ESTIMATING DAMAGE BY RISING SEA LEVELS WITH A FOCUS ON BUSAN METROPOLITAN CITY

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Abstract

In wake of continually rising sea levels due to global warming, this study calculates flood damage to buildings in coastal areas of Busan Metropolitan, a major coastal city in Korea. Comparing climate change scenarios of representative concentration pathways (RCP) 4.5 and 8.5, this study employed flood depth and building asset damage calculation methods of multi-dimensional flood damage analysis (MD-FDA) to ascertain district-wise damage to Busan's building assets. Flood damage was calculated by applying flood transfer rate and flood damage rate, which consider flood depth to assets of measurement items. Damage amount was deduced through unit construction cost and ground area by building structure and purpose of individual flooded buildings. Although MD-FDA applies average unit cost and ground area, this study deduced exact damage amount to flooded buildings by considering characteristics of individual buildings. Flood area and flood damage increased significantly with RCP 8.5 as compared to RCP 4.5. On account of several coastal factories, Nam-gu and Saha-gu showed most extensive damage by districts, with building damage estimated at KRW 79 billion and KRW 61 billion respectively. Gangseo-gu and Haeundae-gu showed largest increase in damage with RCP 8.5. The presence of Gangseo-gu's residential buildings and Haeundae-gu's large-scale cultural facilities and offices will contribute to increased flood damage. Gangseo-gu, which is currently developing, and Haeundae-gu, which is densely populated, are likely to have greater additional damage due to flooding. Comparing and analyzing damage amount to buildings by districts according to climate change

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scenarios can expand awareness on flood damage by rising sea levels. Results can provide local governments with opportunities to review risks, and serve as data to assist in decisions when reacting to flooding sea levels. Future studies should expand on building, industrial, and other assets to prepare for climate change consequences.

Keywords: climate change, rising sea levels, flood damage, building damage, Busan Metropolitan

Introduction

The Intergovernmental Panel on Climate Change (IPCC) Synthesis Report 2014 asserts that climate change increases existing risks and induces new risks for nature and humans. Climate change risks may manifest locally or globally. Rising sea levels, a major risk to coastal systems and lowlands, are expected to continue for centuries—even if earth's average temperatures are stabilized. Long-term rises in sea levels are dangerous for humans, assets, economies, and eco-systems. Although rising sea levels are a sustainable and long-term risk, they are largely neglected in comparison to other impacts of climate change, as damages are not directly or immediately experienced. This study hopes to stir effective counter-measures from citizens and decision-makers to reduce the expected devastation of rising sea levels by calculating the massive foreseeable damage to buildings.

Prior studies on the evaluation of floods in Korea have largely focused on flood damage (Cho, 2015) calculated using MD-FDA with methods of simplifications and improvements (Lee et al., 2006). Improvements, an enhanced version of simplifications, calculates yearly average flood damage before and after river improvements, as suggested in *A Study on the Improvements of the Economic Analysis of the Flood Control Project* (Ministry of Land, Infrastructure and Transport, 2002). Regression was deduced by collecting past data on damage; and damage was calculated using flood area and damage categories as functions. MD-FDA is the reviewed version of the existing improvements that uses the regression equation. *A Study on the Economic Analysis in Flood Control Projects—Multi-Dimensional Flood Damage Analysis* (Shim, 2004) was conducted to quantify flood damage, and Shin (2013) developed the MD-FDA to match conditions in Korea. Shim reviewed units and measurements of the MD-FDA based on *A Study on the Economic Analysis in Flood Control Projects—Multi-Dimensional Flood Damage Analysis* (Ministry of Land, Infrastructure and Transport in 2004) and *Improving Measures of Feasibility Study for Water Resources Projects* (Ministry of Land, Transport and Maritime Affairs and K-Water in 2008) (Shin, 2013).

Table 1: Damage Calculation of Harbor Disaster Vulnerable Areas by MD-FDA (Shin, 2013)

Categories		Items	Notes
Direct Damage	Asset Damage	Damage to residential assets (buildings + building interiors)	General Assets

		Damage to agricultural assets (farmland + crops)	
		Damage to industrial assets (tangible assets + inventory assets)	
		Damage to ships	
		Damage to public facilities (roads, etc.)	
	Human Damage	Loss of human life	
		Flood victims	

MD-FDA is only applicable for direct damages. In Table 1, damage is calculated by ascertaining asset value of each item and then applying damage rate and flood transfer rate considering flood depth. This study deduces flood damage by sea level rises by partially applying the MD-FDA by Shin (2013). As the MD-FDA aims to quantify values to calculating average asset damage and socioeconomic damage to a particular location, it was difficult to closely identify damage to an individual building. In this study, damage to each building was calculated to present detailed loss in each district, thereby emphasizing dangers of rising sea levels. Using Busan City, this study utilized data of flood depth and flood damage to buildings applying RCP 4.5 and RCP 8.5 as of 2050. From the direct damage due to floods, the study focused on damage to building assets to calculate the flood damage amount.

Theory and Method

RCP 4.5 and RCP 8.5

The climate change scenario of RCP predicts how the climate system will develop in the future in relation to the release of greenhouse gasses (RCP Scenario, 2019). As data, this study used results calculated from RCP 4.5, which assumes that greenhouse gas reduction policies will come into sufficient effect, and RCP 8.5, which assumes that greenhouse gasses will be released without reduction policies in 2050.

Figure 1 shows flood areas and flood depths of Busan, which has the greatest population density of coastal cities in Korea and is expected to have extensive building damage due to a rise in sea levels as buildings are largely concentrated along the shore. As seen in Figure 1, the flood damage of Busan shows a higher flood depth at RCP 8.5 than RCP 4.5 and also a broader flood area, which reconfirmed differences between both scenarios. The area of greatest difference between RCP 4.5 and 8.5 is the flood area of Gangseo-gu, depicting a large increase in flood damage. Although no significant differences exist in districts other than Gangseo-gu, it is expected that the amount of building damage will increase more in RCP 8.5 than RCP 4.5, as flood depths will also become greater.

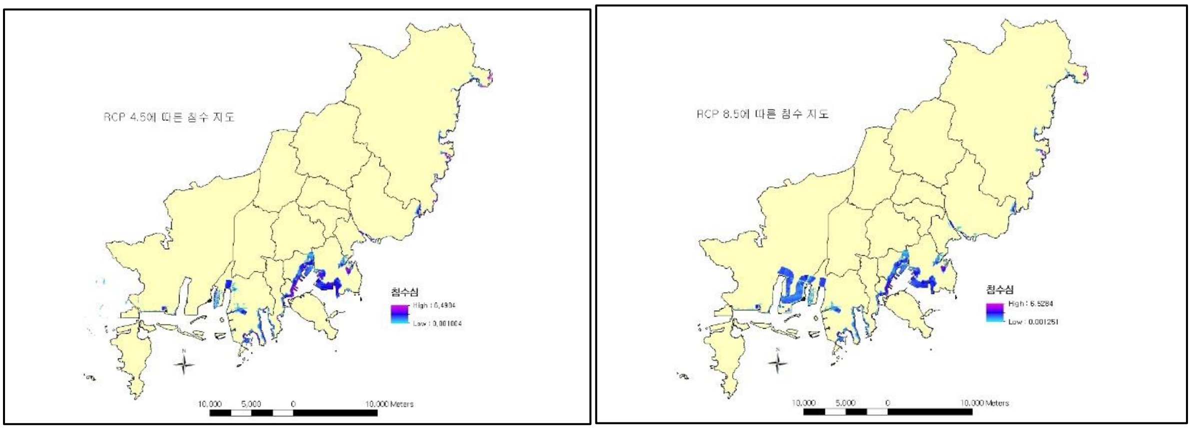

Figure 1. Flood Maps of Busan Metropolitan at RCP 4.5 and RCP 8.5

Calculating Building Flood Damage

1) Calculating Building Assets

This study calculated building assets by referring to the method by Shin (2013) using MD-FDA. MD-FDA first measures assets, then calculates the amount of damage by multiplying it with flood transfer rate and flood damage rate. Shin (2013) suggested an equation to calculate assets of flooded areas. MD-FDA uses unit construction costs by building types, average ground area by building types, and average number of households by residential buildings to calculate building assets for average assets and damage amount. However, as this study deduces damage amount for individual buildings by usage and structure, building asset value was calculated by multiplying unit construction costs by building types and ground area of buildings as shown in Table 2.

Table 2: Comparison of Equations for Values of Building Assets

Category	Values of Building Assets
MD-FDA	= unit construction costs by building types (KRW/m²) * Number of households by floor area of buildings * Average ground area by building types (m²) * Number of households by residential building types (No.) * Deflators of the construction industry of the base year
Present study	= unit construction costs by building types (KRW/m²) * Floor area of the building (m²)

From data on 1,062 buildings with flood damage according to RCP 4.5, 270 were excluded due to lack of ground and floor area measurements, with 3 more excluded due to unclear use of buildings. From data on 1,131 buildings with flood damage according to RCP 8.5, 300 were excluded from the analysis.

2) Unit Construction Costs

The study referred to the Unit Price Table of New Buildings by the Korea Appraisal Board (2016) for unit construction costs. Standard unit cost of a building includes pure construction cost which is calculated with standard quantity per unit proposed by the government and actual costs, overhead expenses (indirect labor expenses, industrial insurances, safety management and other costs, general management fees, profit, etc.), design and supervision cost, and basic electrical equipment costs (lights, electrical line construction costs) (Korea Appraisal Board). This study excluded overhead expenses, construction costs, and supervision costs as they were difficult to include into flood damage amount. Items were organized by use of buildings; average unit construction cost by building structures were calculated. Log houses and steel houses as single-unit houses, dormitories as multi-unit houses, general bathhouses and saunas in commercial facilities, and timber rooms(hall built for a memorial service held before the grave) in religious facilities were excluded. Usage of buildings was categorized based on 'Annex 1 of the Building Act Enforcement Decree', and building structure was categorized and organized based on building structure items such as wood, bricks, blocks, sandwich panels, steel frame, steel framed reinforced concrete construction, and reinforced concrete structure. Average unit cost by building use was applied to buildings that did not meet the criteria for items in Table 3.

Table 3: Unit Construction Costs by Building Structure and Building Use

Unit Cost of New Buildings	Woods	Bricks	Blocks	Sandwich Panels	Steel Frames	Steel Framed Reinforced Concrete Construction	Reinforced Concrete Structure
Multi-unit houses		657,079				1,280,096	1,056,812
Factories	349,998	514,884	358,737		601,626		617,150
Educational and Research Facilities						682,161	575,494
Commercial Facilities	576,687	583,197	502,180		622,374		673,135
Children and Elderly Facilities							747,136
Single-Unit Houses	1,232,892	1,050,509	502,980	316,907			889,272
Animal Related Facilities					388,262		
Culture and Meeting Facilities						1,017,911	866,051
Accommodations		681,102				1,035,627	808,356
Business Facilities		507,619	454,805	309,972		873,933	701,986

Exercise Facilities					996,256	799,991	822,550
Hazard Materials and Waste Facilities					385,661		534,012
Medical Facilities						1,096,274	829,323
Vehicle Related Facilities						439,526	338,459
Funeral Halls							748,987
Religious Facilities							769,281
Warehouse Facilities	253,178	835,732	322,755		498,514		625,848
Sales Facilities						535,300	481,124

3) Flood Transfer Rate and Flood Damage Rate

Flood transfer rate is used to convert total asset value of a particular factor (residential, agricultural, or industrial) within an administration unit to actual asset value of flooded area, and is the proportion of the flooded building within the flooded area (Lee et al., 2011). As this study calculates damage to areas expected to flood according to the actual climate change scenario (Cho, 2015), the flood transfer rate was set at 1.

Flood damage rate of buildings by flood depth was applied based on *Improving Measures of Feasibility Study for Water Resources Projects* by the Ministry of Land, Transport and Maritime Affairs and K-Water (2008) and Shin (2013). Although flood damage rate is irrelevant to building structure, it should consider number of floors; hence it was calculated by dividing damage rate of a single-floor single-unit house by number of floors (Table 4). Number of floors was calculated by dividing the building's ground by its floor area.

Table 4: Flood Damage Rate of Buildings by Flood Depth

Flood Depth	0-0.5m	0.5-1.0m	1.0-2.0m	2.0-3.0m	3.0m and above
Single-Unit House	15	32	64	95	100
Multiple Floors	15/number of floors	32/ number of floors	64/ number of floors	95/number of floors	100/ number of floors

To calculate flood depth, each flood-prone area was divided by scenarios RCP 4.5 and RCP 8.5 into cells with a size of 50*50, and expected flood depth of each cell was calculated. The study used ArcGIS to overlay data on flooded buildings located at the top of flood-prone areas to record flood depth of each building. In case of building pitchers that spanned two or more cells, average flood depth for all cells was used. When combining flood damage rate and flood depth of Table 4 with data on flooded buildings and organizing by climate change scenarios, the result is a database as seen in Tables 5 and 6. Tables 5 and 6 are only a part of the database in an ascending order of flood depth.

Table 5: Data on Flooded Buildings of RCP 4.5

Category	RCP 4.5 (Ascending order of flood depth)						
	Address	Building Usage	Building Structures	Unit Construction Cost (KRW/m^2)	Total Ground Area (m^2)	Flood Depth (m)	Flood Damage Rate (%)
935	Songjung-dong, Gangseo-gu	Factory	Steel Frame	601,626	1071	0.003	7.5
62	2-ga, Shinchang-dong, Jung-gu	Commercial Facility	Steel Frame	622,374	121.28	0.005	7.5
937	Songjung-dong, Gangseo-gu	Factory	Steel Framed Reinforced Concrete Construction	488,479	1850.5	0.006	7.5
…	…	…	…	…	…	…	…

Table 6: Data on Flooded Buildings of RCP 8.5

Category	RCP 8.5 (Ascending order of flood depth)						
	Address	Building Use	Building Structures	Unit Construction Cost (KRW/m^2)	Total Ground Area (m^2)	Flood Depth (m)	Flood Damage Rate (%)
986	Songjung-dong, Gangseo-gu	Factory	Steel Frame	601,626	1472.67	0.002	7.5
425	2-ga, Shinchang-dong, Jung-gu	Commercial Facility	Steel Frame	673,135	597.23	0.004	7.5
1013	Songjung-dong, Gangseo-gu	Factory	Steel Framed Reinforced Concrete Construction	583,197	59.77	0.006	7.5
…	…	…	…	…	…	…	…

Results

As aforementioned, a building's flood damage is calculated by applying flood transfer rate and flood damage rate to building asset, which was calculated by multiplying ground area with unit construction costs. Table 7 shows the amount of flood damage by districts and rate of flooded areas by districts.

Table 7: Flood Damage in Busan City

Districts	RCP 4.5		RCP 8.5	
	Flood Rate (%)	Amount of Flood Damage for Buildings (100 mil. KRW)	Flood Rate (%)	Amount of Flood Damage for Buildings (100 mil. KRW)
Gangseo-gu	0.27	13.0	4.33	148.1
Gijang-gun	1.04	200.1	1.01	205.7
Nam-gu	21.48	793.2	21.10	791.7
Dong-gu	33.08	441.3	33.13	447.7
Busanjin-gu	0.38	5.8	0.38	5.8
Saha-gu	12.27	617.2	12.61	612.0
Seo-gu	6.52	236.4	6.51	241.5
Suyeong-gu	1.74	15.7	3.09	15.9
Jung-gu	32.17	311.0	32.40	311.4
Haeundae-gu	1.30	31.2	1.85	82.8
Total	3.30	2664.8	4.63	2862.6

Applying climate change scenarios for each district (Gu or Gun) of Busan, it was seen that the rate of flooded areas and amount of flood damage of buildings generally increased in RCP 8.5 as compared to RCP 4.5. However, some districts showed a decreasing trend due to a flood damage calculation error that omitted ground and floor area during analysis.

Nam-gu and Saha-gu showed the largest damage by districts. Building damage in Nam-gu was estimated at KRW 79 billion, and in Saha-gu at KRW 61 billion, followed by Dong-gu, Jung-gu and Seo-gu. Although Dong-gu has a larger flooding area, differences in Nam-gu's building uses, particularly factories concentrated in Gamman-dong (compared to Dong-gu's residential areas), contribute to higher building damage. Saha-gu also has factories in coastal areas, which will lead to greater damage as compared to other districts.

Gangseo-gu and Haeundae-gu districts show the largest increase in the ratio of damage in RCP 8.5. Gangseo-gu will have the largest increase in flooded areas and amount of flood damage to buildings. Although only factories in coastal areas were flooded in RCP 4.5, the amount of damage increased in RCP 8.5 due to residential areas, multi-unit houses, commercial facilities, and single-unit houses. Unlike Gangseo-gu, Haeundae-gu district's flood areas in RCP 8.5 expand in commercial areas, which leads to floods in large-scale cultural facilities, office buildings, and accommodation; with building damage high in comparison to the increases in flooded areas.

Discussion

The study's purpose was to deduce flood damage from sea level rises by ascertaining the amount of damage to building assets. Busan, a major coastal city with many buildings on the shoreline was the subject region. Until now, flood damage studies in Korea focused methods of calculating amount of flood damage using MD-FDA, which calculates damage amount by calculating assets of directly damaged items and applying flood transfer rate and flood damage rate by the flood depth, and is most commonly used. This study focused on building assets from MD-FDA items to ascertain damage for individual buildings and damage to flooded areas. Flood data applying climate change scenarios RCP 4.5 and RCP 8.5 based on 2050 were utilized as data for rising sea levels, and amount of damage to flooded buildings was calculated by unit construction costs, building usage, and building structures. For a significant interpretation, the results analysis was conducted using total amount of damage of each district in Busan.

When comparing RCP 4.5 and RCP 8.5, Nam-gu and Saha-gu showed greatest flood damage to buildings in both scenarios. Factories in coastal areas flooded for both Nam-gu and Saha-gu, which resulted in high damage amount. Gangseo-gu and Haeundae-gu were determined to have increases in building damage in the scenario of RCP 8.5. However, both districts displayed different characteristics. Flood-prone areas in Gangseo-gu expanded more to residential areas, which led to inclusion of numerous multi-unit houses and single-unit houses. Haeundae-gu differed from Gangseo-gu as the flood areas expanded to non-residential buildings (cultural and business facilities), leading into an increase in damage.

This shows that effects of damage due to rises in sea level will surpass simple economic loss to various types of damage by districts. First, the fact that many districts showed insignificant differences in the damage amounts in RCP 8.5 and RCP 4.5 is disproved, indicating that it is difficult to prevent rises in sea levels even if there are sufficient policies for reducing greenhouse gasses. This serves as evidence for creation of a more active policy towards climate change and induces interest in this topic.

Second, another potential risk factor is that Gangseo-gu and Haeundae-gu are areas with the largest changes. Haeundae-gu is the second center of Busan, with high population density and high-rises particularly near the coast. This leads to a potential risk of not only building damage, but also human, social, and cultural damage in case of an actual flood. Gangseo-gu is the center of development in western Busan, and it is expected that there will be a more focused population with not only the developed Myeongji New Town but also the forthcoming Eco Delta City. Additionally, as numerous residential buildings are included in RCP 8.5, the rise in sea levels will not only lead to human loss but also affect residents' household budgets.

Third, there is a great risk in terms of industrial aspects. Most buildings in flooded areas are residential units (multi-unit houses, single-unit houses, commercial facilities), followed by factories, warehouse facilities, and business facilities. As industrial buildings cover more area than residential buildings, there is greater damage even when only considering building assets. If there is a flood due to a rise in sea levels, there will be damage to not only building assets but also to industrial assets.

Although this study only focused on building damage due to floods caused by rising sea levels, it was possible to deduce detailed amount of damage as building assets were not applied en bloc. This will lead to a detailed data on assets such as building content asset and industrial asset, which will in turn lead to deducing a detailed injury function that reflects reality. The development of an injury function at a microscopic level that considers characteristics of a region will point to a local reaction for natural disasters from climate change. Further, this process may have applications not only in actual situations but also as basic data to review climate change and its effects by decision makers and citizens.

For future studies, accuracy of data is required. As aforementioned, when calculating results, there was an error in increase or decrease in amount of damage when there was loss of data on flooded buildings. Data that minimize such errors and can calculate an exact result of the economic loss are absolutely necessary. Second, this study only considered rises in sea levels caused by climate change, and not flooding and flood damage due to natural disasters such as typhoons and tsunamis. The study should also be developed as a model to assess damage to coastal areas in cases of serious natural disasters resulting from climate change.

Acknowledgment

“This work is financially supported by Korea Ministry of Land, Infrastructure and Transport(MOLIT) as 「Innovative Talent Education Program for Smart City」".

References

Cho, Kwang Woo. (2015). “Study on quantifying risk of the effects of climate change(II) : focusing on Korean coastal system.” Korea Environment Institute.

Korea Appraisal Board. (2016). “Unit Price Table of New Buildings.” Korea Appraisal Board.

Lee, Giha, Park, Kyoung-Won, Yu, Wansik, Jung, Kwan-Sue, Jang, Chang-Lae. (2011). A Study on Flood Damage Estimation Using DEM-based Flood Inundation Model and MD-FDA. “Journal of the Korean Society of Hazard Mitigation, Vol. 11, No.5” 327-336. Korean Society of Hazard Mitigation.

Lee, Keon-Haeng, Choi, Seungan, Kim, Hung Soo, Shim, Myung Pil. (2006). Application of Multi-Dimensional Flood Damage Analysis for Urban Flood Damage. “Journal of the Korean Society of Civil Engineers B” 363-369. Korean Society of Civil Engineers.

Shim, Myung Pil. (2008). “Improving Measures of Feasibility Study for Water Resources Projects.” Ministry of Land, Transport and Maritime Affairs, K-Water.

Shin, Seung-sik. (2013). Economic Feasibility Study of Port Disaster Prevention Facility from Climate Change Storm Surge Using MD-FDA. “Ocean Policy Research” 133-176. Korea Maritime Institute.