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The Empirical Relationships Between Green Space Characteristics and Flood Events

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Hyomin Kim

The Empirical Relationships Between Green Space Characteristics and Flood Events

Advisor : Dong-Kun Lee

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Hyomin Kim

Confirming the Ph.D. Dissertation written by

Hyomin Kim

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Chair _____________________(Seal)

Vice Chair _____________________(Seal)

Examiner _____________________(Seal)

Examiner _____________________(Seal)

Examiner _____________________(Seal)

Abstract

The Empirical Relationships Between Green Space Characteristics and Flood Events

Hyomin Kim
Interdisciplinary Doctoral Program in Landscape Architecture,
Graduate School, Seoul National University
Supervised by Professor Dong-Kun Lee

Countermeasures for increasing resilience to urban flooding should consider long-term perspectives because climate change impacts are unpredictable and complex. Recent approaches to climate change adaption have emphasized disaster control, sustainable development, and urban green spaces. For flood control, green spaces can evolve dynamically depending on the physical environment of an urban flood; therefore, identifying the regional features of green spaces is necessary to maximize their effect. In this study, flood vulnerable areaflooded areas in Seoul, Korea, were divided into four flooded area types, and statistical analysis was performed to determine how the flooding probability change with green space area, type, and pattern. In this way, regional features that maximize the effects of green spaces on flood resilience were identified and can now be reflected in the planning and design of green spaces.

First, a model to evaluate flood vulnerable areas in Seoul city was developed using MaxEnt. The variables selected for model simulation

included those related to the physical environment, climate environment, green space environment, and flood risk management infrastructure (FRMI). The model was simulated by extracting random points 1000 times considering uncertainty. Flood was not taken place in 43 of 239 drainage basins in Seoul. On this basis, the flood vulnerable areas identified were: Seocho4, Gildong, Shinwol3, Bangbae1, and Hwagok2 drainage basins.

Second, flooded area types were divided into 4 types based on features of flooded area by using multivariate statistics. Type 1 included regions where flooding occurred in a drainage basin that had a FRMI. These basins were located around the Han River and major streams and were bordered by mountains. Basin slopes were gentler than the slope of Seoul city and the was the second highest identified. These basins were characterized by residential and commercial mixed land use. Type 2 is the regions with steep slopes, low TWI, and the best drainage identified. Compared with the other types, the green space ratio was high. These basins were bordered by steep mountains allowing the downward flow of water without attenuation, which was identified as regional feature of flood resistance. Type 3 represented the gentlest sloping areas, and these were associated with the highest TWI value, and the worst soil drainage. In contrast to type 2, the dominant regional feature was the attenuation of standing water. Type 4 had features that were intermediate to those in type 2 and type 3 (e.g., moderate slopes, imperfect soil drainage, and lower than average TWI value).

Third, differences in flooding probability based on green space area, type, and pattern for each flooded area type was comparatively analyzed using logistic regression analysis. We found that green spaces exerted a considerable influence on urban flooding probabilities in Seoul and flooding probabilities could be reduced by over 50% depending on the green space area and the locations where green spaces were introduced. Increasing the area of green spaces was the most effective method of decreasing flooding probability in type 3 areas. In type 2 areas, the maximum hourly precipitation affected the flooding probability significantly, and the flooding probability in these areas was high despite the extensive green space area. On the basis of the results, a formula was developed to identify the green space areas required to reduce flooding probability.

Green spaces were categorized as planted area, grassland, wetland, paddy field, field, orchard, or forest based on their CN value, and the contributions of green space areas to flood control for each flooded area type were analyzed. For type 1, grassland showed the highest contribution, followed by forests and then planted areas. For type 2, only the forest type was analyzed with respect to flood control. For type 3, paddy fields showed the highest contribution, followed by fields, planted areas and forests. As most farmland in Seoul is located on gentle slopes bordered by mountains, natural rainwater is often retained in the basin as confined water. For type 4, forests showed the highest contribution, followed by planted areas and fields.

For the green space patterns of types 1 and 2, the area-weighted Mean Shape Index (AWMSI) represented as significant variable, with complexity increases correlated with increased flooding probability. Type 3 contained an area in which the flood control efficiency of the green space area was high, and the green space area (CA), number of green space patches (NumP), MPS, and AWMSI were found to be significant variables that exerted a positive influence on flooding probability reduction. In Type 4, increases in NumP were correlated with reduced flooding probability.

The results of this study show that green spaces in urban areas can impact upon flooded area type; however, flood control functions also correspond to topographic factors (i.e., slope, TWI, soil drainage); therefore, green spaces should be introduced to areas that will ensure maximum efficiency for flood control. Green space area, type, and pattern were suggested as a factor to reduce flooding probability according to the properties of the flooded area type. In addition, guidelines for increasing flood resilience were developed to assist with the spatial planning of green spaces as countermeasures for urban flooding.

In the case of artificial FRMI such as rainwater retention basins, their value may decrease over time, but increasing the green space area is an eco-friendly solution that will benefit humans and nature over a long period of time. The role of existing green spaces is often limited to the production of ecological benefits for wildlife and aesthetically pleasing landscapes for human residents, but functionally, proper design plans for green space locations could maximize their impact on flood control. Therefore, this study recommends that urban areas devote planning resources for green spaces, and such efforts should determine where the best areas are for their introduction.

It is expected that the approach used in this study and the results obtained will provide a framework for diverse research on green

spaces in the future. Furthermore, the techniques employed may be useful for predicting flood probabilities in urban areas, i.e., the models, which were based on empirical data, had a high explanatory capability.

Keywords : Flood vulnerable area, Flooded area type, Green space area, Green space type, Green space pattern, Logistic regression analysis, Flooding probability

Student number : 2011-30741

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Ⅰ. Introduction

Extreme weather events (e.g., regional torrential rains) have become more frequent as a result of climate change, and this has in turn led to an increase in urban flooding risk. As a result, the development of integrated countermeasures to combat increased rainfall is needed (Kim et al., 2013).

In Seoul, Korea, the temporal and spatial features of rainfall and urban flood damage are recorded (Seoul Metropolitan government (SMG), 2011). According to the National Disaster Management Institute, since the year 2000, concentrated heavy rainfall has increased to levels 2.5 times higher than those in the 1970s. For example, the mean annual frequency (days per year) of hourly rainfall exceeding 50 mm increased from 5.1 in the 1970s to 12.3 in the 2000s. Furthermore, the coverage of impervious pavement, which increases flood likelihood and flood damage, increased from 7.8% in 1962 to 47.64% in 2010, and is predicted to rise to 48.4% by 2020. However, this coverage considers the whole of Seoul city, which includes mountains and water bodies. In reality, the impervious area ratio of the urbanized area is over 90% and almost no rainwater infiltrates underground. Such increases in the impervious layer significantly change natural hydrologic processes; for example, preventing rainwater infiltration and increasing surface and peak runoff (Paul and Meyer, 2001; Whitford et al., 2001; Yao et al., 2015). Before urbanization, surface runoff was not more than 10.3% (based on 1962 data), but by 2010 this value was 51.6%, an increase in surface runoff of ~640 mm/year (SMG, 2013).

Developing policies to combat urban flooding and the environmental issues associated with urbanization remains problematic. First, despite that most important cause of increased flooding being the increase in impervious area, most policies to date have focused on sewer line expansion. Another problem is streamflow depletion in urban streams (e.g., Cheonggaecheon, a typical stream of Seoul city), which reflects infiltration volume decreases and the subsequent drop in underground water levels. Suggested approaches to combat this issue have included increasing flow by tapping outside water basins or by using the inter-stream lesser circulation method. Finally, increasing urban temperatures and water quality problems have distorted water circulation structures.

Recently, approaches to climate change adaption have focused on disaster control, sustainable development, and resilience. Urban space having high resilience is less affected by climate change or disaster, and when disasters occur, the restoration speed is rapid. However, future precipitation and rainfall intensity are predicted to increase further; therefore, long-term countermeasures that increase resilience are needed. To this end, urban regeneration strategies have emphasized the importance of urban green space (TEP, 2008; TEP, 2010).

The impact of green spaces on runoff has been widely investigated (City of Seattle, 2008; Armson et al., 2013; Inkilainen et al., 2013). In particular, urban green spaces have been widely used to reduce runoff and offset the negative effects of urbanization on urban hydrology (Mentens et al., 2006; Bartens et al., 2008; Zhang et al., 2012). Flood control using green spaces varies depending on slope, land use, precipitation, and the existence of flood risk management infrastructure; therefore, implementing effective flood countermeasures requires the identification and analysis of the variables that control flooding.

Urban green space policies are being introduced in Korea; however, so far they have been localized and mainly focused on quantitative expansion for human accessibility. Utilizing diversified functions of green space both positively and efficiently has limitations (Lee and Kang, 2012). In order to achieve high urban resilience and an effective response to climate change, it is required to identify regional features correctly, apply green space of proper type, and then maximize its effect.

In this study, flood vulnerable areas of Seoul city were analyzed, and flooded area were divided into four types. Afterwards, the flooding probability for each type was statistically investigated depending on green space area, type, and pattern. Following this approach, regional features that maximize green space efficiency for flood resilience were identified, and can now be reflected in the planning and design of green space areas.

Ⅱ. Literature review

1. Urban water management and climate change adaptation

Recently, as rainfall has become concentrated over shorter time periods, significant damage has been sustained in urban areas. Disaster damage resulting from urbanization and climate change has been the focus of diverse studies and the consideration of adaptation approaches for sustainable urban water control has increased.

Urbanization in Korea has exceeded 90%, with most of the population residing in urban areas. Parks and green spaces, in which rainwater is infiltrated and stored, have decreased and the coverage of impervious materials has rapidly increased. Areas in which the impervious layer has increased following urbanization show significantly changed patterns of hydrology (Booth and Reinelt, 1993; USEPA, 1993). Changes in land use by urbanization, including increases in the impervious layer, have resulted in reduced evapotranspiration, underground infiltration by rapid runoff, and reduced green space areas (Dreiseitl and Geiger, 1995).

Increased flooding can be attributed to increased rainfall intensity, urbanization, outmoded urban infrastructure, and a lack of existing infrastructure capacity to cope with current rainfall intensity (Kirnbauer et al., 2013). Over the last 30 years, flood risk has increased following repeated meteorological disasters in Seoul city. Mean rainfall data from 1960 to 2009 show that annual mean precipitation and rainfall intensity during concentrated heavy rainfall have increased, with heavy concentrated rainfall even occurring during the traditional dry season. (Choi et al., 2008). From 26 to 28 July 2011, Gwanakgu experienced the highest daily rainfall (348.5 mm) among the districts of Seoul city. This event led to significant damage and reflected the increases in rainfall intensity and the occurrence of 100-year frequency rainfall events.

To combat urbanization and climate change, urban water management has been introduced. This has emphasized the storage of rainwater in sewer lines, but had failed to prevent the runoff and peak flow generated by urbanization. Increases in the impervious rates of concrete and asphalt following urbanization have increased the burden on drainage facilities, even before the increases in rainfall are considered, and this has resulted in increased flood risk, decreased infiltration, decreased evapotranspiration, and increased runoff. As runoff has increased, the greater transportation of pollutants (e.g., bacteria) has aggravated urban water quality (Liu et al., 2014).

Recently, inter-city green spaces have been frequently used to control urban flooding in the USA, Canada, Germany, and New Zealand (Ahiablame et al., 2012). The concepts of Low Impact Development (LID) in the USA, Sustainable Urban Development Systems (SUDS) in the UK, and Water Sensitive Urban Design (WSUD) in Australia have focused on runoff control, water quality control, and rainwater reuse by urbanization. These techniques always include the installation of on-site flood control systems in target areas in order to control rainwater runoff by preserving and recreating natural landscapes (Graham et al., 2004).

Sustainable water management for flooding is focused on controlling rainfall through soil infiltration, and not just on rainfall exclusion. This method attempts to maximizing the soil infiltration area and infiltration velocity in order to decrease rainfall runoff and non-point pollutant discharge load. The expansion of urban green spaces for flood control is an economical and eco-friendly approach that can promote smart growth and urban sustainability, and can also respond to sustainable and highly recoverable urban development and climate change (Benedict and McMahon, 2002, 2006; Gill et al., 2007; Mell, 2009; Dunn, 2010; Foster et al., 2011).

2. Assessment of Flood vulnerable area

Floods frequently occur following sudden heavy rainfall; therefore, research into flooding is performed in related fields. Urban floods endanger human life, private property, and public infrastructure. Furthermore, they destroy stream embankments and dikes, and pollute rivers and urban streams. The urban flood threat will continue to intensify as people experience more frequent extreme weather arising from global climate change (Villarreal et al., 2004; Foster et al., 2011).

Research into flooding is diverse and includes the analysis of correlation between flooding factors and flooding (Kang and Lee 2012; The Seoul Institute, 2011; Sim et al., 2014), the flood vulnerability assessment (Parker, 2007; Lee et al., 2011; Kim et al., 2011; NIER, 2011; Zhou et al., 2012; Kim et al., 2013), and quantitative prediction using hydrologic modeling (Kim, 2006). To predict flood vulnerable areas, proposed methods include multiplying indices of risk, vulnerability, and exposure (Karmakar et al., 2007), and dividing multiplications of risk, exposure, and vulnerability by adapting countermeasures. However, most flood vulnerability research has calculated the vulnerability index by applying indices and weights that reflect the opinions of experts. It is challenging to calculate an index that reflects local features, as most reflect regional averages that fail to reflect reality. There is a clear need for more models to analyze flood vulnerable areas based on hydrologic and statistical approaches (Fenicia et al., 2013).

Flood prediction methods are usually based on hydrologic models or on spatial statistics. Hydrologic models of urban floods (e.g., ILLUDAS, SWMM, TR-55, HSPF, Inforks, and STORM) are used in academic and industrial research. These models are mainly used for the planning and control of urban flooding, and are particularly focused on sewage facilities relevant to water movement (Chen et al., 2015). Traditional hydrologic methods use physical models (e.g., rainfall-runoff modeling techniques) that are not suitable for the integrated analysis of rivers or flooding (Smith and Ward, 1998). Hydrologic methods follow 1-dimensional procedures. In addition, river topography is not constant and has dynamic features reflecting the high erosion potential. A final disadvantage of this method is that it requires precise site surveys, which can be economically prohibitive (Fenicia et al., 2013).

As an alternative, some studies have analyzed flood vulnerability empirically by using a data-based approach, including the development of statistical and machine learning models. Statistical models include empirical models (e.g., GLM, the generalized linear model; GAM, the generalized additive model; and MARS, multivariate adaptive regression splines) and expert knowledge based models (e.g., AHP). Most urban disaster modeling data violate the hypothesis of a linear model and GLM represents an expansion linear model that can be used to process abnormal distributions (Venables and Ripley, 1994). The most general form of GLM is logistic regression analysis (Franklin, 2009).

Pradhan et al. (2010) analyzed flood vulnerability along the eastern coat of Malaysia using logistic regression analysis, and evaluated landslide vulnerability for three areas of Malaysia using fuzzy logic. Other research has evaluated flood vulnerability in Seoul city using frequency ratio (Lee and Kang, 2012). However, in the frequency ratio model, probability analysis is performed by dividing each variable before simulating a model; therefore, it has the disadvantage that features of each area may be distorted when calculating flooding probability by each variable (Kim et al., 2013). Logistics regression analysis and frequency ratio analysis have been widely used in related fields owing to their simple and easily understandable concept (Liao and Carin, 2009).

Machine learning models include decision trees (DT), artificial neural networks (ANNs), the genetic algorithm, and maximum entropy (MaxEnt). The objective of the DT model, one of the most frequently used for disaster prediction, is to classify data into sub-groups based on a range of prediction variables. DT was used to map flood vulnerability in the Kelantan region of Malaysia (Tehrany et al., 2013) and has been used to evaluate other natural disasters (e.g., landslides).

Artificial neural networks are widely used for satellite image classification and have been applied to hydrology and hydraulic engineering. However, this model has a hidden layer; therefore, it has the disadvantage that results are hard to explain accurately, notwithstanding a high classification accuracy as compared with other methods (Flanklin, 2009).

Despite high classification accuracy, the machine-learning model is limited by present/non-present data and by difficulty in explaining the results (Seo et al., 2008). However, Kim et al., (2013) used MaxEnt to select vulnerable areas to urban flood adaptation (i.e., areas with a high flooding probability, based on present data), and created a spatial probability model for Seoul. Evaluation factors and method used to evaluate vulnerability are shown in Table 1.

Table 1. Evaluating variables for flood vulnerable area in literature

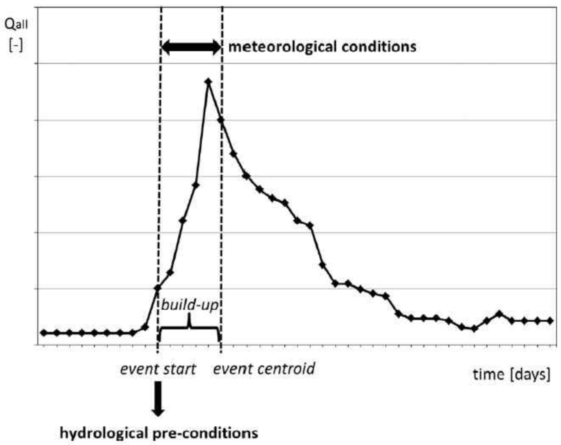
Variables		①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪
Flood damage	Damage cost of property/ damaged population	●				●						
	Flood depth, velocity				●							
	Runoff by unit						●					
Climate exposure	Rainfall intensity/ frequency	●			●		●			●	●	●
	Number of heavy raining days	●			●							
Physical environment	Slope	●				●		●	●	●	●	●
	Elevation	●					●	●	●	●	●	●
	Area of lower land/ stream flood water level	●				●		●				
	Distance from stream/ waterfront status	●								●	●	●
	Area of river	●										
	Soil drainage, effective soil depth, soil class / Geology						●		●	●	●	●
	Curvature								●		●	●
	Topographic wetness index (TWI)							●		●		
	Stream power index										●	●
Artificial environment	River, stream structure		●	●		●						
	Internal Drainage System capacity					●						
	Flood control capacity/ pumping capacity					●	●			●		
	Impervious rate						●	●	●	●		
	Stream improvement rate						●					
	Curve number							●				

green space	Forest area, green infrastructure area		●				●		●	●		
	Green space type						●		●			
	Age of tree, density								●			
social, economic environment	Financial independence rate	●				●						
	Flood prediction and warning facility		●	●								
	Evacuation facility, health service		●	●	●							
	Flood compensation		●									
	Infiltration facility / Distance of sewesr / Lacking capacity of sewers			●		●		●		●		
	Number of civil servant per population Number of civil servant with water management					●						
	Total population/d/population over 65 and below 15					●	●					
	Ratio of built area							●				
	Land use rate					●	●	●		●	●	●

① Kang and Lee (2012), ② Parker, D.J. (2007) ③ Evans et al., (2004) ④ Zhou et al. (2012) ⑤ NIER(2011) ⑥ Kim et al. (2011) ⑦ TSI (2011) ⑧ Lee and Kang(2012) ⑨ Kim et al.(2013) ⑩ Tehrany. et. al. (2014) ⑪ Tehrany. et. al.,(2013)

3. Classification of flooded area type

The hydrological condition of an area before rainfall and the meteorological conditions are two of the main factors affecting flooding. As shown in Figure 1, the time associated with water build-up until the peak time when rainfall starts and runoff becomes a maximum may differ completely depending on these conditions (Nied et al., 2014). The hydrological condition before rainfall can affect flooding due to many physical or environmental variables, such as the altitude, the slope, and the soil features, as well as the capacity of any flood control facility. Therefore, it is important to classify these physical environments by type and establish flood control countermeasures for each type.



	Rain-on-snow flood	Snowmelt flood	Long-rain flood	Short-rain flood	Flash flood
Seasonality	Winter/Spring	Winter/Spring	no	no	Summer
Length of build-up period	medium	long (> 4days)	long (> 4days)	medium	short (~1day)

Figure 1. Schematic drawing about water built-up time (Nied et al., 2014)

Flooded areas are classified by two different methods. One method classifies areas depending on the factors affecting the flooded area and the other method divides the areas depending on the flood damage level. Merz and Bloschl (2003) divided flood types into rain-on-snow floods, snowmelt floods, long-rain floods, short-rain floods, and flash floods depending on the features of the rainfall and the snow. They also discriminate between such features as the flooded spatial area, seasonality, the snow build-up, the condition of the air temperature and the humidity, the precipitation, and the build-up period.

In The Seoul Institute (2002), flood prone areas were divided into type 1 and type 2 based on the river flood level, the land use, the past flooding frequency, and an impervious surface ratio (ISR). Each type of flood prone area was further divided into short-term, medium-term, and long-term, and flood control methods were presented. Lee (2004) analyzed the causes of major flood damage and suggested an improved method for classifying flood prone areas by comparing the business features in the disaster risk area. In addition, in NEMA (2005), flood prone areas were selected nationwide by targeting damage cases autonomously investigated by local governments for flooded areas that occurred from 1993-2003. They categorized the areas by the cause of damage and then presented problems with and solutions for each cause.

The U.K. operates a sequential test that induces developers to develop projects in areas having the least flood risk. To meet this objective, they divided the nation into four flood zones depending on flood risk based on annual flooding probability. They then presented a standard for each area for the required infrastructure to be constructed to prevent flooding (U.K. Communities and Local Government, 2006).

Park et al. (2013) categorized 34 flood prone areas in Seoul city by using a multivariate statistical analysis with relevant factors, such as detached housing area ratio relevant to land use, the apartment ratio, the green space and open space ratio, the average slope of the water basin, and the ratio of the area below the river plain flood level. Through this, the city was divided into three flood types, and a strategy for flood control countermeasures by each type was suggested.

4. Flood control capacity of urban green space

1) Definition and range of urban green space

Urban green space is defined generally as an area combining parks, created green spaces, and natural green spaces in an urban area (Yeom and Park, 2011). Green space is defined specifically in several academic fields, and the term, green space, has been used from the early 19th century in discussing urban spaces. It has been used in a wide range of fields, including urban planning, landscape, environmental studies, and tourism. In broad terms, green space can include any open spaces; and in some narrow definitions, a green space ratio based on certain standards is used (Lim and Kim, 2011).

Recently, some researchers have defined urban green space, comprehensively, as green infrastructure. Lee et al. (2014) defines green infrastructure broadly as the ecosystem for the sustainable life of human beings that is obtained in urban areas by physical connections with nature or open spaces. The meaning of green infrastructure, based on having parks and green space as its main components, was recognized at an early stage as having ecological value (Benedict and McMahon, 2006). They further emphasized that in urban areas, the focus on green infrastructure must be on the creation and control of parks, green spaces, public gardens, rainwater control areas, and urban farmlands rather than on natural green infrastructure, such as wetlands and preservation areas (Schilling and Logan, 2008).

After the 20th century, based on the Environmental Protection Agency (EPA) of the USA, the concept of rainwater control as a main function of green space was defined. The EPA defined technologies and policies that make rainwater control, the process of absorption, evaporation, and recycling of natural water, the function of green infrastructure. It explained that green infrastructure should include all low impact development (LID) techniques, such as green roofs, rain gardens, grassed swales, pervious pavements, and rainwater storage tanks (EPA, 2008a; 2008b). Green infrastructure could be interpreted as when green space and an artificial system, including forests, wetlands, parks, green roofs, and green walls, are converged. This green infrastructure contributes to human benefit through ecological resilience and ecosystem service (Naumann et al., 2010; Pauleit et al., 2011; European Environment Agency, 2012).

In this study, the concept of urban green space is similar to the concept of green infrastructure. However, this research also defined mountain areas, farmlands, grasslands, wetlands, and parks as urban green space and excluded artificial rainwater control facilities. Recently, urban green space has been approached from the perspective of resilience and response to climate change. Resilience could be defined as the capacity of being able to reconstruct after a system disturbance while absorbing impacts and preventing such impacts from being converted to an unrestorable state (Resilience Alliance, 2007). Resilience can also be contrasted with vulnerability (Adger, 2000). As climate change has complicated and unpredictable characteristics, the development of urban green space may become a very important strategy for reducing flood vulnerability.

2) Flood control function of green space

In urban green space research, as the multi-functionality of green space has been emphasized, its importance has increased. Urban green space provides such benefits as the provision of habitats, the removal of pollution sources, the reduction in the heating or cooling requirements of buildings, the moderation of the heat island due to temperature drops in summertime, carbon absorption and oxygen generation in the atmosphere, and the provision of resting places. These functions go beyond its function in flood control through the interception of rainwater (McPherson et al., 1999; Pauleit et a., 2005; Perry, 2008). This study will focus on the urban flood control function of green space.

Urban green space includes trees, lawns, grasslands, and farmlands (Beijing Municipal Commission of Urban Planning, 2009) and exerts a positive influence on urban hydrology by promoting infiltration of the soil and root system, the storage of water, and rainfall interception by tree canopies and plant stems (Gill et al., 2007; Park et al., 2007; Zhang et al., 2012).

Even though soil infiltration was not considered, tree canopy interception in temperate forest areas accounted for 11-36% of the total precipitation in the case of deciduous trees and 9-48% in the case of conifers. In a study of the effect of parks and street trees in Santa Monica, USA, for reducing runoff and controlling floods (Xiao and McPherson, 2002), it was reported that 1.6% of the total rainfall was intercepted by the urban trees. Each tree absorbed 6.6 m^2 of rainfall and annually saved US$110,890 (US$3.6/tree) in flood control costs. In an urban forest, the quantity of crown interception varies depending on the forest structure (the plant species, the layer, and the height), the tree shape (leaf formation time, the surface area of the leaf and stem, the gap ratio, and the surface water retention storage capacity), and meteorological elements (precipitation, the period, the intensity, the frequency, and the evaporation rate).

In the case of permeation of water into the soil, the water movement into the soil and its storage capacity differ depending on features such as soil surface condition and the internal porosity. The hydraulic conductivity and water runoff differ as well. The infiltration rate of rainfall into soil is controlled by the maximum rate of water permeation through the soil/plant surface, the rate of water moving in an unsaturated layer of water, and the rate of discharge from the unsaturated layer to a deeper saturated layer. Until excess precipitation has taken place, the infiltration rate is determined by the lowest rate among these. In the case when soil structure is unstable and soil is exposed without having a coating material, such as a thin membrane that is formed by the destruction of the aggregated soil structure and separation of light silt or clay, the infiltration rate tends to be slow (Ellison and Slater, 1945).

Bonsingnore (2003) suggested that when the green space ratio is reduced to 25% by urbanization, runoff is over 55%, which is an increase of over five times for an area consisting of green space only. This was attributed to an increase in the imperviousness of the soil surface and a reduction of porosity in the soil that decreases the quantity of infiltration. Kirnbauer et al. (2013) performed an analysis by using an i-tree hydrological model based on precipitation for seven years, weather data that showed how much green space affects the rainfall interception, the reduction of runoff, and the rainfall evapotranspiration when ginkgo trees, Plantanus Xhispanica Munchh, sugar maples, and sweet gum trees are planted in soils with different conditions.

Research has been conducted on the benefits obtained from installing green space in urban areas. Alfredo et al. (2009) suggested that construction of a green roof could delay runoff time and roof filtration and reduce peak runoff by 30-78% compared with an existing concrete roof. Dreelin et al. (2006) suggested that pervious pavement reduced the runoff from two parking lots by 98% during a small rainfall (below 2 cm), and Chapman and Horner (2010) determined that installing a water retention facility at a Washington roadside retained 26-52% of the runoff. Schneider and McCuen (2006) clarified that a cistern is not efficient for reducing runoff in large-scale rainfalls but is very effective for small-scale rainfalls. Qin et al. (2013) concluded that a vegetated water channel, pervious pavement, and green roofs are very effective for flood control in heavy rains and for short-term rainfall as compared with general drainage systems. In addition, Kim et al. (2011) clarified that by targeting urban development areas, runoff could be reduced by 41% in the case of a vegetated water retention basin and by approximately 10% in the case of an artificial swamp. Using regression analysis, KEI (2011) determined that a 1% increase in green infrastructure could reduce property damage by approximately 6.4%.

Manchester City in the U.K. utilizes green infrastructure extensively and plans large-scale green infrastructure as a flexible strategy for responding to climate change. At present, it arranges infrastructure preferentially by designating standards and requirements for green infrastructure. It then analyzes any gaps after first analyzing the current status and condition of green infrastructure of the urban area using mapping techniques (TEP, 2008; 2010). The city of Portland in the USA experienced improved water control by three to six times through installing street trees and green space. Annual runoff was reduced by 40%.

In addition, in Chicago, through green roof creation, rainwater runoff was reduced by 76% per 1-inch of rainfall. In New York City, rainfalls of 25 mm that are generated from 10% impervious areas are controlled by installing green infrastructure facilities. It is expected that this policy will provide a cost reduction of US$1.5billion compared to their existing methods (City of New York, 2010; 2011). After installing urban arbors containing 90,000 trees in Modesto, California, the rainwater runoff was reduced by 292,000 m^3, which led to cost reductions of US$616,000 (US$7/tree or US$2.11/m3) (McPherson et al., 1999).

3) Evaluation of urban green space features

Green space is fragmented into various shapes as urban areas are developed. During fragmentation, the number of green patches is increased, the edge length is increased, and the average patch size is decreased (Rutledge, 2003; Collinge, 2009). Figure 2 shows that as one green space is fragmented, its interspersion metrics are increased, and isolation is developed. With a decrease in patch size, the size of the edge is increased.

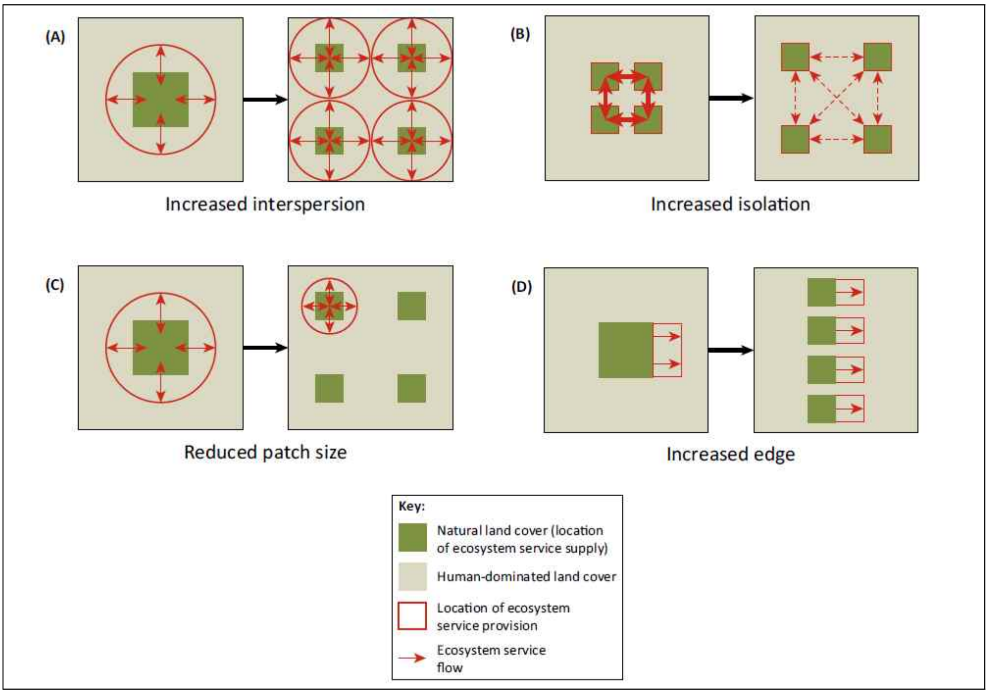


Figure 2. Mechanism of landscape fragmentation
(Fisher et al., 2009; Mitchell et al., 2015)

An index can be applied to evaluate area metrics, the patch density, the size, the edge metrics, the diversity and interspersion metrics, and the core metrics. The landscape index can identify the structure, the function, and the changing pattern of a landscape eco-system as a single numerical number. It is a relative number, not an absolute number (Huh et al., 2007).

Kim and Ahn (1996) identified the fragmentation, the soundness, and the accessibility of an urban park from the perspective of a landscape ecosystem. They analyzed it as a patch having a large area with an ecological effect over a simple sum of small patches with different preservation values as its diversity was high. Kim and Lee (2001) identified forest fragmentation and its effect on the ecosystem and the environment by evaluating green space environment sensitivity. They based their analysis on land use change by analyzing patch area change, the change of the area distribution, and the connectivity between patch shapes using a landscape ecology index targeting Cheonan City.

Huh et al. (2007) used a landscape index in order to analyze quantitatively landscape change by land use change. In order to analyze landscape structure by impervious area change, they estimated and analyzed the landscape index by past land use change and evaluated an impervious ground surface model based on the change of the impervious area, the water quality, and the landscape index. Eom and Lee (2008) deduced that one of variables that significantly effects green space use is accessibility. This was based on a preceding study relevant to urban green space that identified land use by urban citizens through a questionnaire and evaluated urban green space by usability.

Greca et al. (2011) performed a fragmentation analysis using a landscape index for constructing a land adequacy model to establish a land use plan for a non-urbanized area. Paudel and Yuan (2012) quantified temporal and spatial changes in landscape patterns in Minnesota by using a landscape index. Kim et al. (2013) analyzed the forest fragmentation level by area development and linear development based on a selected landscape index that was relevant to fragmentation. Based on this result, they discussed the practical application of a forest fragmentation index. Kim et al. (2014) performed a feature evaluation for applying green infrastructure through an analysis of patch fragmentation and accessibility supplemented by LISA, a spatial autocorrelation analysis.

Zhang et al. (2015) analyzed the temporal and spatial landscape pattern changes of urban green space areas of Beijing for the last 10 years based on a large patch index (LPI) and an aggregation index (AI) together with regional differences in runoff reduction. This study was performed based on the prediction of urban green space capacity for runoff reduction by developing a formula based on the rainfall and a landscape index, not based on actual flood data.

As observed, there are many studies that performed a fragmentation analysis for analyzing landscape changes and comparing the past with the present. However, there is only limited research that deduced the suitability of green space distribution for flood control by evaluating the green space effect quantitatively in order to identify a relationship between flood control and green space distribution features.

In a study similar to this, many artificial rainwater retention basins were introduced in order to solve flooding temporarily, and several studies analyzed the runoff reduction by the location or arrangement of such basins. Han et al. (2012) evaluated the reduction of peak runoff based on the rainwater retention capacity distribution and the location of the retention basin facilities. Park et al. (2013) analyzed runoff and flood damage reduction based on an arrangement of rainwater retention facilities by using XP-SWMM software and by comparing basins with the same storage capacity. Basin type (concentration type, spread type, and mixed type) was analyzed to understand which type of runoff reduction technique minimized flood damage.

4) Identification of runoff coefficient

There are several formulas in estimation method of design flood volume for determining dimension of storm sewer but sewer line that undertakes inner basin drainage in urban basin is designed by using rational formula in most cases (Kim and Hwang, 2014; Lee at al., 2007). As structure of rational formula is simple and convenient for using, even an engineer who has limited knowledge of hydrologic basics could use it without difficulty. However, it has a disadvantage of being unable to apply an effect of factors such as land cover condition of ground surface affecting runoff, basin topography, soil features and return period (Kim, 2003). A procedure of calculating runoff quantity through calculation of rational formula is as shown on following Figure 3.

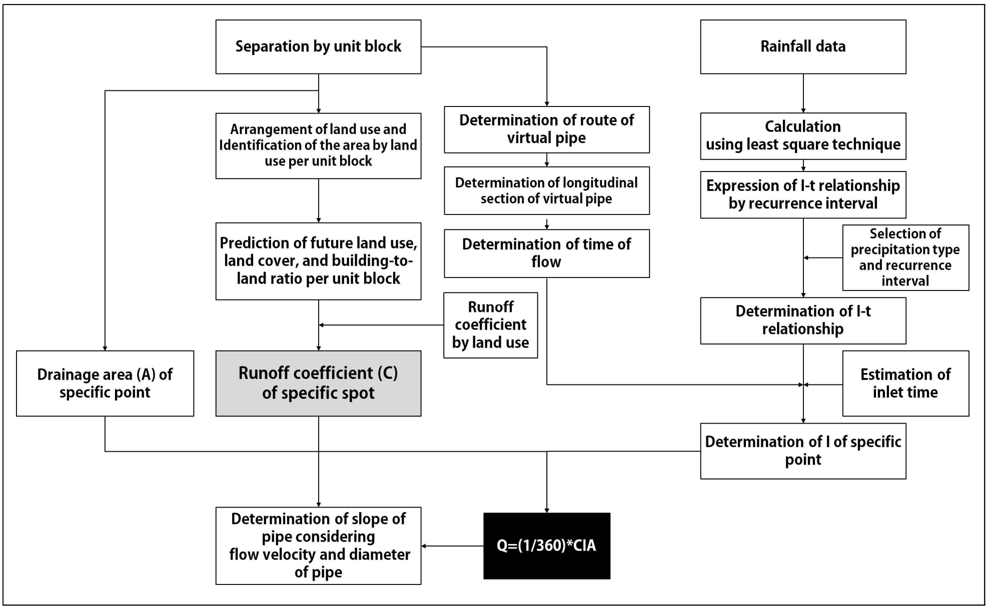


Figure 3. The procedures of calculating design volume of rainfall (ME, 2011)

Most important element in runoff analysis using rational formula is runoff coefficient and as domestic standard for runoff coefficient is not properly established, big difference is represented in its value depending on subjective judgement of the users (Lee et al., 2007). Runoff coefficient being used domestically is presented in 'Stream design standard (MOLIT, 2009)' and ‘Sewerage facility standard (ME, 2011)' being used in sewerage field.

Table 2 shows range of runoff coefficient of rational formula based on land use being presented in stream design standard. This value was prepared based on a value presented by ASCE. That's why correction value based on topography and geological features is presented. However, there is no method by which its suitability status could be determined and designer of sewer line is also using reference value or subjective runoff coefficient value without any evaluation. As residential situation of detached house is not identical with that of the USA, it is specified that caution is required in estimating runoff coefficient. In addition, in case of mountain area, a judgement considering site condition is required at the time of estimating runoff coefficient and in an area where basin area is narrow, big runoff coefficient is required to be used and in an area where basin area is wide, small runoff coefficient should be used (MOLIT, 2009).

Table 2. Runoff coefficient of Stream design standard (MOLIT, 2009)

<table>
<tr><th colspan="2">Land use</th><th>Coefficient</th><th colspan="4">land use</th><th>coefficient</th></tr>
<tr><td rowspan="2">Commercial area</td><td>Urban</td><td>0.70-0.95</td><td colspan="4">Road and street</td><td>0.75-0.85</td></tr>
<tr><td>Suburban</td><td>0.50-0.70</td><td colspan="4">Roof</td><td>0.75-0.95</td></tr>
<tr><td rowspan="5">Residential area</td><td>Detached 1</td><td>0.30-0.50</td><td rowspan="6">Grassland</td><td rowspan="3">Sandy</td><td colspan="2">Flat</td><td>0.05-0.10</td></tr>
<tr><td>Detached 2</td><td>0.40-0.60</td><td colspan="2">Average</td><td>0.10-0.15</td></tr>
<tr><td>Row house</td><td>0.60-0.75</td><td colspan="2">Steep slope</td><td>0.15-0.20</td></tr>
<tr><td>Suburban</td><td>0.25-0.40</td><td rowspan="3">Baryta</td><td colspan="2">Flat</td><td>0.13-0.17</td></tr>
<tr><td>Apartment</td><td>0.50-0.70</td><td colspan="2">Average</td><td>0.18-0.22</td></tr>
<tr><td rowspan="2">Industrial area</td><td>Not dense</td><td>0.50-0.80</td><td colspan="2">Steep slope</td><td>0.25-0.35</td></tr>
<tr><td>Dense</td><td>0.60-0.90</td><td rowspan="8">Agricultural land</td><td rowspan="2">Bare land</td><td colspan="2">Flat</td><td>0.30-0.60</td></tr>
<tr><td colspan="2">Park / Cemetry</td><td>0.10-0.25</td><td colspan="2">Tough surface</td><td>0.20-0.50</td></tr>
<tr><td colspan="2">Play ground</td><td>0.20-0.35</td><td rowspan="4">Farm-land</td><td rowspan="2">Sandy</td><td>Planted</td><td>0.30-0.60</td></tr>
<tr><td colspan="2">Railroad</td><td>0.20-0.40</td><td>Not planted</td><td>0.20-0.50</td></tr>
<tr><td colspan="2">Undeveloped area</td><td>0.10-0.30</td><td rowspan="2">Baryta</td><td>Planted</td><td>0.20-0.40</td></tr>
<tr><td rowspan="4">Road</td><td>Asphalt</td><td>0.70-0.95</td><td>Not planted</td><td>0.10-0.25</td></tr>
<tr><td>Concrete</td><td>0.80-0.95</td><td rowspan="2">Grass-land</td><td colspan="2">Sandy</td><td>0.15-0.45</td></tr>
<tr><td rowspan="2">Brick</td><td rowspan="2">0.70-0.85</td><td colspan="2">Baryta</td><td>0.05-0.25</td></tr>
<tr><td colspan="4">Forest</td><td>0.05-0.25</td></tr>
</table>

Land use could be mainly divided into infiltration area and non-infiltration area, and runoff coefficient of the former differs depending soil character or vegetation and that of the latter contact degree with sewer line. Sewerage facility standard divides land use based on such division and runoff coefficient value is as shown on following Table 3. This standard was deduced based on standard value of runoff coefficient and data of sewerage arrangement basic planning change (SMG, 2002). Runoff coefficient for 11 items being classified in detail by mainly dividing land use into urbanized area and green space area, open space area is presented. In sewerage facility standard, a method of applying upper value of basic runoff coefficient is presented so that flood damage could be reduced to maximum in flood prone area.

Table 3. Standard value of runoff coefficient for land use (Japan Sewer line association)

Surface	Coefficient	Surface	Coefficient
Roof	0.85-0.95	Bare land	0.10-0.30
Road	0.80-0.90	Park with grassland and tree	0.05-0.25
Impervious surface	0.75-0.85	Forest with a gentle slope	0.20-0.40
Water body	1.00	Forest with a steep slope	0.40-0.60

Table 4. Sewerage facility standard (ME, 2011)

Land use		Coefficient range
Transportation facilities area		0.80-0.90
Commercial and business area		0.70-0.95
Public facilities area		0.65-0.75
Residential area		0.50-0.75
Mixed land use area		0.70-0.95
Industrial area		0.60-0.90
Farmland		0.10-0.25
Bare land		0.30-0.40
Urban infrastructure	Planted area	0.10-0.25
	Built area	0.60-0.75
Green space and open space		0.50-0.75

Runoff coefficient considering residential features of Seoul city is presented as shown on following Table 5 by referring sewerage facility standard (2009), stream design standard (2000) and ASCE standard. runoff coefficient regards all the rainfall in target areas as same. It is specified that this runoff coefficient be preferentially applied to new development area or at the time of new installation of sewer line and as for existing sewer line, it be applied after comparatively analyzing runoff presented in other relevant data (SMG, 2009).

Table 5. Runoff coefficient in Sewerage arrangement basic planning change (SMG, 2009)

<table>
<tr><th colspan="3">Average runoff coefficient for region land use</th><th colspan="3">Basic runoff coefficient for land use</th></tr>
<tr><td colspan="3">Commercial and business area</td><td colspan="3">Road</td></tr>
<tr><td></td><td>Urban</td><td>0.70-0.95</td><td></td><td>Asphalt</td><td>0.70-0.95</td></tr>
<tr><td></td><td>Suburban</td><td>0.50-0.70</td><td></td><td>Concrete</td><td>0.80-0.95</td></tr>
<tr><td colspan="3">Residential area</td><td></td><td>Street, parking lot</td><td>0.75-0.85</td></tr>
<tr><td></td><td>Detached house</td><td>0.60-0.75</td><td colspan="2">Roof</td><td>0.75-0.95</td></tr>
<tr><td></td><td>Apartment</td><td>0.50-0.70</td><td colspan="3">Farmland</td></tr>
<tr><td></td><td>Suburban residential area</td><td>0.30-0.40</td><td></td><td>Paddy field</td><td>0.70-0.80</td></tr>
<tr><td colspan="3">Industrial area</td><td></td><td>Field</td><td>0.45-0.60</td></tr>
<tr><td></td><td>Not dense area</td><td>0.50-0.80</td><td colspan="3">Etc.</td></tr>
<tr><td></td><td>Dense area</td><td>0.60-0.90</td><td></td><td>Playground</td><td>0.20-0.35</td></tr>
<tr><td colspan="3">Green space</td><td></td><td>Bareland</td><td>0.40-0.60</td></tr>
<tr><td></td><td>Flat park</td><td>0.10-0.25</td><td></td><td>Water body</td><td>1.0</td></tr>
<tr><td></td><td>A steep slope</td><td>0.75-0.90</td><td></td><td>Grassland</td><td>0.10-0.30</td></tr>
<tr><td></td><td>A gentle slope</td><td>0.50-0.75</td><td colspan="3"></td></tr>
</table>

As a result of analyzing existing runoff coefficient features, similar range of runoff coefficient of urban impervious area was presented by several institutions at home and abroad. However, in case of green space area such as forest, farming land, as regional feature is different, it was analyzed that significant deviation was represented. As a result of this, a lot of researches trying to modify runoff coefficient to be matched with domestic reality are under progress (Lee et al., 2007; Yoo, 2008; Kim, 2003; Kang and Kim, 2008; Kim and Hwang, 2014). However, in spite of this diversified researches, it could be realized that runoff coefficient value of stream design standard, sewerage facility standard was seldom changed. Due to this, runoff coefficient of urban green space area is likely to be underestimated or overestimated and at the time of expanding sewer line for flood prevention, probability of wrong design is increased.

5. Summary

In previous studies, in order to observe urban water management for adapting to climate change and to analyze urban areas vulnerable to floods, flood vulnerability evaluations and spatial statistical models were considered. In addition, green space features in each flooded area type were analyzed in order to observe how flooding probability changed depending on green space features. Relevant existing studies were reviewed and confirmed.

Urban water management that could be applied for adapting to climate change may increase the resilience of urban areas related to flooding. Both at home and abroad, authorities have exerted their efforts in developing flood control methods and adapting them based on diversified sustainable methods. Increasing the ability to adapt to urban floods by using sustainable green space rather than flood control methods using artificial facilities, such as pumping stations and rainwater retention basins, would be required.

Flood vulnerability evaluations in the past were performed using a qualitative standard by establishing an index and weight as in the vulnerability evaluation suggested by the Intergovernmental Panel on Climate Change (IPCC) or by actively analyzing the vulnerable areas using hydrological models. Recently, a study that evaluates flood vulnerable areas by using spatial statistics was conducted. It was found that if spatial statistics are used, quantitative and empirical relationships that were overlooked in the existing qualitative evaluation model were found. In addition, by comparatively analyzing diversified spatial statistical models, a model that may be used in this study was selected.

A study classified by flood type was not varied. There were studies domestically that provided flood control countermeasures by discriminating the flood prone area as a variable after analyzing the area as the target. There was a study developed overseas that classified flood type depending on rainfall type. A study that evaluated green space features analyzed how green space and urbanization level were increased by evaluating the area, the size, the edge features, and the number of patches of green space after specifying a landscape index. Additionally, there was a study that explored the efficiency of runoff reduction and how it could be increased, depending on the arrangement of rainwater retention basins. It was found in a review of green space distribution arrangements.

There were several studies that analyzed runoff reduction by the introduction of green space, but none that analyzed this reduction by introducing green space based on regional features. In particular, as there was almost no existing study exploring the type of green space and the pattern (i.e., the size, the shape, or the spatial arrangement of green space patches) that contributes to flood occurrence, the distinctiveness of this study could be verified.

Ⅲ. Scope and Method

1. Spatial scope

The Seoul Metropolitan City (605.41km^2) was used as the site for this study (Figure 4). Seoul is one of the most highly urbanized cities in Korea and therefore represents an ideal area to study urban flooding. The percentage of impervious area in the city of Seoul has increased from 40.0% in 1962 to 47.7% in 2010, and over 90% of the impervious land cover is impenetrable to rainwater infiltration. In addition, several residential areas and industrial facilities are located near the floodplains; thus, the risk of damage caused by urban flooding is heightened in this region (SMG, 2014).

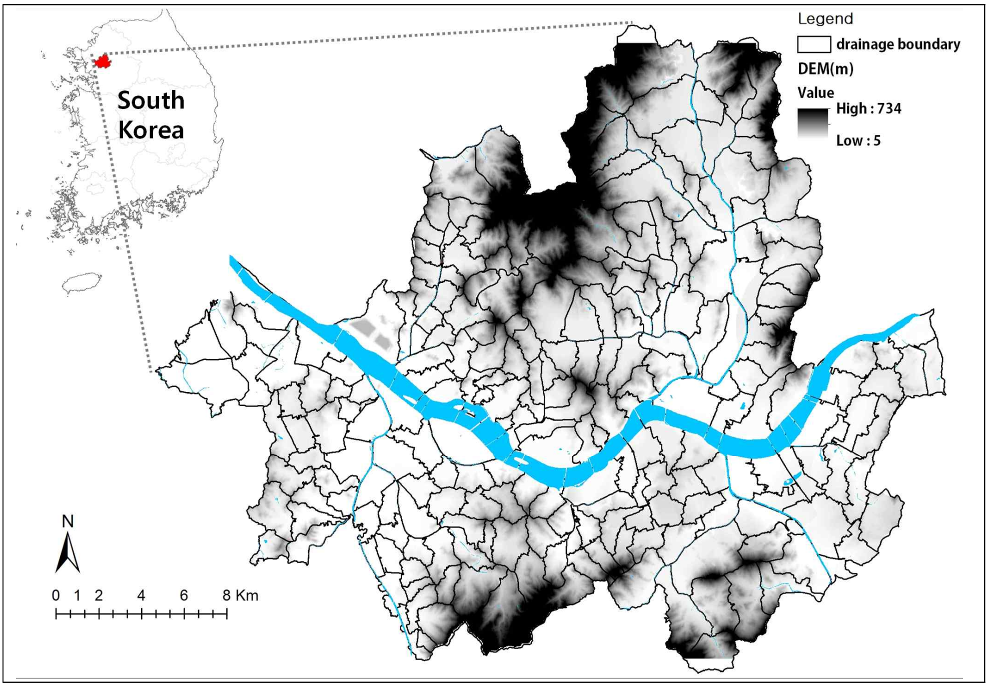


Figure 4. Spatial scope : Seoul Metropolitan City, South Korea

Seoul experienced a heavy flood in 2010 and 2011. Flooded areas during the event were distributed throughout Seoul, but damage was especially severe in Sadang, Seocho and Gangdong, compared to other parts of the city. Additionally, the southwestern part of Seoul, which has low elevation and gently sloping land, experienced severe damage from the flooding. In Seoul city, damage of lowland, semi-underground housing area and damage by capacity problem of sewer line due to severe rain rather than river flood damage by direct inundation of stream or embankment collapse were its mainstream of damage (The Seoul institute, 2011).

When observing annual precipitation hour trend for the recent past 50 years, it was analyzed that while it was reduced by about 1.5 hours every year, maximum continuous precipitation time was increased by 0.08 hours every year (SMG, 2013). While the yearly total of hourly precipitation in Seoul has decreased recently, the maximum hourly precipitation has displayed an increasing trend; thus, it can be inferred that the rainfall intensity and continuous duration of heavy rainfall has increased, and these changes have primarily taken place during the summer. Consequently, Seoul may be more vulnerable to flooding in the future, and it would be prudent for officials to prepare for such situations, in part by implementing sustainable methods to increase flood resilience

An analysis unit of this study varies depending on analysis contents but an analysis was performed based on flooded point unit and drainage basin unit that means a section where sewerage is treated in urban area. It is partially similar to basin unit but in case of urban area, as a place where most of water is gathered is sewer line, considering topographic features, a it is divided into section and this is called drainage basin. Drainage basin of Seoul city is mainly divided into northeastern region, northwestern region and southwestern region and total 239 basin are existent.

2. Content scope

Urban flooding in this study is defined as a phenomenon that causes inconvenience to humans living in the flooded area or human injuries and various tangible and intangible property damage due to inundation of urban areas (SMG, 2013).

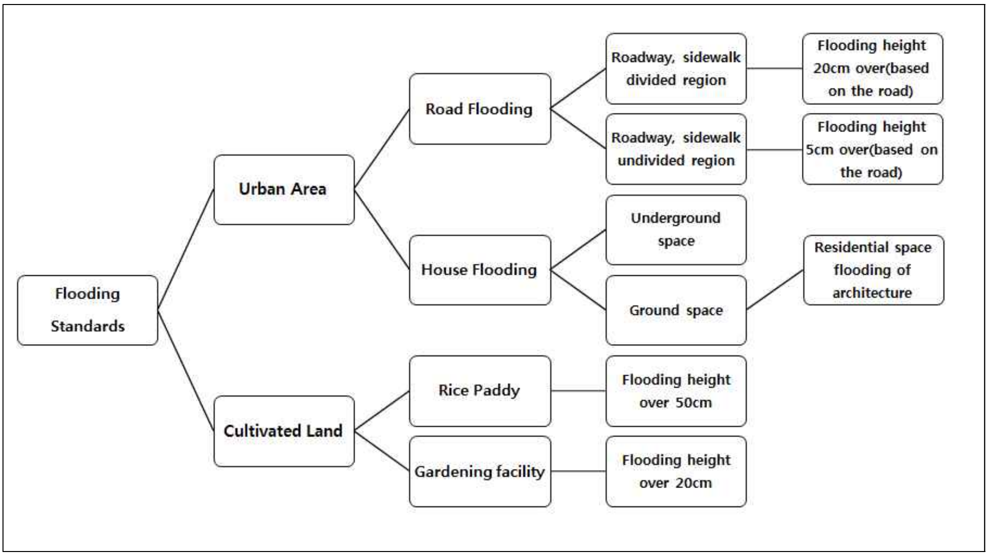


Figure 5. Setting standards flooding (SMG, 2013)

Urban green spaces in this study include forests, farmlands, grasslands, wetlands and other planted types of land, and green space data were derived from land cover maps and urban biotope maps of the region. These green spaces are considered to be critical to the natural water circulation system, as they represent areas where rainwater infiltrates and is retained. Low impact developments and green spaces, including artificial facilities (e.g., rainwater tanks, pervious paving), were excluded from the analyses. The amount of infiltrated water considered in this study includes not only rainwater that falls onto the green spaces, but also water that flows down through ground surface slopes, considered as water flow.

Contents of this study were mainly divided into 3 categories. First is to analyze flood vulnerable area of Seoul city. For this objective, a model was mapped out by selecting flood inducing factors and model to be applied and establishing data to be applied to model. Evaluation variables were divided into physical environment, climate environment, green space environment and artificial environment variable and how its result is changed by adding variable features after reflecting such variables in model sequentially was comparatively analyzed. In order to consider the uncertainty, mean and variance of probability value per each cell were observed through random point extraction of 1000 times. Like this, result by each cell is represented as flooding probability and assuming that an area where flooding probability was represented to be high would be flood vulnerable area, a analysis was summarized. Through this, how flood vulnerability of overall Seoul city would be like was diagnosed.

Second, types of urban flooded areas were divided into categories based on factors affecting the flooding; the groupings were determined by the use of cluster analysis, and discriminant analysis was performed to verify the cluster analysis results. As a result of the discriminant analysis data, the floods were divided into four types. The four flooded area types were then used as ground data in the analysis of green space features during the next research stage. In addition, being linked with the previously analyzed result of flood vulnerable area, flood vulnerability by each divided type was observed.

Third, flood control contributions based on green space area and flooded area type were analyzed. In order to determine the relationship between green space area and flooding, the most adequate evaluation unit was selected, and regression formulas including this green space area variable were deduced. Afterwards, based on regression formulas for the different flooded area types, flooding probabilities for changes in the green space area were analyzed by taking only the green space area as the independent variable and fixing the other variables. As a next step, based on green space type of Seoul city being classified based on CN value, which green space type is dominantly distributed by each flooded type and contributory to flood control were analyzed. Finally, after establishing regression formula by each flooded type considering green space pattern in drainage basin unit, green space features being specialized depending on flooded area type was analyzed.

In this study, based on current situation of Seoul city, how flooding probability by variation of green space area, type and pattern by each flooded area type is changed was analyzed statistically. This could be contributory in selecting an area to be introduced preferentially at the time of planning and designing green space for increasing urban flood resilience and it could provide a guideline for green space features to be introduced for controlling flooding probability. The conceptual framework for this research is shown in Figure 6.

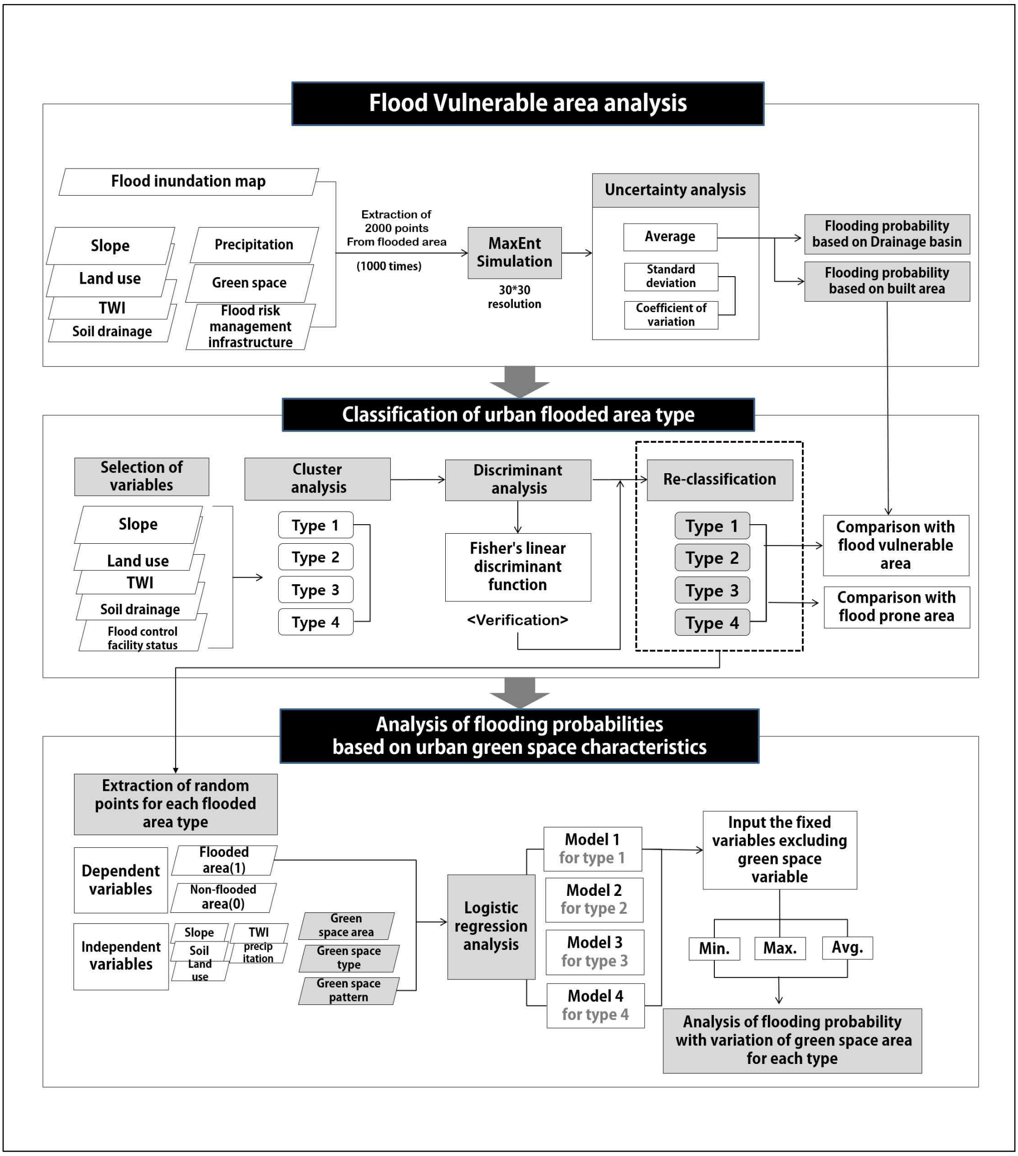


Figure 6. Flow chart of this study

3. Method

1) Analysis of urban flood vulnerable area

As the first method of this study, urban flood vulnerable area was evaluated by using spatial statistic analysis and through this, how much Seoul city is exposed to flood was analyzed. When summarizing existing literature, in order to provide a countermeasure for controlling and adapting to urban flood, it is required to predict an effect of flood and diagnose it more than anything else.

(1) Model selection

Following comparison of the available models, MaxEnt was selected for use in this study. The MaxEnt method is a multipurpose mechanical learning model developed from statistical mechanics and the information theory principle, which explains the probability distribution of having maximum entropy (Franklin, 2009). At an early stage of development, MaxEnt was mainly used in the financial and astronomy sectors, but more recently it has also been used for species distribution modeling (Tuanmu et al., 2010; Kim et al., 2014; Jeong et al., 2015), landslide prediction (Felicisimo et al., 2012; Kim et al., 2013), and flood prediction (Kim et al., 2013).

MaxEnt is optimized to present-only data and allows the modeler to select flooded points and variables and to express non-parametric relationships (Phillips et al., 2006; Phillips and Dudik, 2008; Kim et al., 2014). When using absent data arbitrarily, the model is highly likely to have uncertainty; therefore, in this study a present-only data approach was selected. In this study, analysis was performed based on flood inundation maps for 2010 and 2011. Flooded and non-flooded areas were clear; however, to protect against potential future cases where the distinction is not clear, analyses were performed based on flooded areas only, excluding uncertain non-flooded areas. As shown by Elith et al. (2006) and Phillips et al. (2008), who used the receiver operating characteristics (ROC) curve analysis method, the MaxEnt model has the highest reliability among the models requiring present-only data.

When using hydrologic models, runoff can be estimated using sewer line information; however, identifying environmental features empirically is a challenge. Moreover, hydrological approaches require fieldwork and financial resources (Fenicia et al., 2013). In urban areas, the leakage or clogging of sewage lines can decrease the accuracy of hydrologic models, in addition to increasing the likelihood of flooding. These limitations to the use of hydrological modeling have led researchers to focus on empirical and data driven methods (Tehrany et al., 2013, 2015). In empirical models, basin features are analyzed for each point (i.e., not using a mean value) and data distortion is reduced. The application of MaxEnt in flood studies was proven by Kim et al. (2013). In this study, the freely distributed MaxEnt software package (version 3.3.3k) was used.

(2) Variable selection and data collection

The input data required for modeling urban flood vulnerable areas in Seoul city included flooded area data and relevant variable data. Flooded area data were based on 2010 and 2011 flood inundation maps of Seoul city (Figure 7). The established model well recreated the flooded area data by extracting 2000 points through random sampling using Arc-GIS 10.1. The 2000-point sample size allowed the inclusion of most flooded areas. To test uncertainty, 1000 datasets were established by extracting 2000 points through random sampling performed 1000 times. The inundation map was split 70% and 30% for purposes of training and testing, respectively (Ohlmacher and Davis, 2003).

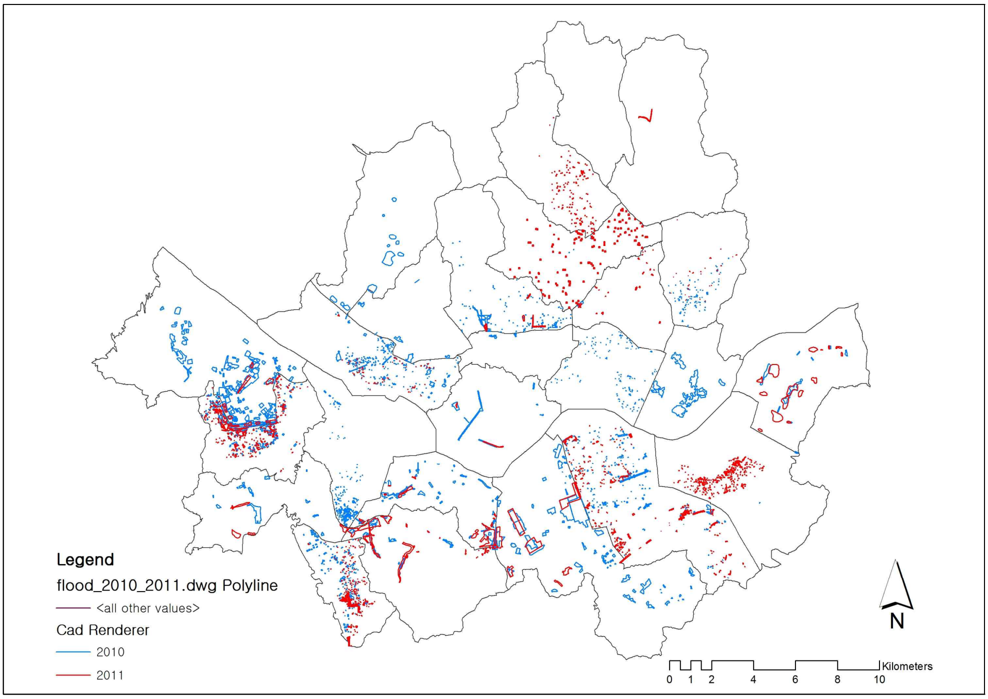


Figure 7. Flood inundation map in Seoul city

For variable data compilation, indices with a relationship to flooding were summarized from previous studies. Among the selected evaluation variables, variables suitable for evaluating adaptation ability to urban flooding were selected based on prominent correlations, and were then excluded from analysis. Finally, through consultation with experts, the final evaluation variables were selected. The variables for evaluating vulnerable urban flood areas included those related to the physical environment, climate, green spaces, and the artificial environment.

Physical environmental variables included slope, soil drainage, the topographic wetness index (TWI), and land use, with analysis performed based on 30 x 30 m grid unit. High precision topographic data are becoming increasingly available for flood application studies in most countries, which has had a direct impact on the output of modeling, as many previous studies were limited by a lack of appropriate topographic data (Bates et al., 2003). In this study, among the topographic variables, slope was selected as particularly significant to flooding and was constructed by generating a Digital Elevation Model (DEM) from a 1:25,000 scale numerical map. Soil drainage data were constructed based on a detailed soil map. TWI is a hydrologic factor that enables determination of wetness status using cumulative upstream flow at the time of rainfall (i.e., the area contributing to runoff) with a dischargeable volume (slope) over the relevant area. TWI shows the relationship between rainfall runoff and topographic features. TWI was calculated from the DEM using Arc-GIS 10.1 (Regmi et al., 2013).

$$TWI = \ln(A_s / \tan\beta)\cdot$$

For the land use variables, flooding probability in each grid was analyzed by dividing into detached housing areas, apartments, commercial, business areas, mixed areas, industrial areas, water treatment facilities (sewerage treatment plant, rainwater retaining basin, water distribution reservoir, water purification plant), other urban infrastructure areas, transportation facility areas, green spaces, open spaces and bare land, streams and lakes, and public facilities areas. After dividing the 12 categories as nominal variables, analysis was performed by generating dummy variables.

Analysis showed that flooding in 2010 was significantly affected by 3-day cumulative precipitation, while flooding in 2011 was seriously affected by maximum hourly precipitation; therefore, these were chosen as the climate variables. Based on automatic weather system (AWS) measurements, data for each area were constructed through interpolation using the spline method in Arc-GIS 10.1.

Green space variables were analyzed based on drainage basins where urban water is gathered, and included green space area (CA), number of green space patches (NumP). Each variable was evaluated based on raster using Patch Analyst in Arc-GIS 10.1, with data established later. Green space areas included paddy fields, fields, equipped farmland, orchards, nursery areas, planted areas, cemeteries, golf courses, botanical gardens, and grasslands, as identified using a 2010 urban biotope map of Seoul city.

Artificial environment variables included extension of sewer line against built-up area and presence of flood risk management infrastructure (e.g., pumping stations and rainwater retaining tank). Sewer line data was based on the basic plan of sewer line arrangement, location of pumping stations, retention basins, and rainwater retaining tank were constructed based on spatial data by Flood Prevention Information homepage of Seoul city. Analysis unit of artificial environment variables is drainage basins where urban rainwater is gathered. Selected variables for evaluating flood vulnerable area are as shown on following Table 6.

Table 6. Selected variables for evaluating flood vulnerable area

Variable	Analysis unit	Variables description	Type	Data
Climate environment	Point	3-day cumulative precipitation	Continuous	AWS
		Maximum hourly precipitation	Continuous	
Physical environment	Point	Slope	Continuous	DEM
		Soil drainage	Categorical	Detailed soil map
		TWI	Continuous	DEM
		Lnad use	Categorical	Urban biotope map
Green space environment	Drainage basin	Green space area (CA)	1/5,000	
		Number of green space patch (NumP)		
Artificial environment	Drainage basin	Extension of sewer line against built-up area	Continuous	Basic plan of sewer line arrangement
		Presence of FRMI	Categorical	

(3) Analysis of flood vulnerable area

Flooding probability was calculated by reflecting the relative contribution of each evaluation variable across the flood occurrence area. To assess changes in flooding probability as a function of each variable, we comparatively analyzed flooding probability based on a single physical variable and additional climate, green space, and artificial environmental variables. The accuracy of the model was measured through the AUC value, which calculates the area of the verifying curve based on the potential index value obtained using the flooded position and ratio for verification per equal area from the potential map. The AUC provides an independent reference value, and it is frequently used to compare models. Perfect models have an AUC value of 1.0; however, values over 0.8 are generally considered sufficient (Thuiller, 2003; Franklin, 2009; Gwon, 2012).

To evaluate the uncertainty, a random point was extracted 1000 times to produce 1000 flood prediction distribution maps. Based on a 30-m grid resolution, mean, standard deviation, and coefficient of variation values were calculated for each map. Standard deviation measures the absolute variation degree. However, when comparing multiple data groups with different measurement scales and central positions, comparison required the measurement of relative variation. The coefficient of variation is a relative variation index calculated by dividing standard deviation by the mean. High coefficients of variation suggest a wide variation from the mean (Lee and Noh, 2012). The coefficient of variation was used to assess the relationship between uncertainty and flooding probability.

The result of the flood prediction model were presented as flooding probability; therefore, to change to a flood/non-flood prediction map, a threshold of distribution probability was established based on a 'maximum training sensitivity plus specificity' value, in which the sum of sensitivity and specificity was maximized (Hu and Jiang, 2011; Tronstad and Andersen, 2011; Heibl and Renner, 2012; Jeon et al., 2014, Kim et al., 2015). This value represents the sum of probability that a flood occurred in an area where flooding was predicted and the probability that flooding did not occur in an area where flooding was not predicted.

Finally, based on the mean flooding probability value, drainage basin-sized flood vulnerable areas were identified. First, flooded areas were estimated in each drainage basin and then compared to establish a ranking, taking into account the built-up area to flooded area ratio.

2) Classification of urban flooded area type

The objective of dividing type of urban flooded area in this study is to maximize flood control effect through introducing green space by each regional features.

At first, 2000 points were extracted randomly from flooded areas based on a flood inundation map for 2011. Except for climate exposure variables that may change every year, variables were selected based on physical variables that have been shown to affect urban flooded regions in previous studies. Through analyses of the correlations between each variable before selection of the final variables, multicollinearity was observed, and variables with correlation coefficient values greater than 0.4 were excluded from further analyses. The variables that were finally selected for the flooded area type classification work included the presence of flood risk management infrastructure (FRMI), land use, slope, Topographic Wetness Index (TWI) and soil drainage. Based on these variables, cluster analysis was performed.

Cluster analysis is a method of forming a group among observed values having similar characteristics by finding out a certain common characteristics among observed targets. Clustering method is mainly divided into hierarchical clustering and non-hierarchical clustering. In hierarchical clustering, one cluster is permitted to be included in other clusters but overlapping among clusters is not permitted. Clustering method includes single linkage, complete linkage, average linkage, centroid linkage, WARD linkage (or minimum variance method) depending on a method of calculating similarity among each clusters. Generally used method is WARD linkage and this method minimizes loss of information to be occurred in a process of clustering (Ward, 1963). Non-hierarchical clustering analysis is used for grouping individual as cluster and K-means method is its typical method and it is effectively used for large data analysis.

Two-stage cluster analysis (Hair and black, 2000) was performed by using the standard scores of major variables affecting the flooded area in Seoul, Korea. In the first stage, this method determines cluster numbers and central points of early clusters using the Ward method, which is a hierarchical cluster analysis technique. In the second stage, cases belonging to each cluster are determined by the K-means method, which is a sequential non-hierarchical cluster analysis technique. Ward linkage is to minimize loss of information being occurred in a process of clustering by using Error Sum of Square (ESS) between cluster mean and individuals. Briefly speaking, if cluster mean for subject X_k should be X_{ik} in ith cluster, ESS in ith cluster is as follows.

$$ESS_i = \sum_{j=1}^{n_i} \sum_{k=1}^{p} (X_{ijk} - \overline{X}_{ik})^2$$

At this time, total ESS is as follows.

$$ESS = \sum_{i=1}^{i} ESS_i$$

The two-stage method is advantageous in that it minimizes the effect of cases that have large separation level impacts at the time of using the hierarchical method for only cluster formation (*i.e.,* it minimizes the impact of outliers). In addition, the K-means cluster analysis was judged to be suitable for this study, as it is capable of making meaningful analyses via changing numbers, even though the ultimate cluster number is determined by the researcher.

Discriminant analysis was performed in order to verify the results for flooded area types classified through this process. Discriminant analysis is a technique of predicting which sample would be belonged to which group by deducing discriminant function that classifies into a specific group after analyzing difference by each group based on already defined explanatory variable. Dependent variable is a categorized type variable representing belonged group of observed data and discriminant score is made through linear combination of independent variables.

As discriminant variables are used to differentiate flooded areas, statistical validation for differences in the mean points of the flooded area types is important to consider. In addition, group features can be identified through the central points of functional groups and canonical discriminant function coefficients. Fisher's linear discriminant function was deduced for each type, and then, by using these discrimination formulas, the results of the cluster analysis were re-classified. Cross-validation that applied relatively strict standards was used in this study.

As a next step, features of each flooded area type was comparatively analyzed based on re-classified 4 types of flood occurrence and by comparing with flood prone area[1] of Seoul, how frequently flooded area is belonged to which type was analyzed. In order to establish data for cluster analysis, Arc-GIS 10.1 was used and for cluster analysis, IBM SPSS 21.0 was used. Finally, by selecting typical sites based on 4 types, features by each type was verified through site survey and analysis of sectional view.

3) Analysis of flood control effect based on green space characteristics

Flood control effect based on urban green space area, type, and pattern of Seoul city by each flood type was analyzed in a statistical method.

(1) Model selection

Because the relationship between flood occurrences and factors that cause floods is explained multi-dimensionally, multivariate

1) Flood prone area is a region where flood damage is predicted repeatedly when rain is falling over designed rainfall.

analysis and a logistic regression model were used. In particular, logistic regression analysis was used when working with a binary variable or category variable in which the dependent variable had a value of 0 or 1 (e.g., the flood occurrence status). Therefore, non-flooded areas were identified through the classification function by classified flooded area type. The independent variables were continuous and categorical. The result values of the model deduced by logistic regression analysis were represented as flooding probabilities between 0 and 1.

The use of a logistic regression analysis for forecasting flood occurrences is advantageous for several reasons. First, an assumption that the variance and co-variance matrices are identical is not required (Lee and Sambath, 2006); second, significance tests of coefficients can be conducted rather easily; and third, correlations between each variable and flood occurrences can be analyzed (Kim, 2006). Lastly, independent variables can be selected via a repetitive selection and removal process during the establishment of the model, and the effect of other variables can be controlled in the model; this proved convenient for identifying the significant green space variables and environment factors that affected flood occurrences.

Meaningful variables by each features are found by performing logistic regression analysis based on three green space features including area, type and pattern of green space and four flood prediction models where variable by each feature is included are deduced. Maximum value of probability of each flood prediction model (p(X)) is 1 and its minimum value is 0. Logistic function being represented as S-shaped curved form is represented as linear form when it is converted to logit and its formula is expressed as follows.

$$E(Y|X) = p(X) = \frac{\exp(\alpha + \beta x)}{1 + \exp(\alpha + \beta x)}$$

$$\log_e\left(\frac{p}{1-p}\right) = \alpha + \beta X$$

Logistic regression model is similar to regression model excepting its dependent variable is log-odds value and it affects in selecting a specific alternative by explanatory variable. Therefore, binary logistic regression model is presumed by substituting efficiency by probability variable and through logit conversion process.

As eventual objective of predictive model is to establish predictive model having high accuracy including generalized minimum error (Maimom and Rokach, 2005), validation of model is required. The flood prediction model that was deduced through logistic regression analysis was verified via the Hosmer and Lemeshow (H&L) validation technique; contingency tables and the relative operating characteristic (ROC) curve were also used. The results for verification with H&L statistics were deemed not statistically significant at a level of $p > 0.05$.

Contingency table shows how accurately flooded area or non-flooded area is predicted to be coincided and AUC of ROC curve is used for evaluating prediction accuracy. Generally, when the area under the curve (AUC) value is greater than 0.7, the data from the model can be viewed as meaningful (Phillips and Dudik, 2008) and when the AUC value is greater than 0.8, the prediction accuracy can be regarded as high (Yilmaz, 2009). In addition, Hansson et al., (2005) divides explanatory power of model by discriminating AUC standard into 5 grades (0.9-1.0: excellent, 0.8-0.9: very good, 0.7-0.8: good, 0.6-0.7: average, 0.5-0.6: poor).

(2) Flood control effect based on green space area

In order to establish a model analyzing flood control effect based on green space area, most suitable unit that evaluate green space area was selected. Most significant variable was explored in order to analyze flood control function of green space by estimating green space area by each district and drainage basin and green space area in 100m, 150m, 200m, 300m buffer from flooded/non-flooded point. As its method, correlation analysis was performed by taking flooded status as dependent variable and explanatory power of each model was analyzed by performing logistic regression analysis based on such result. Afterwards, by summarizing two results, analysis unit of green space area was finally selected.

Flooded (1) and non-flooded (0) point variables were based on the four flooded area types. Random points of non-flooded area data were extracted and matched with the sample number according to each type based on the classification function being deduced at the time of the discriminant analysis. Maximum hourly precipitation data for each point were established through interpolation by the spline method using Arc-GIS 10.1 software and measurement data from Automatic Weather Stations (AWSs) for the city of Seoul.

Before deducing the model, green space features were observed by analyzing the current status of green space area for the city of Seoul and differences in the green space area for each type of flooded area. Finally, a model for analyzing flood probability change depending on green space area was deduced in a regression formula. To analyze the effect of green space area on flooding probability, other variables that affect flooding were fixed, then the flooding probability in each flooded area type was calculated. In the case of each fixed variable, where the minimum, average and maximum value for each variable was applied in the regression formula, flood probability depending on green space change was deduced according to the minimum, average and maximum values. The green space area and ratio required for reducing flooding probability were also considered by summarizing the data for the four types after performing an analysis with identical methods for each flooded area type.

(3) Flood Control effect based on Green Space type

Green space type was classified based on the SCS Runoff curve number (CN) and considered the antecedent soil moisture condition (AMC), the soil type, the land use, the vegetal cover treatment, and the hydrological condition. The CN value can reflect the hydrologic effect by an increase of the urban impervious area, and it is possible to estimate runoff quantity based on the data of hydrologic soil features and vegetation cover only without the actual measurement data for runoff quantity (Yoon, 1998; Kim et al., 1997).

The antecedent moisture condition (AMC)[2] in this study is the

2) AMC is called as antecedent soil moisture condition and it expresses moisture content of basin soil affected by antecedent rainfall based on a time of flood analysis as an index. This

most general soil moisture condition and determinant (AmC-II) of the runoff curve number for the design flood estimation technique (MOLIT, 2012) that is applicable to the water circulation simulation for a basin in ordinary times. The hydrologic soil group[3)] is classified into four groups based on the soil type affecting runoff, the land use, and the management condition. In the case of Seoul city, it was classified based on the soil features of green space. Forest soil belongs to group B, wetlands are in group D, and the remaining

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index is an important factor determining runoff quantity and it could be divided into 3 types as follows.

AMC	Characteristics
AmC-Ⅰ	AMC I conditions represent dry soil with a dormant season rainfall (5-day) of less than 0.5 inches and a growing season rainfall (5-day) of less than 1.4 inches
AmC-Ⅱ	AMC II conditions represent average soil moisture conditions with dormant season rainfall averaging from 0.5 to 1.1 inches and growing season rainfall from 1.4 to 2.1 inches
AmC-Ⅲ	AMC III conditions represent saturated soil with dormant season rainfall of over 1.1 inches and growing season rainfall over 2.1 inches. In general, curve numbers are calculated for AMC II, then adjusted up to simulate AMC III or down to simulate AMC

3) Hydrology basic and application (Yoon, 2009)

Soil characteristic	4	3	2	1
Soil type	Sandy Gravelly quality specifications	Sandy loam-Fine sandy loam	Clay loam-gravel sandy loam	Fine clay loam soil -Clay soil
Soil drainage	Well drained	Moderately drained	Imperfectly drained	Very poorly drained
Permeability (cm/hr)	Very rapid, Rapid (>12.0)	Moderately rapid (12~6.0)	Moderately slow (6.0~0.5)	Slow, Very slow (<0.5)
layer depth preventing infiltration(cm)	nothing	100~50	50~25	Under 25
Hydrologic soil group	A (>13)	B (12~11)	C (10~8)	D (<7)

green space soil is considered as group C.

Based on this, the green space of Seoul city was divided by CN value as shown in Table 7. The shaded part is the CN value suitable for Seoul city. Based on this data, the green space was finally divided into seven types, including planted areas, grasslands, wetlands, paddy fields, field/equipped farmlands, orchards, and forests. Planted areas include parks, golf courses, cemeteries, amusement parks, small-scaled sports facilities, and artificially planted grassland. Field/equipped farmland was one type and paddy fields and orchards were combined and classified as a different type.

Table 7. Hydrological soil group for green space type based on AmC-Ⅱ(MOLIT, 2012)

Green space type		Land use	Hydrological soil group			
			A	B	C	D
1	Planted area	Park	49	69	79	84
		Golf course	49	69	79	84
		Cemetry	49	69	79	84
		Amusement park	49	69	79	84
		Grassland (artificial)	49	69	79	84
2	Grassland (natural)	Grassland (natural)	30	58	71	78
3	Wetland*	Wetland	98	98	98	98
4	Paddy field	Farmland	78	78	78	78
		uncultivated area	78	78	78	78
5	Field	Specialty crop	64	75	82	86
	Equipped farmland*	Plastic house	59	74	82	86
6	Orchard	Orchard	44	66	77	83
7	Forest	Coniferous forest	48	69	79	85
		Decideous forest	48	69	79	85
		Mixed forest	48	69	79	85

* : CN value for land cover classification of land sat image (Bae et al., 2003)

For each green space, a statistical analysis was performed by using a logistic regression analysis after establishing how much of the seven green space types are distributed in the area identified within the 100-m radius from the point that was used in previous green space area analyses.

In order to explore which variable contributes most greatly to flood occurrence among the green space variables in the regression formula, the relative contribution affecting flooding was obtained by standardizing the non-standardized coefficient of each variable. In the logistic regression analysis, as each predictive variable has a different unit of measure, it is hard to compare the magnitude of the influence of each variable. Therefore, by obtaining the standardized coefficient, the magnitude of the influence of each predictive variable could be determined (Menard, 2004). Regarding the standardization method, both partial coefficient standardization methods and complete coefficient standardization methods are available. In this study, as its objective is to explore the relative contribution by each green space, the partial coefficient standardization method, with a relatively convenient calculation method, was selected. This method multiplies the SD of the independent variable by that of the non-standardized coefficient and then divides it by the assumed SD of the dependent variable (Agresti and Finlay, 1997).

(4) Flood control effect by green space pattern

In order to explore a relationship between green space patterns and flood occurrence, an analysis was performed using an index relevant to fragmentation analysis selected from among various landscape pattern indexes. The landscape index is a concept for representing the structure, the function, and the changing aspect of a landscape ecosystem; and it is a relative number, not an absolute number. In order to explore the distribution features of green space, an analysis was performed by selecting indices that may evaluate the size of a green space patch, the degree of scattering, and the irregularity of the shape of the green space.

A typical index representing green space size is class area (CA) and mean patch size (MPS). This is the simplest index measuring fragmentation. MPS is calculated by dividing green space area by the number of green space patches in a drainage basin (McGarigal et al., 2002).

As a variable evaluating the distribution of green space, NumP is used. This is an index representing the number of green space patches in a landscape patch or individual class, and it represents fragmentation. In a particular area, if a large number of patches exist, then the fragmentation level is high.

The variable evaluating irregularity of green space is AWMSI. AWMSI, an index of the area weighted patch form, is an irregularity index reflecting patch size. As this index approaches 1, it is a circular or rectangular form; and as its value becomes larger, it indicates a complex form. While a forest patch under natural conditions has an irregular patch form, a patch being created by artificial development, such as roads or, residential complexes, has geometric features (Lee and Yoon, 2008). A method of evaluating each landscape index is as shown in Table 8.

Table 8. Method of evaluating each landscape index

Criteria	Indices	Formula	Unit	Explanations
Fragmentat-ion	NumP	$\sum_{i=1}^{n} P_i$	none (count)	Where Pi refers to patch of type i
Size	CA	$CA_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}$	ha	Where a_{ij} equals to the area (m^2) of patch j for the ith land cover type; A is the total landscape area (m^2)
Size	MPS	$\frac{\sum_{i=1}^{n} a_i}{NumP}$	ha	Where ai is the patch size, and m is the total number of the ith landscape
Shape	AWMSI	$\sum_{j=1}^{n} [\frac{P_{ij}}{\min P_{ij}} (\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}})]$	none (without limit)	Where P_{ij} is the perimeter of patch ij, min P_{ij} equals to minimum perimeter of patch ij in terms of number of cell edges, and a_{ij} equals to the area (m^2) of patch j for the ith land cover type

An analysis was performed by using the Patch Analyst of Arc-GIS 10.1. This is an analytic program for landscape structure, where the quantitative evaluation of landscape is enabled based on the estimation of several indexes and an analysis for the landscape structure. A similar program, Fragstats, is available also. While Fragstats enables grid file analysis only, Patch Analyst is more convenient, as it enables existing feature file analysis. A landscape index could be analyzed on the level of the landscape element (patch), the landscape type (class), and the overall landscape depending on the objective. In this study, an analysis was performed by designating the drainage basin where water is gathered as a class.

Based on the drainage basin class, a logistic regression analysis was performed by extracting each landscape feature index as a point after performing the landscape index analysis for the green space patch. Through this analysis, a model for each flood type area was produced, and the contribution towards flood control was analyzed based on the green space distribution form by each type.

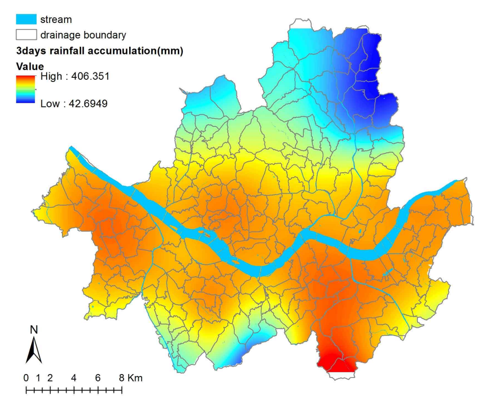
In addition, in order to observe the sensitivity of green space variables, flooding probability based on the change in green space was explored by using the mean value, the minimum value, and the maximum value for other variables, excluding the green space variable based on the formula. Through this, the flooding probability based on green space variables by each flood type was analyzed by determining the required green space pattern to reduce flooding by 10% and by 20%.

Ⅳ Results and Discussion

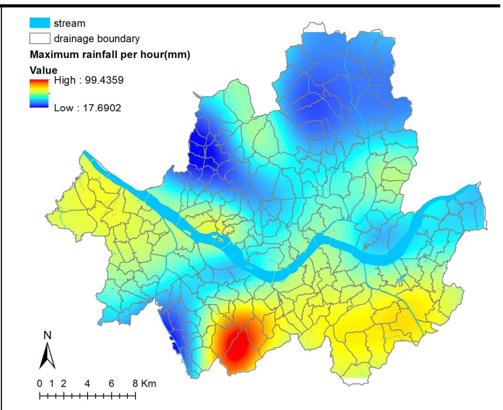
1. Analysis of urban flood vulnerable area

1) Compilation of analysis data

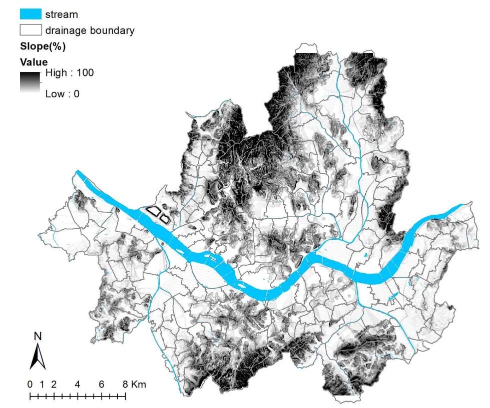
In this study, flooding factor variable required for flood vulnerable area is physical-environmental variable such as slope, soil drainage, precipitation variable, green environment variable and flood control facility variable and total 11 variables were used and a map being constructed based on this data is as shown on Figure. 8.



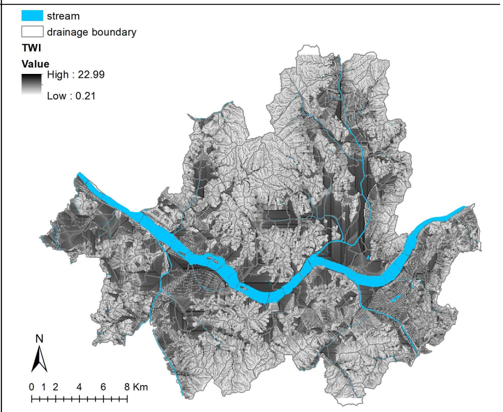
3-day cumulative precipitation (mm)



Maximum hourly precipitation (mm)

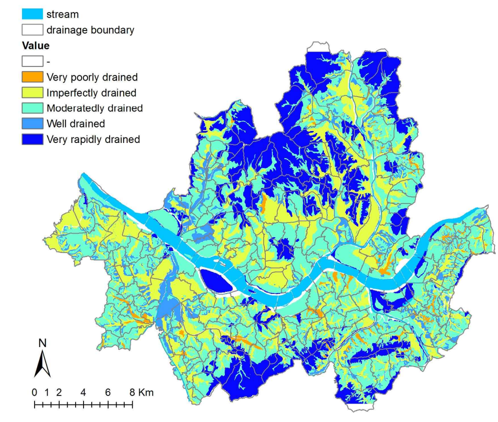


Slope(%)

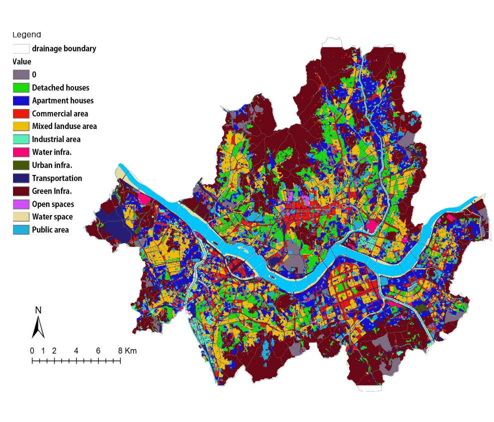


TWI

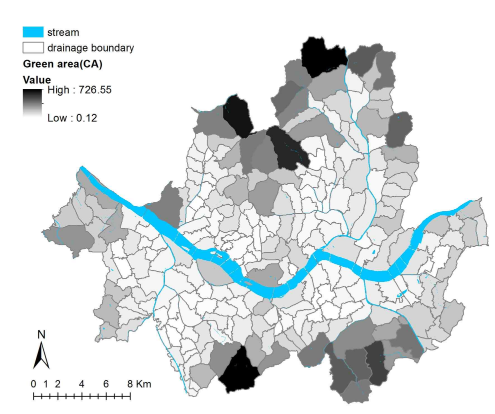
Figure 8. Base maps for flood vulnerability assessment



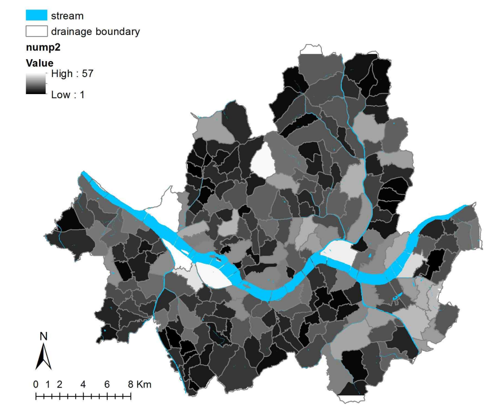
Soil drainage



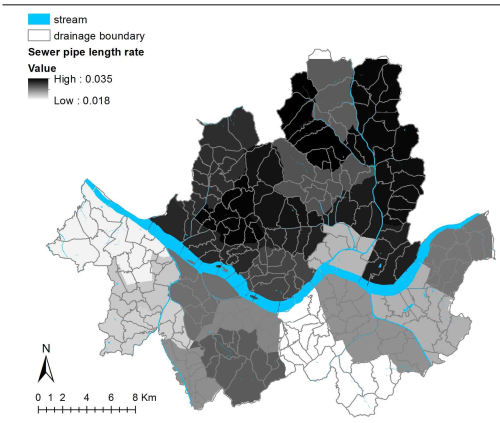
Land use



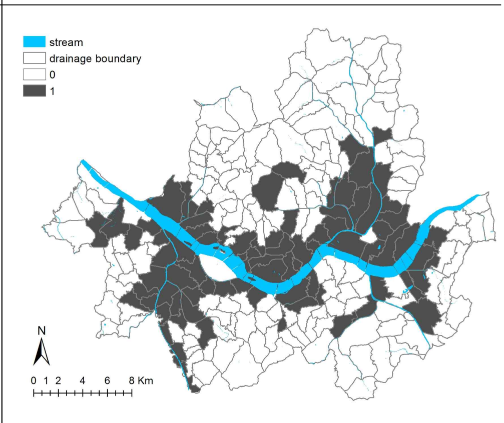
Green area (CA)



Number of green space patch (NumP)



Extension of sewer line against built-up area



The presence of Flood risk management infrastructure

Figure 8. Base maps for flood vulnerability assessment (Continue)

2) Analysis of Flooding probability by each variable

Flooding probability was analyzed using MaxEnt, a typical spatial statistical model selected for its research methodology. Among climate exposure variables, 3-day cumulative precipitation significantly affected the 2010 flooding. When precipitation exceeded 150 mm, flooding rapidly increased, and when it exceeded 300 mm, flooding probability increased significantly again. In contrast, maximum hourly precipitation impacted more significantly on the 2011 flooding, with increased precipitation leading to increased flooding probability, in particular when precipitation exceeded 55 mm. In contrast to 3-day cumulative precipitation, maximum hourly precipitation has a short-term impact and the level of damage may differ depending on land use.

For slope, flooding probability varied from 0 to 20% with gentler slopes associated with increased flooding probability, and flood is seldom taken place over 23% of slope. Increased TWI was also associated with rapidly increasing flooding probability until TWI equaled 5, after which the probability remained over 50%. Areas in which TWI exceeded 10 were considered to be rainfall concentration prone (TSI, 2011).

Soil drainage in Seoul is mostly dominated by moderate grades and the region's mountainous topography results in excellent drainage features. In Seoul, flooding probability was highest in areas with very poor or slightly poor soil drainage conditions, while areas with good soil drainage conditions had lower flooding probabilities.

For land use, flooding probability was highest for detached housing, mixed land use areas, and traffic facilities (e.g., roads). Mixed land use areas resulted in the highest flooding probability. Flooding probability was very low for green space areas, and low for open spaces and public land. Among green space environmental variables, flooding probability decreased as CA increased. In mountainous drainage basins on the outskirts of Seoul the flooding probability was low. In addition, NumP ranged from 1 ea to 47 ea, with higher values associated with lower flooding probability. The constant ratio between NumP and flooding probability suggests that its impact was more significant than the other green space variables. Among the artificial environmental variables, increases in the ratio between sewer line extension and built-up area were correlated with decreased flooding potential when a flood control facility was present.

Overall, land use contributed the most to flood probability (26.1%), followed by the Extension of sewer line against built-up area, slope, and soil drainage; however, of the green space environmental variables, CA contributed the most to flood probability, followed by, NumP (Figure. 9).

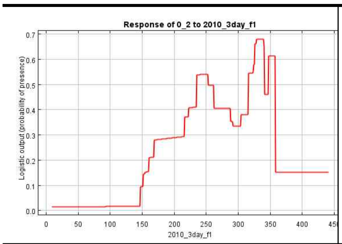
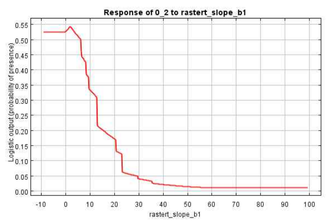
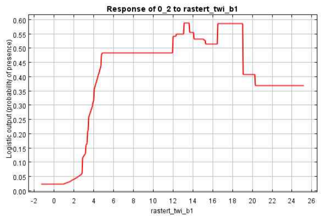
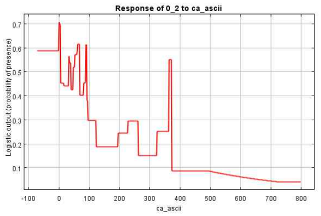
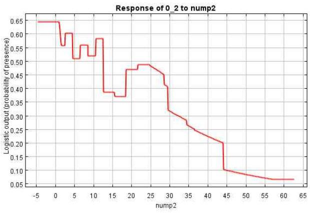
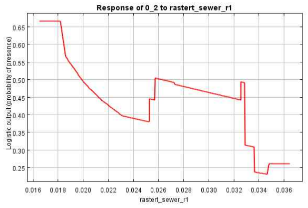
		
3-days cumulative precipitation	Slope	TWI
		
CA	NumP	Extension of sewer line against built-up area

Figure 9. Response graphs for variables provided by the MaxEnt.
(The horizontal axis is the variable value, while the vertical axis indicates the flooding probability)

3) Analysis of flood vulnerable area when inputting variables step-by-step

To analyze urban flood vulnerability stage-by-stage, each variable was added to the calculation in turn. First, the flood prediction map was calculated based only on physical variables (i.e., slope, soil drainage, TWI, land use), with the results showing a predicted flooded area with a maximum probability of 76%. Secondly, climate variables (i.e., 3-day cumulative precipitation, maximum hourly precipitation) were introduced and the maximum probability increased to 84%. For Nowongu and Dobonggu, 3-day cumulative precipitation and maximum hourly precipitation were relatively low, and this was reflected in the low flooding probability. In contrast, Gangseogu had heavy precipitation and as such the flooding probability was high.

Next, the green space area and number of green space patches variables were introduced, and the flood prediction probability increased to a maximum of 86%. For the Gangseogu and Yangcheongu drainage basis, which include extensive farmland and green spaces, flooding probability was seen to decrease. Finally, artificial environmental variables (i.e., sewer line extension against built-up area vs. presence of FRMI) were added and the flooding probability increased to a maximum of ~88%. A pumping stations are located in the Han River area, and its flood control efficiency is significant; therefore, it significantly lowers the flooding probability in numerous drainage basins, particularly Dangsan, Noryang 1, Heukseok, Dongjak, Changjeon, Shimwon, Hyochang, Juseong, Oksu, Seongsu 1, Jeonnong, Seongsan, and Bukgagwa. However, this was not reflected in the model, where only a 2% increase in maximum flooding probability was observed. The modeled result likely reflects the low elevation of the FRMI and the fact that its drainage function is poor and mostly enabled by the physical variables introduced in stage one. In summary, the addition of variables increased the explanatory power of the model, and in turn the accuracy of the flooding probability was increased. In particular, introducing green spaces and flood control facilities increased the flood adaptation ability.

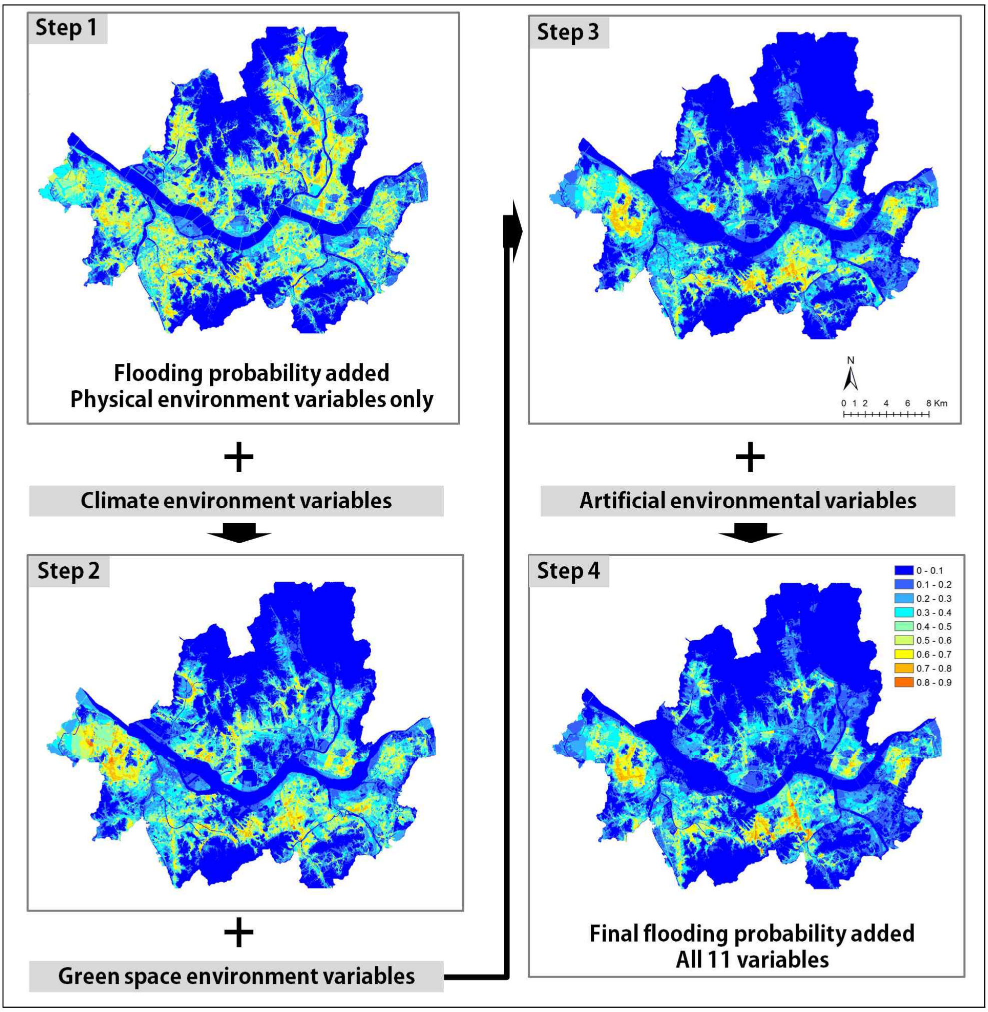


Figure 10. Analysis of flood vulnerable area when inputting variables step-by-step

4) Uncertainty in flood vulnerable area

In order to quantify the uncertainty introduced during random point extraction, a model was simulated by extracting random points 1000 times. As point extraction frequency increased, the mean value and standard deviation tended toward conversion. Once the random points had been extracted 1000 times, the values had essentially ceased to changed.

The mean values of the 1000 flooding probability results are shown in Figure 11. Maximum and minimum values for flooding probability were found to be 0.987 and 0, respectively. In comparison, the maximum value obtained through the 1-time extraction of random points was 0.88. Therefore, the differences in maximum value were significant and depended on the area from which the random point was extracted.

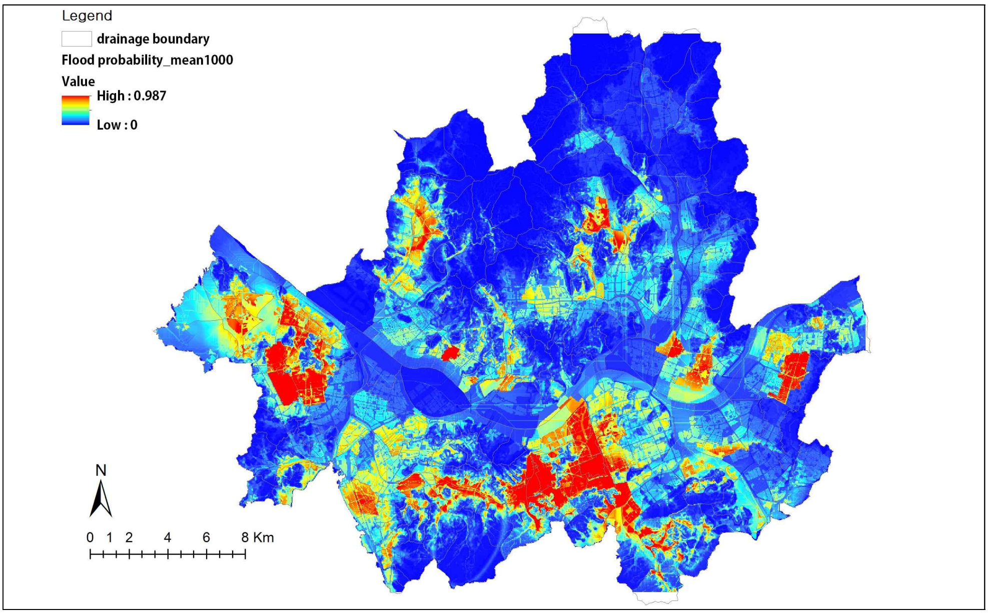


Figure 11. Mean flooding probability using the extraction of random points repeated 1000 times.

Uncertainty in flooding probability can also be observed through the probability distribution per cell. Uncertainty was analyzed using the coefficient of variation, with higher flooding probability found to be correlated with lower coefficients of variance, and vice versa, in particular for green space areas, which had low flooding probability but high coefficients of variance (Figure 12). Coefficients of variance ranged from 0.05 (5%) to 11 (1,100%), with most below 2.0. The highest values occurred for mountainous areas, where flooding probability was low and standard deviation was high. The mean flooding probability was highest in Seocho 4, and this drainage basin also had a very low coefficient of variance (0.07). In contrast, the Bangbae 1, Bangbae 2, and Sinwol 3 drainage basins had high flooding probabilities, but low uncertainty.

However, as the flooding probability ranged by just 1-2%, absolute deviation values (e.g., standard deviation; Figure 13) became meaningful for disaster risk planning. Standard deviation values ranged from 0 to 0.415. For the Seocho 4 drainage basin, where flooding probability was the highest, both the standard deviation and variation coefficient were low (below 0.1), confirming that uncertainty for this drainage basin was low and the flood risk very high. However, for northern mountain areas, both flooding probability and standard deviation were very low, while in the Yeoksam drainage basin, both flooding probability and absolute deviation were high.

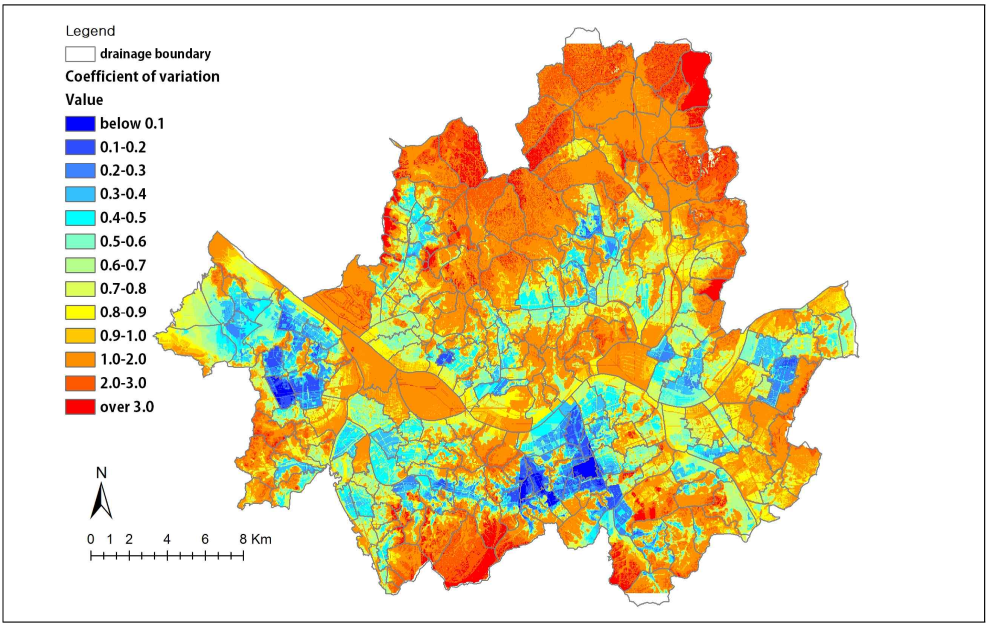


Figure 12. Coefficients of variation for flooding probability based on 1000 random point extractions

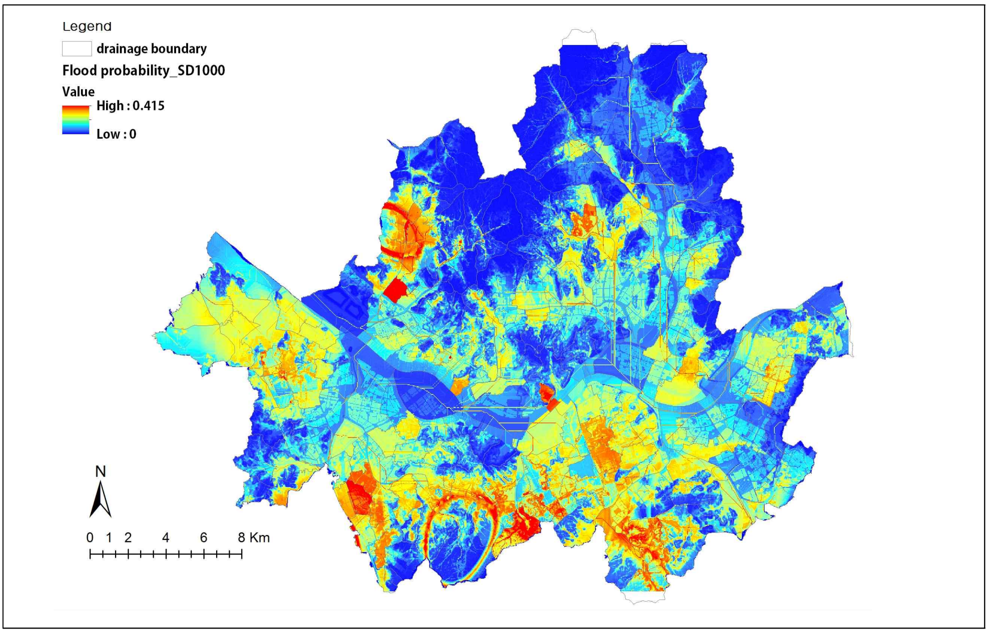


Figure 13. Standard deviations of flooding probability based on 1000 random point extractions

For areas where flooding probability was low but uncertainty was high, flooding probability may be increased by changes in flood inducing factors (e.g., rainfall); therefore, countermeasures for preventing flooding are required. Figure 14 shows the relationship between degree of uncertainty and flooding probability. For the Seocho 4 drainage basin (shown in red), uncertainty was low and flooding probability was high. The lower the flooding probability, the greater the range in uncertainty, while the higher the flooding probability, the smaller the range in uncertainty. An area in which floods occurred 2011, 2010, and 2001 (circled area) was shown to have very high flooding probability and low uncertainty, which provides validation for these results.

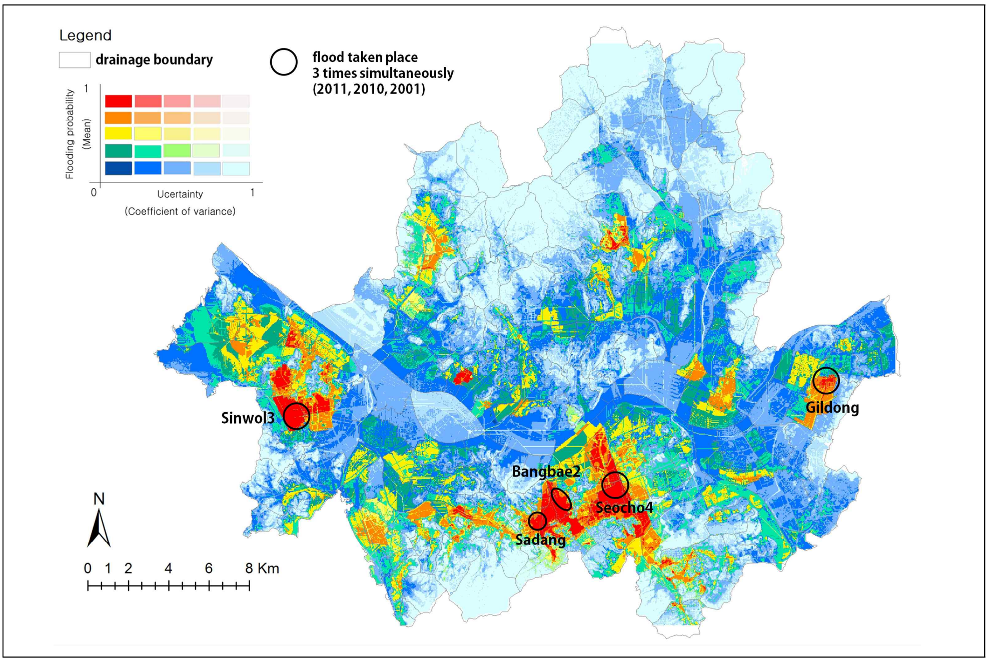


Figure 14. Relationship between flooding probability and uncertainty

The model, which analyzed data 1000 times, was shown to be reliable by an AUC value of 0.887 value, which was higher than the 0.852 value used by Kim et al. (2013) when evaluating flood prone areas. Furthermore, high prediction accuracy was achieved using fewer variables than in previous studies. Tehrany et al. (2015), who evaluated flood vulnerability by using an Arc-GIS based support vector machine model, achieved AUC values of 0.819-0.899 (0.870) with the DT method; therefore, their results had a similar explanatory power to those in our study.

Using a threshold value of 0.354, flood predicted and not-predicted areas were mapped. Among 239 drainage basins, floods have occurred in 193, accounting for 22.6% of the total area.

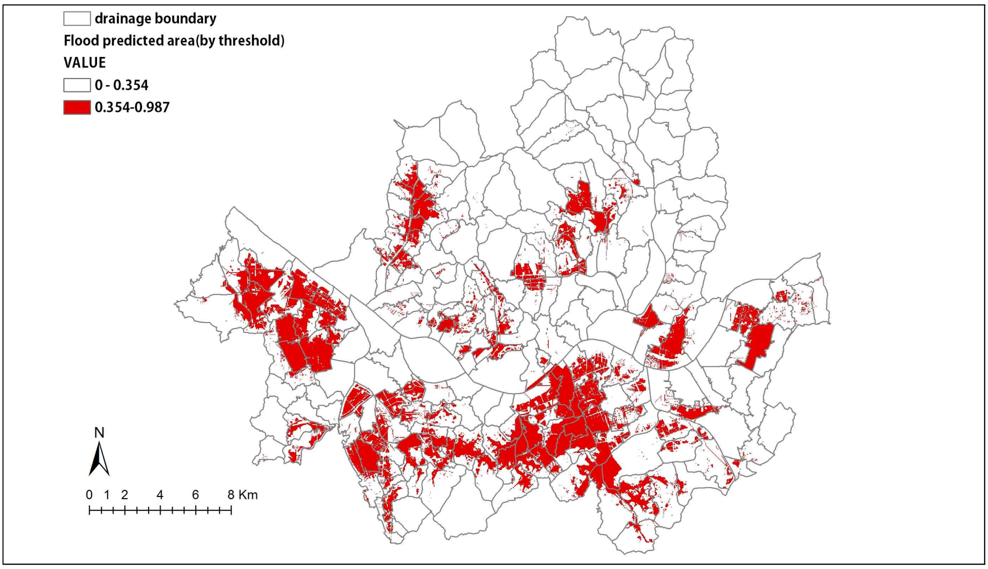


Figure 15. Flood predicted area by threshold

5) Analysis of flood vulnerable area based on drainage basin unit

Based on the flooding probability prediction map, flooding risk in each drainage basin was analyzed. First, using the 0.354 threshold value, the flooded area in each drainage basin was estimated and compared to the total drainage basin area and built-up area. The comparisons of flood prediction area and drainage basin area are shown in Figure 16. Drainage basins denoted in blue (43 of the 239 basins investigated) seldom experienced floods and the drainage basin area to flooded area ratio was less than 1%. In contrast, the drainage basins denoted in red had high flooding probabilities. Some 99% of the Seocho 4 drainage basin was predicated to flood, followed by Gildong, Sinwol 3, Sinsu, Bangbae1, Seocho5, and Shinwol 1, all of which had flood area predictions of over 90%. For the Hwagok 2 and Bangbae 2 drainage basins, more than 80% of the area was predicated to flood.

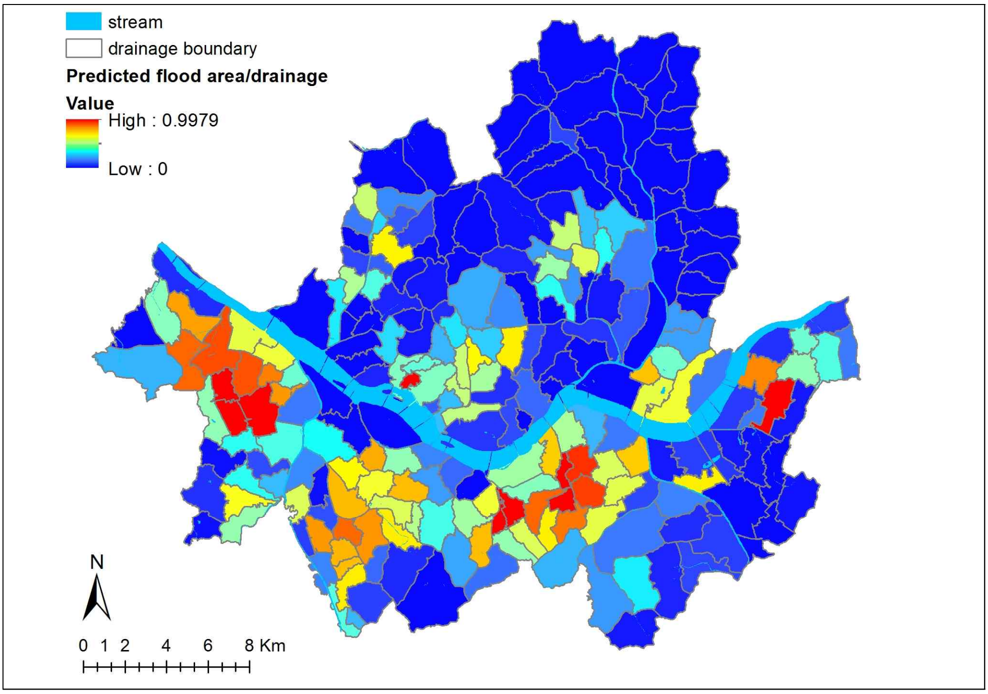


Figure 16 The ratio of flood prediction area against drainage basin area

Flood prediction area as a function of built-up area was also analyzed (Figure 17). The flooding ratio in green space areas was ~4.2% and flooding rarely occurred. In comparison, the ratios for mixed land use area (40.13%), and detached housing complexes (17.83%) were much higher. However, the ratios for green space areas, including forests, could have been underestimated because they were derived after extracting built-up areas from the drainage basins.

When comparing flood prediction area against built-up area, the Yeomgok drainage basin, which borders Guryongsan and

Cheonggyesan, accounted for a large area (255%). The Yeomgok drainage basin is mostly composed of forest green space and the built-up ratio is very small (8.9%), this basin thus had the highest value when flood prediction area was compared to built-up area.

The built-up ratio of the Gayang drainage basin was 47.3%, of which green space (e.g., farmland) accounted for over half, and the flood prediction area against built-up area value was 142.7%. The built-up ratio of Banghwa 1, which borders the Gayang drainage basin, was 53.6% and the built-up area vs. flooded area was 109.4%; therefore, this area is also prone to flooding. After Banghwa 1, the flooding ratio increased in the order: Seocho4, Woibalsan, Bangbae4, and Gildong. As in Namhyeon, the Woohyeon drainage basin is mountainous, and its built-up ratio is below 20%; therefore, the flooded area ratio against built-up area was high.

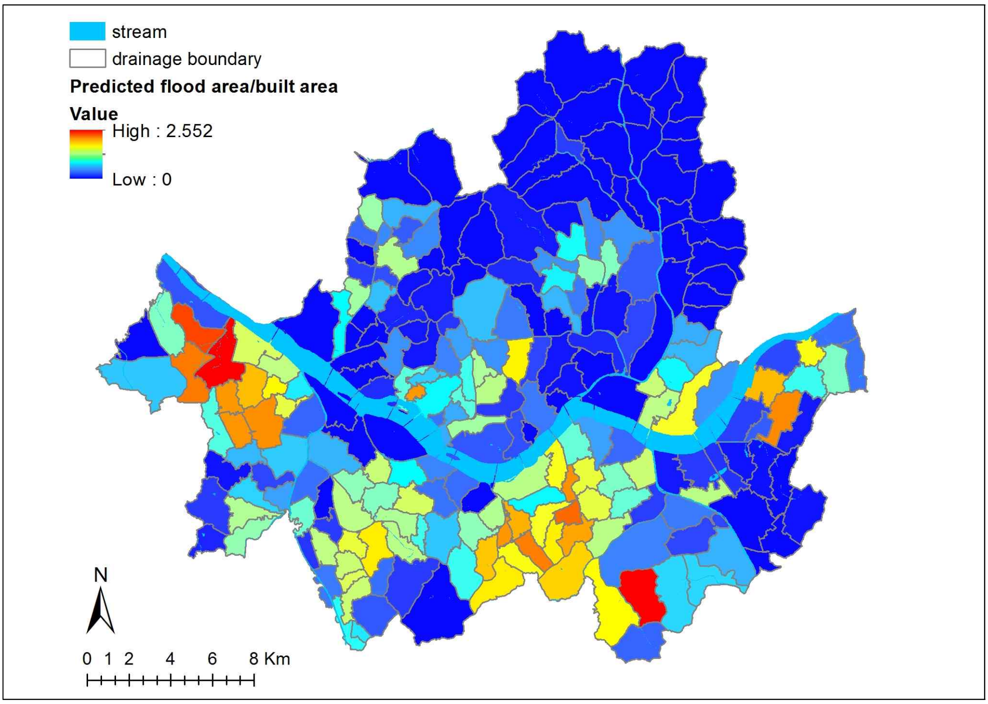


Figure 17. The ratio of flood prediction area against built-up area

The results of this study showed that flood prone areas include the Seocho4, Gildong, Sinwol3, Babgbae1, and Hwagok 2 drainage basins. These basins fall within the Seochogu, Yangcheongu, Dongjakgu, and Gangseogu administrative areas, in which extensive countermeasures are needed. Kang and Lee (2012) evaluated flood vulnerability in Seoul using a spatial statistical model and determined that Youngdeungpogu, Yongsangu, and Mapogu, which are located on both sides of the Hanggan river, are flood prone; however, they failed to consider flood control facilities (e.g., the pumping stations located around the Han River and other major streams). Therefore, the model produced in this study has a higher degree of accuracy.

The details of the flooded area in each drainage basin are shown in Table 9.

Table 9. Predicted flood area ratio by each drainage basin

Drainage basin		Ratio built-up area	Predicted flood area (ha)	Analysis 1 Predicted flood area against drainage basin		Analysis 2 Predicted flood area against built-up area	
Name	Area (ha)			Ratio	Rank	Ratio	Rank
Gayang	389.34	0.473	262.92	0.675	12	1.427	2
Goduck	137.52	0.380	39.71	0.289	78	0.761	26
Guee	530.64	0.615	242.31	0.457	43	0.743	29
Gildong	274.32	0.997	265.55	0.968	2	0.971	7
Namhyun	293.58	0.127	29.56	0.101	127	0.794	21
Daelim	124.92	0.911	80.84	0.647	16	0.710	32
Dolim1	270.72	0.942	151.46	0.559	26	0.594	45
Doksangoji	70.11	0.834	39.03	0.557	28	0.667	35
Doksanjuang ang	123.21	0.907	69.54	0.564	25	0.622	40
Deungchon2	87.21	0.802	54.34	0.623	18	0.776	24
Bangbae1	74.79	0.963	69.11	0.924	5	0.960	10
Bangbae2	136.89	0.892	110.22	0.805	9	0.903	15
Bangbae3	164.61	0.426	53.26	0.324	68	0.760	27
Bangbae4	156.24	0.421	65.32	0.418	53	0.994	6
Bangwho1	264.24	0.536	155.07	0.587	23	1.094	3
Sadang	183.33	0.640	102.08	0.557	27	0.869	18
Sangdo2	194.76	0.853	107.85	0.554	29	0.649	37
seocho1	188.73	0.876	122.51	0.649	15	0.741	30
seocho2	148.59	0.622	73.35	0.494	36	0.793	22
seocho3	178.47	0.686	113.40	0.635	17	0.926	14
seocho4	105.75	0.972	105.53	0.998	1	1.027	4
seocho5	81.99	0.943	74.56	0.909	6	0.964	9
Shingil	134.28	0.927	76.88	0.573	24	0.618	42
Sillim4	254.88	0.750	152.46	0.598	20	0.797	20
Sinsu	51.39	0.986	47.99	0.934	4	0.947	12
Sinwol1	152.28	0.957	137.86	0.905	7	0.946	13
Sinwol3	172.62	0.997	164.03	0.950	3	0.953	11
Yuksam	193.32	0.981	132.95	0.688	11	0.701	34
Yeomgok	409.23	0.089	92.63	0.226	90	2.552	1
Yoybalsan	323.73	0.652	211.44	0.653	14	1.001	5
Woomyeon	407.70	0.204	70.18	0.172	100	0.844	19
Wonji	489.96	0.188	70.48	0.144	111	0.767	25
Jamwon	201.42	0.711	107.51	0.534	32	0.751	28
Cheonho	308.97	0.692	190.22	0.616	19	0.889	16
Pildong	217.35	0.634	107.52	0.495	35	0.780	23
Hwagok1	228.42	0.757	153.30	0.671	13	0.887	17
Hwagok2	325.62	0.872	273.70	0.841	8	0.964	8
Hwagok3	100.71	0.844	59.79	0.594	22	0.703	33

2. Classification of urban flooded area type

1) Variable selection

The variables that were finally selected for the flooded area type classification work included the presence of FRMI, land use, slope, TWI and soil drainage.

FRMI is not a physical variable representing topographical features; instead, it is a dominant solution for preventing flood damage (Mount, 1995; Phillippi, 1996; Smits, et al., 2006). FRMI in this study includes pumping stations and rainwater retention tanks. In Seoul, it has been found that flooding rarely happens after FRMI has been installed in flood-prone areas. Land use also has a significant impact on the level of flooding, and in general, more vegetation density will decrease the tendency for flooding. Compared to forested areas, rainwater flows downward at a faster speed in non-vegetated areas during precipitation events (Lee et al., 2012; Tehrany et al., 2015).

TWI is often used to quantify topographic control on hydrological processes and is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction (Sørensen, R. et al., 2006). Soil drainage is an index that reflects the amount of infiltrating rainwater, and it is an important variable for predicting flood occurrence.

2) Classification of urban flooded area and its verification

First, as a result of observing the dendrogram from the hierarchical cluster analysis performed during the first stage of analysis, flooding was divided into four types. Data were also analyzed preliminarily according to three and five types of flooded areas through the non-hierarchical cluster analysis during the second stage, but the explanatory power and accuracy of the discriminant analysis results were optimal when four types of flooded areas were used.

Second, as a result of verifying the homogeneity of group averages, it was determined that the statistical probabilities for the variables, including land use, slope, TWI and presence of FRMI, were less than 0.001, and thus, these variables were very significant in the model; the average differences among variables for each of the four flooded area types were also significant. Larger F statistic values were associated with more discriminatory power, and the presence of FRMI had the largest discriminatory power among the five variables analyzed when these were used to divide the flooding into four types. The discriminatory powers for the other variables decreased in the order of the slope, TWI, soil drainage and land use.

Table 10. Test value for homogeneity of group average by each flooded area type

Variables	Wilks Λ	F	Sig.
Soil drainage	0.866	100.200	0.000
Land use	0.986	9.058	0.000
Slope	0.377	1073.310	0.000
TWI	0.425	877.064	0.000
Flood control facility status	0.008	77520.405	0.000

Third, through the use of canonical discriminant function coefficients (Table 11) and central points of the functional groups (Table 12), key characteristics of each group could be observed. One variable that contributed greatly to the division of Type 1 flooded area was the presence of FRMI. In the division of Type 2 and 4 flooded area, the slope variable made significant contributions to these groups, while TWI was a major factor for discriminating Type 3 flooded area. Canonical correlation at the relevant level between the discriminant function and groups was excellent, as indicated by the 0.996 correlation coefficient, and 98% of the total variance was explained by the model with an eigenvalue of 127.74.

Table 11. Canonical discriminant function

Description	Soil drainage	Land use	Slope	TWI	FRMI	Constant
Function 1	0.065	-0.018	-0.426	0.050	11.255	0.000
Function 2	0.064	0.087	1.157	-0.832	0.333	0.000
Function 3	0.090	0.122	1.127	1.330	0.021	0.000

Table 12. Central point of function group

Flood prediction type	Canonical discriminant function		
	1	2	3
Type 1	20.440	.043	-.003
Type 2	-6.764	4.364	2.235
Type 3	-6.075	-1.099	.326
Type 4	-6.449	1.265	-1.220

Fourth, the clustered types were re-classified using the discrimination formulas. Fisher's linear discriminant function that determines a discriminant score for each flooded area type was applied (Table 13).

Table 13. Fisher's linear discriminant function

$Z_1(\text{type1}) = 4.624X_1 + 0.812X_2 - 0.113X_3 + 1.972X_4 + 111.569X_5 - 76.389$
$Z2(\text{type2}) = 7.064X_1 + 0.930X_2 + 2.842X_3 + 1.373X_4 + 7.806X_5 - 42.109$
$Z3(\text{type3}) = 4.594X_1 + 0.689X_2 + 0.467X_3 + 2.134X_4 - 0.716X_5 - 22.455$
$Z4(\text{type4}) = 5.104X_1 + 0.706X_2 + 0.892X_3 + 1.104X_4 - 1.731X_5 - 14.716$
* X_1 = Soil drainage, X_2 = Land use, X_3 = Slope, X_4 = TWI, X_5 = Presence of FRMI

The discrimination accuracy rate as determined using a cross-validation technique was 98.1%. In the case of Type 1 flooded area, through the reclassification process performed by discriminant analysis, 459 places that had FRMI in place when flooding occurred were classified as Type 1, and the discrimination accuracy rate increased by 1.1%. Finally, among the total 1951 places where flooding occurred as analyzed in this study, 459 were classified as Type 1, 106 places as Type 2, 961 places as Type 3 and 425 places as Type 4.

Table 14. Comparison the results of existing cluster analysis with re-classification using discriminant analysis

Description			Flood type by discrimination analysis				Total
			1	2	3	4	
Existing cluster analysis	Frequency	1	456	0	0	0	456
		2	3	98	2	2	105
		3	0	2	940	4	946
		4	0	6	19	419	444
		Total	459 (23.53%)	106 (5.43%)	961 (49.26%)	425 (21.78%)	1951 (100%)

Through classification function (Table 13) dividing flooded area type, non-flooded area type was divided as shown on following Figure

18. Flood type division was performed for remaining area excluding an area where data for military zone was not available and flooded area. This division could be utilized as basic data for extracting non-flooded area required for future analysis of flood contribution depending on green space features.

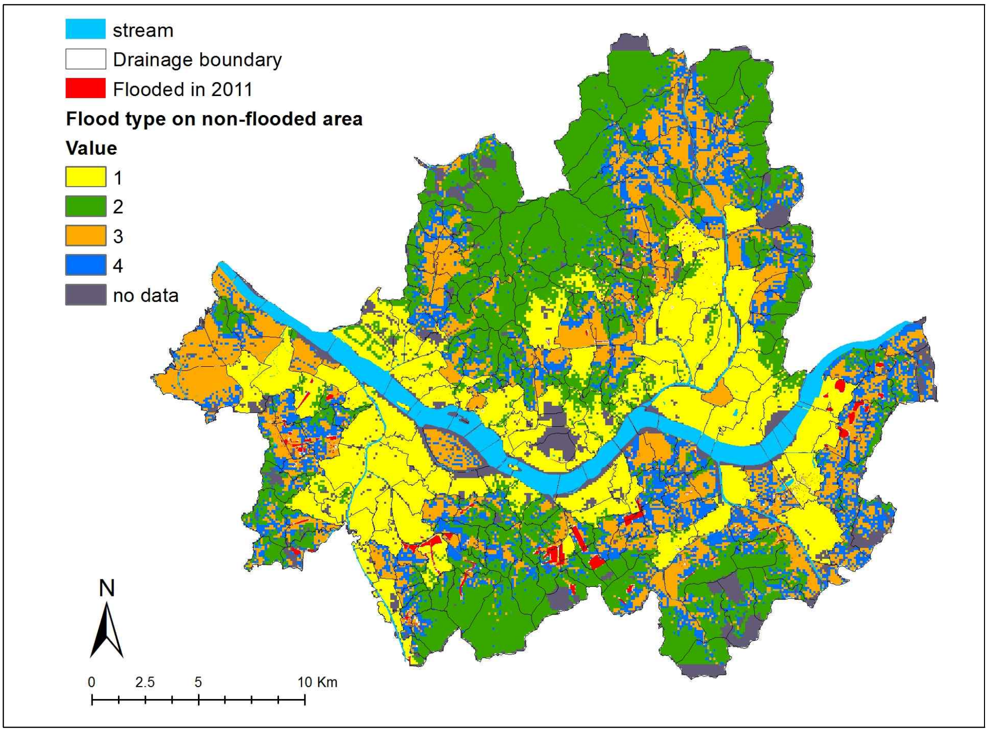


Figure 18. Type of non-flooded area using classification function

3) Physical properties of urban flooded area types

Statistical data for regional characteristic factors in each of the four types of flooded areas are summarized in Table 15 and map of Seoul city representing categorized result is as shown on Figure 19.

Table 15. Statistic features of flooded area type

Type	N	Description	Soil Drainage	Slope	TWI	Presence of FRMI	Land Use
Type 1	459	Average	2.61	1.61	11.95	Contained FRMIs (pumping station, rainwater retaining tank)	Mixed land use area ratio is the highest Located around river and streams
		Coefficient of variation	3.10	0.46	3.09		
		Min.	2	0.00	2.40		
		Max.	5	29.47	19.69		
Type 2	106	Average	3.48	14.06	7.38	None	Green space (forest) ratio is highest No commercial, business and industrial areas
		Coefficient of variation	3.56	3.35	1.76		
		Min.	2	7.86	2.53		
		Max.	5	30.01	19.95		
Type 3	961	Average	2.32	1.29	13.31	None	Detached housing and mixed land use area are relatively high Road ratio is the highest
		Coefficient of variation	3.27	0.72	7.70		
		Min.	1	0.00	9.93		
		Max.	5	8.50	20.24		
Type 4	425	Average	2.58	3.91	5.98	None	Low hill area is highest
		Coefficient of variation	3.46	1.70	3.41		
		Min.	1	0.00	2.78		
		Max.	5	10.00	11.17		
Total average in Seoul			2.70	3.22	10.75	-	-
	Average in flooded area		2.51	2.63	11.07	-	-
	Average in non-flooded area		2.89	3.82	10.42	-	-

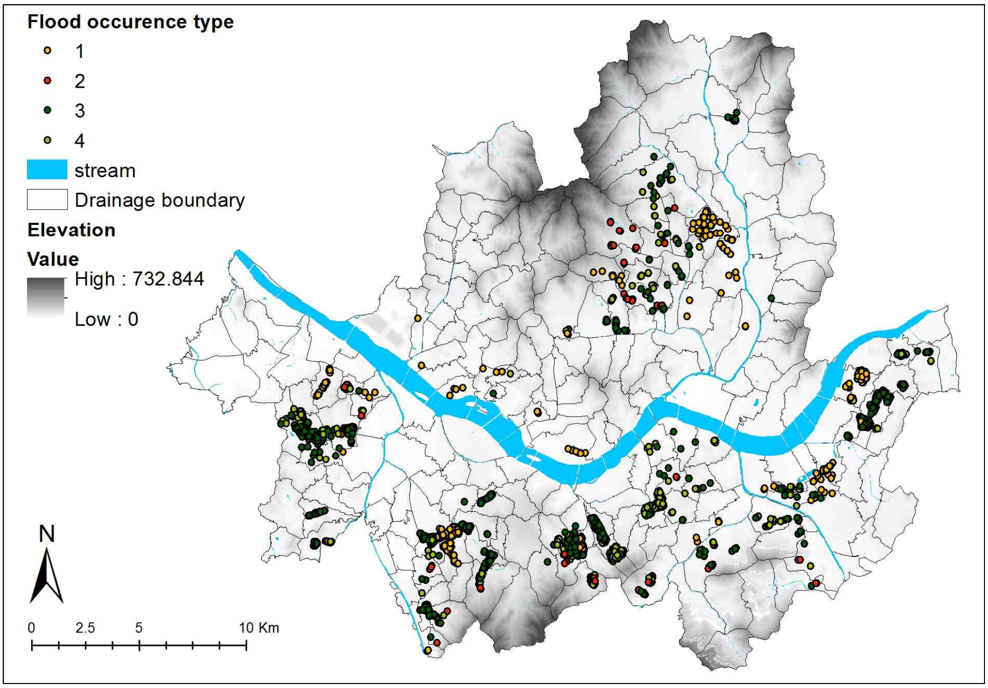


Figure 19. Separated Flood occurrence types

(1) Flooded area type 1

Type 1 flooded areas represent regions where flooding occurred in a drainage basin that contained an FRMI. Specifically, this is a region where FRMIs had been installed because flooding had occurred frequently in the past. The average slope for these regions was 1.61%, which was gentler than the 2.51% average for total flooded regions in Seoul. The TWI in Type 1 areas was the second highest after the TWI in Type 3 areas and was higher than the average for all flooded regions. Soil drainage was imperfect in these regions, which is a regional characteristic factor for high flood risk. Compared to other drainage basins, the occurrence of flooding was significantly limited in general here, but at the time of extreme rainfall in 2011, flooding was excessive, as the capacities of the FRMIs were overwhelmed in this region.

The Type 1 areas were mainly located around the Han River and major streams such as Dorimcheon of Sillim 4 drainage basin, Jangwi, Hwagok 1, Songpa 2, Cheonho drainage basin, and the mixed land use area ratio amounted to 45.5%, which was the highest among all four types. As semi-underground housing consisting of old brick structures is common in the Type 1 flooding areas, this region experienced heavy damage during the flood in 2011.

Sindaebang Station that is one of typical characteristics of type 1 is as shown on Figure 20. This region has roads being bordered with covered Dorimcheon and along the road,

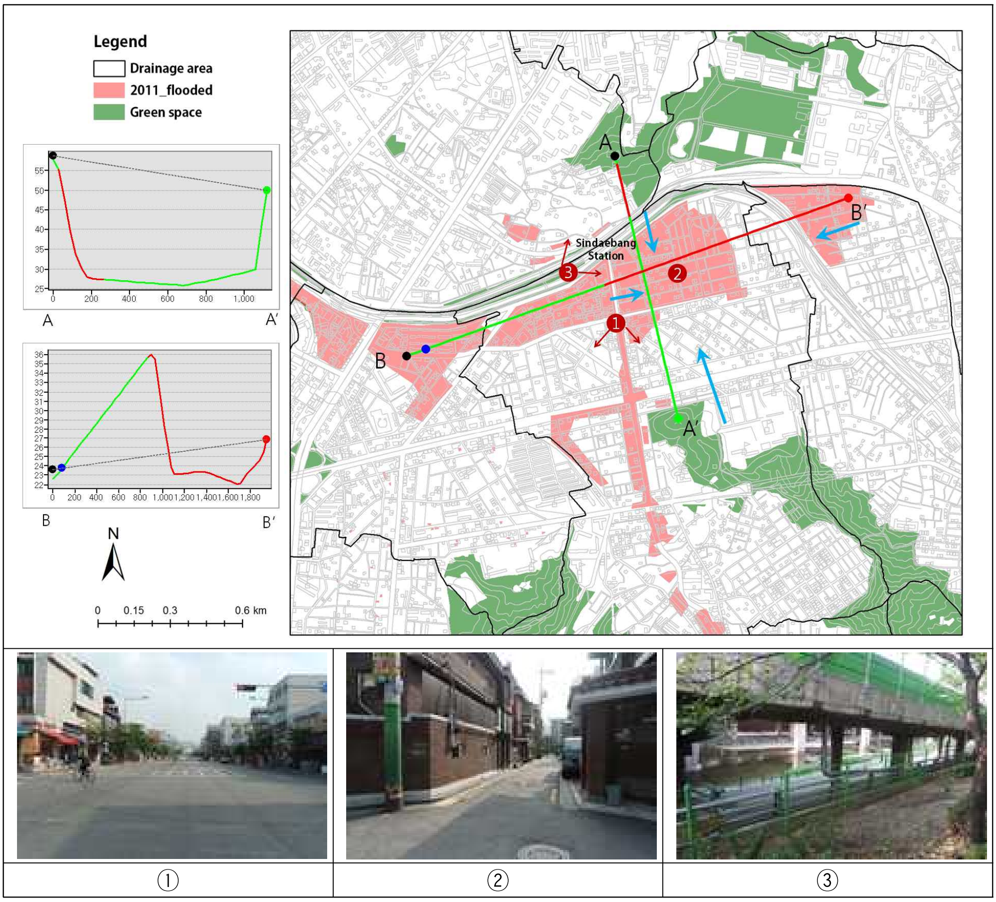


Figure 20. Type 1 : Sillim 4 drainage basin (pictured by author, June 19, 2015)

(2) Flooded area type 2

The average slope for Type 2 flooded areas was 14.06%, which was much steeper than the total area average (3.82%) for non-flooded areas in Seoul. The TWI value was relatively low here, and soil drainage was the most favorable among the four types. Landslides may be a concern for this area, given the steep gradients and vegetated hilly areas. Commercial, business and industrial areas were not present in this region. It was a place where water is prone to flow without attenuation, and hence, flooding did not occur frequently; when it did occur, inundated land in this region made up about 5% of the total flooded area in Seoul. These areas are bordered by mountainous terrain, and several newly-built detached houses are located here, along with many older brick houses. These structures are vulnerable to severe damage during intense discharge of water from the mountains to lower areas. Characteristics of Woomyeonsan landslide region that is a typical form of type 2 are as shown on Figure 21.

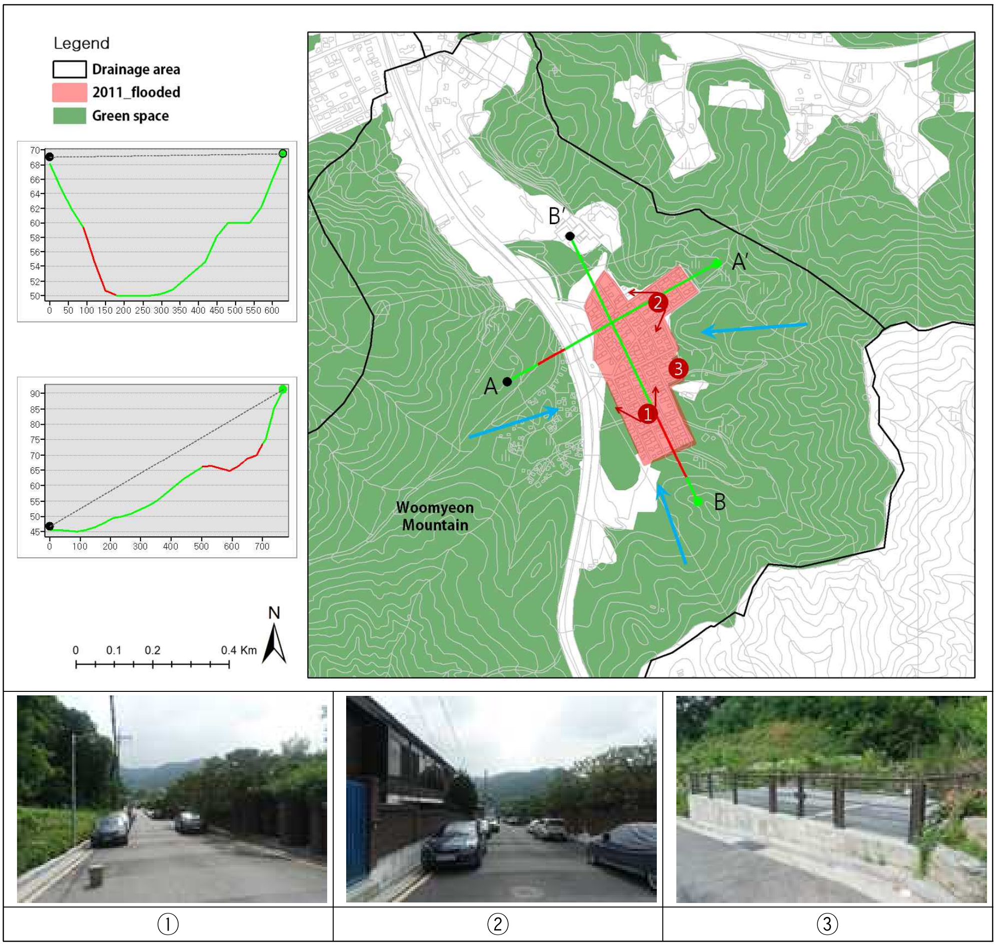


Figure 21. Type 2 : Woomyeon drainage basin (Pictured by author, June 19, 2015)

(3) Flooded area type 3

The average slope of Type 3 areas was 1.29%, which was the gentlest slope in the study areas, and the TWI was the highest among the four flooded area types. In addition, soil drainage was the worst compared to the overall average soil drainage of all flooded areas in Seoul. The ratio of detached housing area and mixed land use area was relatively high, and roads accounted for over 50% of the area.

Type 3 areas had geographical conditions conducive to water attenuation, contrary to Type 2 flooded areas. Given the high TWI values, this region will be prone to future flooding if appropriate drainage systems are not installed.

Type 3 is mainly located at Sadang, Bangbae, Sinwol1, Sinwol3, Hwagok2, Gildong and a part of Daelim, Sillim1, Sillim2 drainage basin in flood at Dolimcheon. Typical form of type 3 is located in around Sadang station as shown on Figure 22.

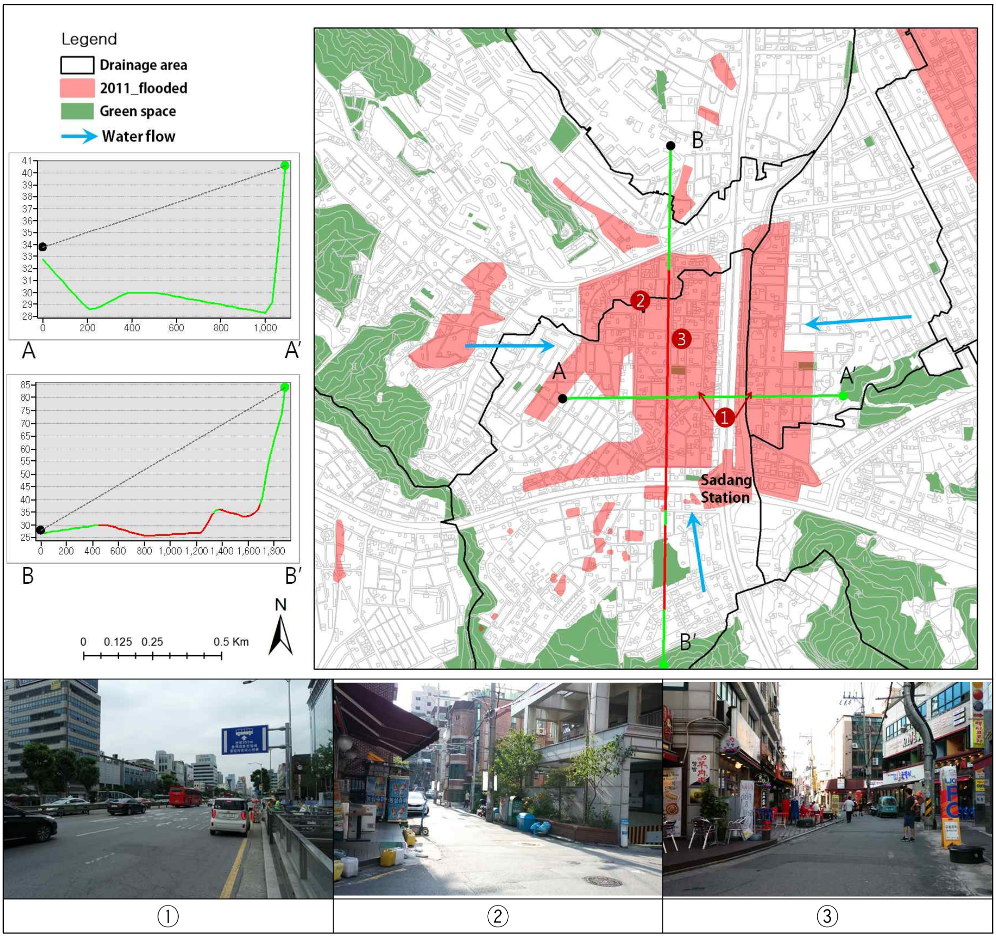


Figure 22. Type 3 : Sadang drainage basin (Pictured by author, June 19, 2015)

(4) Flooded area type 4

The average TWI value for Type 4 flood areas was much lower than the total average of 10.42 for non-flooded areas, and slopes here were moderate. Soils drain imperfectly in this region, as indicated by the soil drainage data. In general, this area had several features that fell between the values for Type 2 and 3 areas; in comparison with all flood area types, the Type 4 area represents a place where the flooding probability can be expected to change considerably based on precipitation.

Type 4 is located throughout Seocho 1, Seocho4, Nonhyeon drainage basin between Gyodae Station and Gangnam Station. In addition, flooded area under Woomyeonsan landslide area of Bangbae 4 drainage basin is included and partially located area neighboring with Type 3 area is present. Characteristics of an area bordered with Nambu ring road located at Bangbae 4 drainage basin is as shown on Figure 23. In this area, flood was taken place before by water flown down from Woomyeonsan as maximum hourly precipitation was increased and in sloped area, many newly built apartments are located.

Figure 23. Type 4 : Bangbae4 drainage basin (Pictured by author, June 19, 2015)

Road image connecting Gyodae Station and Gangnam Station that is connection point of Seocho 1 and 5 drainage basin is as shown on Figure 24. In every direction of an area where flood was taken place, water is collected due to location of slope and compared with Sadang Station of type 3, slope of surrounding area is steep. In its surrounding, apartments are located and it could be seen that its damage is minor than detached housing area.

Figure 24. Type 4 : Seocho1, Seocho5 drainage basin
(Pictured by author, May 9, 2015)

4) Comparison with flood prone area

Time of great flood in Seoul for the recent past 20 years is 1998, 2001, 2010 and 2011. When observing damaged area being represented in past flood inundation map, flood was taken place continuously as physical variables such as altitude, topography and underground soil property were seldom changed even though there is some difference depending on intensity of heavy rain. Park et al., (2013) finally selected 34 flood prone areas by using data of the regions that are extensively controlled by Seoul city as major flood vulnerable area.

As a result of comparing flood inundation map of 2011 with flood prone area of Seoul city in order to discriminate flood type in this study, overlapped part among 34 flood prone area was total 21 areas including Gangseo 1, Yangcheon, Seocho, Gangnam and in areas over 60%, flood was occurred repeatedly. Among the areas being designated as flood prone area, in case of the areas bordered with Songpa and Jungrangcheon, as recent flood was considerably reduced by installation of pump station compared with 1998, 2001 in the past, an area where flood is seldom occurred is also present as well.

When comparing based on occurrence year, overlapped ratio with flooded area in 2011 and 2010 was 37.57%, that with 2001 25.88% and that with 1998 4%, respectively and as year is changed, flooded area was changed by surrounding environment and flood control countermeasure. As flood prone area designated by Seoul city is based on its repeated occurrence for over 2 times, in case of areas where flood was occurred repeatedly in 1998 and 2001, an area where flood was not occurred recently was also included. Therefore, in this study, flood type was divided based on flood occurrence data of 2011 being taken place recently, not by using flood prone area and through this result, flood control effect based on green space features was analyzed.

When comparing features of flood type divided in this study with that of flood prone area where flood was taken place for over 2 times, features of type 1 was 26.70%, that of type 2 10.38%, that of type 3 43.08% and that of type 4 43.29% and it could be seen that flood prone areas are mostly distributed in type 3 and type 4.

5) Comparison with urban flood vulnerable area

Analysis result of division of flood occurrence area in 4 types and that of previously analyzed urban flood vulnerable area was compared. In case of type 3 of which slope is most gentle, TWI is the highest, average value of flooding probability was the highest as 0.582, places having flooding probability over 60% were most frequently observed among 4 types. Type 2 that has an opposite features had the lowest average value and its flood occurrence probability was represented to be very low. In other words, it could be realized that depending on regional features of flood type being divided in this study, risk of flood occurrence varies.

Table 16. Comparison flood vulnerability with Flood occurrence type

Type	Number of sample	Flood occurrence probability according to vulnerability assessment					
		flood occurrence probability	Frequency	Ratio	Average	Min.	Max.
Type 1	459	0-0.2	33	7.19	0.523	0.03	0.84
		0.2-0.4	99	21.57			
		0.4-0.6	146	31.81			
		0.6-0.8	170	37.04			
		0.8-1.0	11	2.40			
Type 2	106	0-0.2	42	39.62	0.293	0.02	0.77
		0.2-0.4	32	30.19			
		0.4-0.6	24	22.64			
		0.6-0.8	8	7.55			
		0.8-1.0	0	0.00			
Type 3	961	0-0.2	31	3.23	0.582	0.01	0.87
		0.2-0.4	156	16.23			
		0.4-0.6	239	24.87			
		0.6-0.8	474	49.32			
		0.8-1.0	61	6.35			
Type 4	425	0-0.2	39	9.18	0.550	0.01	0.85
		0.2-0.4	76	17.88			
		0.4-0.6	113	26.59			
		0.6-0.8	151	35.53			
		0.8-1.0	46	10.82			
Total	1951	-			0.545	0.01	0.87

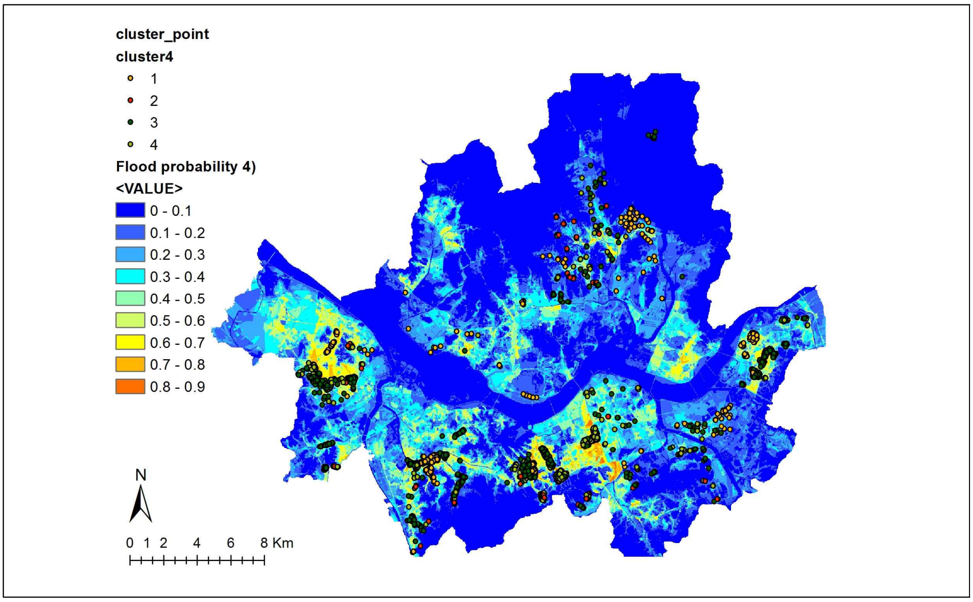


Figure 25. Flood vulnerability map and types of flood occurrence points

3. Analysis of flood control effect based on urban green space features

1) Flood control effect based on green space area

(1) Development of green space area variable

The green space variable represents ‘green space area within a radius of 100 m from the point’, and data were derived from a biotope map. Specifically, these data were calculated by aggregating absolute areas of green spaces within a 100-m radius from flooded and non-flooded points. As a result of establishing multiple logistic models with variables for green spaces within different distances from the point sources, it was determined that the accuracy of the model that contained green spaces within a radius of 100-m from the point was the highest.

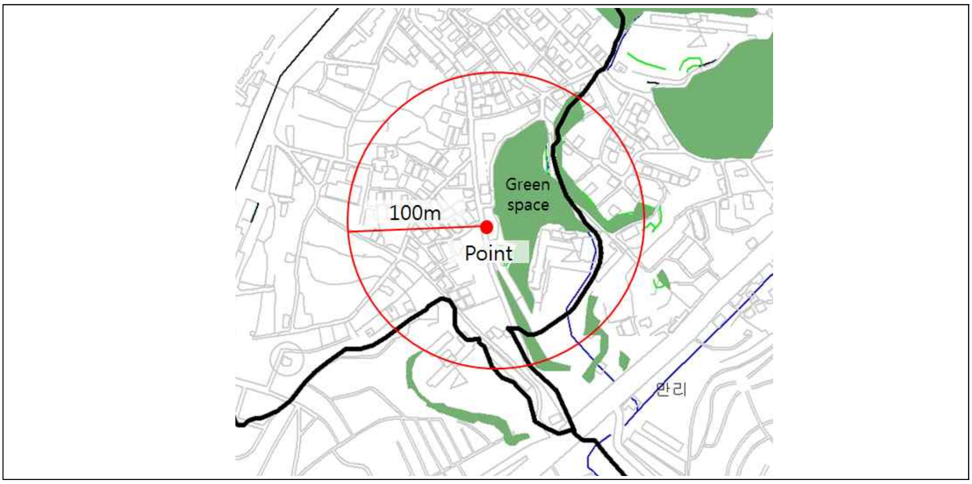


Figure 26. Example of a method estimating green space area within 100-m radius

(2) Characteristics of green space area

Green spaces in the city of Seoul amount to 212.41 km^2, taking up about 35% of the total area. Estimates of the green space area average within a 100-m radius from flooded and non-flooded areas in Seoul are shown in Table 17. The average green space ratio for flooded areas in Seoul city was 4.49%; for Type 1 flood areas, the green space ratio was 2.26%; and for Type 3 areas, the green space ratio was 2.81%, which are values that were below the average value for the city. For Type 2 flood areas, which border mountainous terrain, the green space ratio was 22.48%. The green space ratio within a 100-m radius in non-flooded areas in Seoul was 19.43%, which was very high. Division of total green space and flooded area type of Seoul city is as shown on Figure 27.

Table 17. Average green space area average within a 100-m radius from flooded and non-flooded areas.

Description		Average of Green Space Area within a 100-m Radius	Average of Green Space Area Ratio within a 100-m Radius
Non-flooded		6102.20m^2	19.43%
Flooded		1,410.40m^2	4.49%
	Flooded area type 1	709.78m^2	2.26%
	Flooded area type 2	7058.9m^2	22.48%
	Flooded area type 3	881.36m^2	2.81%
	Flooded area type 4	1,954.52m^2	6.23%

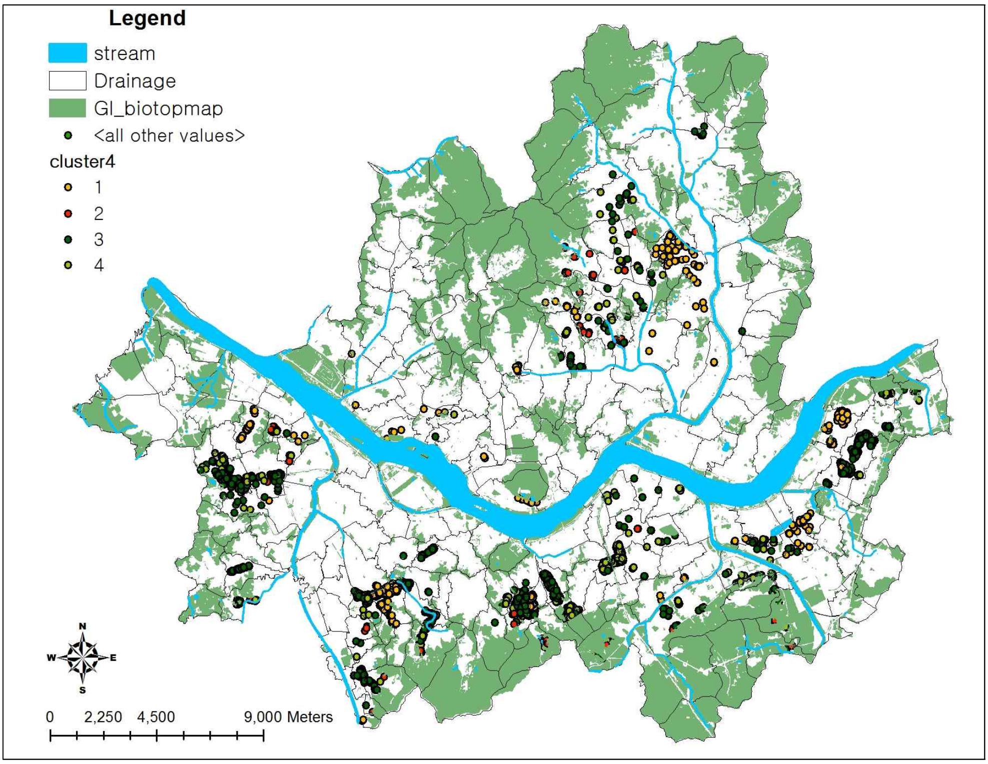


Figure 27. Green space and flooded area type of Seoul city

(3) Flooded area Type 1

For significant variables with the potential to affect the occurrence of floods in Type 1 flood areas, variables including the green space area, soil drainage, detached housing area and mixed land use area were selected as significant variables with the potential to affect the occurrence of floods in Type 1 flooded areas. The flooding probability will be decreased by increasing green space area and better soil drainage. According to the flooding probability model for Type 1 areas (Equation (1)), the probabilities of flooding in detached housing areas and mixed land use areas were 6.7-times and five-times higher than other areas, respectively.

Other variables affecting flooding included the TWI, slope and land use. As these were variables that were used in the previous cluster analysis to divide the study area into four types and because similar factors may be bound by each type, these variables were not selected as significant variables for the regression analysis. All of the variables were determined to be below the significance level of $p < 0.05$; hence, all such variables were statistically significant. The relevant equation is as follows:

$$\begin{aligned} P(x)\ \text{Type1} = {} & 0.499 - 0.116\ \text{Green space area} - 0.460\ \text{Soil drainage} + \\ & 1.614\ \text{Mixed land use area} + 1.896\ \text{Detached housing area} \end{aligned} \tag{1}$$

$$(\text{AUC}= 0.786)$$

Based on this, how flooding probability is changed depending on change of green space area was analyzed. After fixing other variables than green space area, flooding probability was deduced. Soil Drainage range in type 1 was minimum value of 1, mean value of 2.8, maximum value of 5 and range was taken as fixed variables. As Exp (B) value of detached housing area is bigger than that of mixed basin, graph was deduced on the assumption that maximum flood occurrence probability is estimated in case of detached housing area. The flooding probability was distributed from a maximum value of 94.19% (in areas where green space was non-existent, the drainage was very inferior and detached house was present) to a minimum value of 1% (Figure 28).

Table 18. The range of flooding probability according to green space ratio (Type 1)

Green space area ratio	Min.(%)	Average(%)	Max.(%)
0 %	27.87	73.48	94.19
10 %	21.16	65.81	91.94
20 %	15.70	57.19	88.93
30 %	11.46	48.13	84.97
40 %	8.26	39.23	79.95
50 %	5.88	30.96	73.75
60 %	4.15	23.69	66.35
70 %	2.92	17.76	58.17
80 %	2.05	13.04	49.59
90 %	1.43	9.44	40.83
100 %	1.00	6.75	32.71

※ Total area is 31,400㎡ and green area ratio refers to the percentage of the inner circle of 100-m radius from the point.

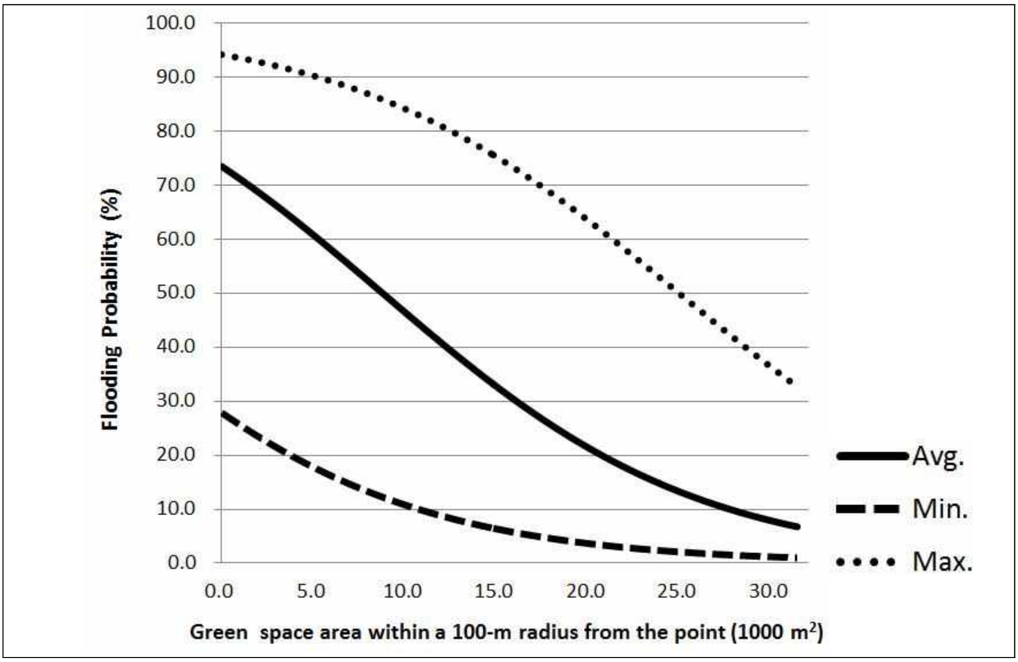


Figure 28. Flooding probability based on green space area (Type 1)

(4) Flooded area type 2

In Type 2 flood areas, green space area, slope and maximum hourly precipitation variables were selected as significant variables with the potential to affect flood occurrence. The estimated coefficient for all of the explanatory variables, except for the constant term, was statistically significant ($p < 0.05$), and more green space area was associated with a reduced occurrence of flooding in this region. During times of high maximum hourly precipitation and in areas with gentle slopes, flood occurrence was increased. The model seemed to yield reasonable results, and the observed accuracy was 91.4%, which was the highest accuracy among the deduced model of four flooded area types. The relevant equation is as follows:

$$P(x)_{\text{Type 2}} = 0.048 - 0.083\ \text{Green space area} - 0.174\ \text{Slope} + 0.079\ \text{Maximum hourly precipitation}\ (\text{AUC} = 0.914) \tag{2}$$

Type 2 was dominated by steep areas bordered by mountainous terrain. As mountain soil is rapidly saturated by regional torrential rains, debris flows occurred that contributed to the flooding. In the Type 2 area, detached houses are densely located in the lower part of the mountainous area, and serious damage is highly likely to occur here during future flooding events.

The flooding probability was distributed from a maximum value of 99.65% (where green space did not exist at all, the slope was minimum and maximum hourly precipitation was maximum) to a minimum value of 0% (Figure 29). Flooding possibilities are minimized in the mountainous area with the steepest slopes according to the deduced (Equation (2)). The steepest areas in the Type 2 flooded area are not considered vulnerable to flooding, because those areas quickly withdraw the exceeded amount of rainfall to the neighboring gentle sloped areas. In cases where the maximum hourly precipitation reaches 87.77 mm, the flood probability is predicted to be greater than 95% regardless of whether green space is increased; thus, this is an area where floods are inevitable, under the current conditions, at times of extreme rainfall. The installation of flood control facilities, such as rainfall retention tanks, would be valuable in such areas.

Table 19. The range of flooding probability according to green space ratio (Type 2)

Green space area ratio	Min.(%)	Average(%)	Max.(%)
0 %	0.00	63.74	99.65
10 %	0.00	57.53	99.54
20 %	0.00	51.01	99.40
30 %	0.00	44.56	99.23
40 %	0.00	38.27	99.00
50 %	0.00	32.30	98.71
60 %	0.00	26.86	98.33
70 %	0.00	22.07	97.84
80 %	0.00	17.95	97.23
90 %	0.00	14.39	96.42
100 %	0.00	11.47	95.41

※ Total area is 31,400㎡ and green area ratio refers to the percentage of the inner circle of 100-m radius from the point.

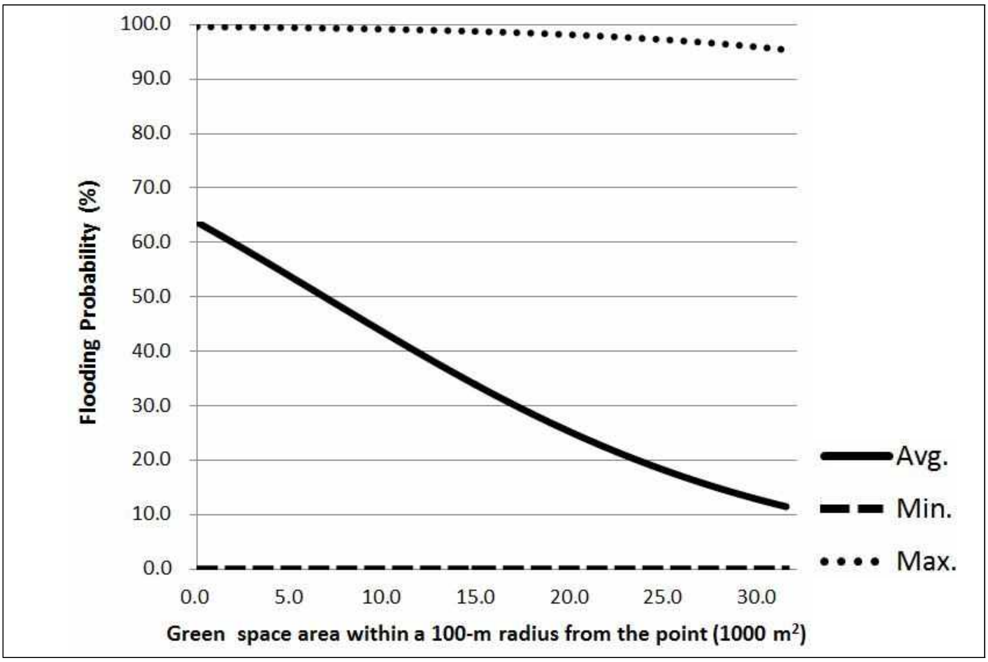


Figure 29. Flooding probability based on green space area (Type 2)

(5) Flooded area type 3

In Type 3 flooded areas, green space area, TWI and detached housing area were selected as significant variables with the potential to affect flood occurrence. As the green space area expanded, the flooding probability decreased, and higher TWI values and more extensive detached housing areas were associated with an increase in flooding probability. The estimated coefficient of all variables was very significant ($p < 0.005$). The explanatory capability of this model was 70%. The relevant equation is as follows:

$$P(x)_{\text{Type 3}} = -1.043 - 0.125\ \text{Green space area} + 0.086\ \text{TWI} + 1.168\ \text{Detached housing area}\ (AUC = 0.702) \quad (3)$$

The flooding probability was distributed from 75.92% to 0% (Figure 30). As TWI, detached housing status variable in addition to green space area and constant term are present, flooding probability was deduced after fixing such variable as shown on Table 20. The range of TWI in type 3 is distributed from 9.41 to 20.97, the average was 13.16, as the result which is generated flooding probability after fixing this variable, it is observed that the flooding probability is distributed from 75.92% (maximum value; in case of the green space area is not at all, TWI is 20.97, and housing area is detached) to 0% (minimum value).

The absolute estimated coefficient for green space area was the largest compared to the other types, and the variation of flood probability due to the change in the green space area was also the largest.

Table 20. The range of flooding probability according to green space ratio (Type 3)

Green space area ratio	Min.(%)	Average(%)	Max.(%)
0 %	44.18	57.41	87.30
10 %	34.83	47.65	82.28
20 %	26.45	37.99	75.80
30 %	19.58	29.31	67.89
40 %	14.14	21.90	58.85
50 %	10.01	15.92	49.13
60 %	6.96	11.30	39.39
70 %	4.82	7.93	30.53
80 %	3.32	5.52	22.99
90 %	2.26	3.78	16.70
100 %	1.53	2.59	11.92

※ Total area is 31,400㎡ and green area ratio refers to the percentage of the inner circle of 100-m radius from the point.

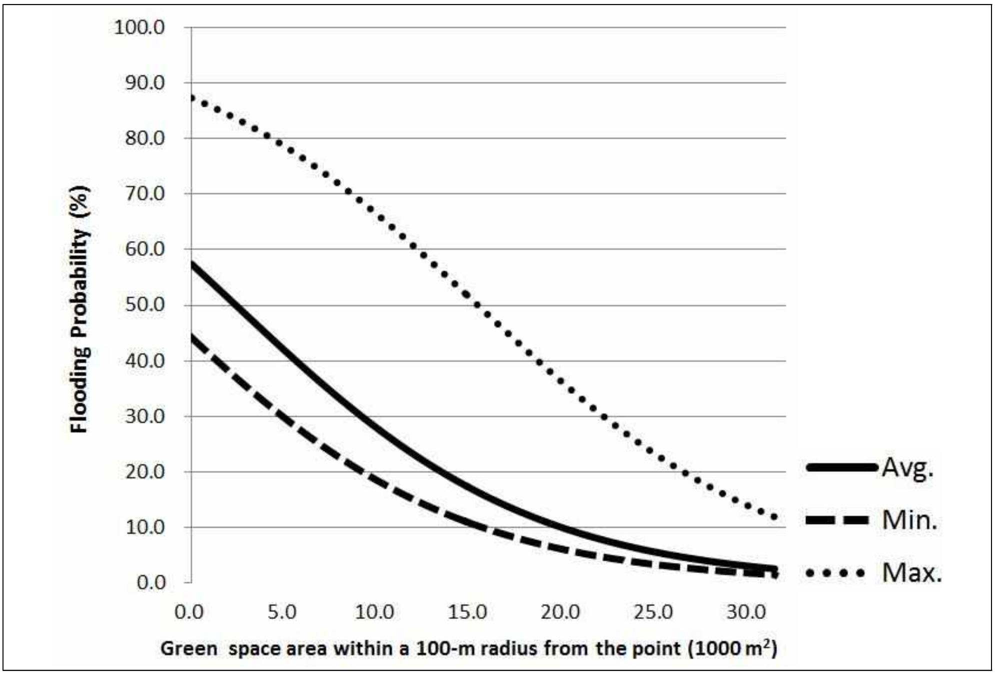


Figure 30. Flooding probability based on green space area (Type 3)

(6) Flooded area type 4

In Type 4 flood areas, green space area, soil drainage and maximum hourly precipitation were selected as significant variables with the potential to affect flood occurrence. When the green space area expanded and the drainage was good, the flood occurrence probability decreased. Conversely, when the maximum hourly precipitation was high, the flood probability increased. All of the variables were very significant ($p < 0.005$). The explanatory capability of the model was 75.6%. The relevant equation is as follows:

$$P(x)_{\text{Type } 4} = -0.997 - 0.085 \text{ Green space area} + 0.048 \text{ Maximum hourly precipitation} - 0.486 \text{ Soil drainage } (AUC = 0.756) \quad (4)$$

The flood probability was distributed from 96.04% to 0.52% (Figure 31). In cases where the maximum precipitation was high and soil drainage was poor, the flood probability was greater than 60%, even when the green space area was at the maximum level. In this region, flood probability was mainly affected by heavy rainfall, and the maximum flooding probability was associated with maximum hourly precipitation.

Table 21. The range of flooding probability according to green space ratio (Type 4)

Green space area ratio	Min.(%)	Average(%)	Max.(%)
0 %	7.08	56.82	96.04
10 %	5.51	50.19	94.89
20 %	4.26	43.50	93.41
30 %	3.30	37.12	91.58
40 %	2.55	31.15	89.29
50 %	1.97	25.73	86.46
60 %	1.51	20.93	82.99
70 %	1.16	16.86	78.89
80 %	0.89	13.47	74.16
90 %	0.68	10.63	68.67
100 %	0.52	8.35	62.66

※ Total area is 31,400㎡ and green area ratio refers to the percentage of the inner circle of 100-m radius from the point.

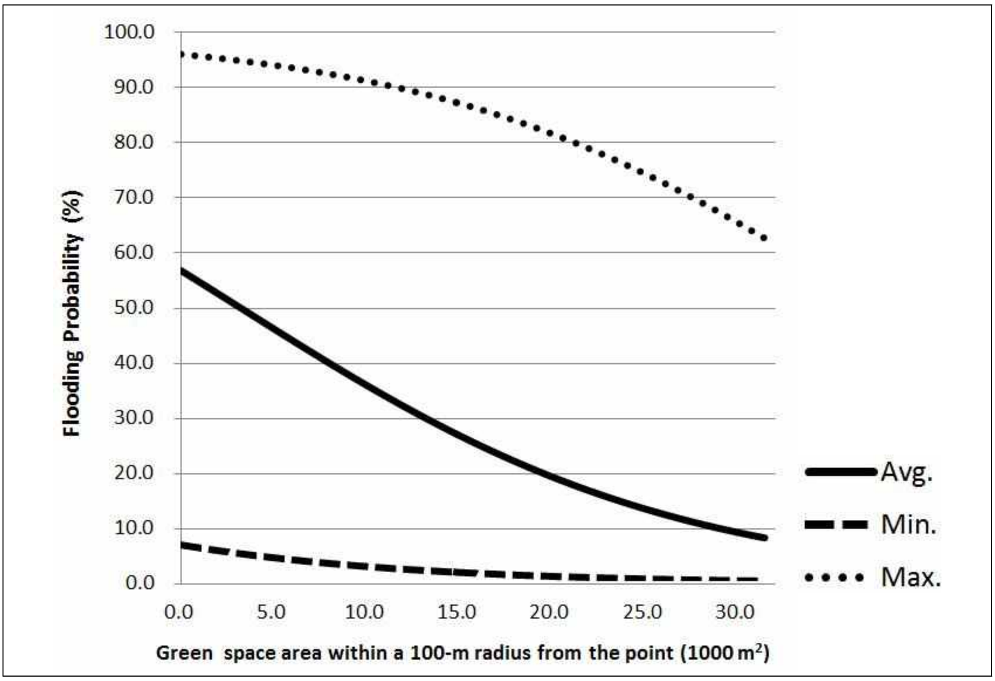


Figure 31. Flooding probability based on green space area (Type 4)

(7) Comparative analysis

Flooding probability is shown to differ with the variation of green space area in each flooded area type. First, when comparing average values in the graph gradients (Figure 28~31) to explore the effects of green space according to each type of flooded area, it was found that Type 1 flooded areas were the most amenable to flood control through increased green space area, followed by Type 3, Type 4 and Type 2. However, while the average value of the gradient was the highest for Type 1, up to about 7000 m^2 of green space area, the graph gradient of Type 3 was the highest among all of the areas. This means that compared to other flooded area type areas, the flood control capacity via green space is relatively large in Type 1 and 3 areas.

Sensitivity analysis of flooding probabilities through the green space area was performed based on Figure 28~31. Flooding probabilities for each flooded area type were changed by not only green space area, but also physical and environmental variables. Therefore, Figure 32 schematizes the difference between maximum and minimum of flooding probability due to green space area to show the scale of the sensitivity of flooding probability depending on the significant variables, except green space area. As a result, the sensitivity of flooding probability reduced as the green space area increased in all flooded area types. Moreover, in Type 3, a range of flooding probabilities due to green space area is the smallest among the four types in spite of other environmental variables' change, that is Type 3 has low sensitivity, followed by Type 1, Type 4 and Type 2.

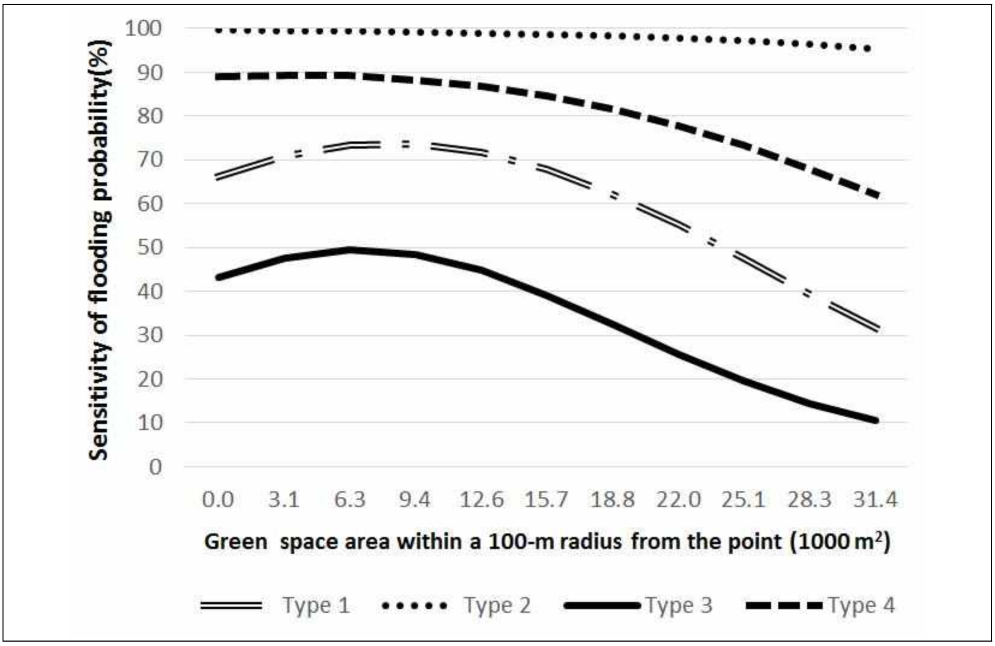


Figure 32. Sensitivity analysis between flooding probabilities

The Type 1 area, which is located in a drainage basin with an FRMI, was a flood-prone area before the FRMI was installed. Since the installation of a pumping station and a rainwater retention tank, the area has become less vulnerable to flood occurrences. It should be noted that in the case of no green space at all, the maximum value for the flood occurrence probability was the highest (73.48%) among the four types. In addition, the flood probability range, which went from a maximum of 73.48% to a minimum of 6.75%, was the greatest among the four types.

In Type 2 and 4 flood areas, when the maximum hourly precipitation was at the maximum level, the flood probability was greater than 60% despite changes in the green space variable; these represent areas where the maximum hourly precipitation significantly affects flood occurrence. Landslides are likely in this area, and these may be influenced by precipitation conditions, topography and geological features; landslides are apt to take place when external factors, such as rainfall impacts ground that has internal vulnerabilities (Kim et al., 2000; Yoon and Koh, 2012). Such a landslide occurred in the Woomyeonsan Mountains in 2011, resulting in 18 deaths, and was caused by flooding and the area's unique geographical features. In the area bordering the mountains, it would be prudent to install flood control facilities, such as rainfall retention tanks, in addition to green spaces, to prevent future flooding.

On the other hand, in the case of Type 3 areas, there were small differences in the flooding probability according to the hourly maximum precipitation. The maximum hourly precipitation variable was not designated as a significant factor. Flooding probability for

Type 3 was highly affected by TWI, green space area and the presence of housing rather than the distribution of precipitation. In particular, as flood occurrence was frequent in the detached housing area, mixed land use area, business area and roadway area, the flooding probability could be reduced effectively by introducing green spaces.

In the Type 3 flooded areas, the flooding probability was reduced to a minimum of 2.59% when the green space area in a 100-m radius is increased to the max. Compared to other types, it had the smallest probability values, and this is an area where the sensitivity to increases in green space area is high. When the green space area changed from 0 to 31,400 m^2, the gradient mean value of flood probability for Types 2 and 4 was similar. However, it could be seen that in the case of Type 2, when the green space area was less than 6940 m^2, it had a gentle gradient compared to Type 4, but at higher values, the graph gradient of Type 4 became gentler. Type 4 had intermediate geographical features between those of Type 2 and 3 and coexisted with Type 2 and 3 rather than achieving an independent existence in the model.

When observing the green space area of a place where the flooding probability was rapidly changing (inflection point), the inflection point occurred at 2380 m^2 in the Type 3 area where the flood control effect based on the green space area was significant. The inflection point can be considered to be an area where the cost-effectiveness of flood control based on increases in green space area is the largest. The inflection point is identical to the green space area required for reducing the flooding probability by 50%.

The green space area required for reducing the flood probability to a 50% increase was in the order of Type 3, Type 4 and Type 2 areas. Specifically, for the Type 3 area, if 7.5% of the total area is converted to green space, the flood probability will be reduced to less than 50%, while in Type 4 and 2 areas, only when 10.3% and 21.7%, respectively, of the total area is covered with green space will the flood probability be reduced by half (Table 22).

Table 22. Comparison of average probability for each type

Type	Co-efficient of green space	Cut-off value of green space area	Green space area to 50% flooding probability	Flooding probability(%)		
				Max.	Min.	Difference
Type1	- 0.116	8,790 m^2	8,790 m^2 (27.9%)	73.48	6.75	66.73
Type2	- 0.083	6,790 m^2	6,790 m^2 (21.7%)	63.74	11.47	52.27
Type3	- 0.125	2,380 m^2	2,380 m^2 (7.5%)	57.41	2.59	54.82
Type4	- 0.085	3,220 m^2	3,220 m^2 (10.3%)	56.82	8.35	48.47

To reduce the size of the area within 10% the flooding probability band in Type 3 areas, i.e., to 47.41% from 57.41% when no green space is present at all, a green space area of 3205 m^2 would be required, and this amount accounts for about 10% of the total area. Similarly, Type 2 would require a green space area of 4990 m^2 in size, which would take up 16% of the total area, to reduce the top ranking 10% of flood probability (Table 23, Figure 33).

Table 23. Green space area and ratio to reduce flooding probability band

Type	Description	(Green Space Area to Reduce by)			
		Upper 10% Probability	upper 20% Probability	upper 30% Probability	upper 40% Probability
Type1	area(m^2)	4,015	7,580	11,040	14,700
	ratio(%)	12.79	24.14	35.16	46.82
Type2	area(m^2)	4,990	9,830	14,950	20,900
	ratio(%)	15.89	31.31	47.61	66.56
Type3	area(m^2)	3,205	6,500	10,180	14,840
	ratio(%)	10.21	20.70	32.42	47.26
Type4	area(m^2)	4,730	9,570	15,040	22,030
	ratio(%)	15.06	30.48	47.90	70.16

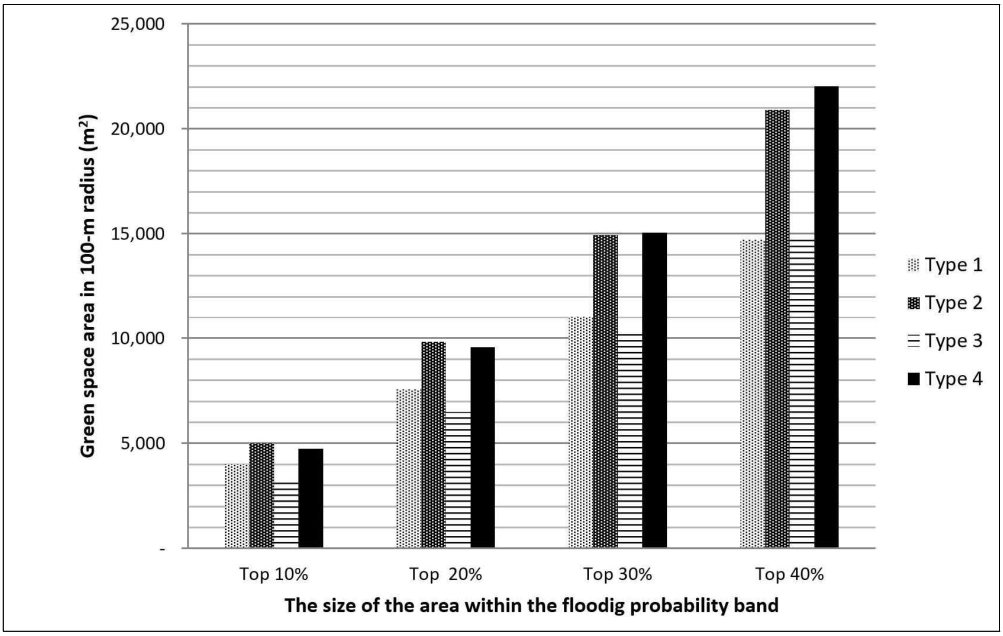


Figure 33. Green space area to reduce the size of the flooding probability band (Total green space area : 31,400m^2)

It is found that green spaces exerted a considerable influence on urban flooding probabilities in Seoul, Korea, and reductions in flooding were noted in several areas with greater amounts of green space. Moreover, different areas showed different sensitivities to the effects of green spaces, and flooding probabilities could potentially be reduced by more than 50%, depending on the amount of green space area and its introduced location. By Zhou et al. (2013), introduction of green spaces would be the best adaptation strategy for future flooding events through their use of a hedonic value evaluation method that considered the expansion of sewerage pipelines and construction of infiltration trenches. In a short-term perspective, expansion of sewerage pipelines may exert a significant influence on flood control, but in a long-term, sustainable and cost-effective perspective, increasing green spaces would represent an efficient way to control flood occurrences.

Green spaces were found to be more effective for decreasing flooding probabilities in Type 3 flood areas where the slope was gentle and the TWI was high, compared to Type 2 areas. This result is similar to one where it was found that creating green spaces such as street plantings in a concave rather than in a convex form by raising the elevation higher than surrounding roadways can be advantageous for reducing flooding by rainwater infiltration. In the case of reconstructing all green spaces in a community to a depth of 5 cm, it was found that runoff could be reduced by a maximum of 16% and the peak outflow by about 25% (Liu et al., 2014). Concave-shaped green spaces could be interpreted in the same context as Type 3 green spaces. This could also be applied to location selections for small-scale gardens at the time of green space planning for entire urban areas.

In the case of Type 3, the average value of flooding probability was the largest, and this was the most flood-prone area included in this study. On the other hand, the effect of green spaces on the reduction of flooding probabilities was greatest in these areas. Generally, in flood-prone areas, installation of large-scale rainwater retention basins as a short-term solution is the preferred method to control flooding. In this study, we found that the green space area has the potential to reduce flooding probability by less than 50% in all flooded area types.

2) Flood control effect based on green space type

(1) Green space type of Seoul city

In this study, green space types were divided into seven types of planted areas: grasslands, wetlands, paddy fields, fields, orchards, and forests. This was based on the runoff curve number (CN) method and the distribution of green space locations. The distribution of green space types are shown in Figure 34. In Seoul city, forests are observed in the northern and southern parts, and farmland is mainly distributed neighboring the forests. Grasslands and wetlands are near the side of streams and neighbor the main streams, such as the Hangang River, the Chunglangcheon, the Anyangcheon, and the Yangjaecheon.

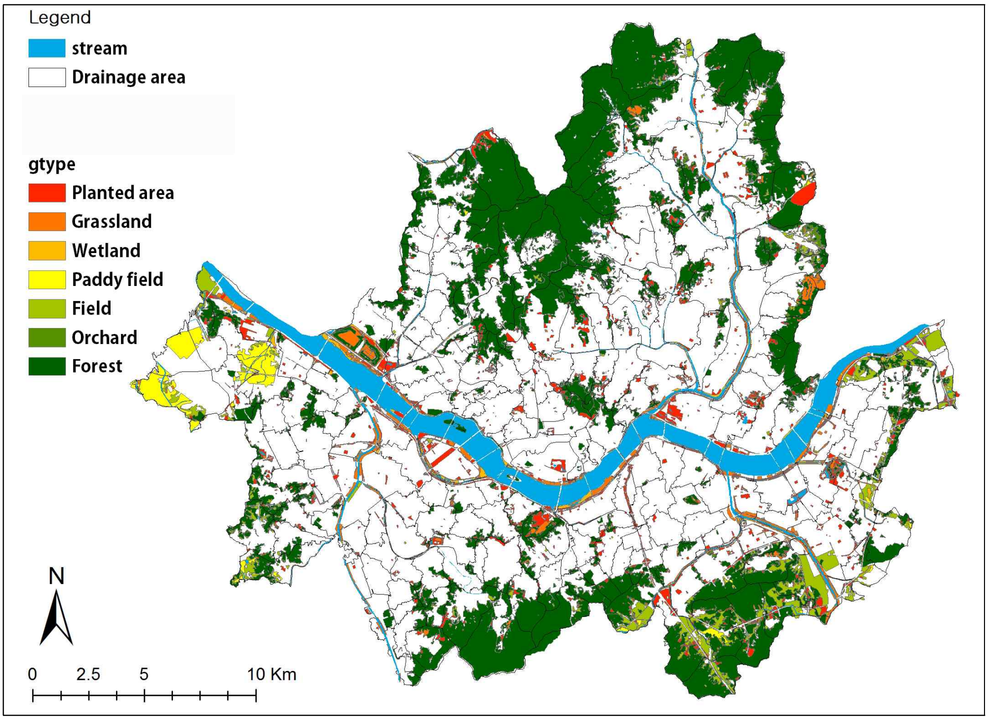


Figure 34. Green space type in Seoul city

In the overall green space of Seoul city, the forest area dominates and accounts for approximately 71%. This is followed by farmland (paddy fields, fields, and orchards) that accounted for 11.70%. Planted areas covered 10.39%, and grasslands and wetlands covered 6.85%. Analyzing this using the Kruskal-Wallis test for units of green space area within a 100 m radius, the result of the probability analysis was less than 0.0001. However, the average difference classified by the seven green space types into flooded versus non-flooded areas was significant. The green space type is definitely significant depending on flooded versus non-flooded observations.

The average green space area within a 100-m radius of a flooded area is 1,404 m^2. This is about one quarter of the level for a non-flooded area. Through this, it is observed that there is a difference of green space area distribution according to the flooded versus non-flooded characteristic. The forest is the largest area in all of Seoul city, and it dominates in both the flooded area and the non-flooded area. The portions are approximately 37.4% and 38.2%, respectively. The absolute green space area differs between flooded and non-flooded; however, it is realized that the area portions of all green space types are similar.

The total planted area of the flooded area is about 2.5 times larger than that of the non-flooded area, with the portion of total green space area accounting for approximately 30% in a 100 m radius from a flooded area and approximately 19.2% from a non-flooded area. The planted area is shown as a large portion of the flooded area. The planted area is mainly distributed in the downtown area with street trees and urban parks, and the downtown area has a high infiltration compared with other regions and is more exposed to flood risk. The flood mitigation effect of the planted area is less than that of other types of green space, because the permeability is lower than the natural ground, as it is mainly located in artificial ground as compared to the forests, the farmlands, the grasslands, and the wetlands.

Table 24. The average area of green space type in flood type (Unit : m^2)

Description	Seoul city		Area within 100-m radius			
			Non-flooded		Flooded	
	area (ha)	ratio (%)	area (m^2)	ratio (%)	area (m^2)	ratio (%)
Planted area	2,175	10.39	1169.6	19.2	429.8	30.6
Grassland	1,142	5.46	462.0	7.6	96.8	6.9
Wetland	291	1.39	152.7	2.5	1.3	0.1
Paddy field	712	3.40	691.8	11.3	4.7	0.3
Field	1,639	7.83	1257.8	20.6	338.8	24.1
Orchard	97	0.46	32.8	0.5	7.5	0.5
Forest	14,878	71.07	2332.3	38.2	525.2	37.4
Total	20.935	100	6,098.9	100	1,404.0	100

※ The total area within 100-m radius is about 31,416m^2.

As a result of analyzing the correlation analysis between each variable and the flooding status in Seoul city, the correlation coefficient of all green space types was represented to be significant below 0.01. It was observed that the forest had the most significant relationship with flooding, followed by the planted areas, fields, paddy fields, and grasslands.

(2) Flooded area type 1

Type 1 is a region that is located near a flood control facility. The pumping station is mainly located in lowland that neighbors the Han River and the main stream, and most rainwater retention basins are installed near forest areas. Due to these geographical conditions, the planted area, including an artificial grassland that is streamside and within a 100-m radius from flooded areas, accounts for an average of 518.1 m^2 (approximately 76%). The forests account for 19%, and the fields account for 2.7% as shown in Figure 35. The forests and planted areas neighboring non-flooded areas account for large portions compared with other types.

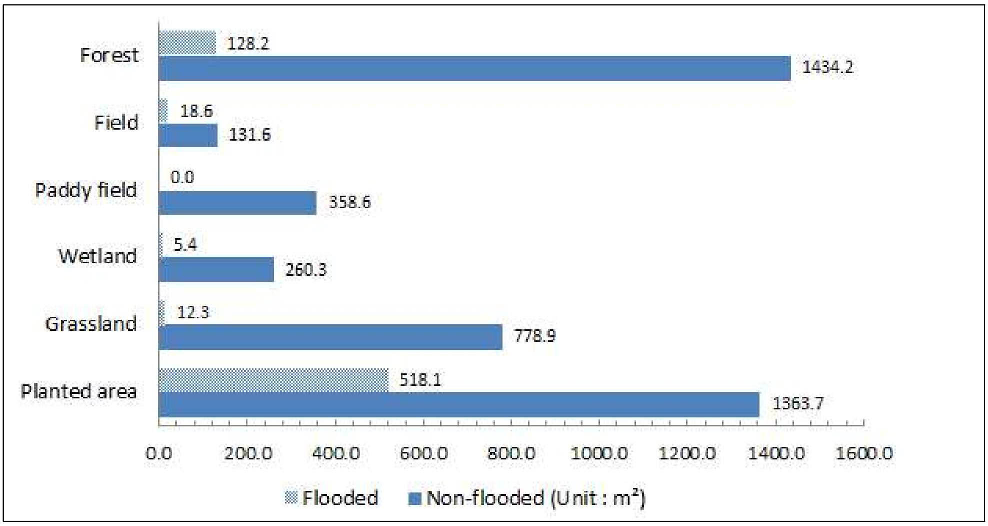


Figure 35. Mean area of green space type within 100-m radius from flooded and non-flooded point (Type 1)

The planted area neighboring with Dorimcheon located near the Shindaebang station is shown in Figure 36. The green space is next to the streamside near the road where flooding has taken placed. It was planted on a steep slope and is not suitable for absorbing the roadside runoff effectively.

	
Planted area adjacent the street	Planted area adjacent the stream

Figure 36. Green space type in flooded area type 1 : near Shindaebang Station around Dorimcheon (Pictured by author, June 19, 2015)

As a result of the logistic regression analysis, the planted areas, the grasslands, and the forest areas were selected as significant variables that affect flooding. As the area covered by these types of each green space within a 100-m radius increased, the flooding probability decreased. As the model explained 73% of the variability, it is considered as highly reliable. In addition, the soil drainage, topographic wetness index (TWI), and locations with mixed residential and business areas were determined to be significant variables. Increased soil drainage is good; and when TWI is low and the portion of mixed business areas is low, the flooding probability is decreased. The relevant equation is as follows:

$$P(x)_{\text{Type 1}} = -0.097 - 0.011\ \text{Planted area} - 0.077\ \text{Grassland} - 0.012\ \text{Forest} - 0.267\ \text{Soil drainage} + 0.068\ \text{TWI} + 0.908\ \text{Mixed land use area(1)}\ (\text{AUC} = 0.730) \tag{5}$$

The relative contribution of variables affecting flood occurrence by green space type by standardizing the non-standardized coefficient of each variable was determined. The grasslands contributed to flood control most extensively as shown on Figure 37, followed by forests and then planted areas. The grassland neighboring with Cheongyecheon and the Han River could be infiltrated with the rainwater when it rains.

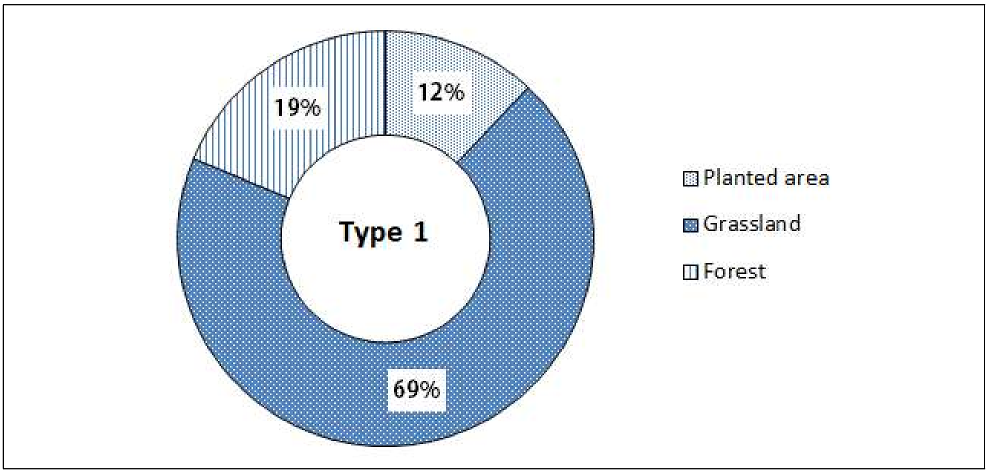


Figure 37. Relative flood control contribution based on the green space type (Type 1)

	
Grassland and wetland near stream (June 19, 2015)	Grassland near Han Riverside (Jan. 25, 2015)

Figure 38. Green space type in flooded area type 1 (Pictured by author)

(3) Flooded area type 2

Type 2 is a place where the slope is steep and soil drainage is good. It accounts for 64% of forests in a 100-m radius of a flooded area. Followed by this, fields accounted for 20%, planted areas 12%, and grasslands 3%, while paddy fields and wetlands were not represented in this category. For the case of non-flooded areas of type 2, forests account for 92% by planted areas.

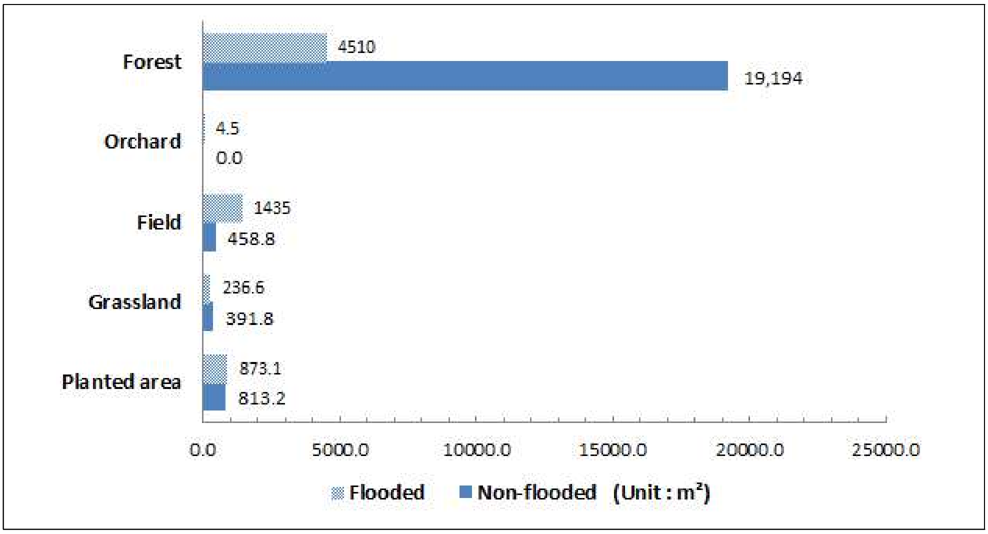


Figure 39. Mean area of green space type within 100m radius from flooded and non-flooded point (Type 2)

As a result of the logistic regression analysis, among green space areas, only forests were significant; and in type 2 areas, when more forest area is included, the flooding probability is decreased. Additionally, when the slope is less steep and maximum hourly precipitation is heavy, flooding probability is decreased. Green space type, excepting for forests, is not a variable affecting flooding status in type 2 areas. In the correlation analysis with flood occurrence, only the forest area was analyzed to be significant based on a Pearson's coefficient of −0.611. The relevant equation is as follows:

$$P(x)_{\text{Type 2}} = -0.012 - 0.010 \text{ Forest} + 0.075 \text{ Maximum hourly precipitation} - 0.162 \text{ Slope (AUC = 0.919)} \tag{6}$$

The efficiency of flood control in type 2 areas was the lowest compared with other areas. Rainwater flows down rapidly in areas having natural ground with very steep slopes. It was shown that water is not absorbed effectively even if there is green space. If a steep average slope is input for the operation of the hydrological model, infiltration seldom takes place and only runoff occurs.

With similar levels of precipitation, over 40% of rainfall can be converted to surface runoff in urban areas with over 50% impervious surfaces; whereas, runoff in woodland areas may be as low as 13% (Bonan, 2002). As in this example, the rainwater infiltration capacity of forests is excellent.

The landslide area of Woomyeonsan, where floods took place in 2010 and 2011, is also included in type 2. However, when observing the features for a flooded/non-flooded area forest, it was seen to have infiltrating rainwater rather than flooding. However, compared with other flood type areas, it may induce flooding in downstream areas by runoff occurring due to limited infiltration.

(4) Flooded area type 3

Type 3 flood areas have a gentle slope, the TWI is the highest, and the planted area accounts for 32% in a 100 m radius from a flooded area. The forest area accounts for 29%, fields 21.77%, and grasslands 15%. Wetlands were not present at all, and orchards and paddy fields accounted for approximately 1%. In type 3 areas where flooding has occurred, roads and housing areas dominate. Planted areas make up the largest portion of the green space in the flooded area.

For the area within a 100-m radius of non-flooded areas, field accounted for the largest portion at 33.65%. This was followed paddy fields that accounted for 21.20% and planted area that accounted for 20%. Compared with other areas, the difference between flooded area and non-flooded area is significant; and, in particular, the largest difference could be observed in the case of paddy fields. As a result of the correlation analysis, it was found that orchards do not affect flooding.

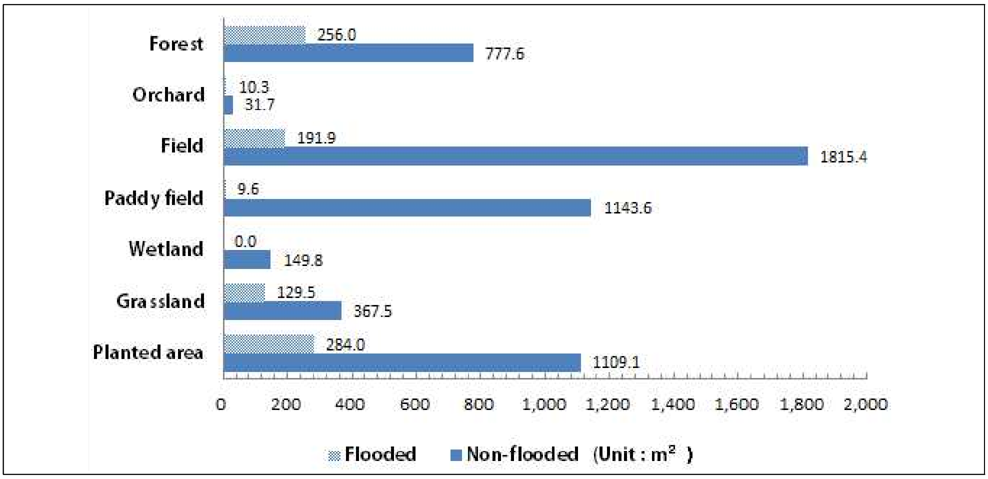


Figure 40. Mean area of green space type within 100-m radius from flooded and non-flooded point (Type 3)

The logistic regression analysis indicated that all variables were significant below 0.05. Among the green space areas, the planted areas, the paddy fields, the fields, and the forests were found to reduce flooding probability if their areas were expanded. The flooding probability in detached housing area and mixed land use area were about 4.5-times and 2.6-times higher than other areas, respectively. The relevant equation is as follows:

$$P(x)_{Type\ 3} = -1.377 - 0.012\ \text{Planted area} - 0.025\ \text{Paddy field} - 0.010\ \text{Field} - 0.011\ \text{Forest} + 1.510\ \text{Detached housing area} + 0.963\ \text{Mixed land use area} + 0.083\ \text{TWI}\ (AUC = 0.729) \quad (7)$$

Using the standardized non-standardization coefficient of each variable, paddy fields were found to contribute to flood control most extensively as shown on Figure 41, followed by fields, planted areas, and forests.

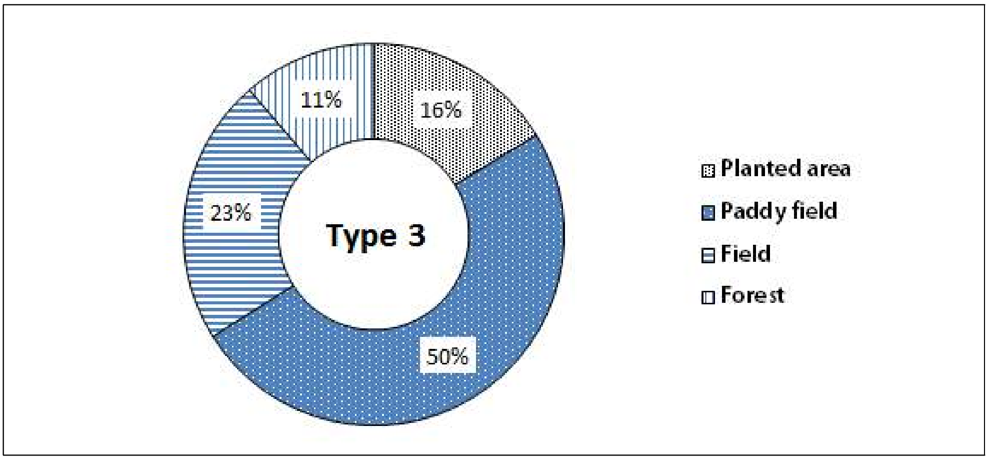


Figure 41. Relative flood control contribution based on the green space type (Type 3)

The paddy fields and the fields in Seoul city are located on gentle slopes mostly neighboring the mountain areas, as shown in Figure 42. This area should be able to store the sediments and any runoff being generated from the mountain. In this case, the area is able to play the role of a rainwater retention basin. In addition, urban parks also play a role in reducing flooding probability, though it is less than that of the paddy fields and fields.

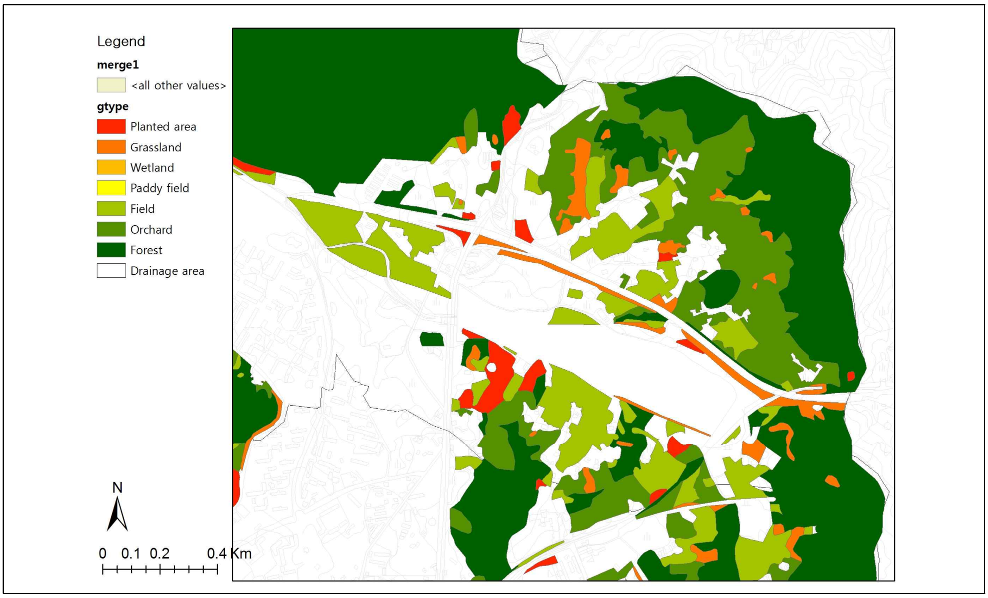


Figure 42. Farmland neighbored with forest (Sinnae1 drainage basin)

	
Farmland near the forest	Planted area

Figure 43. Green space type in flooded area type 3 : around Namtaeryeong Station (Pictured by author, June 19, 2015)

(5) **Flooded area type 4**

In a type 4 area, the slope is normal and TWI is low. Field areas account for 38% of the area in a 100-m radius of flooded areas. Followed by this, forest areas represent 29%, planted areas 28%, and grassland 4%. In the case of non-flooded areas of type 4, forest areas were dominant, followed by field areas and planted areas. The average slope of the non-flooded areas was 4.37%, and it was observed that gentle forest was mostly included in this classification as compared with type 2.

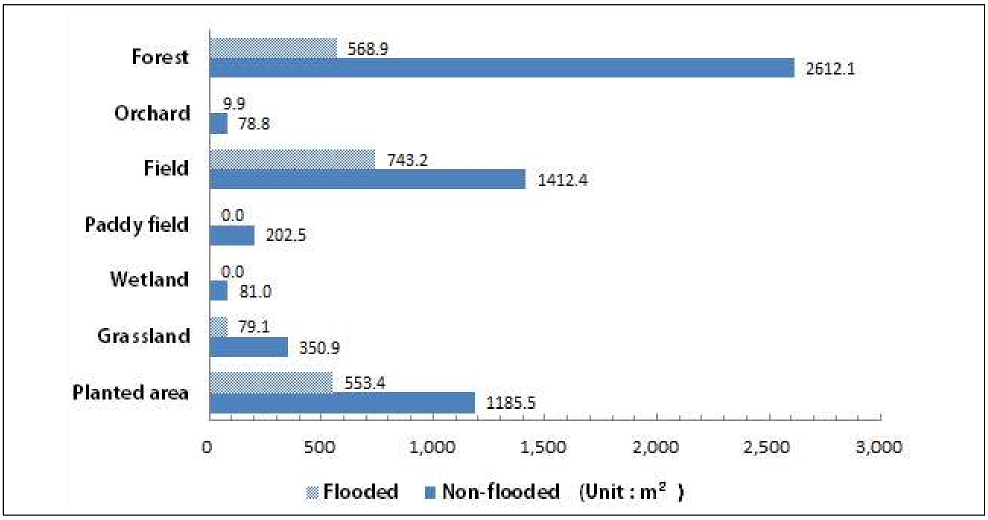


Figure 44. Mean area of green space type within 100-m radius from flooded and non-flooded point (Type 4)

As a result of the logistic regression analysis, planted areas, fields, and forest areas were significant variables that affect flooding. As green space was expanded, the flooding probability was decreased. When the maximum hourly precipitation is heavy and the soil drainage class is poor, the flooding probability is increased. It was forecast that as detached housing areas expand, flooding will take place 2.9 times more frequently than in other flood type areas. This model result is considered to be reliable with an AUC value of 0.76. The relevant equation is as follows:

$$P(x)_{\text{Type 4}} = -1.145 - 0.006\ \text{Planted area} - 0.004\ \text{Field} - 0.014\ \text{Forest} + 0.047\ \text{Maximum hourly precipitation} - 0.514\ \text{Soil drainage} + 1.069\ \text{Detached housing area}\ (\text{AUC} = 0.729) \quad (8)$$

With regards to the relative contribution of the variables affecting flood occurrence, forest areas were found to contribute to flood control most extensively as shown on Figure 45, followed by planted areas and then fields. As type 4 areas include hills with gentle slopes as compared to type 2 areas, rainwater infiltration is higher. Fields neighboring suburban hills also affect flood control. As universities and elementary schools were found extensively in type 4 areas, the planted areas associated with these buildings were found to control flooding effectively.

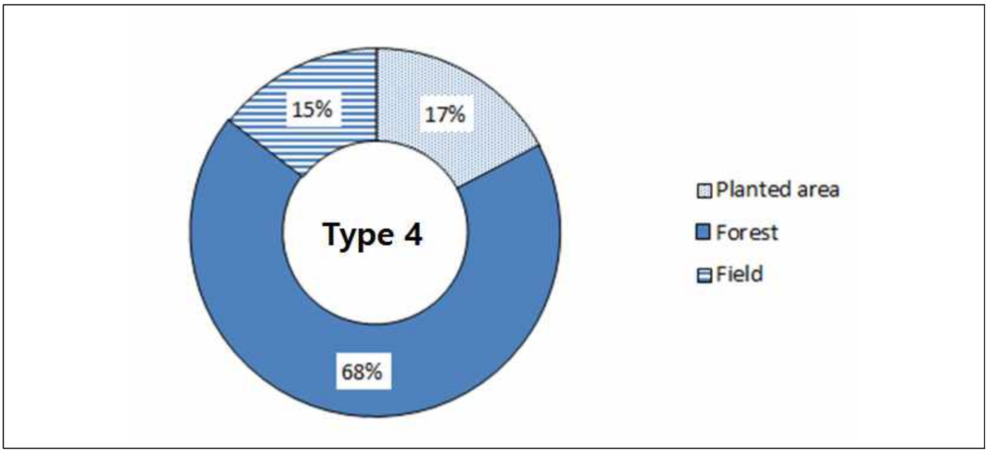


Figure 45. Relative flood control contribution based on the green space type in type 4

Low hill near house	School with low slope

Figure 46. Green space type in flooded area type 4 : Dongjak drainage basin (Pictured by author, June 19, 2015)

3) Flood control effect based on green space pattern

(1) Green space pattern of Seoul city

In order to evaluate the green space pattern features of Seoul city, a landscape pattern analysis based on designation as a drainage basin unit using landscape indexes was performed. Those green space features having significant relationships with flood occurrence, CA, NumP, MPS, and AWMSI indexes, were selected.

The NumP value was 17.47 ea in non-flooded areas and 11.80 ea in flooded areas. As the value increases, non-flooded areas dominate and the number of green space patches tended to increase. The mean value of MPS was 5.70 ha in flooded areas and 9.44 ha in non-flooded areas. As the width of the mean area increases, the probability that the area is designated as non-flooding is high. The CA is a value for absolute green space area size by each drainage basin. As non-flooded areas dominate, the size of the green space areas is large. In case of the AWMSI index, there was no significant difference between the flooded area and the non-flooded area. However, when observing by flood area type, as in the case of type 1 and 2, the index value was analyzed to be high in flooded areas. In type 3 and 4 areas, the index value was larger in non-flooded areas. A comparison of the mean landscape index value for each flood type area is shown in Table 25.

Table 25. Comparison of average green space pattern indexes by each flooded area type

Description		CA (ha)	NumP	MPS	AWMSI
Flooded area type 1		49.40	16.38	3.11	2.71
Flooded area type 2		160.24	12.44	14.06	2.28
Flooded area type 3		48.89	10.04	4.88	2.19
Flooded area type 4		78.80	10.68	8.26	2.09
Total	Flooded	61.57	11.80	5.70	2.29
	Non-flooded	103.83	17.47	9.44	2.30
	Average	82.70	14.64	7.57	2.30

※ CA : Class area (green spae area), Nump : Number of green space patch, MPS : Mean size of patch, AWMSI : Area Weighted Mean Shape Index

From the correlation analysis between each variable and the flooding status for all of Seoul city, when the green space area was large, the number of green space patches was high, and the mean size of a patch was large, the flooding probability was reduced. The analysis of the green space pattern and the results establishing the significant variables are shown in Figure 47.

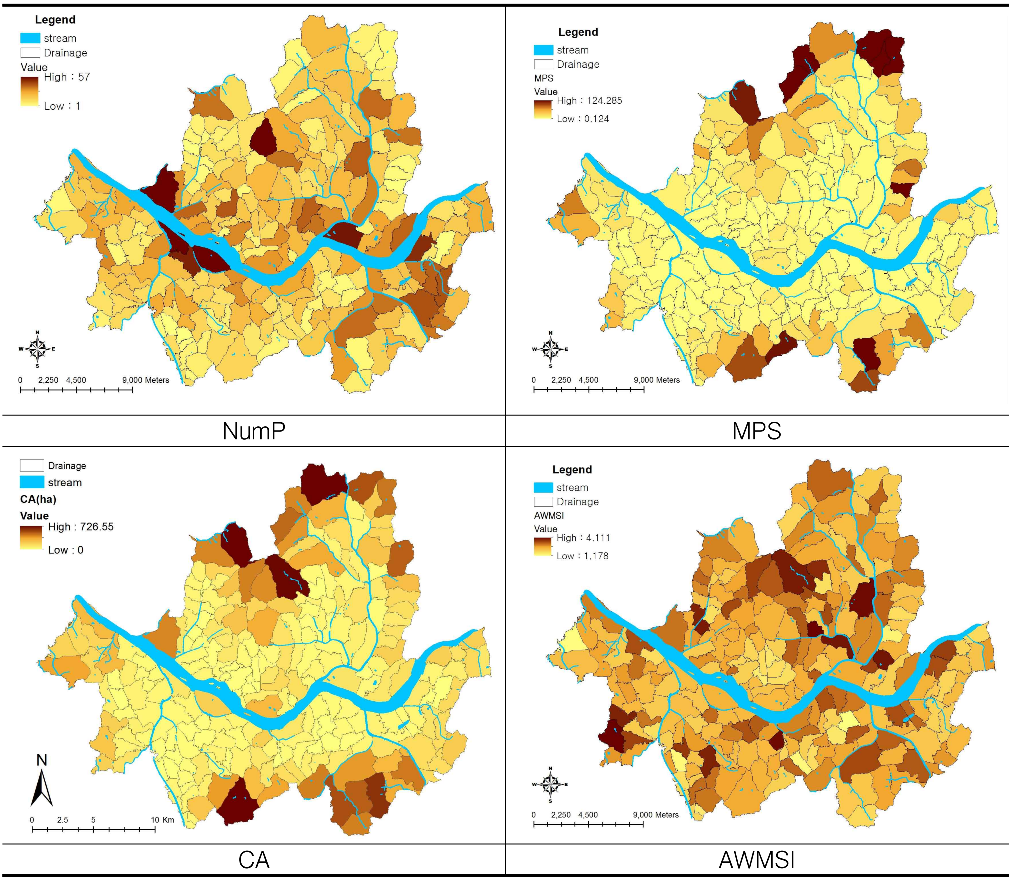


Figure 47. Green space pattern analysis in Seoul through landscape index

(2) Flooded area type 1

A type 1 area is an area where flooding has taken place in a drainage basin with a pump station. Also included in this type are areas where rainwater retention basins are installed near the sides of streams and where pump stations are installed or are upstream of a valley where water flowing from a mountain area is gathered. Seven significant variables were found as a result of the logistic regression analysis. This included the constant term. Variables were significant below the 0.005 level. The physical variables of soil drainage grade (-), TWI (+), mixed area status (+), and detached housing area status (+) were significant, and the landscape variables, CA (-) and AWMSI (+), were significant. Therefore, in type 1 areas, as the green space is enlarged and AWMSI is reduced, there is a positive influence on reducing flooding probability. The model explained 82.9% of the variation and was considered excellent. The relevant equation is as follows:

$$P(x)_{\text{Type 1}} = -3.490 - 0.005\ \text{CA} + 1.220\ \text{AWMSI} + 1.831\ \text{Mixed land use area(1)} + 2.152\ \text{Detached housing area(1)} + 0.08\ \text{TWI} - 0.461\ \text{Soil drainage}\ (\text{AUC} = 0.729) \quad (9)$$

A schematic of a flooded area in a drainage basin having a FRMI, a type 1 area, is shown in Figure 48. It can be seen that the drainage basin where the flood control facility is located is usually at the sides of streams. However, flooding in this area frequently occurred when the capacity of the rainwater retention basin was exceeded by the water flowing down from the mountain area. Green space features in a drainage basin that includes a mountain will include a slope that is steeper than that of the stream area. The green space form is complicated in most cases. As the green space form becomes complicated and has a steep slope, it is judged that flooding is increased where water from higher place is flowing down to lower areas. This is shown in flood type 1 of Seoul city. When the irregularity of green space was high, more flooding occurred.

In addition, as the type 1 area is located around the Hangang River and associated streams, it is affected by streetside green space bordered with streamside grasslands, wetlands, and streams. In the case of the Hangang River and the major streams of Seoul city, it could be seen that the surrounding grassland has many belt-type green spaces and a simple form compared to that of the natural mountain area.

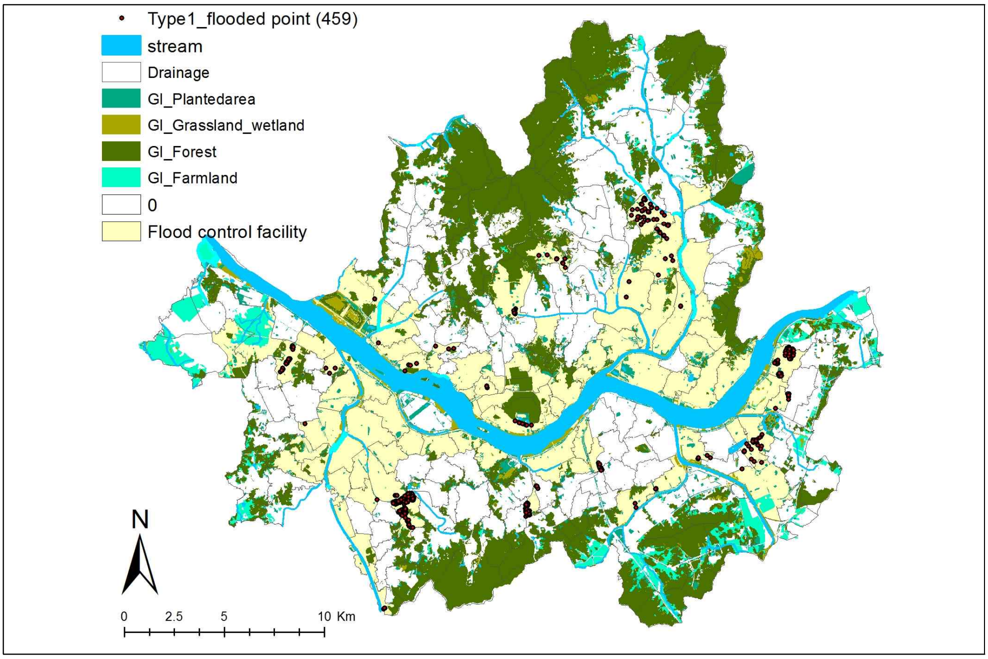


Figure 48. Drainage basin including flood control facilities and flood point (Type 1)

A correlation analysis between the green space pattern and the flood control characteristics of the four flood type areas was conducted. This analyzed the AWMSI index, that is, increases in the irregularity of the green space form, and changes in flooding probability. In this analysis, the green space area was fixed at 80 ha, the total average for Seoul city. It was divided by the mean value, the minimum value, and the maximum value of other variables

(Figure 49). Depending on the change in each variable, in terms of AWMSI distribution, flooding probability was increased from 1.24% when the green space area was set at 80 ha to a maximum of 89.25% when the AWMSI was at its highest level of 3.55.

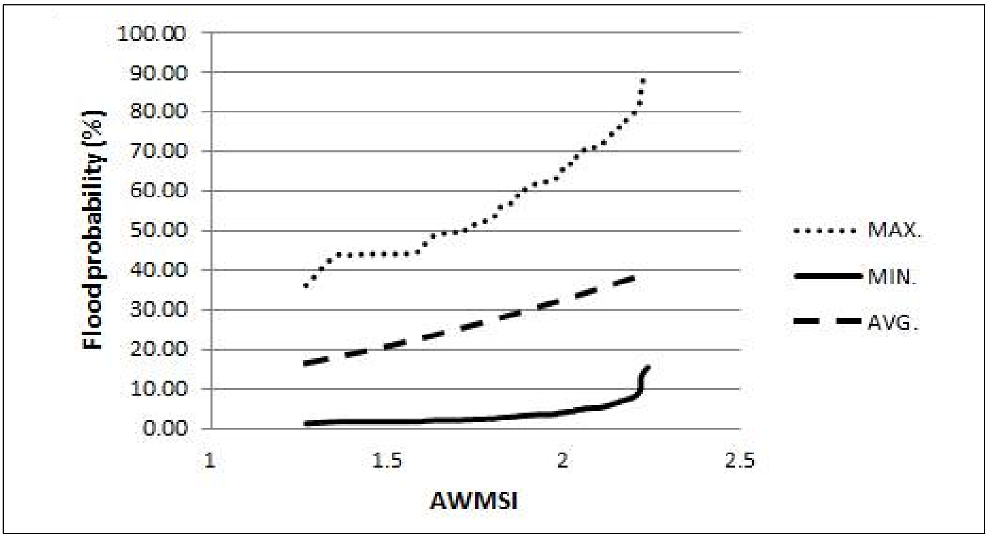


Figure 49. Flooding probability based on AWMSI (Type 1)

(3) Flood type 2

Many forest areas where there are steep slopes and smooth drainage are included in flood type 2. Compared with the other flood type areas, the green space area per drainage basin is over 160 ha in both the flooded and non-flooded areas. Four variables were found to be significant, including the constant. The physical environment variable of maximum hourly precipitation (+) and the landscape variables of CA (-) and AWMSI (+) were significant. In a type 2 area, as the green space area is widened and AWMSI is reduced, there is a positive effect for flooding probability reduction. The model explained

75.9% of the variation, which was considered a good fit. The relevant equation is as follows:

$$P(x)_{Type\ 2} = -3.982 - 0.002CA + 0.066\text{Maximum hourly precipitation} + 0.364AWMSI \quad (AUC = 0.759) \tag{10}$$

The value for CA (total green space area) was set at 80 ha and other values were input so that the flooding probability in type 2 areas could be represented as a maximum or a minimum. The AWMSI index was increased and flooding probability value was estimated as shown in Figure 50. As in type 1 flood areas, areas having steep slopes are dominant, and the more the shape index of the green space area is increased, its edge length is extended. When there is an increase in the locations where water can flow from high places to meet with water in lower places, the flooding probability is increased.

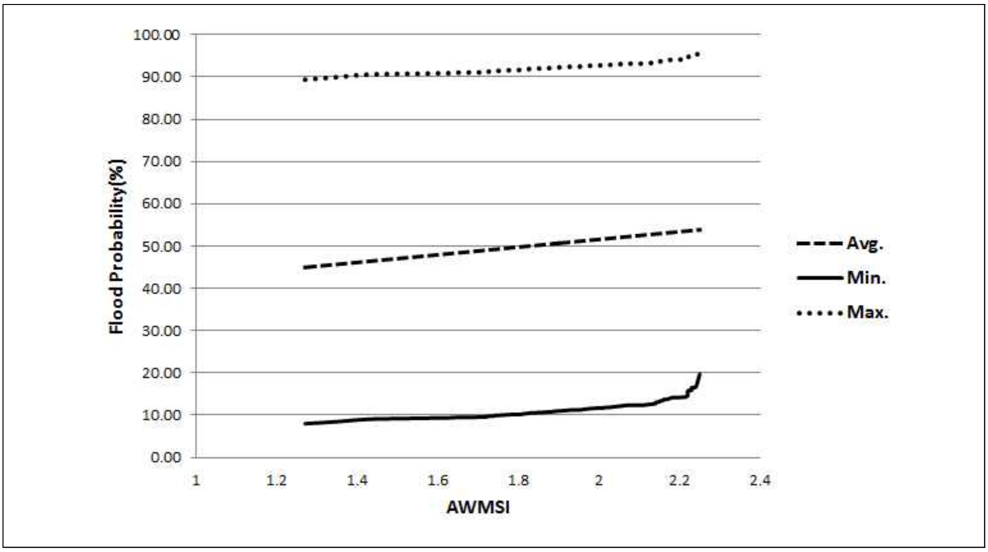


Figure 50. Flooding probability based on AWMSI (Type 2)

(4) Flooded area type 3

The value for NumP in the type 3 flood area is 4 ea. This is the smallest value among the four flood type areas. The CA is 48.89 ha and the MPS is 4.88 ha, making this the smallest area compared to the other three types. Compared with the other flood type areas, green space area is relatively insufficient; and as it is limited, fragmentation of green space is not developed and the size of the average patch is also small. In summary, the green space characteristic variables of the type 3 area are similar to those of a flood prone area, and 961 areas with the highest number of flood occurrences among the four types are included in this type.

The significant variables are shown in Equation (10). In type 3 areas, the flooding probability for detached housing areas is higher than that for non-detached housing areas by 4.3 times. It is higher than for mixed areas by 2.17 times and green space areas by 0.28 times. With higher maximum hourly precipitation, the more flooding takes place.

Type 3 is an area where the slope is very gentle, the TWI is high, and the water is often stagnant. The flood control efficiency of this area is increased greatly with increases in green space. Therefore, if the total green space area of the drainage basin is set as 80 ha, the number of green space patches is sufficient, the mean green space area is large, the mean patch size is large, and the irregularity of the green space is high, flooding probability should be reduced. This area is quite different from the type 1 and 2 areas. Green space is located in areas with gentle topography. As irregular forms of green space absorb water and the water does not flow downwards, the length of the edge is extended and flooding probability should be reduced. The relevant equation is as follows:

$$P(x)_{\text{Type 3}} = -0.963 - 0.001\,\mathbf{CA} - 0.414\,\mathbf{AWMSI} - 0.062\,\mathbf{NumP} - 0.063\,\mathbf{MPS} + 0.053\,\mathbf{Maximum\ hourly\ precipitation} + 1.473\,\mathbf{Detached\ housing\ area(1)} + 0.778\,\mathbf{Mixed\ land\ use\ area(1)} - 1.276\,\mathbf{Presence\ of\ green\ space}\ (\mathrm{AUC} = 0.824) \quad (11)$$

The result of the analysis by fixing each variable in order to analyze how flooding probability is changed when the variables of green space form (AWMSI), the number of green space patches (NumP), and the mean green space area (MPS) indices is changed is shown in Figure 51-53. Based on the mean values, when green space area (CA) is set at 80 ha, if the number of patches is increased by its fragmentation, flooding probability is reduced. If the area and the number of green space patches stay the same, but the size of one patch is increased, flooding probability is decreased. If green space area, the number of patches, and the mean patch size stay the same, increased patch form complexity contributes to a reduction in flooding.

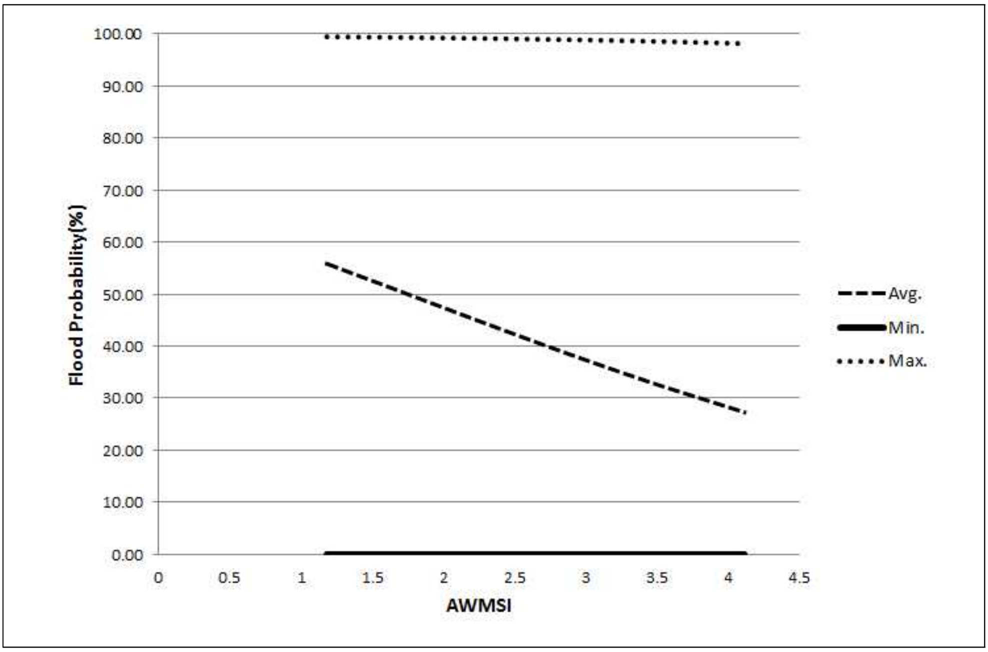


Figure 51. Flooding probability based on AWMSI

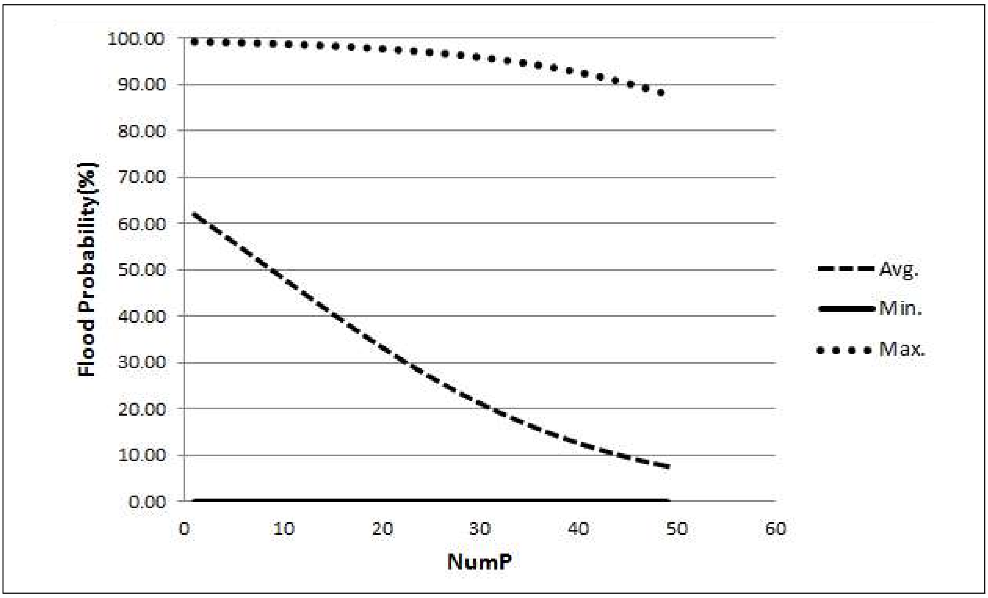


Figure 52. Flooding probability based on NumP

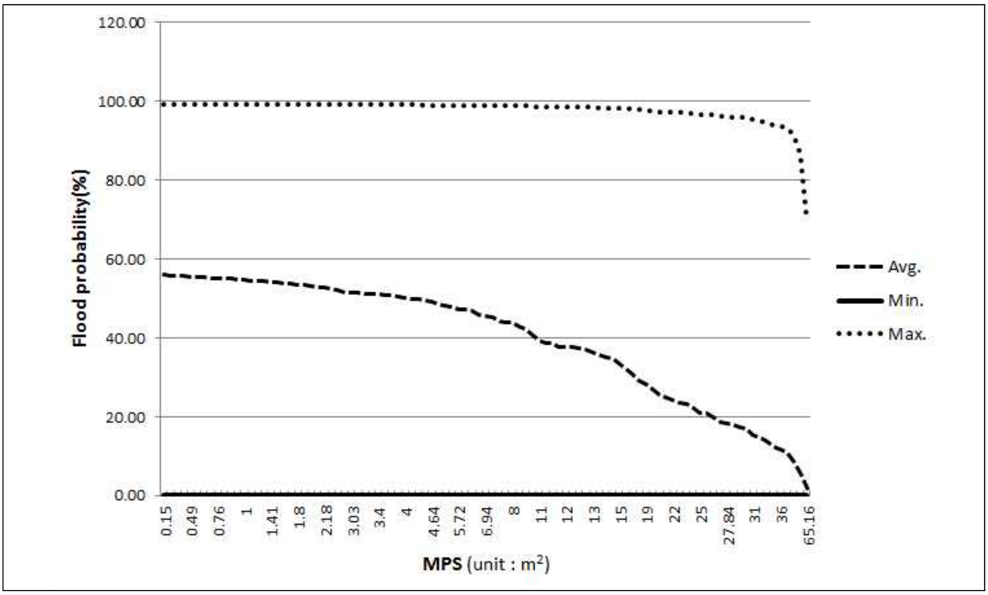


Figure 53 Flooding probability based on MPS

(5) Flood type 4

The NumP value of the flooded areas in type 4 is 10.68, which is lower than the average of the total flooded area of Seoul city. The CA value is 78.80 ha, which is higher than the average of the total area. There were seven significant variables, including the constant. For the environment variables, a higher soil drainage grade is favorable, the maximum hourly precipitation is a minor variable, and the presence of detached housing areas has a limited effect. When CA and NumP increased, flooding is decreased. The relevant equation is as follows :

$$P(x)_{Type\ 4} = -0.696 - 0.002\ CA - 0.037 NumP + 0.047\ \text{Maximum hourly precipitation} + 0.952\ \text{Detached housing area(1)} - 0.488\ \text{Soil drainage} - 1.080\ \text{Presence of green space(1)}\ (AUC = 0.782) \quad (12)$$

When maximum hourly precipitation reaches its peak, flooding probability is predicted to be 90%, even if the number of green space patches is increased.

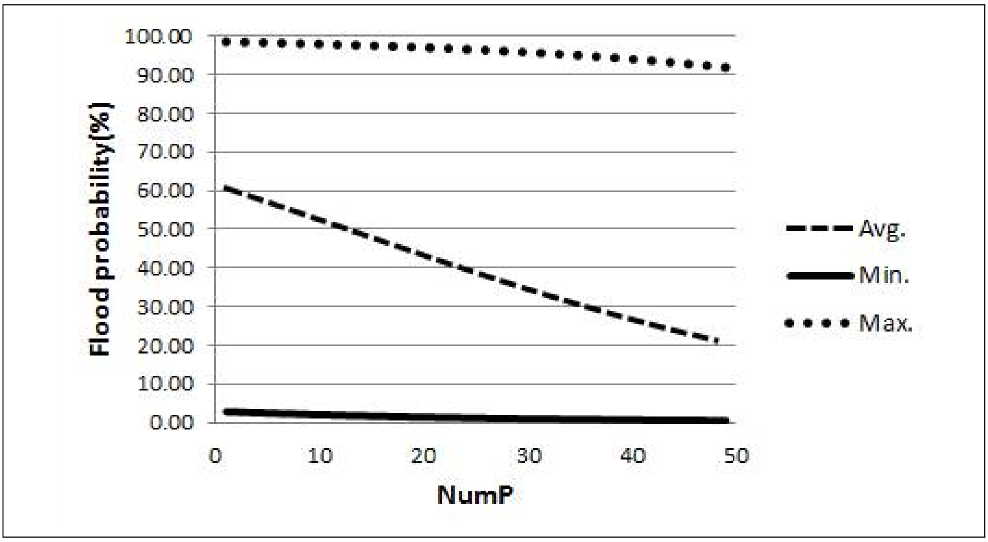


Figure 54. Flooding probability based on NumP (Type 4)

(6) Comparison analysis on flooding probability based on green space pattern for each type

By analyzing the green space pattern for each type of flood area, various relationships can be observed. The green space pattern analysis using indexes of CA, NumP, MPS, and AWMSI affecting flooding in Seoul city was conducted through a logistic regression analysis.

In the case of flood type areas 1, 2 and 3, AWMSI, an index that represents the complexity of green space pattern, was significant, but this index affected the areas differently. In type 1 and 2, when the complexity of green space pattern was high, flooding probability was increased. In type 3, when the complexity of the green space pattern was low, flooding probability was increased. This phenomenon could be explained by differences in regional features. In the case of type 1 and 2 areas, the green space area that may affect flooding is mainly located at a slope. In this case, if the edge length is extended due to a complicated green space pattern, the surface area of the flowing water is widened and flood damage may be further increased. Conversely, in a case where green space area is formed in a lowland having a gentle slope, as the edge length through which water could be infiltrated is extended, flooding may be decreased. In the case of a type 1 area having gentle regional features compared with a type 2 area with steep slopes, as the complexity of green space pattern was increased, flooding probability was further increased (Figure 55).

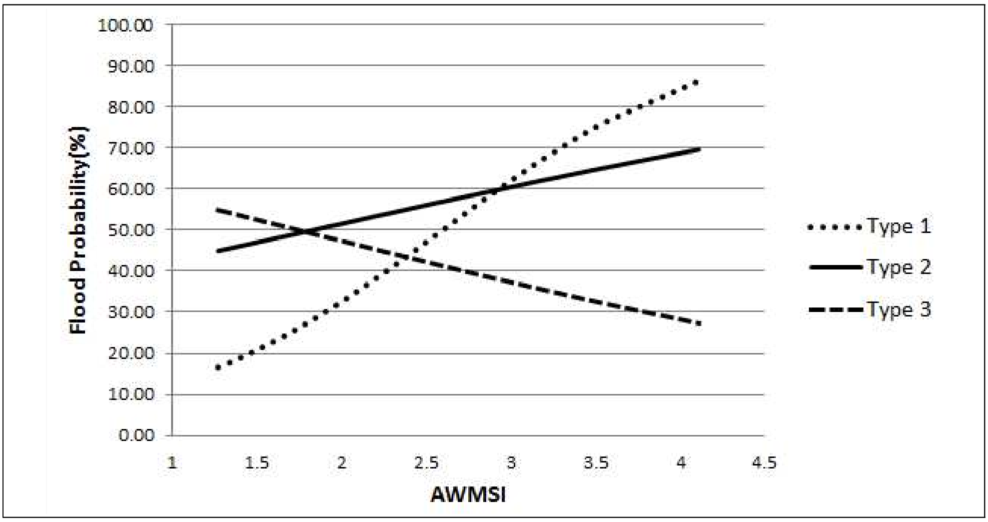


Figure 55. Comparative analysis on flooding probability based on AWMSI change (Type1, Type2, Type3)

In type 3 and 4 flood type areas, the NumP index affects flood control. In both of these types, as the green space patches were increased, flooding probability was decreased. As was analyzed previously, the effect of green space area is significant in areas with gentle slopes. The absolute value of the gradient in flood type 3 areas shows that the gentle slope area is dominant. In flood type 3 areas rather than in type 4 areas, the change in flooding probability is significantly affected by changes in small units of green space patches (Figure 56). In other words, when the total green space area is the same, in order to reduce the flooding probability by 50%, a type 3 area is required to be more fragmented than is a type 4 flood area.

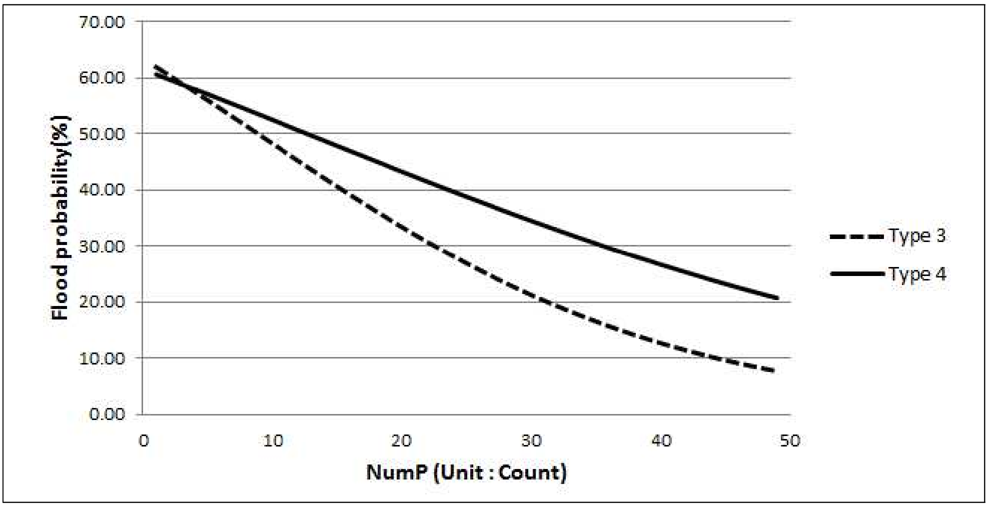


Figure 56. Comparative analysis on flooding probability based on Nump (Type 3, Type 4)

Ryu et al. (2014) analyzed the runoff difference between one big urban park having the same area as several small parks by using Hec-HMS and SWMM. As a result of the hydrological analysis, it was revealed that several small parks rather than one big park are more effective for runoff reduction. Han et al. (2012) reported that by arranging rainwater retention basins in a dispersed form, flooding is reduced as it exerts a positive effect on peak runoff reduction. In addition, Cho et al. (2014) suggested that in order to prepare for local flooding where installation of a large-scale retention basin and rainwater pumping station at a basin estuary is difficult, the installation of multiple dispersion type small-scale retention basins is advantageous in terms of efficiency and/or economics. The retention basin is not a facility for creating a natural water circulation system, but it is considered to play a role in runoff reduction as does a green space area, which has the function of water infiltration and storage.

Under this context, if the area is the same, there is a case for arranging several segmented green space patches rather than one large one. As rainwater could be retained by dividing it in to smaller areas, a more effective result could be obtained. In addition, the installation of green space areas where a permeable lake is included in a dispersed form may produce not only flood control, but it could also affect the sustainable development potential of an urban area on top of the aesthetic, social, and environmental value (Zhou et al., 2013).

Furthermore, it could be seen that the green space area pattern is an element affecting concentration time, which is an important element for estimating runoff. Delaying water flow depending on the size, the distribution, and the shape of the green space areas is effective for slowing down the peak concentration time.

4) Summary

Results deduced in order to analyze the flood control contribution based on green space area, type, and pattern are summarized as shown on following Table 26.

Table 26. Summary on deducing flooding probability model considering green space features by flooded area type

Description		Variable	Type 1	Type 2	Type 3	Type 4
1	Physical environment	Slope		(-)***		
		TWI			(+)***	
		Soil drainage	(-)***			(-)***
		Maximum hourly rainfall		(+)***		(+)***
		Detached house	(+)***		(+)***	
		Mixed land use area	(+)***			
	Green space area	Green space area within 100-m radius	(-)***	(-)***	(-)***	(-)***
	AUC		0.786	0.914	0.702	0.756
2	Physical environment	Slope		(-)***		
		TWI	(+)***		(+)***	
		Soil drainage	(-)***			(-)***
		Maximum hourly rainfall		(+)***		(+)***
		Detached house			(+)***	(+)***
		Mixed land use area	(+)***		(+)***	
	Green space type	Planted area	(-)***		(-)***	(-)***
		Grassland	(-)***			
		Wetland				
		Paddy field			(-)***	
		Field			(-)***	(-)***
		Orchard				
		Forest	(-)***	(-)***	(-)***	(-)***
	AUC		0.730	0.919	0.729	0.764
3	Physical environment	Slope				
		TWI	(+)***			
		Soil drainage	(-)***			(-)***
		Maximum hourly rainfall		(+)***	(+)***	(+)***
		Detached house	(+)***		(+)***	(+)***
		Mixed land use area	(+)***		(+)***	
		Green space status			(-)***	(-)***
	Green space pattern	CA	(-)***	(-)**	(-)*	(-)**
		NumP			(-)***	(-)***
		MPS			(-)***	
		AWMSI	(+)***	(+)*	(-)***	
	AUC		0.829	0.759	0.824	0.782

*: p-value<0.2, **: p-value<0.05, ***: p-value<0.01

4. Application of research results

1) Urban green space planning for flood control

The threat to social infrastructure, human life, and property from flooding is increasing rapidly. To protect urban areas against disaster, flood control and adaptation plans must be developed and implemented, and new land use planning should identify areas of high and low flood potential. In recent years, the necessity for strong urban disaster planning in Korea has been increasingly emphasized (Korea Planning Association, 2014). In Ministry of Land, Infrastructure and Transport (MOLIT), an improved system for extensively utilizing disaster prevention zones for disaster control is being promoted (Shin et al., 2015). In disaster prevention zones, the construction of buildings that hinder disaster prevention is prohibited; however, as this restricts property rights there is public opposition. However, the results of this study showed that flood control can also be effectively achieved using green space areas, the introduction of which would actually improve the urban environment.

The application of diversified urban planning elements, including natural flood risk management and blue-green infrastructure, as well as existing physical sewer line systems, is required to ensure urban management with high resilience. Impervious land cover, such as asphalt and roofs in urban areas, is a key factor that affects flooding, and flood control plans that incorporate green spaces should be created. However, comprehensive studies of green spaces are required to understand how their implementation would affect water circulation in regional drainage basins.

Significant investment and effort is required to prevent urban flooding and the detailed guidelines relating to urban planning and design should highlight the positive role of urban green spaces for flood control. For example, introducing dispersion type green spaces with a water circulation function simultaneously reduces impervious area and runoff. By introducing dispersed green spaces that not only follow existing sewer line systems, but also include focused point sources, the small-scale dispersion of water circulation management systems can be applied. In addition, green space shapes should be designed to maximize flood control. For example, when a green space area is located on a steep slope, short edge lengths are most advantageous for flood control; however, for gentle slopes, longer edges and more complicated shapes are advantageous for flood control.

Table 27 contains a summary of flood control strategies based on features of each flood type. Flood probability is highest for Type 3, which includes most of the flood prone areas. However, the flood control effect of green space areas is significant. Usually, large-scale rainwater retaining basins are preferentially introduced to reduce flood risk; however, the results of this study show that the creation of green space areas would be equally as effective. Type 3 areas have a concave topography that allows for the collection and storage of water; therefore, topographic features impact on the flood control effect.

Table 27. Flood mitigation strategies with green space for each flood type

Type	Characteristics of type		Flood mitigation strategies with green space
Type 1	Drainage	2.61	· Rainwater retaining capacity is required to be increased through expansion of facility capacity, maintenance or introduction of sufficient green space. · Riverside and streamside is suggested changing grassland
	Slope (%)	1.61	
	TWI	11.95	
	· Flood control facility is located · Flood control contribution of grassland is relatively excellent.		
Type 2	Drainage	3.48	· Flood control contribution of forest is relatively excellent. · When maximum hourly precipitation is increased, installation of rainwater retaining basin is required in order to prevent landslide. · In case that mountain edge is long and complicated, flooding risk is high and so, installation of rainwater retaining basin shall be considered preferentially. Land use of low damage occurrence is suggested.
	Slope (%)	14.06	
	TWI	7.38	
	· Bordered with forest · Water is prone to flowing without stagnation · Flood control effect of green space area is relatively low.		
Type 3	Drainage	2.32	· Introduction of urban agriculture could be suggested. · Green space design in which edge has long and complicated shape at gentle area is suggested for ensuring smooth water absorption. · Installing green space area in a dispersed form is very effective for flood control compared with other flood type (such as pocket park). · As an area in which many roads are included, increasing roadside planting was emphasized. · As underground building ratio is high, building restriction and maintenance are required for preventing inundation of underground space. Green space creation plan in detached housing area is required.
	Slope (%)	1.29	
	TWI	13.31	
	· Many detached house, mixed land use area, road are included · Water is prone to be gathered. · Flood control effect of green space area is exceptionally high. · Flood control contribution of paddy field, field is high		
Type 4	Drainage	2.58	· As type 4 is located in connection to type 3, it needs to establish flood control management to flood reduction of type 3 thoroughly. · Installing green space area in a dispersed form is effective for flood control. Compared with type 3, its efficiency is low.
	Slope (%)	3.91	
	TWI	5.98	
	· Medium features and flood control effect of green space between type 2 and 3 · Flood control contribution of forest, planted area is high		

2) Integrated design of urban green space area and LID technique

In four flooded area types, the more green space area was increased, flooding probability showed a tendency of being decreased and depending on features by each type, difference of sensitivity for probability change was represented. In addition, depending on green space type and distribution, flooding probability showed a tendency of being decreased and green space variable was revealed to have close relation with flooding as much as topographic variable such as slope, TWI and soil drainage.

In this study, in the range of urban green space area, flood control method considering low impact development technique or artificial retaining basin being installed in artificial ground was not considered. However, like the result of this study, it may play a considerable role in flood control just based on change of area adjustment and arrangement form of existing natural green space area considering regional features having flooding possibility.

In case of Seoul, as green space area of park is 177.78 km^2 that accounts for 29.37 % of Seoul total area, if this area should be utilized for improving regional disaster prevention performance, it is expected that an disaster control, adaptation effect over large-scaled disaster prevention facility could be demonstrated. Therefore, a new strategy of inducing disaster prevention role by adding runoff control function to park green space including bio retention basin is required as well.

Response strategy to urban flood in advanced countries including

Germany, the USA, Japan has been changed and keeping pace with this trend, in Korea also, a new urban flood response strategy is suggested based on 'Natural disaster prevention act' under the jurisdiction of Ministry of Public Safety and Security, 'Law of national land plan and use', 'Regulation for decision structure and installation standard of urban planned facility', 'Law of urban park and green space area' under jurisdiction of MOLIT. Among these, according to installation and management standard of rainwater retaining facility (relevant to Article 13) of enforcement regulation [Attachment 6], 'Law of urban park and green space area', regarding green space area in area of rainwater retaining facility, it specifies that permanent retaining facility should be over 60% and temporary retaining facility over 40%. Like this, as relevant law and regulation by which green space area could be introduced in urban area are increased. When green space area is introduced, green space planning could be established through quantitative and scientific approach based on flooding probability analysis formula according to green space area and arrangement features being suggested in the result of this study.

3) Suggestions for modifying the runoff coefficient of green space

As the runoff coefficient is affected by the rainfall intensity, the concentration time, the basin size, the soil type, the land use, the preceding rainfall condition, the return period, and the ground surface slope, a great deal of experience and theoretical knowledge are required to estimate the runoff coefficient. The runoff coefficient is usually used based on a brief table, but there is a considerable difference in the runoff coefficient value depending on variables being considered at the time of estimating runoff by each institution.

According to the results in this study, when the land cover is a green space area or it is densely distributed (fragmented) in the surroundings, flooding probability is low. The reason is that flooding is reduced by rainwater infiltration or storage in the green space area. However, the runoff coefficient of the green space area was overestimated by underestimating the flood control effect of green space area at the time of sewer line design. Since a large sewer line was installed by overestimating the flood volume due to a large runoff coefficient, flooding was reduced.

In the case of forests, the runoff coefficient varied depending on the reference year as shown in Table 28. The standard for runoff coefficient for domestic stream design before 1993 was 0.75-0.8. In 2000, it was changed to 0.05-0.25; and in 2002, it was changed to 0.3-0.8. This was due to the variation in the runoff coefficient for the different reference years, and design personnel experienced a lot of confusion. In addition, as sewer lines were designed by using the continuously changing runoff coefficient, the flood volume in the basin where the urban forest was located was not identified correctly. If the runoff coefficient of the forest is overestimated, flooding does not take place in that basin, as sewer line capacity was over-designed. However, a problem with overinvestment emerged.

As in the results of this study, the forest acts as a cause of flooding in the surrounding area if hourly precipitation is increased. However, for the overall area of Seoul city, the mountain area reduced flooding. In particular, in case of type 2 and 4 areas, the mountain area was selected as a significant variable for flooding. The more the forest area was widened, the flooding probability was reduced. In the type 2 area, the most influential flood variable was the slope followed by the mountain area and the maximum hourly precipitation, which contributed to flooding at a similar rate. In the type 4 area, the maximum hourly precipitation was the most influential flood variable, followed by the forest contribution to flooding. In a forest, the rainwater infiltration ratio may be moderate if it has a gentle slope. However, when it reduces runoff by sufficient infiltration, a value of 0.5-0.7, similar to the runoff coefficient in an urbanized area, is considered to be overestimated.

Table 28. Runoff coefficient of forest in each standards

Standard	Year	Forest runoff coefficient	
Stream design standard	1993	0.75-0.80	
	2000	0.05-0.25	
	2002	Steep slope	0.40-0.80
		Gentle slope	0.30-0.70
	2009	Steep slope	0.40-0.80
		Gentle slope	0.30-0.70
Basic planning change for sewerage arrangement in seoul	2009	Gentle slope park	0.10-0.25
		Gentle slope	0.50-0.75
		Steep slope	0.75-0.90
Sewerage facility standard	1998	Park with grassland and tree	0.05-0.25
		Gentle slope	0.20-0.40
		Steep slope	0.40-0.60
	2011	Planted area	0.10-0.25
		Green space and open space	0.50-0.75

As in the forest areas, the farming area runoff coefficient value is different depending on each standard (Table 29). According to the 'basic planning change for sewerage arrangement of Seoul city (2009)', in the case of paddy fields, a runoff coefficient value of 0.7-0.8 was determined. However, according to the sewerage facility standard (2011), its value is 0.1-0.25. Based on the results of this study, it was revealed that paddy fields most significantly contributed to a reduced flooding probability in type 3 areas. This means that around paddy fields in a type 3 area, the flooding probability is low. As a paddy field is composed of clay, infiltration is marginal; but it could prevent runoff, as it is able to retain water. However, according to the basic planning change for sewerage arrangements (2009) in Seoul city, a value over 0.7 was presented as the runoff coefficient for paddy fields. The same trend was shown in that the infiltration capacity of paddy fields is weaker than for fields, but the absolute value is overestimated.

In addition, as was clarified in this study, as the flood control effect of green space area differs depending on regional features, a different runoff coefficient value is required to be presented depending on specific features for the location even though the areas of the paddy field and the field are the same.

Table 29. Runoff coefficient of farmland in each standards

<table>
<tr><th>Description</th><th colspan="3">Land use</th><th>Runoff coefficient</th></tr>
<tr><td rowspan="4">Stream design principle (2009)</td><td rowspan="4">Farmland</td><td rowspan="2">Sandy soil</td><td>Planted</td><td>0.30-0.60</td></tr>
<tr><td>Not planted</td><td>0.20-0.50</td></tr>
<tr><td rowspan="2">Baryta</td><td>Planted</td><td>0.20-0.40</td></tr>
<tr><td>Not planted</td><td>0.10-0.25</td></tr>
<tr><td rowspan="2">Basic planning change for sewerage arrangement of Seoul city (2009)</td><td colspan="3">Paddy field</td><td>0.70-0.80</td></tr>
<tr><td colspan="3">Field</td><td>0.45-0.60</td></tr>
<tr><td>Sewerage facility standard (2011)</td><td colspan="3">Farmland</td><td>0.10-0.25</td></tr>
</table>

When higher values of runoff coefficient are applied as compared to the actual values, the targeted sewer lines that are calculated to be of insufficient capacity are overestimated, and overinvestment may take place. In addition, sewer lines may be expanded unnecessarily in areas where there is no problem related to bad drainage or local flooding. A careful approach is required when applying the runoff coefficient. In particular, the runoff coefficient of green space areas where differences exist depending on regional features should be reflected by matching it with domestic reality. The features of an area should be fully analyzed when a sewer line is installed in order to estimate flood volume.

4) Integrated green space plan procedure for urban flood control

The result deduced in this study could be used as a base of green space introduction and planning at the time of implementing diversified researches and projects including redevelopment of existing town and complex construction as well as new town planning and through a procedure as shown on following Figure 57, it could be applied at the time of green space planning for flood controlin urban area.

When project site is selected in Seoul city, how target area to be planned through flood vulnerability analysis is vulnerable to flood is analyzed. If site is determined to be an area vulnerable to flood through an analysis, to what type of flood such area is belonged is determined based on classification function and regional feature variable after establishing a flood control goal. Afterwards, through a formula deduced by each flood type in this study, ‘green space area and type’ having the highest contribution for flood reduction is found and then, combination planning scenarios for achieving a flood control goal is deduced. Finally, optimized 'green space distribution' fit for features of target area is determined. Through this, not only large-scaled urban planning but also optimal green space arrangement plan for flood control could be suggested at complex design stage and prototype depending on features by each type could be developed.

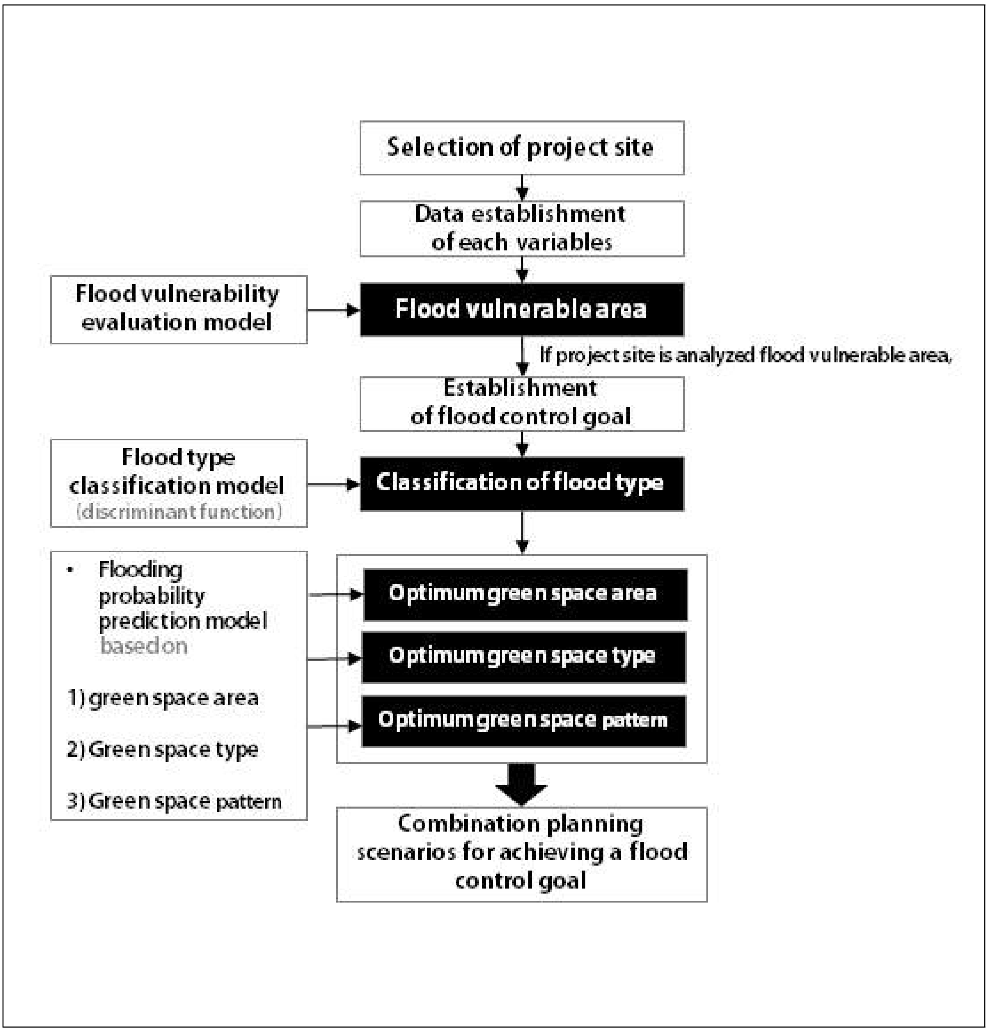


Figure 57. Procedure of Green space planning for flood reduction using the results in this study

V Conclusions

1. Major result of the study and its significance

In this study, how flooding probability is changed by green space area, type and patterns was analyzed statistically by each flood type after analyzing flood vulnerable area of Seoul city and dividing flooded areas into 4 types by using spatial statistics. Through this, a quantitative guideline as to in what way urban green space area would be spatially planned for establishing sustainable and basic countermeasure for urban flood is suggested.

Summary of the research result is as follows. First, a model that could evaluate urban flood vulnerable areas using MaxEnt by targeting total area of Seoul city was developed. Variables being selected for model simulation were physical environment. climate exposure, green space environment, flood control facility variables. The model was simulated by extracting random point for 1000 times to consider uncertainty. Flood was not taken place at all in 43 drainage basins among total 239 drainage and flood vulnerable area was represented as Seocho4, Gildong, Shinwol3, Bangbae1, Hwagok2 drainage basin.

Second, flood type was divided into 4 types based on features of flooded area by using multivariate statistic analysis. Type 1 has flood control facility in drainage basin and a part of urban area that is located around Han River and major streams and bordered with mountain areas was represented as flooded area. Its slope is more gentle than total average slope of Seoul city and TWI is second highest and residential, commercial mixed area ratio was most dominantly represented. In case of type 2, its slope is steep, TWI is low and drainage is the best. Compared with other types, green space ratio is also high and it could be seen that this area is bordered with mountains having steep slope and it has a regional features of flood resistance as water is flowing down without stagnation. In case of type 3, its slope is very gentle, TWI is the highest and drainage is the worst among 4 types and contrary to type 2, this area has a regional features that water is apt to be stagnated and gathered. A ratio of detached housing area and mixed land use area is high and over 50% of roads are located at this area. Type 4 has a medium features of type 2 and 3 and its slope is fair and TWI is relatively low. This area experienced worst damage by maximum hourly precipitation.

Third, by using logistic regression analysis, difference of flooding probability change based on green space area, type, pattern features by each flood type was comparatively analyzed. It could be realized that green space area is more effective for decreasing flooding probability in type 3 area where slope is gentle and TWI is high rather than type 2 and this result is coincided with that of several studies reporting that at the time of creating urban green space area, making garden in concave form is more effective for decreasing flooding probability. In area with a steep slope like the case of type 2 and 4, as maximum hourly precipitation variable affects flooding probability significantly, flooding probability in this area was represented to be high however extensively green space area should be increased. Reversely, it was analyzed that topographic features rather than maximum hourly precipitation affects flooding more extensively in flood type 3. Besides, a result of threshold in which an effect is maximized when green space area is introduced for flood control through deduced formula and green space area required for achieving flooding probability goal was deduced.

By dividing green space type into planted area, grassland, wetland, paddy field, field, orchard and forest considering CN value, how green space area contributes to flood control by each flood type was analyzed. In flood type 1, grassland showed the highest contribution and then followed by forest, planted area. In flood type 2, as a variable contributing to flood control, only forest was analyzed and in flood type 3, contribution was analyzed in the order of paddy field, field, planted area and forest. As most of farming land of Seoul is located at gentle space bordered with mountain area, it could be seen that it plays a role of natural rainwater retaining basin having capacity of confining water of farming land. Type 4 represents to exert influence on flood control in the order of forest, planted area, field.

In case of green space pattern of flood type 1 and 2, AWMSI was represented as significant variable and it could be seen that the more complexity is increased, flooding probability is increased accordingly. As type 3 is an area where flood control efficiency of green space area is high, NumP, MPS, AWMSI, CA that are indices for green space distribution were selected as significant variables. It could be realized that the more NumP, MPS and AWMSI are high, it exerts a positive influence on flooding probability reduction when green space area is same. In type 4, it was analyzed that the more NumP is increased, it exerts positive effect on flooding.

According to this study, green space in urban area shows partial difference by each flooding type but it was analyzed to have a flood control function corresponding to topographic factors such as slope, TWI, drainage grade. Therefore, in case of introducing green space area in an area where green space efficiency is maximized, far more flood control effect could be represented. Significance of this study is that a result was deduced by quantitatively analyzing flooding probability based on features of green space area, type, pattern by each regional features based on statistics. In addition, by performing not only district scale but also landscape scale, multi-scale analysis results for green space planning was deduced.

In the case of artificial FRMI, such as rainwater retention basins, their value may decrease over time, but increasing the green space area is an eco-friendly solution that will benefit humans and nature over a long period of time. The role of existing green spaces is often limited to the production of ecological benefits for wildlife and aesthetically-pleasing landscapes for human residents, but functionally, proper design plans for green space locations could maximize their impact on flood control. Therefore, this study recommends that urban areas devote planning resources for green spaces, and such efforts should determine where the best areas are for their introduction.

It is expected that the approach used in this study and the results obtained will provide a framework for diverse research on green spaces in the future. Furthermore, the techniques employed may be useful for predicting flood probabilities in urban areas, i.e., the models, which were based on empirical data, had a high explanatory capability.

2. Limitation and future task

Some limitations were encountered. First, artificial flood control capacity was included in an analysis of flood vulnerable area through variables of flood control facility status and sewer line extension ratio but hydraudynamic variable for water flow by bending condition of sewer line was not considered. Accuracy of a model being constructed in this study is explained on the level of 88% but remaining 12% is a part that could not be explained by a model constructed in this study and it is considered to be its limitation. In case of using hydroligic model for analysis of flood vulnerable area, it has an advantage of reflecting features of sewer line but its deterioration level, leakage, clogging are hard to be reflected. It is hard to reflect detailed topographic information in a model and as a lot of budget and effort may be required in precise site survey and collecting data, analyzing flood vulnerability by using data-based empirical method would be also a big advantage.

Second, data were analyzed based on land cover maps and urban biotope maps. Hence, in this study, only green space area, type, and pattern were used as a variable, but more detailed information on planting types or structures of green spaces would be useful for future analyses of the impacts of green spaces on urban flooding. Such information could be identified through site surveys.

Third, flooded point data were established from a flood inundation map for 2011, so analysis was performed using only one year of data. The extracted flooded/non-flooded point for 10 years had many precipitation data because flooding often occurred in the same area.

Therefore, it is difficult to use the logistic regression analysis. If points were extracted from more flood inundation maps over many years, the accuracy of the results could be higher.

Fourth, the model was constructed based on the total area of the city of Seoul. However, if a site-based model could be constructed and supplemented after identifying detailed small green spaces through site surveys in the future, the applicability of the model could be further increased as more accurate data were incorporated.

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국 문 초 록

기후변화로 인해 국지성 집중호우가 잦아지면서 아스팔트와 시멘트로 덮인 대도시의 배수시설이 폭우를 감당하지 못해 물에 잠기는 도시홍수가 최근 들어 자주 발생하고 있어, 이에 대한 근본적인 대책이 필요한 시점이다. 서울 도심에서 홍수피해가 발생하는 1차적 배경은 집중강우의 발생으로 강우의 시간 공간적 분포의 집중성으로 보고되고 있다. 또한 도시개발에 따른 불투수층 증가는 자연 수문학적 과정을 크게 변화시키고 빗물 침투를 막으며 지표유출 및 첨두유출량을 증가시키게 된다.

최근 기후변화 적응, 재해저감, 지속가능한 개발의 접점에 있는 중요한 대안으로 도시녹지의 중요성이 크게 강조되고 있다. 기후변화 영향으로 방재시설 용량을 초과하는 집중호우시에는 방재시설만으로는 한계가 있으므로, 지속가능하고 장기적인 관점에서 방재시설뿐만 아니라 녹지도입과 같이 근원을 해결할 수 있는 접근이 필요하다.

도시녹지는 유출을 감소시키고 도시수문에 대한 도시화의 부정적인 효과를 저감시키기 위한 조치로서 널리 이용되고 있다. 녹지의 홍수저감에 대한 개별효과 외에도 도시홍수에 영향을 미치는 경사, 토지이용, 강우량, 홍수저감시설 유무 등에 따라 녹지의 효과는 달라질 수 있다. 그러므로 홍수가 발생하는 다양한 요인에 대해 파악하고 이들이 유기적으로 어떻게 홍수에 영향을 미치는지 분석하여 홍수저감을 위한 대책마련이 필요하다. 홍수에 대한 레질리언스가 높은 도시를 지향하기 위해서는 지역별 특성을 정확히 파악하고 필요에 따라 적절한 유형의 녹지를 적용하고 이에 따른 효과를 최대화해야 한다. 이를 위해 본 연구에서는 서울시의 홍수 취약지역을 분석하고, 홍수발생지역을 4가지 유형으로 구분한 후, 각 유형별로 녹지의 면적, 유형, 분포 특성에 따라 홍수발생확률이 어떻게 변화하는지 통계학적으로 분석하였다.

연구결과를 요약하면 다음과 같다. 첫째, 공간통계모델인 MaxEnt를 이용하

여 서울시 전체 지역을 대상으로 도시홍수 취약지역을 분석하였다. 모델 구동을 위해 선정된 변수는 누적3일강우량, 시간최대강우량의 기후노출변수, TWI, 토양배수, 토지이용 등의 물리적 변수와 홍수를 저감시킬 수 있는 녹지환경 변수와 홍수저감시설 변수이며, 불확실성을 고려하여 1000회의 랜덤포인트 추출을 통해 결과를 평균과 표준편차로 나타내었다. 239개 배수분구 중 43개의 배수분구에서는 홍수발생이 전혀 일어나지 않았으며, 홍수에 취약한 지역은 서초4, 길동, 신월3, 방배1, 화곡2 등의 지역으로 나타났다.

둘째, 다변량 통계분석을 이용하여 홍수 발생지역의 유형을 4개로 구분하였다. 유형1은 배수분구 내에 홍수저감시설이 있는데 홍수가 발생한 지역으로 한강 및 주요 하천 주변에 위치하고 산과 인접한 도시 일부에서 나타난다. 기존에 홍수로 위험했던 지역이므로 경사가 서울시 전체 평균보다 완만하고 TWI는 두 번째로 높은 지역이며, 주거·상업혼합지 비율이 가장 높게 차지하고 있다. 유형2는 경사가 매우 급하며, TWI는 낮으며, 배수는 가장 양호한 지역이다. 다른 유형에 비해 녹지 비율도 높은 곳으로 경사가 급한 산지와 인접한 부분임을 알 수 있으며, 물이 정체되지 않고 흘러내리거나 침투되어 홍수가 잘 나지 않는 지역 특성을 가진 지역이다. 유형3은 경사가 매우 완만하고 TWI도 가장 높은 지역이며, 배수등급도 4개의 유형중 가장 불량한 지역으로, 유형2의 특성과는 반대로 물이 잘 정체되어 고일 수 있는 특성을 가진다. 단독주택지와 주거상업혼합지의 비율이 높고 도로의 50%이상이 위치한다. 유형4는 유형2와 유형3의 중간적인 특성을 가진 지역이고, 경사가 보통이고 TWI는 낮은 편이다. 시간최대 강우량의 가장 큰 피해가 발생하는 지역이다.

셋째, 로지스틱 회귀분석을 이용하여 홍수발생유형별로 녹지면적, 유형, 분포 특성에 따른 홍수발생확률 변화 차이를 비교 분석하였다. 녹지면적은 경사가 가파르고 배수가 양호한 유형2지역보다는 경사가 완만하고 TWI가 높은 유형3지역에서 홍수발생확률을 낮추는데 더 효과적임을 알 수 있었고, 경사가 급한 지역이 포함된 유형2와 유형4는 시간최대강우량 변수가 홍수발생확률에 큰 영향을 미치고 있어 녹지면적을 아무리 증가시켜도 홍수발생확률이 높게 나타

났다. 반대로 유형3은 시간최대 강우량보다 지형적인 특성이 홍수발생에 더 영향을 미친다.

녹지유형은 CN 값을 근거로 조경식재지, 논, 밭, 과수원, 초지, 습지, 산림지의 7가지 유형으로 나누어 홍수유형별로 홍수조절에 어떤 기여도를 하고 있는지 분석해 보았다. 유형1의 경우 초지가 가장 높은 기여도를 보였으며, 그 다음으로 산림, 조경수목식재지 순으로 나타났다. 유형2는 홍수조절에 기여하는 녹지변수로 산림지만 분석되었으며, 유형3은 논, 밭, 조경수목식재지, 산림의 순으로 기여도가 분석되었다. 서울의 경작지는 대부분 산지와 인접한 완만한 공간에 위치하므로 경작지의 물을 가둘 수 있는 능력을 통해 자연 저류조와 같은 역할을 하고 있음을 알 수 있다. 유형4는 산림지, 조경수목식재지, 밭 순으로 홍수조절에 영향력을 나타내고 있다. 유형4의 경우 야산이 많이 존재하여 이 지역에서의 홍수조절이 컸음을 유추해볼 수 있다.

녹지 분포는 유형1과 유형2의 경우 AWMSI가 유의한 변수로 나타났으며, 녹지의 복잡성이 높아질수록 홍수가 발생확률이 증가함을 알 수 있다. 유형3은 녹지의 홍수저감효율이 높은 지역인만큼 녹지 분포에 대한 지수도 NumP, MPS, AWMSI, CA가 유의한 변수로 선택되었다. 같은 면적이라면 NumP는 클수록, MPS는 클수록, AWMSI는 클수록 홍수저감효과가 크다. 유형4는 NumP가 늘어날수록 홍수발생에 긍정적인 영향을 주는 것으로 분석되었다.

본 연구에 따르면 도시 내 녹지면적은 홍수발생유형별로 일부 차이는 있지만 경사, TWI, 배수등급 등의 지형적인 요인에 버금가는 만큼의 홍수조절기능을 갖는 것으로 분석되었다. 그러므로 앞서 홍수발생 유형별로 녹지의 효율이 최대가 되는 지역에 녹지를 도입할 경우에는 훨씬 더 많은 홍수저감 효과를 나타낼 수 있는 것이다. 본 연구는 각 지역유형 특성별로 녹지면적, 녹지유형, 녹지분포 특성에 따른 홍수발생확률을 통계를 기반으로 정량적으로 분석하여 결과를 도출했다는 데에 중요한 의미를 갖는다. 또한 녹지특성 평가시 지역단위뿐만 아니라 경관단위까지 포함하는 다규모 분석(multi-scale analysis)을 시행하여 녹지의 다각도적인 분석 결과가 도출되었다.

저류조와 같은 인공적인 홍수저감시설은 시간이 지나면 그 가치가 감소하지만 녹지는 시간이 지날수록 인간과 자연에게 주는 긍정적인 효과가 더 커지는 친환경적인 정책이다. 그러므로 본 연구는 도시녹지의 홍수저감능력을 중심으로 하여 이 효과를 가장 효율적으로 발휘할 수 있는 곳에 배치할 수 있게 녹지가 도입될 지역특성에 따라 녹지면적, 녹지유형, 녹지분포에 대한 계획 근거를 제시하였다. 이 같은 녹지 도입에 대한 근거를 제시했다는 데에 향후 다양한 관련 연구에 적용될 수 있을 것으로 기대되며, 수문학적 모델을 사용하지 않고도 경험적이고 데이터에 기반한 방법을 이용하여 충분히 설명력 높은 홍수발생을 예측할 수 있다는 것에서도 유용한 도구로 활용될 것으로 기대할 수 있다.

주요어 : 홍수취약지역, 홍수지역유형구분, 도시녹지면적, 도시녹지유형, 도시녹지패턴, 로지스틱회귀분석, 홍수발생확률

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The Empirical Relationships Between Green Space Characteristics and Flood Events

도시녹지 특성에 따른 홍수조절효과 분석

- 녹지면적 유형, 패턴을 중심으로 -

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Hyomin Kim

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Hyomin Kim

Confirming the Ph.D. Dissertation written by

Hyomin Kim

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Chair ________________________(Seal)

Vice Chair ________________________(Seal)

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Abstract

The Empirical Relationships Between Green Space Characteristics and Flood Events

Hyomin Kim
Interdisciplinary Doctoral Program in Landscape Architecture,
Graduate School, Seoul National University
Supervised by Professor Dong-Kun Lee

Countermeasures for increasing resilience to urban flooding should consider long-term perspectives because climate change impacts are unpredictable and complex. Recent approaches to climate change adaption have emphasized disaster control, sustainable development, and urban green spaces. For flood control, green spaces can evolve dynamically depending on the physical environment of an urban flood; therefore, identifying the regional features of green spaces is necessary to maximize their effect. In this study, flood vulnerable areaflooded areas in Seoul, Korea, were divided into four flooded area types, and statistical analysis was performed to determine how the flooding probability change with green space area, type, and pattern. In this way, regional features that maximize the effects of green spaces on flood resilience were identified and can now be reflected in the planning and design of green spaces.

First, a model to evaluate flood vulnerable areas in Seoul city was developed using MaxEnt. The variables selected for model simulation

included those related to the physical environment, climate environment, green space environment, and flood risk management infrastructure (FRMI). The model was simulated by extracting random points 1000 times considering uncertainty. Flood was not taken place in 43 of 239 drainage basins in Seoul. On this basis, the flood vulnerable areas identified were: Seocho4, Gildong, Shinwol3, Bangbae1, and Hwagok2 drainage basins.

Second, flooded area types were divided into 4 types based on features of flooded area by using multivariate statistics. Type 1 included regions where flooding occurred in a drainage basin that had a FRMI. These basins were located around the Han River and major streams and were bordered by mountains. Basin slopes were gentler than the slope of Seoul city and the was the second highest identified. These basins were characterized by residential and commercial mixed land use. Type 2 is the regions with steep slopes, low TWI, and the best drainage identified. Compared with the other types, the green space ratio was high. These basins were bordered by steep mountains allowing the downward flow of water without attenuation, which was identified as regional feature of flood resistance. Type 3 represented the gentlest sloping areas, and these were associated with the highest TWI value, and the worst soil drainage. In contrast to type 2, the dominant regional feature was the attenuation of standing water. Type 4 had features that were intermediate to those in type 2 and type 3 (e.g., moderate slopes, imperfect soil drainage, and lower than average TWI value).

Third, differences in flooding probability based on green space area, type, and pattern for each flooded area type was comparatively analyzed using logistic regression analysis. We found that green spaces exerted a considerable influence on urban flooding probabilities in Seoul and flooding probabilities could be reduced by over 50% depending on the green space area and the locations where green spaces were introduced. Increasing the area of green spaces was the most effective method of decreasing flooding probability in type 3 areas. In type 2 areas, the maximum hourly precipitation affected the flooding probability significantly, and the flooding probability in these areas was high despite the extensive green space area. On the basis of the results, a formula was developed to identify the green space areas required to reduce flooding probability.

Green spaces were categorized as planted area, grassland, wetland, paddy field, field, orchard, or forest based on their CN value, and the contributions of green space areas to flood control for each flooded area type were analyzed. For type 1, grassland showed the highest contribution, followed by forests and then planted areas. For type 2, only the forest type was analyzed with respect to flood control. For type 3, paddy fields showed the highest contribution, followed by fields, planted areas and forests. As most farmland in Seoul is located on gentle slopes bordered by mountains, natural rainwater is often retained in the basin as confined water. For type 4, forests showed the highest contribution, followed by planted areas and fields.

For the green space patterns of types 1 and 2, the area-weighted Mean Shape Index (AWMSI) represented as significant variable, with complexity increases correlated with increased flooding probability. Type 3 contained an area in which the flood control efficiency of the green space area was high, and the green space area (CA), number of green space patches (NumP), MPS, and AWMSI were found to be significant variables that exerted a positive influence on flooding probability reduction. In Type 4, increases in NumP were correlated with reduced flooding probability.

The results of this study show that green spaces in urban areas can impact upon flooded area type; however, flood control functions also correspond to topographic factors (i.e., slope, TWI, soil drainage); therefore, green spaces should be introduced to areas that will ensure maximum efficiency for flood control. Green space area, type, and pattern were suggested as a factor to reduce flooding probability according to the properties of the flooded area type. In addition, guidelines for increasing flood resilience were developed to assist with the spatial planning of green spaces as countermeasures for urban flooding.

In the case of artificial FRMI such as rainwater retention basins, their value may decrease over time, but increasing the green space area is an eco-friendly solution that will benefit humans and nature over a long period of time. The role of existing green spaces is often limited to the production of ecological benefits for wildlife and aesthetically pleasing landscapes for human residents, but functionally, proper design plans for green space locations could maximize their impact on flood control. Therefore, this study recommends that urban areas devote planning resources for green spaces, and such efforts should determine where the best areas are for their introduction.

It is expected that the approach used in this study and the results obtained will provide a framework for diverse research on green

spaces in the future. Furthermore, the techniques employed may be useful for predicting flood probabilities in urban areas, i.e., the models, which were based on empirical data, had a high explanatory capability.

Keywords : Flood vulnerable area, Flooded area type, Green space area, Green space type, Green space pattern, Logistic regression analysis, Flooding probability

Student number : 2011-30741

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Ⅰ. Introduction

Extreme weather events (e.g., regional torrential rains) have become more frequent as a result of climate change, and this has in turn led to an increase in urban flooding risk. As a result, the development of integrated countermeasures to combat increased rainfall is needed (Kim et al., 2013).

In Seoul, Korea, the temporal and spatial features of rainfall and urban flood damage are recorded (Seoul Metropolitan government (SMG), 2011). According to the National Disaster Management Institute, since the year 2000, concentrated heavy rainfall has increased to levels 2.5 times higher than those in the 1970s. For example, the mean annual frequency (days per year) of hourly rainfall exceeding 50 mm increased from 5.1 in the 1970s to 12.3 in the 2000s. Furthermore, the coverage of impervious pavement, which increases flood likelihood and flood damage, increased from 7.8% in 1962 to 47.64% in 2010, and is predicted to rise to 48.4% by 2020. However, this coverage considers the whole of Seoul city, which includes mountains and water bodies. In reality, the impervious area ratio of the urbanized area is over 90% and almost no rainwater infiltrates underground. Such increases in the impervious layer significantly change natural hydrologic processes; for example, preventing rainwater infiltration and increasing surface and peak runoff (Paul and Meyer, 2001; Whitford et al., 2001; Yao et al., 2015). Before urbanization, surface runoff was not more than 10.3% (based on 1962 data), but by 2010 this value was 51.6%, an increase in surface runoff of ~640 mm/year (SMG, 2013).

Developing policies to combat urban flooding and the environmental issues associated with urbanization remains problematic. First, despite that most important cause of increased flooding being the increase in impervious area, most policies to date have focused on sewer line expansion. Another problem is streamflow depletion in urban streams (e.g., Cheonggaecheon, a typical stream of Seoul city), which reflects infiltration volume decreases and the subsequent drop in underground water levels. Suggested approaches to combat this issue have included increasing flow by tapping outside water basins or by using the inter-stream lesser circulation method. Finally, increasing urban temperatures and water quality problems have distorted water circulation structures.

Recently, approaches to climate change adaption have focused on disaster control, sustainable development, and resilience. Urban space having high resilience is less affected by climate change or disaster, and when disasters occur, the restoration speed is rapid. However, future precipitation and rainfall intensity are predicted to increase further; therefore, long-term countermeasures that increase resilience are needed. To this end, urban regeneration strategies have emphasized the importance of urban green space (TEP, 2008; TEP, 2010).

The impact of green spaces on runoff has been widely investigated (City of Seattle, 2008; Armson et al., 2013; Inkilainen et al., 2013). In particular, urban green spaces have been widely used to reduce runoff and offset the negative effects of urbanization on urban hydrology (Mentens et al., 2006; Bartens et al., 2008; Zhang et al., 2012). Flood control using green spaces varies depending on slope, land use, precipitation, and the existence of flood risk management infrastructure; therefore, implementing effective flood countermeasures requires the identification and analysis of the variables that control flooding.

Urban green space policies are being introduced in Korea; however, so far they have been localized and mainly focused on quantitative expansion for human accessibility. Utilizing diversified functions of green space both positively and efficiently has limitations (Lee and Kang, 2012). In order to achieve high urban resilience and an effective response to climate change, it is required to identify regional features correctly, apply green space of proper type, and then maximize its effect.

In this study, flood vulnerable areas of Seoul city were analyzed, and flooded area were divided into four types. Afterwards, the flooding probability for each type was statistically investigated depending on green space area, type, and pattern. Following this approach, regional features that maximize green space efficiency for flood resilience were identified, and can now be reflected in the planning and design of green space areas.

Ⅱ. Literature review

1. Urban water management and climate change adaptation

Recently, as rainfall has become concentrated over shorter time periods, significant damage has been sustained in urban areas. Disaster damage resulting from urbanization and climate change has been the focus of diverse studies and the consideration of adaptation approaches for sustainable urban water control has increased.

Urbanization in Korea has exceeded 90%, with most of the population residing in urban areas. Parks and green spaces, in which rainwater is infiltrated and stored, have decreased and the coverage of impervious materials has rapidly increased. Areas in which the impervious layer has increased following urbanization show significantly changed patterns of hydrology (Booth and Reinelt, 1993; USEPA, 1993). Changes in land use by urbanization, including increases in the impervious layer, have resulted in reduced evapotranspiration, underground infiltration by rapid runoff, and reduced green space areas (Dreiseitl and Geiger, 1995).

Increased flooding can be attributed to increased rainfall intensity, urbanization, outmoded urban infrastructure, and a lack of existing infrastructure capacity to cope with current rainfall intensity (Kirnbauer et al., 2013). Over the last 30 years, flood risk has increased following repeated meteorological disasters in Seoul city. Mean rainfall data from 1960 to 2009 show that annual mean precipitation and rainfall intensity during concentrated heavy rainfall have increased, with heavy concentrated rainfall even occurring during the traditional dry season. (Choi et al., 2008). From 26 to 28 July 2011, Gwanakgu experienced the highest daily rainfall (348.5 mm) among the districts of Seoul city. This event led to significant damage and reflected the increases in rainfall intensity and the occurrence of 100-year frequency rainfall events.

To combat urbanization and climate change, urban water management has been introduced. This has emphasized the storage of rainwater in sewer lines, but had failed to prevent the runoff and peak flow generated by urbanization. Increases in the impervious rates of concrete and asphalt following urbanization have increased the burden on drainage facilities, even before the increases in rainfall are considered, and this has resulted in increased flood risk, decreased infiltration, decreased evapotranspiration, and increased runoff. As runoff has increased, the greater transportation of pollutants (e.g., bacteria) has aggravated urban water quality (Liu et al., 2014).

Recently, inter-city green spaces have been frequently used to control urban flooding in the USA, Canada, Germany, and New Zealand (Ahiablame et al., 2012). The concepts of Low Impact Development (LID) in the USA, Sustainable Urban Development Systems (SUDS) in the UK, and Water Sensitive Urban Design (WSUD) in Australia have focused on runoff control, water quality control, and rainwater reuse by urbanization. These techniques always include the installation of on-site flood control systems in target areas in order to control rainwater runoff by preserving and recreating natural landscapes (Graham et al., 2004).

Sustainable water management for flooding is focused on controlling rainfall through soil infiltration, and not just on rainfall exclusion. This method attempts to maximizing the soil infiltration area and infiltration velocity in order to decrease rainfall runoff and non-point pollutant discharge load. The expansion of urban green spaces for flood control is an economical and eco-friendly approach that can promote smart growth and urban sustainability, and can also respond to sustainable and highly recoverable urban development and climate change (Benedict and McMahon, 2002, 2006; Gill et al., 2007; Mell, 2009; Dunn, 2010; Foster et al., 2011).

2. Assessment of Flood vulnerable area

Floods frequently occur following sudden heavy rainfall; therefore, research into flooding is performed in related fields. Urban floods endanger human life, private property, and public infrastructure. Furthermore, they destroy stream embankments and dikes, and pollute rivers and urban streams. The urban flood threat will continue to intensify as people experience more frequent extreme weather arising from global climate change (Villarreal et al., 2004; Foster et al., 2011).

Research into flooding is diverse and includes the analysis of correlation between flooding factors and flooding (Kang and Lee 2012; The Seoul Institute, 2011; Sim et al., 2014), the flood vulnerability assessment (Parker, 2007; Lee et al., 2011; Kim et al., 2011; NIER, 2011; Zhou et al., 2012; Kim et al., 2013), and quantitative prediction using hydrologic modeling (Kim, 2006). To predict flood vulnerable areas, proposed methods include multiplying indices of risk, vulnerability, and exposure (Karmakar et al., 2007), and dividing multiplications of risk, exposure, and vulnerability by adapting countermeasures. However, most flood vulnerability research has calculated the vulnerability index by applying indices and weights that reflect the opinions of experts. It is challenging to calculate an index that reflects local features, as most reflect regional averages that fail to reflect reality. There is a clear need for more models to analyze flood vulnerable areas based on hydrologic and statistical approaches (Fenicia et al., 2013).

Flood prediction methods are usually based on hydrologic models or on spatial statistics. Hydrologic models of urban floods (e.g., ILLUDAS, SWMM, TR-55, HSPF, Inforks, and STORM) are used in academic and industrial research. These models are mainly used for the planning and control of urban flooding, and are particularly focused on sewage facilities relevant to water movement (Chen et al., 2015). Traditional hydrologic methods use physical models (e.g., rainfall-runoff modeling techniques) that are not suitable for the integrated analysis of rivers or flooding (Smith and Ward, 1998). Hydrologic methods follow 1-dimensional procedures. In addition, river topography is not constant and has dynamic features reflecting the high erosion potential. A final disadvantage of this method is that it requires precise site surveys, which can be economically prohibitive (Fenicia et al., 2013).

As an alternative, some studies have analyzed flood vulnerability empirically by using a data-based approach, including the development of statistical and machine learning models. Statistical models include empirical models (e.g., GLM, the generalized linear model; GAM, the generalized additive model; and MARS, multivariate adaptive regression splines) and expert knowledge based models (e.g., AHP). Most urban disaster modeling data violate the hypothesis of a linear model and GLM represents an expansion linear model that can be used to process abnormal distributions (Venables and Ripley, 1994). The most general form of GLM is logistic regression analysis (Franklin, 2009).

Pradhan et al. (2010) analyzed flood vulnerability along the eastern coat of Malaysia using logistic regression analysis, and evaluated landslide vulnerability for three areas of Malaysia using fuzzy logic. Other research has evaluated flood vulnerability in Seoul city using frequency ratio (Lee and Kang, 2012). However, in the frequency ratio model, probability analysis is performed by dividing each variable before simulating a model; therefore, it has the disadvantage that features of each area may be distorted when calculating flooding probability by each variable (Kim et al., 2013). Logistics regression analysis and frequency ratio analysis have been widely used in related fields owing to their simple and easily understandable concept (Liao and Carin, 2009).

Machine learning models include decision trees (DT), artificial neural networks (ANNs), the genetic algorithm, and maximum entropy (MaxEnt). The objective of the DT model, one of the most frequently used for disaster prediction, is to classify data into sub-groups based on a range of prediction variables. DT was used to map flood vulnerability in the Kelantan region of Malaysia (Tehrany et al., 2013) and has been used to evaluate other natural disasters (e.g., landslides).

Artificial neural networks are widely used for satellite image classification and have been applied to hydrology and hydraulic engineering. However, this model has a hidden layer; therefore, it has the disadvantage that results are hard to explain accurately, notwithstanding a high classification accuracy as compared with other methods (Flanklin, 2009).

Despite high classification accuracy, the machine-learning model is limited by present/non-present data and by difficulty in explaining the results (Seo et al., 2008). However, Kim et al., (2013) used MaxEnt to select vulnerable areas to urban flood adaptation (i.e., areas with a high flooding probability, based on present data), and created a spatial probability model for Seoul. Evaluation factors and method used to evaluate vulnerability are shown in Table 1.

Table 1. Evaluating variables for flood vulnerable area in literature

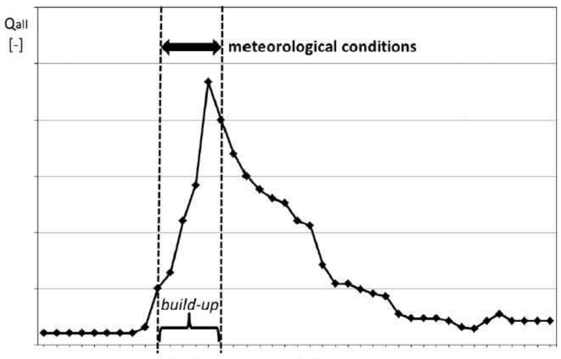
Variables		①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪
Flood damage	Damage cost of property/ damaged population	●				●						
	Flood depth, velocity				●							
	Runoff by unit						●					
Climate exposure	Rainfall intensity/ frequency	●			●		●			●	●	●
	Number of heavy raining days	●			●							
Physical environment	Slope	●				●		●	●	●	●	●
	Elevation	●					●	●	●	●	●	●
	Area of lower land/ stream flood water level	●				●		●				
	Distance from stream/ waterfront status	●								●	●	●
	Area of river	●										
	Soil drainage, effective soil depth, soil class / Geology						●		●	●	●	●
	Curvature								●		●	●
	Topographic wetness index (TWI)							●		●		
	Stream power index										●	●
Artificial environment	River, stream structure		●	●		●						
	Internal Drainage System capacity					●						
	Flood control capacity/ pumping capacity					●	●			●		
	Impervious rate						●	●	●	●		
	Stream improvement rate						●					
	Curve number							●				

green space	Forest area, green infrastructure area		●				●		●	●		
	Green space type						●		●			
	Age of tree, density								●			
social, economic environment	Financial independence rate	●				●						
	Flood prediction and warning facility		●	●								
	Evacuation facility, health service		●	●	●							
	Flood compensation		●									
	Infiltration facility / Distance of sewesr / Lacking capacity of sewers			●		●		●		●		
	Number of civil servant per population Number of civil servant with water management					●						
	Total population/d/population over 65 and below 15					●	●					
	Ratio of built area							●				
	Land use rate					●	●	●		●	●	●

① Kang and Lee (2012), ② Parker, D.J. (2007) ③ Evans et al., (2004) ④ Zhou et al. (2012) ⑤ NIER(2011) ⑥ Kim et al. (2011) ⑦ TSI (2011) ⑧ Lee and Kang(2012) ⑨ Kim et al.(2013) ⑩ Tehrany. et. al. (2014) ⑪ Tehrany. et. al.,(2013)

3. Classification of flooded area type

The hydrological condition of an area before rainfall and the meteorological conditions are two of the main factors affecting flooding. As shown in Figure 1, the time associated with water build-up until the peak time when rainfall starts and runoff becomes a maximum may differ completely depending on these conditions (Nied et al., 2014). The hydrological condition before rainfall can affect flooding due to many physical or environmental variables, such as the altitude, the slope, and the soil features, as well as the capacity of any flood control facility. Therefore, it is important to classify these physical environments by type and establish flood control countermeasures for each type.



	Rain-on-snow flood	Snowmelt flood	Long-rain flood	Short-rain flood	Flash flood
Seasonality	Winter/Spring	Winter/Spring	no	no	Summer
Length of build-up period	medium	long (> 4days)	long (> 4days)	medium	short (~1day)

Figure 1. Schematic drawing about water built-up time (Nied et al., 2014)

Flooded areas are classified by two different methods. One method classifies areas depending on the factors affecting the flooded area and the other method divides the areas depending on the flood damage level. Merz and Bloschl (2003) divided flood types into rain-on-snow floods, snowmelt floods, long-rain floods, short-rain floods, and flash floods depending on the features of the rainfall and the snow. They also discriminate between such features as the flooded spatial area, seasonality, the snow build-up, the condition of the air temperature and the humidity, the precipitation, and the build-up period.

In The Seoul Institute (2002), flood prone areas were divided into type 1 and type 2 based on the river flood level, the land use, the past flooding frequency, and an impervious surface ratio (ISR). Each type of flood prone area was further divided into short-term, medium-term, and long-term, and flood control methods were presented. Lee (2004) analyzed the causes of major flood damage and suggested an improved method for classifying flood prone areas by comparing the business features in the disaster risk area. In addition, in NEMA (2005), flood prone areas were selected nationwide by targeting damage cases autonomously investigated by local governments for flooded areas that occurred from 1993-2003. They categorized the areas by the cause of damage and then presented problems with and solutions for each cause.

The U.K. operates a sequential test that induces developers to develop projects in areas having the least flood risk. To meet this objective, they divided the nation into four flood zones depending on flood risk based on annual flooding probability. They then presented a standard for each area for the required infrastructure to be constructed to prevent flooding (U.K. Communities and Local Government, 2006).

Park et al. (2013) categorized 34 flood prone areas in Seoul city by using a multivariate statistical analysis with relevant factors, such as detached housing area ratio relevant to land use, the apartment ratio, the green space and open space ratio, the average slope of the water basin, and the ratio of the area below the river plain flood level. Through this, the city was divided into three flood types, and a strategy for flood control countermeasures by each type was suggested.

4. Flood control capacity of urban green space

1) Definition and range of urban green space

Urban green space is defined generally as an area combining parks, created green spaces, and natural green spaces in an urban area (Yeom and Park, 2011). Green space is defined specifically in several academic fields, and the term, green space, has been used from the early 19th century in discussing urban spaces. It has been used in a wide range of fields, including urban planning, landscape, environmental studies, and tourism. In broad terms, green space can include any open spaces; and in some narrow definitions, a green space ratio based on certain standards is used (Lim and Kim, 2011).

Recently, some researchers have defined urban green space, comprehensively, as green infrastructure. Lee et al. (2014) defines green infrastructure broadly as the ecosystem for the sustainable life of human beings that is obtained in urban areas by physical connections with nature or open spaces. The meaning of green infrastructure, based on having parks and green space as its main components, was recognized at an early stage as having ecological value (Benedict and McMahon, 2006). They further emphasized that in urban areas, the focus on green infrastructure must be on the creation and control of parks, green spaces, public gardens, rainwater control areas, and urban farmlands rather than on natural green infrastructure, such as wetlands and preservation areas (Schilling and Logan, 2008).

After the 20th century, based on the Environmental Protection Agency (EPA) of the USA, the concept of rainwater control as a main function of green space was defined. The EPA defined technologies and policies that make rainwater control, the process of absorption, evaporation, and recycling of natural water, the function of green infrastructure. It explained that green infrastructure should include all low impact development (LID) techniques, such as green roofs, rain gardens, grassed swales, pervious pavements, and rainwater storage tanks (EPA, 2008a; 2008b). Green infrastructure could be interpreted as when green space and an artificial system, including forests, wetlands, parks, green roofs, and green walls, are converged. This green infrastructure contributes to human benefit through ecological resilience and ecosystem service (Naumann et al., 2010; Pauleit et al., 2011; European Environment Agency, 2012).

In this study, the concept of urban green space is similar to the concept of green infrastructure. However, this research also defined mountain areas, farmlands, grasslands, wetlands, and parks as urban green space and excluded artificial rainwater control facilities. Recently, urban green space has been approached from the perspective of resilience and response to climate change. Resilience could be defined as the capacity of being able to reconstruct after a system disturbance while absorbing impacts and preventing such impacts from being converted to an unrestorable state (Resilience Alliance, 2007). Resilience can also be contrasted with vulnerability (Adger, 2000). As climate change has complicated and unpredictable characteristics, the development of urban green space may become a very important strategy for reducing flood vulnerability.

2) Flood control function of green space

In urban green space research, as the multi-functionality of green space has been emphasized, its importance has increased. Urban green space provides such benefits as the provision of habitats, the removal of pollution sources, the reduction in the heating or cooling requirements of buildings, the moderation of the heat island due to temperature drops in summertime, carbon absorption and oxygen generation in the atmosphere, and the provision of resting places. These functions go beyond its function in flood control through the interception of rainwater (McPherson et al., 1999; Pauleit et a., 2005; Perry, 2008). This study will focus on the urban flood control function of green space.

Urban green space includes trees, lawns, grasslands, and farmlands (Beijing Municipal Commission of Urban Planning, 2009) and exerts a positive influence on urban hydrology by promoting infiltration of the soil and root system, the storage of water, and rainfall interception by tree canopies and plant stems (Gill et al., 2007; Park et al., 2007; Zhang et al., 2012).

Even though soil infiltration was not considered, tree canopy interception in temperate forest areas accounted for 11-36% of the total precipitation in the case of deciduous trees and 9-48% in the case of conifers. In a study of the effect of parks and street trees in Santa Monica, USA, for reducing runoff and controlling floods (Xiao and McPherson, 2002), it was reported that 1.6% of the total rainfall was intercepted by the urban trees. Each tree absorbed 6.6 m^2 of rainfall and annually saved US$110,890 (US$3.6/tree) in flood control costs. In an urban forest, the quantity of crown interception varies depending on the forest structure (the plant species, the layer, and the height), the tree shape (leaf formation time, the surface area of the leaf and stem, the gap ratio, and the surface water retention storage capacity), and meteorological elements (precipitation, the period, the intensity, the frequency, and the evaporation rate).

In the case of permeation of water into the soil, the water movement into the soil and its storage capacity differ depending on features such as soil surface condition and the internal porosity. The hydraulic conductivity and water runoff differ as well. The infiltration rate of rainfall into soil is controlled by the maximum rate of water permeation through the soil/plant surface, the rate of water moving in an unsaturated layer of water, and the rate of discharge from the unsaturated layer to a deeper saturated layer. Until excess precipitation has taken place, the infiltration rate is determined by the lowest rate among these. In the case when soil structure is unstable and soil is exposed without having a coating material, such as a thin membrane that is formed by the destruction of the aggregated soil structure and separation of light silt or clay, the infiltration rate tends to be slow (Ellison and Slater, 1945).

Bonsingnore (2003) suggested that when the green space ratio is reduced to 25% by urbanization, runoff is over 55%, which is an increase of over five times for an area consisting of green space only. This was attributed to an increase in the imperviousness of the soil surface and a reduction of porosity in the soil that decreases the quantity of infiltration. Kirnbauer et al. (2013) performed an analysis by using an i-tree hydrological model based on precipitation for seven years, weather data that showed how much green space affects the rainfall interception, the reduction of runoff, and the rainfall evapotranspiration when ginkgo trees, Plantanus Xhispanica Munchh, sugar maples, and sweet gum trees are planted in soils with different conditions.

Research has been conducted on the benefits obtained from installing green space in urban areas. Alfredo et al. (2009) suggested that construction of a green roof could delay runoff time and roof filtration and reduce peak runoff by 30-78% compared with an existing concrete roof. Dreelin et al. (2006) suggested that pervious pavement reduced the runoff from two parking lots by 98% during a small rainfall (below 2 cm), and Chapman and Horner (2010) determined that installing a water retention facility at a Washington roadside retained 26-52% of the runoff. Schneider and McCuen (2006) clarified that a cistern is not efficient for reducing runoff in large-scale rainfalls but is very effective for small-scale rainfalls. Qin et al. (2013) concluded that a vegetated water channel, pervious pavement, and green roofs are very effective for flood control in heavy rains and for short-term rainfall as compared with general drainage systems. In addition, Kim et al. (2011) clarified that by targeting urban development areas, runoff could be reduced by 41% in the case of a vegetated water retention basin and by approximately 10% in the case of an artificial swamp. Using regression analysis, KEI (2011) determined that a 1% increase in green infrastructure could reduce property damage by approximately 6.4%.

Manchester City in the U.K. utilizes green infrastructure extensively and plans large-scale green infrastructure as a flexible strategy for responding to climate change. At present, it arranges infrastructure preferentially by designating standards and requirements for green infrastructure. It then analyzes any gaps after first analyzing the current status and condition of green infrastructure of the urban area using mapping techniques (TEP, 2008; 2010). The city of Portland in the USA experienced improved water control by three to six times through installing street trees and green space. Annual runoff was reduced by 40%.

In addition, in Chicago, through green roof creation, rainwater runoff was reduced by 76% per 1-inch of rainfall. In New York City, rainfalls of 25 mm that are generated from 10% impervious areas are controlled by installing green infrastructure facilities. It is expected that this policy will provide a cost reduction of US$1.5billion compared to their existing methods (City of New York, 2010; 2011). After installing urban arbors containing 90,000 trees in Modesto, California, the rainwater runoff was reduced by 292,000 m^3, which led to cost reductions of US$616,000 (US$7/tree or US$2.11/m3) (McPherson et al., 1999).

3) Evaluation of urban green space features

Green space is fragmented into various shapes as urban areas are developed. During fragmentation, the number of green patches is increased, the edge length is increased, and the average patch size is decreased (Rutledge, 2003; Collinge, 2009). Figure 2 shows that as one green space is fragmented, its interspersion metrics are increased, and isolation is developed. With a decrease in patch size, the size of the edge is increased.

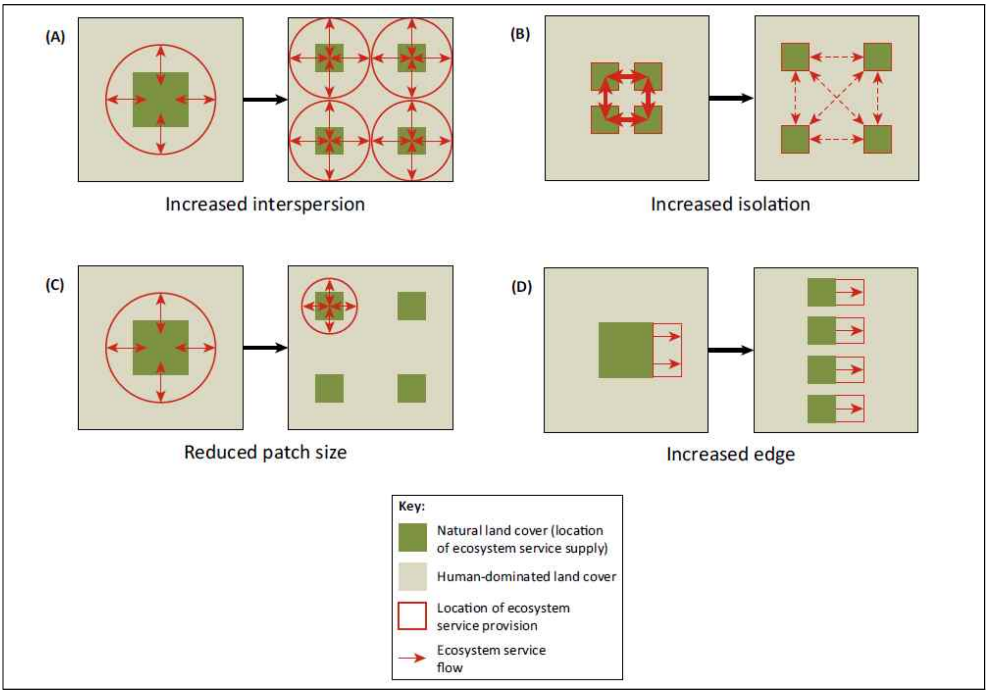


Figure 2. Mechanism of landscape fragmentation
(Fisher et al., 2009; Mitchell et al., 2015)

An index can be applied to evaluate area metrics, the patch density, the size, the edge metrics, the diversity and interspersion metrics, and the core metrics. The landscape index can identify the structure, the function, and the changing pattern of a landscape eco-system as a single numerical number. It is a relative number, not an absolute number (Huh et al., 2007).

Kim and Ahn (1996) identified the fragmentation, the soundness, and the accessibility of an urban park from the perspective of a landscape ecosystem. They analyzed it as a patch having a large area with an ecological effect over a simple sum of small patches with different preservation values as its diversity was high. Kim and Lee (2001) identified forest fragmentation and its effect on the ecosystem and the environment by evaluating green space environment sensitivity. They based their analysis on land use change by analyzing patch area change, the change of the area distribution, and the connectivity between patch shapes using a landscape ecology index targeting Cheonan City.

Huh et al. (2007) used a landscape index in order to analyze quantitatively landscape change by land use change. In order to analyze landscape structure by impervious area change, they estimated and analyzed the landscape index by past land use change and evaluated an impervious ground surface model based on the change of the impervious area, the water quality, and the landscape index. Eom and Lee (2008) deduced that one of variables that significantly effects green space use is accessibility. This was based on a preceding study relevant to urban green space that identified land use by urban citizens through a questionnaire and evaluated urban green space by usability.

Greca et al. (2011) performed a fragmentation analysis using a landscape index for constructing a land adequacy model to establish a land use plan for a non-urbanized area. Paudel and Yuan (2012) quantified temporal and spatial changes in landscape patterns in Minnesota by using a landscape index. Kim et al. (2013) analyzed the forest fragmentation level by area development and linear development based on a selected landscape index that was relevant to fragmentation. Based on this result, they discussed the practical application of a forest fragmentation index. Kim et al. (2014) performed a feature evaluation for applying green infrastructure through an analysis of patch fragmentation and accessibility supplemented by LISA, a spatial autocorrelation analysis.

Zhang et al. (2015) analyzed the temporal and spatial landscape pattern changes of urban green space areas of Beijing for the last 10 years based on a large patch index (LPI) and an aggregation index (AI) together with regional differences in runoff reduction. This study was performed based on the prediction of urban green space capacity for runoff reduction by developing a formula based on the rainfall and a landscape index, not based on actual flood data.

As observed, there are many studies that performed a fragmentation analysis for analyzing landscape changes and comparing the past with the present. However, there is only limited research that deduced the suitability of green space distribution for flood control by evaluating the green space effect quantitatively in order to identify a relationship between flood control and green space distribution features.

In a study similar to this, many artificial rainwater retention basins were introduced in order to solve flooding temporarily, and several studies analyzed the runoff reduction by the location or arrangement of such basins. Han et al. (2012) evaluated the reduction of peak runoff based on the rainwater retention capacity distribution and the location of the retention basin facilities. Park et al. (2013) analyzed runoff and flood damage reduction based on an arrangement of rainwater retention facilities by using XP-SWMM software and by comparing basins with the same storage capacity. Basin type (concentration type, spread type, and mixed type) was analyzed to understand which type of runoff reduction technique minimized flood damage.

4) Identification of runoff coefficient

There are several formulas in estimation method of design flood volume for determining dimension of storm sewer but sewer line that undertakes inner basin drainage in urban basin is designed by using rational formula in most cases (Kim and Hwang, 2014; Lee at al., 2007). As structure of rational formula is simple and convenient for using, even an engineer who has limited knowledge of hydrologic basics could use it without difficulty. However, it has a disadvantage of being unable to apply an effect of factors such as land cover condition of ground surface affecting runoff, basin topography, soil features and return period (Kim, 2003). A procedure of calculating runoff quantity through calculation of rational formula is as shown on following Figure 3.

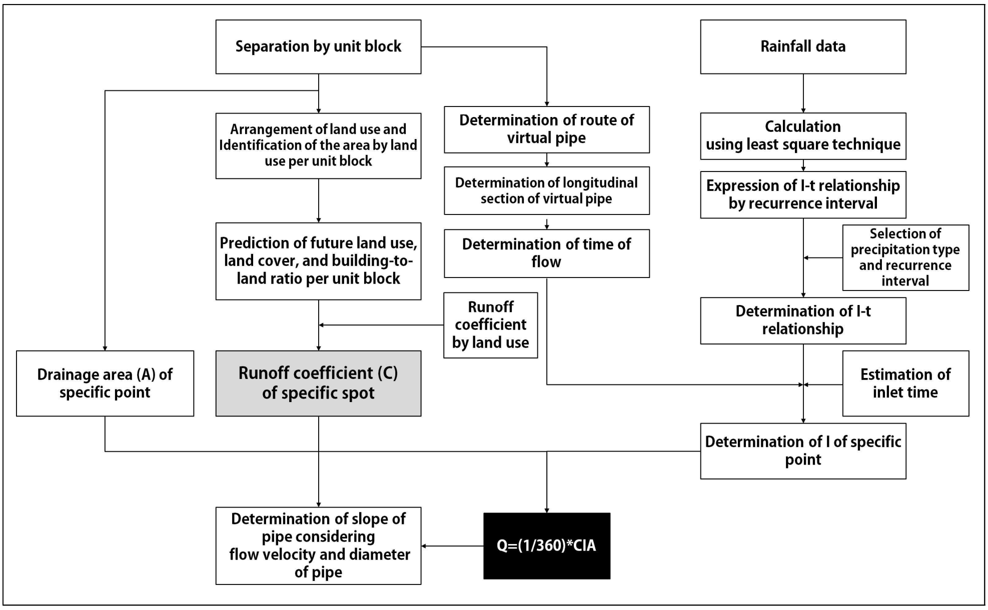


Figure 3. The procedures of calculating design volume of rainfall (ME, 2011)

Most important element in runoff analysis using rational formula is runoff coefficient and as domestic standard for runoff coefficient is not properly established, big difference is represented in its value depending on subjective judgement of the users (Lee et al., 2007). Runoff coefficient being used domestically is presented in 'Stream design standard (MOLIT, 2009)' and ‘Sewerage facility standard (ME, 2011)' being used in sewerage field.

Table 2 shows range of runoff coefficient of rational formula based on land use being presented in stream design standard. This value was prepared based on a value presented by ASCE. That's why correction value based on topography and geological features is presented. However, there is no method by which its suitability status could be determined and designer of sewer line is also using reference value or subjective runoff coefficient value without any evaluation. As residential situation of detached house is not identical with that of the USA, it is specified that caution is required in estimating runoff coefficient. In addition, in case of mountain area, a judgement considering site condition is required at the time of estimating runoff coefficient and in an area where basin area is narrow, big runoff coefficient is required to be used and in an area where basin area is wide, small runoff coefficient should be used (MOLIT, 2009).

Table 2. Runoff coefficient of Stream design standard (MOLIT, 2009)

<table>
<tr><th colspan="2">Land use</th><th>Coefficient</th><th colspan="4">land use</th><th>coefficient</th></tr>
<tr><td rowspan="2">Commercial area</td><td>Urban</td><td>0.70-0.95</td><td colspan="4">Road and street</td><td>0.75-0.85</td></tr>
<tr><td>Suburban</td><td>0.50-0.70</td><td colspan="4">Roof</td><td>0.75-0.95</td></tr>
<tr><td rowspan="5">Residential area</td><td>Detached 1</td><td>0.30-0.50</td><td rowspan="6">Grassland</td><td rowspan="3">Sandy</td><td colspan="2">Flat</td><td>0.05-0.10</td></tr>
<tr><td>Detached 2</td><td>0.40-0.60</td><td colspan="2">Average</td><td>0.10-0.15</td></tr>
<tr><td>Row house</td><td>0.60-0.75</td><td colspan="2">Steep slope</td><td>0.15-0.20</td></tr>
<tr><td>Suburban</td><td>0.25-0.40</td><td rowspan="3">Baryta</td><td colspan="2">Flat</td><td>0.13-0.17</td></tr>
<tr><td>Apartment</td><td>0.50-0.70</td><td colspan="2">Average</td><td>0.18-0.22</td></tr>
<tr><td rowspan="2">Industrial area</td><td>Not dense</td><td>0.50-0.80</td><td colspan="2">Steep slope</td><td>0.25-0.35</td></tr>
<tr><td>Dense</td><td>0.60-0.90</td><td rowspan="8">Agricultural land</td><td rowspan="2">Bare land</td><td colspan="2">Flat</td><td>0.30-0.60</td></tr>
<tr><td colspan="2">Park / Cemetry</td><td>0.10-0.25</td><td colspan="2">Tough surface</td><td>0.20-0.50</td></tr>
<tr><td colspan="2">Play ground</td><td>0.20-0.35</td><td rowspan="4">Farm -land</td><td rowspan="2">Sandy</td><td>Planted</td><td>0.30-0.60</td></tr>
<tr><td colspan="2">Railroad</td><td>0.20-0.40</td><td>Not planted</td><td>0.20-0.50</td></tr>
<tr><td colspan="2">Undeveloped area</td><td>0.10-0.30</td><td rowspan="2">Baryta</td><td>Planted</td><td>0.20-0.40</td></tr>
<tr><td rowspan="3">Road</td><td>Asphalt</td><td>0.70-0.95</td><td>Not planted</td><td>0.10-0.25</td></tr>
<tr><td>Concrete</td><td>0.80-0.95</td><td rowspan="2">Grass -land</td><td colspan="2">Sandy</td><td>0.15-0.45</td></tr>
<tr><td rowspan="2">Brick</td><td rowspan="2">0.70-0.85</td><td colspan="2">Baryta</td><td>0.05-0.25</td></tr>
<tr><td colspan="4">Forest</td><td>0.05-0.25</td></tr>
</table>

Land use could be mainly divided into infiltration area and non-infiltration area, and runoff coefficient of the former differs depending soil character or vegetation and that of the latter contact degree with sewer line. Sewerage facility standard divides land use based on such division and runoff coefficient value is as shown on following Table 3. This standard was deduced based on standard value of runoff coefficient and data of sewerage arrangement basic planning change (SMG, 2002). Runoff coefficient for 11 items being classified in detail by mainly dividing land use into urbanized area and green space area, open space area is presented. In sewerage facility standard, a method of applying upper value of basic runoff coefficient is presented so that flood damage could be reduced to maximum in flood prone area.

Table 3. Standard value of runoff coefficient for land use (Japan Sewer line association)

Surface	Coefficient	Surface	Coefficient
Roof	0.85-0.95	Bare land	0.10-0.30
Road	0.80-0.90	Park with grassland and tree	0.05-0.25
Impervious surface	0.75-0.85	Forest with a gentle slope	0.20-0.40
Water body	1.00	Forest with a steep slope	0.40-0.60

Table 4. Sewerage facility standard (ME, 2011)

<table>
<tr><th colspan="2">Land use</th><th>Coefficient range</th></tr>
<tr><td colspan="2">Transportation facilities area</td><td>0.80-0.90</td></tr>
<tr><td colspan="2">Commercial and business area</td><td>0.70-0.95</td></tr>
<tr><td colspan="2">Public facilities area</td><td>0.65-0.75</td></tr>
<tr><td colspan="2">Residential area</td><td>0.50-0.75</td></tr>
<tr><td colspan="2">Mixed land use area</td><td>0.70-0.95</td></tr>
<tr><td colspan="2">Industrial area</td><td>0.60-0.90</td></tr>
<tr><td colspan="2">Farmland</td><td>0.10-0.25</td></tr>
<tr><td colspan="2">Bare land</td><td>0.30-0.40</td></tr>
<tr><td rowspan="2">Urban infrastructure</td><td>Planted area</td><td>0.10-0.25</td></tr>
<tr><td>Built area</td><td>0.60-0.75</td></tr>
<tr><td colspan="2">Green space and open space</td><td>0.50-0.75</td></tr>
</table>

Runoff coefficient considering residential features of Seoul city is presented as shown on following Table 5 by referring sewerage facility standard (2009), stream design standard (2000) and ASCE standard. runoff coefficient regards all the rainfall in target areas as same. It is specified that this runoff coefficient be preferentially applied to new development area or at the time of new installation of sewer line and as for existing sewer line, it be applied after comparatively analyzing runoff presented in other relevant data (SMG, 2009).

Table 5. Runoff coefficient in Sewerage arrangement basic planning change (SMG, 2009)

Average runoff coefficient for region land use			Basic runoff coefficient for land use		
Commercial and business area			Road		
	Urban	0.70-0.95		Asphalt	0.70-0.95
	Suburban	0.50-0.70		Concrete	0.80-0.95
Residential area				Street, parking lot	0.75-0.85
	Detached house	0.60-0.75	Roof		0.75-0.95
	Apartment	0.50-0.70	Farmland		
	Suburban residential area	0.30-0.40		Paddy field	0.70-0.80
Industrial area				Field	0.45-0.60
	Not dense area	0.50-0.80	Etc.		
	Dense area	0.60-0.90		Playground	0.20-0.35
Green space				Bareland	0.40-0.60
	Flat park	0.10-0.25		Water body	1.0
	A steep slope	0.75-0.90		Grassland	0.10-0.30
	A gentle slope	0.50-0.75			

As a result of analyzing existing runoff coefficient features, similar range of runoff coefficient of urban impervious area was presented by several institutions at home and abroad. However, in case of green space area such as forest, farming land, as regional feature is different, it was analyzed that significant deviation was represented. As a result of this, a lot of researches trying to modify runoff coefficient to be matched with domestic reality are under progress (Lee et al., 2007; Yoo, 2008; Kim, 2003; Kang and Kim, 2008; Kim and Hwang, 2014). However, in spite of this diversified researches, it could be realized that runoff coefficient value of stream design standard, sewerage facility standard was seldom changed. Due to this, runoff coefficient of urban green space area is likely to be underestimated or overestimated and at the time of expanding sewer line for flood prevention, probability of wrong design is increased.

5. Summary

In previous studies, in order to observe urban water management for adapting to climate change and to analyze urban areas vulnerable to floods, flood vulnerability evaluations and spatial statistical models were considered. In addition, green space features in each flooded area type were analyzed in order to observe how flooding probability changed depending on green space features. Relevant existing studies were reviewed and confirmed.

Urban water management that could be applied for adapting to climate change may increase the resilience of urban areas related to flooding. Both at home and abroad, authorities have exerted their efforts in developing flood control methods and adapting them based on diversified sustainable methods. Increasing the ability to adapt to urban floods by using sustainable green space rather than flood control methods using artificial facilities, such as pumping stations and rainwater retention basins, would be required.

Flood vulnerability evaluations in the past were performed using a qualitative standard by establishing an index and weight as in the vulnerability evaluation suggested by the Intergovernmental Panel on Climate Change (IPCC) or by actively analyzing the vulnerable areas using hydrological models. Recently, a study that evaluates flood vulnerable areas by using spatial statistics was conducted. It was found that if spatial statistics are used, quantitative and empirical relationships that were overlooked in the existing qualitative evaluation model were found. In addition, by comparatively analyzing diversified spatial statistical models, a model that may be used in this study was selected.

A study classified by flood type was not varied. There were studies domestically that provided flood control countermeasures by discriminating the flood prone area as a variable after analyzing the area as the target. There was a study developed overseas that classified flood type depending on rainfall type. A study that evaluated green space features analyzed how green space and urbanization level were increased by evaluating the area, the size, the edge features, and the number of patches of green space after specifying a landscape index. Additionally, there was a study that explored the efficiency of runoff reduction and how it could be increased, depending on the arrangement of rainwater retention basins. It was found in a review of green space distribution arrangements.

There were several studies that analyzed runoff reduction by the introduction of green space, but none that analyzed this reduction by introducing green space based on regional features. In particular, as there was almost no existing study exploring the type of green space and the pattern (i.e., the size, the shape, or the spatial arrangement of green space patches) that contributes to flood occurrence, the distinctiveness of this study could be verified.

Ⅲ. Scope and Method

1. Spatial scope

The Seoul Metropolitan City (605.41km^2) was used as the site for this study (Figure 4). Seoul is one of the most highly urbanized cities in Korea and therefore represents an ideal area to study urban flooding. The percentage of impervious area in the city of Seoul has increased from 40.0% in 1962 to 47.7% in 2010, and over 90% of the impervious land cover is impenetrable to rainwater infiltration. In addition, several residential areas and industrial facilities are located near the floodplains; thus, the risk of damage caused by urban flooding is heightened in this region (SMG, 2014).

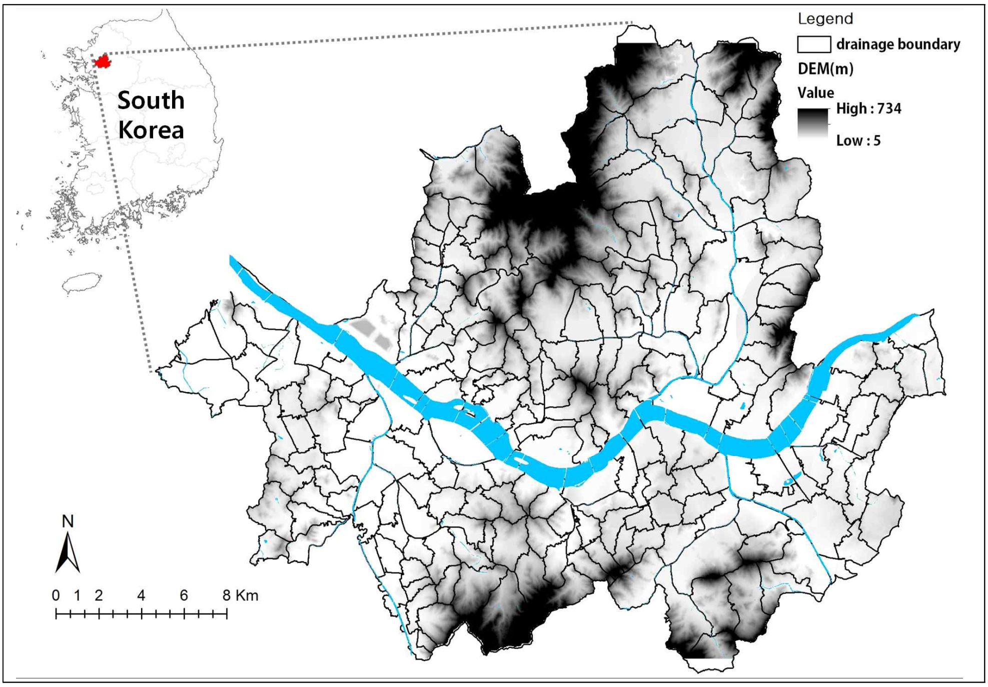


Figure 4. Spatial scope : Seoul Metropolitan City, South Korea

Seoul experienced a heavy flood in 2010 and 2011. Flooded areas during the event were distributed throughout Seoul, but damage was especially severe in Sadang, Seocho and Gangdong, compared to other parts of the city. Additionally, the southwestern part of Seoul, which has low elevation and gently sloping land, experienced severe damage from the flooding. In Seoul city, damage of lowland, semi-underground housing area and damage by capacity problem of sewer line due to severe rain rather than river flood damage by direct inundation of stream or embankment collapse were its mainstream of damage (The Seoul institute, 2011).

When observing annual precipitation hour trend for the recent past 50 years, it was analyzed that while it was reduced by about 1.5 hours every year, maximum continuous precipitation time was increased by 0.08 hours every year (SMG, 2013). While the yearly total of hourly precipitation in Seoul has decreased recently, the maximum hourly precipitation has displayed an increasing trend; thus, it can be inferred that the rainfall intensity and continuous duration of heavy rainfall has increased, and these changes have primarily taken place during the summer. Consequently, Seoul may be more vulnerable to flooding in the future, and it would be prudent for officials to prepare for such situations, in part by implementing sustainable methods to increase flood resilience

An analysis unit of this study varies depending on analysis contents but an analysis was performed based on flooded point unit and drainage basin unit that means a section where sewerage is treated in urban area. It is partially similar to basin unit but in case of urban area, as a place where most of water is gathered is sewer line, considering topographic features, a it is divided into section and this is called drainage basin. Drainage basin of Seoul city is mainly divided into northeastern region, northwestern region and southwestern region and total 239 basin are existent.

2. Content scope

Urban flooding in this study is defined as a phenomenon that causes inconvenience to humans living in the flooded area or human injuries and various tangible and intangible property damage due to inundation of urban areas (SMG, 2013).

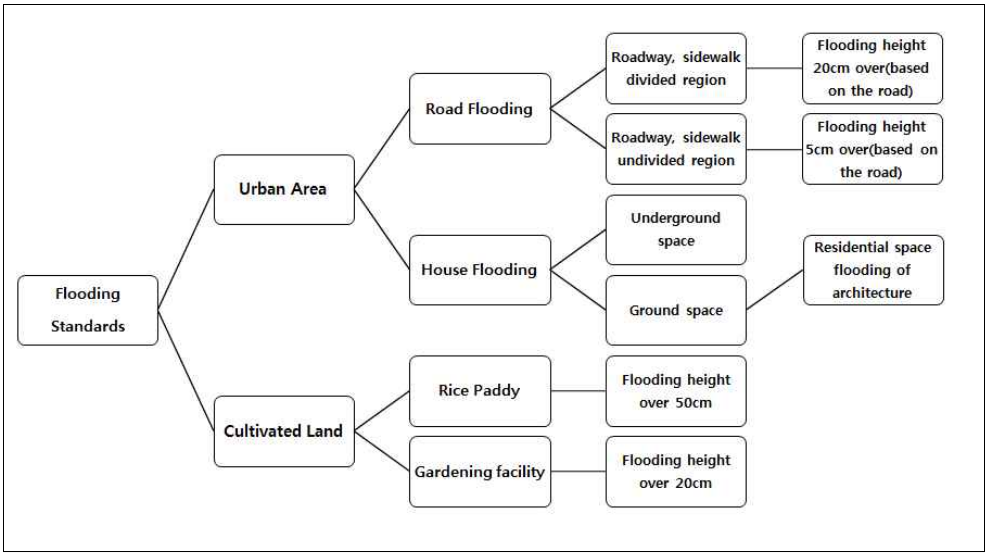


Figure 5. Setting standards flooding (SMG, 2013)

Urban green spaces in this study include forests, farmlands, grasslands, wetlands and other planted types of land, and green space data were derived from land cover maps and urban biotope maps of the region. These green spaces are considered to be critical to the natural water circulation system, as they represent areas where rainwater infiltrates and is retained. Low impact developments and green spaces, including artificial facilities (e.g., rainwater tanks, pervious paving), were excluded from the analyses. The amount of infiltrated water considered in this study includes not only rainwater that falls onto the green spaces, but also water that flows down through ground surface slopes, considered as water flow.

Contents of this study were mainly divided into 3 categories. First is to analyze flood vulnerable area of Seoul city. For this objective, a model was mapped out by selecting flood inducing factors and model to be applied and establishing data to be applied to model. Evaluation variables were divided into physical environment, climate environment, green space environment and artificial environment variable and how its result is changed by adding variable features after reflecting such variables in model sequentially was comparatively analyzed. In order to consider the uncertainty, mean and variance of probability value per each cell were observed through random point extraction of 1000 times. Like this, result by each cell is represented as flooding probability and assuming that an area where flooding probability was represented to be high would be flood vulnerable area, a analysis was summarized. Through this, how flood vulnerability of overall Seoul city would be like was diagnosed.

Second, types of urban flooded areas were divided into categories based on factors affecting the flooding; the groupings were determined by the use of cluster analysis, and discriminant analysis was performed to verify the cluster analysis results. As a result of the discriminant analysis data, the floods were divided into four types. The four flooded area types were then used as ground data in the analysis of green space features during the next research stage. In addition, being linked with the previously analyzed result of flood vulnerable area, flood vulnerability by each divided type was observed.

Third, flood control contributions based on green space area and flooded area type were analyzed. In order to determine the relationship between green space area and flooding, the most adequate evaluation unit was selected, and regression formulas including this green space area variable were deduced. Afterwards, based on regression formulas for the different flooded area types, flooding probabilities for changes in the green space area were analyzed by taking only the green space area as the independent variable and fixing the other variables. As a next step, based on green space type of Seoul city being classified based on CN value, which green space type is dominantly distributed by each flooded type and contributory to flood control were analyzed. Finally, after establishing regression formula by each flooded type considering green space pattern in drainage basin unit, green space features being specialized depending on flooded area type was analyzed.

In this study, based on current situation of Seoul city, how flooding probability by variation of green space area, type and pattern by each flooded area type is changed was analyzed statistically. This could be contributory in selecting an area to be introduced preferentially at the time of planning and designing green space for increasing urban flood resilience and it could provide a guideline for green space features to be introduced for controlling flooding probability. The conceptual framework for this research is shown in Figure 6.

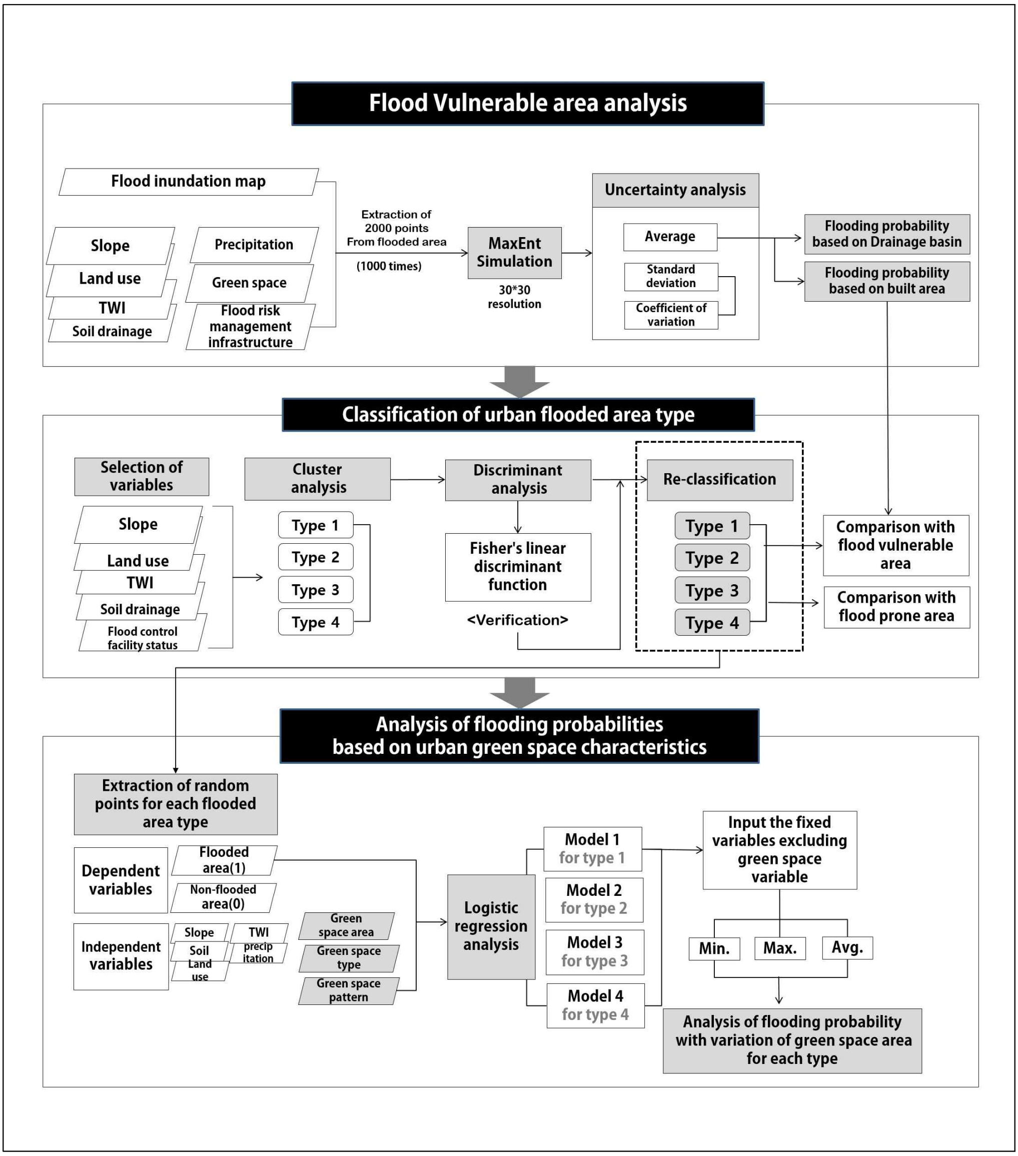


Figure 6. Flow chart of this study

3. Method

1) Analysis of urban flood vulnerable area

As the first method of this study, urban flood vulnerable area was evaluated by using spatial statistic analysis and through this, how much Seoul city is exposed to flood was analyzed. When summarizing existing literature, in order to provide a countermeasure for controlling and adapting to urban flood, it is required to predict an effect of flood and diagnose it more than anything else.

(1) Model selection

Following comparison of the available models, MaxEnt was selected for use in this study. The MaxEnt method is a multipurpose mechanical learning model developed from statistical mechanics and the information theory principle, which explains the probability distribution of having maximum entropy (Franklin, 2009). At an early stage of development, MaxEnt was mainly used in the financial and astronomy sectors, but more recently it has also been used for species distribution modeling (Tuanmu et al., 2010; Kim et al., 2014; Jeong et al., 2015), landslide prediction (Felicisimo et al., 2012; Kim et al., 2013), and flood prediction (Kim et al., 2013).

MaxEnt is optimized to present-only data and allows the modeler to select flooded points and variables and to express non-parametric relationships (Phillips et al., 2006; Phillips and Dudik, 2008; Kim et al., 2014). When using absent data arbitrarily, the model is highly likely to have uncertainty; therefore, in this study a present-only data approach was selected. In this study, analysis was performed based on flood inundation maps for 2010 and 2011. Flooded and non-flooded areas were clear; however, to protect against potential future cases where the distinction is not clear, analyses were performed based on flooded areas only, excluding uncertain non-flooded areas. As shown by Elith et al. (2006) and Phillips et al. (2008), who used the receiver operating characteristics (ROC) curve analysis method, the MaxEnt model has the highest reliability among the models requiring present-only data.

When using hydrologic models, runoff can be estimated using sewer line information; however, identifying environmental features empirically is a challenge. Moreover, hydrological approaches require fieldwork and financial resources (Fenicia et al., 2013). In urban areas, the leakage or clogging of sewage lines can decrease the accuracy of hydrologic models, in addition to increasing the likelihood of flooding. These limitations to the use of hydrological modeling have led researchers to focus on empirical and data driven methods (Tehrany et al., 2013, 2015). In empirical models, basin features are analyzed for each point (i.e., not using a mean value) and data distortion is reduced. The application of MaxEnt in flood studies was proven by Kim et al. (2013). In this study, the freely distributed MaxEnt software package (version 3.3.3k) was used.

(2) Variable selection and data collection

The input data required for modeling urban flood vulnerable areas in Seoul city included flooded area data and relevant variable data. Flooded area data were based on 2010 and 2011 flood inundation maps of Seoul city (Figure 7). The established model well recreated the flooded area data by extracting 2000 points through random sampling using Arc-GIS 10.1. The 2000-point sample size allowed the inclusion of most flooded areas. To test uncertainty, 1000 datasets were established by extracting 2000 points through random sampling performed 1000 times. The inundation map was split 70% and 30% for purposes of training and testing, respectively (Ohlmacher and Davis, 2003).

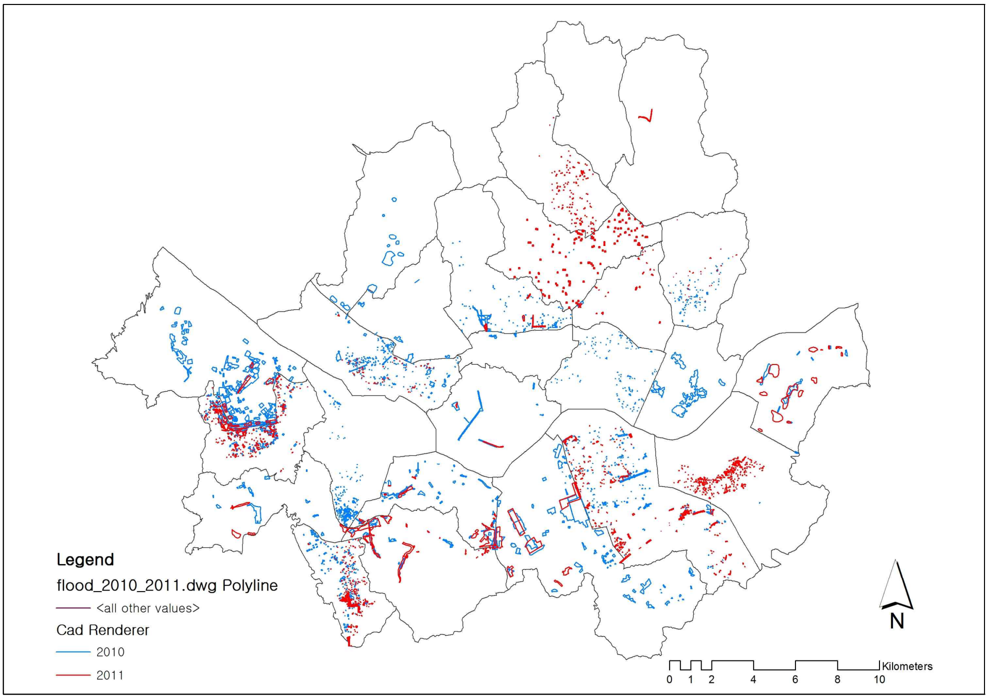


Figure 7. Flood inundation map in Seoul city

For variable data compilation, indices with a relationship to flooding were summarized from previous studies. Among the selected evaluation variables, variables suitable for evaluating adaptation ability to urban flooding were selected based on prominent correlations, and were then excluded from analysis. Finally, through consultation with experts, the final evaluation variables were selected. The variables for evaluating vulnerable urban flood areas included those related to the physical environment, climate, green spaces, and the artificial environment.

Physical environmental variables included slope, soil drainage, the topographic wetness index (TWI), and land use, with analysis performed based on 30 x 30 m grid unit. High precision topographic data are becoming increasingly available for flood application studies in most countries, which has had a direct impact on the output of modeling, as many previous studies were limited by a lack of appropriate topographic data (Bates et al., 2003). In this study, among the topographic variables, slope was selected as particularly significant to flooding and was constructed by generating a Digital Elevation Model (DEM) from a 1:25,000 scale numerical map. Soil drainage data were constructed based on a detailed soil map. TWI is a hydrologic factor that enables determination of wetness status using cumulative upstream flow at the time of rainfall (i.e., the area contributing to runoff) with a dischargeable volume (slope) over the relevant area. TWI shows the relationship between rainfall runoff and topographic features. TWI was calculated from the DEM using Arc-GIS 10.1 (Regmi et al., 2013).

$$TWI = \ln(A_s / \tan\beta)\cdot$$

For the land use variables, flooding probability in each grid was analyzed by dividing into detached housing areas, apartments, commercial, business areas, mixed areas, industrial areas, water treatment facilities (sewerage treatment plant, rainwater retaining basin, water distribution reservoir, water purification plant), other urban infrastructure areas, transportation facility areas, green spaces, open spaces and bare land, streams and lakes, and public facilities areas. After dividing the 12 categories as nominal variables, analysis was performed by generating dummy variables.

Analysis showed that flooding in 2010 was significantly affected by 3-day cumulative precipitation, while flooding in 2011 was seriously affected by maximum hourly precipitation; therefore, these were chosen as the climate variables. Based on automatic weather system (AWS) measurements, data for each area were constructed through interpolation using the spline method in Arc-GIS 10.1.

Green space variables were analyzed based on drainage basins where urban water is gathered, and included green space area (CA), number of green space patches (NumP). Each variable was evaluated based on raster using Patch Analyst in Arc-GIS 10.1, with data established later. Green space areas included paddy fields, fields, equipped farmland, orchards, nursery areas, planted areas, cemeteries, golf courses, botanical gardens, and grasslands, as identified using a 2010 urban biotope map of Seoul city.

Artificial environment variables included extension of sewer line against built-up area and presence of flood risk management infrastructure (e.g., pumping stations and rainwater retaining tank). Sewer line data was based on the basic plan of sewer line arrangement, location of pumping stations, retention basins, and rainwater retaining tank were constructed based on spatial data by Flood Prevention Information homepage of Seoul city. Analysis unit of artificial environment variables is drainage basins where urban rainwater is gathered. Selected variables for evaluating flood vulnerable area are as shown on following Table 6.

Table 6. Selected variables for evaluating flood vulnerable area

Variable	Analysis unit	Variables description	Type	Data
Climate environment	Point	3-day cumulative precipitation	Continuous	AWS
		Maximum hourly precipitation	Continuous	
Physical environment	Point	Slope	Continuous	DEM
		Soil drainage	Categorical	Detailed soil map
		TWI	Continuous	DEM
		Lnad use	Categorical	Urban biotope map
Green space environment	Drainage basin	Green space area (CA)	1/5,000	
		Number of green space patch (NumP)		
Artificial environment	Drainage basin	Extension of sewer line against built-up area	Continuous	Basic plan of sewer line arrangement
		Presence of FRMI	Categorical	

(3) Analysis of flood vulnerable area

Flooding probability was calculated by reflecting the relative contribution of each evaluation variable across the flood occurrence area. To assess changes in flooding probability as a function of each variable, we comparatively analyzed flooding probability based on a single physical variable and additional climate, green space, and artificial environmental variables. The accuracy of the model was measured through the AUC value, which calculates the area of the verifying curve based on the potential index value obtained using the flooded position and ratio for verification per equal area from the potential map. The AUC provides an independent reference value, and it is frequently used to compare models. Perfect models have an AUC value of 1.0; however, values over 0.8 are generally considered sufficient (Thuiller, 2003; Franklin, 2009; Gwon, 2012).

To evaluate the uncertainty, a random point was extracted 1000 times to produce 1000 flood prediction distribution maps. Based on a 30-m grid resolution, mean, standard deviation, and coefficient of variation values were calculated for each map. Standard deviation measures the absolute variation degree. However, when comparing multiple data groups with different measurement scales and central positions, comparison required the measurement of relative variation. The coefficient of variation is a relative variation index calculated by dividing standard deviation by the mean. High coefficients of variation suggest a wide variation from the mean (Lee and Noh, 2012). The coefficient of variation was used to assess the relationship between uncertainty and flooding probability.

The result of the flood prediction model were presented as flooding probability; therefore, to change to a flood/non-flood prediction map, a threshold of distribution probability was established based on a 'maximum training sensitivity plus specificity' value, in which the sum of sensitivity and specificity was maximized (Hu and Jiang, 2011; Tronstad and Andersen, 2011; Heibl and Renner, 2012; Jeon et al., 2014, Kim et al., 2015). This value represents the sum of probability that a flood occurred in an area where flooding was predicted and the probability that flooding did not occur in an area where flooding was not predicted.

Finally, based on the mean flooding probability value, drainage basin-sized flood vulnerable areas were identified. First, flooded areas were estimated in each drainage basin and then compared to establish a ranking, taking into account the built-up area to flooded area ratio.

2) Classification of urban flooded area type

The objective of dividing type of urban flooded area in this study is to maximize flood control effect through introducing green space by each regional features.

At first, 2000 points were extracted randomly from flooded areas based on a flood inundation map for 2011. Except for climate exposure variables that may change every year, variables were selected based on physical variables that have been shown to affect urban flooded regions in previous studies. Through analyses of the correlations between each variable before selection of the final variables, multicollinearity was observed, and variables with correlation coefficient values greater than 0.4 were excluded from further analyses. The variables that were finally selected for the flooded area type classification work included the presence of flood risk management infrastructure (FRMI), land use, slope, Topographic Wetness Index (TWI) and soil drainage. Based on these variables, cluster analysis was performed.

Cluster analysis is a method of forming a group among observed values having similar characteristics by finding out a certain common characteristics among observed targets. Clustering method is mainly divided into hierarchical clustering and non-hierarchical clustering. In hierarchical clustering, one cluster is permitted to be included in other clusters but overlapping among clusters is not permitted. Clustering method includes single linkage, complete linkage, average linkage, centroid linkage, WARD linkage (or minimum variance method) depending on a method of calculating similarity among each clusters. Generally used method is WARD linkage and this method minimizes loss of information to be occurred in a process of clustering (Ward, 1963). Non-hierarchical clustering analysis is used for grouping individual as cluster and K-means method is its typical method and it is effectively used for large data analysis.

Two-stage cluster analysis (Hair and black, 2000) was performed by using the standard scores of major variables affecting the flooded area in Seoul, Korea. In the first stage, this method determines cluster numbers and central points of early clusters using the Ward method, which is a hierarchical cluster analysis technique. In the second stage, cases belonging to each cluster are determined by the K-means method, which is a sequential non-hierarchical cluster analysis technique. Ward linkage is to minimize loss of information being occurred in a process of clustering by using Error Sum of Square (ESS) between cluster mean and individuals. Briefly speaking, if cluster mean for subject X_k should be X_{ik} in ith cluster, ESS in ith cluster is as follows.

$$ESS_i = \sum_{j=1}^{n_i} \sum_{k=1}^{p} (X_{ijk} - \overline{X}_{ik})^2$$

At this time, total ESS is as follows.

$$ESS = \sum_{i=1}^{i} ESS_i$$

The two-stage method is advantageous in that it minimizes the effect of cases that have large separation level impacts at the time of using the hierarchical method for only cluster formation (*i.e.,* it minimizes the impact of outliers). In addition, the K-means cluster analysis was judged to be suitable for this study, as it is capable of making meaningful analyses via changing numbers, even though the ultimate cluster number is determined by the researcher.

Discriminant analysis was performed in order to verify the results for flooded area types classified through this process. Discriminant analysis is a technique of predicting which sample would be belonged to which group by deducing discriminant function that classifies into a specific group after analyzing difference by each group based on already defined explanatory variable. Dependent variable is a categorized type variable representing belonged group of observed data and discriminant score is made through linear combination of independent variables.

As discriminant variables are used to differentiate flooded areas, statistical validation for differences in the mean points of the flooded area types is important to consider. In addition, group features can be identified through the central points of functional groups and canonical discriminant function coefficients. Fisher's linear discriminant function was deduced for each type, and then, by using these discrimination formulas, the results of the cluster analysis were re-classified. Cross-validation that applied relatively strict standards was used in this study.

As a next step, features of each flooded area type was comparatively analyzed based on re-classified 4 types of flood occurrence and by comparing with flood prone area[1] of Seoul, how frequently flooded area is belonged to which type was analyzed. In order to establish data for cluster analysis, Arc-GIS 10.1 was used and for cluster analysis, IBM SPSS 21.0 was used. Finally, by selecting typical sites based on 4 types, features by each type was verified through site survey and analysis of sectional view.

3) Analysis of flood control effect based on green space characteristics

Flood control effect based on urban green space area, type, and pattern of Seoul city by each flood type was analyzed in a statistical method.

(1) Model selection

Because the relationship between flood occurrences and factors that cause floods is explained multi-dimensionally, multivariate

1) Flood prone area is a region where flood damage is predicted repeatedly when rain is falling over designed rainfall.

analysis and a logistic regression model were used. In particular, logistic regression analysis was used when working with a binary variable or category variable in which the dependent variable had a value of 0 or 1 (e.g., the flood occurrence status). Therefore, non-flooded areas were identified through the classification function by classified flooded area type. The independent variables were continuous and categorical. The result values of the model deduced by logistic regression analysis were represented as flooding probabilities between 0 and 1.

The use of a logistic regression analysis for forecasting flood occurrences is advantageous for several reasons. First, an assumption that the variance and co-variance matrices are identical is not required (Lee and Sambath, 2006); second, significance tests of coefficients can be conducted rather easily; and third, correlations between each variable and flood occurrences can be analyzed (Kim, 2006). Lastly, independent variables can be selected via a repetitive selection and removal process during the establishment of the model, and the effect of other variables can be controlled in the model; this proved convenient for identifying the significant green space variables and environment factors that affected flood occurrences.

Meaningful variables by each features are found by performing logistic regression analysis based on three green space features including area, type and pattern of green space and four flood prediction models where variable by each feature is included are deduced. Maximum value of probability of each flood prediction model (p(X)) is 1 and its minimum value is 0. Logistic function being represented as S-shaped curved form is represented as linear form when it is converted to logit and its formula is expressed as follows.

$$E(Y|X) = p(X) = \frac{\exp(\alpha + \beta x)}{1 + \exp(\alpha + \beta x)}$$

$$\log_e\left(\frac{p}{1-p}\right) = \alpha + \beta X$$

Logistic regression model is similar to regression model excepting its dependent variable is log-odds value and it affects in selecting a specific alternative by explanatory variable. Therefore, binary logistic regression model is presumed by substituting efficiency by probability variable and through logit conversion process.

As eventual objective of predictive model is to establish predictive model having high accuracy including generalized minimum error (Maimom and Rokach, 2005), validation of model is required. The flood prediction model that was deduced through logistic regression analysis was verified via the Hosmer and Lemeshow (H&L) validation technique; contingency tables and the relative operating characteristic (ROC) curve were also used. The results for verification with H&L statistics were deemed not statistically significant at a level of $p > 0.05$.

Contingency table shows how accurately flooded area or non-flooded area is predicted to be coincided and AUC of ROC curve is used for evaluating prediction accuracy. Generally, when the area under the curve (AUC) value is greater than 0.7, the data from the model can be viewed as meaningful (Phillips and Dudik, 2008) and when the AUC value is greater than 0.8, the prediction accuracy can be regarded as high (Yilmaz, 2009). In addition, Hansson et al., (2005) divides explanatory power of model by discriminating AUC standard into 5 grades (0.9-1.0: excellent, 0.8-0.9: very good, 0.7-0.8: good, 0.6-0.7: average, 0.5-0.6: poor).

(2) Flood control effect based on green space area

In order to establish a model analyzing flood control effect based on green space area, most suitable unit that evaluate green space area was selected. Most significant variable was explored in order to analyze flood control function of green space by estimating green space area by each district and drainage basin and green space area in 100m, 150m, 200m, 300m buffer from flooded/non-flooded point. As its method, correlation analysis was performed by taking flooded status as dependent variable and explanatory power of each model was analyzed by performing logistic regression analysis based on such result. Afterwards, by summarizing two results, analysis unit of green space area was finally selected.

Flooded (1) and non-flooded (0) point variables were based on the four flooded area types. Random points of non-flooded area data were extracted and matched with the sample number according to each type based on the classification function being deduced at the time of the discriminant analysis. Maximum hourly precipitation data for each point were established through interpolation by the spline method using Arc-GIS 10.1 software and measurement data from Automatic Weather Stations (AWSs) for the city of Seoul.

Before deducing the model, green space features were observed by analyzing the current status of green space area for the city of Seoul and differences in the green space area for each type of flooded area. Finally, a model for analyzing flood probability change depending on green space area was deduced in a regression formula. To analyze the effect of green space area on flooding probability, other variables that affect flooding were fixed, then the flooding probability in each flooded area type was calculated. In the case of each fixed variable, where the minimum, average and maximum value for each variable was applied in the regression formula, flood probability depending on green space change was deduced according to the minimum, average and maximum values. The green space area and ratio required for reducing flooding probability were also considered by summarizing the data for the four types after performing an analysis with identical methods for each flooded area type.

(3) Flood Control effect based on Green Space type

Green space type was classified based on the SCS Runoff curve number (CN) and considered the antecedent soil moisture condition (AMC), the soil type, the land use, the vegetal cover treatment, and the hydrological condition. The CN value can reflect the hydrologic effect by an increase of the urban impervious area, and it is possible to estimate runoff quantity based on the data of hydrologic soil features and vegetation cover only without the actual measurement data for runoff quantity (Yoon, 1998; Kim et al., 1997).

The antecedent moisture condition (AMC)[2] in this study is the

2) AMC is called as antecedent soil moisture condition and it expresses moisture content of basin soil affected by antecedent rainfall based on a time of flood analysis as an index. This

most general soil moisture condition and determinant (AmC-II) of the runoff curve number for the design flood estimation technique (MOLIT, 2012) that is applicable to the water circulation simulation for a basin in ordinary times. The hydrologic soil group[3] is classified into four groups based on the soil type affecting runoff, the land use, and the management condition. In the case of Seoul city, it was classified based on the soil features of green space. Forest soil belongs to group B, wetlands are in group D, and the remaining

index is an important factor determining runoff quantity and it could be divided into 3 types as follows.

AMC	Characteristics
AmC-Ⅰ	AMC I conditions represent dry soil with a dormant season rainfall (5-day) of less than 0.5 inches and a growing season rainfall (5-day) of less than 1.4 inches
AmC-Ⅱ	AMC II conditions represent average soil moisture conditions with dormant season rainfall averaging from 0.5 to 1.1 inches and growing season rainfall from 1.4 to 2.1 inches
AmC-Ⅲ	AMC III conditions represent saturated soil with dormant season rainfall of over 1.1 inches and growing season rainfall over 2.1 inches. In general, curve numbers are calculated for AMC II, then adjusted up to simulate AMC III or down to simulate AMC

3) Hydrology basic and application (Yoon, 2009)

Soil characteristic	4	3	2	1
Soil type	Sandy Gravelly quality specifications	Sandy loam-Fine sandy loam	Clay loam-gravel sandy loam	Fine clay loam soil -Clay soil
Soil drainage	Well drained	Moderately drained	Imperfectly drained	Very poorly drained
Permeability (cm/hr)	Very rapid, Rapid (>12.0)	Moderately rapid (12~6.0)	Moderately slow (6.0~0.5)	Slow, Very slow (<0.5)
layer depth preventing infiltration(cm)	nothing	100~50	50~25	Under 25
Hydrologic soil group	A (>13)	B (12~11)	C (10~8)	D (<7)

green space soil is considered as group C.

Based on this, the green space of Seoul city was divided by CN value as shown in Table 7. The shaded part is the CN value suitable for Seoul city. Based on this data, the green space was finally divided into seven types, including planted areas, grasslands, wetlands, paddy fields, field/equipped farmlands, orchards, and forests. Planted areas include parks, golf courses, cemeteries, amusement parks, small-scaled sports facilities, and artificially planted grassland. Field/equipped farmland was one type and paddy fields and orchards were combined and classified as a different type.

Table 7. Hydrological soil group for green space type based on AmC-Ⅱ(MOLIT, 2012)

Green space type		Land use	Hydrological soil group			
			A	B	C	D
1	Planted area	Park	49	69	79	84
		Golf course	49	69	79	84
		Cemetry	49	69	79	84
		Amusement park	49	69	79	84
		Grassland (artificial)	49	69	79	84
2	Grassland (natural)	Grassland (natural)	30	58	71	78
3	Wetland*	Wetland	98	98	98	98
4	Paddy field	Farmland	78	78	78	78
		uncultivated area	78	78	78	78
5	Field	Specialty crop	64	75	82	86
	Equipped farmland*	Plastic house	59	74	82	86
6	Orchard	Orchard	44	66	77	83
7	Forest	Coniferous forest	48	69	79	85
		Decideous forest	48	69	79	85
		Mixed forest	48	69	79	85

* : CN value for land cover classification of land sat image (Bae et al., 2003)

For each green space, a statistical analysis was performed by using a logistic regression analysis after establishing how much of the seven green space types are distributed in the area identified within the 100-m radius from the point that was used in previous green space area analyses.

In order to explore which variable contributes most greatly to flood occurrence among the green space variables in the regression formula, the relative contribution affecting flooding was obtained by standardizing the non-standardized coefficient of each variable. In the logistic regression analysis, as each predictive variable has a different unit of measure, it is hard to compare the magnitude of the influence of each variable. Therefore, by obtaining the standardized coefficient, the magnitude of the influence of each predictive variable could be determined (Menard, 2004). Regarding the standardization method, both partial coefficient standardization methods and complete coefficient standardization methods are available. In this study, as its objective is to explore the relative contribution by each green space, the partial coefficient standardization method, with a relatively convenient calculation method, was selected. This method multiplies the SD of the independent variable by that of the non-standardized coefficient and then divides it by the assumed SD of the dependent variable (Agresti and Finlay, 1997).

(4) Flood control effect by green space pattern

In order to explore a relationship between green space patterns and flood occurrence, an analysis was performed using an index relevant to fragmentation analysis selected from among various landscape pattern indexes. The landscape index is a concept for representing the structure, the function, and the changing aspect of a landscape ecosystem; and it is a relative number, not an absolute number. In order to explore the distribution features of green space, an analysis was performed by selecting indices that may evaluate the size of a green space patch, the degree of scattering, and the irregularity of the shape of the green space.

A typical index representing green space size is class area (CA) and mean patch size (MPS). This is the simplest index measuring fragmentation. MPS is calculated by dividing green space area by the number of green space patches in a drainage basin (McGarigal et al., 2002).

As a variable evaluating the distribution of green space, NumP is used. This is an index representing the number of green space patches in a landscape patch or individual class, and it represents fragmentation. In a particular area, if a large number of patches exist, then the fragmentation level is high.

The variable evaluating irregularity of green space is AWMSI. AWMSI, an index of the area weighted patch form, is an irregularity index reflecting patch size. As this index approaches 1, it is a circular or rectangular form; and as its value becomes larger, it indicates a complex form. While a forest patch under natural conditions has an irregular patch form, a patch being created by artificial development, such as roads or, residential complexes, has geometric features (Lee and Yoon, 2008). A method of evaluating each landscape index is as shown in Table 8.

Table 8. Method of evaluating each landscape index

Criteria	Indices	Formula	Unit	Explanations
Fragmentat-ion	NumP	$\sum_{i=1}^{n} P_i$	none (count)	Where Pi refers to patch of type i
Size	CA	$CA_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}$	ha	Where a_{ij} equals to the area (m^2) of patch j for the ith land cover type; A is the total landscape area (m^2)
Size	MPS	$\frac{\sum_{i=1}^{n} a_i}{NumP}$	ha	Where ai is the patch size, and m is the total number of the ith landscape
Shape	AWMSI	$\sum_{j=1}^{n} [\frac{P_{ij}}{\min P_{ij}} (\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}})]$	none (without limit)	Where P_{ij} is the perimeter of patch ij, min P_{ij} equals to minimum perimeter of patch ij in terms of number of cell edges, and a_{ij} equals to the area (m^2) of patch j for the ith land cover type

An analysis was performed by using the Patch Analyst of Arc-GIS 10.1. This is an analytic program for landscape structure, where the quantitative evaluation of landscape is enabled based on the estimation of several indexes and an analysis for the landscape structure. A similar program, Fragstats, is available also. While Fragstats enables grid file analysis only, Patch Analyst is more convenient, as it enables existing feature file analysis. A landscape index could be analyzed on the level of the landscape element (patch), the landscape type (class), and the overall landscape depending on the objective. In this study, an analysis was performed by designating the drainage basin where water is gathered as a class.

Based on the drainage basin class, a logistic regression analysis was performed by extracting each landscape feature index as a point after performing the landscape index analysis for the green space patch. Through this analysis, a model for each flood type area was produced, and the contribution towards flood control was analyzed based on the green space distribution form by each type.

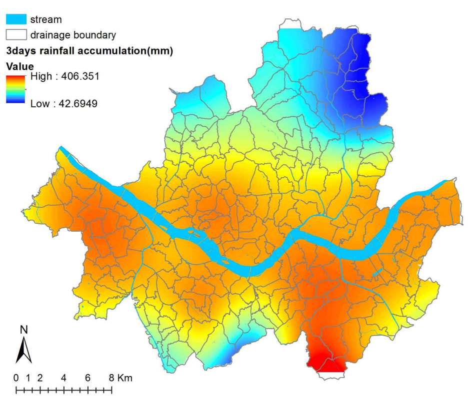
In addition, in order to observe the sensitivity of green space variables, flooding probability based on the change in green space was explored by using the mean value, the minimum value, and the maximum value for other variables, excluding the green space variable based on the formula. Through this, the flooding probability based on green space variables by each flood type was analyzed by determining the required green space pattern to reduce flooding by 10% and by 20%.

Ⅳ Results and Discussion

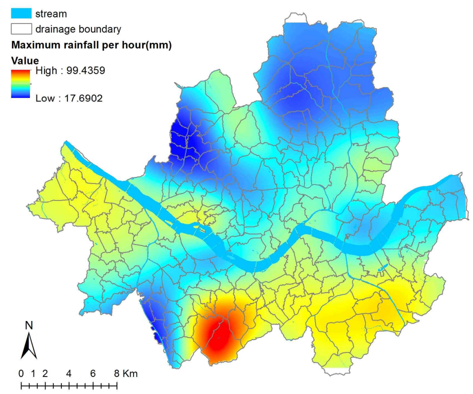
1. Analysis of urban flood vulnerable area

1) Compilation of analysis data

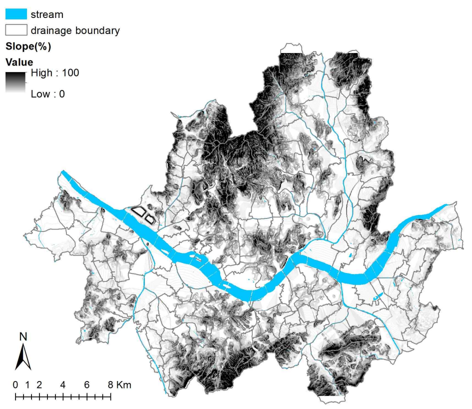
In this study, flooding factor variable required for flood vulnerable area is physical-environmental variable such as slope, soil drainage, precipitation variable, green environment variable and flood control facility variable and total 11 variables were used and a map being constructed based on this data is as shown on Figure. 8.



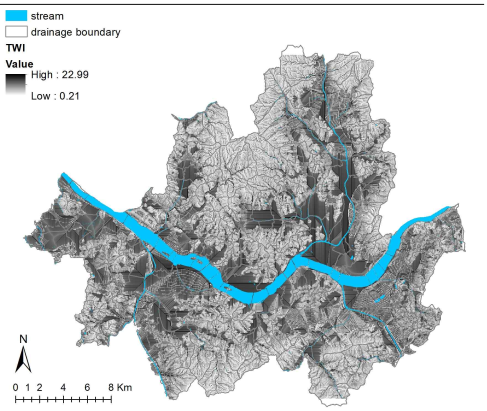
3-day cumulative precipitation (mm)



Maximum hourly precipitation (mm)

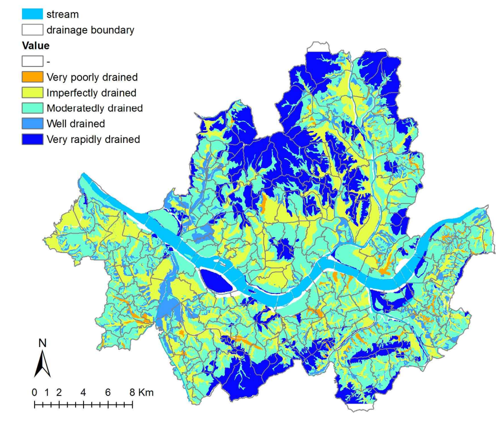


Slope(%)

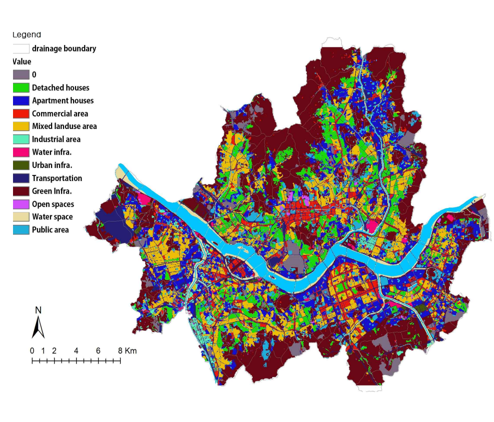


TWI

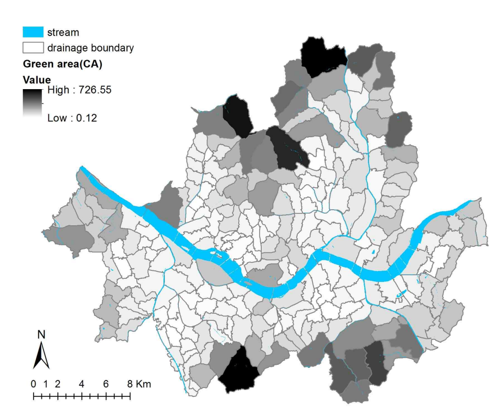
Figure 8. Base maps for flood vulnerability assessment



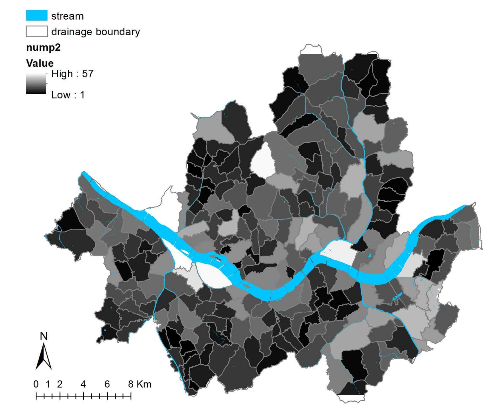
Soil drainage



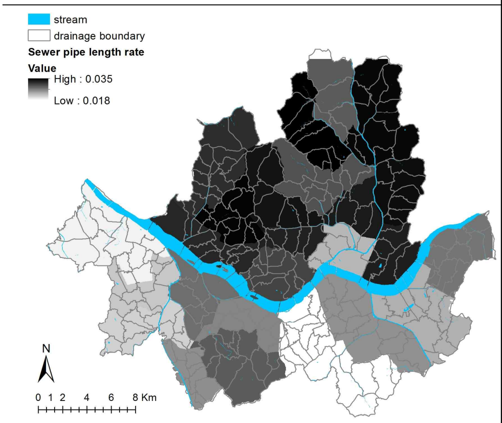
Land use



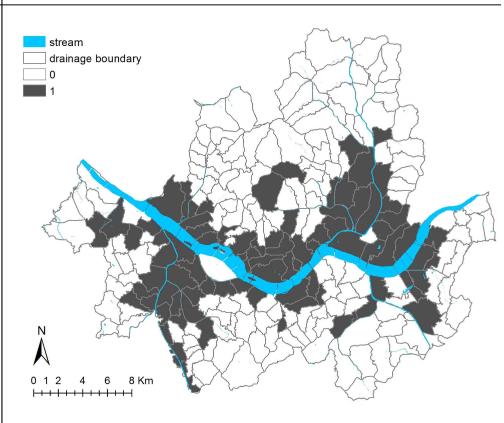
Green area (CA)



Number of green space patch (NumP)



Extension of sewer line against built-up area



The presence of Flood risk management infrastructure

Figure 8. Base maps for flood vulnerability assessment (Continue)

2) Analysis of Flooding probability by each variable

Flooding probability was analyzed using MaxEnt, a typical spatial statistical model selected for its research methodology. Among climate exposure variables, 3-day cumulative precipitation significantly affected the 2010 flooding. When precipitation exceeded 150 mm, flooding rapidly increased, and when it exceeded 300 mm, flooding probability increased significantly again. In contrast, maximum hourly precipitation impacted more significantly on the 2011 flooding, with increased precipitation leading to increased flooding probability, in particular when precipitation exceeded 55 mm. In contrast to 3-day cumulative precipitation, maximum hourly precipitation has a short-term impact and the level of damage may differ depending on land use.

For slope, flooding probability varied from 0 to 20% with gentler slopes associated with increased flooding probability, and flood is seldom taken place over 23% of slope. Increased TWI was also associated with rapidly increasing flooding probability until TWI equaled 5, after which the probability remained over 50%. Areas in which TWI exceeded 10 were considered to be rainfall concentration prone (TSI, 2011).

Soil drainage in Seoul is mostly dominated by moderate grades and the region's mountainous topography results in excellent drainage features. In Seoul, flooding probability was highest in areas with very poor or slightly poor soil drainage conditions, while areas with good soil drainage conditions had lower flooding probabilities.

For land use, flooding probability was highest for detached housing, mixed land use areas, and traffic facilities (e.g., roads). Mixed land use areas resulted in the highest flooding probability. Flooding probability was very low for green space areas, and low for open spaces and public land. Among green space environmental variables, flooding probability decreased as CA increased. In mountainous drainage basins on the outskirts of Seoul the flooding probability was low. In addition, NumP ranged from 1 ea to 47 ea, with higher values associated with lower flooding probability. The constant ratio between NumP and flooding probability suggests that its impact was more significant than the other green space variables. Among the artificial environmental variables, increases in the ratio between sewer line extension and built-up area were correlated with decreased flooding potential when a flood control facility was present.

Overall, land use contributed the most to flood probability (26.1%), followed by the Extension of sewer line against built-up area, slope, and soil drainage; however, of the green space environmental variables, CA contributed the most to flood probability, followed by, NumP (Figure. 9).

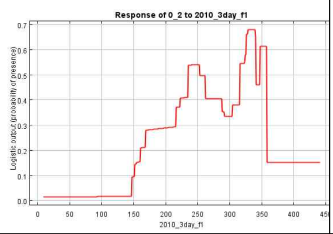
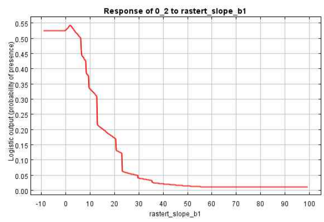
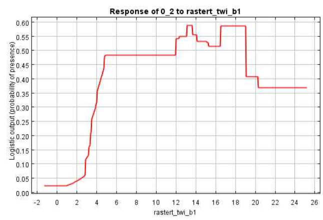
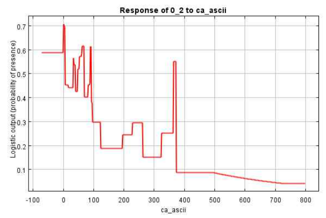
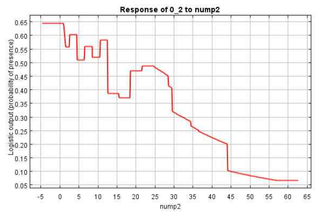
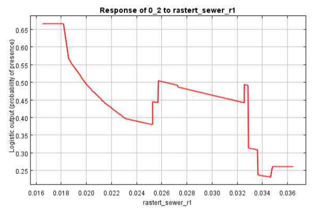
		
3-days cumulative precipitation	Slope	TWI
		
CA	NumP	Extension of sewer line against built-up area

Figure 9. Response graphs for variables provided by the MaxEnt.
(The horizontal axis is the variable value, while the vertical axis indicates the flooding probability)

3) Analysis of flood vulnerable area when inputting variables step-by-step

To analyze urban flood vulnerability stage-by-stage, each variable was added to the calculation in turn. First, the flood prediction map was calculated based only on physical variables (i.e., slope, soil drainage, TWI, land use), with the results showing a predicted flooded area with a maximum probability of 76%. Secondly, climate variables (i.e., 3-day cumulative precipitation, maximum hourly precipitation) were introduced and the maximum probability increased to 84%. For Nowongu and Dobonggu, 3-day cumulative precipitation and maximum hourly precipitation were relatively low, and this was reflected in the low flooding probability. In contrast, Gangseogu had heavy precipitation and as such the flooding probability was high.

Next, the green space area and number of green space patches variables were introduced, and the flood prediction probability increased to a maximum of 86%. For the Gangseogu and Yangcheongu drainage basis, which include extensive farmland and green spaces, flooding probability was seen to decrease. Finally, artificial environmental variables (i.e., sewer line extension against built-up area vs. presence of FRMI) were added and the flooding probability increased to a maximum of ~88%. A pumping stations are located in the Han River area, and its flood control efficiency is significant; therefore, it significantly lowers the flooding probability in numerous drainage basins, particularly Dangsan, Noryang 1, Heukseok, Dongjak, Changjeon, Shimwon, Hyochang, Juseong, Oksu, Seongsu 1, Jeonnong, Seongsan, and Bukgagwa. However, this was not reflected in the model, where only a 2% increase in maximum flooding probability was observed. The modeled result likely reflects the low elevation of the FRMI and the fact that its drainage function is poor and mostly enabled by the physical variables introduced in stage one. In summary, the addition of variables increased the explanatory power of the model, and in turn the accuracy of the flooding probability was increased. In particular, introducing green spaces and flood control facilities increased the flood adaptation ability.

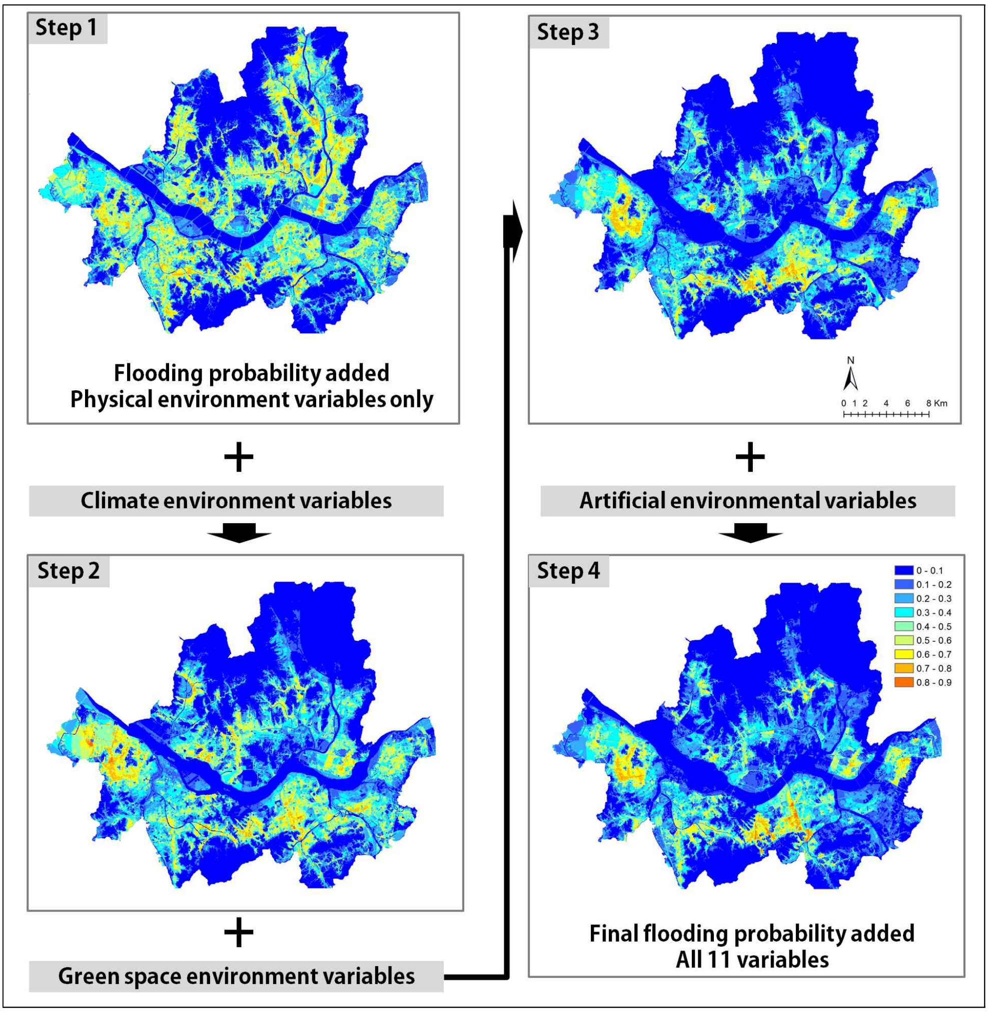


Figure 10. Analysis of flood vulnerable area when inputting variables step-by-step

4) Uncertainty in flood vulnerable area

In order to quantify the uncertainty introduced during random point extraction, a model was simulated by extracting random points 1000 times. As point extraction frequency increased, the mean value and standard deviation tended toward conversion. Once the random points had been extracted 1000 times, the values had essentially ceased to changed.

The mean values of the 1000 flooding probability results are shown in Figure 11. Maximum and minimum values for flooding probability were found to be 0.987 and 0, respectively. In comparison, the maximum value obtained through the 1-time extraction of random points was 0.88. Therefore, the differences in maximum value were significant and depended on the area from which the random point was extracted.

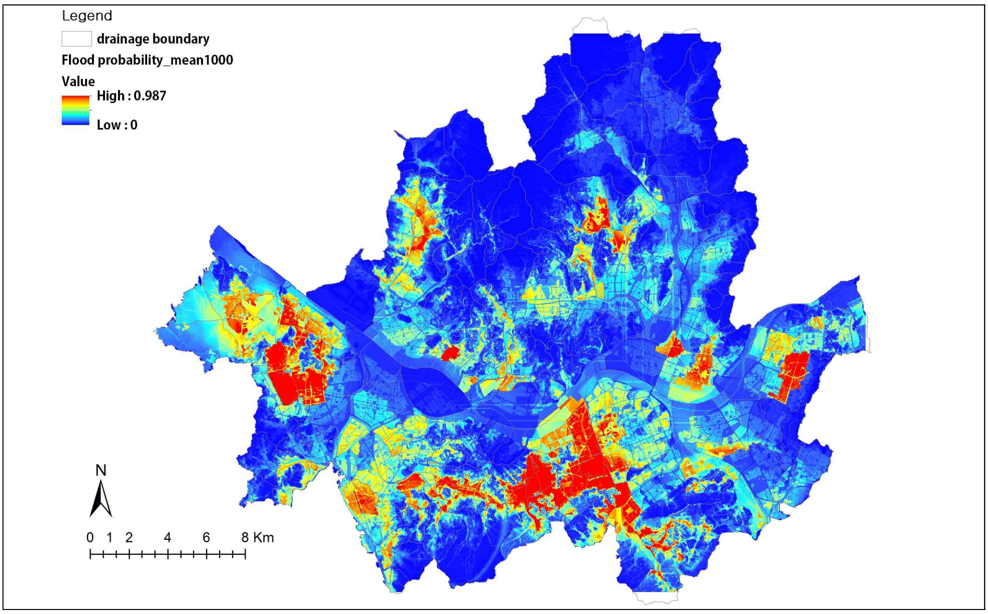


Figure 11. Mean flooding probability using the extraction of random points repeated 1000 times.

Uncertainty in flooding probability can also be observed through the probability distribution per cell. Uncertainty was analyzed using the coefficient of variation, with higher flooding probability found to be correlated with lower coefficients of variance, and vice versa, in particular for green space areas, which had low flooding probability but high coefficients of variance (Figure 12). Coefficients of variance ranged from 0.05 (5%) to 11 (1,100%), with most below 2.0. The highest values occurred for mountainous areas, where flooding probability was low and standard deviation was high. The mean flooding probability was highest in Seocho 4, and this drainage basin also had a very low coefficient of variance (0.07). In contrast, the Bangbae 1, Bangbae 2, and Sinwol 3 drainage basins had high flooding probabilities, but low uncertainty.

However, as the flooding probability ranged by just 1-2%, absolute deviation values (e.g., standard deviation; Figure 13) became meaningful for disaster risk planning. Standard deviation values ranged from 0 to 0.415. For the Seocho 4 drainage basin, where flooding probability was the highest, both the standard deviation and variation coefficient were low (below 0.1), confirming that uncertainty for this drainage basin was low and the flood risk very high. However, for northern mountain areas, both flooding probability and standard deviation were very low, while in the Yeoksam drainage basin, both flooding probability and absolute deviation were high.

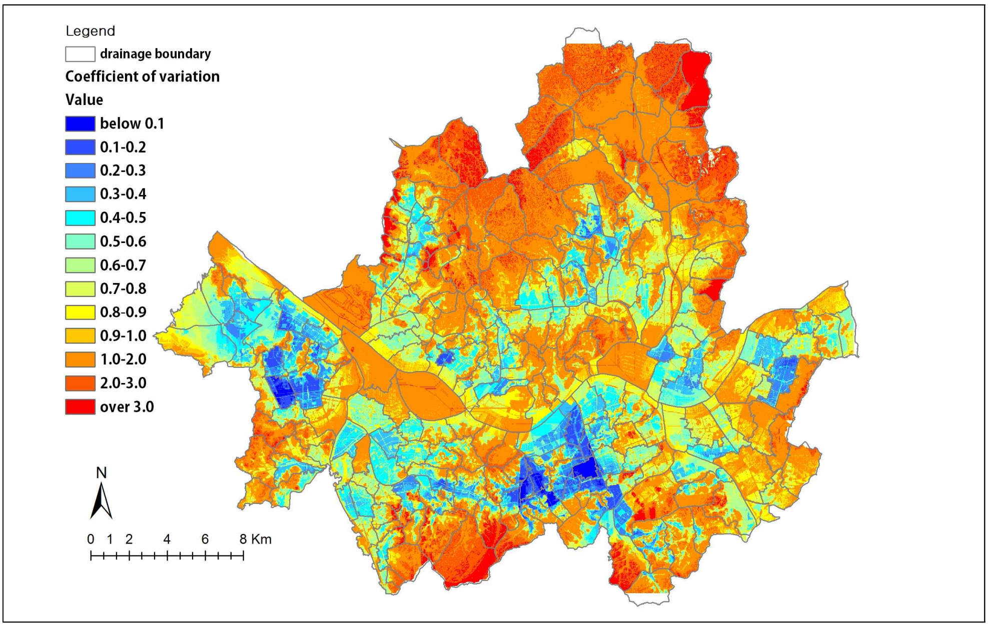


Figure 12. Coefficients of variation for flooding probability based on 1000 random point extractions

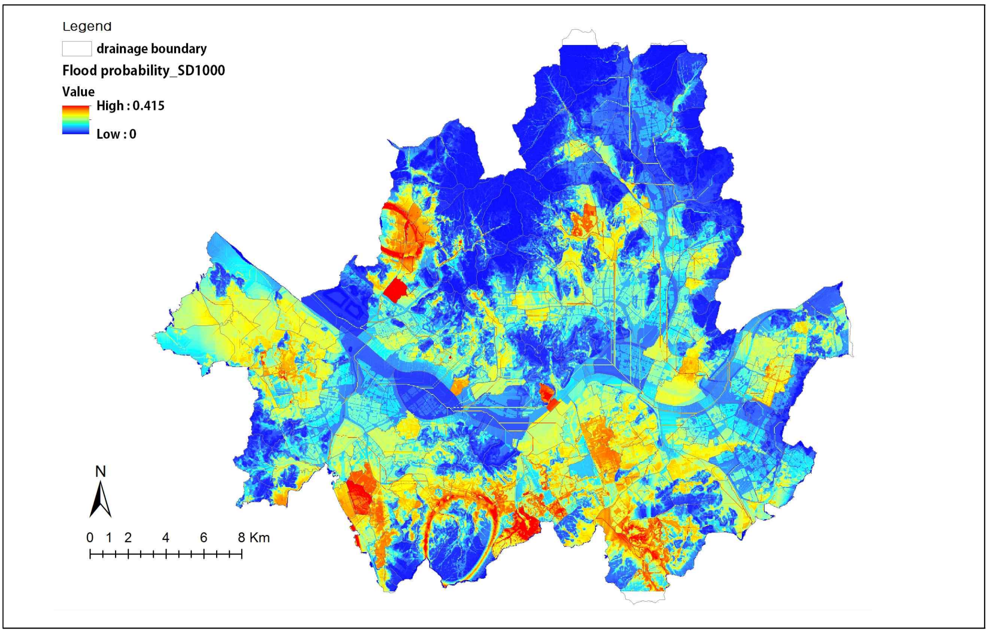


Figure 13. Standard deviations of flooding probability based on 1000 random point extractions

For areas where flooding probability was low but uncertainty was high, flooding probability may be increased by changes in flood inducing factors (e.g., rainfall); therefore, countermeasures for preventing flooding are required. Figure 14 shows the relationship between degree of uncertainty and flooding probability. For the Seocho 4 drainage basin (shown in red), uncertainty was low and flooding probability was high. The lower the flooding probability, the greater the range in uncertainty, while the higher the flooding probability, the smaller the range in uncertainty. An area in which floods occurred 2011, 2010, and 2001 (circled area) was shown to have very high flooding probability and low uncertainty, which provides validation for these results.

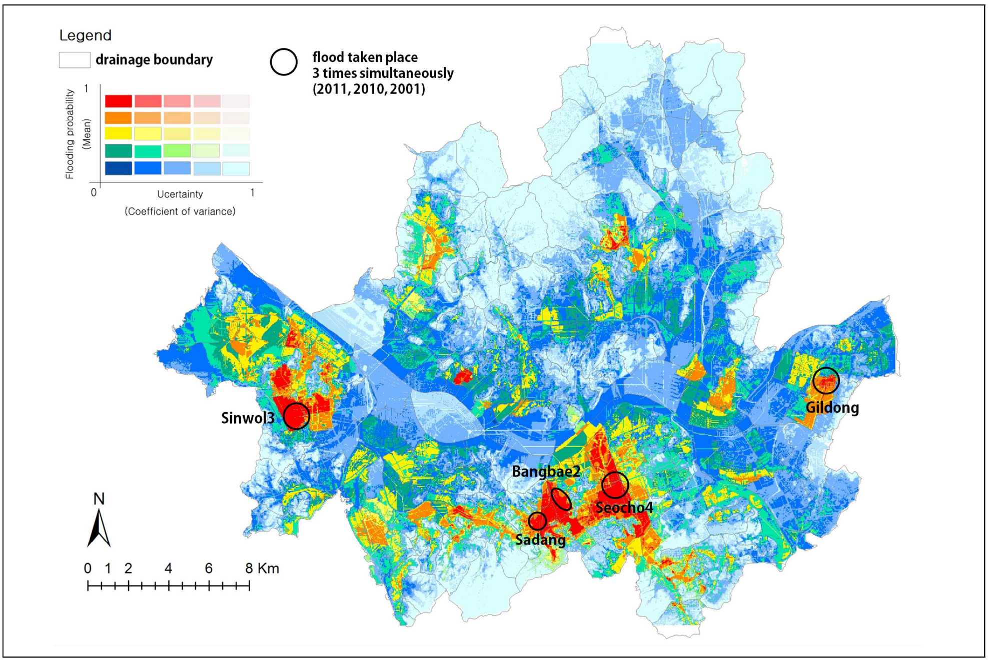


Figure 14. Relationship between flooding probability and uncertainty

The model, which analyzed data 1000 times, was shown to be reliable by an AUC value of 0.887 value, which was higher than the 0.852 value used by Kim et al. (2013) when evaluating flood prone areas. Furthermore, high prediction accuracy was achieved using fewer variables than in previous studies. Tehrany et al. (2015), who evaluated flood vulnerability by using an Arc-GIS based support vector machine model, achieved AUC values of 0.819-0.899 (0.870) with the DT method; therefore, their results had a similar explanatory power to those in our study.

Using a threshold value of 0.354, flood predicted and not-predicted areas were mapped. Among 239 drainage basins, floods have occurred in 193, accounting for 22.6% of the total area.

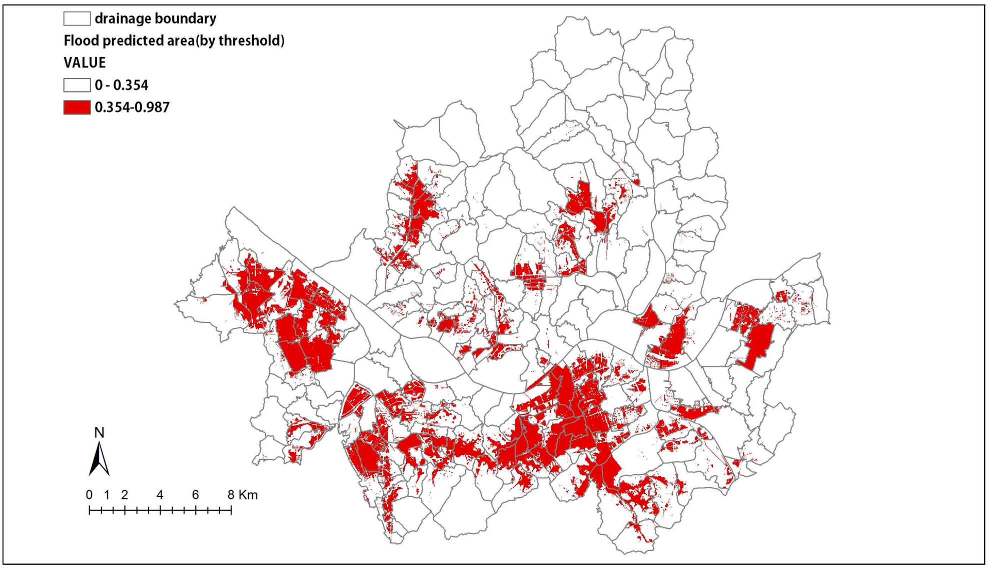


Figure 15. Flood predicted area by threshold

5) Analysis of flood vulnerable area based on drainage basin unit

Based on the flooding probability prediction map, flooding risk in each drainage basin was analyzed. First, using the 0.354 threshold value, the flooded area in each drainage basin was estimated and compared to the total drainage basin area and built-up area. The comparisons of flood prediction area and drainage basin area are shown in Figure 16. Drainage basins denoted in blue (43 of the 239 basins investigated) seldom experienced floods and the drainage basin area to flooded area ratio was less than 1%. In contrast, the drainage basins denoted in red had high flooding probabilities. Some 99% of the Seocho 4 drainage basin was predicated to flood, followed by Gildong, Sinwol 3, Sinsu, Bangbae1, Seocho5, and Shinwol 1, all of which had flood area predictions of over 90%. For the Hwagok 2 and Bangbae 2 drainage basins, more than 80% of the area was predicated to flood.

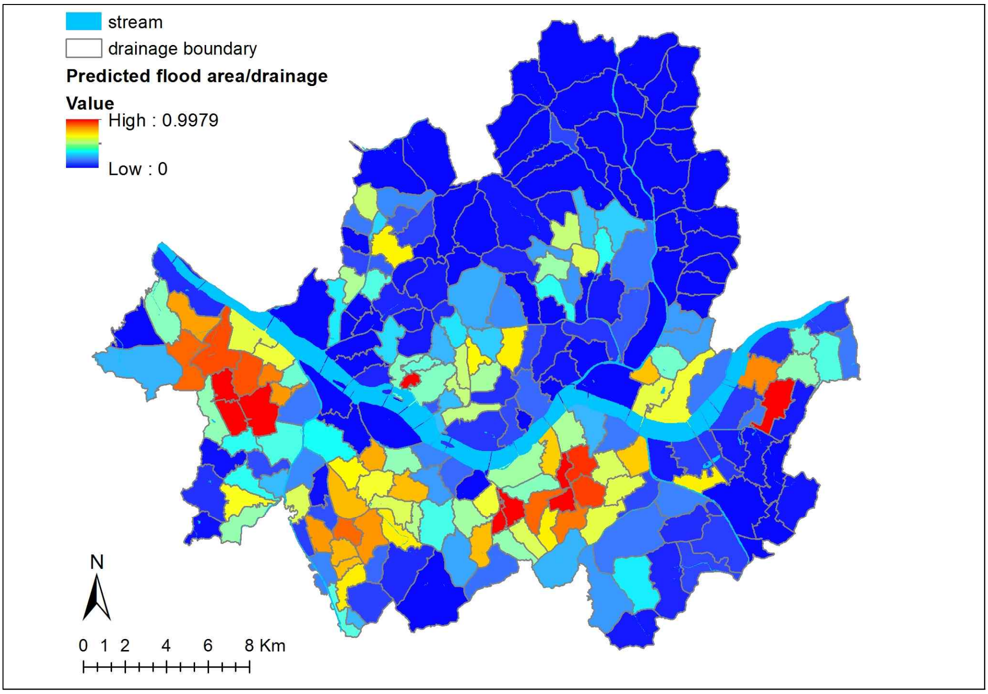


Figure 16 The ratio of flood prediction area against drainage basin area

Flood prediction area as a function of built-up area was also analyzed (Figure 17). The flooding ratio in green space areas was ~4.2% and flooding rarely occurred. In comparison, the ratios for mixed land use area (40.13%), and detached housing complexes (17.83%) were much higher. However, the ratios for green space areas, including forests, could have been underestimated because they were derived after extracting built-up areas from the drainage basins.

When comparing flood prediction area against built-up area, the Yeomgok drainage basin, which borders Guryongsan and

Cheonggyesan, accounted for a large area (255%). The Yeomgok drainage basin is mostly composed of forest green space and the built-up ratio is very small (8.9%), this basin thus had the highest value when flood prediction area was compared to built-up area.

The built-up ratio of the Gayang drainage basin was 47.3%, of which green space (e.g., farmland) accounted for over half, and the flood prediction area against built-up area value was 142.7%. The built-up ratio of Banghwa 1, which borders the Gayang drainage basin, was 53.6% and the built-up area vs. flooded area was 109.4%; therefore, this area is also prone to flooding. After Banghwa 1, the flooding ratio increased in the order: Seocho4, Woibalsan, Bangbae4, and Gildong. As in Namhyeon, the Woohyeon drainage basin is mountainous, and its built-up ratio is below 20%; therefore, the flooded area ratio against built-up area was high.

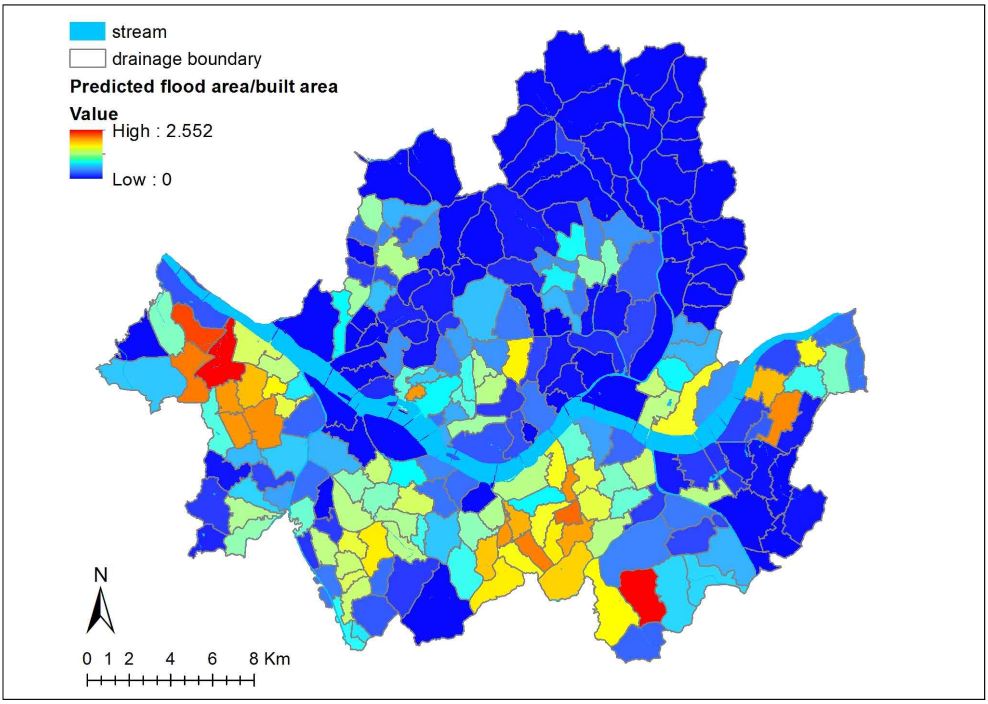


Figure 17. The ratio of flood prediction area against built-up area

The results of this study showed that flood prone areas include the Seocho4, Gildong, Sinwol3, Babgbae1, and Hwagok 2 drainage basins. These basins fall within the Seochogu, Yangcheongu, Dongjakgu, and Gangseogu administrative areas, in which extensive countermeasures are needed. Kang and Lee (2012) evaluated flood vulnerability in Seoul using a spatial statistical model and determined that Youngdeungpogu, Yongsangu, and Mapogu, which are located on both sides of the Hanggan river, are flood prone; however, they failed to consider flood control facilities (e.g., the pumping stations located around the Han River and other major streams). Therefore, the model produced in this study has a higher degree of accuracy.

The details of the flooded area in each drainage basin are shown in Table 9.

Table 9. Predicted flood area ratio by each drainage basin

Drainage basin		Ratio built-up area	Predicted flood area (ha)	Analysis 1 Predicted flood area against drainage basin		Analysis 2 Predicted flood area against built-up area	
Name	Area (ha)			Ratio	Rank	Ratio	Rank
Gayang	389.34	0.473	262.92	0.675	12	1.427	2
Goduck	137.52	0.380	39.71	0.289	78	0.761	26
Guee	530.64	0.615	242.31	0.457	43	0.743	29
Gildong	274.32	0.997	265.55	0.968	2	0.971	7
Namhyun	293.58	0.127	29.56	0.101	127	0.794	21
Daelim	124.92	0.911	80.84	0.647	16	0.710	32
Dolim1	270.72	0.942	151.46	0.559	26	0.594	45
Doksangoji	70.11	0.834	39.03	0.557	28	0.667	35
Doksanjuang ang	123.21	0.907	69.54	0.564	25	0.622	40
Deungchon2	87.21	0.802	54.34	0.623	18	0.776	24
Bangbae1	74.79	0.963	69.11	0.924	5	0.960	10
Bangbae2	136.89	0.892	110.22	0.805	9	0.903	15
Bangbae3	164.61	0.426	53.26	0.324	68	0.760	27
Bangbae4	156.24	0.421	65.32	0.418	53	0.994	6
Bangwho1	264.24	0.536	155.07	0.587	23	1.094	3
Sadang	183.33	0.640	102.08	0.557	27	0.869	18
Sangdo2	194.76	0.853	107.85	0.554	29	0.649	37
seocho1	188.73	0.876	122.51	0.649	15	0.741	30
seocho2	148.59	0.622	73.35	0.494	36	0.793	22
seocho3	178.47	0.686	113.40	0.635	17	0.926	14
seocho4	105.75	0.972	105.53	0.998	1	1.027	4
seocho5	81.99	0.943	74.56	0.909	6	0.964	9
Shingil	134.28	0.927	76.88	0.573	24	0.618	42
Sillim4	254.88	0.750	152.46	0.598	20	0.797	20
Sinsu	51.39	0.986	47.99	0.934	4	0.947	12
Sinwol1	152.28	0.957	137.86	0.905	7	0.946	13
Sinwol3	172.62	0.997	164.03	0.950	3	0.953	11
Yuksam	193.32	0.981	132.95	0.688	11	0.701	34
Yeomgok	409.23	0.089	92.63	0.226	90	2.552	1
Yoybalsan	323.73	0.652	211.44	0.653	14	1.001	5
Woomyeon	407.70	0.204	70.18	0.172	100	0.844	19
Wonji	489.96	0.188	70.48	0.144	111	0.767	25
Jamwon	201.42	0.711	107.51	0.534	32	0.751	28
Cheonho	308.97	0.692	190.22	0.616	19	0.889	16
Pildong	217.35	0.634	107.52	0.495	35	0.780	23
Hwagok1	228.42	0.757	153.30	0.671	13	0.887	17
Hwagok2	325.62	0.872	273.70	0.841	8	0.964	8
Hwagok3	100.71	0.844	59.79	0.594	22	0.703	33

2. Classification of urban flooded area type

1) Variable selection

The variables that were finally selected for the flooded area type classification work included the presence of FRMI, land use, slope, TWI and soil drainage.

FRMI is not a physical variable representing topographical features; instead, it is a dominant solution for preventing flood damage (Mount, 1995; Phillippi, 1996; Smits, et al., 2006). FRMI in this study includes pumping stations and rainwater retention tanks. In Seoul, it has been found that flooding rarely happens after FRMI has been installed in flood-prone areas. Land use also has a significant impact on the level of flooding, and in general, more vegetation density will decrease the tendency for flooding. Compared to forested areas, rainwater flows downward at a faster speed in non-vegetated areas during precipitation events (Lee et al., 2012; Tehrany et al., 2015).

TWI is often used to quantify topographic control on hydrological processes and is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction (Sørensen, R. et al., 2006). Soil drainage is an index that reflects the amount of infiltrating rainwater, and it is an important variable for predicting flood occurrence.

2) Classification of urban flooded area and its verification

First, as a result of observing the dendrogram from the hierarchical cluster analysis performed during the first stage of analysis, flooding was divided into four types. Data were also analyzed preliminarily according to three and five types of flooded areas through the non-hierarchical cluster analysis during the second stage, but the explanatory power and accuracy of the discriminant analysis results were optimal when four types of flooded areas were used.

Second, as a result of verifying the homogeneity of group averages, it was determined that the statistical probabilities for the variables, including land use, slope, TWI and presence of FRMI, were less than 0.001, and thus, these variables were very significant in the model; the average differences among variables for each of the four flooded area types were also significant. Larger F statistic values were associated with more discriminatory power, and the presence of FRMI had the largest discriminatory power among the five variables analyzed when these were used to divide the flooding into four types. The discriminatory powers for the other variables decreased in the order of the slope, TWI, soil drainage and land use.

Table 10. Test value for homogeneity of group average by each flooded area type

Variables	Wilks Λ	F	Sig.
Soil drainage	0.866	100.200	0.000
Land use	0.986	9.058	0.000
Slope	0.377	1073.310	0.000
TWI	0.425	877.064	0.000
Flood control facility status	0.008	77520.405	0.000

Third, through the use of canonical discriminant function coefficients (Table 11) and central points of the functional groups (Table 12), key characteristics of each group could be observed. One variable that contributed greatly to the division of Type 1 flooded area was the presence of FRMI. In the division of Type 2 and 4 flooded area, the slope variable made significant contributions to these groups, while TWI was a major factor for discriminating Type 3 flooded area. Canonical correlation at the relevant level between the discriminant function and groups was excellent, as indicated by the 0.996 correlation coefficient, and 98% of the total variance was explained by the model with an eigenvalue of 127.74.

Table 11. Canonical discriminant function

Description	Soil drainage	Land use	Slope	TWI	FRMI	Constant
Function 1	0.065	-0.018	-0.426	0.050	11.255	0.000
Function 2	0.064	0.087	1.157	-0.832	0.333	0.000
Function 3	0.090	0.122	1.127	1.330	0.021	0.000

Table 12. Central point of function group

Flood prediction type	Canonical discriminant function		
	1	2	3
Type 1	20.440	.043	-.003
Type 2	-6.764	4.364	2.235
Type 3	-6.075	-1.099	.326
Type 4	-6.449	1.265	-1.220

Fourth, the clustered types were re-classified using the discrimination formulas. Fisher's linear discriminant function that determines a discriminant score for each flooded area type was applied (Table 13).

Table 13. Fisher's linear discriminant function

$Z_1(\text{type1}) = 4.624X_1 + 0.812X_2 - 0.113X_3 + 1.972X_4 + 111.569X_5 - 76.389$
$Z2(\text{type2}) = 7.064X_1 + 0.930X_2 + 2.842X_3 + 1.373X_4 + 7.806X_5 - 42.109$
$Z3(\text{type3}) = 4.594X_1 + 0.689X_2 + 0.467X_3 + 2.134X_4 - 0.716X_5 - 22.455$
$Z4(\text{type4}) = 5.104X_1 + 0.706X_2 + 0.892X_3 + 1.104X_4 - 1.731X_5 - 14.716$
* X_1 = Soil drainage, X_2 = Land use, X_3 = Slope, X_4 = TWI, X_5 = Presence of FRMI

The discrimination accuracy rate as determined using a cross-validation technique was 98.1%. In the case of Type 1 flooded area, through the reclassification process performed by discriminant analysis, 459 places that had FRMI in place when flooding occurred were classified as Type 1, and the discrimination accuracy rate increased by 1.1%. Finally, among the total 1951 places where flooding occurred as analyzed in this study, 459 were classified as Type 1, 106 places as Type 2, 961 places as Type 3 and 425 places as Type 4.

Table 14. Comparison the results of existing cluster analysis with re-classification using discriminant analysis

Description			Flood type by discrimination analysis				Total
			1	2	3	4	
Existing cluster analysis	Frequency	1	456	0	0	0	456
		2	3	98	2	2	105
		3	0	2	940	4	946
		4	0	6	19	419	444
		Total	459 (23.53%)	106 (5.43%)	961 (49.26%)	425 (21.78%)	1951 (100%)

Through classification function (Table 13) dividing flooded area type, non-flooded area type was divided as shown on following Figure

18. Flood type division was performed for remaining area excluding an area where data for military zone was not available and flooded area. This division could be utilized as basic data for extracting non-flooded area required for future analysis of flood contribution depending on green space features.

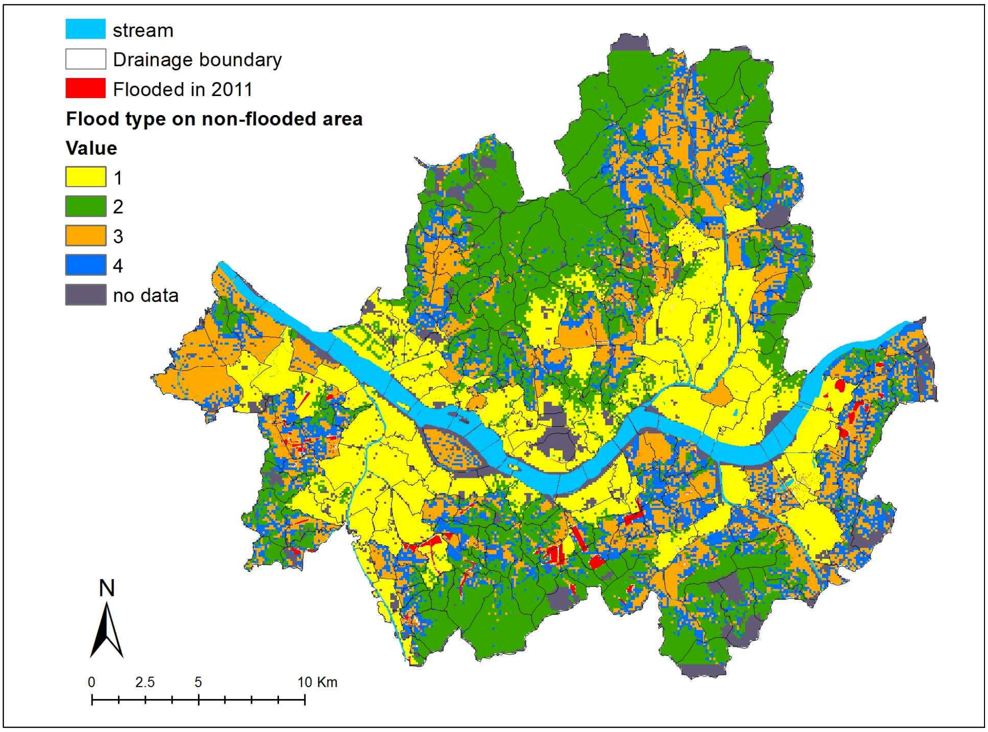


Figure 18. Type of non-flooded area using classification function

3) Physical properties of urban flooded area types

Statistical data for regional characteristic factors in each of the four types of flooded areas are summarized in Table 15 and map of Seoul city representing categorized result is as shown on Figure 19.

Table 15. Statistic features of flooded area type

Type	N	Description	Soil Drainage	Slope	TWI	Presence of FRMI	Land Use
Type 1	459	Average	2.61	1.61	11.95	Contained FRMIs (pumping station, rainwater retaining tank)	Mixed land use area ratio is the highest Located around river and streams
		Coefficient of variation	3.10	0.46	3.09		
		Min.	2	0.00	2.40		
		Max.	5	29.47	19.69		
Type 2	106	Average	3.48	14.06	7.38	None	Green space (forest) ratio is highest No commercial, business and industrial areas
		Coefficient of variation	3.56	3.35	1.76		
		Min.	2	7.86	2.53		
		Max.	5	30.01	19.95		
Type 3	961	Average	2.32	1.29	13.31	None	Detached housing and mixed land use area are relatively high Road ratio is the highest
		Coefficient of variation	3.27	0.72	7.70		
		Min.	1	0.00	9.93		
		Max.	5	8.50	20.24		
Type 4	425	Average	2.58	3.91	5.98	None	Low hill area is highest
		Coefficient of variation	3.46	1.70	3.41		
		Min.	1	0.00	2.78		
		Max.	5	10.00	11.17		
Total average in Seoul			2.70	3.22	10.75	-	-
	Average in flooded area		2.51	2.63	11.07	-	-
	Average in non-flooded area		2.89	3.82	10.42	-	-

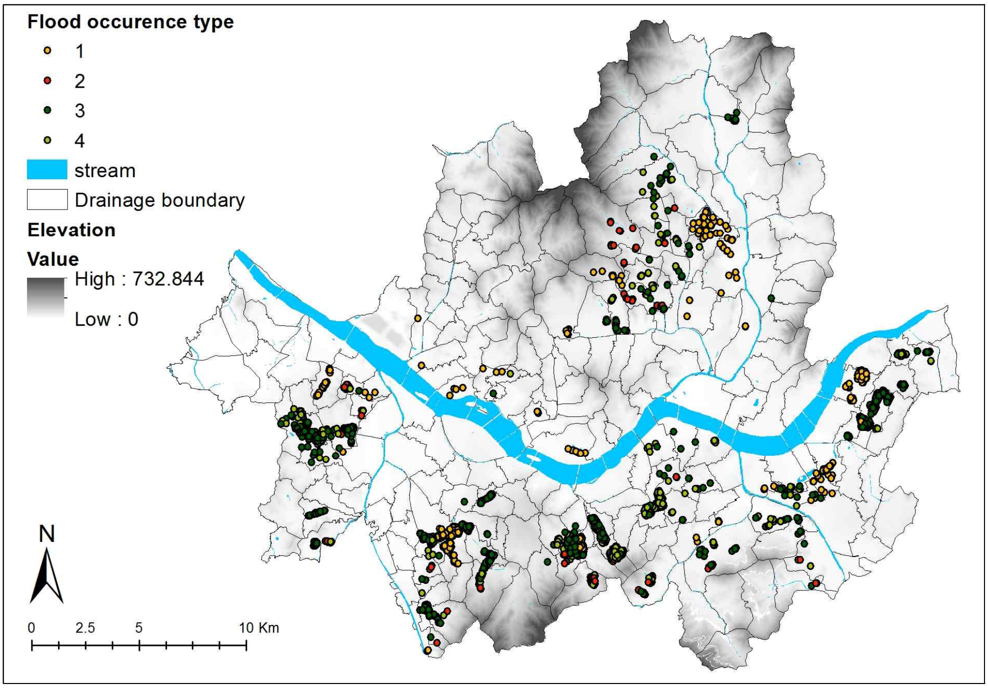


Figure 19. Separated Flood occurrence types

(1) Flooded area type 1

Type 1 flooded areas represent regions where flooding occurred in a drainage basin that contained an FRMI. Specifically, this is a region where FRMIs had been installed because flooding had occurred frequently in the past. The average slope for these regions was 1.61%, which was gentler than the 2.51% average for total flooded regions in Seoul. The TWI in Type 1 areas was the second highest after the TWI in Type 3 areas and was higher than the average for all flooded regions. Soil drainage was imperfect in these regions, which is a regional characteristic factor for high flood risk. Compared to other drainage basins, the occurrence of flooding was significantly limited in general here, but at the time of extreme rainfall in 2011, flooding was excessive, as the capacities of the FRMIs were overwhelmed in this region.

The Type 1 areas were mainly located around the Han River and major streams such as Dorimcheon of Sillim 4 drainage basin, Jangwi, Hwagok 1, Songpa 2, Cheonho drainage basin, and the mixed land use area ratio amounted to 45.5%, which was the highest among all four types. As semi-underground housing consisting of old brick structures is common in the Type 1 flooding areas, this region experienced heavy damage during the flood in 2011.

Sindaebang Station that is one of typical characteristics of type 1 is as shown on Figure 20. This region has roads being bordered with covered Dorimcheon and along the road,

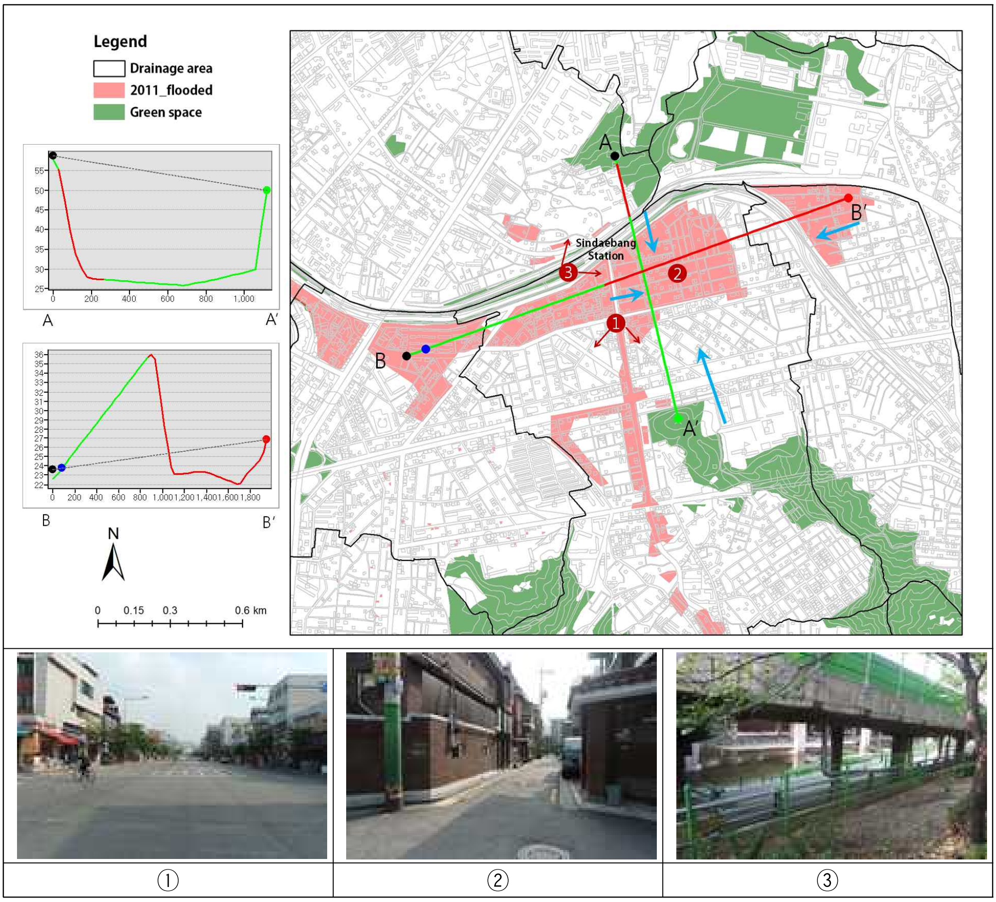


Figure 20. Type 1 : Sillim 4 drainage basin (pictured by author, June 19, 2015)

(2) Flooded area type 2

The average slope for Type 2 flooded areas was 14.06%, which was much steeper than the total area average (3.82%) for non-flooded areas in Seoul. The TWI value was relatively low here, and soil drainage was the most favorable among the four types. Landslides may be a concern for this area, given the steep gradients and vegetated hilly areas. Commercial, business and industrial areas were not present in this region. It was a place where water is prone to flow without attenuation, and hence, flooding did not occur frequently; when it did occur, inundated land in this region made up about 5% of the total flooded area in Seoul. These areas are bordered by mountainous terrain, and several newly-built detached houses are located here, along with many older brick houses. These structures are vulnerable to severe damage during intense discharge of water from the mountains to lower areas. Characteristics of Woomyeonsan landslide region that is a typical form of type 2 are as shown on Figure 21.

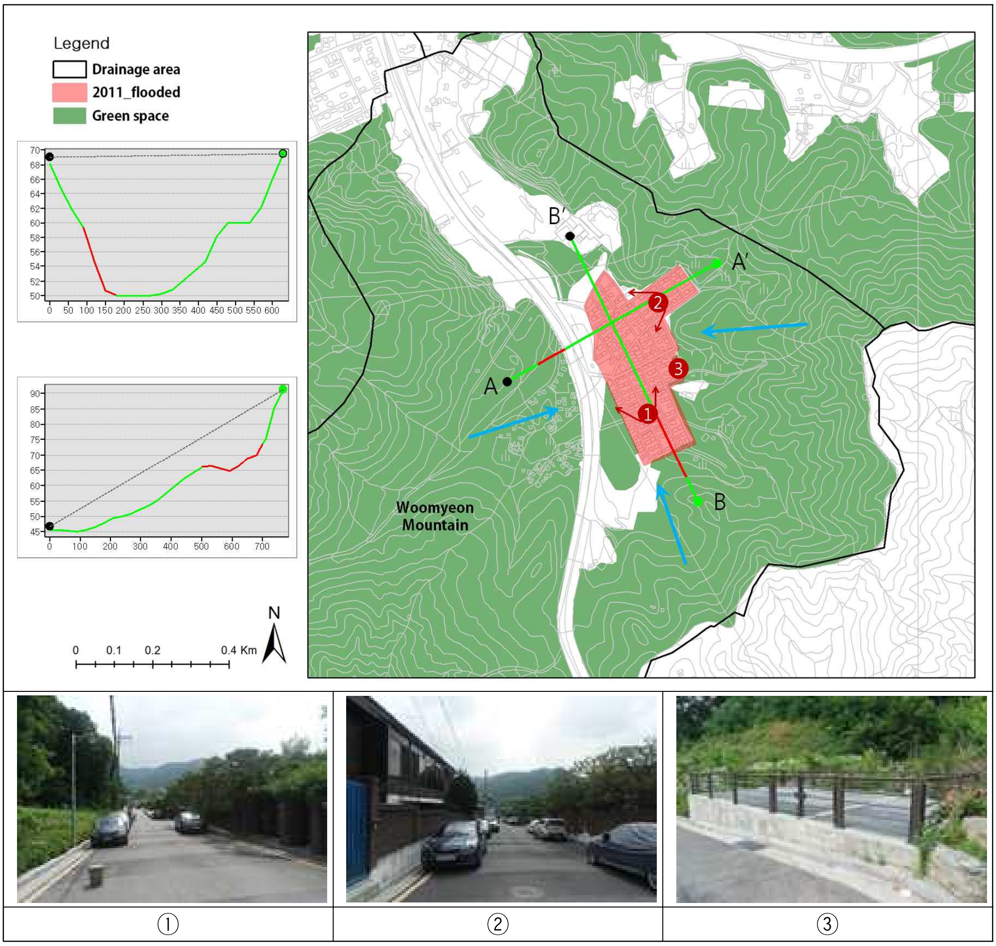


Figure 21. Type 2 : Woomyeon drainage basin (Pictured by author, June 19, 2015)

(3) Flooded area type 3

The average slope of Type 3 areas was 1.29%, which was the gentlest slope in the study areas, and the TWI was the highest among the four flooded area types. In addition, soil drainage was the worst compared to the overall average soil drainage of all flooded areas in Seoul. The ratio of detached housing area and mixed land use area was relatively high, and roads accounted for over 50% of the area.

Type 3 areas had geographical conditions conducive to water attenuation, contrary to Type 2 flooded areas. Given the high TWI values, this region will be prone to future flooding if appropriate drainage systems are not installed.

Type 3 is mainly located at Sadang, Bangbae, Sinwol1, Sinwol3, Hwagok2, Gildong and a part of Daelim, Sillim1, Sillim2 drainage basin in flood at Dolimcheon. Typical form of type 3 is located in around Sadang station as shown on Figure 22.

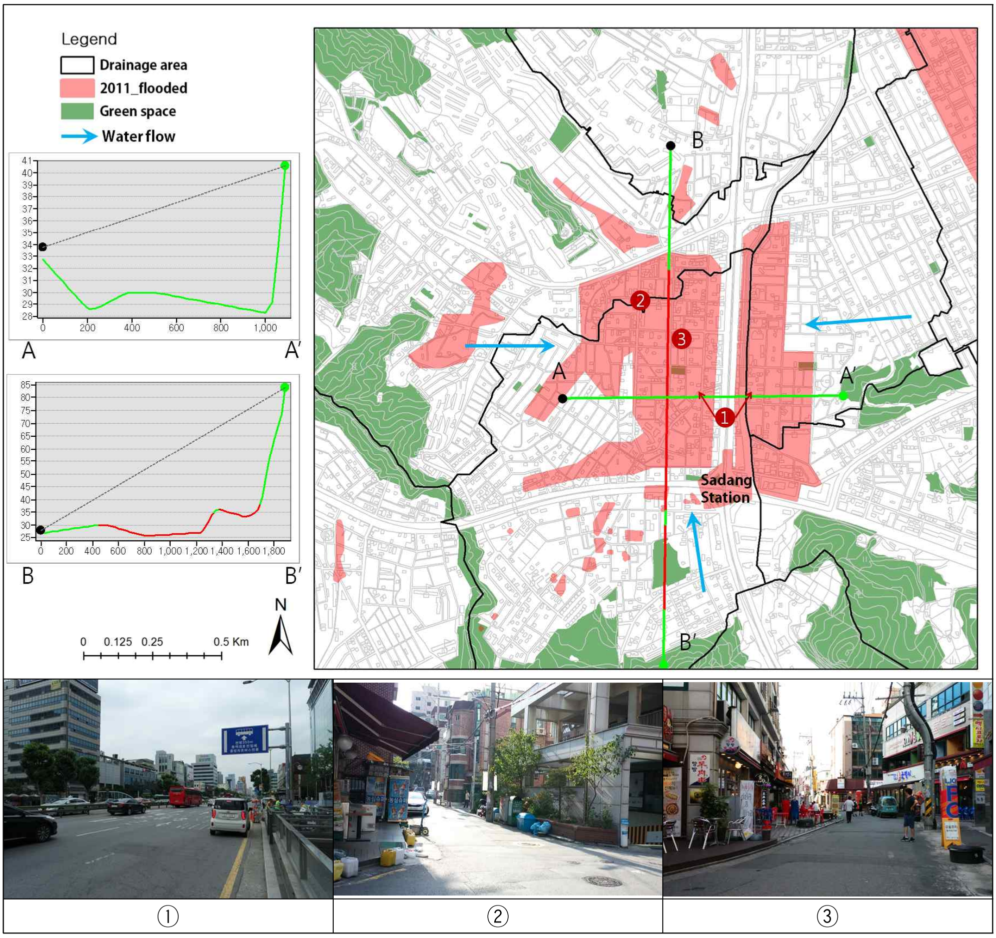


Figure 22. Type 3 : Sadang drainage basin (Pictured by author, June 19, 2015)

(4) Flooded area type 4

The average TWI value for Type 4 flood areas was much lower than the total average of 10.42 for non-flooded areas, and slopes here were moderate. Soils drain imperfectly in this region, as indicated by the soil drainage data. In general, this area had several features that fell between the values for Type 2 and 3 areas; in comparison with all flood area types, the Type 4 area represents a place where the flooding probability can be expected to change considerably based on precipitation.

Type 4 is located throughout Seocho 1, Seocho4, Nonhyeon drainage basin between Gyodae Station and Gangnam Station. In addition, flooded area under Woomyeonsan landslide area of Bangbae 4 drainage basin is included and partially located area neighboring with Type 3 area is present. Characteristics of an area bordered with Nambu ring road located at Bangbae 4 drainage basin is as shown on Figure 23. In this area, flood was taken place before by water flown down from Woomyeonsan as maximum hourly precipitation was increased and in sloped area, many newly built apartments are located.

Figure 23. Type 4 : Bangbae4 drainage basin (Pictured by author, June 19, 2015)

Road image connecting Gyodae Station and Gangnam Station that is connection point of Seocho 1 and 5 drainage basin is as shown on Figure 24. In every direction of an area where flood was taken place, water is collected due to location of slope and compared with Sadang Station of type 3, slope of surrounding area is steep. In its surrounding, apartments are located and it could be seen that its damage is minor than detached housing area.

Figure 24. Type 4 : Seocho1, Seocho5 drainage basin
(Pictured by author, May 9, 2015)

4) Comparison with flood prone area

Time of great flood in Seoul for the recent past 20 years is 1998, 2001, 2010 and 2011. When observing damaged area being represented in past flood inundation map, flood was taken place continuously as physical variables such as altitude, topography and underground soil property were seldom changed even though there is some difference depending on intensity of heavy rain. Park et al., (2013) finally selected 34 flood prone areas by using data of the regions that are extensively controlled by Seoul city as major flood vulnerable area.

As a result of comparing flood inundation map of 2011 with flood prone area of Seoul city in order to discriminate flood type in this study, overlapped part among 34 flood prone area was total 21 areas including Gangseo 1, Yangcheon, Seocho, Gangnam and in areas over 60%, flood was occurred repeatedly. Among the areas being designated as flood prone area, in case of the areas bordered with Songpa and Jungrangcheon, as recent flood was considerably reduced by installation of pump station compared with 1998, 2001 in the past, an area where flood is seldom occurred is also present as well.

When comparing based on occurrence year, overlapped ratio with flooded area in 2011 and 2010 was 37.57%, that with 2001 25.88% and that with 1998 4%, respectively and as year is changed, flooded area was changed by surrounding environment and flood control countermeasure. As flood prone area designated by Seoul city is based on its repeated occurrence for over 2 times, in case of areas where flood was occurred repeatedly in 1998 and 2001, an area where flood was not occurred recently was also included. Therefore, in this study, flood type was divided based on flood occurrence data of 2011 being taken place recently, not by using flood prone area and through this result, flood control effect based on green space features was analyzed.

When comparing features of flood type divided in this study with that of flood prone area where flood was taken place for over 2 times, features of type 1 was 26.70%, that of type 2 10.38%, that of type 3 43.08% and that of type 4 43.29% and it could be seen that flood prone areas are mostly distributed in type 3 and type 4.

5) Comparison with urban flood vulnerable area

Analysis result of division of flood occurrence area in 4 types and that of previously analyzed urban flood vulnerable area was compared. In case of type 3 of which slope is most gentle, TWI is the highest, average value of flooding probability was the highest as 0.582, places having flooding probability over 60% were most frequently observed among 4 types. Type 2 that has an opposite features had the lowest average value and its flood occurrence probability was represented to be very low. In other words, it could be realized that depending on regional features of flood type being divided in this study, risk of flood occurrence varies.

Table 16. Comparison flood vulnerability with Flood occurrence type

Type	Number of sample	Flood occurrence probability according to vulnerability assessment					
		flood occurrence probability	Frequency	Ratio	Average	Min.	Max.
Type 1	459	0-0.2	33	7.19	0.523	0.03	0.84
		0.2-0.4	99	21.57			
		0.4-0.6	146	31.81			
		0.6-0.8	170	37.04			
		0.8-1.0	11	2.40			
Type 2	106	0-0.2	42	39.62	0.293	0.02	0.77
		0.2-0.4	32	30.19			
		0.4-0.6	24	22.64			
		0.6-0.8	8	7.55			
		0.8-1.0	0	0.00			
Type 3	961	0-0.2	31	3.23	0.582	0.01	0.87
		0.2-0.4	156	16.23			
		0.4-0.6	239	24.87			
		0.6-0.8	474	49.32			
		0.8-1.0	61	6.35			
Type 4	425	0-0.2	39	9.18	0.550	0.01	0.85
		0.2-0.4	76	17.88			
		0.4-0.6	113	26.59			
		0.6-0.8	151	35.53			
		0.8-1.0	46	10.82			
Total	1951	-			0.545	0.01	0.87

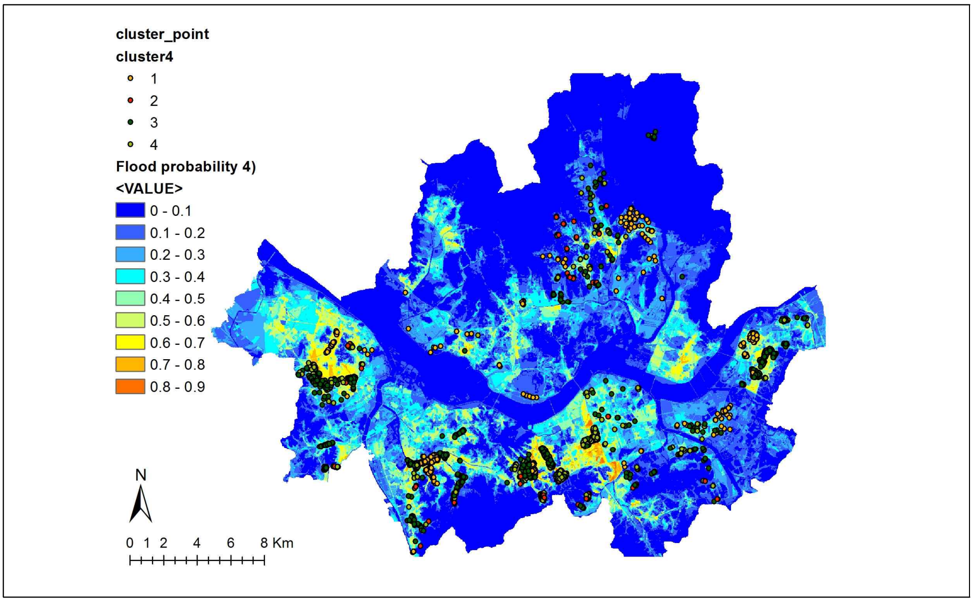


Figure 25. Flood vulnerability map and types of flood occurrence points

3. Analysis of flood control effect based on urban green space features

1) Flood control effect based on green space area

(1) Development of green space area variable

The green space variable represents 'green space area within a radius of 100 m from the point', and data were derived from a biotope map. Specifically, these data were calculated by aggregating absolute areas of green spaces within a 100-m radius from flooded and non-flooded points. As a result of establishing multiple logistic models with variables for green spaces within different distances from the point sources, it was determined that the accuracy of the model that contained green spaces within a radius of 100-m from the point was the highest.

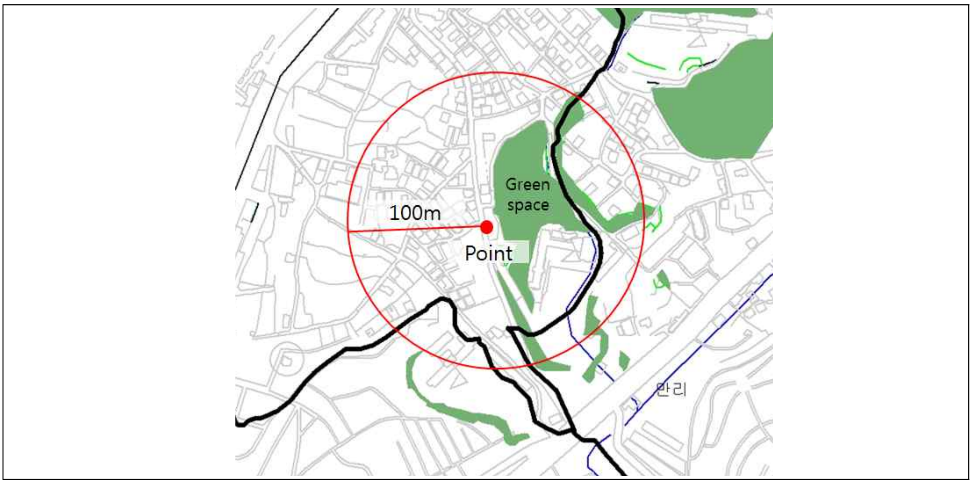


Figure 26. Example of a method estimating green space area within 100-m radius

(2) Characteristics of green space area

Green spaces in the city of Seoul amount to 212.41 km^2, taking up about 35% of the total area. Estimates of the green space area average within a 100-m radius from flooded and non-flooded areas in Seoul are shown in Table 17. The average green space ratio for flooded areas in Seoul city was 4.49%; for Type 1 flood areas, the green space ratio was 2.26%; and for Type 3 areas, the green space ratio was 2.81%, which are values that were below the average value for the city. For Type 2 flood areas, which border mountainous terrain, the green space ratio was 22.48%. The green space ratio within a 100-m radius in non-flooded areas in Seoul was 19.43%, which was very high. Division of total green space and flooded area type of Seoul city is as shown on Figure 27.

Table 17. Average green space area average within a 100-m radius from flooded and non-flooded areas.

Description		Average of Green Space Area within a 100-m Radius	Average of Green Space Area Ratio within a 100-m Radius
Non-flooded		6102.20m^2	19.43%
Flooded		1,410.40m^2	4.49%
	Flooded area type 1	709.78m^2	2.26%
	Flooded area type 2	7058.9m^2	22.48%
	Flooded area type 3	881.36m^2	2.81%
	Flooded area type 4	1,954.52m^2	6.23%

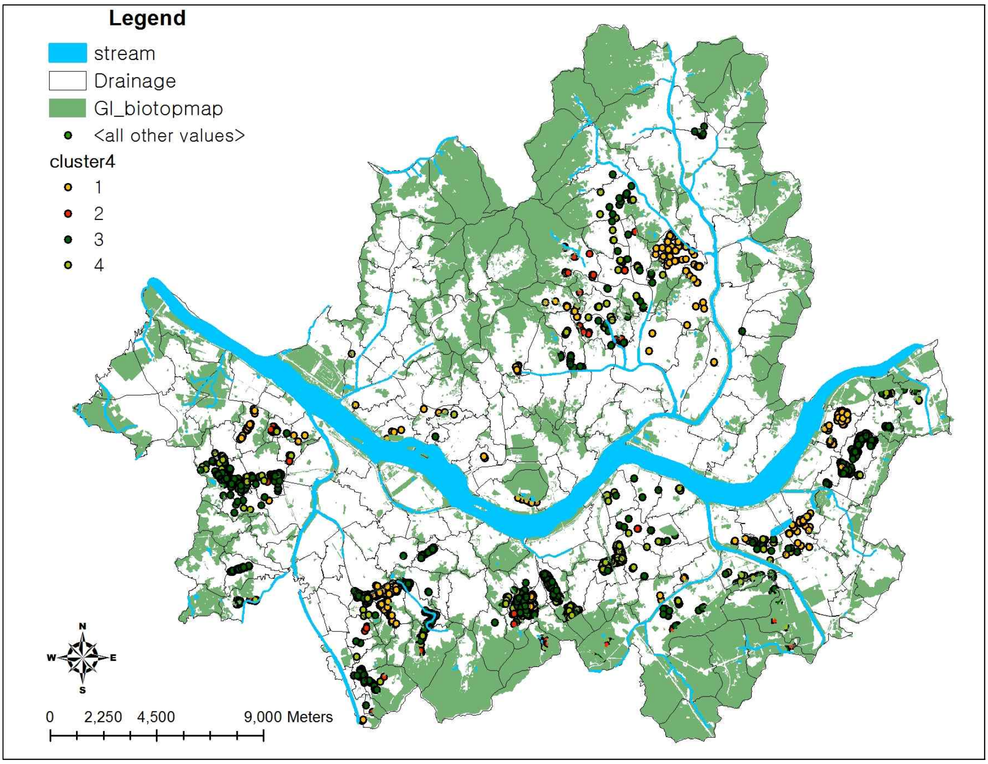


Figure 27. Green space and flooded area type of Seoul city

(3) Flooded area Type 1

For significant variables with the potential to affect the occurrence of floods in Type 1 flood areas, variables including the green space area, soil drainage, detached housing area and mixed land use area were selected as significant variables with the potential to affect the occurrence of floods in Type 1 flooded areas. The flooding probability will be decreased by increasing green space area and better soil drainage. According to the flooding probability model for Type 1 areas (Equation (1)), the probabilities of flooding in detached housing areas and mixed land use areas were 6.7-times and five-times higher than other areas, respectively.

Other variables affecting flooding included the TWI, slope and land use. As these were variables that were used in the previous cluster analysis to divide the study area into four types and because similar factors may be bound by each type, these variables were not selected as significant variables for the regression analysis. All of the variables were determined to be below the significance level of $p < 0.05$; hence, all such variables were statistically significant. The relevant equation is as follows:

$$P(x)\ \text{Type1} = 0.499 - 0.116\ \text{Green space area} - 0.460\ \text{Soil drainage} + 1.614\ \text{Mixed land use area} + 1.896\ \text{Detached housing area} \quad (1)$$

(AUC= 0.786)

Based on this, how flooding probability is changed depending on change of green space area was analyzed. After fixing other variables than green space area, flooding probability was deduced. Soil Drainage range in type 1 was minimum value of 1, mean value of 2.8, maximum value of 5 and range was taken as fixed variables. As Exp (B) value of detached housing area is bigger than that of mixed basin, graph was deduced on the assumption that maximum flood occurrence probability is estimated in case of detached housing area. The flooding probability was distributed from a maximum value of 94.19% (in areas where green space was non-existent, the drainage was very inferior and detached house was present) to a minimum value of 1% (Figure 28).

Table 18. The range of flooding probability according to green space ratio (Type 1)

Green space area ratio	Min.(%)	Average(%)	Max.(%)
0 %	27.87	73.48	94.19
10 %	21.16	65.81	91.94
20 %	15.70	57.19	88.93
30 %	11.46	48.13	84.97
40 %	8.26	39.23	79.95
50 %	5.88	30.96	73.75
60 %	4.15	23.69	66.35
70 %	2.92	17.76	58.17
80 %	2.05	13.04	49.59
90 %	1.43	9.44	40.83
100 %	1.00	6.75	32.71

※ Total area is 31,400㎡ and green area ratio refers to the percentage of the inner circle of 100-m radius from the point.

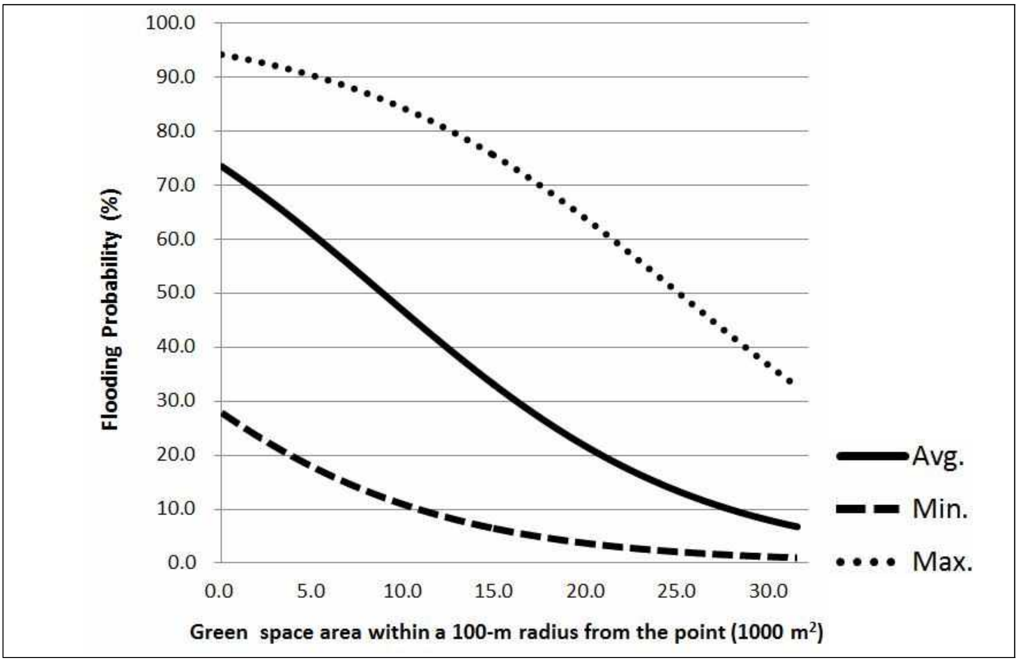


Figure 28. Flooding probability based on green space area (Type 1)

(4) Flooded area type 2

In Type 2 flood areas, green space area, slope and maximum hourly precipitation variables were selected as significant variables with the potential to affect flood occurrence. The estimated coefficient for all of the explanatory variables, except for the constant term, was statistically significant ($p < 0.05$), and more green space area was associated with a reduced occurrence of flooding in this region. During times of high maximum hourly precipitation and in areas with gentle slopes, flood occurrence was increased. The model seemed to yield reasonable results, and the observed accuracy was 91.4%, which was the highest accuracy among the deduced model of four flooded area types. The relevant equation is as follows:

$$P(x)_{\text{Type 2}} = 0.048 - 0.083\ \text{Green space area} - 0.174\ \text{Slope} + 0.079\ \text{Maximum hourly precipitation}\ (\text{AUC} = 0.914) \tag{2}$$

Type 2 was dominated by steep areas bordered by mountainous terrain. As mountain soil is rapidly saturated by regional torrential rains, debris flows occurred that contributed to the flooding. In the Type 2 area, detached houses are densely located in the lower part of the mountainous area, and serious damage is highly likely to occur here during future flooding events.

The flooding probability was distributed from a maximum value of 99.65% (where green space did not exist at all, the slope was minimum and maximum hourly precipitation was maximum) to a minimum value of 0% (Figure 29). Flooding possibilities are minimized in the mountainous area with the steepest slopes according to the deduced (Equation (2)). The steepest areas in the Type 2 flooded area are not considered vulnerable to flooding, because those areas quickly withdraw the exceeded amount of rainfall to the neighboring gentle sloped areas. In cases where the maximum hourly precipitation reaches 87.77 mm, the flood probability is predicted to be greater than 95% regardless of whether green space is increased; thus, this is an area where floods are inevitable, under the current conditions, at times of extreme rainfall. The installation of flood control facilities, such as rainfall retention tanks, would be valuable in such areas.

Table 19. The range of flooding probability according to green space ratio (Type 2)

Green space area ratio	Min.(%)	Average(%)	Max.(%)
0 %	0.00	63.74	99.65
10 %	0.00	57.53	99.54
20 %	0.00	51.01	99.40
30 %	0.00	44.56	99.23
40 %	0.00	38.27	99.00
50 %	0.00	32.30	98.71
60 %	0.00	26.86	98.33
70 %	0.00	22.07	97.84
80 %	0.00	17.95	97.23
90 %	0.00	14.39	96.42
100 %	0.00	11.47	95.41

※ Total area is 31,400㎡ and green area ratio refers to the percentage of the inner circle of 100-m radius from the point.

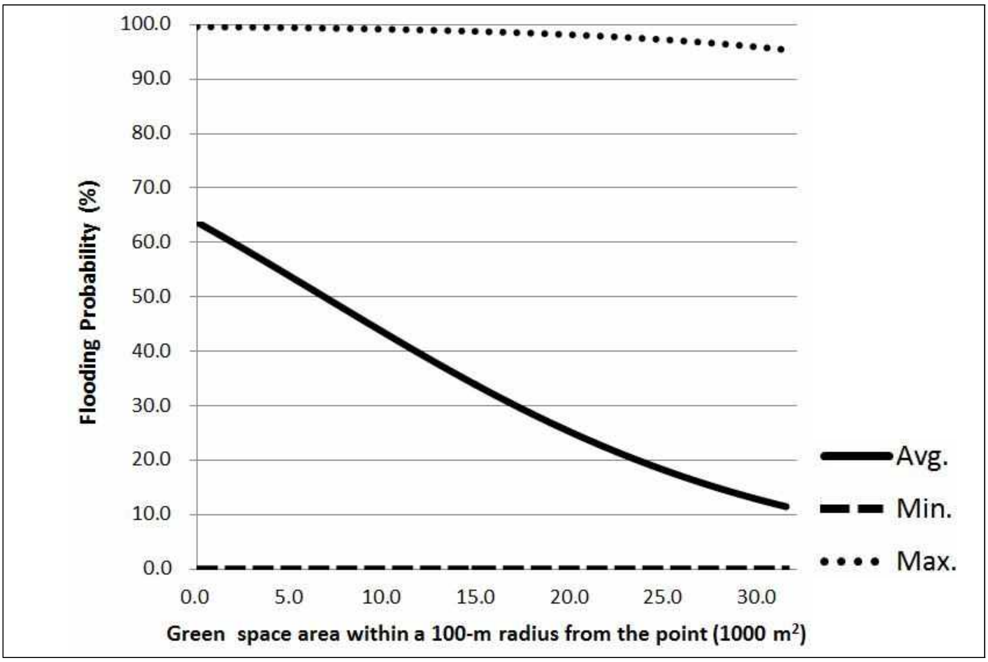


Figure 29. Flooding probability based on green space area (Type 2)

(5) Flooded area type 3

In Type 3 flooded areas, green space area, TWI and detached housing area were selected as significant variables with the potential to affect flood occurrence. As the green space area expanded, the flooding probability decreased, and higher TWI values and more extensive detached housing areas were associated with an increase in flooding probability. The estimated coefficient of all variables was very significant ($p < 0.005$). The explanatory capability of this model was 70%. The relevant equation is as follows:

$$P(x)_{\text{Type 3}} = -1.043 - 0.125\ \text{Green space area} + 0.086\ \text{TWI} + 1.168\ \text{Detached housing area}\ (\text{AUC} = 0.702) \tag{3}$$

The flooding probability was distributed from 75.92% to 0% (Figure 30). As TWI, detached housing status variable in addition to green space area and constant term are present, flooding probability was deduced after fixing such variable as shown on Table 20. The range of TWI in type 3 is distributed from 9.41 to 20.97, the average was 13.16, as the result which is generated flooding probability after fixing this variable, it is observed that the flooding probability is distributed from 75.92% (maximum value; in case of the green space area is not at all, TWI is 20.97, and housing area is detached) to 0% (minimum value).

The absolute estimated coefficient for green space area was the largest compared to the other types, and the variation of flood probability due to the change in the green space area was also the largest.

Table 20. The range of flooding probability according to green space ratio (Type 3)

Green space area ratio	Min.(%)	Average(%)	Max.(%)
0 %	44.18	57.41	87.30
10 %	34.83	47.65	82.28
20 %	26.45	37.99	75.80
30 %	19.58	29.31	67.89
40 %	14.14	21.90	58.85
50 %	10.01	15.92	49.13
60 %	6.96	11.30	39.39
70 %	4.82	7.93	30.53
80 %	3.32	5.52	22.99
90 %	2.26	3.78	16.70
100 %	1.53	2.59	11.92

※ Total area is 31,400㎡ and green area ratio refers to the percentage of the inner circle of 100-m radius from the point.

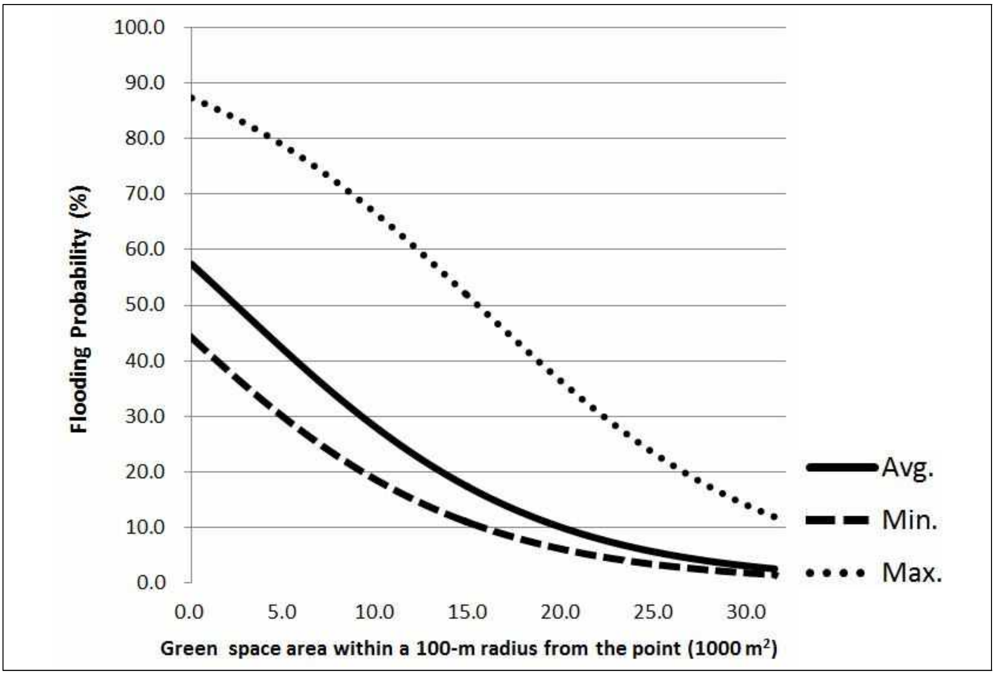


Figure 30. Flooding probability based on green space area (Type 3)

(6) Flooded area type 4

In Type 4 flood areas, green space area, soil drainage and maximum hourly precipitation were selected as significant variables with the potential to affect flood occurrence. When the green space area expanded and the drainage was good, the flood occurrence probability decreased. Conversely, when the maximum hourly precipitation was high, the flood probability increased. All of the variables were very significant ($p < 0.005$). The explanatory capability of the model was 75.6%. The relevant equation is as follows:

$$P(x)_{Type\ 4} = -0.997 - 0.085\ \text{Green space area} + 0.048\ \text{Maximum hourly precipitation} - 0.486\ \text{Soil drainage}\ (AUC = 0.756) \quad (4)$$

The flood probability was distributed from 96.04% to 0.52% (Figure 31). In cases where the maximum precipitation was high and soil drainage was poor, the flood probability was greater than 60%, even when the green space area was at the maximum level. In this region, flood probability was mainly affected by heavy rainfall, and the maximum flooding probability was associated with maximum hourly precipitation.

Table 21. The range of flooding probability according to green space ratio (Type 4)

Green space area ratio	Min.(%)	Average(%)	Max.(%)
0 %	7.08	56.82	96.04
10 %	5.51	50.19	94.89
20 %	4.26	43.50	93.41
30 %	3.30	37.12	91.58
40 %	2.55	31.15	89.29
50 %	1.97	25.73	86.46
60 %	1.51	20.93	82.99
70 %	1.16	16.86	78.89
80 %	0.89	13.47	74.16
90 %	0.68	10.63	68.67
100 %	0.52	8.35	62.66

※ Total area is 31,400㎡ and green area ratio refers to the percentage of the inner circle of 100-m radius from the point.

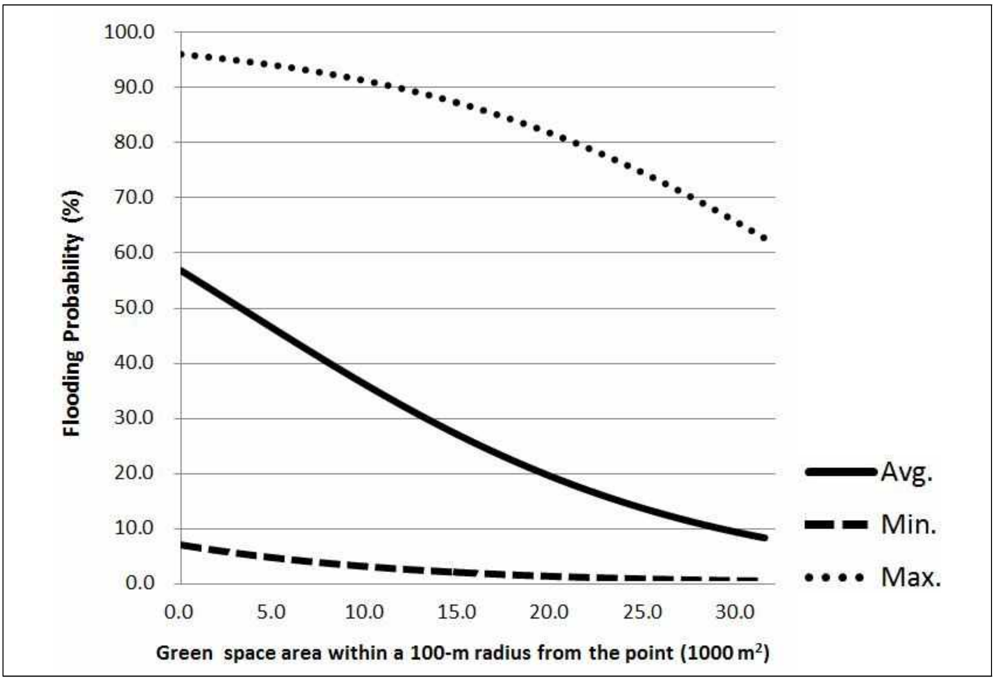


Figure 31. Flooding probability based on green space area (Type 4)

(7) Comparative analysis

Flooding probability is shown to differ with the variation of green space area in each flooded area type. First, when comparing average values in the graph gradients (Figure 28~31) to explore the effects of green space according to each type of flooded area, it was found that Type 1 flooded areas were the most amenable to flood control through increased green space area, followed by Type 3, Type 4 and Type 2. However, while the average value of the gradient was the highest for Type 1, up to about 7000 m^2 of green space area, the graph gradient of Type 3 was the highest among all of the areas. This means that compared to other flooded area type areas, the flood control capacity via green space is relatively large in Type 1 and 3 areas.

Sensitivity analysis of flooding probabilities through the green space area was performed based on Figure 28~31. Flooding probabilities for each flooded area type were changed by not only green space area, but also physical and environmental variables. Therefore, Figure 32 schematizes the difference between maximum and minimum of flooding probability due to green space area to show the scale of the sensitivity of flooding probability depending on the significant variables, except green space area. As a result, the sensitivity of flooding probability reduced as the green space area increased in all flooded area types. Moreover, in Type 3, a range of flooding probabilities due to green space area is the smallest among the four types in spite of other environmental variables' change, that is Type 3 has low sensitivity, followed by Type 1, Type 4 and Type 2.

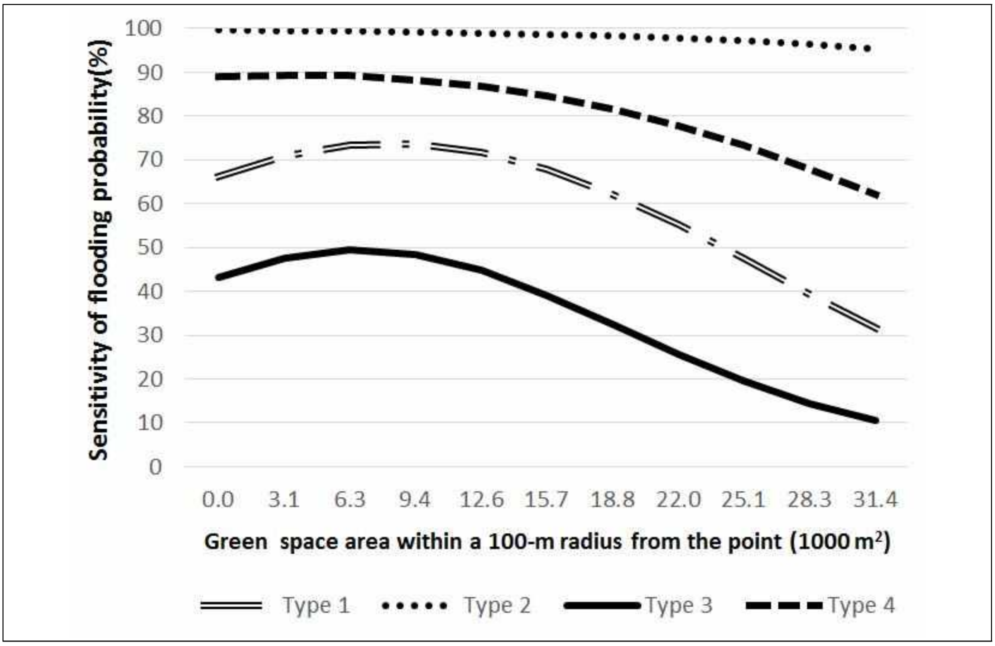


Figure 32. Sensitivity analysis between flooding probabilities

The Type 1 area, which is located in a drainage basin with an FRMI, was a flood-prone area before the FRMI was installed. Since the installation of a pumping station and a rainwater retention tank, the area has become less vulnerable to flood occurrences. It should be noted that in the case of no green space at all, the maximum value for the flood occurrence probability was the highest (73.48%) among the four types. In addition, the flood probability range, which went from a maximum of 73.48% to a minimum of 6.75%, was the greatest among the four types.

In Type 2 and 4 flood areas, when the maximum hourly precipitation was at the maximum level, the flood probability was greater than 60% despite changes in the green space variable; these represent areas where the maximum hourly precipitation significantly affects flood occurrence. Landslides are likely in this area, and these may be influenced by precipitation conditions, topography and geological features; landslides are apt to take place when external factors, such as rainfall impacts ground that has internal vulnerabilities (Kim et al., 2000; Yoon and Koh, 2012). Such a landslide occurred in the Woomyeonsan Mountains in 2011, resulting in 18 deaths, and was caused by flooding and the area's unique geographical features. In the area bordering the mountains, it would be prudent to install flood control facilities, such as rainfall retention tanks, in addition to green spaces, to prevent future flooding.

On the other hand, in the case of Type 3 areas, there were small differences in the flooding probability according to the hourly maximum precipitation. The maximum hourly precipitation variable was not designated as a significant factor. Flooding probability for

Type 3 was highly affected by TWI, green space area and the presence of housing rather than the distribution of precipitation. In particular, as flood occurrence was frequent in the detached housing area, mixed land use area, business area and roadway area, the flooding probability could be reduced effectively by introducing green spaces.

In the Type 3 flooded areas, the flooding probability was reduced to a minimum of 2.59% when the green space area in a 100-m radius is increased to the max. Compared to other types, it had the smallest probability values, and this is an area where the sensitivity to increases in green space area is high. When the green space area changed from 0 to 31,400 m^2, the gradient mean value of flood probability for Types 2 and 4 was similar. However, it could be seen that in the case of Type 2, when the green space area was less than 6940 m^2, it had a gentle gradient compared to Type 4, but at higher values, the graph gradient of Type 4 became gentler. Type 4 had intermediate geographical features between those of Type 2 and 3 and coexisted with Type 2 and 3 rather than achieving an independent existence in the model.

When observing the green space area of a place where the flooding probability was rapidly changing (inflection point), the inflection point occurred at 2380 m^2 in the Type 3 area where the flood control effect based on the green space area was significant. The inflection point can be considered to be an area where the cost-effectiveness of flood control based on increases in green space area is the largest. The inflection point is identical to the green space area required for reducing the flooding probability by 50%.

The green space area required for reducing the flood probability to a 50% increase was in the order of Type 3, Type 4 and Type 2 areas. Specifically, for the Type 3 area, if 7.5% of the total area is converted to green space, the flood probability will be reduced to less than 50%, while in Type 4 and 2 areas, only when 10.3% and 21.7%, respectively, of the total area is covered with green space will the flood probability be reduced by half (Table 22).

Table 22. Comparison of average probability for each type

Type	Co-efficient of green space	Cut-off value of green space area	Green space area to 50% flooding probability	Flooding probability(%)		
				Max.	Min.	Difference
Type1	- 0.116	8,790 m^2	8,790 m^2 (27.9%)	73.48	6.75	66.73
Type2	- 0.083	6,790 m^2	6,790 m^2 (21.7%)	63.74	11.47	52.27
Type3	- 0.125	2,380 m^2	2,380 m^2 (7.5%)	57.41	2.59	54.82
Type4	- 0.085	3,220 m^2	3,220 m^2 (10.3%)	56.82	8.35	48.47

To reduce the size of the area within 10% the flooding probability band in Type 3 areas, i.e., to 47.41% from 57.41% when no green space is present at all, a green space area of 3205 m^2 would be required, and this amount accounts for about 10% of the total area. Similarly, Type 2 would require a green space area of 4990 m^2 in size, which would take up 16% of the total area, to reduce the top ranking 10% of flood probability (Table 23, Figure 33).

Table 23. Green space area and ratio to reduce flooding probability band

Type	Description	(Green Space Area to Reduce by)			
		Upper 10% Probability	upper 20% Probability	upper 30% Probability	upper 40% Probability
Type1	area(m^2)	4,015	7,580	11,040	14,700
	ratio(%)	12.79	24.14	35.16	46.82
Type2	area(m^2)	4,990	9,830	14,950	20,900
	ratio(%)	15.89	31.31	47.61	66.56
Type3	area(m^2)	3,205	6,500	10,180	14,840
	ratio(%)	10.21	20.70	32.42	47.26
Type4	area(m^2)	4,730	9,570	15,040	22,030
	ratio(%)	15.06	30.48	47.90	70.16

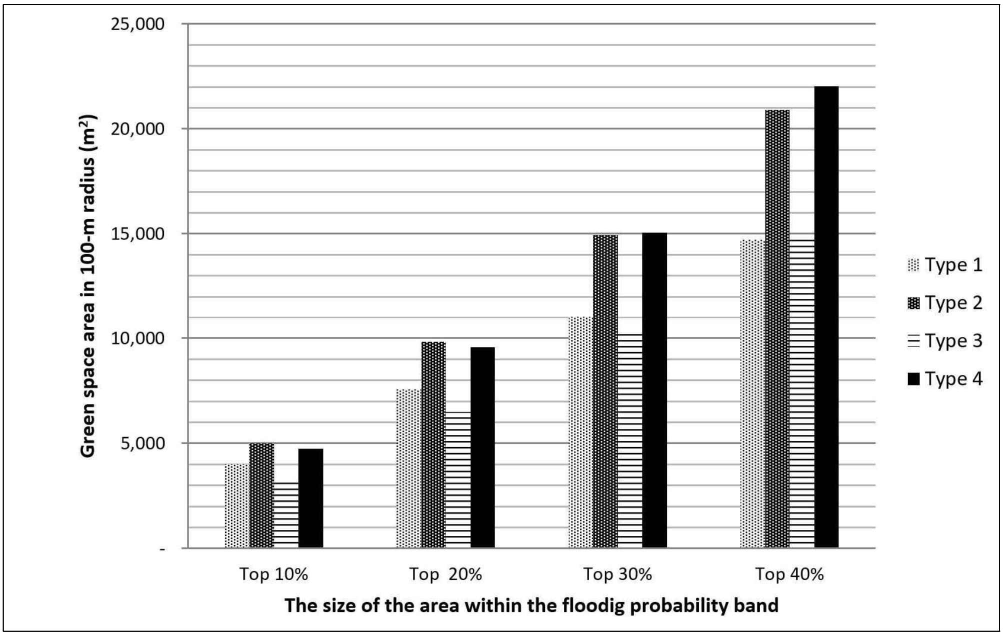


Figure 33. Green space area to reduce the size of the flooding probability band (Total green space area : 31,400m^2)

It is found that green spaces exerted a considerable influence on urban flooding probabilities in Seoul, Korea, and reductions in flooding were noted in several areas with greater amounts of green space. Moreover, different areas showed different sensitivities to the effects of green spaces, and flooding probabilities could potentially be reduced by more than 50%, depending on the amount of green space area and its introduced location. By Zhou et al. (2013), introduction of green spaces would be the best adaptation strategy for future flooding events through their use of a hedonic value evaluation method that considered the expansion of sewerage pipelines and construction of infiltration trenches. In a short-term perspective, expansion of sewerage pipelines may exert a significant influence on flood control, but in a long-term, sustainable and cost-effective perspective, increasing green spaces would represent an efficient way to control flood occurrences.

Green spaces were found to be more effective for decreasing flooding probabilities in Type 3 flood areas where the slope was gentle and the TWI was high, compared to Type 2 areas. This result is similar to one where it was found that creating green spaces such as street plantings in a concave rather than in a convex form by raising the elevation higher than surrounding roadways can be advantageous for reducing flooding by rainwater infiltration. In the case of reconstructing all green spaces in a community to a depth of 5 cm, it was found that runoff could be reduced by a maximum of 16% and the peak outflow by about 25% (Liu et al., 2014). Concave-shaped green spaces could be interpreted in the same context as Type 3 green spaces. This could also be applied to location selections for small-scale gardens at the time of green space planning for entire urban areas.

In the case of Type 3, the average value of flooding probability was the largest, and this was the most flood-prone area included in this study. On the other hand, the effect of green spaces on the reduction of flooding probabilities was greatest in these areas. Generally, in flood-prone areas, installation of large-scale rainwater retention basins as a short-term solution is the preferred method to control flooding. In this study, we found that the green space area has the potential to reduce flooding probability by less than 50% in all flooded area types.

2) Flood control effect based on green space type

(1) Green space type of Seoul city

In this study, green space types were divided into seven types of planted areas: grasslands, wetlands, paddy fields, fields, orchards, and forests. This was based on the runoff curve number (CN) method and the distribution of green space locations. The distribution of green space types are shown in Figure 34. In Seoul city, forests are observed in the northern and southern parts, and farmland is mainly distributed neighboring the forests. Grasslands and wetlands are near the side of streams and neighbor the main streams, such as the Hangang River, the Chunglangcheon, the Anyangcheon, and the Yangjaecheon.

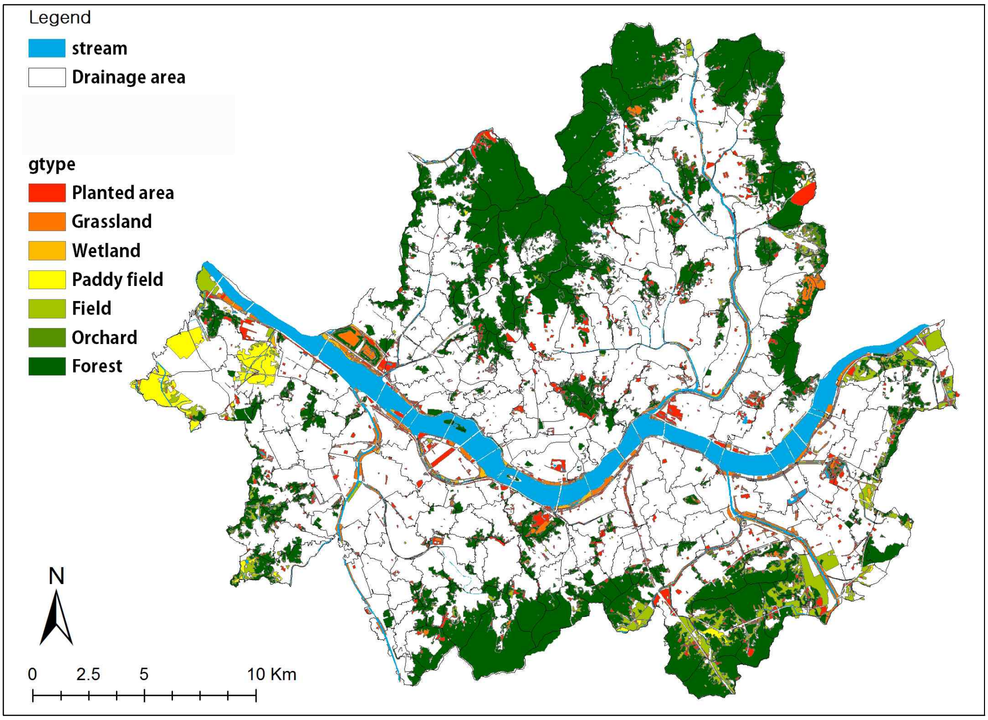


Figure 34. Green space type in Seoul city

In the overall green space of Seoul city, the forest area dominates and accounts for approximately 71%. This is followed by farmland (paddy fields, fields, and orchards) that accounted for 11.70%. Planted areas covered 10.39%, and grasslands and wetlands covered 6.85%. Analyzing this using the Kruskal-Wallis test for units of green space area within a 100 m radius, the result of the probability analysis was less than 0.0001. However, the average difference classified by the seven green space types into flooded versus non-flooded areas was significant. The green space type is definitely significant depending on flooded versus non-flooded observations.

The average green space area within a 100-m radius of a flooded area is 1,404 m^2. This is about one quarter of the level for a non-flooded area. Through this, it is observed that there is a difference of green space area distribution according to the flooded versus non-flooded characteristic. The forest is the largest area in all of Seoul city, and it dominates in both the flooded area and the non-flooded area. The portions are approximately 37.4% and 38.2%, respectively. The absolute green space area differs between flooded and non-flooded; however, it is realized that the area portions of all green space types are similar.

The total planted area of the flooded area is about 2.5 times larger than that of the non-flooded area, with the portion of total green space area accounting for approximately 30% in a 100 m radius from a flooded area and approximately 19.2% from a non-flooded area. The planted area is shown as a large portion of the flooded area. The planted area is mainly distributed in the downtown area with street trees and urban parks, and the downtown area has a high infiltration compared with other regions and is more exposed to flood risk. The flood mitigation effect of the planted area is less than that of other types of green space, because the permeability is lower than the natural ground, as it is mainly located in artificial ground as compared to the forests, the farmlands, the grasslands, and the wetlands.

Table 24. The average area of green space type in flood type (Unit : m^2)

Description	Seoul city		Area within 100-m radius			
			Non-flooded		Flooded	
	area (ha)	ratio (%)	area (m^2)	ratio (%)	area (m^2)	ratio (%)
Planted area	2,175	10.39	1169.6	19.2	429.8	30.6
Grassland	1,142	5.46	462.0	7.6	96.8	6.9
Wetland	291	1.39	152.7	2.5	1.3	0.1
Paddy field	712	3.40	691.8	11.3	4.7	0.3
Field	1,639	7.83	1257.8	20.6	338.8	24.1
Orchard	97	0.46	32.8	0.5	7.5	0.5
Forest	14,878	71.07	2332.3	38.2	525.2	37.4
Total	20.935	100	6,098.9	100	1,404.0	100

※ The total area within 100–m radius is about 31,416m^2.

As a result of analyzing the correlation analysis between each variable and the flooding status in Seoul city, the correlation coefficient of all green space types was represented to be significant below 0.01. It was observed that the forest had the most significant relationship with flooding, followed by the planted areas, fields, paddy fields, and grasslands.

(2) Flooded area type 1

Type 1 is a region that is located near a flood control facility. The pumping station is mainly located in lowland that neighbors the Han River and the main stream, and most rainwater retention basins are installed near forest areas. Due to these geographical conditions, the planted area, including an artificial grassland that is streamside and within a 100-m radius from flooded areas, accounts for an average of 518.1 m^2 (approximately 76%). The forests account for 19%, and the fields account for 2.7% as shown in Figure 35. The forests and planted areas neighboring non-flooded areas account for large portions compared with other types.

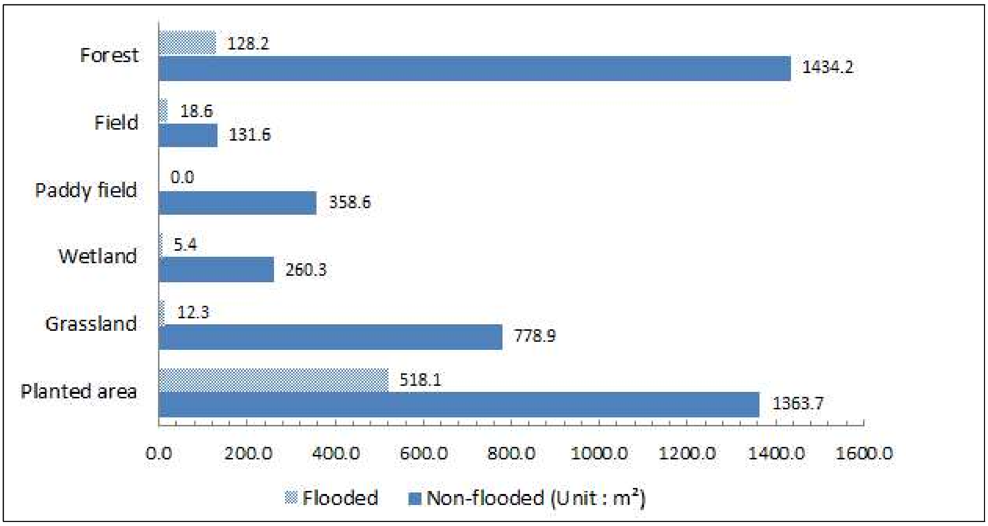


Figure 35. Mean area of green space type within 100-m radius from flooded and non-flooded point (Type 1)

The planted area neighboring with Dorimcheon located near the Shindaebang station is shown in Figure 36. The green space is next to the streamside near the road where flooding has taken placed. It was planted on a steep slope and is not suitable for absorbing the roadside runoff effectively.

Planted area adjacent the street	Planted area adjacent the stream

Figure 36. Green space type in flooded area type 1 : near Shindaebang Station around Dorimcheon (Pictured by author, June 19, 2015)

As a result of the logistic regression analysis, the planted areas, the grasslands, and the forest areas were selected as significant variables that affect flooding. As the area covered by these types of each green space within a 100-m radius increased, the flooding probability decreased. As the model explained 73% of the variability, it is considered as highly reliable. In addition, the soil drainage, topographic wetness index (TWI), and locations with mixed residential and business areas were determined to be significant variables. Increased soil drainage is good; and when TWI is low and the portion of mixed business areas is low, the flooding probability is decreased. The relevant equation is as follows:

$$P(x)_{\text{Type 1}} = -0.097 - 0.011 \text{ Planted area} - 0.077 \text{ Grassland} - 0.012 \text{ Forest} - 0.267 \text{ Soil drainage} + 0.068 \text{ TWI} + 0.908 \text{ Mixed land use area(1)} \ (AUC = 0.730) \tag{5}$$

The relative contribution of variables affecting flood occurrence by green space type by standardizing the non-standardized coefficient of each variable was determined. The grasslands contributed to flood control most extensively as shown on Figure 37, followed by forests and then planted areas. The grassland neighboring with Cheongyecheon and the Han River could be infiltrated with the rainwater when it rains.

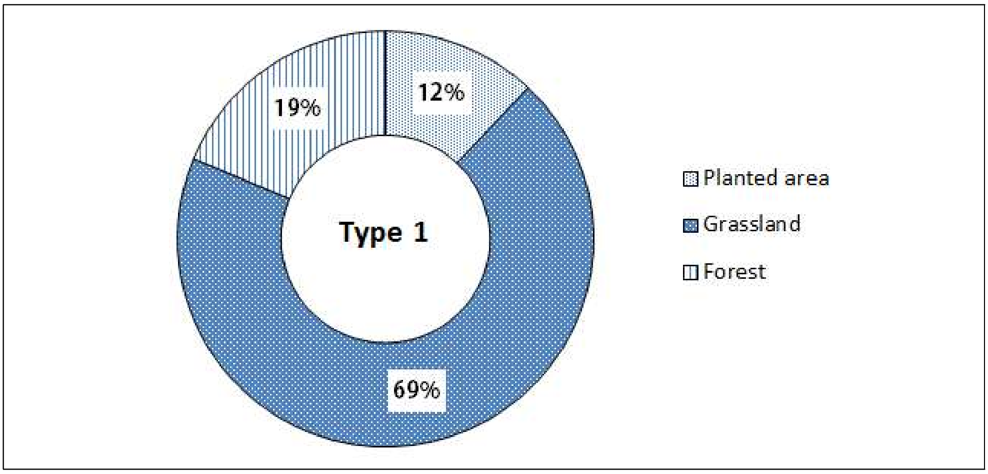


Figure 37. Relative flood control contribution based on the green space type (Type 1)

	
Grassland and wetland near stream (June 19, 2015)	Grassland near Han Riverside (Jan. 25, 2015)

Figure 38. Green space type in flooded area type 1 (Pictured by author)

(3) Flooded area type 2

Type 2 is a place where the slope is steep and soil drainage is good. It accounts for 64% of forests in a 100-m radius of a flooded area. Followed by this, fields accounted for 20%, planted areas 12%, and grasslands 3%, while paddy fields and wetlands were not represented in this category. For the case of non-flooded areas of type 2, forests account for 92% by planted areas.

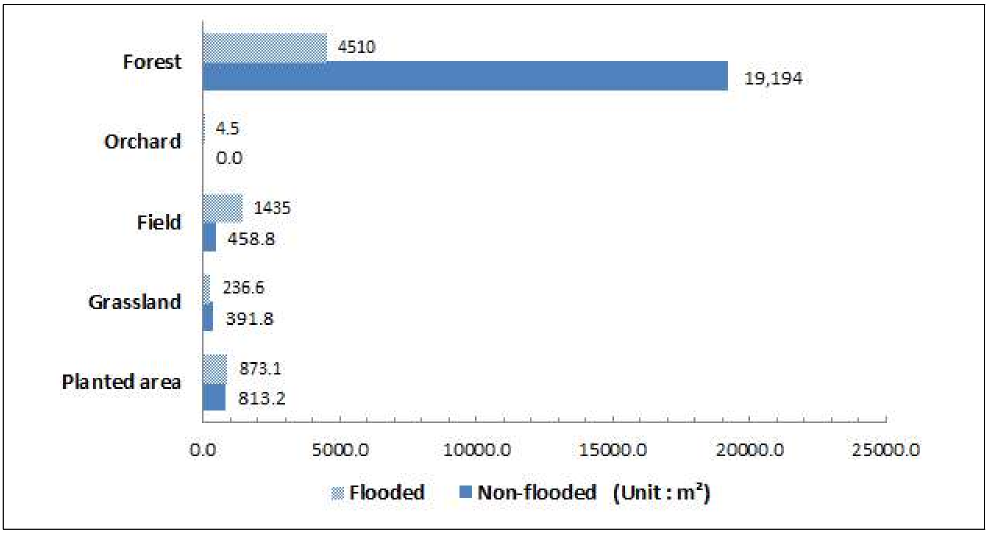


Figure 39. Mean area of green space type within 100m radius from flooded and non-flooded point (Type 2)

As a result of the logistic regression analysis, among green space areas, only forests were significant; and in type 2 areas, when more forest area is included, the flooding probability is decreased. Additionally, when the slope is less steep and maximum hourly precipitation is heavy, flooding probability is decreased. Green space type, excepting for forests, is not a variable affecting flooding status in type 2 areas. In the correlation analysis with flood occurrence, only the forest area was analyzed to be significant based on a Pearson's coefficient of −0.611. The relevant equation is as follows:

$$P(x)_{\text{Type 2}} = -0.012 - 0.010\ \text{Forest} + 0.075\ \text{Maximum hourly precipitation} - 0.162\ \text{Slope}\ (\text{AUC} = 0.919) \tag{6}$$

The efficiency of flood control in type 2 areas was the lowest compared with other areas. Rainwater flows down rapidly in areas having natural ground with very steep slopes. It was shown that water is not absorbed effectively even if there is green space. If a steep average slope is input for the operation of the hydrological model, infiltration seldom takes place and only runoff occurs.

With similar levels of precipitation, over 40% of rainfall can be converted to surface runoff in urban areas with over 50% impervious surfaces; whereas, runoff in woodland areas may be as low as 13% (Bonan, 2002). As in this example, the rainwater infiltration capacity of forests is excellent.

The landslide area of Woomyeonsan, where floods took place in 2010 and 2011, is also included in type 2. However, when observing the features for a flooded/non-flooded area forest, it was seen to have infiltrating rainwater rather than flooding. However, compared with other flood type areas, it may induce flooding in downstream areas by runoff occurring due to limited infiltration.

(4) Flooded area type 3

Type 3 flood areas have a gentle slope, the TWI is the highest, and the planted area accounts for 32% in a 100 m radius from a flooded area. The forest area accounts for 29%, fields 21.77%, and grasslands 15%. Wetlands were not present at all, and orchards and paddy fields accounted for approximately 1%. In type 3 areas where flooding has occurred, roads and housing areas dominate. Planted areas make up the largest portion of the green space in the flooded area.

For the area within a 100-m radius of non-flooded areas, field accounted for the largest portion at 33.65%. This was followed paddy fields that accounted for 21.20% and planted area that accounted for 20%. Compared with other areas, the difference between flooded area and non-flooded area is significant; and, in particular, the largest difference could be observed in the case of paddy fields. As a result of the correlation analysis, it was found that orchards do not affect flooding.

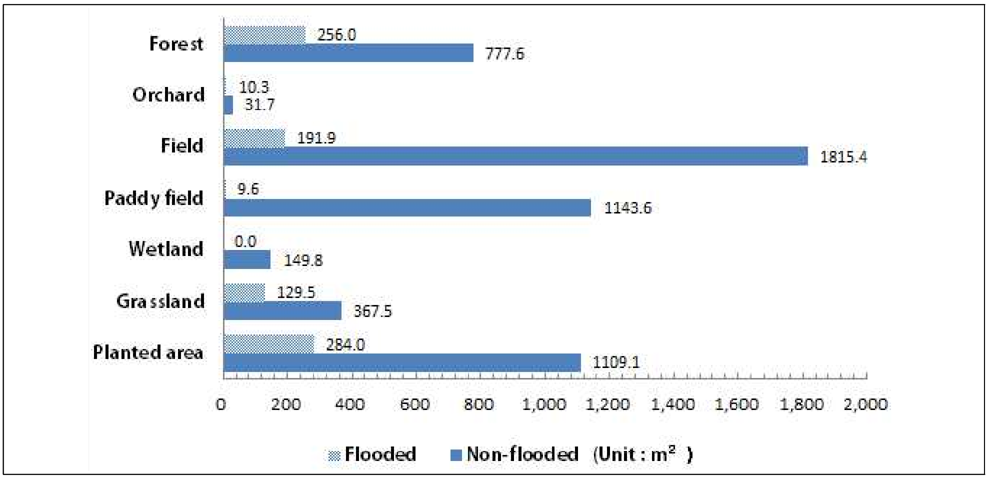


Figure 40. Mean area of green space type within 100-m radius from flooded and non-flooded point (Type 3)

The logistic regression analysis indicated that all variables were significant below 0.05. Among the green space areas, the planted areas, the paddy fields, the fields, and the forests were found to reduce flooding probability if their areas were expanded. The flooding probability in detached housing area and mixed land use area were about 4.5-times and 2.6-times higher than other areas, respectively. The relevant equation is as follows:

$$P(x)_{\text{Type 3}} = -1.377 - 0.012\ \text{Planted area} - 0.025\ \text{Paddy field} - 0.010\ \text{Field} - 0.011\ \text{Forest} + 1.510\ \text{Detached housing area} + 0.963\ \text{Mixed land use area} + 0.083\ \text{TWI}\ (\text{AUC} = 0.729) \tag{7}$$

Using the standardized non-standardization coefficient of each variable, paddy fields were found to contribute to flood control most extensively as shown on Figure 41, followed by fields, planted areas, and forests.

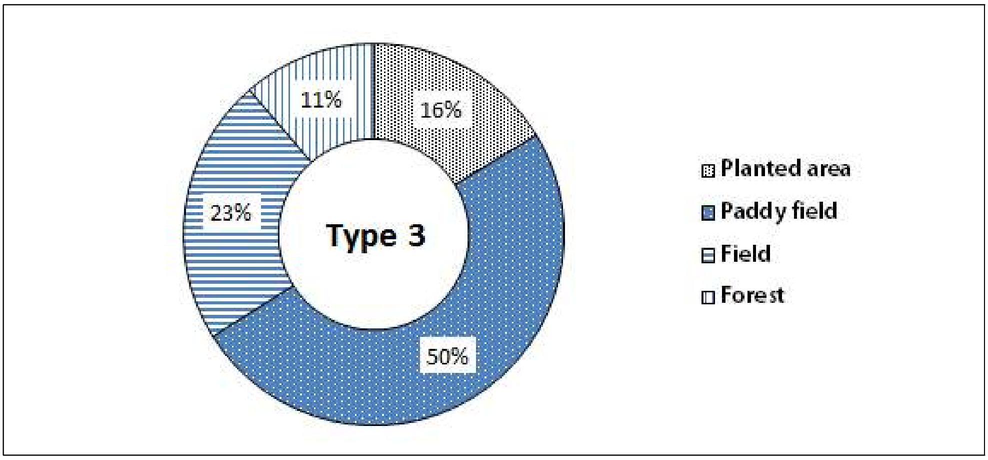


Figure 41. Relative flood control contribution based on the green space type (Type 3)

The paddy fields and the fields in Seoul city are located on gentle slopes mostly neighboring the mountain areas, as shown in Figure 42. This area should be able to store the sediments and any runoff being generated from the mountain. In this case, the area is able to play the role of a rainwater retention basin. In addition, urban parks also play a role in reducing flooding probability, though it is less than that of the paddy fields and fields.

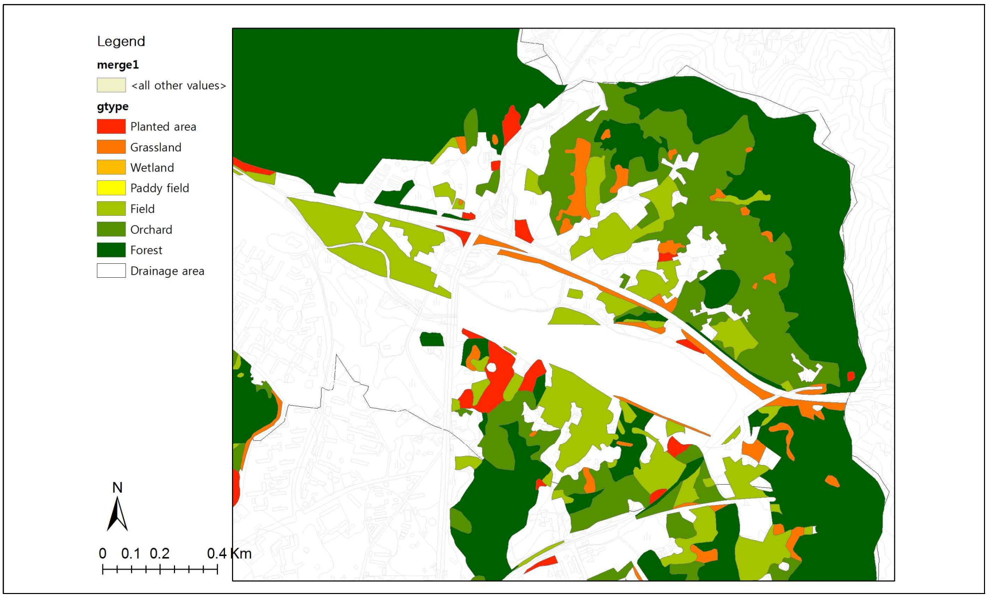


Figure 42. Farmland neighbored with forest (Sinnae1 drainage basin)

Farmland near the forest	Planted area

Figure 43. Green space type in flooded area type 3 : around Namtaeryeong Station (Pictured by author, June 19, 2015)

(5) Flooded area type 4

In a type 4 area, the slope is normal and TWI is low. Field areas account for 38% of the area in a 100-m radius of flooded areas. Followed by this, forest areas represent 29%, planted areas 28%, and grassland 4%. In the case of non-flooded areas of type 4, forest areas were dominant, followed by field areas and planted areas. The average slope of the non-flooded areas was 4.37%, and it was observed that gentle forest was mostly included in this classification as compared with type 2.

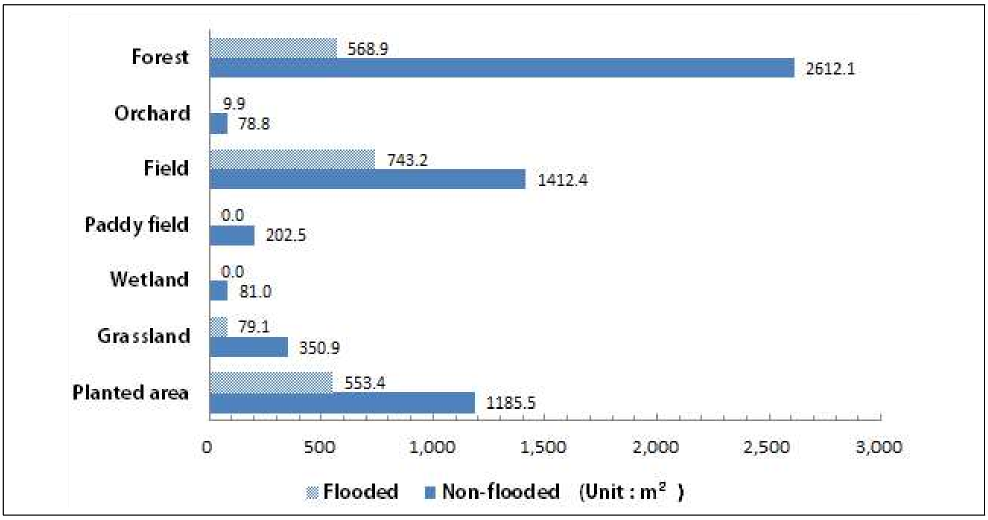


Figure 44. Mean area of green space type within 100-m radius from flooded and non-flooded point (Type 4)

As a result of the logistic regression analysis, planted areas, fields, and forest areas were significant variables that affect flooding. As green space was expanded, the flooding probability was decreased. When the maximum hourly precipitation is heavy and the soil drainage class is poor, the flooding probability is increased. It was forecast that as detached housing areas expand, flooding will take place 2.9 times more frequently than in other flood type areas. This model result is considered to be reliable with an AUC value of 0.76. The relevant equation is as follows:

$$P(x)_{\text{Type } 4} = -1.145 - 0.006 \text{ Planted area} - 0.004 \text{ Field} - 0.014 \text{ Forest} + 0.047 \text{ Maximum hourly precipitation} - 0.514 \text{ Soil drainage} + 1.069 \text{ Detached housing area} \ (AUC = 0.729) \quad (8)$$

With regards to the relative contribution of the variables affecting flood occurrence, forest areas were found to contribute to flood control most extensively as shown on Figure 45, followed by planted areas and then fields. As type 4 areas include hills with gentle slopes as compared to type 2 areas, rainwater infiltration is higher. Fields neighboring suburban hills also affect flood control. As universities and elementary schools were found extensively in type 4 areas, the planted areas associated with these buildings were found to control flooding effectively.

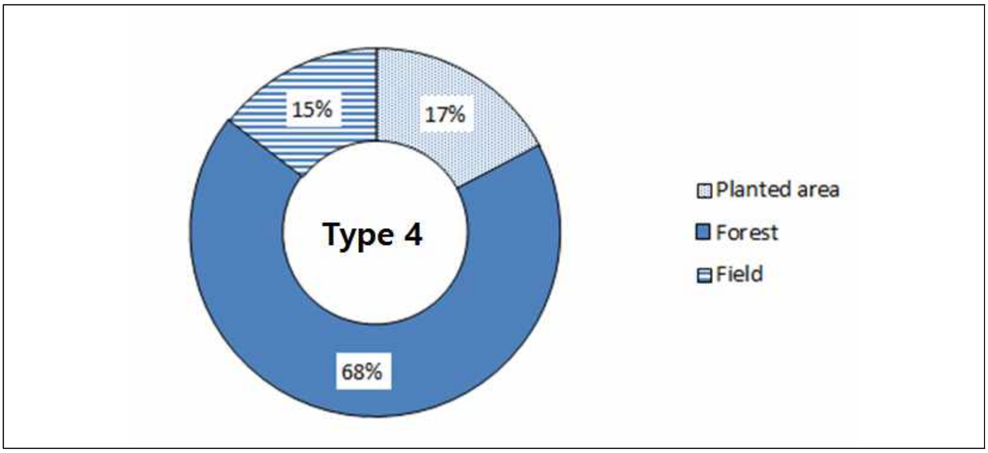


Figure 45. Relative flood control contribution based on the green space type in type 4

Low hill near house	School with low slope

Figure 46. Green space type in flooded area type 4 : Dongjak drainage basin (Pictured by author, June 19, 2015)

3) Flood control effect based on green space pattern

(1) Green space pattern of Seoul city

In order to evaluate the green space pattern features of Seoul city, a landscape pattern analysis based on designation as a drainage basin unit using landscape indexes was performed. Those green space features having significant relationships with flood occurrence, CA, NumP, MPS, and AWMSI indexes, were selected.

The NumP value was 17.47 ea in non-flooded areas and 11.80 ea in flooded areas. As the value increases, non-flooded areas dominate and the number of green space patches tended to increase. The mean value of MPS was 5.70 ha in flooded areas and 9.44 ha in non-flooded areas. As the width of the mean area increases, the probability that the area is designated as non-flooding is high. The CA is a value for absolute green space area size by each drainage basin. As non-flooded areas dominate, the size of the green space areas is large. In case of the AWMSI index, there was no significant difference between the flooded area and the non-flooded area. However, when observing by flood area type, as in the case of type 1 and 2, the index value was analyzed to be high in flooded areas. In type 3 and 4 areas, the index value was larger in non-flooded areas. A comparison of the mean landscape index value for each flood type area is shown in Table 25.

Table 25. Comparison of average green space pattern indexes by each flooded area type

Description		CA (ha)	NumP	MPS	AWMSI
Flooded area type 1		49.40	16.38	3.11	2.71
Flooded area type 2		160.24	12.44	14.06	2.28
Flooded area type 3		48.89	10.04	4.88	2.19
Flooded area type 4		78.80	10.68	8.26	2.09
Total	Flooded	61.57	11.80	5.70	2.29
	Non-flooded	103.83	17.47	9.44	2.30
	Average	82.70	14.64	7.57	2.30

※ CA : Class area (green spae area), Nump : Number of green space patch, MPS : Mean size of patch, AWMSI : Area Weighted Mean Shape Index

From the correlation analysis between each variable and the flooding status for all of Seoul city, when the green space area was large, the number of green space patches was high, and the mean size of a patch was large, the flooding probability was reduced. The analysis of the green space pattern and the results establishing the significant variables are shown in Figure 47.

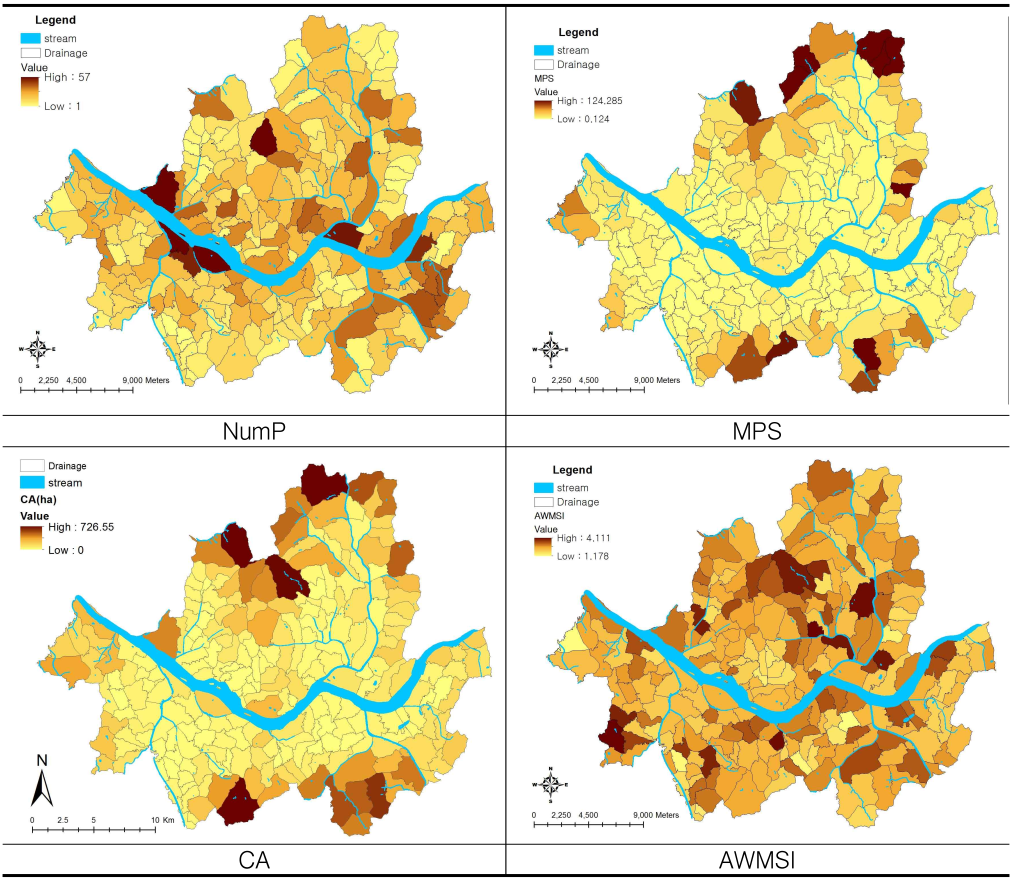


Figure 47. Green space pattern analysis in Seoul through landscape index

(2) Flooded area type 1

A type 1 area is an area where flooding has taken place in a drainage basin with a pump station. Also included in this type are areas where rainwater retention basins are installed near the sides of streams and where pump stations are installed or are upstream of a valley where water flowing from a mountain area is gathered. Seven significant variables were found as a result of the logistic regression analysis. This included the constant term. Variables were significant below the 0.005 level. The physical variables of soil drainage grade (-), TWI (+), mixed area status (+), and detached housing area status (+) were significant, and the landscape variables, CA (-) and AWMSI (+), were significant. Therefore, in type 1 areas, as the green space is enlarged and AWMSI is reduced, there is a positive influence on reducing flooding probability. The model explained 82.9% of the variation and was considered excellent. The relevant equation is as follows:

$$P(x)_{\text{Type } 1} = -3.490 - 0.005\ \text{CA} + 1.220\ \text{AWMSI} + 1.831\ \text{Mixed land use area(1)} + 2.152\ \text{Detached housing area(1)} + 0.08\ \text{TWI} - 0.461\ \text{Soil drainage}\ (\text{AUC} = 0.729) \quad (9)$$

A schematic of a flooded area in a drainage basin having a FRMI, a type 1 area, is shown in Figure 48. It can be seen that the drainage basin where the flood control facility is located is usually at the sides of streams. However, flooding in this area frequently occurred when the capacity of the rainwater retention basin was exceeded by the water flowing down from the mountain area. Green space features in a drainage basin that includes a mountain will include a slope that is steeper than that of the stream area. The green space form is complicated in most cases. As the green space form becomes complicated and has a steep slope, it is judged that flooding is increased where water from higher place is flowing down to lower areas. This is shown in flood type 1 of Seoul city. When the irregularity of green space was high, more flooding occurred.

In addition, as the type 1 area is located around the Hangang River and associated streams, it is affected by streetside green space bordered with streamside grasslands, wetlands, and streams. In the case of the Hangang River and the major streams of Seoul city, it could be seen that the surrounding grassland has many belt-type green spaces and a simple form compared to that of the natural mountain area.

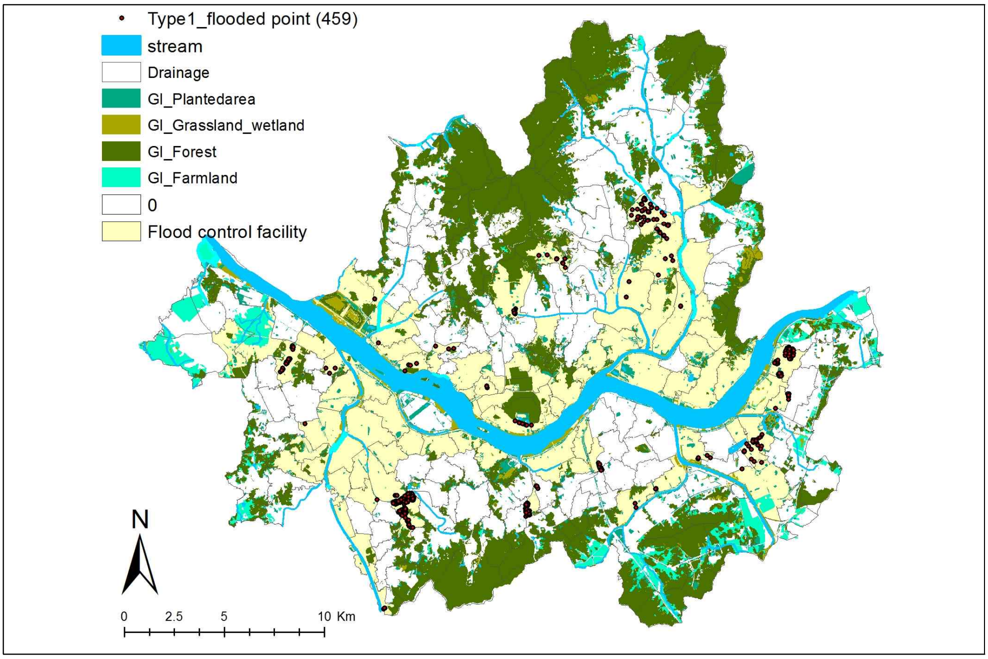


Figure 48. Drainage basin including flood control facilities and flood point (Type 1)

A correlation analysis between the green space pattern and the flood control characteristics of the four flood type areas was conducted. This analyzed the AWMSI index, that is, increases in the irregularity of the green space form, and changes in flooding probability. In this analysis, the green space area was fixed at 80 ha, the total average for Seoul city. It was divided by the mean value, the minimum value, and the maximum value of other variables

(Figure 49). Depending on the change in each variable, in terms of AWMSI distribution, flooding probability was increased from 1.24% when the green space area was set at 80 ha to a maximum of 89.25% when the AWMSI was at its highest level of 3.55.

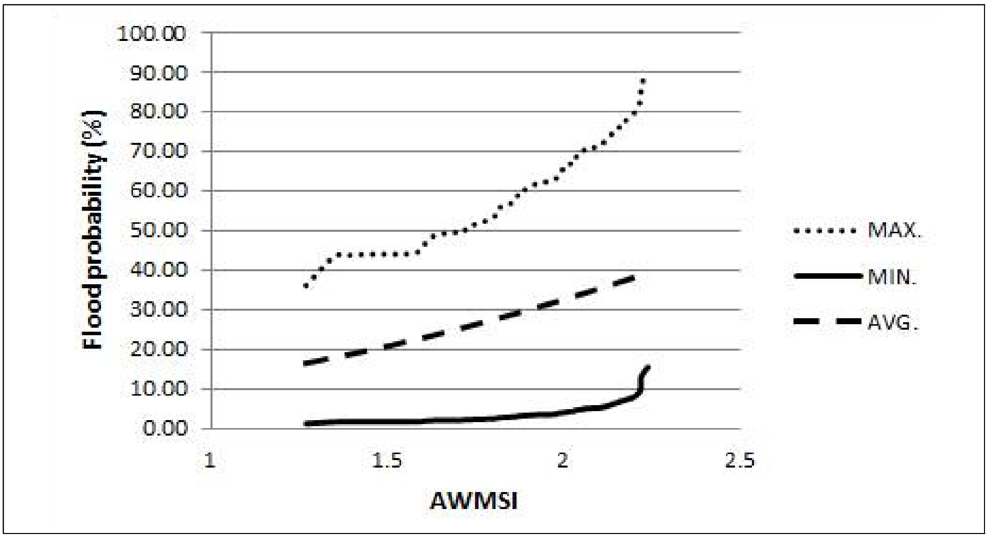


Figure 49. Flooding probability based on AWMSI (Type 1)

(3) Flood type 2

Many forest areas where there are steep slopes and smooth drainage are included in flood type 2. Compared with the other flood type areas, the green space area per drainage basin is over 160 ha in both the flooded and non-flooded areas. Four variables were found to be significant, including the constant. The physical environment variable of maximum hourly precipitation (+) and the landscape variables of CA (-) and AWMSI (+) were significant. In a type 2 area, as the green space area is widened and AWMSI is reduced, there is a positive effect for flooding probability reduction. The model explained

75.9% of the variation, which was considered a good fit. The relevant equation is as follows:

$$P(x)_{\text{Type 2}} = -3.982 - 0.002CA + 0.066\text{Maximum hourly precipitation} + 0.364AWMSI \ (AUC = 0.759) \quad (10)$$

The value for CA (total green space area) was set at 80 ha and other values were input so that the flooding probability in type 2 areas could be represented as a maximum or a minimum. The AWMSI index was increased and flooding probability value was estimated as shown in Figure 50. As in type 1 flood areas, areas having steep slopes are dominant, and the more the shape index of the green space area is increased, its edge length is extended. When there is an increase in the locations where water can flow from high places to meet with water in lower places, the flooding probability is increased.

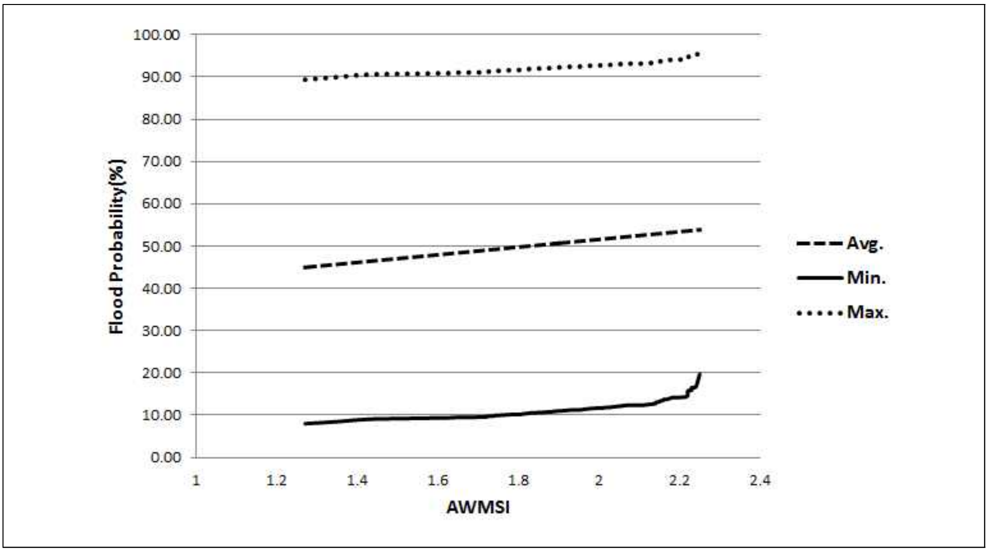


Figure 50. Flooding probability based on AWMSI (Type 2)

(4) Flooded area type 3

The value for NumP in the type 3 flood area is 4 ea. This is the smallest value among the four flood type areas. The CA is 48.89 ha and the MPS is 4.88 ha, making this the smallest area compared to the other three types. Compared with the other flood type areas, green space area is relatively insufficient; and as it is limited, fragmentation of green space is not developed and the size of the average patch is also small. In summary, the green space characteristic variables of the type 3 area are similar to those of a flood prone area, and 961 areas with the highest number of flood occurrences among the four types are included in this type.

The significant variables are shown in Equation (10). In type 3 areas, the flooding probability for detached housing areas is higher than that for non-detached housing areas by 4.3 times. It is higher than for mixed areas by 2.17 times and green space areas by 0.28 times. With higher maximum hourly precipitation, the more flooding takes place.

Type 3 is an area where the slope is very gentle, the TWI is high, and the water is often stagnant. The flood control efficiency of this area is increased greatly with increases in green space. Therefore, if the total green space area of the drainage basin is set as 80 ha, the number of green space patches is sufficient, the mean green space area is large, the mean patch size is large, and the irregularity of the green space is high, flooding probability should be reduced. This area is quite different from the type 1 and 2 areas. Green space is located in areas with gentle topography. As irregular forms of green space absorb water and the water does not flow downwards, the length of the edge is extended and flooding probability should be reduced. The relevant equation is as follows:

$$P(x)_{\text{Type 3}} = -0.963 - 0.001\ \mathbf{CA} - 0.414\ \mathbf{AWMSI} - 0.062\ \mathbf{NumP} - 0.063\ \mathbf{MPS} + 0.053\ \mathbf{Maximum\ hourly\ precipitation} + 1.473\ \mathbf{Detached\ housing\ area(1)} + 0.778\ \mathbf{Mixed\ land\ use\ area(1)} - 1.276\ \mathbf{Presence\ of\ green\ space}\ (AUC = 0.824) \tag{11}$$

The result of the analysis by fixing each variable in order to analyze how flooding probability is changed when the variables of green space form (AWMSI), the number of green space patches (NumP), and the mean green space area (MPS) indices is changed is shown in Figure 51-53. Based on the mean values, when green space area (CA) is set at 80 ha, if the number of patches is increased by its fragmentation, flooding probability is reduced. If the area and the number of green space patches stay the same, but the size of one patch is increased, flooding probability is decreased. If green space area, the number of patches, and the mean patch size stay the same, increased patch form complexity contributes to a reduction in flooding.

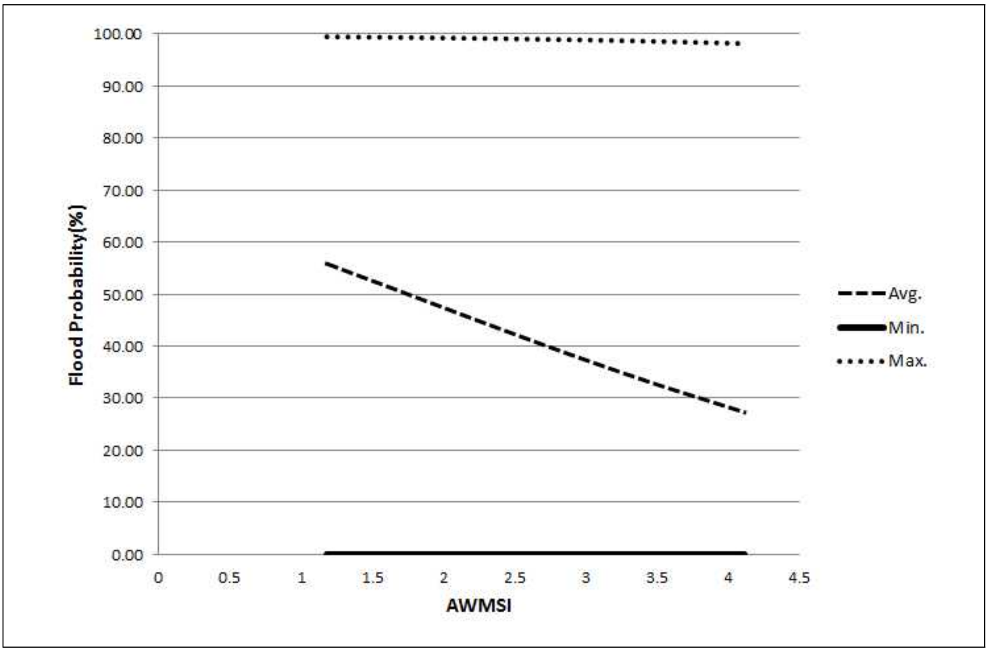


Figure 51. Flooding probability based on AWMSI

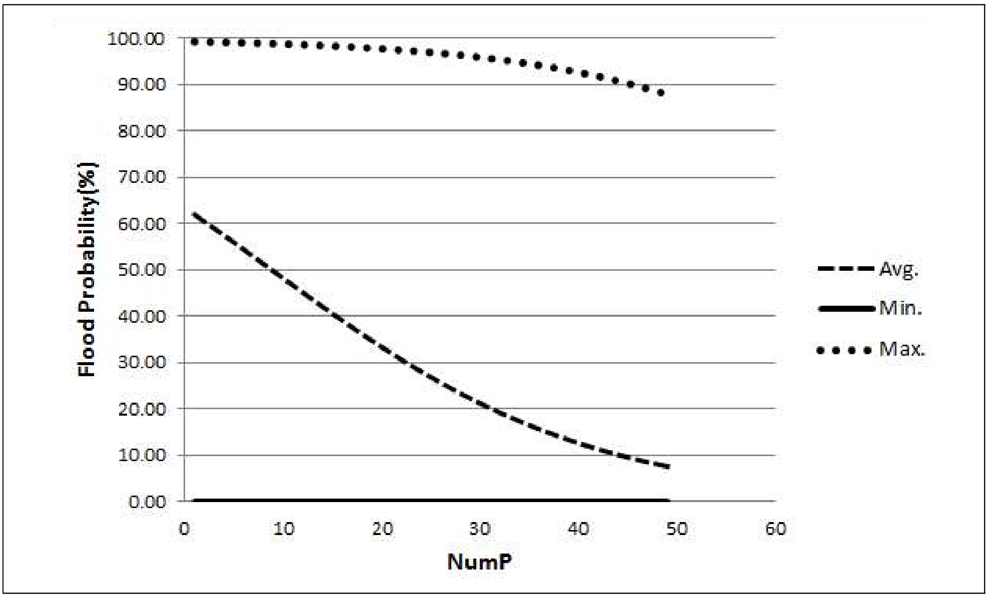


Figure 52. Flooding probability based on NumP

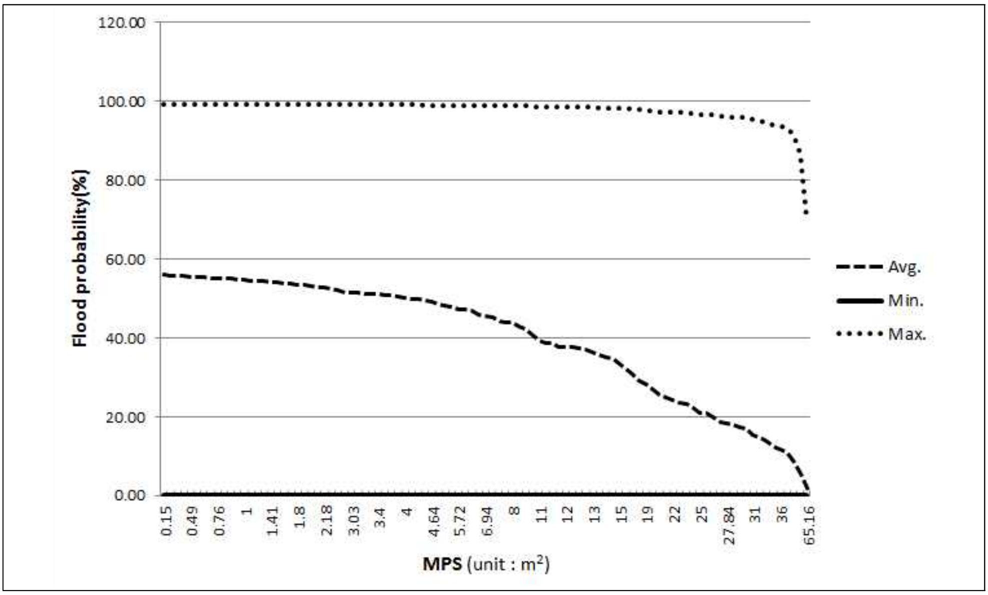


Figure 53 Flooding probability based on MPS

(5) Flood type 4

The NumP value of the flooded areas in type 4 is 10.68, which is lower than the average of the total flooded area of Seoul city. The CA value is 78.80 ha, which is higher than the average of the total area. There were seven significant variables, including the constant. For the environment variables, a higher soil drainage grade is favorable, the maximum hourly precipitation is a minor variable, and the presence of detached housing areas has a limited effect. When CA and NumP increased, flooding is decreased. The relevant equation is as follows :

$$P(x)_{\text{Type 4}} = -0.696 - 0.002\ \text{CA} - 0.037\text{NumP} + 0.047\ \text{Maximum hourly precipitation} + 0.952\ \text{Detached housing area(1)} - 0.488\ \text{Soil drainage} - 1.080\ \text{Presence of green space(1)}\ (\text{AUC} = 0.782) \quad (12)$$

When maximum hourly precipitation reaches its peak, flooding probability is predicted to be 90%, even if the number of green space patches is increased.

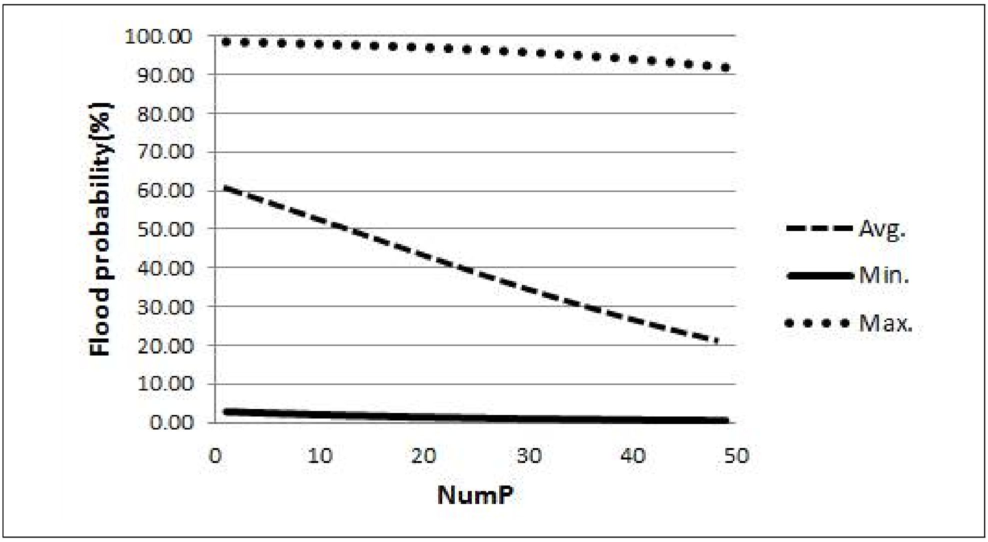


Figure 54. Flooding probability based on NumP (Type 4)

(6) Comparison analysis on flooding probability based on green space pattern for each type

By analyzing the green space pattern for each type of flood area, various relationships can be observed. The green space pattern analysis using indexes of CA, NumP, MPS, and AWMSI affecting flooding in Seoul city was conducted through a logistic regression analysis.

In the case of flood type areas 1, 2 and 3, AWMSI, an index that represents the complexity of green space pattern, was significant, but this index affected the areas differently. In type 1 and 2, when the complexity of green space pattern was high, flooding probability was increased. In type 3, when the complexity of the green space pattern was low, flooding probability was increased. This phenomenon could be explained by differences in regional features. In the case of type 1 and 2 areas, the green space area that may affect flooding is mainly located at a slope. In this case, if the edge length is extended due to a complicated green space pattern, the surface area of the flowing water is widened and flood damage may be further increased. Conversely, in a case where green space area is formed in a lowland having a gentle slope, as the edge length through which water could be infiltrated is extended, flooding may be decreased. In the case of a type 1 area having gentle regional features compared with a type 2 area with steep slopes, as the complexity of green space pattern was increased, flooding probability was further increased (Figure 55).

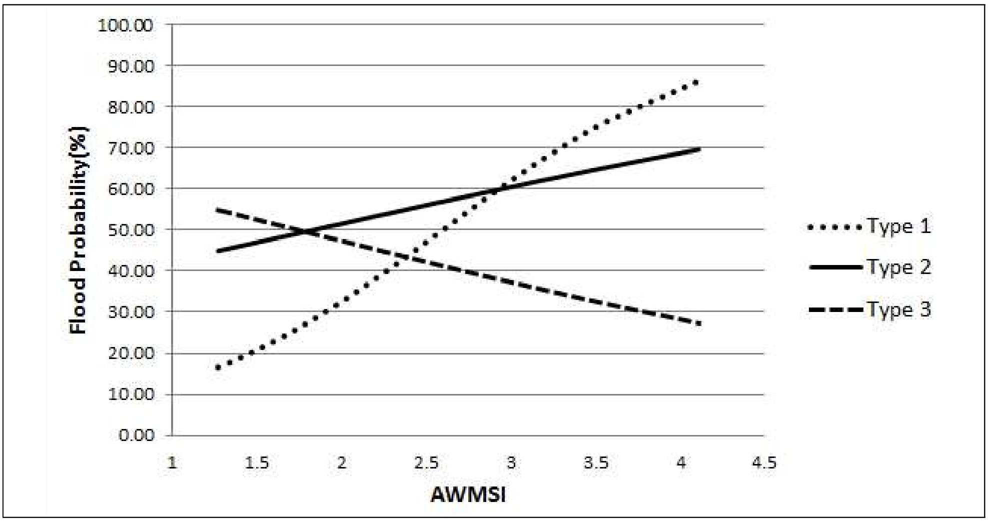


Figure 55. Comparative analysis on flooding probability based on AWMSI change (Type1, Type2, Type3)

In type 3 and 4 flood type areas, the NumP index affects flood control. In both of these types, as the green space patches were increased, flooding probability was decreased. As was analyzed previously, the effect of green space area is significant in areas with gentle slopes. The absolute value of the gradient in flood type 3 areas shows that the gentle slope area is dominant. In flood type 3 areas rather than in type 4 areas, the change in flooding probability is significantly affected by changes in small units of green space patches (Figure 56). In other words, when the total green space area is the same, in order to reduce the flooding probability by 50%, a type 3 area is required to be more fragmented than is a type 4 flood area.

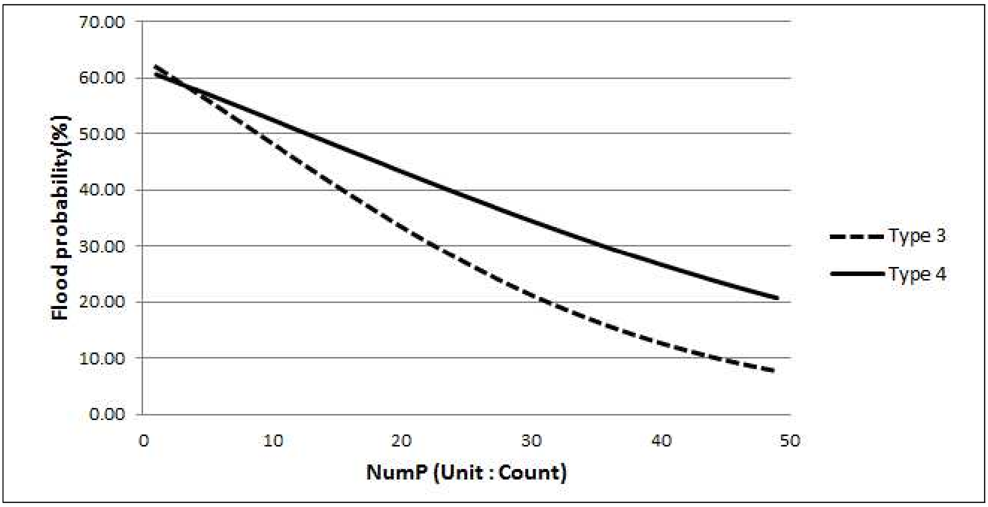


Figure 56. Comparative analysis on flooding probability based on Nump (Type 3, Type 4)

Ryu et al. (2014) analyzed the runoff difference between one big urban park having the same area as several small parks by using Hec-HMS and SWMM. As a result of the hydrological analysis, it was revealed that several small parks rather than one big park are more effective for runoff reduction. Han et al. (2012) reported that by arranging rainwater retention basins in a dispersed form, flooding is reduced as it exerts a positive effect on peak runoff reduction. In addition, Cho et al. (2014) suggested that in order to prepare for local flooding where installation of a large-scale retention basin and rainwater pumping station at a basin estuary is difficult, the installation of multiple dispersion type small-scale retention basins is advantageous in terms of efficiency and/or economics. The retention basin is not a facility for creating a natural water circulation system, but it is considered to play a role in runoff reduction as does a green space area, which has the function of water infiltration and storage.

Under this context, if the area is the same, there is a case for arranging several segmented green space patches rather than one large one. As rainwater could be retained by dividing it in to smaller areas, a more effective result could be obtained. In addition, the installation of green space areas where a permeable lake is included in a dispersed form may produce not only flood control, but it could also affect the sustainable development potential of an urban area on top of the aesthetic, social, and environmental value (Zhou et al., 2013).

Furthermore, it could be seen that the green space area pattern is an element affecting concentration time, which is an important element for estimating runoff. Delaying water flow depending on the size, the distribution, and the shape of the green space areas is effective for slowing down the peak concentration time.

4) Summary

Results deduced in order to analyze the flood control contribution based on green space area, type, and pattern are summarized as shown on following Table 26.

Table 26. Summary on deducing flooding probability model considering green space features by flooded area type

Description		Variable	Type 1	Type 2	Type 3	Type 4
1	Physical environment	Slope		(-)***		
		TWI			(+)***	
		Soil drainage	(-)***			(-)***
		Maximum hourly rainfall		(+)***		(+)***
		Detached house	(+)***		(+)***	
		Mixed land use area	(+)***			
	Green space area	Green space area within 100-m radius	(-)***	(-)***	(-)***	(-)***
	AUC		0.786	0.914	0.702	0.756
2	Physical environment	Slope		(-)***		
		TWI	(+)***		(+)***	
		Soil drainage	(-)***			(-)***
		Maximum hourly rainfall		(+)***		(+)***
		Detached house			(+)***	(+)***
		Mixed land use area	(+)***		(+)***	
	Green space type	Planted area	(-)***		(-)***	(-)***
		Grassland	(-)***			
		Wetland				
		Paddy field			(-)***	
		Field			(-)***	(-)***
		Orchard				
		Forest	(-)***	(-)***	(-)***	(-)***
	AUC		0.730	0.919	0.729	0.764
3	Physical environment	Slope				
		TWI	(+)***			
		Soil drainage	(-)***			(-)***
		Maximum hourly rainfall		(+)***	(+)***	(+)***
		Detached house	(+)***		(+)***	(+)***
		Mixed land use area	(+)***		(+)***	
		Green space status			(-)***	(-)***
	Green space pattern	CA	(-)***	(-)**	(-)*	(-)**
		NumP			(-)***	(-)***
		MPS			(-)***	
		AWMSI	(+)***	(+)*	(-)***	
	AUC		0.829	0.759	0.824	0.782

*: p-value<0.2, **: p-value<0.05, ***: p-value<0.01

4. Application of research results

1) Urban green space planning for flood control

The threat to social infrastructure, human life, and property from flooding is increasing rapidly. To protect urban areas against disaster, flood control and adaptation plans must be developed and implemented, and new land use planning should identify areas of high and low flood potential. In recent years, the necessity for strong urban disaster planning in Korea has been increasingly emphasized (Korea Planning Association, 2014). In Ministry of Land, Infrastructure and Transport (MOLIT), an improved system for extensively utilizing disaster prevention zones for disaster control is being promoted (Shin et al., 2015). In disaster prevention zones, the construction of buildings that hinder disaster prevention is prohibited; however, as this restricts property rights there is public opposition. However, the results of this study showed that flood control can also be effectively achieved using green space areas, the introduction of which would actually improve the urban environment.

The application of diversified urban planning elements, including natural flood risk management and blue-green infrastructure, as well as existing physical sewer line systems, is required to ensure urban management with high resilience. Impervious land cover, such as asphalt and roofs in urban areas, is a key factor that affects flooding, and flood control plans that incorporate green spaces should be created. However, comprehensive studies of green spaces are required to understand how their implementation would affect water circulation in regional drainage basins.

Significant investment and effort is required to prevent urban flooding and the detailed guidelines relating to urban planning and design should highlight the positive role of urban green spaces for flood control. For example, introducing dispersion type green spaces with a water circulation function simultaneously reduces impervious area and runoff. By introducing dispersed green spaces that not only follow existing sewer line systems, but also include focused point sources, the small-scale dispersion of water circulation management systems can be applied. In addition, green space shapes should be designed to maximize flood control. For example, when a green space area is located on a steep slope, short edge lengths are most advantageous for flood control; however, for gentle slopes, longer edges and more complicated shapes are advantageous for flood control.

Table 27 contains a summary of flood control strategies based on features of each flood type. Flood probability is highest for Type 3, which includes most of the flood prone areas. However, the flood control effect of green space areas is significant. Usually, large-scale rainwater retaining basins are preferentially introduced to reduce flood risk; however, the results of this study show that the creation of green space areas would be equally as effective. Type 3 areas have a concave topography that allows for the collection and storage of water; therefore, topographic features impact on the flood control effect.

Table 27. Flood mitigation strategies with green space for each flood type

<table>
<tr><th>Type</th><th colspan="2">Characteristics of type</th><th>Flood mitigation strategies with green space</th></tr>
<tr><td rowspan="4">Type 1</td><td>Drainage</td><td>2.61</td><td rowspan="4">· Rainwater retaining capacity is required to be increased through expansion of facility capacity, maintenance or introduction of sufficient green space.
· Riverside and streamside is suggested changing grassland</td></tr>
<tr><td>Slope (%)</td><td>1.61</td></tr>
<tr><td>TWI</td><td>11.95</td></tr>
<tr><td colspan="2">· Flood control facility is located
· Flood control contribution of grassland is relatively excellent.</td></tr>
<tr><td rowspan="4">Type 2</td><td>Drainage</td><td>3.48</td><td rowspan="4">· Flood control contribution of forest is relatively excellent.
· When maximum hourly precipitation is increased, installation of rainwater retaining basin is required in order to prevent landslide.
· In case that mountain edge is long and complicated, flooding risk is high and so, installation of rainwater retaining basin shall be considered preferentially. Land use of low damage occurrence is suggested.</td></tr>
<tr><td>Slope (%)</td><td>14.06</td></tr>
<tr><td>TWI</td><td>7.38</td></tr>
<tr><td colspan="2">· Bordered with forest
· Water is prone to flowing without stagnation
· Flood control effect of green space area is relatively low.</td></tr>
<tr><td rowspan="4">Type 3</td><td>Drainage</td><td>2.32</td><td rowspan="4">· Introduction of urban agriculture could be suggested.
· Green space design in which edge has long and complicated shape at gentle area is suggested for ensuring smooth water absorption.
· Installing green space area in a dispersed form is very effective for flood control compared with other flood type (such as pocket park).
· As an area in which many roads are included, increasing roadside planting was emphasized.
· As underground building ratio is high, building restriction and maintenance are required for preventing inundation of underground space. Green space creation plan in detached housing area is required.</td></tr>
<tr><td>Slope (%)</td><td>1.29</td></tr>
<tr><td>TWI</td><td>13.31</td></tr>
<tr><td colspan="2">· Many detached house, mixed land use area, road are included
· Water is prone to be gathered.
· Flood control effect of green space area is exceptionally high.
· Flood control contribution of paddy field, field is high</td></tr>
<tr><td rowspan="4">Type 4</td><td>Drainage</td><td>2.58</td><td rowspan="4">· As type 4 is located in connection to type 3, it needs to establish flood control management to flood reduction of type 3 thoroughly.
· Installing green space area in a dispersed form is effective for flood control. Compared with type 3, its efficiency is low.</td></tr>
<tr><td>Slope (%)</td><td>3.91</td></tr>
<tr><td>TWI</td><td>5.98</td></tr>
<tr><td colspan="2">· Medium features and flood control effect of green space between type 2 and 3
· Flood control contribution of forest, planted area is high</td></tr>
</table>

2) Integrated design of urban green space area and LID technique

In four flooded area types, the more green space area was increased, flooding probability showed a tendency of being decreased and depending on features by each type, difference of sensitivity for probability change was represented. In addition, depending on green space type and distribution, flooding probability showed a tendency of being decreased and green space variable was revealed to have close relation with flooding as much as topographic variable such as slope, TWI and soil drainage.

In this study, in the range of urban green space area, flood control method considering low impact development technique or artificial retaining basin being installed in artificial ground was not considered. However, like the result of this study, it may play a considerable role in flood control just based on change of area adjustment and arrangement form of existing natural green space area considering regional features having flooding possibility.

In case of Seoul, as green space area of park is 177.78 km^2 that accounts for 29.37 % of Seoul total area, if this area should be utilized for improving regional disaster prevention performance, it is expected that an disaster control, adaptation effect over large-scaled disaster prevention facility could be demonstrated. Therefore, a new strategy of inducing disaster prevention role by adding runoff control function to park green space including bio retention basin is required as well.

Response strategy to urban flood in advanced countries including

Germany, the USA, Japan has been changed and keeping pace with this trend, in Korea also, a new urban flood response strategy is suggested based on 'Natural disaster prevention act' under the jurisdiction of Ministry of Public Safety and Security, 'Law of national land plan and use', 'Regulation for decision structure and installation standard of urban planned facility', 'Law of urban park and green space area' under jurisdiction of MOLIT. Among these, according to installation and management standard of rainwater retaining facility (relevant to Article 13) of enforcement regulation [Attachment 6], 'Law of urban park and green space area', regarding green space area in area of rainwater retaining facility, it specifies that permanent retaining facility should be over 60% and temporary retaining facility over 40%. Like this, as relevant law and regulation by which green space area could be introduced in urban area are increased. When green space area is introduced, green space planning could be established through quantitative and scientific approach based on flooding probability analysis formula according to green space area and arrangement features being suggested in the result of this study.

3) Suggestions for modifying the runoff coefficient of green space

As the runoff coefficient is affected by the rainfall intensity, the concentration time, the basin size, the soil type, the land use, the preceding rainfall condition, the return period, and the ground surface slope, a great deal of experience and theoretical knowledge are required to estimate the runoff coefficient. The runoff coefficient is usually used based on a brief table, but there is a considerable difference in the runoff coefficient value depending on variables being considered at the time of estimating runoff by each institution.

According to the results in this study, when the land cover is a green space area or it is densely distributed (fragmented) in the surroundings, flooding probability is low. The reason is that flooding is reduced by rainwater infiltration or storage in the green space area. However, the runoff coefficient of the green space area was overestimated by underestimating the flood control effect of green space area at the time of sewer line design. Since a large sewer line was installed by overestimating the flood volume due to a large runoff coefficient, flooding was reduced.

In the case of forests, the runoff coefficient varied depending on the reference year as shown in Table 28. The standard for runoff coefficient for domestic stream design before 1993 was 0.75-0.8. In 2000, it was changed to 0.05-0.25; and in 2002, it was changed to 0.3-0.8. This was due to the variation in the runoff coefficient for the different reference years, and design personnel experienced a lot of confusion. In addition, as sewer lines were designed by using the continuously changing runoff coefficient, the flood volume in the basin where the urban forest was located was not identified correctly. If the runoff coefficient of the forest is overestimated, flooding does not take place in that basin, as sewer line capacity was over-designed. However, a problem with overinvestment emerged.

As in the results of this study, the forest acts as a cause of flooding in the surrounding area if hourly precipitation is increased. However, for the overall area of Seoul city, the mountain area reduced flooding. In particular, in case of type 2 and 4 areas, the mountain area was selected as a significant variable for flooding. The more the forest area was widened, the flooding probability was reduced. In the type 2 area, the most influential flood variable was the slope followed by the mountain area and the maximum hourly precipitation, which contributed to flooding at a similar rate. In the type 4 area, the maximum hourly precipitation was the most influential flood variable, followed by the forest contribution to flooding. In a forest, the rainwater infiltration ratio may be moderate if it has a gentle slope. However, when it reduces runoff by sufficient infiltration, a value of 0.5-0.7, similar to the runoff coefficient in an urbanized area, is considered to be overestimated.

Table 28. Runoff coefficient of forest in each standards

Standard	Year	Forest runoff coefficient	
Stream design standard	1993	0.75-0.80	
	2000	0.05-0.25	
	2002	Steep slope	0.40-0.80
		Gentle slope	0.30-0.70
	2009	Steep slope	0.40-0.80
		Gentle slope	0.30-0.70
Basic planning change for sewerage arrangement in seoul	2009	Gentle slope park	0.10-0.25
		Gentle slope	0.50-0.75
		Steep slope	0.75-0.90
Sewerage facility standard	1998	Park with grassland and tree	0.05-0.25
		Gentle slope	0.20-0.40
		Steep slope	0.40-0.60
	2011	Planted area	0.10-0.25
		Green space and open space	0.50-0.75

As in the forest areas, the farming area runoff coefficient value is different depending on each standard (Table 29). According to the 'basic planning change for sewerage arrangement of Seoul city (2009)', in the case of paddy fields, a runoff coefficient value of 0.7-0.8 was determined. However, according to the sewerage facility standard (2011), its value is 0.1-0.25. Based on the results of this study, it was revealed that paddy fields most significantly contributed to a reduced flooding probability in type 3 areas. This means that around paddy fields in a type 3 area, the flooding probability is low. As a paddy field is composed of clay, infiltration is marginal; but it could prevent runoff, as it is able to retain water. However, according to the basic planning change for sewerage arrangements (2009) in Seoul city, a value over 0.7 was presented as the runoff coefficient for paddy fields. The same trend was shown in that the infiltration capacity of paddy fields is weaker than for fields, but the absolute value is overestimated.

In addition, as was clarified in this study, as the flood control effect of green space area differs depending on regional features, a different runoff coefficient value is required to be presented depending on specific features for the location even though the areas of the paddy field and the field are the same.

Table 29. Runoff coefficient of farmland in each standards

<table>
<tr><th>Description</th><th colspan="3">Land use</th><th>Runoff coefficient</th></tr>
<tr><td rowspan="4">Stream design principle (2009)</td><td rowspan="4">Farmland</td><td rowspan="2">Sandy soil</td><td>Planted</td><td>0.30-0.60</td></tr>
<tr><td>Not planted</td><td>0.20-0.50</td></tr>
<tr><td rowspan="2">Baryta</td><td>Planted</td><td>0.20-0.40</td></tr>
<tr><td>Not planted</td><td>0.10-0.25</td></tr>
<tr><td rowspan="2">Basic planning change for sewerage arrangement of Seoul city (2009)</td><td colspan="3">Paddy field</td><td>0.70-0.80</td></tr>
<tr><td colspan="3">Field</td><td>0.45-0.60</td></tr>
<tr><td>Sewerage facility standard (2011)</td><td colspan="3">Farmland</td><td>0.10-0.25</td></tr>
</table>

When higher values of runoff coefficient are applied as compared to the actual values, the targeted sewer lines that are calculated to be of insufficient capacity are overestimated, and overinvestment may take place. In addition, sewer lines may be expanded unnecessarily in areas where there is no problem related to bad drainage or local flooding. A careful approach is required when applying the runoff coefficient. In particular, the runoff coefficient of green space areas where differences exist depending on regional features should be reflected by matching it with domestic reality. The features of an area should be fully analyzed when a sewer line is installed in order to estimate flood volume.

4) Integrated green space plan procedure for urban flood control

The result deduced in this study could be used as a base of green space introduction and planning at the time of implementing diversified researches and projects including redevelopment of existing town and complex construction as well as new town planning and through a procedure as shown on following Figure 57, it could be applied at the time of green space planning for flood controlin urban area.

When project site is selected in Seoul city, how target area to be planned through flood vulnerability analysis is vulnerable to flood is analyzed. If site is determined to be an area vulnerable to flood through an analysis, to what type of flood such area is belonged is determined based on classification function and regional feature variable after establishing a flood control goal. Afterwards, through a formula deduced by each flood type in this study, ‘green space area and type’ having the highest contribution for flood reduction is found and then, combination planning scenarios for achieving a flood control goal is deduced. Finally, optimized 'green space distribution' fit for features of target area is determined. Through this, not only large-scaled urban planning but also optimal green space arrangement plan for flood control could be suggested at complex design stage and prototype depending on features by each type could be developed.

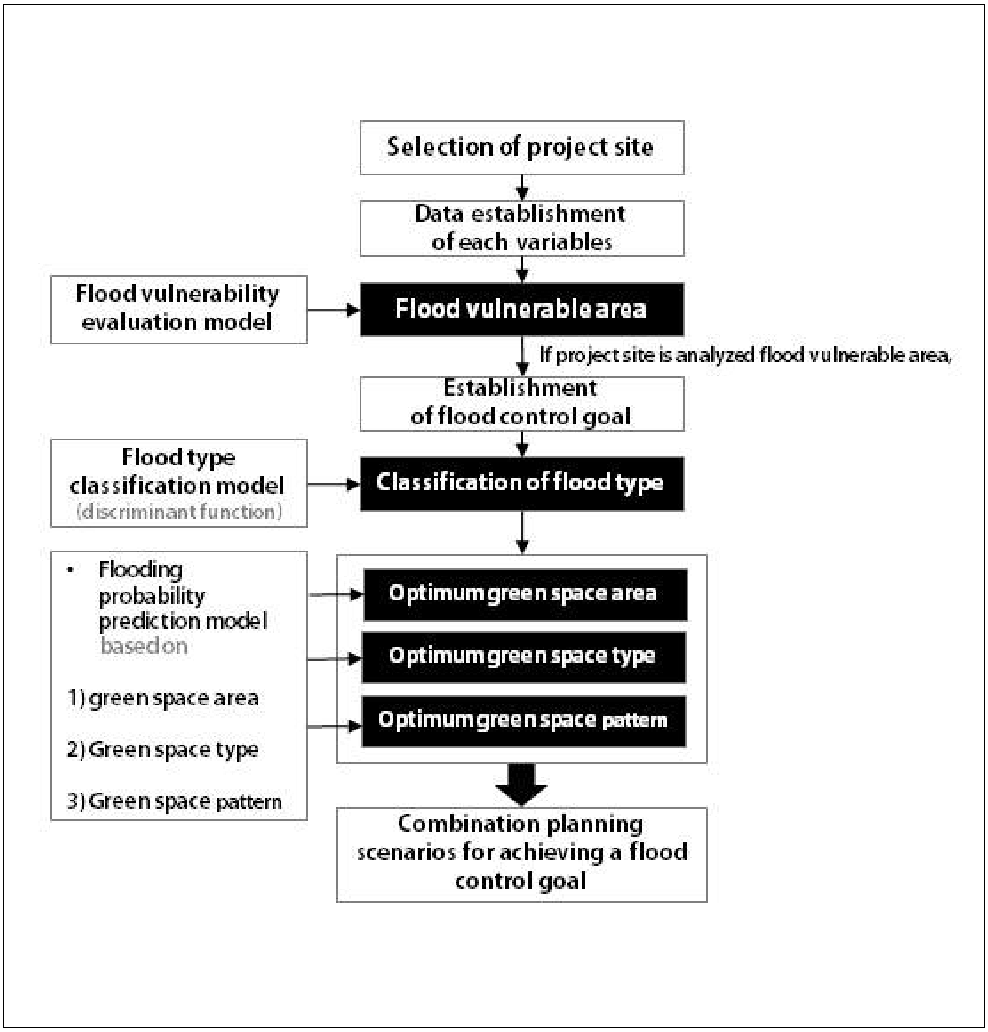


Figure 57. Procedure of Green space planning for flood reduction using the results in this study

V Conclusions

1. Major result of the study and its significance

In this study, how flooding probability is changed by green space area, type and patterns was analyzed statistically by each flood type after analyzing flood vulnerable area of Seoul city and dividing flooded areas into 4 types by using spatial statistics. Through this, a quantitative guideline as to in what way urban green space area would be spatially planned for establishing sustainable and basic countermeasure for urban flood is suggested.

Summary of the research result is as follows. First, a model that could evaluate urban flood vulnerable areas using MaxEnt by targeting total area of Seoul city was developed. Variables being selected for model simulation were physical environment. climate exposure, green space environment, flood control facility variables. The model was simulated by extracting random point for 1000 times to consider uncertainty. Flood was not taken place at all in 43 drainage basins among total 239 drainage and flood vulnerable area was represented as Seocho4, Gildong, Shinwol3, Bangbae1, Hwagok2 drainage basin.

Second, flood type was divided into 4 types based on features of flooded area by using multivariate statistic analysis. Type 1 has flood control facility in drainage basin and a part of urban area that is located around Han River and major streams and bordered with mountain areas was represented as flooded area. Its slope is more gentle than total average slope of Seoul city and TWI is second highest and residential, commercial mixed area ratio was most dominantly represented. In case of type 2, its slope is steep, TWI is low and drainage is the best. Compared with other types, green space ratio is also high and it could be seen that this area is bordered with mountains having steep slope and it has a regional features of flood resistance as water is flowing down without stagnation. In case of type 3, its slope is very gentle, TWI is the highest and drainage is the worst among 4 types and contrary to type 2, this area has a regional features that water is apt to be stagnated and gathered. A ratio of detached housing area and mixed land use area is high and over 50% of roads are located at this area. Type 4 has a medium features of type 2 and 3 and its slope is fair and TWI is relatively low. This area experienced worst damage by maximum hourly precipitation.

Third, by using logistic regression analysis, difference of flooding probability change based on green space area, type, pattern features by each flood type was comparatively analyzed. It could be realized that green space area is more effective for decreasing flooding probability in type 3 area where slope is gentle and TWI is high rather than type 2 and this result is coincided with that of several studies reporting that at the time of creating urban green space area, making garden in concave form is more effective for decreasing flooding probability. In area with a steep slope like the case of type 2 and 4, as maximum hourly precipitation variable affects flooding probability significantly, flooding probability in this area was represented to be high however extensively green space area should be increased. Reversely, it was analyzed that topographic features rather than maximum hourly precipitation affects flooding more extensively in flood type 3. Besides, a result of threshold in which an effect is maximized when green space area is introduced for flood control through deduced formula and green space area required for achieving flooding probability goal was deduced.

By dividing green space type into planted area, grassland, wetland, paddy field, field, orchard and forest considering CN value, how green space area contributes to flood control by each flood type was analyzed. In flood type 1, grassland showed the highest contribution and then followed by forest, planted area. In flood type 2, as a variable contributing to flood control, only forest was analyzed and in flood type 3, contribution was analyzed in the order of paddy field, field, planted area and forest. As most of farming land of Seoul is located at gentle space bordered with mountain area, it could be seen that it plays a role of natural rainwater retaining basin having capacity of confining water of farming land. Type 4 represents to exert influence on flood control in the order of forest, planted area, field.

In case of green space pattern of flood type 1 and 2, AWMSI was represented as significant variable and it could be seen that the more complexity is increased, flooding probability is increased accordingly. As type 3 is an area where flood control efficiency of green space area is high, NumP, MPS, AWMSI, CA that are indices for green space distribution were selected as significant variables. It could be realized that the more NumP, MPS and AWMSI are high, it exerts a positive influence on flooding probability reduction when green space area is same. In type 4, it was analyzed that the more NumP is increased, it exerts positive effect on flooding.

According to this study, green space in urban area shows partial difference by each flooding type but it was analyzed to have a flood control function corresponding to topographic factors such as slope, TWI, drainage grade. Therefore, in case of introducing green space area in an area where green space efficiency is maximized, far more flood control effect could be represented. Significance of this study is that a result was deduced by quantitatively analyzing flooding probability based on features of green space area, type, pattern by each regional features based on statistics. In addition, by performing not only district scale but also landscape scale, multi-scale analysis results for green space planning was deduced.

In the case of artificial FRMI, such as rainwater retention basins, their value may decrease over time, but increasing the green space area is an eco-friendly solution that will benefit humans and nature over a long period of time. The role of existing green spaces is often limited to the production of ecological benefits for wildlife and aesthetically-pleasing landscapes for human residents, but functionally, proper design plans for green space locations could maximize their impact on flood control. Therefore, this study recommends that urban areas devote planning resources for green spaces, and such efforts should determine where the best areas are for their introduction.

It is expected that the approach used in this study and the results obtained will provide a framework for diverse research on green spaces in the future. Furthermore, the techniques employed may be useful for predicting flood probabilities in urban areas, i.e., the models, which were based on empirical data, had a high explanatory capability.

2. Limitation and future task

Some limitations were encountered. First, artificial flood control capacity was included in an analysis of flood vulnerable area through variables of flood control facility status and sewer line extension ratio but hydraudynamic variable for water flow by bending condition of sewer line was not considered. Accuracy of a model being constructed in this study is explained on the level of 88% but remaining 12% is a part that could not be explained by a model constructed in this study and it is considered to be its limitation. In case of using hydroligic model for analysis of flood vulnerable area, it has an advantage of reflecting features of sewer line but its deterioration level, leakage, clogging are hard to be reflected. It is hard to reflect detailed topographic information in a model and as a lot of budget and effort may be required in precise site survey and collecting data, analyzing flood vulnerability by using data-based empirical method would be also a big advantage.

Second, data were analyzed based on land cover maps and urban biotope maps. Hence, in this study, only green space area, type, and pattern were used as a variable, but more detailed information on planting types or structures of green spaces would be useful for future analyses of the impacts of green spaces on urban flooding. Such information could be identified through site surveys.

Third, flooded point data were established from a flood inundation map for 2011, so analysis was performed using only one year of data. The extracted flooded/non-flooded point for 10 years had many precipitation data because flooding often occurred in the same area.

Therefore, it is difficult to use the logistic regression analysis. If points were extracted from more flood inundation maps over many years, the accuracy of the results could be higher.

Fourth, the model was constructed based on the total area of the city of Seoul. However, if a site-based model could be constructed and supplemented after identifying detailed small green spaces through site surveys in the future, the applicability of the model could be further increased as more accurate data were incorporated.

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국 문 초 록

기후변화로 인해 국지성 집중호우가 잦아지면서 아스팔트와 시멘트로 덮인 대도시의 배수시설이 폭우를 감당하지 못해 물에 잠기는 도시홍수가 최근 들어 자주 발생하고 있어, 이에 대한 근본적인 대책이 필요한 시점이다. 서울 도심에서 홍수피해가 발생하는 1차적 배경은 집중강우의 발생으로 강우의 시간 공간적 분포의 집중성으로 보고되고 있다. 또한 도시개발에 따른 불투수층 증가는 자연 수문학적 과정을 크게 변화시키고 빗물 침투를 막으며 지표유출 및 첨두 유출량을 증가시키게 된다.

최근 기후변화 적응, 재해저감, 지속가능한 개발의 접점에 있는 중요한 대안으로 도시녹지의 중요성이 크게 강조되고 있다. 기후변화 영향으로 방재시설 용량을 초과하는 집중호우시에는 방재시설만으로는 한계가 있으므로, 지속가능하고 장기적인 관점에서 방재시설뿐만 아니라 녹지도입과 같이 근원을 해결할 수 있는 접근이 필요하다.

도시녹지는 유출을 감소시키고 도시수문에 대한 도시화의 부정적인 효과를 저감시키기 위한 조치로서 널리 이용되고 있다. 녹지의 홍수저감에 대한 개별 효과 외에도 도시홍수에 영향을 미치는 경사, 토지이용, 강우량, 홍수저감시설 유무 등에 따라 녹지의 효과는 달라질 수 있다. 그러므로 홍수가 발생하는 다양한 요인에 대해 파악하고 이들이 유기적으로 어떻게 홍수에 영향을 미치는지 분석하여 홍수저감을 위한 대책마련이 필요하다. 홍수에 대한 레질리언스가 높은 도시를 지향하기 위해서는 지역별 특성을 정확히 파악하고 필요에 따라 적절한 유형의 녹지를 적용하고 이에 따른 효과를 최대화해야 한다. 이를 위해 본 연구에서는 서울시의 홍수 취약지역을 분석하고, 홍수발생지역을 4가지 유형으로 구분한 후, 각 유형별로 녹지의 면적, 유형, 분포 특성에 따라 홍수발생 확률이 어떻게 변화하는지 통계학적으로 분석하였다.

연구결과를 요약하면 다음과 같다. 첫째, 공간통계모델인 MaxEnt를 이용하

여 서울시 전체 지역을 대상으로 도시홍수 취약지역을 분석하였다. 모델 구동을 위해 선정된 변수는 누적3일강우량, 시간최대강우량의 기후노출변수, TWI, 토양배수, 토지이용 등의 물리적 변수와 홍수를 저감시킬 수 있는 녹지환경 변수와 홍수저감시설 변수이며, 불확실성을 고려하여 1000회의 랜덤포인트 추출을 통해 결과를 평균과 표준편차로 나타내었다. 239개 배수분구 중 43개의 배수분구에서는 홍수발생이 전혀 일어나지 않았으며, 홍수에 취약한 지역은 서초4, 길동, 신월3, 방배1, 화곡2 등의 지역으로 나타났다.

둘째, 다변량 통계분석을 이용하여 홍수 발생지역의 유형을 4개로 구분하였다. 유형1은 배수분구 내에 홍수저감시설이 있는데 홍수가 발생한 지역으로 한강 및 주요 하천 주변에 위치하고 산과 인접한 도시 일부에서 나타난다. 기존에 홍수로 위험했던 지역이므로 경사가 서울시 전체 평균보다 완만하고 TWI는 두 번째로 높은 지역이며, 주거·상업혼합지 비율이 가장 높게 차지하고 있다. 유형2는 경사가 매우 급하며, TWI는 낮으며, 배수는 가장 양호한 지역이다. 다른 유형에 비해 녹지 비율도 높은 곳으로 경사가 급한 산지와 인접한 부분임을 알 수 있으며, 물이 정체되지 않고 흘러내리거나 침투되어 홍수가 잘 나지 않는 지역 특성을 가진 지역이다. 유형3은 경사가 매우 완만하고 TWI도 가장 높은 지역이며, 배수등급도 4개의 유형중 가장 불량한 지역으로, 유형2의 특성과는 반대로 물이 잘 정체되어 고일 수 있는 특성을 가진다. 단독주택지와 주거상업혼합지의 비율이 높고 도로의 50%이상이 위치한다. 유형4는 유형2와 유형3의 중간적인 특성을 가진 지역이고, 경사가 보통이고 TWI는 낮은 편이다. 시간최대 강우량의 가장 큰 피해가 발생하는 지역이다.

셋째, 로지스틱 회귀분석을 이용하여 홍수발생유형별로 녹지면적, 유형, 분포 특성에 따른 홍수발생확률 변화 차이를 비교 분석하였다. 녹지면적은 경사가 가파르고 배수가 양호한 유형2지역보다는 경사가 완만하고 TWI가 높은 유형3지역에서 홍수발생확률을 낮추는데 더 효과적임을 알 수 있었고, 경사가 급한 지역이 포함된 유형2와 유형4는 시간최대강우량 변수가 홍수발생확률에 큰 영향을 미치고 있어 녹지면적을 아무리 증가시켜도 홍수발생확률이 높게 나타

났다. 반대로 유형3은 시간최대 강우량보다 지형적인 특성이 홍수발생에 더 영향을 미친다.

녹지유형은 CN 값을 근거로 조경식재지, 논, 밭, 과수원, 초지, 습지, 산림지의 7가지 유형으로 나누어 홍수유형별로 홍수조절에 어떤 기여도를 하고 있는지 분석해 보았다. 유형1의 경우 초지가 가장 높은 기여도를 보였으며, 그 다음으로 산림, 조경수목식재지 순으로 나타났다. 유형2는 홍수조절에 기여하는 녹지변수로 산림지만 분석되었으며, 유형3은 논, 밭, 조경수목식재지, 산림의 순으로 기여도가 분석되었다. 서울의 경작지는 대부분 산지와 인접한 완만한 공간에 위치하므로 경작지의 물을 가둘 수 있는 능력을 통해 자연 저류조와 같은 역할을 하고 있음을 알 수 있다. 유형4는 산림지, 조경수목식재지, 밭 순으로 홍수조절에 영향력을 나타내고 있다. 유형4의 경우 야산이 많이 존재하여 이 지역에서의 홍수조절이 컸음을 유추해볼 수 있다.

녹지 분포는 유형1과 유형2의 경우 AWMSI가 유의한 변수로 나타났으며, 녹지의 복잡성이 높아질수록 홍수가 발생확률이 증가함을 알 수 있다. 유형3은 녹지의 홍수저감효율이 높은 지역인만큼 녹지 분포에 대한 지수도 NumP, MPS, AWMSI, CA가 유의한 변수로 선택되었다. 같은 면적이라면 NumP는 클수록, MPS는 클수록, AWMSI는 클수록 홍수저감효과가 크다. 유형4는 NumP가 늘어날수록 홍수발생에 긍정적인 영향을 주는 것으로 분석되었다.

본 연구에 따르면 도시 내 녹지면적은 홍수발생유형별로 일부 차이는 있지만 경사, TWI, 배수등급 등의 지형적인 요인에 버금가는 만큼의 홍수조절기능을 갖는 것으로 분석되었다. 그러므로 앞서 홍수발생 유형별로 녹지의 효율이 최대가 되는 지역에 녹지를 도입할 경우에는 훨씬 더 많은 홍수저감 효과를 나타낼 수 있는 것이다. 본 연구는 각 지역유형 특성별로 녹지면적, 녹지유형, 녹지분포 특성에 따른 홍수발생확률을 통계를 기반으로 정량적으로 분석하여 결과를 도출했다는 데에 중요한 의미를 갖는다. 또한 녹지특성 평가시 지역단위뿐만 아니라 경관단위까지 포함하는 다규모 분석(multi-scale analysis)을 시행하여 녹지의 다각도적인 분석 결과가 도출되었다.

저류조와 같은 인공적인 홍수저감시설은 시간이 지나면 그 가치가 감소하지만 녹지는 시간이 지날수록 인간과 자연에게 주는 긍정적인 효과가 더 커지는 친환경적인 정책이다. 그러므로 본 연구는 도시녹지의 홍수저감능력을 중심으로 하여 이 효과를 가장 효율적으로 발휘할 수 있는 곳에 배치할 수 있게 녹지가 도입될 지역특성에 따라 녹지면적, 녹지유형, 녹지분포에 대한 계획 근거를 제시하였다. 이 같은 녹지 도입에 대한 근거를 제시했다는 데에 향후 다양한 관련 연구에 적용될 수 있을 것으로 기대되며, 수문학적 모델을 사용하지 않고도 경험적이고 데이터에 기반한 방법을 이용하여 충분히 설명력 높은 홍수발생을 예측할 수 있다는 것에서도 유용한 도구로 활용될 것으로 기대할 수 있다.

주요어 : 홍수취약지역, 홍수지역유형구분, 도시녹지면적, 도시녹지유형, 도시녹지패턴, 로지스틱회귀분석, 홍수발생확률

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