sustainability

MDPI

Article

The Effect of Urban Green Infrastructure on Disaster Mitigation in Korea

So Yoon Kim [1] and Brian H. S. Kim [1,2,*]

[1] Department of Agricultural Economic and Rural Development, Seoul National University, Seoul 151-921, Korea; sohyoon.k@snu.ac.kr

[2] Program in Agricultural and Forest Meteorology, Research Institute for Agriculture and Life Sciences, Seoul National University, Seoul 151-921, Korea

* Correspondence: briankim66@snu.ac.kr; Tel.: +82-2-880-4717; Fax: +82-2-873-5080

Received: 9 February 2017; Accepted: 10 June 2017; Published: 15 June 2017

Abstract: Increasing precipitation by climate change and the growing number of impervious areas present greater risk of disaster damage in urban areas. Urban green infrastructure can be an effective mitigation alternative in highly developed and concentrated area. This study investigates the effect of various types of urban green infrastructure on mitigating disaster damage in Korea. Tobit model is used to analyze the factors that determine disaster damage. Damage variation is predicted with scenarios of RCP 8.5 and urban green spaces. Seventy-four districts and counties in seven metropolitan areas are defined as the unit and the period from 2005 to 2013 is considered in the analysis. The results indicate that higher urban green ratio, sewer length, financial independence rate, and local government's budget are relating to lower disaster damage. Based on a precipitation level of RCP 8.5 scenario in 2050, an increase in economic damage is expected to range from 262 to 1086%. However, with an increase in urban green ratio by 10%, increased economic damage is only expected to range from 217 to 1013%. The results suggest that green spaces play important role to mitigate precipitation related disasters. Highly concentrated urban areas need to consider various types of urban green infrastructure to prepare for an increase in precipitation due to climate change.

Keywords: climate change; disaster mitigation; urban green infrastructure; Tobit model; Korea metropolitan areas

1. Introduction

Nowadays, climate change issues are frequently associated with global warming, extreme precipitation, and sea-level rise. The cause from continuation of these perilous events can be significant for the countries and regions with highly concentrated population and economic activities. A growing number of countries are recognizing and experiencing uncertain risks associated with natural phenomena related to climate change [1]. International institutions, such as the Intergovernmental Panel on Climate Change (IPCC), provide assessment reports and policy recommendations related to global climate change. According to Climate Change 2014 Synthesis Report from IPCC, more countries and regions will likely suffer a greater frequency of heat waves, heavy precipitation, and increasing sea-level rise. They also warned that recent climate-related extremes will present significant vulnerability and exposure to the ecosystems and more human systems to current climate variability [2].

Korea is one of the countries who repeatedly suffers from extreme precipitation, typhoons, and heat waves, especially during the summer [3]. Even with their great economic success, vulnerability and risks in many parts of the country have also been increased due to many transformations in their infrastructure, natural capital, and social environment. The major metropolitan areas in Korea are inhabited by more than 60% of the total population with high concentrations of infrastructure and economic systems. Therefore, with the major natural disaster events, these areas are highly vulnerable and likely to suffer greater economic losses than other regions of the country [4].

According to the National Emergency Management Agency (NEMA) in Korea, 85% of disaster damage in the past 20 years has been caused by typhoons and extreme precipitation. The intensity of damage has been increasing in recent years, and many of the damages are concentrated in the metropolitan areas [5]. As climate change progresses, the frequency and intensity of natural phenomena are likely to continue. It then becomes necessary for urban planners and policy decision makers to pay more attention to effective mitigation methods to reduce impacts and prevent the risks of hazards through proactive measures before disasters occur to minimize the damage. However, the growing expansion of urban areas and development at high density causing higher exposure to the greater risk for stormwater runoff with increasing impervious areas and decreasing areas for retention basins. It is important for Korea to reshape ongoing development activities in the light of climate change mitigation and tailor climate change activities in support of positive development outcomes [6].

Traditionally, sewage facilities and retention basins are utilized to reduce the precipitation damage. However, with the recent recognition of the importance of resilience as part of the sustainable development, mitigation strategies have been shifted from direct development of prevention facilities to more of an urban planning prevention approach. It is now necessary to develop the capacity for social, economic, and ecological systems to absorb, adapt, and maintain practical responses to face the risk imposed by climate change and natural disaster. As a result of this change, Low Impact Development (LID), Sustainable Drainage System (SuDS), and waterways are used in urban planning to reduce the stormwater runoff and minimizing vulnerable areas. Particularly, LID and SuDS have received continual interest in their approach utilizing various types of green spaces and minimizing the stormwater runoff in urban areas [7,8]. Adopting LID and SuDS can be ideal, especially in highly developed and concentrated urban areas, and can increase the function of permeability and stormwater retention with the various types of green spaces.

Urban green infrastructure has the ability to improve air quality [9,10], mitigate the heat island [9–12], and reduce stormwater runoff [13–16]. Pauleit and Duhme [17] found that the infiltration rate of stormwater is 18.7% when the impervious pavement area ratio is 65% in the residential area of Germany, whereas the infiltration rate is 6% when the impervious area ratio is increased to 95%, respectively. The increase of impervious area from urbanization prevents the stormwater from infiltrating the ground, increasing runoff that leads to flooding. Therefore, various types of urban green infrastructure can be utilized as method to increase infiltration ability of the land and reducing the rainfall runoff [12,18–20]. Zhang et al. [12] found that the urban green spaces in Beijing, China could control 17% to 23% of the rainfall runoff annually.

Because of the difficulty to securing sufficient spaces for new parks and open spaces in urban areas, conventional types of greening may not be suitable. As alternatives, various types of greening can be considered such as street trees, gardening, waterfront and rooftop and wall greening [18,21]. They can be effective green infrastructure in reducing stormwater runoff, even as a small proportion of green space in an urban area [15,22–24].

In this context, the objective of this study is to understand the factors affecting disaster damage and analyze the effect of urban green spaces on disaster mitigation. National Urban Forest Statistics in Korea defines various types of urban green infrastructure (i.e., street trees, rooftop greenery, wall greens, parks, and mountains). In order to investigate the effect of urban green infrastructure on disaster damage mitigation, the variations of damage are estimated under the different range of urban green space ratios and climate change scenarios. The spatial range is set within 74 districts and counties in 7 metropolitan areas in Korea, and the time period from 2005 to 2013 are considered in the analysis.

2. Materials and Methods

2.1. Tobit Model

The Tobit model proposed by the economist Tobin [25] is commonly used when the observations of dependent variables take censored data. If the limited values (censored data) are included in dependent variable, then the estimator by the ordinary least square (OLS) is biased and inconsistent. The Tobit model can be used, in this case, to control the censored data and solve problems [26].

The dependent variable used in this study is the disaster damage. A natural disaster is an event that occurs irregularly in different regions and different period of time. Therefore, it is likely that some regions and some years have no disaster events such that the data have the '0' values. In order to reflect these censored data with limited values, the Tobit model is suitable for the analysis.

The general regression function of the Tobit model is shown in the equation

$$y_i^* = x_i'\beta + \epsilon_i,\ i = 1, \cdots, N \tag{1}$$

where y_i^* is a dependent variable, which depends on independent variable x_i via a parameter β and normally distributed error term ε_i is an independent variable. The dependent variable y_i^* is indirectly observed by y_i as in Equation (2).

$$y_i = \begin{cases} y_i^*,\ if\ y_i^* > 0 \\ 0,\ if\ y_i^* \le 0 \end{cases} \tag{2}$$

Equation (2) indicates that the dependent variable y_i^* is observed when y_i^* is greater than 0, otherwise 0 when y_i^* is same or less than 0.

The Tobit model is estimated with the maximum likelihood method (MLM). The MLM calculates the parameter that maximizes log-likelihood function. The log-likelihood function for the Tobit model can be expressed as in Equation (3).

$$logL\left(\beta, \sigma^2\right) = \sum_{y_{i=0}} \log\left(1 - \Phi\left(\frac{x_i'\beta}{\sigma}\right)\right) + \sum_{y_{i>0}} log\left[\frac{1}{\sigma}\phi\left(\frac{y_i - y_i'\beta}{\sigma}\right)\right] \tag{3}$$

Because of nonlinearity of the Tobit model, the estimated coefficients are not the marginal effect of variables. Therefore, the marginal effect of the Tobit model can be estimated with the equation

$$\frac{\partial E\ (y|x_i)}{\partial x_i} = \beta Ref\left(\frac{x_i\beta}{\sigma}\right) \tag{4}$$

where $\Phi\left(\frac{x_i\beta}{\sigma}\right)$ is the probability that y_i^* is not observed as 0. The marginal effect obtained with Equation (4) allows us to recognize the degree of the change of specific variable that affects the change of dependent variable when other variables are constant. By estimating these marginal effects of each independent variables, the changes in disaster damage due to changes in precipitation and urban green infrastructure ratio can be predicted under the climate change scenarios.

2.2. Data

This study covers 74 districts and counties in 7 major metropolitan areas in Korea including Seoul, Busan, Daegu, Incheon, Gwangju, Daejeon, and Ulsan. These areas occupy a minimum of 14.30% to a maximum of 60.21% with urbanization area, which is very high compared to an average urbanization area of 3.04% in other regions. Therefore, it is ideal to explore these seven major metropolitan areas with the highest ratio of impervious areas and development. The range of the study years is from 2005 to 2013 in order to reflect the recent change of climate phenomenon and damage patterns in Korea. The variables used in the analysis are shown in Table 1. These variables are selected by referring to the related previous studies.

Table 1. Variable description.

Classification		Variable	Explanation	Unit	Data Source	Reference Sources
Dependent Variable		DAMAGE	Disaster damage per km^2	million won	National Disaster Information Center	
Independent variable	Green Factor	UG	Urban green infrastructure ratio (Total green area (km^2)/total city area (km^2))	%	National Urban Forest Statistics	[15,19,20,23]
	Climatic Factor	ATP	Annual total precipitation	mm	National Climate Data Service System	[17]
		HHP	Max. hourly precipitation ratio (No of days w/hourly precipitation of more than 30 mm/total no. of categorized precipitation days)	%		
		WIND	Maximum wind speed days ratio (No. of days w/higher than 13.9 m/s winds/total no. of categorized windy days	%		
	Vulnerable Factor	IMPA	Impervious area ratio (total built-up area (km^2)/total city area (km^2))	%	Korean Statistical Information Service	[27,28]
		RIVER	River area ratio (total river area (km^2)/total city area (km^2))	%		[29–31]
	Preventive Factor	SEWER	Storm sewer length ratio (total length of storm sewer (km)/total city area (km^2))	%	Environmental Statistical Information Service	[31,32]
		BASIN	Retention basin capacity ratio (retention basin volume (m^3)/total city area (km^2))	%		[33,34]
		FINANCE	Financial independence rate	%	Ministry of Interior	[35]
		BUDGET	Annual budget	billion won		

As a dependent variable, the disaster damage is the total amount of annual damage (in Korean won) and is provided by Korean national disaster information center. The amount of damage for each year from 2005 to 2012 is adjusted with the real value by using the inflation rate with a based year of 2013. In the report, the data indicates that the larger areas are expose to greater risk to the disasters and the damage. Therefore, it is necessary to re-scale the damage amount by the size of area (km^2) and use the unit with total damage amount per km^2.

Independent variables are categorized with four main factors depending on the properties of each variable: green, climate, vulnerable, and preventive. First, the green factor is the urban green infrastructure ratio, which refers to the proportion of urban green infrastructure areas in each metropolitan area. The urban green infrastructure areas are based on the National Urban Forest Statistics (NUFS) where they defined these areas with various types of urban forest. The NUFS is published biannually by Korea Forest Service since 2005 and provides urban forest statistics on a city and county basis. Urban forests are regulated on the basis of two laws: Act of Forest Resources Establishment and Management and the Act of Urban Parks and Greenery. The mountains and natural recreation forests within urban areas are part of these regulations and play an important role in minimizing and preventing disasters. However, they are not considered in the analysis because of inflexibility of these areas in urban planning process to change the urban green infrastructure ratios. It is the objective of this study to observe the effect of change in urban green infrastructure ratios through planning process, such as increasing rooftop and wall greening and roadside greenery, on the disaster damage.

Climate factors include annual total precipitation, maximum hourly precipitation ratio, and maximum wind speed ratio. These data are provided by the Korea Meteorological Administration (KMA) and are observed through the Automatic Weather System (AWS) at approximately 460 locations nationwide. Actual observed data are used for the study areas with AWS sites, however the average data of neighborhood districts are used for the study areas without AWS sites.

Vulnerable factors consist of impervious area ratio and river area ratio that can stress the disaster risk in urban areas. The impervious area is the total area with hard infrastructures, such as buildings, factories, and roads, with impervious pavements and less infiltration function. The river area is the total area of rivers in each study area. Both built-up and river area data are provided by the Korea Statistical Information Service on national land use.

Preventive factors refer to physical and financial factors for disaster prevention. The physical factors include storm sewer length ratio and retention basin capacity ratio, which are commonly used disaster prevention facilities. The storm sewer length is the combined length of double type sewer pipe and rain water pipe lines, whereas the retention basin is the total capacity of retention basin located in each study area. Financial factors include financial independence rate and annual total budgets of local governments, which is provided by "overview of local governments integrated finance" report from Ministry of Interior.

3. Results

3.1. Factors Effecting Disaster Damage in Urban Area

The Tobit model is used to investigate the determinants of disaster damage in urban areas. The significance of the estimated model can be verified by the Likelihood Ratio (LR) Chi-Sqaure test. The test statistics results shown in Table 2 indicates that the value of LR Chi-Square statistics is 151.38, and the null hypothesis that "all the estimation coefficients are 0" is rejected at the 1% significance level. Therefore, estimated Tobit model is statistically significant. Among the 370 observations, 202 observations are censored. The variance inflation factor (VIF) and the tolerance can be used to test the multicollinearities. The values of VIF and tolerance of the variables presented in Table 3 are less than 3 and higher than 0.5, respectively, indicating that there is no multicollinearity problem in this model.

Table 2. Test statistics of the Tobit model.

Classification	Statistics
LR Chi2 (10)	179.98
Prob > chi2	0.0000
Pseudo R2	0.1232
Log likelihood	−460.5568
Number of Observations	370 (202 censored)

Table 3. Estimated results of the Tobit model.

Classification	Variable	Coefficient	S.E.	VIF	Tolerance	Marginal Effect
Green Factor	UG	−0.0738 *	0.039	1.36	0.73	−0.0371
Climatic Factor	ATP	0.0142 ***	0.0017	1.65	0.61	0.0072
	HHP	1.0466 ***	0.3837	1.74	0.57	0.5261
	WIND	0.1724 ***	0.0451	1.29	0.77	0.0867
Vulnerable Factor	IMPA	−0.1953 ***	0.047	6.95	0.14	0.0982
	ln(RIVER)	−0.3771	0.2283	1.21	0.83	−0.1896
Preventive Factor	SEWER	0.0002 **	0.0001	6.56	0.15	0.0001
	ln(BASIN)	0.0686	0.1028	1.45	0.69	0.0345
	FINANCE	0.0304	0.027	1.40	0.71	0.0153
	BUDGET	−0.0110 ***	0.0047	1.59	0.63	−0.0055
	cons	5.9047	2.3204			
	sigma	−0.0738	0.3626			

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The estimated results of the Tobit model are shown in Table 3. The estimated coefficient for urban green infrastructure (UG) ratio is negative and statistically significant at the 10% level. This results indicate that the change in UG ratio will have a positive effect on mitigating the disaster damage. The marginal effect also shows that 1% increase of UG ratio reduces the disaster damage by 3.71% at an average condition. This result is consistent with the results in previous studies of Kim et al. [19], Farrugia et al. [24], Mentens et al. [15], and Gill et al. [36]. They suggest that urban green infrastructures and spaces, such as street trees, rooftop greenery, parks, etc., can reduce the stormwater runoff and can be used as an alternative strategy to mitigate the disaster damage in urban area.

The estimated coefficient of all three variables (ATP, HHP, and WIND) of climatic factors are positive and statistically significant at the 1% level. The HHP has a greater influence than ATP on the increase of disaster damage. However the standard deviation from the baseline of ATP is 273.01 mm and of HHP is 13.40 mm that the variation of ATP is larger and the degree of its effect to increase the disaster damage is greater. On the other hand, the WIND showed an 8.67% increase in disaster damage with an increase of 1% in the ratio of strong windy days with respect to the total number of categorized windy days in a year. The characteristics of disaster in Korea are often accompanied by strong winds and heavy rainfall. Therefore, it is expected that the effects of increasing in both the rainfall and the wind speed simultaneously will have the greater effect on total disaster damages in Korea.

Two variables corresponding to the vulnerability factors, IMPA is statistically significant with a negative coefficient, and the coefficient value of ln(RIVER) is negative and not significant. The extent to which disaster damage changes with a unit change can be large by IMPA. This is unexpected result that the disaster damage is increased by 9.82% for 1% increase in the proportion of impervious area with respect to the total city area. This result is not consistent with previous studies of Choi [37] and Choi and Seo [29] that the change of urban land use with increasing impervious area leads to the greater risks of disaster damage. River areas are generally classified as disaster prevention facilities in urban areas. However, in the case of heavy storms and rainfall, the damage can increase with the high levels of river that cause flooding in the vicinity near the rivers. This may perhaps explain the insignificance of ln(RIVER) variable in the estimation. The result in the study of Choi [37] derived the river area is a factor to increase the disaster damage.

All preventive factors, except ln(BASIN) and FINANCE, are statistically significant at 5% level. The retention basins are conventional disaster prevention facilities in urban areas [38]. The results show that 1% increase in ratio of the length of sewer lines with respect to the total area of the city can reduce the damage by 0.01%. Insignificance of estimated ln(BASIN) coefficient can be explained with insufficient capacity design of the retention basin. Consistent urbanization and heavy rainfall cause runoffs exceeding the previously established retention basin capacity that results flooding damage near the retention basin area. Kim [39] and Jeong et al. [34] explained that the cause of degraded disaster prevention function of retention basin is due to insufficient capacity design that does not reflect the consistent progress of urbanization. For these reasons, it is necessary to design an effective disaster prevention facility in preparation for extreme rainfall due to climate change.

If the SEWER and ln(BASINS) are physical factors of prevention, then the FINANCE and BUDGET are economic factors. Only the BUDGET is statistically significant at a 1% level and has a positive effect on reducing the disaster damage. Insignificance of estimated FINANCE coefficient can be explained with an inconsistent relationship of financial independence with the investment in disaster mitigation. The results show that 1 billion won (US$909,090) increase in annual budget can reduce damage by 0.55%. This results can be interpreted that the size of financial resource allocation for disaster prevention programs and facilities is closely relate to the capacity of disaster prevention. Kahn [35] study also suggest that the cities with strong financial position can respond to the disaster more effectively, thereby reducing risks with more investments in facilities and activities for disaster mitigation.

3.2. Prediction of Damage under Climate Change Scenarios

According to the Korea Climate Change Report, the average annual precipitations in Korea are increased by 162.84 mm in the past 30 years [40]. This increase in precipitation level is nearly four times compare to the global average, and it is expected that this trend will continue because of persistent climate change. Therefore, it is important to understand and predict the range of precipitation levels with the possible climate change scenarios.

IPCC addressed in their fifth comprehensive report of climate change that the extreme climate phenomenon with heavy storms and typhoons are likely to occur in coming years. They predicted that extreme precipitation will occur more frequently in most of the mid-latitude continent where Korea is located, and its intensity is likely to increase based on Representative Concentration Pathway (RCP) scenarios [2]. Among the four scenarios (RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5) adopted by IPCC, RCP 4.5 and RCP 8.5 scenarios show a 4.1% and 5.9% increase of precipitation in the second half of 21st century compared to the precipitation level in the last 30 years.

This study pursues to estimate the disaster damage by applying the projected precipitation to the estimated model in the previous section. RCP 8.5 scenario is the most extreme scenario among the four RCP scenarios, assuming that current greenhouse gas emissions trends continue without any reductions. Under the RCP 8.5 scenario, the precipitation of the metropolitan areas in Korea is expected to increase by an average of 532.5 mm through 2050. Table 4 shows the results of precipitation and disaster damage change in each metropolitan area using the estimated marginal effects in Table 3 and the projected precipitation change under the RCP 8.5 scenario.

According to the results, the largest increase in damage occurs in Busan when annual precipitation increases under the RCP 8.5 scenario, followed by Ulsan, Gwangju, Seoul, Daejeon, Daegu, and Incheon, respectively. The expected damage in Busan is estimated to increase by 1098% compared to the current level of damage. This result is due to a relatively small amount of current precipitation in Busan, but, under the RCP 8.5 scenario, their precipitation is expected to be the largest in 2050 compared to other major metropolitan areas. In addition, according to the status of the metropolitan areas shown in Table 5, the extreme wind speed and lower financial independence rate in Busan can also be considered to cause the greater damage in this city.

Table 6 presents expected regional economic damage in 2050 under RCP 8.5 scenarios. The results of seven metropolitan areas show that large increase in precipitation will cause greater economic damage. Busan is expected to have the economic damage with about 317 billion won (US$288 million). Ulsan, where second largest damage is expected with 1000% increase, is estimated to have about 250 billion won (US$227 million) in economic damage by 2050. Although Ulsan has a relatively small amount of current precipitation (1135.18 mm), their having the largest share of impervious areas (26.52 km^2) makes the city highly vulnerable to the disaster risks.

Meanwhile, Incheon is expected to have the smallest rainfall increase (about 293 mm) among the seven metropolitan areas. The damages are predicted to increase at the lowest level, up 295% from the current amount of damage. However, the expected economic damage in Incheon is about 5.6 billion won (US$5.1 million), which is larger than that of Daejeon and Daegu, where the expected increase in precipitation is greater. This result is due to larger current economic damage in Incheon (about 1.4 billion won (US$1.3 million)) compared to Daejeon and Daegu (about 1 billion won (US$909,090) and 0.02 billion won (US$18,200), respectively).

The change of urban green space ratio scenarios is also employed to observe its effect on regional damage and economic benefit changes under the RCP 8.5 scenario. Current urban green space ratios in seven metropolitan areas are in the range from 6.13 to 13.65%. Relevant urban green space ratio scenarios are necessary for each metropolitan areas to adopt in their urban green space planning strategies. Since most of the seven metropolitan areas are pursuing more green space to provide better amenity to their citizens, an ideal application is to present the scenarios from less to more aggressive strategies.

The first scenario employed in the analysis is 2% increase in urban green space ratio. From 2005 to 2013, the urban green space ratio is changed by about 2%, on average, in seven metropolitan areas. Based on these changes, more aggressive scenarios are applied with 5% and 10% increase in urban green space ratios. The results from these scenarios are presented in Tables 4 and 6. All seven metropolitan areas showed decline in expected damages and increase in economic benefit with higher green space ratios. The effects are in the order of Busan, Ulsan, Gwangju, Seoul, Daejeon, Incheon, and Daegu. The damage in Busan is expected to decline from 1097 to 1013% with the 10% change in their urban green space. This effect leads to about 19.5 billion won (US$17.7 million) in predicted economic benefit. Daegu has least effect from the scenarios with expected damage declines from 262 to 217% and an approximate 9 million won (US$8200) increase in expected economic benefit.

Based on the results from the RCP 8.5 scenario and urban green space ratio scenarios, it is suggested that managing vulnerable factors with proper preparation strategies are important in the regions where the increase of precipitation is expected to be large under the climate change. Also countermeasures of the climate change in the regions with a large amount of current damage will be necessary because the damage caused by disasters in these regions can be significant.

Table 4. Prediction of damage change by region in 2050 under RCP 8.5 scenario.

Region	Expected Precipitation Increase (mm)	Expected Damage Change (%)	Expected Damage Change with Urban Green Space Increasing Ratios (%)		
			2%	5%	10%
Seoul	461.4	423.58	411.40	393.32	363.68
Busan	883.1	1086.23	1071.61	1049.70	1013.23
Daegu	419.4	261.91	252.61	238.92	216.81
Incheon	292.5	295.06	283.01	265.13	235.84
Gwangju	561.7	705.77	691.40	669.88	634.14
Daejeon	299.8	319.43	306.89	288.25	257.65
Ulsan	809.3	887.59	873.34	852.02	816.64

Table 5. Main factors affecting disaster damage by region (2009–2013).

Region	Urban Green Space Ratio (%)	Annual Precipitation (mm)	High Precipitation Day (%)	High Wind Speed Day (%)	Impervious Area Ratio (%)	River Area Ratio (%)	Financial Independence Rate (%)	Budget (Billion Won)
Seoul	13.65	1414.80	2.39	2.99	55.82	8.4	48.27	285.03
Busan	12.86	1268.86	1.34	12.9	42.87	4.12	26.70	160.59
Daegu	9.13	1066.59	1.76	2.15	42.53	4.13	27.78	220.81
Incheon	6.13	1279.38	2.28	5.9	38.57	0.58	31.61	230.07
Gwangju	9.20	1308.35	2.27	12.95	24.19	3.97	21.01	201.09
Daejeon	11.26	1388.89	1.81	0.84	22.24	3.81	25.70	208.72
Ulsan	6.71	1135.18	1.29	7.93	27.42	3.46	38.73	188.94

Table 6. Prediction economic damage by region in 2050 under RCP 8.5 scenario (in units of 1 billion won).

Region	Current Economic Damage	Predicted Economic Damage	Predicted Economic Damage with Urban Green Space Increase Ratios		
			2%	5%	10%
Seoul	4.681	24.509	23.939	23.092	21.705
Busan	26.728	317.056	313.148	307.291	297.544
Daegu	0.019	0.069	0.067	0.064	0.06
Incheon	1.423	5.622	5.45	5.196	4.779
Gwangju	5.137	41.393	40.654	39.549	37.713
Daejeon	1.031	4.324	4.195	4.003	3.687
Ulsan	25.349	250.345	246.733	241.327	232.358

4. Discussion and Conclusions

The risks from natural disasters are relentlessly increasing due to climate change. Especially because many urban areas are exposed to higher risks and greater damage due to increase of impervious areas. The need for a sustainable disaster prevention system has been emphasized in relation to these problems. Among them, the disaster prevention function of urban green spaces has become important as an element of green infrastructure. Especially in the highly urbanized areas, there is roadside greenery, flower beds, and wall and rooftop greenery presented as alternative green spaces. The objective of this study is to investigate the effect of urban green infrastructure on disaster damage mitigation in Korea. The variations of damage are estimated under the different range of urban green space ratios. Tobit model is used to analyze the factors that determine disaster damage in urban areas and to predict how much damage will increase when precipitation increases according to climate change scenarios. We also predicted the degree of damage reduction when the urban green space ratio increases. 74 districts and counties in 7 metropolitan areas are defined as unit of analysis because they have high urbanization rate in Korea. The range of the study was set from 2005 to 2013 in order to reflect the recent changing climate phenomenon and damage patterns. The results and implications are summarized as follows:

First, the urban green infrastructure and budget are factors that can reduce disaster damage, while the annual precipitation, the maximum precipitation per hour, the maximum wind speed, sewer, and impervious area are factors that can increase disaster damage. The result of the urban green infrastructure shows the importance of its function as the method to mitigating the disaster. Furthermore, not only parks and green areas but also street trees and wall and rooftop greening are effective methods for mitigating disaster damage.

Second, when precipitation increase with extreme climate change scenarios, disaster damage in 2050 will increase from a minimum of 262% to a maximum of 1086% of the current damage. Notably, it is predicted that the increase of precipitation in Busan and Ulsan is the highest among seven metropolitan areas and their consequent disaster damage will also expect to rise significantly. These results suggest that countermeasures should be prepared in response to climate change focusing on the factors that increase disaster damage by each local government.

Third, when urban green space ratio increases up to 10%, the damage increase rate will be decreased by up to 20%. The economic benefit from the decline is estimated to be about 15 billion won

(US$13.6 million). The result shows the importance of urban green infrastructure areas in response to increasing precipitation due to climate change.

It is imperative for local governments to establish a strategic and comprehensive master plan for reducing storm and flood damage. In this regard, the results of this study suggest that managing vulnerable factors with proper preparation strategies are important and presents the significance of urban green infrastructure functions in urban areas to minimize the disaster damage.

This study has the following limitations. First, the climate factors used in this study play the major role in determining the disaster damage. Since climate factors are representative spatial data, it is necessary to consider the spatial correlation of the data. However, due to limitations of the data provided by national statistical service, it was difficult of consider the spatial correlation in the analysis. Secondly, the data used to predict the disaster damage under the climate change scenarios are based on current states. It is possible to use the forest data published by the meteorological agency, however other factors are assumed to continue according to present conditions. More accurate predictions can be possible with better predicted values of each factor.

Acknowledgments: This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2016S1A5A2A01927813). Open access fee is supported by the Research Institute for Agriculture and Life Sciences, Seoul National University.

Author Contributions: Both authors have contributed to the idea of the paper. Soyoon Kim's contribution analyze the data, interpretation of the results and drafting the article. Brian H. S. Kim provided core advice, revising it critically for important intellectual contents, English revision, and final approval of the version to be published.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. The World Bank. *Improving the Assessment of Disaster Risks to Strengthen Financial Resilience: A Special Joint G20 Publication by the Government of Mexico and the World Bank*; The World Bank: Washington, DC, USA, 2012.
2. Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2014: Synthesis Report*; Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Pachauri, R.K., Meyer, L.A., Eds.; IPCC: Geneva, Switzerland, 2014.
3. Yoon, D.K.; Kang, J.E.; Brody, S.D. A measurement of community disaster resilience in Korea. *Int. J. Urban Sci.* **2016**, *59*, 436–460. [CrossRef]
4. Dolcemascolo, G.; Kim, Y.; Mu, T.L. Reducing disaster risk in cities—The Republic of Korea's experience. *World Meteorol. Organ. Bull.* **2011**, *60*, 113.
5. National Emergency Management Agency (NEMA). 2013 Disaster Annual Report. Available online: http://www.mpss.go.kr/home/policy/statistics/statisticsData/?boardId=bbs_0000000000000042&mode=view&cntId=28&category=&pageIdx=&searchCondition=&searchKeyword= (accessed on 12 December 2016). (In Korean)
6. Lee, J.K.; Lee, S. Reviewing Korea's strategic plan for adaptation and mitigation for sustainable development and climate change. *Int. J. Urban Sci.* **2010**, *14*, 60–72. [CrossRef]
7. Charlesworth, S.M.; Harker, E.; Rickard, S. A review of sustainable drainage systems (SuDS): A soft option for hard drainage questions? *Geography* **2003**, *88*, 99–107.
8. Dietz, M.E. Low impact development practices: A review of current research and recommendations for future directions. *Water Air Soil Pollut.* **2007**, *186*, 351–363. [CrossRef]
9. Kwon, Y.A.; Lee, H.Y. Spatial distribution of temperature in and around urban parks—A case study of around Changkyeong Palace, Changdeok Palace and Jongmyo in Seoul. *J. Korean Geogr. Soc.* **2001**, *36*, 126–140.
10. Park, S.H.; Lee, S.H. The impact of urban green space on the change of air temperature of its surrounding area: A case of Seoul-Sup. *J. Clim. Res.* **2010**, *5*, 250–262.
11. Kim, D.H.; Kim, E.G.; Yang, J.S.; Kim, H.G.; Shin, H.J. An econometric analysis of mitigating urban heat island effect with urban forest. *J. Korean For. Soc.* **2011**, *100*, 79–87.
12. Zhang, B.; Xie, G.; Zhang, C.; Zhang, J. The economic benefits of rainwater runoff reduction by urban green spaces: A case study in Beijing, China. *J. Environ. Manag.* **2012**, *100*, 65–71. [CrossRef] [PubMed]

13. Beard, J.B.; Green, R.L. The role of turf grasses in environmental protection and their benefits to humans. *J. Environ. Qual.* **1994**, *23*, 452–460. [CrossRef]
14. Keeley, M.; Koburger, A.; Dolowitz, D.P.; Medearis, D.; Nickel, D.; Shuster, W. Perspectives on the use of green infrastructure for stormwater management in Cleveland and Milwaukee. *Environ. Manag.* **2013**, *51*, 1093–1108. [CrossRef] [PubMed]
15. Mentens, J.; Raes, D.; Hermy, M. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landsc. Urban Plan.* **2006**, *77*, 217–226. [CrossRef]
16. Shepherd, J.M. Evidence of urban-induced precipitation variability in arid climate regimes. *J. Arid Environ.* **2006**, *67*, 607–628. [CrossRef]
17. Pauleit, S.; Duhme, F. Assessing the environmental performance of land cover types for urban lanning. *Landsc. Urban Plan.* **2000**, *52*, 1–20. [CrossRef]
18. Armour, T.; Armour, S.; Hargrave, J.; Revell, T. *Cities Alive: Rethinking Green Infrastructure*; Arup: London, UK, 2014.
19. Kim, H.; Lee, D.K.; Sung, S. Effect of urban green spaces and flooded area type on flooding probability. *Sustainability* **2016**, *8*, 134. [CrossRef]
20. Laura, Grant. *Multi-Functional Urban Green Infrastructure*; Chartered Institution of Water and Environmental Management (CIWEM): London, UK, 2010.
21. Schilling, J.; Logan, J. Greening the rust belt: A green infrastructure model for right sizing America's shrinking cities. *J. Am. Plan. Assoc.* **2008**, *74*, 451–466. [CrossRef]
22. Armson, D.; Stringer, P.; Ennos, A.R. The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. *Urban For. Urban Green.* **2013**, *12*, 282–286. [CrossRef]
23. Bartens, J.; Day, S.D.; Harris, J.R.; Dove, J.E.; Wynn, T.M. Can urban tree roots improve infiltration through compacted subsoils for stormwater management? *J. Environ. Qual.* **2008**, *37*, 2048–2057. [CrossRef] [PubMed]
24. Farrugia, S.; Hudson, M.D.; McCulloch, L. An evaluation of flood control and urban cooling ecosystem services delivered by urban green infrastructure. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* **2013**, *9*, 136–145. [CrossRef]
25. Tobin, J. Estimation of relationships for limited dependent variables. *Econometrica* **1958**, *26*, 24–36. [CrossRef]
26. Hill, R.C.; Griffiths, W.E.; Lim, G.C. *Principles of Econometrics*, 3rd ed.; Lee, B.R., Trans, L., Eds.; Sigma Press: Seoul, Korea, 2010.
27. Miller, J.D.; Kim, H.; Kjeldsen, T.R.; Packman, J.; Grebby, S.; Dearden, R. Assessing the impact of urbanization on storm runoff in a peri-urban catchment using historical change in impervious cover. *J. Hydrol.* **2014**, *515*, 59–70. [CrossRef]
28. Shi, P.J.; Yuan, Y.; Zheng, J.; Wang, J.A.; Ge, Y.; Qiu, G.Y. The effect of land use/cover change on surface runoff in Shenzhen region, China. *Catena* **2007**, *69*, 31–35. [CrossRef]
29. Choi, Y.; Seo, M.H. Assessing the impact of the factors of urban characteristics on the damages caused by natural disaster using panel model. *J. Korea Plan. Assoc.* **2013**, *48*, 309–318.
30. Kang, J.E.; Lee, M.J.; Gu, Y.S.; Cho, G.W.; Lee, J.W. Urban renewal strategy for adapting to climate change: Use of green infrastructure on flood mitigation. *KEI Res. Rep.* **2011**, *7*, 85. (In Korean)
31. Lee, C.S.; Ho, H.Y.; Lee, K.T.; Wang, Y.C.; Guo, W.D.; Chen, D.Y.C.; Kuo, H.C. Assessment of sewer flooding model based on ensemble quantitative precipitation forecast. *J. Hydrol.* **2013**, *506*, 101–113. [CrossRef]
32. Olsson, J.; Amaguchi, H.; Alsterhag, E.; Dåverhög, M.; Adrian, P.E.; Kawamura, A. Adaptation to climate change impacts on urban storm water: A case study in Arvika, Sweden. *Clim. Chang.* **2013**, *116*, 231–247. [CrossRef]
33. Castellarin, A.; Di Baldassarre, G.; Brath, A. Floodplain management strategies for flood attenuation in the river Po. *River Res. Appl.* **2011**, *27*, 1037–1047. [CrossRef]
34. Jeong, G.H.; Shim, G.B.; Kim, E.S. Study on design capacity of stormwater pipe and pumping station considering peak rainfall intensity. *J. Korea Water Resour. Assoc.* **2014**, *47*, 777–787.
35. Kahn, M.E. The death toll from natural disasters: The role of income, geography, and institutions. *Rev. Econ. Stat.* **2005**, *87*, 271–284. [CrossRef]
36. Gill, S.E.; Handley, J.F.; Ennos, A.R. Adapting cities for climate change: The role of the green infrastructure. *Built Environ.* **2007**, *33*, 115–133.
37. Choi, C.I. A Study on natural hazards vulnerability in urban area by urban land use change—Case of Kyonggi province. *J. Korea Plan. Assoc.* **2003**, *38*, 35–48.

38. Shin, S.Y. Improvement of urban planning for natural disaster reduction. *Real Estate Focus* **2014**, *75*, 4–15.
39. Kim, J.H. Local severe rain strom and flood damage around retarding basin. *J. Korean Soc. Hazard Mitig.* **2002**, *2*, 27–34.
40. Korea Meteorological Administration. 2012 Korea Climate Change Report. Available online: http://www.kma.go.kr/weather/climate/average_south.jsp (accessed on 3 January 2017). (In Korean)