most important step in a series of activities related to disaster management. The person in charge of duty should first evaluate the situation and warn it to people. The person in charge should take appropriate immediate action by confirming the actual situation, relating it to one of the scenarios described in the disaster management plan, and referring others to disaster measures in the selected scenario as specified in the plan. During the disaster stage, activities such as warning, evacuation of residents of affected areas, traffic control, stockpiling sandbags, supply of emergency food and water, and evacuation of high value-added goods in flooded areas should be carried out.

In July 2020, the general manager of disaster response in Busan returned home without giving specific instructions such as evacuation orders and initial response measures even after being reported on the flooding of underground roads (Yonhap News, 2020). The Busan Disaster Response Team responded inappropriately to the manual and prepared false minutes, just as the general manager of disaster response held the meeting when the heavy rain warning was issued. Despite specific responsibilities and obligations related to disaster response, such as underground road facility management, officials at Dong-gu Office in Busan poorly managed underground road drainage and underground road access billboards, did not monitor heavy rain conditions, and did not prohibit vehicles from entering the underground road (JungAng Ilbo, 2020).

This is an accident that combines complacent consciousness and disaster response, such as neglecting broken vehicle control electronic boards, poor management of drainage pumps, and lack of monitoring to determine the situation (JungAng Ilbo, 2020). In February 2021, the following year, a public official in charge was arrested in connection with the accident in which three people died when the underground road in Dong-gu, Busan was submerged. Prosecutors charged him with professional negligence resulting from poor safety management such as road control while the underground roadway was submerged, and added charges of writing false official documents that he had decorated documents as if he had a meeting to determine circumstances that were not actually done. It is very unusual to hold public officials responsible for accidents caused by natural disasters (KBS, 2021).

The primary cause of flooding is that a large amount of rainwater flows into the underground roadway for a long time due to torrential rain and significantly more rainwater than the design conditions of the drainage facility. However, the facility management, monitoring, and response systems are seriously insufficient. The reason why there is a strong perception that flood damage occurring in cities is a disaster caused by people, not natural disasters, also has a problem that the urban flood response system is unsatisfactory.

4.3 Post-disaster stage

In the post-disaster stage, an evaluation of the causes and effects of floods should be conducted and recommendations should be made to reduce losses in the future (Price & Vojinovic, 2008), and residual risks should be reevaluated to feedback to prevention stage (Tingsanchali, 2012). In the case of the 2020 flood accident in Busan, the problem in the post-disaster response stage was attempted to be derived based on the framework, but there was a limit to understanding what happened after the flood response.

In Korea, white papers are published not to repeat the damage by identifying the causes of the damage and problems in response to large-scale disasters and large-scale casualties at the national level. However, in the case of urban flood damage, statistical data are not established in most countries, including Korea, although the scale of property and human damage is large and the amount required for recovery easily exceeds the amount of damage. Only data on damage investigation in some areas are provided during certain years when the damage from urban floods is severe (Kim, 2020).

Only through media reports, it was possible to confirm what happened before and during the disaster response process, and it is quite regrettable that it is difficult to confirm what happened in detail at the stage after the disaster response. However, one encouraging fact is that as part of damage assessment and Mitigation, on September 2, 2021, Busan

Metropolitan City updated urban flooding disaster map information and natural disaster concern area information so that citizens can check the submerged area.

The disaster map is a data that expresses the results of surveys on habitual flooding areas where disaster recovery and support costs have been continuously invested due to floods in the past, and is one of the main data for urban flood countermeasures such as designation and maintenance of natural disaster risk improvement zones. In Japan and Europe, disaster maps such as flood traces for past floods and flood risks expected in the future are mandatory, and disaster resolution maps are actively used to establish urban flood prevention measures (Lee, 2017). In Korea, after responding to floods, measures to utilize disaster maps have been required to evaluate damage and mitigate damage (Lee, 2014). Despite the fact that the disaster map is provided to the public through the Internet, many local residents are not aware of the related system and the reliability of the flood-damaged area data is low. Even the inundation map, which investigated and marked the flood inundation traces, had a problem of poor utilization, such as excluding any damage caused at housing and shopping malls due to opposition from residents concerned about falling property prices (Hong et al., 2017). In light of these past conditions, it is quite encouraging that urban flooding disaster guidance information is provided to citizens in real time a year after the flooding accident of Busan underground cars in 2020.

As a result of analyzing the problems based on the framework, it was confirmed that in the case of flood damage in 2020, there were problems in the Pre-disaster and During disaster stages, respectively. First, in the pre-disaster stage, when abnormal rain falls, the defense capacity of urban flood prevention facilities can be fundamentally insufficient. Second, in the disaster response stage, there is a problem that the urban flood response system is insufficient.

Table 11. Summary of analysis results

Stage	Pre-disaster	During disaster	After disaster
Required Action	Pre-risk analysis by occurrence frequency and preemptive measures to strengthen flood defense	Appropriate immediate action by all responsible personnel according to the chain of command	Damage assessment, mitigation, and reduction measures (using disaster maps)
Analysis result	Uniform design frequency application that does not take the climate and topographic characteristics of each facility into account	Lack of response ability, lack of facility management, and lack of monitoring by the general manager and officers	Urban flooding disaster information provided to the public one year after the damage occurred
Problem	Lack of defense capabilities of urban flood prevention facilities	Insufficient urban flood response system	

5. Proposal for improvement

5.1 Improving urban flood defense capabilities

In 2020, record-breaking torrential rains occurred for the longest time ever. Prior to this phenomenon, abnormal rainfall exceeded the frequency of 500 years in 2018. It is time to take measures to cope with future floods that exceed expectations. In the pre-disaster stage, risk should be evaluated in advance and preemptive measures should be taken to reduce Hazards and Risks related to flood response facilities by quantifying the degree of flood damage (Price & Vojinovic, 2008).

The sewage pipeline in Busan was installed with a design frequency of 10 years (77.4mm per hour), but precipitation of more than 80mm per hour occurred. This means rainfall with a design frequency of 10 to 20 years. The sewage pipeline in Daejeon was installed with a design frequency of 10 years (65 mm per hour), but precipitation of more than 100 mm per hour has fallen, which corresponds to precipitation exceeding 30 years of design frequency. As such, urban flood prevention facilities have a fundamental problem that their treatment capacity may be insufficient due to abnormal rainfall exceeding expectations.

However, it is unreasonable to unconditionally raise the design criteria whenever abnormal rainfall records are updated every time. Not only does it take a huge amount of money and time due to the vicious cycle of raising design standards (Abnormal precipitation - Increase design frequency - More abnormal precipitation - Re-increase design frequency), but also it is difficult to secure a site for facility installation due to a lack of free space in the city center.

Therefore, it is necessary to prepare measures considering economic feasibility and effectiveness. Rather than applying a uniform design frequency according to the importance of the structure, it is necessary to comprehensively consider the size and importance of urban flood prevention facilities, as well as urban rainfall types and topographic conditions. Design standards for flood prevention facilities that can appropriately respond to climate change should be recalculated.

In addition, rather than uniformly applying the design standards for each facility to all regions, it is necessary to prepare a plan to raise the design standards for each facility according to the flood defense plan considering the current status of land-use by region, such as cities and farming and fishing villages. It is also necessary to prepare a plan to first raise the design standards and regularly check whether the upgraded design standards are appropriate, focusing on major flood prevention facilities (such as estuary banks, flood control sites, waterproofing channels, etc.).

5.2 Advanced urban flood response system

In addition to preventive measures against urban floods, it is necessary to systematically establish an urban flood response system to minimize damage in the event of an urban flood. After the September 11 terrorist attacks in 2001, the United States adopted a plan to integrate and manage 22 existing disaster response government organizations centered on DHS (Department of Homeland Security). In Korea, due to Typhoon Maemi in 2003, Daegu Subway arson in 2003, and 9.11 in the United States, comprehensive crisis management measures began to be established and systematized after 2004. In order to improve the efficiency of integrated disaster management, it is necessary to change the perspective of the information system (Bae, 2004).

Government ministries and public institutions collect and provide some overlapping water resource information. Data collected from various sources are operated by each institution, and a lot of time and effort are consumed due to overlapping management of the same and similar data (Kim et al., 2016). This implies a problem of deteriorating reliability of data due to reasons such as error verification of previously collected and stored data, and inability to immediately update data collected in real time.

Table 12. Public data related to water resources

Institution		Public data related to water resources
Ministry of Public Administration and Security		Data related to water supply facilities, disaster year data, disaster safety guides, etc.
Ministry of Environment	Flood control center	Standard basin management data, river management data, river water use permit data, facility data for each flood control station, standard floodgate DB, 4 major Rivers' (Hangang, Nakdonggang, Geumgang, Yeongsangang)' floodgate DB, standard flow rate management data, etc.
	Korea Water Resources Corporation	Groundwater data, auxiliary groundwater observation data, national groundwater observation network data, groundwater map data, groundwater use data, groundwater control data, flowwater observation data, water quality data, etc.
	Korea Environment Corporation	Sewage data, sewage treatment facility-related data, etc.

	National Institute of Environmental Research	Automatic water quality measurement data, underground water quality measurement DB, pollution source DB, aquatic ecology DB, water quality DB, water quality test result data, wetland survey data
	The Meteorological Administration	Typhoon and weather data, climate forecast data, world weather observation data, climate statistics analysis data, climate forecast data, climate change scenario, climate change monitoring data, weather warning data, radar data
Ministry of Agriculture, Forestry and Fisheries	Korea Rural Community Corporation	Water level and seawall measurement data, reservoir water level DB

Table 13. Information systems and functions related to water resources

Institution	System	Functions related to water resources
Ministry of Public Administration and Security	Status delivery system	As a situation transmission system, central ministries, local governments, and government-affiliated organizations use it for 24-hour disaster situation management and situation transmission
	Disaster management system of central and local government	As a central and local disaster management system, disaster information is collected and disseminated by disaster type such as storm and flood damage, heavy snow, earthquake, etc.
	Disaster management information DB center	As a disaster management information system, DB Center, standardization of disaster information, and support decision-making through scientific analysis and prediction based on accumulated disaster information
Ministry of Environment	WAMIS	As a comprehensive information system for national water resource management, 10 fields of hydrological, basin, river, dam, groundwater, water, water supply, environmental ecology, natural disaster, and topographic space are provided
	Flood risk map system	As a flood risk map system, information on the flooding range and depth of flooding in the surrounding area of the river under the assumption that extreme situations such as embankment collapse and embankment overflow occur due to flooding exceeding the design frequency of the river embankment
	RAS	As a river water use management system, river water use permission information and river water use status in national and local rivers are managed
	Water Information System	As a water environment information system, water environment-related data such as water quality measurement network, total quantity measurement network, automatic measurement network, sediment measurement network, radioactive material measurement network, biometrics network, and non-point pollutant measurement network are provided

	National Waterworks Information System	As a national water supply information system, data such as tap water quality data, water quality information in our neighborhood, water supply statistics, water facility status, and basic water maintenance plan are provided
	Combined Meteorological Information System	As a comprehensive weather information system, all weather-related information at home and abroad is collected, analyzed, stored, and distributed
Ministry of Land, Infrastructure and Transport	RIMGIS	As a river management and geographic information system, information related to GIS-based Korea River View and river facilities is provided
Ministry of Agriculture, Forestry and Fisheries	RAWRIS	As a comprehensive rural water information system, comprehensive information in rural water fields such as agricultural production infrastructure, disaster, and water resources is provided
	Rural Groundwater Net	As a groundwater management system for farming and fishing villages, agricultural groundwater information such as groundwater quantity, water quality, and usage status in farming and fishing villages is collected and groundwater information services are provided

In order to advance the urban flood response system, it is necessary to integrate and utilize water resource information collected by various government ministries and public institutions. For example, the distribution and travel route of rainfall can be more effectively monitored by basically utilizing rainfall observation and prediction data from the Meteorological Administration and linking large radar observation information operated by the Ministry of Environment and Meteorological Administration. In addition, by linking rainfall observation data collected by flood control centers, local governments, K-water, and Korea Rural Community Corporation in administrative districts and deriving supplementary measures through redundancy review, observation efficiency can be increased and budget for observation facility installation and management costs can be reduced. It is necessary to establish a comprehensive (information linkage, integration, verification, and utilization) information management system, such as integrating data collected by each institution, developing effective processing and analysis technologies for data.

Based on inter-agency linkage, integration, and standardized information, the entire process of flood management should be integrated and managed according to the process of monitoring, prediction, forecasting, and response to ensure rapid and effective response. In the event of heavy rain of a certain size or more, it is required to establish a system that automatically restricts or controls access to facilities in habitual flooding areas and expected flooding areas utilizing ICT (Information and Communications Technology). In the case of flooding of underground roads in Busan on July 23th, 2020, if such a system had been equipped, vehicle isolation and death accidents could have been prevented.

Table 14. Proposal for during disaster phase

Process	Suggestions for improvement
Monitoring	Based on GIS, efficiency and accuracy are improved by linking water level observation data by related organizations in administrative districts and installing IoT sensors in vulnerable areas.
Prediction	Establish a pre-prediction simulation database using digital twins, etc., the impact of water level rise and arrival time by rainfall is identified in advance and systematically dataized.
Forecast warning	Establish effective forecasting standards according to river levels for each major point that comprehensively reviewed the past flood history, basin characteristics, and facility status.
Response	Decision-making standards should be established to determine whether emergency measures such as evacuation of local residents are implemented within the golden time as soon as possible.

6. Conclusion

Due to climate change and urbanization, potential flood risks are increasing in urban areas where assets and populations are concentrated. Flood damage in urban areas is a task to be actively responded to, especially in that it causes enormous human and property damage, and much more effort should be put into proactive prevention than follow-up measures in that the amount of restoration easily exceeds the amount of damage. In this study, the framework was derived based on the response activity factors commonly emphasized by Price & Vojinovic (2008) and Tingsanchali (2012) and the importance of the post-disaster feedback system, and the causes of recent damage case was analyzed and two problems were derived.

First, urban flood prevention facilities should be installed in consideration of climate and topography for each facility. However, uniform design frequencies are applied depending on the importance of the structure, which may fundamentally lack defense capabilities in the event of abnormal rainfalls. To solve this problem, it is necessary to apply different design standards for each facility in consideration of the current status of land use by region, rainfall type, and topographic conditions such as cities and farming and fishing villages and periodically review whether they are appropriate. Since recent precipitation forms show large regional variations and occur suddenly and intensively, measures suitable for regional and facility characteristics should be established rather than uniform measures to reduce flood damage caused by torrential rain. Second, the response system such as facility management and monitoring is insufficient to the extent that the flood damage occurring in the city center is widely recognized as a disaster caused by a person, not a natural disaster. Therefore, this study suggested using the information system as a means and advancing the response system by linking, integrating, and standardizing information distributed among institutions rather than taking issue with the insufficient capabilities of the disaster response manager.

This study has limitations in that the analysis was conducted based on fragmentary damage cases caused by abnormal precipitation, and future studies need to find indicators that can quantify the contents of flood damage cases and supplement the analysis. The government has been conducting an annual flood damage survey since 2017 to help reduce flood damage and establish permanent measures. Although the period and place of flood damage were different every year, the causes and countermeasures are generally similar. Of course, there is no single flood management blueprint because all flood risk scenarios differ depending on the situation and conditions. However, if efforts are added to derive problems based on damage cases and find ways to improve them one by one, it is expected that the results of repeated damage due to at least the same cause may gradually decrease. Just like the reason why we have to study history.

Bibliography

Bae, Y. S., Baek, M. H., Ku, W. H., & Shin, H. J. (2014). A Study on the Consciousness of Officials for the Establishment of an Integrated Disaster Response Management System. 3. Paper Collection of the Korean Society of Disaster Prevention, 2014, 288-288.

Cavaleri, L., Bajo, M., Barbariol, F., Bastianini, M., Benetazzo, A., Bertotti, L., ... & Umgiesser, G. (2020). The 2019 flooding of Venice and its implications for future predictions. Oceanography, 33(1), 42-49.

Choi, S. D., Um, T. S., Shin, E. T., & Song, C. K. (2020). Numerical comparison of flow characteristics according to individual and complex considerations of river flooding. Convergence Information Paper, 10(10) and 115-122

CRED (Centre for Research on the Epidemiology of Disasters). (2020). Disaster Year in Review 2019.

Hong, S. J., Joo, H. J., & Kim, K. T. (2017). A study on the improvement of the flood risk calculation technique considering the expected flood damage area. Journal of the Korean Wetland Association, 19(4), 459-469.

Hwang, S. H., Yoon, J. S., Kang, N. R., Lee, D. R., & Noh, H. S. (2020). Current status of flood forecasting and warning system and technology in Korea. Journal of Korean Civil Engineering, 68(9), 74-83.

JoongAng Ilbo Hwang, S. Y. (Sep. 14th, 2020) Busan underground car accident "human resources"··"returned home without any action. https://www.joongang.co.kr/article/23871804#home (approach on Feb. 11th, 2022)

KBS Jung, M. K. (Feb. 9th, 2021) Arrested public officials related to the "Busan Choryang Underground road accident https://news.kbs.co.kr/news/view.do?ncd=5114899

(approach on Feb. 11th, 2022)

Kim, B. G., & Lee, Y. S. (2021). Suggestions for river planning and management of Jungnangcheon Stream (centered on national rivers). Water for future, 54(8), 79-91.

Kim, J. W., Bu, K. O., Choi, J. T., & Byun, Y. H. (2018). Climate change over 100 years on the Korean Peninsula.

Kim, J., Kang, M. S., Kim, D. S., Kim, H. M., Kim, H. S., Ryu, Y. R., & Lee, M. H. (2020). Korean Climate Change Assessment Report 2020. Meteorological Administration.

Kim, Y. R. (2015). Seoul Metropolitan Government's flood control measures.

Kim, Y., Kang, N., Jung, J., & Kim, H. S. (2016). A review on the management of water resources information based on big data and cloud computing. Journal of wetlands research, 18(1), 100-112.

Lee, H. N., Kim, J. S., Seo, J. S., Kim, S. E., & Kim, S. (2021). Development of urban flooding analysis method using unstructured data and deep learning. In Proceedings of the Korea Water Resources Association Conference (pp. 194-194). Korea Water Resources Association.

Lee, H. S., Lee, J. J., & Heo, J. H. (2015). Vulnerability evaluation and risk analysis in urban river basins. Academic Presentation of the Korean Society of Water Resources, 469-469.

Lee, J. H. (2017). Disaster prevention education in Japan using hazards map. Research on Education in Japan, Korea, 21(2), 1-21.

Lee, J. W. (2014). A case study for the establishment of an institutional system for flood prevention in small and medium river basins. Journal of the National Geographic Society, 48(2), 177-202.

Lee, J. W. (2017). A Study on the Strengthening of Response Confidence for the Disaster Site.

Lee, S. S., Lee, M. H., & Kang, H. S. (2020). Current status of floods in 2020 and directions for permanent measures.

Lee, S. Y., & Park, J. W. (2018). Improvement of the water resource planning system according to the enforcement of the Water Resources Act. Water for future, 51(3), 6-10.

Lim, Y. T., & Choi, H. I. (2020). Regression model of flood damage data on rainfall characteristics for estimating flood damage by region. Journal of the Korean Wetland Association, 22(4), 302-311.

Ministry of Environment. (2018). 2018 Flood Damage Survey.

Ministry of Public Administration and Security (2019). 2018 Disaster Yearbook.

Ministry of Public Administration and Security. (2020). 2019 Disaster Yearbook.

Moon, J. I. (2015). Current status of urban floods, flood countermeasures, and safety measures for adaptation to climate change.

Park, S. H., Ro, H. J., & Ahn, D. S. (2004). Network analysis of disaster management administration. (Korean Journal of Public Administration), 42.

Price, R. K., & Vojinovic, Z. (2008). Urban flood disaster management. Urban water journal, 5(3), 259-276.

REUTERS Francesca Landini (2019.11.17.) Venice hit by another exceptional high tide; worst week in 150 years. https://www.reuters.com/article/us-italy-weather-venice-idUSKBN1XR0CL(approach on Feb. 11th, 2022)

Song, J. H., Jang, H. Y., Choi, H. I., & Ji, H. K. (2011) Review of unstructured flood reduction measures. Academic Presentation of the Korean Water Resources Association, 429-429

The 5th IPCC Report; Climate Change Science, Response, and Adaptation Reports prepared to conclude an Interstate Agreement on Climate Change

Tingsanchali, T. (2012). Urban flood disaster management. Procedia engineering, 32, 25-37.

Yonhap News Kim, S. H. (Sep. 14th, 2020) Conclusion of a police underground car accident and talent…Opinion on prosecution by the head of Busan and public officials https://www.yna.co.kr/view/AKR20200914078051051 (approach on Feb. 11th, 2022)

Yoo, J. H., Kim, K. H., Park, Y. G., Lee, G. H., Kim, S. J., & Jung, C. G. (2018). A study on the use of GIS-based time series spatial data for streamflow depletion assessment. Journal of the Korean Association of Geographic Information Studies, 21(4), 50-63.