EXAMINING THE IMPACT OF BUILT ENVIRONMENT ON FLOOD LOSSES IN SEOUL, KOREA

A Dissertation

by

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ABSTRACT

Floods have been the costliest and most disruptive among all natural hazards worldwide. In particular, urban flooding continues to be a concern for both developed and developing countries. Increasing physical risk associated with environmental changes combined with rapid land use change and development make many urban areas more vulnerable to floods. Floods are not solely based on hydro-meteorological conditions, but result from human activities as well such as unplanned land use or haphazard development.

While there is a growing body of research focused on understanding the role of human systems on flood impacts in the United States, little empirical research has been conducted outside of the country although many other nations experiencing urban flooding. In particular, many countries in South and East Asia have undergone rapid urbanization concurrent with industrialization and population growth, resulting in worsening flood problems over time.

To address this knowledge gap, this study statistically examines the factors contributing to flood loss in Seoul, Korea, with particular focus on the built environment. Panel regression models are analyzed using actual flood loss data in Seoul from 2003 to 2012. The dependent variable is observed property loss from floods recorded each year across 25 districts and the built environment is measured by land use category and the existence of Central Business Districts (CBD). The control variables are analyzed along four dimensions: biophysical, socioeconomic, flood mitigation, and organizational capacity factors. Results indicate that urban built-up land with higher impervious surfaces and agricultural land causes more flood damage than other land use analyzed in the study. However, CBD with high development density decreases flood loss. These results indicate the importance of resilient land use planning in urban area. Also, hourly maximum precipitation increases flood loss while total precipitation is not statistically significant. This result indicates that rainfall intensity is more influential than the quantity of precipitation, providing an important indication to local governments that they should focus on improving the capacity of drainage infrastructure within urban cores. Overall, this study provides insights to planners and decision makers on how they can effectively reduce flood risk and associated adverse impacts.

DEDICATION

To my family

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CHAPTER I

INTRODUCTION

1.1 Research Background

Floods have been the most frequent, disruptive, and costly among all natural hazards worldwide. In particular, urban flooding and associated damages continue to be a concern for both developed and developing countries (Jha et al., 2012). The damage caused by flooding events in urban areas have increased across the world due to the high concentration of population and asset values. As of 2008, half of humanity lives in cities and it is expected that 70% of the world's population will reside in urban areas by 2050 (Un-Habitat, 2008). This trend makes urban flooding more challenging to cope with due to the fact that high population density, critical infrastructure, and expensive commercial and residential structures are considered to be more vulnerable to hazards (Klein et al., 2003). In Europe, more than 75% of flood damages occur in urban areas and a number of cities in South and East Asia have suffered from recurred flooding as they have undergone rapid urbanization (Van Ree et al., 2011). In particular, many countries with warm and humid climates have experienced intensive floods throughout their history. Since these countries have a long history of rice paddy agriculture that depends on this climate, communities have tended to develop in flood-prone areas (Kundzewicz & Takeuchi, 1999). As these localities underwent rapid urbanization concurrent with industrialization and population growth, the flood problem worsened over time.

Floods are not solely based on hydro-meteorological conditions, but result from human activities as well such as unplanned land use or haphazard development (Brody et al., 2011b; Matthai, 1990; Mileti & Gailus, 2005). Urban areas are characterized by a high proportion of paved streets and development within these areas usually involves alteration of the natural landscape to impermeable surfaces, which lead to increased overland flow and discharge. Therefore, improper land use planning and development can make many urban areas more vulnerable to floods when combined with increased physical risk associated with environmental change.

While there is a growing body of research explaining the role of human systems on floods in the United States, very little empirical research has been conducted elsewhere despite the fact that many other countries experience urban flooding. Recent attention has been given to flood impacts in several Asian megacities (Klein et al., 2003), but few studies have been conducted in these areas to examine the factors that cause urban flooding.

To address this knowledge gap, this study statistically examines the factors contributing to flood loss in Seoul, Korea, with particular focus on the built environment. Seoul is the capital and largest metropolis in South Korea with a population of 10 million. This megacity has experienced urban flooding at the center of the city due to unusual localized heavy rains since 2010. The busiest region within the city was crippled by the worst floods ever recorded in both 2010 and 2011. For over ten years the total economic losses, including property damage from floods, was valued at approximately $65 million with more than $50 million lost in 2010 and 2011 alone. In

2011, such a disaster caused 24 causalities and inundated 21,832 buildings (Kang & Lee, 2012; Kim et al., 2012b; The Seoul Government, 2012).

The problem is that localized heavy rains, which had not been usual in Korea, have become chronic and repetitive. Regular floods in the same areas in Seoul suggest that these events may be driven not solely by biophysical factors, but also by human behavior and the built environment (Mileti & Gailus, 2005). In response to this problem, decision makers such as planners and policy makers are required to fully understand the impact of built environment that can cause flooding and exacerbate the associated damage to incorporate the concept of flood risk into plans and policy formation process.

1.2 Research Purpose and Objectives

This study addresses the lack of knowledge discussed above by examining the factors contributing to flood loss in Seoul using 10 years (2003-2012) of panel data with a particular focus on the built environment. Twenty-five municipal districts, called '*gu*,' are selected and quantitatively analyzed to understand the impacts of built environmental characteristics on observed flood damage. Multivariate statistical models are used to control for multiple environmental, socioeconomic, and political context variables to isolate the effect of the built environment on damages resulting from flood events. Policy recommendation based on the results of this study are then suggested that can help inform local communities on how to develop in a more flood-resilient manner.

The following section addresses the context of Korea to understand the political, socioeconomic, and historical background of the study area. The proceeding literature review section outlines anecdotal and empirical studies examining the factors of flooding and associated damage. Then, a conceptual model composed of variables derived from the literature review is generated and hypotheses are described. Next, the research methods section addresses the process of data analysis and potential validity threats of this study. The following section presents the results of analysis and finally the discussions and conclusions section contains key findings of the dissertation and discusses the policy implications based on the results.

The specific research questions and corresponding objectives are listed below.

1.2.1 Research Questions

To fill the knowledge gap addressed in the previous section, this study was conducted based on the three specific research questions and objectives with regards to examining the impacts of built environment on flood losses in Seoul, Korea.

The research questions of this study are:

- What are the significant factors influencing flood damage in Seoul and which factor is the most influential?
- Does the built environment have statistically significant impacts on flood damage in Seoul?
- How can the 25 districts in Seoul become more flood-resilient urban communities over the long run?

1.2.2 Research Objectives

To address the research questions listed above, this dissertation entails several research objectives. First, I investigate in detail the repetition of urban flooding events that has recently occurred at the center of the city. This objective involves measuring the extent and frequency of flood losses across the study area. Second, I derive independent and contextual control variables stemming from the literature and existing studies of factors associated with flooding and flood damage. Specific attention is paid to understanding and measuring the characteristics of the built environment that may have impacts on flood damage at a local level. Third, I construct and analyze a statistical model that isolates the impact of the built environment on observed flood losses over time, while controlling for multiple environmental and socioeconomic variables. Finally, based on these results, I provide policy guidance for planners and policy makers in Seoul on more effectively managing urban flood-prone environments.

1.3 Floods in Korean Context

Seoul, a mega city with over 10 million people, contains more than 20 percent of the national population. It was not until the late 1960s that Seoul recovered from the damage of the Korean War (1950-1953). After the war, the Korean government made considerable efforts to develop economically and Seoul began to experience rapid industrialization and urbanization. As a result, Korea's economy grew rapidly and was named one of the 'Asian tigers'(Kim & Han, 2012). As Korea experienced rapid growth, the population of Seoul increased from 1.6 million to 10.4 million between the years of 1955 and 2012 (Korea Statistics, 2013) and the portion of developed area increased from 29% to 65% between 1973 and 2001 (Kim, 2008).

Seoul consists of 25 districts under the Seoul Metropolitan Government (SMG). The SMG is an upper level (provincial or regional) local government, and the districts are the lower level (municipal) local governments. The Korean administrative system has three levels of hierarchy: central, provincial, and municipal. The provincial (regional) and municipal governments are referred to as local governments, and since these entities have autonomy, the areas within the jurisdictions are governed by elected mayors and council members (KRILA, 2011). Despite this local control, Korea has a rigidly hierarchical system as a centralized unitary state. Korean local governments are considered sub-national governments, and the central government can control local decisions through various means. Local governments also rely heavily upon financial contributions from upper level governments through intergovernmental transfers such as subsidies and grants. In this sense, local governments in Korea have substantially limited autonomy in every aspect when compared to those in the United States.

In the United States, it is argued that strong leadership from state and federal government is necessary for building and implementing effective flood mitigation strategies (Mileti, 1999). However in Korea, it is asserted that the functionally and financially limited autonomy of Korean local governments caused by the centralized rigid hierarchical system is responsible for the lack of proper flood mitigation measures at the local level (Cho, 2000). For example, there are 120 drainage (rainwater) pump stations[1] in Seoul that are under the direction of the Seoul Metropolitan Government. These facilities are in need of capacity improvement but local governments have neither the rights to make decisions on this agenda nor enough financial resources to implement change.

As stated earlier, approximately 80% of property damage from floods in the last decade occurred in 2011 and 2012. This is inconsistent with the results from the studies conducted in the United States arguing that high density or a compact development patterns are favorable to reduce adverse impacts from flooding; throughout this dissertation I will explore these inconsistencies.

Regarding the socio-economic context, Seoul varies socially from many other cities in the United States in that it is a racially homogeneous. Despite this homogeneity, there have been social polarization and segregation problems due to income inequality and expensive housing prices in Seoul (Kim & Han, 2012). These worsened as Korea went through the Asian Economic Crisis from 1997 to 1998 which made the middle class substantially smaller. Although the Seoul Metropolitan Government has been trying to reduce this problem and promote social cohesion, it was found that the gap between wealthy and poor districts is not decreasing (Kim et al., 2012b; Maeng, 2009, 2010).

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[1] They are usually located in areas where the ground level is lower than streams or rivers to prevent surrounding communities from being inundated when heavy rainfalls. The facilities are designed to forcibly discharge rainwater with pumping systems.

It is important to note that Seoul has its own social and economic context which distinguishes it from other study areas in the United States. Therefore, applying the methods from the studies conducted in the United States to Seoul, a completely different location with different contexts, is meaningful in that it has never been done before. This first-of-its-kind study will allow me to test the generalizability of the existing studies and see if results are consistent with analyses in the United States.

In addition, there are few studies using longitudinal data to examine the factors of flood loss. The cross-sectional studies are only able to show a snapshot in time regarding impacts on flood damage and therefore are in need of improvement (Brody et al., 2007a). This study uses longitudinal data to discover the factors that have pushed Seoul across the threshold for flooding and caused the city to experience urban floods every year since 2010.

It is necessary to understand the overall Korean political, cultural, economic context before examining the flood problems in Korea. The following section will investigate the political system of Korea with particular attention to the local governmental system (the unit of analysis in this study is a district, *gu*).

1.3.1 Local Governmental Systems in Korea and Autonomous Districts in Seoul

The Korean administrative system has three levels of hierarchy: central, provincial, and municipal (KRILA, 2011). As illustrated in Figure 1.1, the local government is a two-tier system: the upper (regional) and lower (municipal) level (Choi et al., 2012). These governments have autonomy, so the areas within their jurisdictions are governed by elected mayors and council members. All municipalities have wards as sub-levels, which are administrative units without autonomy (KRILA, 2011).

The Seoul Metropolitan Government (SMG) is an upper level local government. Seoul has a special status that comes from its mayor's position which is equivalent to ministers of the central government unlike governors of other metropolitan cities and provinces. The 25 autonomous districts in Seoul, or '*gu*,' are at the municipal level under the SMG.

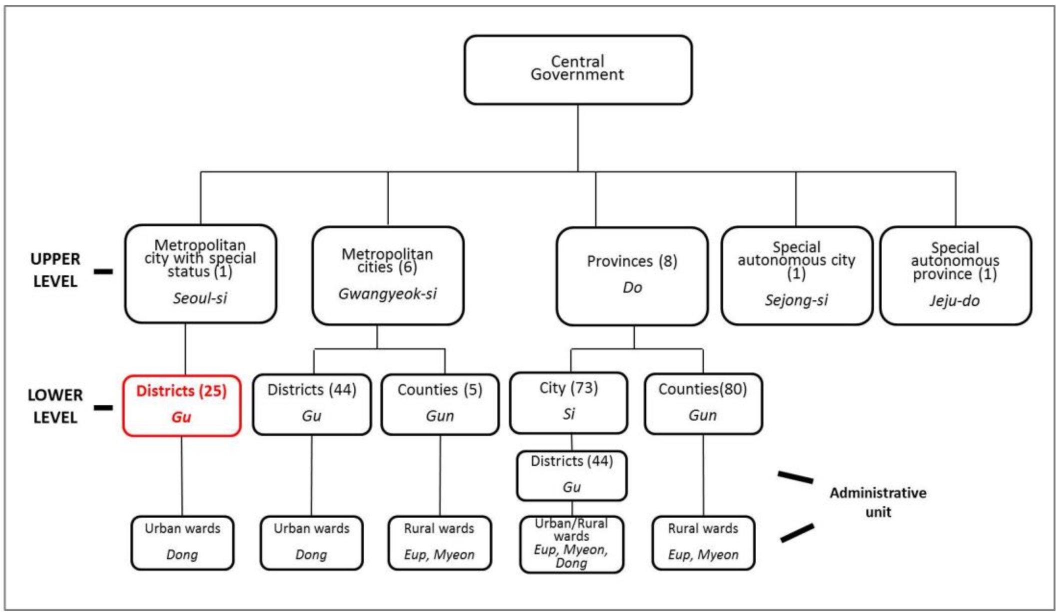

Figure 1.1 Local government systems in Korea (Choi et al., 2012; KRILA, 2011)

Gu used to be an administrative unit of a city until the Local Autonomy Act (LAA) was revised in 1988.[2] The system of local administration was replaced with the local government system in 1995 with the first direct election of local chief executives (Park, 2006). Since then, districts within Seoul and six other metropolitan cities were authorized as local governments with autonomy. The other districts[3] under provinces remain as administrative units and their chiefs are designated by the central government.

Since Korea has a rigidly hierarchical system as a centralized unitary state, local governments are considered sub-national governments (KRILA, 2011). Therefore, the autonomy and authority of local governments is meant to be delegated by the central government. Local governments must implement assigned tasks from both the central and upper level local governments as well as their autonomous functions which are stipulated in the Korean constitution[4]. With this background, local governments in Korea have substantially limited autonomy compared to those in federal states (Park, 2006).[5] The Korean constitution recognizes the autonomy of local governments. According to Article 118 of the constitution, local governments have administrative authority and legislature with the responsibility of representing local residents and

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[2] Although the Local Autonomy Act (LAA) was legislated in 1949 for the first time, the first local elections were not held until 1960. In 1961, a military coup occurred thus suspending local autonomy. It was not until 1988 that the LAA was revised extensively and came into effect (Park, 2006).

[3] They are also called "*gu*". To prevent confusion, autonomous districts are called "*Jachi-gu*" (Jachi meaning autonomy in Korean).

[4] When a local government performs assigned tasks, the local chief executive acts as a local administrative agency or proxy of upper level governments under the control of the central government (Park, 2006).

[5] In Korea, only the central government has police authority. Thus, the police apparatus in each locale is considered as a branch of the national police. With this reason, some scholars argue that the lower level local governments should be referred as local autonomous "entities" rather than governments.

implementing local policies. However, the constitution does not clearly stipulate the authority of decision-making and the local autonomy system in Korea is seen as self-administration rather than self-governing (KRILA, 2011).

Although the LAA outlines the six functions of local governments[6], the conditional clause actually limits the scope of authority: "Despite the functions specified in this law, the central government may exercise its own power and control over any function, if other laws define them as the functions of the central government" (Choi et al., 2012, p. 29). Also, the local governments have a certain degree of authority to enact ordinances but there are strict constraints stating that local ordinances should be consistent with laws and regulations of upper level of governments.

1.3.2 Local Tax System and Fiscal Capacity

Since local governments have the responsibility to execute tasks assigned by the central and upper level local governments, there is fiscal support for local governments (Park, 2006). In the case of autonomous districts in Seoul, they are funded by the central government in addition to city tax revenue from the mayor of Seoul (Kim et al., 2002).

As illustrated in Table 1.1, local revenues of 25 districts break down into self-financed revenues and intergovernmental transfers from the national and Seoul

[6] The six categories of local governmental functions are: "1. Functions related to the territorial jurisdiction, organizational and managerial aspects of local governments"; 2. Functions to promote the general welfare of local residents; 3. Functions related to regional development and the construction and management of environmental facilities; 4. Functions to promote education, athletic activities, culture and art; 5. Functions related to civil defense and firefighting" (Choi et al., 2012, p. 29).

government. The ratio of two is called "Fiscal Self-Reliance Ratio"[7] and is the most widely used index to measure the fiscal capacity of local governments in Korea. Self-financed revenues of districts are composed of local taxes and non-tax revenues. The most important revenue source for districts is property tax which accounts for more than 80% of entire local taxes[8]. Non-tax revenues include user charges, fees, rent, and so on. Since local governments have more leeway to increase or decrease non-tax revenues with ordinances than they do local taxes, which are ruled by national tax law; these factors impact the ability of local governments to govern their districts (Kim et al., 2012a).

Intergovernmental transfers are divided into local grants from the SMG and subsidies from the national government. These account for approximately 54% of the total revenue of the 25 districts and are greater than the proportion of self-financed revenues.

[7] Fiscal Self-Reliance Ratio (%) = (local taxes + non-tax revenues) / total revenues * 100

[8] Property tax accounts approximately 83.2% of districts' total local taxes in 2012

Table 1.1 Tax structure and total revenue of 25 districts in Seoul, 2012 (The Seoul Government, 2013a)

Self-financed Revenues			Intergovernmental Transfers	
Local Taxes	**Non-tax Revenues**		**Central Government**	**Seoul Metropolitan Government**
- Property Tax - Registration & License Tax - Tax from the previous year	Current	Temporary	- National Treasury Subsidy	- Local subsidy - Grants
	User Charges, fees, rent, other current revenue	Property Disposal Revenue, Net annual surplus, Other temporary revenue		
2,012,207[9] (57%)	1,514,482 (43%)		1,283,475 (31%)	2,850,831 (69%)
3,526,690 (46%)			4,134,306 (54%)	
Total: 7,660,996 (unit: million, KRW)				

As mentioned previously, the fiscal capacity of a local government in Korea is usually measured by the Fiscal Self-Reliance Ratio (FSRR). FSRR focuses on the capacity of local governments to finance themselves with their own resources. This is important as the subsidies and grants from upper level governments are usually designated for specified projects or expenses due to delegated tasks. In addition, local governments with low self-financed revenues receive larger amounts of financial aid

[9] Property tax: 1,673,324 (KRW)

through intergovernmental transfers. This means that local governments receiving fewer grants or subsidies from the central or upper level governments are financially sound. In a nutshell, districts receiving fewer intergovernmental transfers are the wealthier communities. In this context, measuring the fiscal capacity based on total revenue (which includes intergovernmental transfers), is considered inadequate to reflect the actual ability of local governments to finance their own projects. This is the main reason why FSRR is referred to as the most effective way to measure financial capacity or autonomy of local governments in Korea.

It has been known that the quality of administrative services and the level of residents' satisfaction with their local governments are substantially influenced by FSRR. The major fiscal issue for autonomous districts in Seoul is the fiscal disparity amongst the 25 districts. As illustrated in Figure 1.2, among the 25 districts, the highest FSRR is nearly four times higher than that of the lowest district. This imbalance is caused by a property tax oriented tax system that impedes social cohesion among districts and results in gaps of public services and the overall residential satisfaction of citizens between said districts (Kim, 2013).

According to C. -D. Kim et al. (2012), the average FSRR of 25 districts of Seoul has been decreasing over the last two decades (1992: 69.9%, 2012: 46.03%) resulting in local governments having difficulty building autonomy and therefore causing them to rely heavily on the upper and central government when planning and executing local projects.

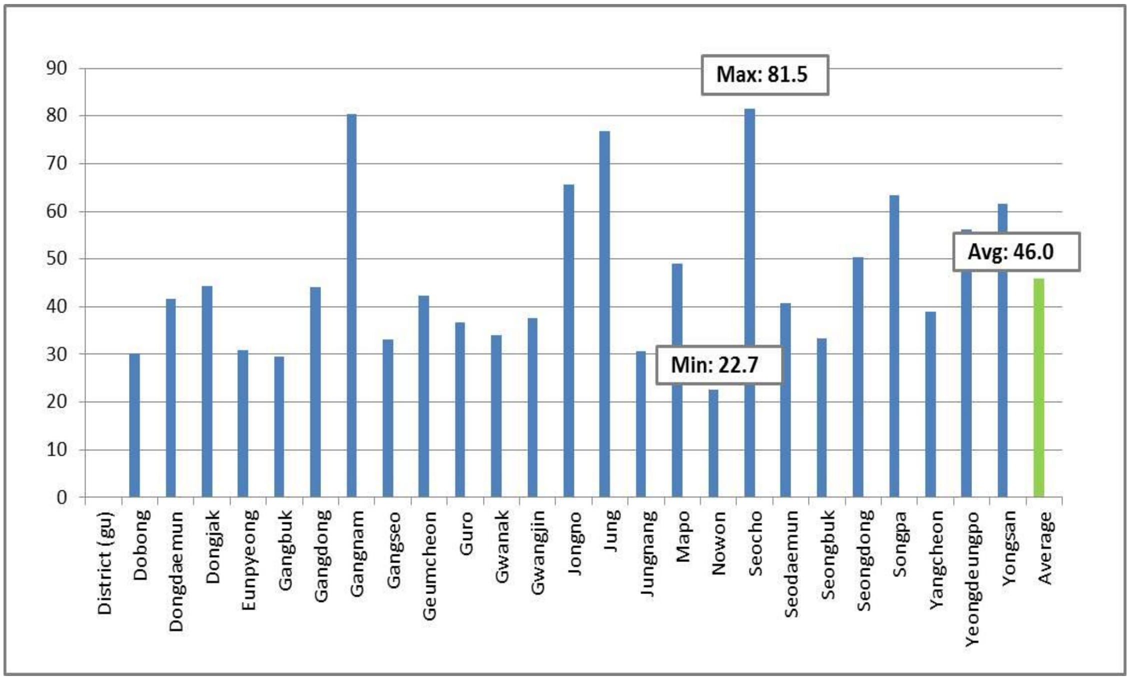

Figure 1.2 Fiscal Self-Reliance Ratio of 25 districts in Seoul, 2012 (The Seoul Government, 2013a)

This functionally and financially limited autonomy of district governments has been blamed as the primary reason for their low capacity to deal with hazard management for their citizens (Cho, 2000).

1.3.3 Local Councils and Ordinances

While there are various types of local governments in Europe and the United States, all the Korean local governments have a single type of governing structure: the mayor-council system. As illustrated in Figure 1.3, the mayor-council structure consists of the chief executive (governor for regional level governments or mayor for local level governments) and the local council (Choi et al., 2012). As stated earlier, the chief executives are elected by citizens every four year and councilors are elected by universal suffrage (Kim et al., 2002).

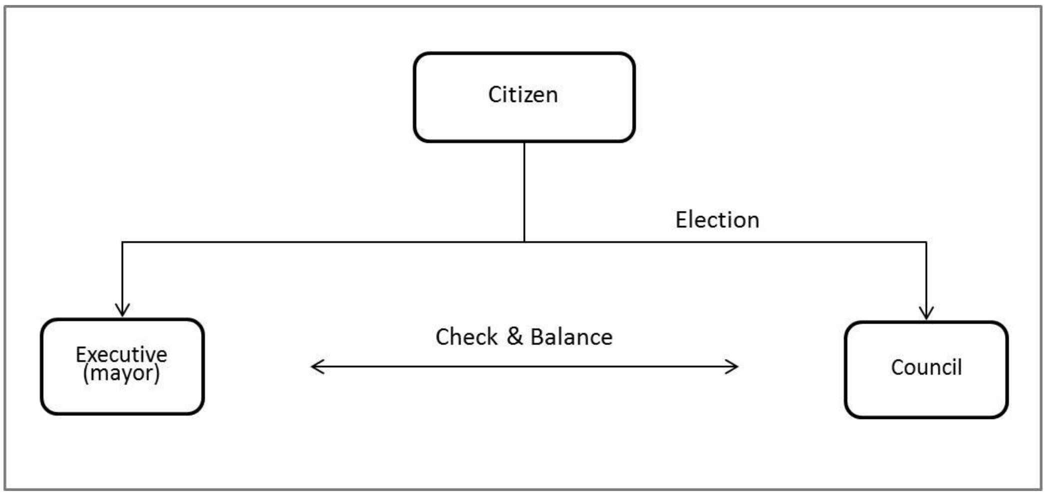

Figure 1.3 Structure of local government in Korea (Choi et al., 2012)

According to the LAA, local councils have the authority to: “Enactment, revision and abolition of Municipal Ordinances; Deliberation and confirmation of a budget…; Imposition and collection of user fee, commission, allotted charges, local tax and entrance fee; Establishment and disposal of public facilities; Acceptance and resolution of petitions; … (KRILA, 2011, p. 22)”. However, the Korean local government system has a strong mayor/weak council form (Park, 2006). Although the LAA stipulates the authorities and functions of local council, the role of the council is substantially limited in reality because the mayor dominates the political process and there is no legal basis to regulate when the mayor disregards a decision procedure (Kim, 2012). For instance, the mayor can veto ordinances that the local council passed. In addition, the political environment is more favorable to the mayor because he/she has the authority to appoint local bureaucrats. These political conditions result in demoralization among local councils and results in a lack of the necessary ordinances to ensure citizens' safety (Kim, 2012). It seems that this political environment is partially responsible for the current poor flood policy of the 25 districts in Seoul. When it comes to the flood ordinance, which is one of the variables in this study, more than half of districts do not have any ordinances related to floods or various types of hazards. It is interesting to note that four districts used to have flood ordinances in the past but eventually abolished these ordinances despite the fact that the city continuously experiences increasing flood damage.

CHAPTER II

LITERATURE REVIEW

This section provides an understanding of various factors that cause or exacerbate flooding. Specifically, it explores existing studies addressing the potential impacts of built environment, natural environment, mitigation measures, socioeconomic characteristics, and local government organizational capacity on flooding and associated damages. Next, it investigates the built environment and its impact on flooding in detail. Finally, based on the review, it derives independent variables and hypotheses for statistical analysis.

2.1 Factors Contributing to Flooding and Flood Losses

Many parts of the world have suffered from destructive floods for a long time, and the study area, Seoul, is no exception. Notably, the floods that inflict severe damage to communities tend to be chronic and localized, occurring repeatedly in the same area (Berke et al., 2009; Brody et al., 2011b; Kundzewicz & Takeuchi, 1999). This indicates that disasters like floods have societal and human behavioral causes as well as natural ones (Mileti & Gailus, 2005). Mileti and Gailus (2005) suggest a holistic view when dealing with disasters and argued that losses from disasters are “the predictable results of interactions among three major systems” (p. 494) the physical environment, which indicates the hazard events themselves; the social and demographic characteristics of the communities experiencing the events; and the built environment including features such as buildings, roads, bridges. The more complicated the interactions between these systems, the more difficult it is to determine the exact factors influencing the hazards.

Brody et al. (2011b), who stressed an interdisciplinary approach to solving flood problems, also categorized the factors influencing floods in the same context as Mileti and Gailus (2005) but broke them into five categories: natural environment, built environment, socioeconomic, flood mitigation, and organizational capacity. This is illustrated in Table 2.1.

Table 2.1 Factors influencing flooding and flood damage (Brody et al., 2011b)

Natural Environment	**Built Environment**	**Socioeconomic Factors**	**Flood mitigation**	**Organizational capacity**
Basin area	Impervious surfaces	Housing values	Structural	Collaboration
Basin shape	Wetland alterations	Education	Non-structural	Competency
Topography	Development density	Population change		Individual characteristics
Precipitation	Housing units	Income		
Soil				

There have been significant works among scholars to identify the major factors contributing to flood hazards. The majority of these studies have been conducted in coastal areas in the United States, and they seem to be quite successful in statistically examining the impacts of factors. Therefore, the research designs and variables of those studies will be thoroughly investigated and adapted to this study after being modified for the contextual circumstances of Seoul.

As seen in Table 2.2, many empirical studies using analytical methods have been conducted by scholars. They found statistically significant factors influencing flood damage and suggested policy implications that can be or should be implemented at the local level based on the results. These studies will be reviewed according to the categories addressed in Table 2.1 to inform the selection of independent variables for this study.

Table 2.2 Existing studies on factors contributing to floods[10] [11] [12]

Studies	Study Area	Dependent Variable	Research Method	Independent Variable	Control Variable
(Khan, 2005)	Houston, TX	-	Correlation	- Flooding - Urbanization	-
(Brody et al., 2007a)	85 adjacent coastal watersheds in TX & FL	Number of times a stream gauge exceeding 12 years average	Regression	<Number of wetland alteration permits issued> Individual Permits (+) General Permits (+) Letter of Permission (-) Nationwide Permits	<u>Precipitation (+)</u> Impervious surface (+) State (FL:0, TX:1) (+) Topography Drainage network Watershed area Dams Population density Household income
(Brody et al., 2007b)	54 coastal counties in FL	Flood damage	Regression/ Binary Logistic	<Planning decision> Wetland alteration (+) Flood mitigation (-) Impervious surface Dam construction	Adjacent property-damage (+) Housing value (+) <u>Precipitation (+)</u> Flood duration (+) Stream density Floodplain

[10] Underlined: the most powerful predictor among independent variables; directions in parenthesis: the direction of impacts on dependent variable; independent variables without directions means they are statistically insignificant.
[11] All the studies on the table are quantitative research.
[12] Underlined: the most powerful predictor among independent variables; directions in the parenthesis: the direction of impacts on dependent variable; independent variables without directions means statistically insignificant.

Table 2.2 Continued

Studies	Study Area	Dependent Variable	Research Method	Independent Variable	Control Variable
(Brody et al., 2008)	37 counties in eastern TX	Flood damage	Regression	<Built environment> Wetland alteration (+) Dams (-) Impervious surface	Precipitation[13] (+) Precipitation[14] (+) Flood duration (+) Floodplain Flood mitigation (+) FEMA rating score Household income
(Kim et al., 2011)	46 jurisdictions, Korea	Flood damage	Factor Analysis	Topography Precipitation Socioeconomic Damage Social vulnerability	-
(Brody et al., 2011a)	144 coastal counties and parishes along the Gulf of Mexico	Flood damage	Regression	<Development pattern> High Intensity (-) Low Intensity (+)	Floodplain (+) Wetland alteration (+) Precipitation (+) Storm surge (+) Household income (+) Housing units (+) Soil permeability
(Brody et al., 2012)	144 coastal counties and parishes along the Gulf of Mexico	Flood damage	Regression	<Ecological indicators> Non-floodplain area (-) Soil permeability (-) Wetland alteration (+) Previous Surface	Precipitation (+) Storm surge (+) Household income (+)Housing units (+) Flood mitigation
(Highfield & Brody, 2013)	450 communities participating in the FEMA's CRS	Flood damage: Total/within/with out FEMA 1% flood zones	Linear Panel Regression	<Local mitigation activities> "8 CRS activities and 4 elements within the 400, 500, and 600 series" (-)	Floodplain (+) Soil permeability (-) Slope (+) Precipitation (+) Storm surge (+) Population (+) NFIP policies (+) NFIP policies (+) Years built
(Brody & Highfield, 2013)	450 communities participating in the FEMA's CRS	Flood damage	Cross-sectional time series	<Open space preservation> "Number of CRS credit points through Activity 420 (-)"	Floodplain (+) Soil permeability (-) Slope (+) Precipitation (+) Storm surge (+) Population (+) Flood mitigation (+) NFIP policies (+) Impervious Surface Years built
(Brody et al., 2013a)	7900 households in the Clear Creek watershed, TX	Flood damage	OLS Spatial-lag model	<Land use land cover> High intensity dvpt. (+) Medium intensity dvpt. (-) Low intensity dvpt. (+) Developed open space (-) Grassland (-) Scrub (+) Palustrine wetland (-) Estuarine wetland Agriculture Forest Barren	Elevation (-) Precipitation (+) Property value (+) Floodplain (-) Spatial lag (+) Age of structure

[13] Precipitation the day before the actual flood event
[14] Precipitation the day of the actual flood event

Table 2.2 Continued

(Brody et al., 2013b)	144 coastal counties and parishes along the Gulf of Mexico	Flood damage	Regression	<Development patterns> High intensity (+) Medium intensity (-) Low intensity (+)	Floodplain (+) Soil permeability (-) Precipitation (+) Storm surge (+) Housing units (+) Home value (+) Wetland alteration Flood mitigation
Kang, Under reiview	53 local jurisdictions, FL	Flood damage	Regression	<Flood mitigation policy> Plan quality Planning capacity Budget Leadership (-) Commitment	Precipitation Flood duration Floodplain Stream length Storm surge area Coastal location (+) Impervious surface Wetland alteration (+) Dams (-) Population Income Insurance Public participation

2.1.1 Natural Environment Factors

Intuitively, we can assume that the characteristics of the natural environment have an immediate impact on floods. In fact, as seen from Table 2.2, precipitation usually turns out to have the greatest impact on the degree of flood loss among many empirical studies (Brody et al., 2013a; Brody et al., 2008; Brody et al., 2007a; Brody et al., 2007b; Highfield & Brody, 2013). Based on the standardized beta (β), which helps us to compare the magnitude of the impact of each independent variable on the dependent variable, precipitation is the most powerful predictor in most studies.

Topography, specifically slope, has a statistically significant impact on the increase of floods (Brody & Highfield, 2013; Highfield & Brody, 2013) because steeper slopes expedite the stream peaks by increasing rainfall concentration (Matthai, 1990). Soil characteristics, such as permeability, which indicates the capacity at which water flows through a soil, have also been included in predicting flood loss (Brody et al., 2011b). Some empirical studies found that increased soil permeability reduce the adverse impacts of floods (Brody & Highfield, 2013; Brody et al., 2012; Highfield & Brody, 2013).

Another significant natrual environment factor is the presence of wetlands. There are many examples showing that wetlands reduce floods because they act like a sponge (Bullock & Acreman, 2003). Thus, the effort to conserve wetlands can help to attenuate damages from floods. However, inland wetlands have been reduced due to wetland alterations. Naturally occurring wetland alterations have increased and consequently caused the loss of flood water storage capacity and wildlife habitats due to an increase in the number of Section 404 permits that have been issued (Ogawa & Male, 1986). Ogawa and Male (1986) conducted a simulation research and reported that a 100% wetland encroachment generated more than a 100% increase in peak flow. Therefore, wetland alterations can be seen as one of built environmental characteristics since the consequences of alterations usually increase impervious surfaces followed by developments. In this context, Brody et al. (2007a) examined the impact of the number of permits under Section 404 on the amount of flooding in Texas and Florida coastal watersheds. They found that two out of four types of permits increased the flood frequency. Similarly, it has also been reported that wetland alterations affect flood damage at the county level (Brody et al., 2011a; Brody et al., 2008; Brody et al., 2007a; Brody et al., 2012; Brody et al., 2007b).

2.1.2 Socioeconomic Factors

Socioeconomic characteristics such as population, income, and education of residents are closely related to the amount of flood damage. These factors usually have a statistically significant association with flood loss. Therefore, many empirical studies examining the impacts of floods include these factors as control variables. Also, there are numerous studies focusing on these socioeconomic characteristics as actual variables of interest from a social vulnerability perspective. It is not difficult to understand the relationships between these characteristics and damage caused by floods. If property values or household incomes are high, or more people reside in the flood-prone area, the amount of property damage from flooding will also be high (Brody et al., 2013a; Brody & Highfield, 2013; Brody et al., 2007a; Brody et al., 2013b; Highfield & Brody, 2013).

When it comes to hazards, socioeconomic characteristics can be a critical issue since these are closely related to social vulnerability to hazards. In general, vulnerability to environmental hazards indicates potential for loss. Cutter et al. (2003) described social vulnerability by individual characteristics such as age, race, health, income, etc. They also argued that social vulnerability partially comes from social inequalities and that those characteristics impact an individual's ability to respond to hazards. The vulnerability issue related to natural events has been discussed over decades. Studies found that poor households are likely to experience higher mortality rates (Blaikie et al., 2004), more severe housing damage (Cochrane, 1975), and take more time to recover after hazards (Bolin, 1986). Zahran et al. (2008) examined whether socially vulnerable people experience significanltly greater injury or fatality from floods. The authors created social vulnerability index by measuring portions of poverty and non-white population and income. They found that, controlling the natural and built environmental factors, more pepole were injured or died in communities with a more socially vulnerable population.

The social disparity among the 25 districts has been one of the most controversial issue in Seoul. After Korea experienced the Asian Economic Crisis in 1997 and 1998, the middle class has been substantially shrinking. Income inequality combined with expensive living cost in Seoul has caused social polarization and housing segregation in Seoul (Kim & Han, 2012).

The Seoul Metropolitan Government has tried to reduce this imbalance and promote social cohesion for a long time by development of socially mixed housing in the form of apartment complexes. However, studies found that the gap between wealthy and poor districts is still growing despite these efforts (Kim et al., 2012b; Maeng, 2009, 2010). Maeng (2009) examined the disparities among 25 districts in Seoul with 14 indicators in five categories: population, built environments, residential environments, economy, and infrastructure and public facility. The regional disparity issue is not limited to Seoul, but exists nationwide. Kim et al. (2012b) conducted a study examining regional disparities in Korea with 75 indicators categorized by four areas: urban infrastructures, economy and industry, social welfare, and culture and creativity. They found that the disparities amongst region get more severe in Korea.

2.1.3 Flood Mitigation Factors

Flood mitigation efforts of local governments can moderate flood loss. As seen in Table 2.3, the strategies are divided into structural and nonstructural mitigation. Structural mitigation usually includes dams, reservoirs, levees, and channelization (Thampapillai & Musgrave, 1985). Examples of nonstructural mitigation include land use zoning, education and training, systems for warning and evacuation, and environmentally vulnerable area protection (Berke et al., 2009; Brody et al., 2011b; Kundzewicz & Takeuchi, 1999). It is obvious that planners can find numerous opportunities here to make flood resilient communities with their substantive knowledge of planning techniques, especially in nonstructural mitigation.

Table 2.3 Flood mitigation strategies and techniques (Brody et al., 2011b)

Structural Strategies	**Non-structural strategies**
Retention	Stand-alone flood plans
Channelization	Setbacks and buffers
Debris clearing	Land acquisition
Levees	Zoning and land use restrictions
Dams	Protected areas
	Education
	Intergovernmental agreements
	Computer models/forecasting
	Specific policies in a comprehensive plan
	Training/technical assistance
	Referendums
	Community block grants
	Land development codes
	Construction codes

Many studies have attempted to statistically examine the effects of structural and nonstructural mitigations on flood damage. Some studies produced results indicating that nonstructural mitigations are associated with increased flood loss (Brody & Highfield, 2013; Brody et al., 2008; Highfield & Brody, 2013). This might be because the presence of mitigation strategies indicates frequent and severe floods in those areas. But still, different types of mitigation strategies reduced the flood damages in the same studies.

In general, hazard mitigation can be defined as actions which are taken ahead of events to reduce or eliminate long-term risks that can inflict damage to people and property (Godschalk, 2003; Peacock et al., 2010). These actions are generally divided into structural and nonstructural mitigation. According to Kundzewicz (1999), while the aim of structural migitation is to attempt to "eliminate floods", nonstructural mitigation can be uderstood as an effort to "live with floods". Examples of mitigation strategies for floods are shown in Figure 2.1 and Table 2.3.

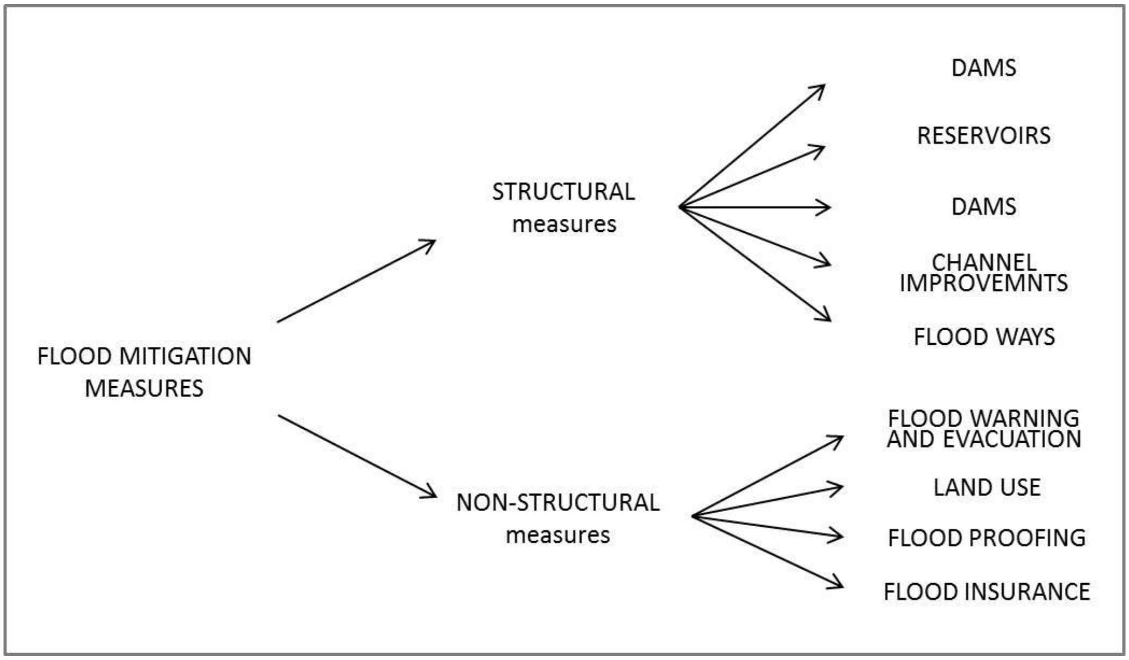

Figure 2.1 Classification of flood mitigation measures (Thampapillai & Musgrave, 1985)

As we can see from Figure 2.1 and Table 2.3, there are numerous mitigation activities that can be applied to reduce the adverse impacts of floods. However, not all strategies are successful and may even exacerbate flood damage (Tobin, 1995).

Besides the two studies above, many other researchers have addressed the shortcomings of structural mitigation which was applied extensively in the past. First, stuctural mitigation such as the construction of levees or dams usually puts substantial pressure on surrounging natural environment (Tobin, 1995). Since these structures are often accompanied by deforestation or natural wetland alterations, they can harm the ecosystem in the vicinity. Second, if the flood occurrence excceeds the limit of the structure, the consequences are much more severe than they were when the area did not house the mitigation structure (Brody et al., 2011b). Third, the structure may bring about “a false sense of security” (p. 343) to the inhabitants in the area so the people residing downstream can be encouraged to pursue indiscriminate developments that can increase risks when the structure does not function as well as exepcted (Tobin, 1995). Last, structural methods usually impose extremely high financial pressure on governments compared to non-structural strategies since these approaches are accompanied by long-term maintenance (Brody et al., 2009).

According to Brody et al. (2008), wetland alterations have a greater impact on property damage from floods than dams. This means that dams are not very effective in compensating for flood loss as long as wetland alterations are continued. In other words, preventing wetland alterations can generate far greater effects on reducing flood loss than constructing dams, which is extremely costly. In addition, Brody et al. (2007b) reported that nonstructural mitigation as measured by the Federal Emergency Management Agency (FEMA) Community Rating System (CRS) and wetland alterations are more effective and have greater impacts than dams in reducing flood loss in Florida. In this study, dams were not even statistically significant. This result indicates that nonstuctural mitigation, which is usually less expensive than structrual measures, can generate equal or more positive effects in reducing damage from floods. It also implies that local governments and planners who pursue building a flood-resilient community should consider nonstructural measures as more important than structural ones.

While non-structural mitigation measures are increasingly being considered as effective ways to reduce the adverse impacts of floods, structural measures can also be important components to a successful local flood protection program. In reality, an approach that includes both structural and non-structural elements working together will be the most effective way to avoid flood losses over time (Brody et al., 2011b).

2.1.4 Organizational Capacity Factors

Organizational capacity can be understood as the ability to implement adopted policies or strategies of organizations such as local government and agencies. It involves critical elements of learning, adaptation, and creativity that are essential for the local governments to possess in order to effectively build a hazard resilient community (Peacock et al., 2010). Thus, when it comes to flood mitigation, the organizational capacity of local governments is closely related to the ability of jurisdictions to adopt and implement flood mitigation strategies. Since we now understand, through reviewing the results of empirical studies illustrated in Table 2.2, that mitigation strategies can reduce the adverse impacts of floods, it can be said that organizational capacity is also a critical factor for reducing flood loss. For example, Kang (2009) conducted a study explaining the mitigating effects of local comprehensive planning on flood loss in Florida. The organizational capacity was included as planning efforts of local governments; number of staff, financial capacity, leadership, and planner's commitment. The study found that the strong leadership of a local government in developing and implementing flood mitigation policies has a statistically significant abating effect on flood loss.

Brody et al. (2009) examined the organizational capacity evaluating local flood mitigation strategies. To address this issue, they conducted a survey among planning directors in local jurisdictions in the Texas and Florida coastal areas. The organizational capacity was measured by various variables (see Table 2.4), and they found that there was a statistically significant relationship between organizational capacity and local flood mitigation implementation. In their later study, Brody et al. (2010) also stated that there was a strong positive correlation between organizational capacity and flood mitigation implementation. They also argued that the organizational capacity of the local government is essential for abating the adverse impacts of flood events at the local level. Brody, et al. (2010) defined organizational capacity in the context of building a flood-resilient community as, "the ability to anticipate flooding, make informed decisions about mitigation, and implement effective policies (p.171)", and the key characteristics are financial resources, staffing, technical expertise, communication and information sharing, leadership, and a commitment to flood protection. They stressed the ability for individuals to work together toward a common goal. The authors also highlighted the ability of planners to flexibly adjust policies facing uncertainty, surprise, and policy failure as adaptive management. In addition, collaboration among various contributing actors was stated as one of the important characteristics of organizational capacity.

Table 2.4 Organizational capacity composition (Brody et al., 2010)

Organizational Capacity	
Collaboration	Strong communication
	Sharing information
	Pooling of resources across organizational units
Competency	Number of staff
	Level of funding
	Quality of data
	Ability to retain personnel over the long term
Individual characteristic	Personal commitment to flood mitigation
	Strong leadership within organization
	Ability to think and act long range
	Ability to see the interplay between human and natural systems

Brody et al. (2009; 2010) showed that Florida has stronger organizational capacity than Texas with more engagement of public officials and the public in planning for a flood resilient community. The authors stated that Florida seems to have a greater ability to hire key staff members with a low turnover rate among them. In addition, Florida has better financial resources than Texas. They pointed out that these differences have made coastal communities in Florida more flood-resilient compared to those in Texas. Although Florida has relatively more unfavorable conditions that can result in more severe flood damages than Texas – more yearly precipitation, more expensive structures in flood-prone areas, and a greater population residing in a 100-year floodplain – the flood damage in Florida is significantly lower than that of Texas. The authors speculated that it is partly due to the strong organizational capacity that the Florida local governments possess; that capacity has enabled more and extensive flood mitigation strategies to be implemented at the local level. Eventually, it has led to Florida coastal communities being more flood-resilient than those in Texas.

Based on the review, it seems planners should focus more on built environmental factors which can be more easily altered or modified than the natural and socioeconomic characteristics. To do so, planners also need to have in-depth knowledge of planning tools and techniques which can be utilized as nonstructural mitigation strategies. Specifically, studies highlighted the importance of naturally occurring wetlands due to their ability to function as natural mitigation devices; communities can take advantage of these wetlands by doing nothing more than conservation. Also, the pivotal role of flood mitigating policies is highlighted. For instance, Brody et al. (2007b) reported that wetlands can produce more positive effects on reducing flood damage than dams can. In addition, the authors argued that FEMA's Community Rating System has a greater flood loss reducing effect.

2.2 Built Environment and Flooding

The built environment most reflects human activity compared to other factors, thus it is considered a "powerful lever" on the problems of flooding (Brody et al., 2011b). Unlike the natural environmental characteristics which are hard to manage, the built environment can be more easily altered by planning and implementation of policies to reduce the adverse effects of floods. Thus, this study will pay particular attention to the influences of the built environment in Seoul rather than other factors.

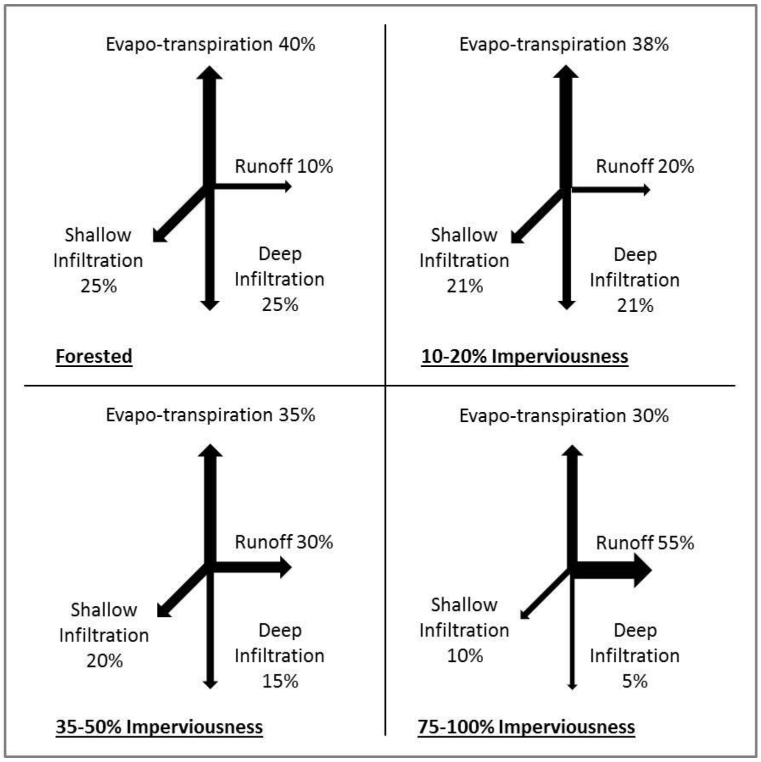

Figure 2.2 Changes in hydrologic flows with increasing impervious surface cover in urbanizing catchments (Paul & Meyer, 2001)

As seen in Table 2.2, many studies focus on the impacts of the built environment. A substantial numbers of studies include impervious surfaces as one of the control variables (Brody & Highfield, 2013; Brody et al., 2008; Brody et al., 2007a; Brody et al., 2012; Brody et al., 2007b). There appears to be a consensus that imperviousness is a quantifiable and accurate predictor of urbanization and it has unfavorable impacts on hydrological cycles (Arnold & Gibbons, 1996). Impervious surfaces are the result of urbanization and it has been reported that increased impervious surfaces cause higher runoff peaks and volume with a shortened lag time (Shuster et al., 2005). As we can see from Figure 2.2, increased imperviousness increases runoff volume and decreases infiltration.

Rose and Peters (2001) reported that peak discharge increases by 80% in urban catchments with 50% impervous area; peak flow is also 30-100% higher than in rural areas. In addition, other studies found that when impervious surface cover exceeds 10% of the watershed, runoff increases by 200-500% (Arnold & Gibbons, 1996; Paul & Meyer, 2001). Many other studies have noted the association between increased impervious surfaces and flood magnitudes (Dietz & Clausen, 2008; White & Greer, 2006; Williams & Wise, 2006).

While impervious surface pertains to development intensity and location issues, development density is about the pattern (Brody et al., 2011b). Since it is frequently assumed that development patterns in urban and suburban areas have impacts on environmental, social, and economic conditions of local communities (Brody et al., 2013b), studies focusing on the influence of development patterns on flood damage have increased recently. The flood problems caused by development density are mainly associated with sprawl due to rapid popluation growth and it accompanies haphazard outwardly expanding developments which inevitably result in land conversion. Also, land conversion usually becomes an issue when land surface changes from pervious to impervious. Sprawl is characterized by low density residential unit development and an over-consumption of land which used to be open space, wetlands, or agriculture (Brody et al., 2011b). Sprawl has also been a problem in Korea, particularly in the outskirts of Seoul. Due to this problem, the Korean government created a Green Belt around the city of Seoul in the 1970s.[15] Although sprawl is not as problematic as it was in the 1970s to the 1980s, the substantial portion of land in Seoul was converted from pervious to impervious.

These conversions of land increase the proportion of impervious surfaces which make these areas vulnerable to floods. Furthermore, the long distance between each area makes it difficult to foster effective flood resilient communities since it forces residents to rely on automobiles and increases the need for roads and parking lots which are mostly impermeable surfaces (Brody et al., 2013b). Brody et al. (2011a) conducted an empirical study examining the impact of development patterns on flood damage and found that high intensity development patterns have a positive effect on reducing flood loss while low intensity development adversely affects flood damange. They also addressed the negative correlation between development intensity and percentage of 100-year floodplain and suggested that the development should be located outside of vulnerable areas if low density development cannot be avoided.

However, Brody, et al. (2013a) later found that a high intensity development pattern actually increases the flood loss in spite of the presence of a drainage infrastructure. They explained that this conflicting result between those two studies might be caused by the presence of a high proportion of impervious surfaces in the high intensity developed area. It implies that high intensity development will be effective to

[15] As a growth management strategy, any kind of development was strictly prohibited within this area. Since 1999, this regulation has been gradually relaxed.

reduce the adverse impacts of floods only when pervious surface and drainage structures are considered at the same time.

While earlier studies usually measured patterns by development density, Brody et al. (2013b) employed landscape metrics to measure development patterns. In general, ecologists have used landscape metrics to identify the characteristics of natural landscape patterns of habitats or ecosystem structures. Brody et al. (2013b) measured five landscape metrics: total class area, number of patches, patch density, proximity, and connectance as indicators of urban development patterns across three development densities: high, medium, and low. They found that low intensity development has a far greater impact on increasing flood loss than a high intensity development. They concluded that medium intensity developments are negatively associated with flood damage since they are usually dense, relatively recently built suburban communities based on a master plan. Using land use/land cover change to measure development patterns, Brody et al. (2013a) generated the same results when it came to development patterns and pointed out that high intensity development reduces flood damage as long as urban development is located far from vulnerable areas such as a floodplain.

Another significant built environment factor is the presence of housing units. The number of housing units also increases the amount of property damage from flooding and it has been shown as statistically significant in some studies (Brody et al., 2011a; Brody et al., 2012).

These findings imply a ripple effect of the built environment on flood damage. Accumulated decisions made by individuals and governments when they build a new subdivision or even a small structure can bring about more severe damage from flood events if those decisions are made without consideration of long-term impacts of the built environment. In this sense, it is worth investigating the impact of built environment on flooding and associated losses in depth to guide decision makers to make the informed decisions. Additionally, built environment should be focused rather than other factors because planners and policy makers can modify the built environment with more ease by means of planning techniques and policies, compared to the socioeconomic and natural environment characteristics of a certain area. In doing so, we can expect that the levers which exacerbate flood damage can be found and fixed.

Based on the literature review so far, the next chapter will address the derived independent and contextual control variables including natural environmental factors that can contribute to flood loss by suggesting a conceptual framework for an analysis foundation.

CHAPTER III

CONCEPTUAL FRAMEWORK AND HYPOTHESES

3.1 Conceptual Framework

As discussed in the literature review, floods are the result of combinations of various factors including the physical (natural) environment, social and demographic (socioeconomic) characteristics, built environment, as well as flood mitigation and organizational capacity (Brody et al., 2011b; Mileti & Gailus, 2005). To isolate the impact of the built environment in explaining flood damage, other factors contributing to flood losses must be examined as control variables. For this study, built environment factors are the independent variables and other four groups of factors are included in the model as control variables: the natural environment, the socioeconomic characteristics, mitigation, and organizational capacity.

Natural environmental factors are considered a major driver of flooding. As discussed in the literature review, many anecdotal and empirical studies pointed to the significant influence that natural environmental factors have on flood damage. It is also intuitive that natural environmental characteristics, such as precipitation and slope, will influence floods and flood damage. As discussed in the previous section, disasters are not solely created by nature, but the way societies behave; since damage from floods is mostly the result of interactions among systems that exist in a society, socioeconomic factors also must be considered in the model (Mileti & Gailus, 2005).

For decision makers, the built environmental, mitigation, and organizational factors can be more approachable than natural environmental variables and socioeconomic factors; this is due to the fact that these variables are easier to control as opposed to attempting to change the climate pattern or characteristics of the residents when building flood risk reduction strategies. To reduce the adverse impacts of floods from a planning perspective, natural environmental factors such as the amount of precipitation or topographic characteristics are less likely to be the objects of planning. The built environment and the mitigation or organizational capacity of the local governments in dealing with hazards has more possibility for improvement by planning measures such as managing development density or increasing the capacity of drainage infrastructure using proper land use or hazard plans. With this reason in mind, the built environment characteristics of Seoul are viewed as variables of interests while assessing the factors that leading to flood damage among districts in Seoul.

The conceptual framework of this study has been generated based on the literature review and is illustrated in Figure 3.1. This figure shows the conceptual relationship between the factors driving flood damage, which are then statistically analyzed in the study. Five categories of variable, the built environment, natural environment, socioeconomic factors, mitigation, and organizational capacity are statistically examined using a panel regression model. This analysis allows us to gain a better understanding of the impacts of built environment factors (independent variable) on flood damage (dependent variable), while controlling the influences of other groups of variables (control variables).

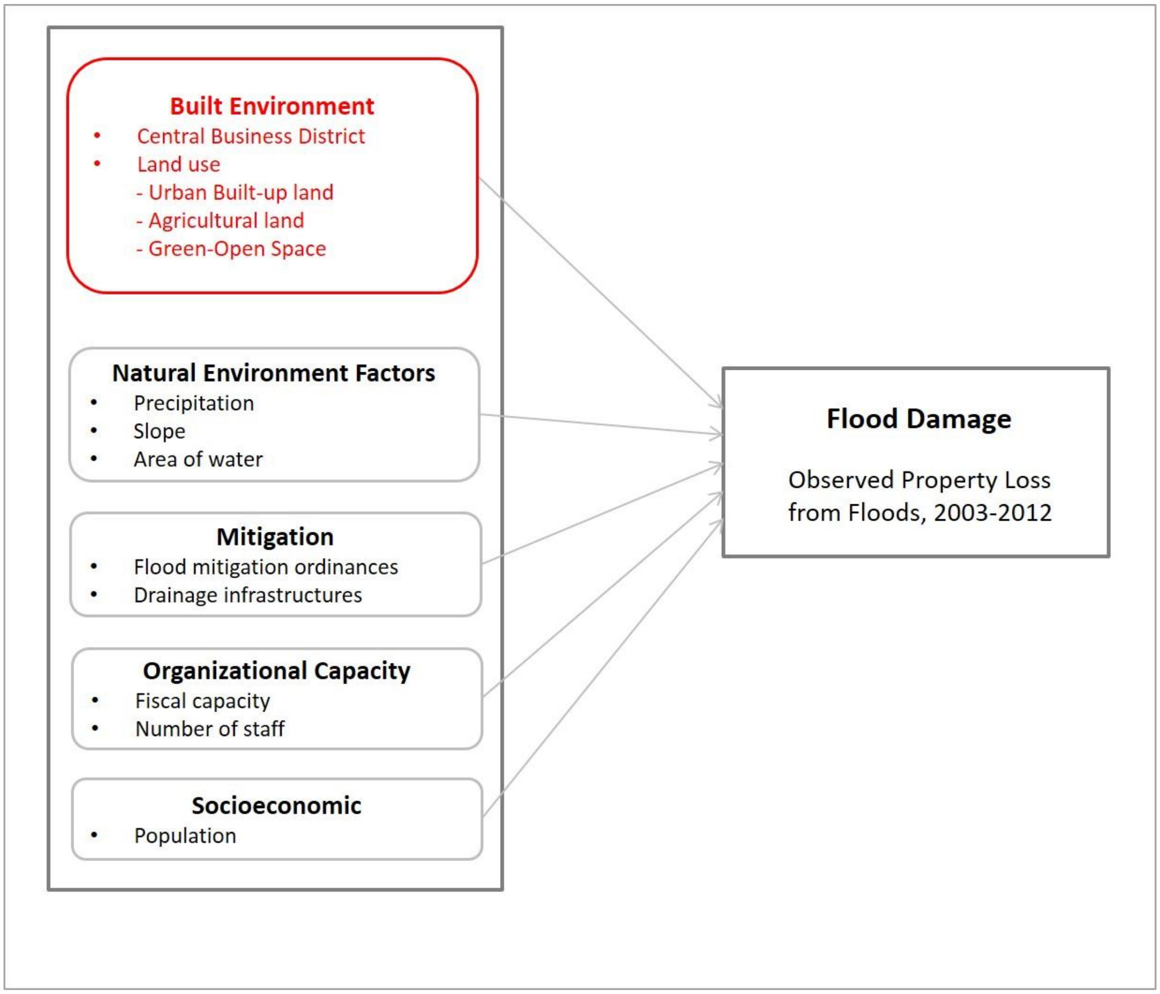

Figure 3.1 Research framework

3.2 Dependent Variable: Flood Loss

The dependent variable of this study is actual property loss from flooding each year for 10 years from 2003 to 2012 across 25 districts in Seoul. Although there is no academic consensus on the definition of flood loss or flood damage, the term generally refers to "something that is lost as a result of floods (Kang, 2009, p. 65)". In this study, the flood loss indicates the property loss from flooding, including buildings (private and public), vessels, agricultural land, and crops[16] (NDIC, 2013). Due to limited accurate data sources, the total property loss of the year was used. There are three data sources where the district level flood loss data is available: Water Resources Management Information System (WAMIS), National Disaster Information Center (NDIC), and the Seoul Metropolitan Government (Seoul Statistics). While WAMIS provides categorized property loss data, it does not have data for the years 2007, 2011, or 2012. NDIC also has categorized loss, but it only has the data from 2008. The other available source is Seoul Statistics under the supervision of the Seoul government. This database covers the entire study period from 2003 to 2012, but reports the total property loss data only since 2006.

The data of the property damage from flooding is collected by the lowest level of administrative ward[17] (*dong*) through reports by the property owners and investigations by officials. The data then goes to the Ministry of Public Safety and Security through *Gu* (autonomous districts) and *Si* (the Seoul Metropolitan Government). Based on the gathered data, the Ministry of Public Safety and Security publishes a nation-wide year book of natural disasters regarding the statistics of the disasters the country experiences each year[18]. It provides data from national and regional level flood loss, not the local level.

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[16] The proportion of the loss of vessels is negligible.
[17] As of 2013, the number of *dong* in Seoul is 522 (The Seoul Government, 2013b).
[18] It does not contain the local level flood loss.

3.3 Independent Variable: Built Environment

As discussed in the literature review, a number of previous studies have attempted to investigate the influence of the built environment on flooding and flood losses. Most of these studies concluded that built environment characteristics of the study area such as impervious surfaces, development pattern, and land use/land cover has certain impact on flooding.

This study examined two groups of built environment characteristics as independent variables: land use and Central Business District (CBD).

3.3.1 Land Use

The previously conducted studies on the effects of the built environment on flooding found that land use/land cover (LULC) does affect flood losses and each category of LULC has different magnitude and direction of the impact. LULC can be divided into two groups according to its properties. One is natural land cover such as soils and vegetation and the other one is human land use, where human development occurs. Urban development usually creates impermeable surfaces covered by concrete or cement such as streets, parking lots, or sidewalks, which makes infiltration of rain water difficult (Highfield, 2008). As discussed at length in Section 2, impervious surfaces are the result of development and have unfavorable impacts on flooding. In this sense, land use status can be a good indicator of impervious surfaces, which are a major driver of flooding.

Anderson (1976) classifies LULC into two levels (Level 1 and Level 2) based upon remote sensor data. This study utilizes Anderson's classification schemes to categorize the land use in Seoul by choosing three measures: urban built-up land, agricultural land, and green-open space.

3.3.1.1 Urban Built-up Land

According to Anderson 1976, urban built-up land is predominantly covered by manmade structures with large portions of the land being occupied by roads, utilities, institutions, and residential, industrial and commercial complexes (Anderson, 1976). With high development density, urban built-up land is likely to have a high proportion of impervious surfaces and should have increase flood loss.

Hypothesis 1: Urban built-up land will increase the amount of flood losses in the district.

3.3.1.2 Agricultural Land

Agricultural land is another type of land cover that may influence the extent of flood loss in a district. It is comprised of the land occupied by cropland, orchards and vineyards. Although agricultural land is not considered as developed as urban built-up land, it is thought that modern agricultural operations may have an adverse impact on flood damage due to soil compaction caused by ploughing and heavy machinery, which increases the rate of surface runoff (O'Connell et al., 2007; Pattison & Lane, 2011).

Hypothesis 2: Agricultural land will increase the amount of flood losses in the district.

3.3.1.3 Green/Open Space

While it is widely known that vegetation covered land can decrease flooding and flood losses with its low imperviousness and ability to absorb rain water due to plants, relatively little attention has been given to the role of open space. Recently, many studies have found a positive effect of open space on flood risk reduction, as such the National Flood Insurance Program (NFIP) Community Rating System (CRS) encourages communities to preserve open space as an avoidance strategy for flood mitigation (Brody & Highfield, 2013). Having open space in flood-prone areas can force people and their property away from possible flood damage. Also, even if it is not in a flood-prone area, open space (such as a playground) can act as a form of water detention by allowing the water to flood into the open space as opposed to critical facilities.

Hypothesis 3: Green-open space will increase the amount of flood losses in the district.

3.3.2 Central Business District (CBD)

While many existing studies have addressed the impact of the built environment as a land use or land cover category, there has been little attention given to CBD as an explanatory variable to show the characteristics of the built environment in urban areas. Although there is no general consensus on the definition of CBD, it is usually characterized by a concentration of high rise buildings with a commercial and financial center of a large city (Fogelson, 1993). CBD is differentiated from urban built-up land in that it has few residential areas in it.

As addressed in Section 1, Seoul experienced rapid urbanization and population concentration in the 1960s (Lee et al., 2009). To prevent over-concentration in the center of Seoul and to promote balanced development of the city, a decentralization of urban development was implemented in the late 1960s. Two sub-centers were planned and built away from the CBD to disperse facilities that attract population concentration. These areas were previously agricultural land until the 1970s and were developed as a new town, including a massive apartment complex, commercial area, and financial institutions with well-established infrastructure. To encourage people to move to the new town from the center of the city, the national government decided to relocate several prestigious schools first and prevented the opening of new schools in the center of Seoul. As a result, *Gangnam-gu*, one of newly planned sub-centers, and its two adjacent districts (*Seocho-gu* and *Songpa-gu*) became the wealthiest communities in Seoul (Kim & Han, 2012). Currently, Seoul has three more spontaneously formed sub-centers.

The CBD can be an indicator showing high flood risk and the possibility of flood loss in an area. If a CBD or secondary CBD is located in a district, the area is likely to have a large migrating population and be densely developed. [19] Thus, high impervious

[19] The secondary CBD is a sub-center of a big city. In general, as a city grows to become a mega city with over 10 million populations, some sub-centers emerge around the edge of a city that can function as a CBD. These sub-centers absorb or prevent influx of population, traffic, or industries into the CBD. It is called, “Secondary CBD” in Korea

surfaces accompanied by concentration of high rise buildings can lead to higher runoff peaks and volume with a shortened lag time. On the other hand, this area may be well equipped with drainage infrastructures to protect the critical function of the district. Therefore, whether a district contains a CBD can be one of the factors contributing to the amount of flood damage, however the direction of the result is tentative. The traditional CBD (*Jongno-gu*) and one of the secondary CBDs (*Gangnam-gu*) experienced flash flooding which resulted in inundation in 2010 and 2011.

Hypothesis 4: Existence of a CBD or secondary CBD will have an impact on the amount of flood losses in the district.

3.4 Control Variables

3.4.1 Natural Environment Factors

3.4.1.1 Precipitation

Precipitation is usually the strongest factor responsible for causing floods and many existing studies have found that precipitation has the greatest impact on increasing flood damage (Brody et al., 2013a; Brody et al., 2008; Brody et al., 2007a; Brody et al., 2007b; Highfield & Brody, 2013). South Korea has been experiencing increased precipitation due to climate change and this is assumed to be a primary responsible for flash floods at the center of the city. There are four characteristics of precipitation that contribute to flooding: intensity, depth (amount), duration and distribution across the drainage basin (Highfield, 2008). Usually, the amount of precipitation is highly correlated with duration and distribution cannot be detected without spatial information about precipitation. Thus, this study examines the amount of rainfall and its intensity. The intensity of precipitation can be measured by the amount of rainfall within a certain time. If heavy rainfall is concentrated in a short period time, it can result in flooding because it exceeds the capacity of absorbing water of soil. Due to these factors, precipitation is expected to have a positive effect on flood damage.

3.4.1.2 Slope

It is widely known that the topography of a basin contributes to flooding. In general, steeper slopes can accelerate lag time thereby leading to faster runoff peaks and increased rainfall concentration (Brody et al., 2011b; Matthai, 1990). Many studies show that slope has a statistically significant impact on flood damage (Brody & Highfield, 2013; Highfield & Brody, 2013). Since Seoul is located in basin surrounded by high mountains and has a drastic variation in elevation throughout the city, it is assumed that the slope of the surrounding area has an impact on flood damage. The slope variable is measured by the average slope of the district using Digital Elevation Model (DEM) data of Seoul.

3.4.1.3 Area of Running Water

The existence of running water such as rivers or streams in the area can have impacts on flooding and associated damage. Usually water area has been measured by its shape – length and width – in the previous studies. Streams in longer and narrower basins are more likely to cause flooding than regularly shaped basins (Matthai, 1990). However, this study utilizes the area of running water in a district and it is expected to have an adverse impact on flood damage. Even so, examining the influence water area is still meaningful in that existence of water nearby increases the chance of inundation because typical flooding occurs from the overflowing of river or stream.

3.4.2 Socioeconomic Factors

3.4.2.1 Population

The population of Seoul has significantly increased since the early 1960s in tandem with rapid economic growth (Choi, 1999). Although Seoul accounts for less than one percent of the country's area, approximately 25% of the total population resided in Seoul as of 2010; this is a 42% increase from the year 1975 (KOSIS, 2013; The Seoul Government, 2013c).

Population change has been shown to be an important factor influencing flooding and corresponding damages. It also reflects the current state of the area such as its economic status and the degree of urbanization associated with development patterns (Brody et al., 2011b). Since these all contribute to the extent of flood damage, it is necessary to include the impact of population trends in this study. This variable is measured by the number of people who reside in the district and is expected to have positive effect on flood losses.

3.4.3 Organizational Capacity Factors

3.4.3.1 Local Governments' Fiscal Capacity

According to Brody, et al. (2010), orgnizational capacity can help reduce flood damage through a local governments' level of funding. Additionally, the financial resources a community possesses will impact its ability to implement flood mitigation measures, with wealthier communities having a larger capacity for mitigation. This study examines the fiscal capacity of municipalities using the revenue of local government based on property tax. It is expected that districts with higher fiscal capacity of the government are more likely to invest more on flood protection.

3.4.3.2 Number of Staff

The number of staff in a local government is also another indicator of organizational capacity. The more officials in a local government, the more effective hazard management can be expected. Because the number of staff and technical expertise can reflect the level of local governments' commitment to the citizen's safety and also increase the odds of implementation of flood mitigation policies (Kang, 2009). Thus, districts with a larger number of officials will experience lower amounts of losses from flooding events.

3.4.4 Flood Mitigation Factors

3.4.4.1 Flood mitigation ordinances

Flood mitigation ordinances of a local jurisdiction can capture the willingness of local government to reduce flooding and flood losses. The existence of flood mitigation ordinances demonstrate how a local jurisdiction is prepared to deal with hazards. Thus, it is related to the general attitude toward flood mitigation, as well as the level of commitment of a local government to alleviate flooding problems.

Since the 25 districts of Seoul do not have the authority to establish plans, their efforts to mitigate flood damage can only be reflected in district ordinances that are made and enforced by local councils of district governments. The dummy variable of flood mitigation ordinances can capture the effect of districts' efforts on the property damage that results from flooding events.

As of 2013, nine districts have enacted hazard related ordinances. *Gangnam-gu*, where floods occurred in 2011 and 2012, has enforcement regulations to recover and prevent future hazards. They added or modified floods related clauses after experiencing floods in 2011. These included the adoption of an alert system as well as the funding of plans for research and studies regarding hazards from an administrative perspective. However, *Seocho-gu*, which also experienced the same floods and recorded the largest flood loss from the flooding event, does not have such clauses even though they do have hazard related ordinances. Meanwhile, there are districts with no hazard related ordinances at all (ELIS, 2014). It is expected that districts with flood mitigation ordinances will experience lower amounts of flood losses.

3.4.4.2 Drainage Infrastructure

Drainage systems in urban areas are essential in reducing flood risks. Since urban areas are characterized by large proportions of impervious surfaces due to high development density, adequate drainage infrastructure with sufficient carrying capacity is considered the most effective way to prevent flooding. Lack of proper drainage infrastructure or ageing drainage system are some of the main factors impacting urban flooding (Jha et al., 2012). Since 2009, the Seoul Metropolitan Government has planned to increase the carrying capacity of drainage system in the city to cope with heavy rainfall due to climate change. It is expected that a district with more drainage infrastructure will experience less amount of flood loss.

CHAPTER IV

RESEARCH METHODS

This section consists of three sub-sections and outlines and addresses the research methods applied in this study. First, selected study area for this research is presented and described. Then, concept measurement of each variable employed is explained. The third section addresses data analysis methods used in this study. Finally, the validity threats of this study is discussed in the last sub-section.

4.1 Study Area

The spatial sample frame for this study is Seoul (37.33N, 127E), the capital city of South Korea located in the heart of the Korean Peninsula. As of 2014, approximately 10.3 million people – 21% of total population – living in an area of 605.41 Km^2 – 0.6% of the total land area of the country. The city is diverse in elevation being surrounded by a number of mountain peaks of 500 meters or more above sea level. The climate of Seoul is temperate but it is changing to sub-tropic (The Seoul Government, 2013b). Based on 30 years data (1981-2010), the annual mean precipitation is 1450.5 *mm*, more than 70% of annual precipitation concentrates on June to September showing substantial seasonal fluctuation (KMA, 2014).

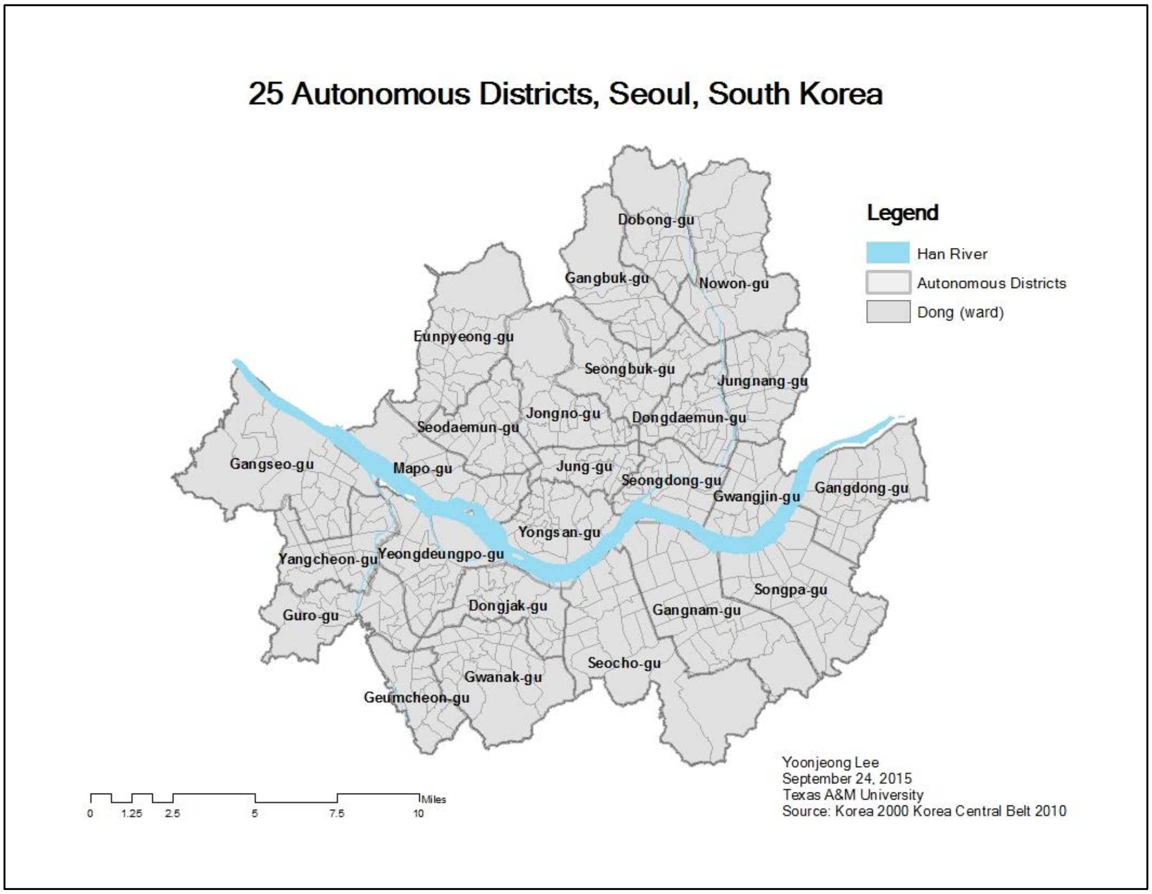

Figure 4.1 25 Districts in Seoul, Korea

The unit of analysis is *gu*, administrative districts under the Seoul Metropolitan Government. As illustrated in Figure 4.1, there are 25 districts in Seoul and the study period is 2003 to 2012. The data was collected based on each jurisdiction considering the data availability and accessibility.

As discussed at length in Section 1, Seoul experienced rapid and intensive urbanization since the 1960s after devastation by the Korean War (1950-1953). While the city accomplished remarkable economic growth, explosive population increase and high density development occurred subsequently. These built environment transformation has been combined with climate change and caused urban flooding issue since the late 2000s. With 10-year panel data, this sample should allow the results of the study to be generalized to other mega cities that share similar climatic characteristics.

4.2 Concept Measurement

4.2.1 Dependent Variable: Flood Loss

The dependent variable of this study is observed property loss from floods recorded each year, measured as the actual loss (monetary unit is Korean won[20]) for 10 years from 2003 to 2012 across 25 administrative districts in Seoul. It is flood property loss, which consists of buildings, vessels[21], agricultural land, and crops (NDIC, 2013). Considering the inflation, the actual flood loss of each year was multiplied by the Consumer Price Index (year 2010=100). The data was collected from two sources: Water Resources Management Information System (WAMIS) and Seoul Statistics. Flood loss data is skewed so it was log-transformed to derive normal distribution.

4.2.2 Independent Variables: Built Environment

4.2.2.1 Land Use (Category)

The Land use variables are broken into three categories: urban/built-up land,

[20] 1 dollar ≈ 1070.21 won as of February 12, 2014

[21] The year of 2007, 2011 and 2012 data were collected from Seoul Statistics because WAMIS does not have those years' data. Seoul Statistics reports the total flood loss only so the loss of vessels had to be included. However, the portion is negligible.

agricultural land, and green/open space. These are measured by the proportion of each "land category" occupied, based on the cadastral records which were generated by the Ministry of Land, Infrastructure, and Transportation (MOLIT). According to the "Act on Land Survey, Waterway Survey and Cadastral Records", the definition of land category is "a kind of land which is classified according to its primary use, and registered in the cadastral record" (See Figure 4.2). The purpose of the cadastral records is to have accurate information of each parcel of land for tax purposes in the jurisdiction. The purpose of the cadastral records is to have accurate information of each parcel of land for tax purposes in the jurisdiction. These records contain the location/area, identification number, and the land category indicating the primary use of the land. The land category is designated after a strict examination by the municipality of zoning and other accompanying land use plans. When the primary use of land changes or a landowner wants to change it, any landowner must file a land category change application with the authority. Alteration of a land category also needs to go through rigorous investigation by authorities due to the fact that it influences the tax revenue because it is directly related to the land's market value.

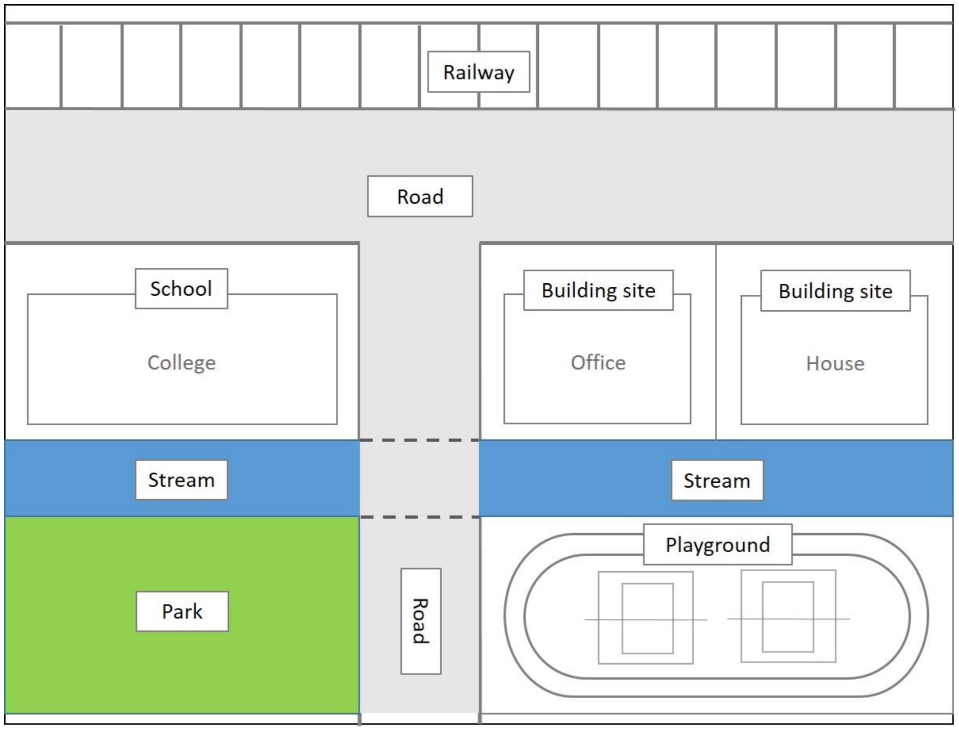

Figure 4.2 Land categories based on the primary use and current status (Lee, 2015)

` There are 28 land categories that are used and three of them do not exist in Seoul (mineral spring site, saltern, and fish farm). Among 25 land categories, I reclassified them into three groups based on Anderson's Level 2 Land Use Classification: urban/built-up land, agricultural land, and green/open space (Anderson, 1976). Cronbach's Alpha test[22] was conducted when reclassified to assure the reliability.

$$Land\ Use\ (\%) = \frac{\sum Area\ of\ the\ land\ category}{total\ land}(m^2) * 100$$

As illustrated in Figure 4.3, the urban/built-up land variable is a sum of eight

[22] Agricultural land: 0.7564, Urban built-up land: 0.7565, Green-open space: 0.7553

land categories: commercial and residential land (building site), school, parking lot, warehouse, factory, railway, road, and gas station. These land categories are likely to be accompanied by high impervious surfaces, high development density, and high population; the combination of these variables can cause flooding and flood loss. Urban built-up land accounts for approximately 60% of total land in Seoul. The agricultural land variable is measured by merging three types of land, paddy field, dry paddy field and orchard. Although the proportion of agricultural land in Seoul is relatively small as 4%, it needs to be included in the model because the flood loss counts the damage to agricultural land and crops. The last land use variable is green/open space and it is measured by the sum of park, recreation park and playground. The land category of forestland had to be dropped due to high correlation with slope ($r = 0.89$, $p < 0.01$) even though it talks up 23% of total land in Seoul. The green/open space variable in this study occupies 2.2% of total land in Seoul. Although rangeland in Anderson's Classification is matched with 'ranch' in Cadastral Records, I decided not to include ranchland into the model because the area of ranchland in Seoul is negligible[23]. Wetland, barren land, tundra, and perennial snow or ice in Anderson's LULC classification are either nonexistent or undefined in Korean Land Cadastral Records. Two of control variables, area of running water and drainage infrastructure were also measured by using the same scheme. It will be addressed in detail in Section 4.2.3. Control Variables section.

[23] Only two out of twenty-five districts have ranchland (a proportion of 0.0011 of the total land in Seoul).

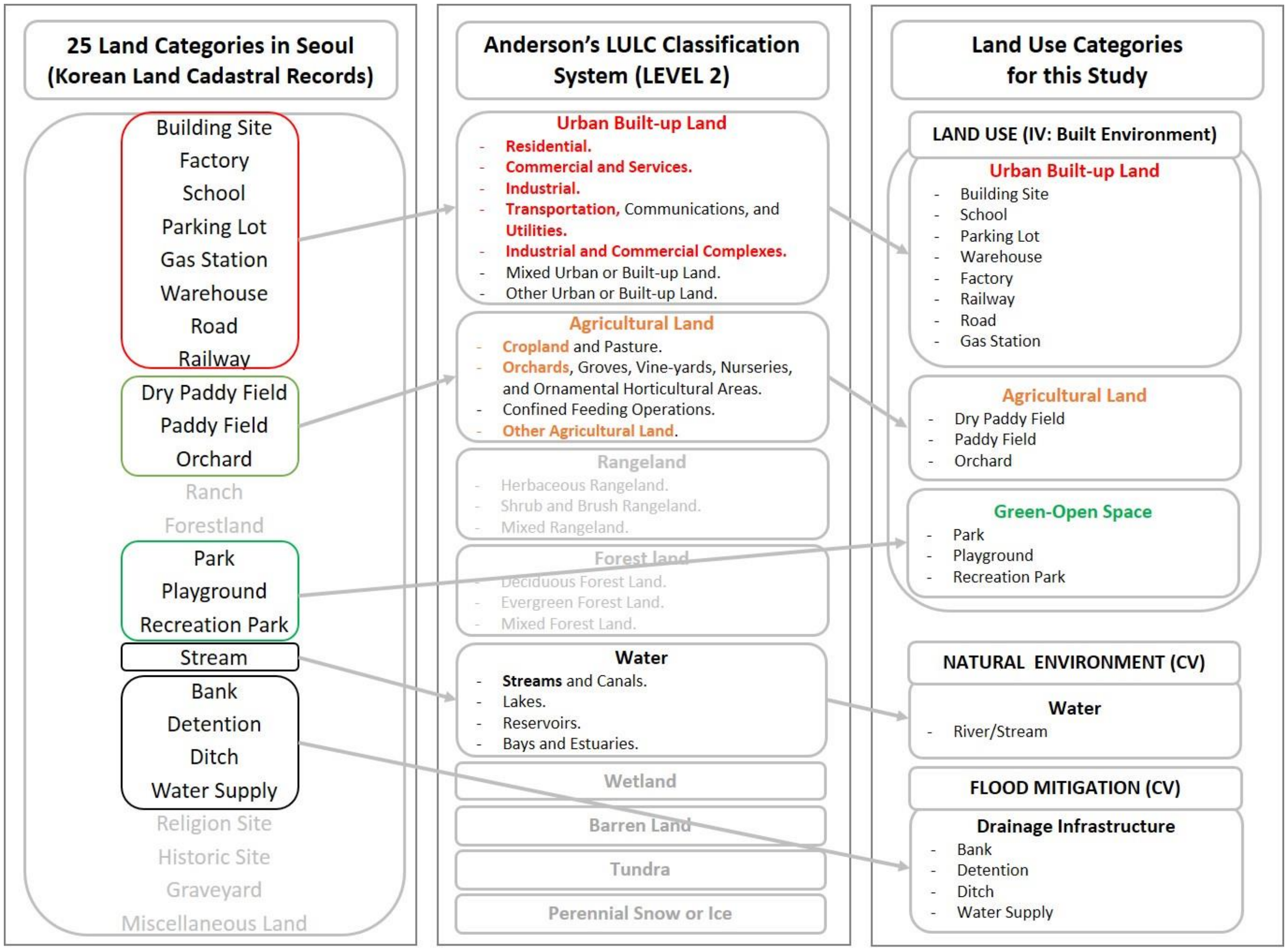

Figure 4.3 Reclassification of land use categories for variables[24]

[24] IV=Independent Variable, CV: Control Variable

4.2.2.2 Central Business District (CBD)

The Central Business District (CBD) is measured as a dummy variable: coded 1if a CBD or secondary CBD is located in a district or 0 if the district lacks a CBD.

4.2.3 Control Variables

To effectively estimate the impacts of the built environment on flood loss, it is essential to include other factors explaining flood damage as control variables. For this study, four categories of control variables are examined: natural environment, socio-economic, mitigation, and organizational capacity factors.

4.2.3.1 Natural Environment Factors

In this model, four environment factors are measured as predictors: total precipitation, hourly maximum precipitation, mean slope, and the area of running water (river/stream).

Precipitation

Precipitation data was obtained from the National Climate Data Service System (NCDSS) where data was recorded by weather centers in each district. Every district has one weather station to monitor the weather conditions of the city. The total precipitation is the annual surface precipitation during 2003 – 2012. In addition to total precipitation, hourly maximum precipitation was included in the model to estimate the impact of rain intensity and was measured by the average annual maximum value of precipitation within an hour.

Slope

Mean slope of each district was calculated in ArcGIS using the native DEM file, obtained from the Ministry of Environment. A slope raster was created from the DEM and the mean slope of each district was calculated using Zonal Statistics in Spatial Analyst tools.

Area of Running water

The area of running water data was obtained from the land cadastral records and measured by the proportion land that was occupied by moving water (river/stream) within the district. Under the “Act on Land Survey, Waterway Survey and Cadastral Records”, the Ministry of Land, Infrastructure, and Transportation investigates the area of running water every year and records yearly changes on water area due to stream flow diversion or drought.

4.2.3.2 Socioeconomic Factors

Number of Registered Population

The registered population refers to the number of individuals registered to the district each year. Unlike the census, it also includes the number of individuals who may not physically reside in the district. However, it shows yearly movement of immigrants and emigrants better than the census because it is generated every year by the district government. The data was obtained from Korean Statistical Information Service (KOSIS).

4.2.3.3 Flood Mitigation Factors

Drainage Infrastructure

As illustrated in Figure 4.3, drainage infrastructure is measured by the proportion of the land occupied by drainage infrastructure in the district: bank, ditch (drain), detention pond and water supply system (water inlet, reservoir, water conveyance, and water distributing facilities). These are artificial infrastructures, and are expected to function to reduce flood risk. There are existing studies that attempted to examine the effects of drainage infrastructure explaining flood damage. However, these studies were limited to simply accounting for the number of dams in the study areas. Such studies could improve the models used elsewhere by including the drainage infrastructure as one of the control variables.

The drainage infrastructure included here is calculated as follows.

$$Drainage\ Infrastructure\ (\%) = \frac{\sum Area\ of\ the\ land\ being\ used\ for\ Drainage\ Infrastructure}{total\ land}(m^2) * 100$$

The data was collected from the Seoul Statistics which is generated by the Seoul Government.

Flood Ordinance

This variable was measured as a dummy variable and the panel data was lagged to capture the effect of the established ordinances from the previous year. Although most of the hazard ordinances in Seoul are likely to be vague and merely state the will of district government to reduce flood damage (rather than specific strategies or action plan), it is still meaningful to examine the effect of these ordinances because they show the main agenda for district governments of the year. The dummy variable of flood mitigation ordinances is coded 1 if a district has a flood related clause in their hazard ordinance. If a district does not have any hazard ordinance or used to have one but abolished it sometime in the past, it is coded as 0. The data was collected from Enhanced Local Laws and Regulations Information System (ELIS) under supervision of the Ministry of the Interior.

4.2.3.4 Organizational Capacity Factors

In this study, two organizational capacity factors were examined: fiscal capacity and the number of officials.

Fiscal Self-Reliance Ratio (FSRR)

The fiscal capacity of municipalities is measured by the Fiscal Self-Reliance Ratio of each district. The local revenues of the 25 districts break down into self-financed revenues and intergovernmental transfers from the national and Seoul government. The ratio of the two is called the Fiscal Self-Reliance Ratio (FSRR) and it is calculated as below. FSRR is the most widely used index when measuring the fiscal capacity of local governments in Korea. Self-financed revenues of districts are composed of local taxes and non-tax revenues. The most important revenue source for districts is property tax which accounts for more than 80% of entire local taxes.[25] Non-tax revenues include user charges, fees, rents, and so on. (Kim et al., 2012a). Measuring the fiscal capacity based on total revenue, which includes intergovernmental transfers, is considered inadequate to reflect the actual ability of local governments financing their own projects. This is the main reason why FSRR is referred to as the most effective way of measuring the financial capacity or autonomy of local governments in Korea. This is one of the variables that previous studies did not measure when they explain flood loss.

[25] Property tax accounts approximately 83.2% of districts' total local taxes in 2012

Considering the impact that the fiscal capacity of local governments has on flood mitigation implementation, including this variable is expected to improve the model explaining flood loss. These data were obtained from The Seoul Government official website.

$$\text{Fiscal Self-Reliance Ratio (\%)} = \frac{local\ taxes + non\text{-}tax\ revenues}{total\ revenues} \times 100$$

The Number of Staff

The number of staff is measured by the number of public officers working for the district government during 2003-2012 and the data was acquired from the Seoul Statistics which is generated by the Seoul Government.

Table 4.1 summarizes the characteristics of each variable that were employed in this study.

Table 4.1 Variable descriptions

Variables	Operation	Type/ Unit	Source	Expected direction
Flood Loss	Property loss from flooding (won)[26]	won	WAMIS	
Natural Environment				
Precipitation	Mean annual / Hourly maximum precipitation in each district (mm)	continuous/mm	NCDSS	+
Slope	Mean slope of district (%)	continuous/ %	ME	+
Area of water	Proportion of water in district classified natural stream (%)	continuous / %	Seoul Statistic	+
Socioeconomic				
Population	Number of registered population in district	continuous	KOSIS	+
Built environment				
CBD/Secondary CBD	If a district contains a CBD or secondary CBD: 1 or 0	dummy	Previous Studies	+
Urban built-up land	Proportion of district classified as land for building site (residential/commercial), factory, school, parking lot, gas station, warehouse, road, railway (%)	continuous / %	Seoul Statistic	
Agricultural land	Proportion of district classified as land for dry paddy field, paddy field, and orchard (%)	continuous / %	Seoul Statistic	
Green-Open space	Proportion of district classified as land for park, playground, and recreation park (%)	continuous / %	Seoul Statistic	
Mitigation				
Flood ordinance	dummy (lagged) O: 1; X: 0	dummy	ELIS	-
Drainage infrastructure	Proportions of district classified as land for detention, ditch, water supply system (water inlet, water conveyance, water distributing facilities, rainwater pumping stations)	continuous / %	Seoul Statistic	-
Organizational Capacity				
Municipalities' fiscal capacity	Fiscal Self-Reliance Ratio	continuous / %	Statistics Korea	-
Number of staff	Number of officials of *gu*	continuous	Seoul Statistic	-

[26] Converted to US dollars for analysis.

4.3 Data Analysis

Data analysis for this study focuses on detecting the impact of the built environment on flood losses using panel regression model. The unit of analysis is administrative district, *gu* (n=25) and the study period is from 2003 to 2012. The analysis was conducted in two stages. The first phase of analysis aimed to better understand the trend of flood loss and land use status in the study area over the study period using descriptive statistics. This portion of the study also provides insights on the variation of flood loss and land use status among the 25 districts.

Second, using a panel regression model, the impacts of the built environment on observed property loss from floods were identified while controlling for multiple contextual variables across the study area. Panel data allowed me to overcome the limitations of cross-sectional and time-series analysis by controlling for individual and temporal effects. The utilization of a panel model addresses unobservable omitted variables more effectively than cross-sectional or time-series (Choi, 2004). A panel model seeks to test the hypotheses established in Section 3 through the use of multivariate statistical techniques. To select the proper panel model, a Hausman test was conducted first; the p-value of this test (p=0.9239)[27] suggests that a random-effects model should be used as opposed to a fixed-effects model. Additionally, the fact that the panel model for this study includes time-invariant variables such the CBD dummy and

[27] This is a robust model clustered by district.

the mean slope of each district further supports the use of random-effect model. The panel model for this study is determined to be as follows:

$$
\begin{aligned}
\ln floodloss_{it} = \; & \beta_0 + \beta_1 prech_{it} + \beta_2 prect_{it} + \beta_3 slope_i + \beta_4 water_{it} + \beta_5 pop_{it} \\
& + \beta_6 CBD_i + \beta_7 urbanbt_{it} + \beta_8 agri_{it} + \beta_9 grop_{it} + \beta_{10} drainf_{it} \\
& + \beta_{11} l\_ord_{it} + \beta_{12} fiscal_{it} + \beta_{13} staff_{it} + \varepsilon_{it}
\end{aligned}
$$

Where,

i: unit of analysis, gu, 1-25,

t: year, 2003-2012

$\ln floodloss$ = Log transformed flood loss

$prech$ = Hourly maximum precipitation

$prect$ = Average Annual Surface precipitation

$Slope$ = Mean slope

$water$ = River/Stream

Pop = Number of population

CBD = CBD or Secondary CBD dummy

$urbanbt$ = Urban built-up land

$agri$ = Agricultural land

$grop$ = Green-open space

$drainf$ = Drainage infrastructure

l_ord = Flood related ordinance dummy (lagged)

$fiscal$ = Fiscal Self-Reliance ratio

$staff$ = Number of staff

ε = Error term

Longitudinal analysis allows one to overcome the limitations of cross-sectional and time-series analysis by controlling for individual and temporal effects. The utilization of a panel model addresses unobservable omitted variables more effectively than cross-sectional or time-series do (Choi, 2004). Specifically, panel analyses can assess the dynamics of change over time, which cross-sectional models cannot detect. Also, it provides more degrees of freedom and more efficiency, compared to cross-sectional model.

Additionally, data analysis included conducting a series of tests to overcome potential violations. Although a panel regression allows researchers to break through the limitations that cross-sectional analysis poses, it can potentially violate assumptions that are different from those that cross-sectional studies encounter, such as serial autocorrelation, because observations in a panel model are not likely to be independent over time. In addition, multicollinearity and spatial autocorrelation can be issues as they are in cross-sectional design. To detect these potential violations, serial autocorrelation and spatial autocorrelation tests were carried out as well as correlation analysis using STATA. The test results indicate that the panel model used in this study did not violate any of these assumptions. Also, because the model used robust standard errors, it is expected that it will also be robust to conditional heteroscedasticity (Drukker, 2003).

To detect serial autocorrelation, a Wooldridge test for autocorrelation in panel data was conducted with the null hypothesis that no first-order autocorrelation exists; with the p-value, 0.1058, null hypothesis cannot be rejected. For the spatial autocorrelation test, a Moran's *I* test was employed and its resulting values indicate that the statistical model of this study is free from spatial autocorrelation issues as shown in Table 4.2.

Table 4.2 Spatial autocorrelation tests

H0: Error has No Spatial Autocorrelation	
LM Error (Burridge)	= 1.4605 (p = 0.2269)
H0: Spatial Lagged Dependent Variable has No Spatial Autocorrelation	
LM Lag (Anselin)	= 0.1566 (p = 0.6923)
H0: No General Spatial Autocorrelation	
LM SAC	= 4.2618 (p = 0.1187)

4.4 Validity Threats

Although all the efforts have been made to generate accurate results, it is not possible to completely avoid validity threats when conducting research. Cook and Campbell (1979) addressed four types of validity threats: statistical conclusion validity, construct validity, internal validity, and external validity.

4.4.1 Statistical Conclusion Validity

Statistical conclusion validity can be threated when:

- Assumptions of statistical tests are violated;
- The reliability of measures/treatment implementation is low;
- The sample size is small (low statistical power).

These situations can increase the possibility of Type I – "falsely rejecting the null hypothesis" – and Type II error – "falsely accepting the null hypothesis." This study has potential to risk experiencing a lower statistical power due to the comparatively small sample size by creating a wide confidence interval and therefore the critical region can contain zero. This will lead to misidentifying the impacts of independent variables. Specifically, there is a possibility of obtaining no statistically significant impact of built environment on floods even though the p-value of coefficients are reported as significant.

Due to data availability issues, local governments lower than *gu* were not able to be used as a unit of analysis thereby resulting in an annual sample size of 25. Although longitudinal analysis of the data increased the level of statistical power with an overall sample size of 250, it cannot be considered as substantially large number.

4.4.2 Internal Validity

Since multivariate statistical models allow us to estimate the effect of each independent variable holding other factors constant, a certain level of internal validity can be expected to be ensured as long as the required assumptions are satisfied. However, it is impossible to control all of the factors that may influence flood loss in this complex system, and therefore internal validity may be threatened which can lower the explanatory power of the model. I believe that the use of longitudinal analysis can reduce any possible threat and including all the necessary control variables based on the literatures increased internal validity.

4.4.3 Construct Validity

Construct validity seems to the most menacing of validity threats in this study as one of the main purposes of this study was to examine the effects of land use status on flood loss. According to the literature, the most proper method to measure the land use status is to use remote sensor data. However, this study utilizes land category data based on land cadastral data. Although Korean land cadastral data is known for its accuracy due to strict regulations and a long history since early 1900s, it has not been verified how well it reflects the actual land use status when compared to remote sensor data. The reclassification based on Anderson's scheme with careful matching of land category may alleviate this threat.

4.4.4 External Validity

External validity refers the generalizability of the results of this study to other places and context. Since this study focuses only on Seoul, there may be low external validity when trying to generalize the results and apply them to other situations. Specifically, Seoul is diverse in elevation since the city is surrounded by number of high mountains. Thus, the results of this study might not be applicable to a city with relatively flat topography. Since every community has different contextual characteristics, it is difficult to avoid low external validity completely.

CHAPTER V

RESULTS

This section consists of three parts related to data and analysis conducted as described in the previous Research Methods section. The first part of this section summarizes the descriptive statistics of variables employed in the model with particular focus on the dependent variable, flood losses and the independent variable of interest, land use in Seoul. The next portion presents the results of correlation analysis among all of the variables. Finally, the last part addresses the impacts of the built environment on flood losses in Seoul using panel regression analysis.

5.1 Descriptive Statistics and Preliminary Analysis

5.1.1 Flood Losses and Precipitation in Seoul

Over the study period (2003-2012), the total flood related property loss in Seoul was approximately $53,710,000 (in 2010 year prices) with over 85% of this amount occurring in 2010 and 2011 (See Figure 5.1). As seen on Figure 5.1, the flood losses in 2010 and 2011 are significantly larger than the losses from all other years. During these two years Seoul experienced urban flooding at the center of the city, which had not been observed before 2010. In 2010, the representing CBD and the secondary CBD area of Seoul were inundated resulting in large amounts of property damage. A year later, 2011, these two areas were flooded again causing higher damages than the year 2010. Severe torrential downpour triggered landslides in *Seocho-gu*, one of the 25 districts in Seoul, killing 24 people and resulting in tremendous property damages (See the flood loss of *Seocho-gu* in Figure 5.2 and 5.3, in the middle of the second line from the bottom).

These repetitive losses indicate failure on the part of both the Seoul Government as well as local jurisdictions to undertake preventative measures to avert the impact of potential floods.

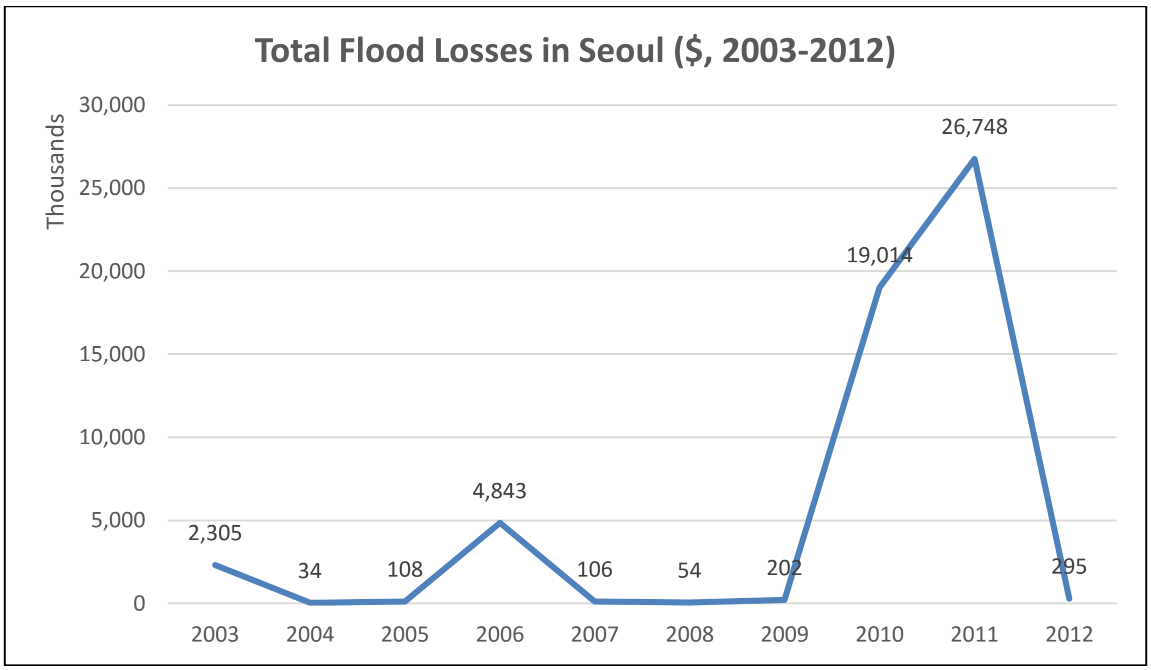

Figure 5.1 Trend of total flood losses in Seoul, 2003-2012

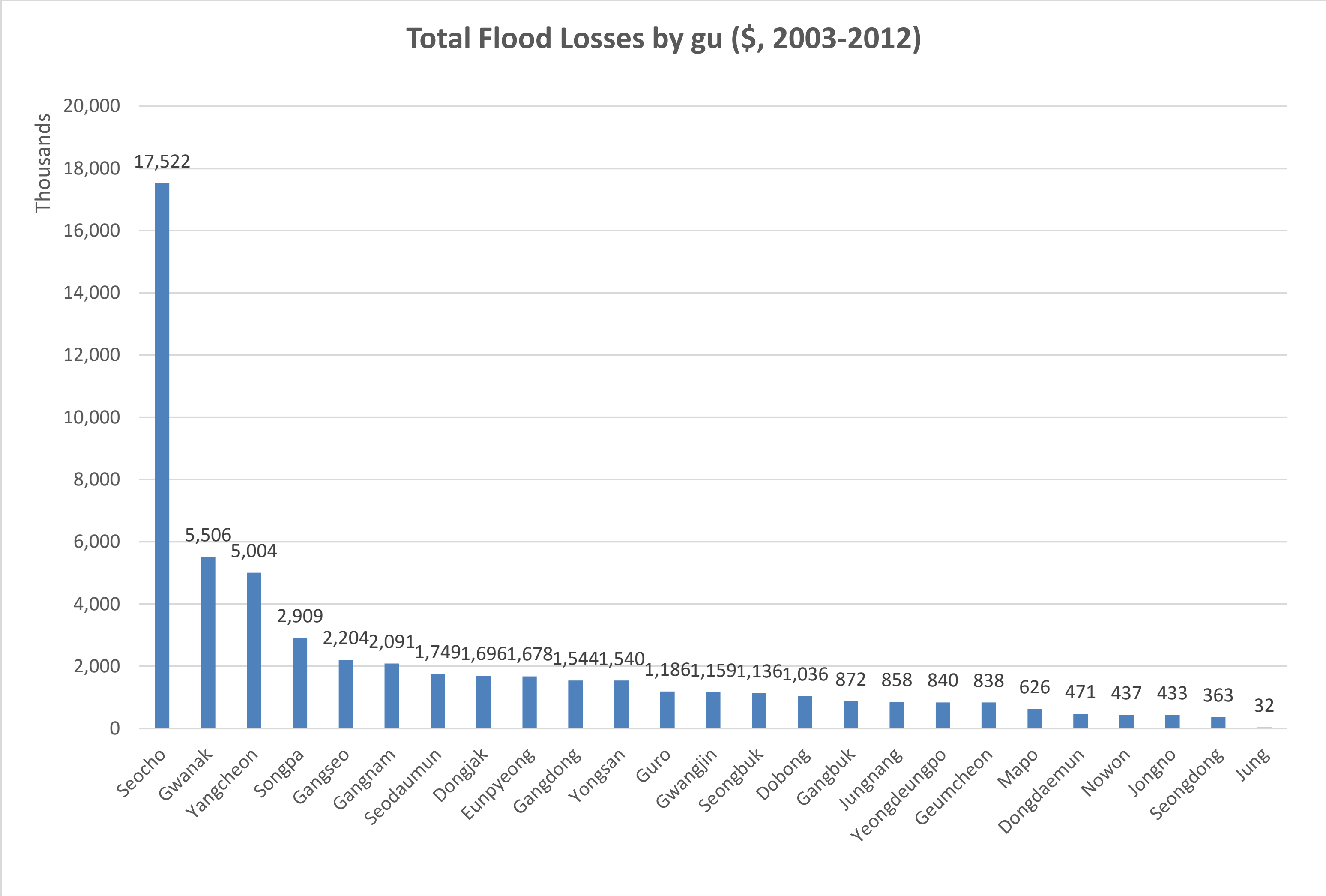

Figure 5.2 Rank of total flood losses in Seoul by *Gu*, 2003-2012

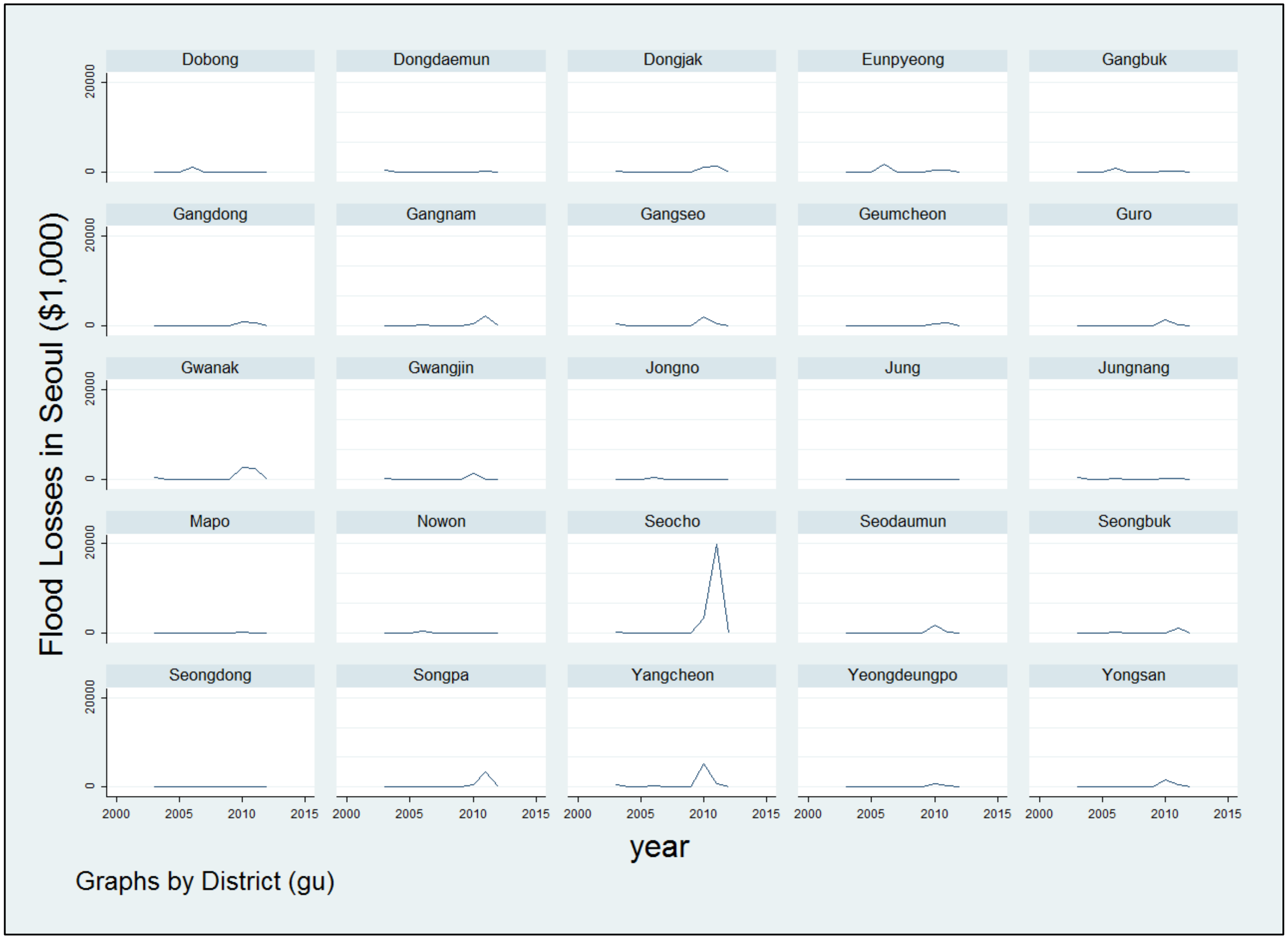

Figure 5.3 Trend of total flood losses in Seoul by *Gu*, 2003-2012

5.1.2 Descriptive Statistics of Variables

As a preliminary step to explanatory analyses, investigating descriptive statistics allows one to have better understanding of the nature of each variable by briefly sketching the characteristics of modeled variables. Table 5.1 presents the descriptive statistics of each variable employed in the panel regression model.

The total flood loss, the dependent variable of this study, is observed property loss from floods recorded each year from 2003 to 2012 across the 25 administrative districts (*gu*) in Seoul, and is given in US dollars. The Consumer Price Index was used to convert flood losses into real 2010 prices. Average flood loss was $254,200 with an inordinate standard deviation of $1,208,983 and the median at $859. Since flood losses are skewed to the right, the log transformation was used to derive a normal distribution. The following correlation analysis and panel regression model employed the log-transformed flood loss as the dependent variable.

Table 5.1 Descriptive statistics of variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Flood Losses (converted to $)[28]	246	218,332	1,038,396	0	14,737,805
Built Environment					
Urban built-up land (%)	250	57.23	12.72	35.91	85.44
Agricultural land (%)	250	3.84	4.44	0	20.09
Green-open space (%)	250	2.18	1.66	0.16	7.45
CBD (dummy)	250	0.24	0.43	0	1
Natural Environment					
Precipitation (Annual Mean, *mm*)	243	1,493.68	304.58	33	2,196.5
Precipitation (Hourly Maximum, *mm*)	243	61.89	43.94	2.5	317
Area of River/Stream (%)	250	8.4	8.66	0.3	32.67
Mean Slope (%)	250	5.32	3.15	0.8	12.21
Flood Mitigation					
Drainage Infrastructure (%)	250	1.9	1.28	0.46	5.28
Flood Ordinance (Lagged)	225	0.26	0.44	0	1
Organizational Capacity					
Financial Capacity (FSRR, %)	250	49.18	18.21	23	93
Number of Officials	250	1,237.15	91.83	1,064	1,468
Socioeconomic Characteristics					
Number of Population	250	408,220.6	125,358.3	129,465	685,279

All explanatory variables were grouped into categories related to the built and natural environment, flood mitigation and organizational capacity, as well as the socio-economic characteristics. As described in the Research Methods section, the data for

[28] Korean monetary unit (won) converted to US dollar.

land use variables were derived from the ‘Land Category’ in the cadastral records by reclassifying categories into three groups based on Anderson’s LULC classification scheme: urban built-up land, agricultural land and green-open space.

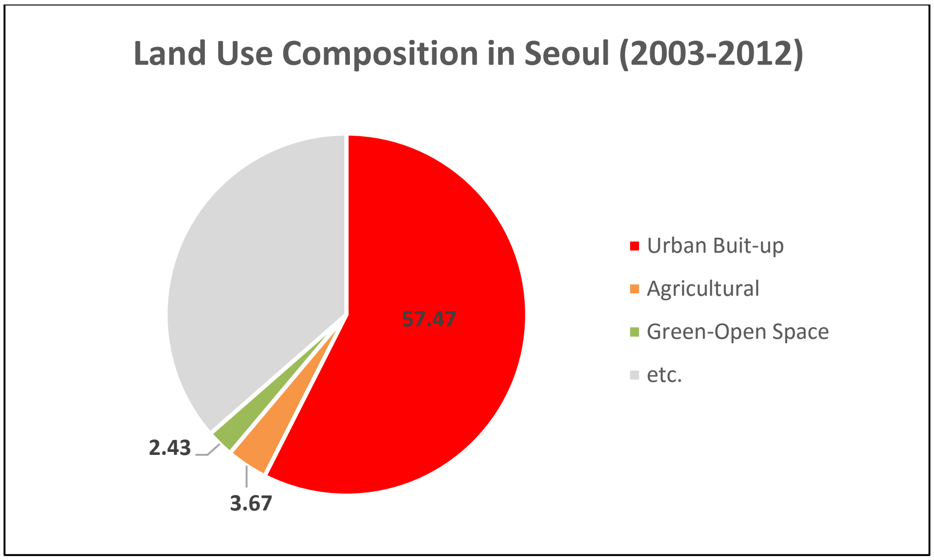

Figure 5.4 Land use composition in Seoul, 2003-2012

As illustrated in Figure 5.4, the urban built-up land accounts for approximately 57.23 percent of the study area in average. It ranges from 35.91 to 85.44 percent with a standard deviation of 12.72. Since Seoul had been already fully urbanized in the 1980s, there is no dramatic land use change observed over the study period. However, as shown in Figure 5.5, urban built-up land shows a steady increase over years.

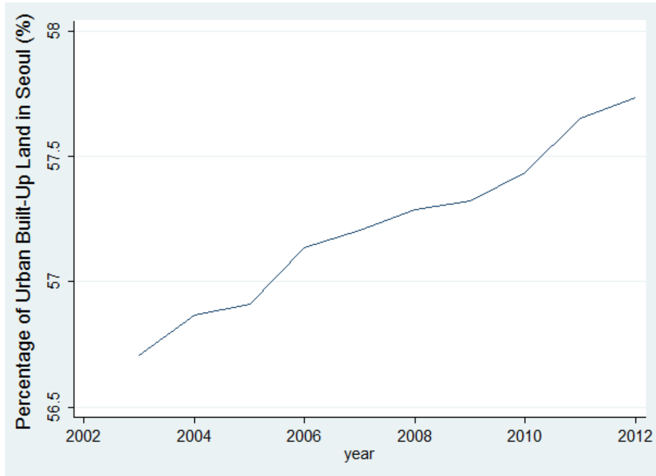

Figure 5.5 Proportion change of urban built-up land in Seoul, 2003-2012

On the contrary, agricultural land has decreased consistently over these years as illustrated by Figure 5.6. Agricultural land takes up 3.84 percent of the total land use and it ranges from 0 to 20.99 percent with a standard deviation of 4.44.

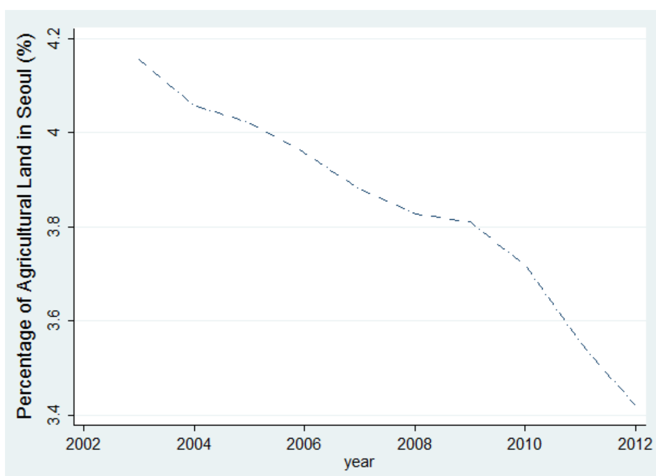

Figure 5.6 Proportion change of agricultural land in Seoul, 2003-2012

Green-open space accounts for approximately 2.18 percent of the total land use in average with a standard deviation of 1.66 and a range of 0.16 to 7.45 percent. As shown in Figure 5.7, green-open space shows a steady increase over the study period.

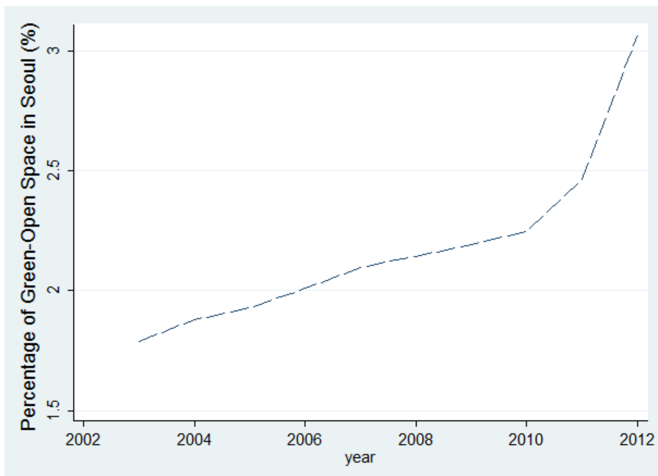

Figure 5.7 Proportion change of green-open space in Seoul, 2003-2012

With regard to natural environment variables, the average mean annual precipitation was 1493.68 *mm* and had minimum and maximum values of 33 *mm* (in 2010) and 2196.5 *mm* (in 2003), respectively, with a standard deviation of 304.58. Hourly maximum precipitation ranges from 2.5 *mm* (in 2010) to 317 *mm* (in 2006) with a standard deviation of 43.94 *mm* and an average of 61.89 *mm*. There has been a general consensus that Korea is experiencing climate change from temperate to sub-tropical, thus heavy rainfall in a short period of time has become more frequent (Chung et al., 2004; Kwon, 2007). While flooding events were triggered by heavy rainfall, the impacts cannot be fully attributed to meteorological factors. The data shows that Seoul recorded the highest total precipitation in 2003 and greatest hourly maximum precipitation in 2006 (See Figure 5.8), while the highest recorded damages were in 2010 and 2011. This result indicates that there are other factors besides meteorological changes that have contributed to increased flooding.

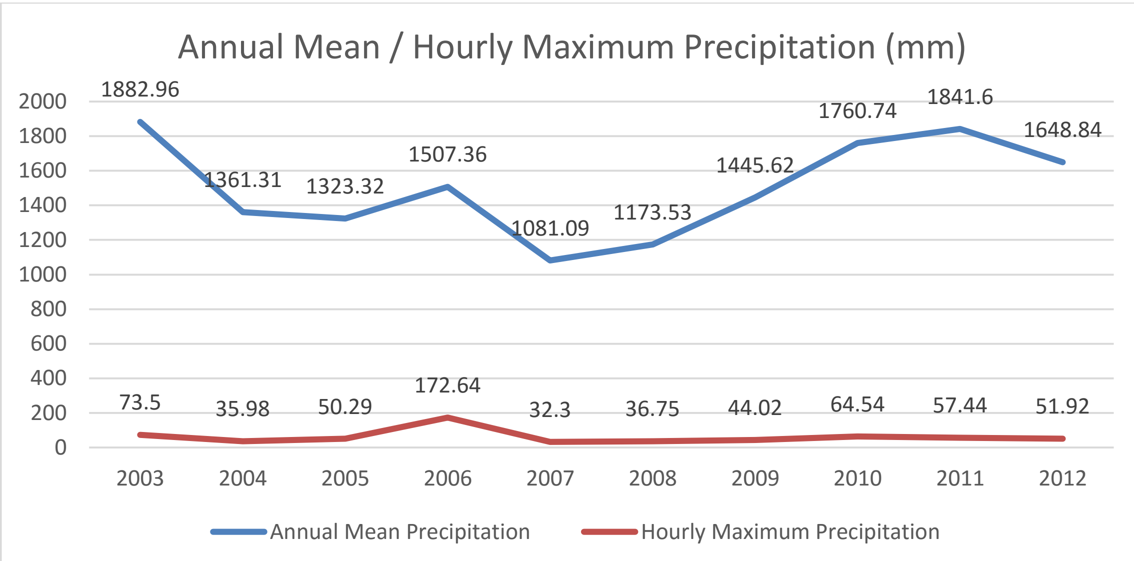

Figure 5.8 Annual mean and hourly maximum precipitation in Seoul, 2003-2012

5.1.3 Correlation Analysis

Prior to the panel regression, a correlation analysis among variables was conducted to explore the piece-wise correlation among model variables and to identify potential multicollinearity issues[29]. The panel regression model used does not contain any variables showing a high correlation coefficient (r), (where r >0.7). Although the correlation coefficients do not show causal effects of the independent variables on the dependent variable, it is still helpful to view a snapshot of the relationships amongst employed variables.

As seen in the correlation matrix presented in Table 5.2, the log transformed flood loss is correlated with six variables. Among the three land use variables, only agricultural land shows a statistically significant correlation with flood loss with the coefficient of 0.13 at the 0.05 level of significance. With regard to environmental characteristics control variables, two precipitation variables are positively correlated with flood losses at the 0.01 significance level. The coefficient of total precipitation is 0.4 and that of hourly maximum precipitation is 0.33. This result is consistent with the existing studies as well as the research hypothesis that precipitation is usually the strongest determinant of flooding and associated damages.

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[29] By conducting Pearson's correlation analysis, variables showing statistically significant high correlation (> 0.7) were dropped such as forestland (with slope, -0.9), the number of business (with Fiscal Self-Reliance Ratio, 0.8), education (with number of population, 0.8). With respect to the number of business and education, the Fiscal Self-Reliance Ratio (FSRR) can be considered as a proxy variable because FSRR reflects the Gross Regional Domestic Product; it is known that the wealth of community can reflect the education level of its residents. However, regarding forestland category, attempts were made to incorporate it into the model due to the fact that there was no proper proxy among the included variables and the proportion occupied by forestland in Seoul is substantial (> 20 percent). Also, before the correlation test was conducted, the panel model including forestland as a subset of green open space returned a substantially significant result showing that green open space is statistically significantly associated with reduced flood loss. Instead of slope, which showed high correlation with forestland, elevation or Topographic Wetness Index (TWI) was employed and analyzed, however both of these variables also produced high correlation with forestland. Therefore, I changed these slope related variables into normalized data (between 0 and 1) and interval data (quantile value), but these still showed high correlation with forestland. Finally, I tried to change the elements of green open space to include forestland while excluding other subsets. However, none of these attempts worked so the forestland variable was dropped.

Table 5.2 Correlation matrix

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Flood Loss (logged)	1													
2	Urban Built-up Land	-.061	1												
3	Agricultural Land	.134**	-.441***	1											
4	Green-Open Space	-.024	.303***	.076	1										
5	Central Business District	-.092	.40***	-.072	0.184***	1									
6	Precipitation (Total)	.395***	-.076	-.026	-.036	-.066	1								
7	Precipitation (Hourly Maximum)	-.33***	-.058	.022	-.071	-.072	.311***	1							
8	River/Stream	-.006	.075	.057	.182***	.028	-.046	-.023	1						
9	Mean Slope	-.003	-.497***	-.282***	-.482***	-.109*	.097	.035	-.582***	1					
10	Drainage Infrastructure	.000	.176***	.29***	.40***	-.285***	-.089	-.007	.398***	-.606***	1				
11	Flood Ordinance (lagged)	-.045	.131**	-.094	-.246***	.327***	-.039	-.043	.286***	-.137**	-.127**	1			
12	Fiscal Self-Reliance Ratio	.003	.206***	.14**	.311***	.602***	-.163**	-.07	.236***	-.231***	-.107*	.203***	1		
13	Number of Staff	.03	-.076	.28***	.24***	.339***	-.122*	.04	.152**	-.228***	-.146**	.151**	.393***	1	
14	Number of Population	.09	-.37***	.448***	.214***	-.254***	.074	.048	.022	-.018***	.204***	-.05	-.203***	.541***	1

Significant at *<0.1, **<0.05, ***0.01

In addition to the correlation between flood loss and independent variables, some noteworthy correlations were observed. Among the built environmental variables, urban built-up land, as expected, is negatively correlated with agricultural land ($r = -0.44$, $p<0.01$), but shows positive correlation with green open space ($r = 0.30$, $p<0.01$). This is not surprising as the green-open spaces which consists of park, recreational park, and playgrounds, etc. are likely to be located near urban built-up areas such as residential/commercial areas and schools. Urban built-up land also shows a positive correlation with drainage infrastructure ($r = 0.18$, $p<0.01$), which suggests that these urban-built up areas are well equipped with drainage systems. On the contrary, urban-built up land is negatively correlated with the registered population ($r = -0.37$, $p<0.01$). Perhaps this is because the urban built-up land variable includes sites not only for residential areas but also warehouses, gas stations, factories and schools, which are not likely to be places where people reside.

As expected, urban built-up land shows a positive correlation with the financial capacity of district governments, FSRR, ($r = 0.21$, $p<0.01$). The main source of FSRR is property tax that is usually levied on real estate for residential and commercial use. FSRR is also positively correlated with green-open space ($r = 0.31$, $p<0.01$) and is suggestive that wealthier communities have a larger budget to preserve green-open space or funds with which to create new parks or open spaces for public use.

Green-open space also shows a somewhat high positive correlation with drainage infrastructure with the coefficient of 0.4 at the 0.01 significance level. This is because the drainage infrastructure variable includes multi-function flood mitigation facilities such as public parks with rainwater storage/detention facilities. Agricultural land is also positively correlated with drainage infrastructure (r = 0.29, p<0.01), which can be attributed to the existence of irrigation and water supply system, which are necessary for agricultural operations.

Another built environment variable, CBD, is negatively correlated with drainage infrastructure as opposed to the hypothesis (r = -0.29, p<0.01). This may be due to the fact that the CBD is an indicator variable for whether or not a district has a CBD. Thus the CBD variable simply indicates the existence of a CBD or secondary CBD within a district, and does not necessarily represent CBD area, which, contrary to these results would likely be positively correlated with drainage infrastructure.

With respect to environment characteristic variables, two precipitation variables, annual mean and hourly maximum precipitation, are positively correlated as expected (r = 0.31, p<0.01). Mean slope shows negative correlations with urban built-up land, agricultural land, green-open space, and river/stream as anticipated, therefore adding reliability to the measurement of environment characteristic variables.

In terms of flood mitigation variables, drainage infrastructure presents some interesting but unexpected correlations with organizational capacity variables. Drainage infrastructure is negatively correlated with the lagged flood ordinance variable (r = -0.17, p<0.1), FSRR (r = -0.11, p<0.1), and the number of officials (r = -0.15, p<0.05). This result may imply that district governments in Seoul do not invest in building drainage infrastructure. Drainage infrastructure is positively correlated with the number of population (r = 0.2, p<0.05) because residential and commercial development is usually required to secure a certain level of drainage capacity by law. The other mitigation variable, lagged flood ordinance, demonstrates negative correlation with green-open space (r = -0.25, p<0.01) and mean slope (r = -0.14, p<0.01). This may indicate that districts with enough green-open space or steeper mean slope do not experience excessive flooding events and are therefore not in need of many drainage systems. On the contrary, flood ordinance is positively related with urban built-up land (r = 0.13, p<0.05), suggesting that the urbanized area where development occurs is well resourced with drainage infrastructure.

When it comes to organizational capacity variables, the financial capacity of a district government, FSRR, is positively correlated with the lagged flood ordinance variable as anticipated (r = 0.2, p<0.01). Wealthier local governments have more financial resources to implement flood mitigation strategies. Similarly, the number of officials are positively correlated with flood ordinance (r = 0.02, p<0.05) and FSRR (r = 0.39, p<0.01). The number of staff also presents relatively high positive correlation with the number of population (r = 0.54, p<0.01). Lastly, the number of population is negatively correlated with FSRR (r = -0.2, p<0.01) which implies that the financial capacity of local governments is not necessarily related with the number of registered residents within a district.

On the whole, the correlations amongst variables are mostly as expected and none of the model variables are highly correlated which would suggest a multicollinearity issue. While simple correlation amongst variables gives some guidance as to the relationships between variables, correlation analysis neither indicates causal effects nor controls for the indirect effects of other variables, thus making it impossible to assess the isolated contribution of each variable to flood loss. As such, the following section presents the results of a panel regression model in order to identify the marginal effects of each predictor variable when other variables are accounted for.

5.2 Examining the Impact of Built Environment on Flood Loss

This part of the analysis examines the impact of the built environment on observed flood losses over time, while controlling for the following control variables: environmental characteristics, socioeconomic characteristics and organizational capacity. Specifically, this sub-section seeks answers to the research questions that were posited in Section one;

1) What are the significant factors influencing flood damage in Seoul and which factor is the most influential?
2) Does the built environment have statistically significant impacts on flood damage in Seoul?

To answer those research questions, the dependent variable, property loss from flooding, was analyzed by conducting the panel regression model that was described in Section 4.

Table 5.3 Panel regression on flood loss

	Coefficient	Beta Coefficient	Robust Standard Error	Z	p-value	95% Confidence Interval	
Built Environment – Land Use & CBD							
Urban Built-up	0.1249	0.2779	0.0311	4.01	0.000	0.0639	0.1860
Agricultural	0.4037	0.3134	0.0805	5.01	0.000	0.2460	0.5614
Green-Open	-0.1096	-0.0318	0.2254	-0.49	0.627	-0.5513	0.3321
CBD	-2.8780	-0.2154	0.7512	-3.83	0.000	-4.3503	-1.4056
Natural Environment							
Precipitation (Annual Mean)	-0.0015	-0.0819	0.0014	-1.11	0.267	-0.0043	0.0012
Precipitation (Hourly Maximum)	0.0589	0.4527	0.0113	5.22	0.000	0.0368	0.0810
River/Stream	0.0712	0.1078	0.0343	2.08	0.038	0.0040	0.1384
Mean Slope	0.5443	0.3001	0.1670	3.26	0.001	0.2170	0.8717
Flood Mitigation							
Drainage Infrastructure	-0.0776	-0.0174	0.3327	-0.23	0.815	-0.7296	0.5744
Flood Ordinance (lagged)	0.5825	0.0449	0.6433	0.91	0.365	-0.6784	1.8433
Organizational Capacity							
Fiscal Self-Reliance Ratio	0.0184	0.0587	0.0192	0.96	0.336	-0.0191	0.0560
Number of Staff	0.0096	0.1541	0.0046	2.10	0.036	0.0006	0.0186
Socioeconomic							
Population	-0.0000	-0.0869	0.0000	-0.64	0.514	-0.0000	0.0000
Wald χ^2	11564.40						
p-value	0.0000						
R^2	0.599						n=215

5.2.1 The Impact of Built Environment on Flood Loss

With regard to land use factors, it was expected that land use status has statistically significant impacts on flood damage. Based on the results reported in Table 5.3, two out of three land use categories showed significant effects on flood loss: urban built-up land and agricultural land. The urban built-up land use variable was positive and significant at 0.001 level, which supports Hypothesis 1, 'Urban built-up land will increase the amount of flood losses in the district'. This result indicates that when all else is held constant, land uses, which include pavement causing high imperviousness such as residential, commercial and services (building site – for residential and commercial use –, school, parking lot, gas station, warehouse), industrial (factory), and transportation (road, railway), are associated with increased flood losses. The coefficient of the urban built-up land variable is 0.1249, which means a one percent increase in urban built-up land in a district will increase the flood loss by approximately 12.49%.

Another significant land use variable is agricultural land. The agricultural land variable had a statistically significant positive impact on flood loss at the 0.001 level, supporting Hypothesis 2 and agreeing with the result of the correlation analysis. Dry paddy field, paddy field, and orchard have adverse impacts on flood damage as many existing studies assert (Brody et al., 2013a; O'Connell et al., 2007; Pattison & Lane, 2011). The coefficient of agricultural land is 0.4037 and is interpreted that if agricultural land in a district increases by a one percent, the flood loss will be increased by approximately 40.37%. As expected, increasing the green-open space variable, which consists of park, recreational park, and playground, had a negative effect on flood loss, however, the effect was found to be statistically insignificant.

The last built environment variable, the CBD dummy, was negative and significant at the level of 0.001 with the coefficient of -2.8780, therefore supporting Hypothesis 3, which stated that the existence of a CBD or secondary CBD in a district will have a mitigating impact on the amount of flood losses in the district. The result showed that a district that has a CBD or secondary CBD area will experience almost 287.80% less flood damage than a district that does not have a CBD area in it.

With respect to the magnitude of the effect of each of the built environment variables, it was surprising to note that the most influential factor was agricultural land with a standardized coefficient (β) 0.3134. The second and third highest influential factors were urban built-up land (0.2779) and CBD (-0.2154).

Overall, three out of four built environment variables significantly supported hypotheses and confirmed that the built environment has statistically significant impacts on flood related property damage.

5.2.2 The Impact of Other Factors on Flood Loss

Other than the impacts of the built environment on flood damage, the panel regression model reported some noteworthy results regarding the influence of other control variables on flood loss. With regard to natural environment factors, three out of four variables appear to have statistically significant impacts on flood loss. First, there are two precipitation variables in the model: average annual surface precipitation and hourly maximum precipitation. As opposed to the correlation analysis that showed that both precipitation variables were positively correlated with flood loss, when controlling for other factors, the total precipitation was not significant in the panel regression model. However, hourly maximum precipitation was positive and highly significant at less than 1% significance level with the coefficient of 0.0589. Thus, a 1 *mm* increase in hourly maximum precipitation is associated with 5.89% increase in flood losses. This result suggests that rain intensity is more influential on the degree of flood damage than the actual amount of rainfall.

As expected, the mean slope of a district also showed a statistically significant positive effect on flood loss at the 1% significance level, which shows that a district with steeper slope is likely to experience more flood loss. The coefficient of the mean slope is 0.5443, which means that a one percent increase in the average slope of a district is associated with a 54.43% increase in flood damage. The last natural environment variable is area of river/stream; this variable was positive and significant at the 5% significance level with the coefficient of 0.0712, indicating that, when controlling other factors, a one percent increase in the area of moving water increases flood loss by 7.12%. This result suggests that a district with more running water experiences more flood loss.

The second group of control factors is flood mitigation and neither of the mitigation variables were found to be significant. Drainage infrastructure had a negative sign, but was statistically insignificant. Conversely, flood ordinance showed positive sign but like drainage infrastructure, was not statistically significant. Similar to drainage infrastructure variables, organizational capacity variables, produced results that were contrary to expectations. The financial capacity of *gu* (FSRR) had a positive effect on the dependent variable, but was statistically insignificant. Regarding the number of staff, results were found to be statistically significant but, surprisingly, positive at the 5% significance level with a coefficient of 0.0096. This may be due to the fact that other variables exist with respect to the human element that were not taken into account in this model, however this will be discussed in more length in the next section. Lastly, as expected the population had a positive effect on flood damages, but the effect was statistically insignificant.

Overall, the panel regression model seems to well predict the impact of the built environment on flood loss. With an exception of green-open space, other land use variables and the CBD dummy showed statistically significant results that support the Hypotheses posited in Section 3. Both urban built-up and agricultural land appeared to have adverse impacts on flood damage. In addition, the results suggest that CBD areas are likely to experience less flood loss, which could be due to better drainage infrastructure.

CHAPTER VI

DISCUSSIONS AND CONCLUSIONS

This sections includes a detailed discussion on the results of the statistical analyses conducted in the previous section. In addition, the topics that are worthy of further discussion are addressed. First, the key findings of explanatory analyses in terms of the independent and control variables that appeared to have effects on flood-related property loss are discussed. Then, policy implications and recommendations are provided for planners and policy makers based on the discussion. Next, the limitations of the study as well as the future research plans to overcome those limitations will be discussed. Finally, I describe the conclusions of the study.

6.1 Discussions

6.1.1 Discussions on the Results of Built Environment Factors

The results of the panel regression analysis focusing on the impacts of the built environment on flood losses revealed some notable findings. Two out of three land use categories as well as the CBD dummy variable had statistically significant impacts on flood related property losses in Seoul.

Surprisingly, the most influential of these variables was agricultural land. The agricultural land variable not only had the largest coefficient of 0.4037, but also showed the highest standardized coefficient (β) among the built environment variables. For the average area of *gu*, which was 24.2 km^2 with a mean flood loss of $ 218,332, the addition of 100 m^2 (approximately 1,076 ft^2) to the existing agricultural land was associated with an average increase of $36.42 in flood loss[30]. This result confirmed the conclusions of existing studies which have pointed out the adverse effects of agricultural land on flooding and its associated property damage due to modern agriculture operations, which are characterized by soil compaction from ploughing and heavy machinery (O'Connell et al., 2007; Pattison & Lane, 2011).

In particular, rice paddy agriculture, which is common in many Asian countries, necessitates the locking up of water to grow plants, this makes it difficult to drain water quickly when there is heavy rainfall. Although this study did not include floodplains as one of the variables, the location of agricultural land within the floodplain can be another reason for increased flooding. Much like many other large Asian cities, the city of Seoul was naturally formed around the flood plains which were useful for rice farming that could support a dietary culture which relied heavily on rice (Kundzewicz & Takeuchi, 1999). The location of agricultural land within the floodplain may naturally make it more vulnerable to flooding. Although the proportion of agricultural land in Seoul is

[30] Since the coefficients are semi-elastic due to log-transformed flood loss, the interpretation of the coefficients is '1 unit increase in explanatory variable is associated with β_{it} % increase/decrease in flood loss'. For land use variables in the panel regression model, the unit is percent, so 1 percent increase in agricultural land (242,000 m^2 = 0.01*24.2 km^2 results in a 40.37% increase in flood loss. Thus, 0.4037 * $218,332 (Average Flood Loss) = $88,140.63. Then, to scale this figure to 100 m^2 (1,076.39 ft^2) for a more intuitive interpretation, the average increase of flood loss, $88,140.63 was divided by 2,420.

relatively small (at 3.84%) and has been steadily decreasing over years (See Figure 5.6.), the level of impact is not negligible.

Another built environment variable that appears to have contributed to increased flood loss was urban built-up land, which accounts for almost 60% of the total land in Seoul. Although the coefficient and its magnitude of urban built-up land are relatively small compared to those of agricultural land, it is a great concern considering the steadily increasing proportion of urban built-up land in Seoul over the years.

The coefficient of urban built-up land was 0.1249 and in this case it is interpreted that 100 m^2 urban built-up land results in an approximate average increase of $11.27 in flood losses. This amount may look diminutive, but it indicates that a one percent increase in the urban built-up land in Seoul can result in approximately $682,300 in flood losses when all else is held constant. This result supports numerous existing studies that assert the unfavorable effect of urbanization or urban built-up land, characterized by high imperviousness, on flooding and its accompanying property loss (Arnold & Gibbons, 1996; Brody & Highfield, 2013; Brody et al., 2013b; Brody et al., 2012; Paul & Meyer, 2001). These findings also suggest the possible contribution of accumulated urban built-up land on the extraordinary urban flash flooding of Seoul in 2011 and 2012. The inundated CBD and the secondary CBD areas located in *Jongno-gu* and *Gangnam-gu* had never experienced flooding before 2010. The accumulated impervious surfaces due to the increased urban built-up land are likely to have crossed a threshold for flooding during heavy rainfall and thus contributed to flooding events.

The other built environment variable that appeared to have statistically significant effect on flood loss is the CBD dummy. Among the 25 districts, six had CBD or secondary CBD areas, and as expected, had a coefficient with a negative sign. The coefficient of CBD was -2.8780; this can be translated that when districts have a CBD or a secondary CBD, they will experience approximately $239,901.98[31] less flood damage than communities that do not have a CBD, when holding other factors constant. This result corroborated previous studies that demonstrated the importance of compact or cluster development in creating flood-resilient communities. As long as the development is planned in the 'right place', – avoiding flood-prone areas such as floodplain or coastal surge zones – new urban design, featured by higher net density, mixed land use, and pedestrian-friendly streets can contribute mitigating flood risks in urban areas (Arnold & Gibbons, 1996; Berke & Conroy, 2000; Berke et al., 2009; Brody et al., 2013b; Stevens et al., 2010; Williams & Wise, 2006).

In addition to supporting these existing studies, there are other potential reasons that could explain the favorable effect of CBD in this study. First, as described earlier, CBD areas are characterized by a concentration of high rise buildings in a large city with few dwelling units because the CBD is a center for commercial and financial business (Fogelson, 1993). Even if there are buildings present for residential use, they are likely to be mixed-use high rise buildings due to zonings and high land price. Thus, if flooding events occur, potential damage of residential structures can be diminished. Second,

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[31] The marginal effect of the CBD dummy variable was calculated with the following formula: y(exp(β) – 1). Thus, \$ 218,332 * ($e^{-2.8780}$ – 1) = - 239,901.98.

high-density urban areas tend to be equipped with strong drainage infrastructures, which can also contribute to mitigating flood related property loss within the CBD (Brody et al., 2013b).

Indeed, although the oldest CBD area of Seoul, located in *Jongno-gu*, experienced severe flash flooding in 2010 and 2011 that caused inundation of 10,000 m^2, including the widest traffic lanes in the country and 110 buildings; the amount of total flood loss over the study period was relatively small when compared to the repercussion of flooding outside of the CBD that brought about to the city (See Figure 5.2, the flood losses of *Jongno-gu* are fourth lowest among the 25 districts). This results could be due, in part, to the fact that this district had never been flooded before 2006 and no residential units exist along the inundated streets because this area is designated as the business and commercial zone as regulated by the zoning system. This may imply that flooding events do not necessarily lead to flood loss and the severity of flooding may not be directly related to the amount of flood loss depending upon the location where the flooding occurs.

6.1.2 Discussions on the Results of Other Factors

Another important result stemming from the panel regression analysis is the influence of other control variables contributing to flood losses. Among nine control variables, four factors appeared to have statistically significant effects on property damage from flooding. For the natural environment group, all the variables, except for total precipitation, were significant with expected directions. Hourly maximum precipitation was not only significant, but also had the highest standardized beta (β = 0.4527) among the entirety of variables that were employed in the panel regression model. This result confirmed previous studies that reported precipitation as the strongest factor influencing flood damage (Brody et al., 2013a; Brody et al., 2008; Brody et al., 2007a; Brody et al., 2007b; Highfield & Brody, 2013). The coefficient of hourly maximum precipitation was 0.0589 and is interpreted that a 1 *mm* increase in hourly maximum precipitation is associated with $12,860 in flood losses. This implies that the rain intensity is a more important driving factor rather than the total amount of rainfall received.

Two other natural environment variables, area of moving water and mean slope were significant and had the expected positive signs with regard to flood loss. The coefficient of moving water was 0.0711 and that of the mean slope was 0.5443. These results can be interpreted that a 100 m^2 increase in area of running water increases flood losses by approximately $6.41 and a one percent increase in mean slope can result in an approximate average increase of $118,833 in flood losses.

The rest of flood mitigation, organizational capacity, and the number of population were either insignificant or had the opposite direction of expectation. Drainage infrastructure had a negative sign but was not significant. Flood ordinance had a positive sign, opposed to the expectation, but was insignificant. Also, the number of population had a negative sign, but was not significant.

One unexpected effect was the coefficient representing the number of officials in a district government. Not only did it display a positive sign, but also was statistically significant. Some previous studies found the same negative significant effect of mitigation measures on flood damage and explained that this might be due to the fact that the presence of mitigation strategies acts as an indicator of frequent and severe floods in those communities (Brody & Highfield, 2013; Highfield & Brody, 2013). In this case, it can be interpreted that a larger number of staff might indicate the existence of urgent issues in a district that should be dealt with.

Usually, opposite direction against the expected direction may indicate the existence of multicollinearity (Highfield, 2008). However, no symptom of multicollinearity was detected when correlation and VIF analyses were conducted. There are two possible scenarios that brought about the opposite direction of impact of the number of staff. First, this might be contributed by a variable measurement issue. Since many of the districts in Seoul do not have a department or staff solely working on hazard mitigation but a temporary taskforce team is organized when flooding occurs. Thus, this study employed the total number of staff to explain the organizational capacity of a district government on flood loss, not the specific personnel working toward to hazard mitigation. This might be the one of reasons that resulted in the unexpected effect. Another possible reason for this counterintuitive direction might also be the fact that severe flash flooding occurred in only two of the recent years out of the ten-year study period. This may mean that the increase in efforts and number of city officials may not be reflected in the study period due to a lag affect[32]. As described in

[32] The model was also run using the lagged variable however results remained significant with a positive coefficient.

Section 3, *Gangnam-gu* established a flood related ordinance and increased the number of staff (an increase of 13 individuals in one year following the previous five years of non-hiring) after they experienced the first flooding event in 2010. However, despite their efforts they still experienced more flooding in 2011 and the flood loss was almost five times more than 2010. This might imply that one needs more time to examine the effect of increased numbers of staff on contributions to mitigating flood losses in a district.

6.2 Policy Implications and Recommendations

Based on the findings from examining the impacts of the built environment on flood losses, this portion of the study provides guidance for policy makers and city planners to be better informed about potential flood mitigation strategies within their respective urban areas. The key findings of this study specify the detrimental impacts of urban built-up land on flood losses. As urban built-up land accumulates over time, it can cause a community to cross a certain threshold which will result in flooding in previously unflooded areas. Another notable finding of this study is the importance of compact or cluster development, which has a favorable effect with respect to abating flood losses.

6.2.1 Need for Resilient Land Use Planning and Development

The finding of detrimental effects of urban built-up land on flood loss within this study requires planners and policy makers in urban areas to pay greater attention to the impervious surfaces that accompany urban built-up land use in order to reduce flood risk. Also, the magnitude of the effects of agricultural land on increased flood loss suggest that there is a need for systematic observations of the changes within land use patterns and their accompanying regulations. Considering the fact that agricultural land is usually converted to urban-built up land, a steady decrease in agricultural land is likely paired with an increase in urban built-up land as supported by the correlation within this study. Therefore, authorities such as a jurisdictional or a local government can resort to imposing regulations or land use ordinances prohibiting the conversion of agricultural land to urban built-up land in an effort to regulate this conversion. Additionally, land owners who convert agricultural land to green-open space or install/upgrade the capacity of corresponding drainage systems may be offered tax exemptions, waiver land conversion fees, subsidies, or matching funds as an incentive to help prevent flood loss.

In the case of Seoul, the Seoul Metropolitan Government has established a comprehensive plan review every 10 years since 1990. However, the comprehensive plan does not consider the relationship between land use and different kinds of hazards. 'The 2030 Seoul Plan', published in 2014, consists of three books (over 1,000 pages long) including factual basis, land use status and the future land plan; surprisingly, the terms 'flood' or 'hazard' are not even mentioned once. This lack of attention to the effect of the built environment on flooding may lead to even more severe flooding events in the future.

It seems that the Seoul Metropolitan Government and its 25 districts tend to approach flooding issues from a structural mitigation perspective only. After the city experienced urban flooding, the City of Seoul announced the plan to increase the capacity of drainage system in the flooded CBD and the secondary CBD area as well as installation of underground rainwater storage facilities. These structural measures will definitely contribute to decreasing flood losses in the city. However, the underlying problem of repetitive and localized flooding might not be effectively solved with structural mitigation strategies only and without a land use plan, which take into account and reflect the effect of the built environment on flooding and its related losses.

6.2.2 Focusing on High Density Compact Development

The abating effect of CBD on flood losses found in this study suggests that the potential favorable effects of compact and cluster development as well as new urban designs. Although there are some studies that do not support the virtue of compact development on flood risk reduction (Berke et al., 2009; Stevens et al., 2010), high density compact development can be an ideal approach for urban areas pursuing flood resilient communities. The characteristics of compact development are high net density, mixed-use, and a pedestrian focused street design, which can cancel the adverse impact of impervious surfaces of urban developments. If we cannot stop development that causes impermeable surfaces to increase within urban areas, attention should be given to developing minimizing the overall amount of impervious surfaces.

There are some key principals that should be followed when implementing compact developmental strategies. First, such development should not be located in a vulnerable area, i.e. high density development in 100-year floodplain or surge zones, which will simply serve to increase the risk of flooding (Berke et al., 2009). Second, strong drainage infrastructure with sufficient capacity must be secured or high intensity precipitation will cause a high risk of flooding and associated damage because of the large number of population and concentrated property within a smaller total area.

6.2.3 Improving Drainage Infrastructure and Building Multi-Functional Flood Mitigation Facilities

The most effective way to attenuate the damage from flooding might, in fact, be leaving flood-prone areas empty by prohibiting development (Brody & Highfield, 2013; Stevens et al., 2010). However, this avoidance strategy is not likely to be an option for flood mitigation in already developed areas. In this case, insuring the presence of drainage infrastructure and flood mitigation facilities (such as detention ponds) with sufficient capacity is necessary.

The finding that hourly maximum precipitation had the largest marginal effect as well as the strongest magnitude, supports the need for better drainage infrastructure in Seoul which can deal with increasing rain intensity due to climate change. The drainage infrastructure of Seoul was devised for handling up to 75mm/hour. However, the 10-

year panel data showed that there have been many times that hourly maximum precipitation exceeded 75mm/hour. The highest value observed was 317 mm/hour, which is four times higher than the given capacity. In response to this, the City of Seoul announced a plan to increase the capacity of drainage system by 95 mm/hour by 2019.

While the drainage infrastructure improvement is under the charge of the Seoul Metropolitan Government, a district can contribute to managing heavy rainfall by building multi-functional flood mitigation facilities such as a public park with rainwater storage/detention facilities. In fact, *Seocho-gu*, which recorded the highest total flood losses due to the flooding in 2011, decided to construct a rainwater storage facility in the lowest lying land. Since this was designed to be built in highly developed area, an existing urban park, named Yongheori was selected as a site, beneath it a stormwater storage tank was built. This allowed the public to keep the park – green open space – for recreational purposes while it also functioned as a flood control measure. This facility has the capacity to store 550 thousand ft^3 of rainwater and is expected to increase the lag time by storing the rainwater before release.

6.3 Study Limitations and Future Research

Although this study provides a greater insight into the urban flash flooding in Seoul by conducting a study from a planning perspective, it has several limitations that can be used to develop future research plans. First, despite the fact that longitudinal data was used, the number of observations in this study was still too small at N=215. Theoretically, this number should have been enough to avoid issues from insufficient sample size but not large enough to be completely free from the concern of lowering statistical power. This is partly due to the limited data accessibility and the need for data integrity and consistency by acquiring reliable sets of data with all the necessary variables covering a span of years. With this reason, I had to limit the study period to 10 years (2003-2012). Future research should have a temporally longer study period with a larger sample size to increase the statistical power of the model.

Second, many focal data that were supposed to be included in the model were given up because they were not acquirable for the following reasons. First, some data was only available at the upper level of local government rather than at the district level. In particular, annual impervious surface rate[33] is one of the most suitable variables for explaining the effect of development on flooding as well as its related loss in urban areas. However, impervious surface data is only available at the *si* level, which is the upper level of local government, the City of Seoul. Second, there were several data that are only available during a portion of the study period. For example, spatial data of inundation is acquirable only for the years 2010 and 2011. Also, some data was not accessible even though they exist; the data which can explain development density such as Floor Area Ratio (vertical density), Building Coverage Ratio (horizontal density), and the number of structures was not publically available. However, during the data collection, I observed that the Seoul Government and many districts are in the process of building data bases at the district level, as well. Also, since 2014, the Korea national

[33] Available at district level in 2010 only.

government has promoted open access to public documents and information that national and local governments store which is gradually expanding the range of the data and information that is available to the public (MOI, 2014). In the future, it is likely that research will be able to be conducted with more suitable data that will better explain the observed flood losses.

Third, this study did not show the status and change of land use visually. This is due to the fact that resolution of accessible land cover data was too coarse to use. Considering the fact that land use is time variant and appears to affect the flood losses in this study, it would have been helpful in drawing more insightful policy implications and planning recommendations if spatial information was usable. The next step of this study will be pursuing not only presenting the land use change visually, but also conducting various spatial analyses so geographically specific planning and policy recommendations may be provided.

Finally, this study did not include many socioeconomic factors, such as level of education[34] or property value[35], even though it is known that these characteristics also have impact on flooding and its related losses. Future study should include more socioeconomic characteristics of a district into the model and should be extended to examine the effect of social vulnerability on flood losses in Seoul.

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[34] The education level was dropped because of its high correlation with FSRR.
[35] The property value was only available from 2006.

6.4 Conclusions and Contributions of the Study

The results of this study confirm the notion that property loss from flooding is the predictable consequence of interaction among various factors. Aside from the effect of natural environmental factors, this study showed that property loss from flooding might be a matter of the built environment resulting from human developmental activities rather than the population or the wealth of a community. This finding indicates that flood losses can be reduced with intervention from local governments, planners, and policy makers by adjusting the built environment with proper management techniques.

The most notable finding was the opposing effects of urban built-up land and CBD areas on flood losses. Specifically, unfavorable effects of urban built-up land on flood losses confirmed the general consensus on the adverse impacts of impervious surfaces from urbanization. Additionally, CBD areas, characterized by high density compact development, showed diminishing effects on flood losses suggesting the compact development style as a prominent strategy for building flood resilient urban areas. This also underlines the attention and commitment of local governments to urge planners and decision makers to focus on status and change of the built environment within urban cores.

Despite the limitations listed above, this research is one of a few studies attempting to explain the flood losses in Seoul that employs longitudinal analysis and approaches the results from a planning perspective and with a holistic view. As discussed earlier, even after two consecutive years of flooding, the City of Seoul did not include flood risk assessment when establishing the 2030 comprehensive plan. This is because the flooding in Korea is currently viewed as a natural disaster that is caused solely by climate change, so the mitigation strategies are primarily focused on structural flood accommodation measures from an engineering perspective. The results of this study should encourage local governments to change their flood mitigation approach and focus on developing flood-resilient cities.

REFERENCES

Anderson, J. R. (1976). *A land use and land cover classification system for use with remote sensor data* (Vol. 964). Washington, DC: U.S. Government Printing Office.

Arnold, C. L., & Gibbons, J. C. (1996). Impervious surface coverage: The emergence of a key environmental indicator. *Journal of the American Planning Association, 62*(2), 243-258.

Berke, P. R., & Conroy, M. M. (2000). Are we planning for sustainable development? An evaluation of 30 comprehensive plans. *Journal of the American Planning Association, 66*(1), 21-33.

Berke, P. R., Song, Y., & Stevens, M. (2009). Integrating hazard mitigation into new urban and conventional developments. *Journal of Planning Education and Research, 28*(4), 441-455.

Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (2004). *At risk: Natural hazards, people's vulnerability and disasters* (2nd ed.). New York, NY: Routledge.

Bolin, R. C. (1986). Disaster impact and recovery: A comparison of black and white victims. *International Journal of Mass Emergencies and Disasters, 4*(1), 35-50.

Brody, S., Brody, J., Gunn, W., & Peacock, W. E. (2011a). Examining the influence of development patterns on flood damages along the Gulf of Mexico. *Journal of Planning Education and Research, 31*(4), 438-448.

Brody, S. D., Blessing, R., Sebastian, A., & Bedient, P. (2013a). Examining the impact of land use/land cover characteristics on flood losses. *Journal of Environmental Planning and Management, 57*(8), 1252-1265.

Brody, S. D., & Highfield, W. E. (2013). Open space protection and flood mitigation: A national study. *Land Use Policy, 32,* 89-95.

Brody, S. D., Highfield, W. E., Grover, H., & Vedlitz, A. (2008). Identifying the impact of the built environment on flood damage in Texas. *Disasters, 32*(1), 1-18.

Brody, S. D., Highfield, W. E., & Kang, J.-E. (2011b). *Rising waters :The causes and consequences of flooding in the United States*. New York, NY: Cambridge University Press.

Brody, S. D., Highfield, W. E., Ryu, H.-C., & Spanel-Weber, L. (2007a). Examining the relationship between wetland alteration and watershed flooding in Texas and Florida. *Natural Hazards, 40*(2), 413-428.

Brody, S. D., Kang, J.-E., & Bernhardt, S. (2010). Identifying factors influencing flood mitigation at the local level in Texas and Florida: The role of organizational capacity. *Natural Hazards, 52*(1), 167-184.

Brody, S. D., Kim, H., & Gunn, J. (2013b). Examining the impacts of development patterns on flooding on the Gulf of Mexico coast. *Urban Studies, 50*(4), 789-806.

Brody, S. D., Peacock, W. G., & Gunn, J. (2012). Ecological indicators of flood risk along the Gulf of Mexico. *Ecological Indicators, 18,* 493-500.

Brody, S. D., Zahran, S., Highfield, W. E., Bernhardt, S., & Vedlitz, A. (2009). Policy learning for flood mitigation: A longitudinal assessment of the Community Rating System in Florida. *RiskA Analysis, 29*(6), 912-929.

Brody, S. D., Zahran, S., Maghelal, P., Grover, H., & Highfield, W. E. (2007b). The rising costs of floods: Examining the impact of planning and development decisions on property damage in Florida. *Journal of the American Planning Association, 73*(3), 330-345.

Bullock, A., & Acreman, M. (2003). The role of wetlands in the hydrological cycle. *Hydrology and Earth System Sciences, 7*(3), 358.

Cho, J. (2000). A study on autonomous districts system. *Legislation Forum, 578*, 23-36.

Choi, C.-I. (2004). Panel models about determining factors of urban flood damages. *Journal of Korea Planners Association, 39*(7), 49-67.

Choi, G. (1999). A study on changes of urban spatial economy and urban development policies: Is Seoul post-industrial city? (1981-1996). *Journal of Urban Management, 12*, 75-98.

Choi, J.-W., Choe, C. S., & Kim, J. (2012). *Local government and public administration in Korea*. Jeonbuk, Korea: Local Government Officials Development Institute.

Chung, Y.-S., Yoon, M.-B., & Kim, H.-S. (2004). On climate variations and changes observed in South Korea. *Climatic Change, 66*(1-2), 151-161.

Cochrane, H. C. (1975). *Natural hazards and their distributive effects: A research assessment*. Boulder, CO: University of Colorado.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly, 84*(2), 242-261.

Dietz, M. E., & Clausen, J. C. (2008). Stormwater runoff and export changes with development in a traditional and low impact subdivision. *Journal of Environmental Management, 87*(4), 560-566.

Drukker, D. M. (2003). Testing for serial correlation in linear panel-data models. *Stata Journal, 3*(2), 168-177.

ELIS. (2014). Local Ordinances. Retrieved June 30, 2014, from http://www.elis.go.kr/newlaib/laibLaws/h1126/laws.jsp?regionId=11740&isfez=

Fogelson, R. M. (1993). *The fragmented metropolis: Los Angeles, 1850-1930* (Vol. 3). Los Angeles, CA: University of California Press.

Godschalk, D. R. (2003). Urban hazard mitigation: Creating resilient cities. *Natural Hazards Review, 4*(3), 136-143.

Highfield, W. E. (2008). *Section 404 permitting in coastal Texas from 1996-2003: Patterns and effects on streamflow* (Unpublished doctoral dissertation). Texas A&M University, College Station, TX.

Highfield, W. E., & Brody, S. D. (2013). Evaluating the effectiveness of local mitigation activities in reducing flood losses. *Natural Hazards Review, 14*(4), 229-236.

Jha, A. K., Bloch, R., & Lamond, J. (2012). *Cities and flooding: a guide to integrated urban flood risk management for the 21st century*. Washington, DC: World Bank Publications.

Kang, J.-E., & Lee, M. (2012). Assessment of flood vulnerability to climate change using fuzzy model and GIS in Seoul. *Journal of the Korean Association of Geographic Information, 15*(3), 119-136.

Kang, J. E. (2009). *Mitigating flood loss through local comprehensive planning in Florida* (Unpublished doctoral dissertation). Texas A&M University, College Station, TX.

Khan, S. D. (2005). Urban development and flooding in Houston Texas, inferences from remote sensing data using neural network technique. *Environmental Geology, 47*(8), 1120-1127.

Kim, B., Jang, D., Jang, N., & Yang, D. (2011). The deduction of urban flood risk factor considering climate change. *Korean Reivew of Crisis and Emergeny Management*, *7*(1), 125-142.

Kim, C.-D., Kim, G., & Oh, S.-H. (2012a). Urban policy's performance and vision for 20 years in local autonomy: Focused on decentralization level of public management in Seoul government (Research Report No. 2011-PR-57). Retrieved June 28, 2016, from Seoul Institue website: http://www.si.re.kr/sites/default/files/2011-PR-57_0.pdf.

Kim, D. (2008). *Geomorphological background and urbanized feature of Seoul.* (Unpublished doctoral dissertation). Korea National University of Education, Chungju, Korea.

Kim, D. (2013). *A study on the consciousness of civil servants for regional inequalities in Seoul.* (Unpublished Master's thesis). University of Seoul, Seoul, Korea.

Kim, H. M., & Han, S. S. (2012). Seoul. *Cities, 29*(2), 142-154.

Kim, I., Oh, Y.-K., & Lee, J. (2012b). *A mutually beneficial development strategy to resolve regional disparities, and the role of Seoul*. Seoul, Korea: The Seoul Institute.

Kim, J. (2012). *A Study on the relationship between the head of local autonomous government and the local councils: A case analysis on restraining function of Seoul Metropolitan Council and an alternative for improvement.* (Unpublished Doctoral thesis). Yonsei University, Seoul, Korea.

Kim, S.-H., Cho, S.-J., Keum, C.-H., Joo, J.-B., & Kim, S.-K. (2002). *Local Government in Korea* (A.-R. Hwang, Y.-H. Ahn, S. Kim & E. Kim Eds.). Seoul, Korea: Korea Research Institute for Local Administration.

Klein, R. J., Nicholls, R. J., & Thomalla, F. (2003). Resilience to natural hazards: How useful is this concept? *Global Environmental Change Part B: Environmental Hazards*, *5*(1), 35-45.

KMA. (2014). Climate of Seoul. Retrieved April 17, 2014, from http://www.kma.go.kr/index.jsp

Korea Statistics. (2013). e-National Index. Retrieved February 17, 2014, from http://www.index.go.kr/potal/main/EachDtlPageDetail.do?idx_cd=2458

KOSIS. (2013). Statistics: Population. Retrieved November 3, 2013, from Korea Statistical Information Service http://kosis.kr/

KRILA. (2011). *Local government in Korea*. Seoul, Korea: Korea Research Institute for Local Administration.

Kundzewicz, Z. W., & Takeuchi, K. (1999). Flood protection and management: quo vadimus? *Hydrological Sciences Journal*, *44*(3), 417-432.

Kwon, W. T. (2007). The application of regional climate change scenario for the national climate change report (Report No.3). Retrieved April 13, 2016, from Research on Korea Adaptation Center for Climate Change website: http://ccas.kei.re.kr/adapt_Info/adapt/list.do#

Lee, J. (2015). Land category. Retrieved January 25, 2016, from http://navercast.naver.com/contents.nhn?rid=2901&contents_id=91519

Lee, S.-H., Lee, K.-S., Jin, W.-C., & Song, H.-K. (2009). Effect of an urban park on air temperature differences in a central business district area. *Landscape and Ecological Engineering, 5*(2), 183-191.

Maeng, D.-M. (2009). *Seoul's spatial characteristics: Local disparity analysis in the built environment.* Seoul, Korea: The Seoul Institute.

Maeng, D.-M. (2010). *The change of urban space in Seoul.* Seoul, Korea: The Seoul Institute.

Matthai, H. F. (1990). Floods. In M. G. Wolman & H. C. Riggs (Eds.), *Surface water hydrology* (Vol. O-1, pp. 97-120). Boulder, CO: Geological Society of America.

Mileti, D. (1999). *Disasters by design: A reassessment of natural hazards in the United States.* Washington, DC: National Academies Press.

Mileti, D., & Gailus, J. L. (2005). Sustainable development and hazards mitigation in the United States: disasters by design revisited. *Mitigation and Adaptation Strategies for Global Change*, *10*(3), 491-504.

MOI. (2014). About: Access to Public Documents. Retrieved March 24, 2016, from https://www.open.go.kr/

NDIC. (2013). Disasters records. Retrieved May 6, 2014, from http://www.safekorea.go.kr

O'Connell, P., Ewen, J., O'Donnell, G., & Quinn, P. (2007). Is there a link between agricultural land-use management and flooding? *Hydrology and Earth System Sciences, 11*(1), 96-107.

Ogawa, H., & Male, J. W. (1986). Simulating the flood mitigation role of wetlands. *Journal of Water Resources Planning and Management*, *112*(1), 114-128.

Park, Chong-Min. (2006). Local governance and community power in Korea. *Korea Journal, 46*(4), 9-32.

Pattison, I., & Lane, S. N. (2011). The link between land-use management and fluvial flood risk: A chaotic conception? *Progress in Physical Geography, 36*(1), 72-92.

Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. *Annual Review of Ecology and Systematics, 32*(1), 333-365.

Peacock, W. G., Brody, S. D., Seitz, W. A., Merrell, W. J., Vedlitz, A., Zahran, S., . . . Stickney, R. R. (2010). Advancing resilience of coastal localities: Developing, implementing, and sustaining the use of coastal resilience indicators: A final report (Research Report No. 10-02). Retrieved February 20, 2014, from Hazard Reduction and Recovery Center website: http://hrrc.arch.tamu.edu/_common/documents/10-02R.pdf.

Rose, S., & Peters, N. E. (2001). Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): a comparative hydrological approach. *Hydrological Processes, 15*(8), 1441-1457.

Shuster, W., Bonta, J., Thurston, H., Warnemuende, E., & Smith, D. (2005). Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal, 2*(4), 263-275.

Stevens, M. R., Song, Y., & Berke, P. R. (2010). New urbanist developments in flood-prone areas: safe development, or safe development paradox? *Natural Hazards, 53*(3), 605-629.

Thampapillai, D. J., & Musgrave, W. F. (1985). Flood damage mitigation: a review of structural and nonstructural measures and alternative decision frameworks. *Water Resources Research, 21*(4), 411-424.

The Seoul Government. (2012). Water-Relate Disaster in 2011 [White Paper]. Seoul, Korea: The Seoul Government.

The Seoul Government. (2013a). 2012 Fiscal Self-Reliance Ratio of 25 districts in Seoul. Retrieved July 20, 2014, from http://stat.seoul.go.kr/index.jsp

The Seoul Government. (2013b). Facts: Location. Retrieved January 12, 2014, from http://english.seoul.go.kr/gtk/about/fact.php?pidx=1

The Seoul Government. (2013c). Facts: Population. Retrieved January 12, 2014, from http://english.seoul.go.kr/gtk/about/fact.php?pidx=2

Tobin, G. A. (1995). The levee love affair: A stormy relationship. *Journal of the American Water Resources Association, 31*(3), 359-367.

UN-Habitat. (2008). *State of the world's cities 2008-2009: Harmonious Cities*. London, UK: Earthscan.

Van Ree, C., Van, M., Heilemann, K., Morris, M., Royet, P., & Zevenbergen, C. (2011). FloodProBE: technologies for improved safety of the built environment in relation to flood events. *Environmental Science & Policy, 14*(7), 874-883.

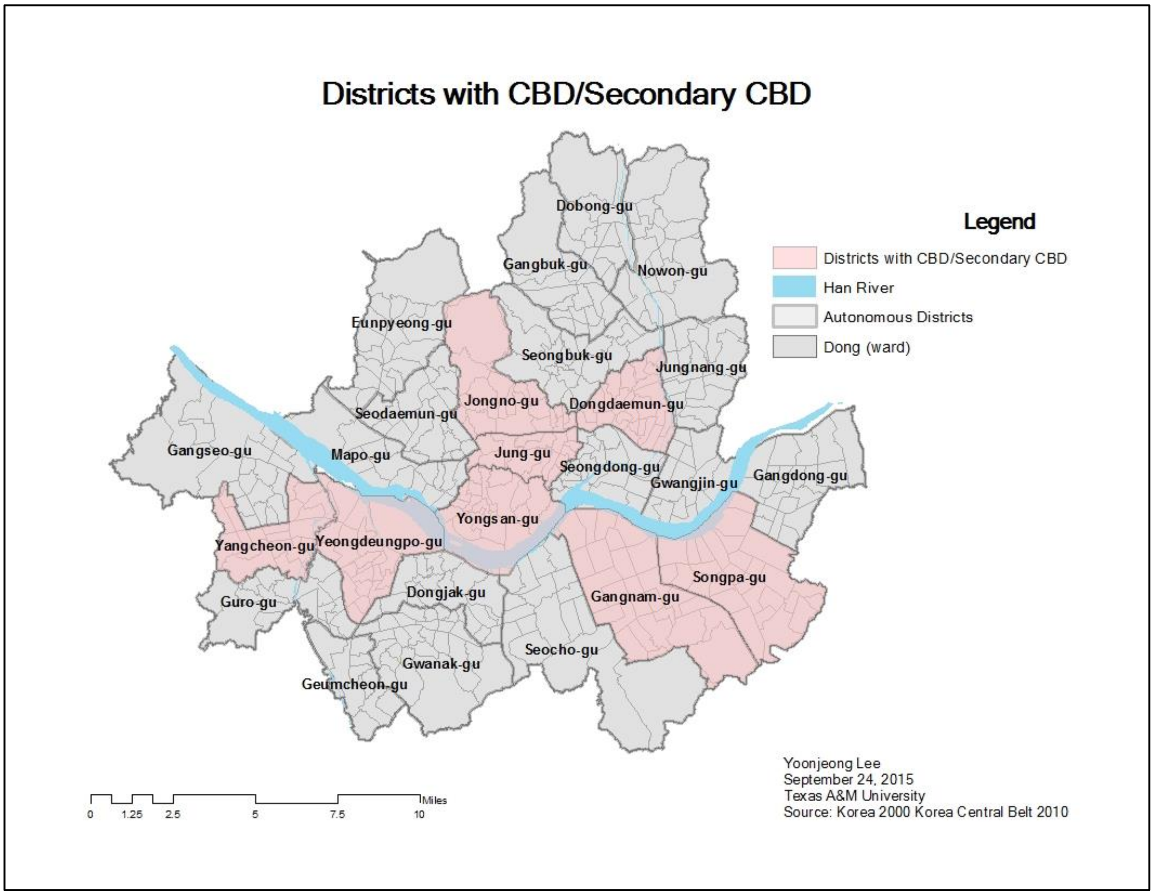
White, M. D., & Greer, K. A. (2006). The effects of watershed urbanization on the stream hydrology and riparian vegetation of Los Penasquitos Creek, California. *Landscape and Urban Planning, 74*(2), 125-138.

Williams, E. S., & Wise, W. R. (2006). Hydrologic impacts of alternative approaches to storm water management and land development. *Journal of the Amercan Water Resources Association, 42*(2), 443-455.

Zahran, S., Brody, S. D., Peacock, W. G., Vedlitz, A., & Grover, H. (2008). Social vulnerability and the natural and built environment: A model of flood causalities in Texas. *Disasters, 32*(4), 537-560.

APPENDIX A

CBD AND SECONDARY CBD LOCATIONS IN SEOUL



APPENDIX B

NUMBER OF POPULATION IN SEOUL 1975 TO 2012

Year	Number of Population
1975	6,889,440
1980	8,364,379
1985	9,639,110
1990	10,612,577
1995	10,231,217
2000	9,895,217
2005	9,820,171
2012	9,794,304