Analyzing green space as a flooding mitigation – storm Chaba case in South Korea

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ABSTRACT
A tropical storm Chaba hit the southeastern part of South Korea in 2016. Ulsan, the 8th largest city in terms of the number of population, was especially damaged with heavy flooding, and the calculated damage was approximately $500 million. By using Normalized Differences in Vegetation Index (NDVI), four districts and 46 sub-districts in Ulsan city, South Korea. Analysis results indicate that having a higher proportion of green space inside a city could have a reduction effect on flooding risks. 1 km² of increase in green space could reduce financial insurance payment of flooding by $44,099. In addition, an increase in non-green space also could have raised insurance payment by $691,094. The result confirms that green space inside floodplain is more effective than its existence outside floodplain. The difference is about 21 times ($44,099 vs. $953,755). Green space can mitigate flooding impact to a certain degree and it could be used to determine how natural disaster policy in municipal level should be organized. In addition, it can also provide a foundation for claiming insurance payments to those facilities without careful considerations on environmental planning.

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1. Introduction
Rapid urbanization has created massive changes in urban and regional environment. This is especially true for high-density city centers, because a large amount of new developments such as roads, parking lots, and large-scale architecture have made a significant amount of impervious surfaces. This change could induce unexpected events, which can in return greatly influence human inhabitant. For example, an increase in impervious surface can affect storing capability of flowing water that can cause a larger amount of flooding in hazardous sites (Foster et al. 2011, Meerow and Newell 2017, Liu and Jensen 2018).

In South Korean case, the society has experienced about 17% increase in rainfall over the last 100 years and 18% increase in the number of raining days (Lee and Kim...
As a consequence, many countries have started to pay attention to the use of green space in an urban and regional scale. This study is designed as a part of this ongoing research effort and focuses on particular study area to respond to disasters that alarmed many related officials. Korea is consistently experiencing heavy seasonal flooding in summer and diverse efforts were applied to ease the problem. However, due to changes in weather conditions and other related environment concerns, such as global warming or urban heat island effect, flooding damages tend to diminish very slowly. Accordingly, the central government and local municipalities are seeking for possible remedies that could change to a resilient built environment. Implementing green space is one of government-focused strategies and accurately assessing national stock became a very important task (Lamia et al. 2011, Choi et al. 2018).

This study is designed to accurately estimate how much green space exists in a region and how it is located inside a city. To facilitate green space’s availability in flooding risks, it is important to understand how much stock locates within the study boundary and how to utilize them to minimize the impact of flooding. By using high-resolution satellite images, the author identifies the differences in calculating the amount of green space. Compared to general land cover dataset, high-resolution satellite images provide clearer perspectives, and this difference can make strategic changes in local policy implementation.

In addition, the Normalized Differences in Vegetation Index (NDVI) was used to calculate a precise amount of green space within the study boundary. NDVI provides a clearer picture on the amount and patterns of green space (Jeevalakshmi et al. 2016, Kong et al. 2016, Shao et al. 2016, Pang et al. 2017). Using NDVI information, the author analyzes the relationship between the amount of green space and the estimated damages by flooding. Using Ulsan city as the study area, four districts and 46 sub-districts are tested to assess the amount of green space.

2. Backgrounds and literature reviews
2.1. Green space

Recently, there has been a large amount of interests raised on green space and its utilization. Not just from civil engineering point of view, many experts in urban and regional planning emphasize the importance of green space in environmental planning. Especially, the relationship between green space and flood mitigation received a greater attention than before. Green space has its origin in planning and conservation theory, concerned with the linkage between parks and other green spaces and their
potential benefits. It is also rooted in conservation efforts that deal with habitat fragmentation and link natural areas with biodiversity (Benedict and McMahon 2006).

The term ‘green space’ as well as the implementation of its concepts and values has been applied frequently since 1999 (Benedict and McMahon 2006, Liu and Jensen 2018). Green space is identified as an interconnected network of green space that maintains natural ecological processes, sustains air and water resources, and contributes to the health and quality of life in communities (Derkzen et al. 2017, Jayasooriya et al. 2017, Meerow and Newell 2017, Lee 2018). In addition, green space has been diversely defined depending on respective professional discipline or the scale at which green space is implemented (Foster et al. 2011, Connop et al. 2016, Snäll et al. 2016).

Considering rapid population growth and expanding residential areas, green space is distinguished from conventional open space planning because green space addresses issues related to land development, growth management, and built infrastructure planning (Jayasooriya et al. 2017, Sanesi et al. 2017, Lee 2018). Green space has become an emerging topic as a hazard mitigation tool due to positive outcomes that facilitate more effective reduction of flood impact in urban areas. Rapidly expanding urban development results in conversion of open space and added impermeability, thus increasing adverse hazard impacts, such as stormwater runoff and flooding (Blessing et al. 2017, Brody et al. 2017).

2.2. Land cover & NDVI

Previous empirical research measures green space using different types of datasets, such as the National Land Cover Database (NLCD) or the Coastal Change Analysis Program (C-CAP) Land Use Land Cover (LULC) Data (Highfield and Brody 2017, Newman et al. 2017). However, using 30 m LULC data is not precise enough to capture detailed green space, especially in urban areas. These datasets sometimes overlook green space that is not captured due to a coarse resolution, and they do not consider green areas besides those in green-related classifications. For example, green areas in high-intensity developed LULC type are not considered in the analysis of the relationship between LULC and streamflow measurement. As different land uses have different degrees of development, variation in green space, such as canopy cover exists across land-use types (Grekousis et al. 2016, Rahman 2016). Zoning ordinances for regulating land use include tree canopy cover in some municipalities. For instance, Chesapeake, Virginia required through its zoning ordinance the maintenance of 10% canopy cover on parcels in non-residential zones, 15% canopy cover in multi-family residential zones, and 20% canopy cover in single-family residential zones (Jeevalakshmi et al. 2016, Kong et al. 2016, Shao et al. 2016, Lee 2018, Lee 2020).

In order to measure these variations in green space across different land uses, an empirical study with more detailed green space measurement should be followed. This study utilized high resolution satellite images to assess green space at a finer scale. Conventional approaches employed the NLCD, C-CAP land-cover data, which are gathered at a 30 M x 30 M resolution (Jeevalakshmi et al. 2016, Shao et al. 2016). However, this study utilized satellite imagery data produced by the Korea Aero Research Institute (KARI) to compute normalized difference vegetation index (NDVI) with 1 M x 1 M resolution data.
3. Materials and methods

3.1. Study area

As described previously, Ulsan, the 8th largest city in South Korea in terms of population, experienced a significant tropical storm Chaba in 2016. Chaba was not the strongest storm that the Korean territory has experienced, but it indeed was one of the significant ones in its history. Due to its recordable results, the 2nd place in the maximum wind speed recorded, it has created a large amount of impact to human inhabitant (Choi et al. 2018, Lee et al. 2018). Ulsan was one of the biggest victims of Chaba and experienced a maximum of 139 mm of rains in an hour (Lee et al. 2018, Yang et al. 2018). Not only schools and other buildings were flooded, two people were dead and many were lost in the flows of water. Since then, the municipal government of Ulsan and the central government paid a strong attention to recovery and precautionary measures so that no more tragedy could take a place in the region (Son and Lee 2018).

Figure 1 illustrates study boundary and its location from Seoul. Ulsan is located in the southeastern part of Korea and the distance from the capital is about 310 km. It is famous for heavy industries, such as Hyundai Motors factories. There are 5 main districts in Ulsan city and Ulju-gun is the latest consolidated district with the largest amount of crop lands. Due to its mountainous character and the distance from the East Sea, Ulju-gun had experienced relatively less damages from the same storm Chaba. Therefore, the study area is set to where the damages are prevalent and focuses on the four other districts of Ulsan city.

3.2. Datasets and analysis

To properly understand green space situations in Ulsan city, the author first examined overall land cover datasets in 30 years. Analyzing the amount of green space changes could give an insight on how Ulsan city has progressed over time and how much changes can be observed due to a rapid urbanization. The Ministry of
Environment provides a decennial land cover data with 7 different classifications in 30 M x 30 M resolution. Until 2015, the ministry has launched 18 satellites and 6 are under their mission now days. Among them, 3 satellites are dedicated for monitoring land situations in Korea providing both land cover and higher resolution satellite images.

However, conventional land cover datasets do not provide a detailed insight about the changes in a land use, and therefore, higher resolution datasets should be examined. Satellite datasets with higher resolution, 1 M x 1 M, were analyzed using Geographic Information Systems (GIS). Image analysis and Map Algebra functions in ArcGIS allow to calculate NDVI with satellite images by using near-infrared and red bands.

After that, each NDVI values are extracted by each sub-district and determined if the value is higher than 0.5 making it closer to green space. Using this information, a linear regression analysis was conducted to test the relationship between the insurance payment and the amount of green space. The Ministry of Interior and Safety (MIS) provides annual flooding damages in terms of insurance payments. The payments are categorized into sub-district levels and can be used for a statistical analysis.

Before conducting a statistical analysis, the author examined the overall dataset for spatial dependency. The study contains spatial dataset and thus, requiring for a scrutiny in spatial autocorrelation. Table 1 explains about global and local Moran’s Index (Moran’s I). As can be seen, all the variables in the dataset shows a certain extent of spatial dependency, resulting in a slight clustering (0.3 > Moran’s I > 0.1). Getis-Ord Gi* values also came out as slightly positive and thus indicating there is a small chance of clustering within the study boundary. However, as both global and local spatial dependency results came out as a low dependency, the author decided to conduct regular statistical analysis.

4. Results

4.1. Land Cover changes in 30 years

The Ministry of Environment of South Korea provides a land cover data with 7 different classifications. Among those, 5 classifications relate to green space. The authors first identified the amount of green space changes in Korea for 30 years. Using land cover data from 1980, 1990, and 2000, land cover changes were calculated. According to the Ministry of Environment, 1980 land cover was gathered in the late-1980s, so it

|             | Green Space | Non-Green Space | Floodplain | Insurance |
|-------------|-------------|-----------------|------------|-----------|
| Moran’s I   | 0.20301     | 0.21236         | 0.29637    | 0.20451   |
| Variance    | 0.00154     | 0.00226         | 0.00209    | 0.00154   |
| z-score     | 3.59641     | 3.75317         | 3.29241    | 3.59641   |
| p-value     | 0.00032     | 0.00018         | 0.00999    | 0.00032   |
| Getis-Ord Gi*| 0.00004     | 0.00006         | 0.00007    | 0.00009   |
| Variance    | 0.00122     | 0.00235         | 0.00194    | 0.00127   |
| z-score     | −1.78642    | −2.58828        | −1.35904   | −1.18533  |
| p-value     | 0.07403     | 0.00965         | 0.18186    | 0.23589   |
could be regarded as near 1990 data. The same logic applies to other two data sets, meaning that although 2000 data is named as 2000, it depicts the late-2000s’ land cover situation in Korea (Lee et al. 2018, Yang et al. 2018).

Table 2 depicts the area changes of South Korea land cover since 1980. As can be seen, urban areas have gradually added its numbers and expanding its size to almost double in 2000 compared to 1980. On the other hands, some natural areas, such as pasture and wetlands have constantly experienced a decrease and have reduced by about 25% and 59% between 1980 and 2000. Considering that Korean society has developed rapidly over the last few decades, changes in each land cover seems quite reasonable (Organization for Economic Cooperation and Development 2014). However, these changes can lead to unexpected consequences in environmental impact.

Ulsan also experienced a rapid change in land cover through years. Table 3 provides area changes of Ulsan regarding 7 classifications. As can be seen, urban areas gained a large portion of its size over the past 3 decades, whereas pasture and crop lands have experienced decrease in their sizes. Since 1980, Ulsan has doubled its size in urban areas but has reduced by 30~40% in crop lands and pasture. Interesting observation is that wetlands have gained about 280% of its size in 2000 compared to 1980. This can be regarded as a good sign but it should rather be understood that Korean society in the 1980s did not have enough attention on environmental protections. Meaningful policy contributions about environmental protection mostly appeared in the 1990s. Therefore, a significant increase in wetlands and herbaceous between 1980 and 2000 should be examined with policy implementation.

With this broad dataset, however, it is quite hard to pinpoint the precise amount of green space. It is obvious that urban areas are not ecologically planned places. However, there are many green lands that can be regarded as green space in the core of urban areas and it will be analyzed with the NDVI. But with the land cover dataset at this point, the author can assume that urban areas do not contain green space. In addition, open water cannot be included as green space with the given coarse dataset. The land cover data contains some of the sea areas which are regarded as open water and it needs to be distinguished. Table 4 explains Ulsan city’s total green space changes over the 3 decades using conventional land cover datasets.

It is interesting to see that Ulsan has experienced a small amount of gains, 4.9% in green space between 1980 and 1990, but it soon decreased by 5.1% in 2000. In addition, there has been a change in non-green space amount according to the land cover dataset.
dataset. Between 1980 and 1990, Ulsan has experienced about 8.1% decrease in non-green space areas. This is a quite controversial result as the general belief stands against it. As a city rapidly evolves itself, it is believed that non-green space will highly likely to expand its size and gains its proportion to green areas. On the other hands, between 1990 and 2000, there has been 9.5% increase of non-green space in Ulsan city. Figure 2 illustrates all the changes in green space for 3 decades. As can be seen, it is clear that Ulsan city in 2000 has lost a large portion of green space compared to 1990. However, with the given dataset, it is hard to precisely analyze the amount of green space, and for that reason, a high resolution satellite image with NDVI need to be utilized.

4.2. High resolution satellite and NDVI

The Korea Aero Research Institute (KARI) has 6 different satellites orbiting the earth. Among 6, three are still under their missions and two satellites are dedicated to collect land cover and other associated datasets (Jeong et al. 2013). Upon requests, KARI provides a certain amount of high resolution land cover datasets with charges and the author specifically requested August 2016 datasets. The reason for selecting the summer of 2016 is because summer has the minimum interferences from the clouds increasing the accuracy of land cover analysis. In addition, the Chaba appeared in 2016 summer and having the same year’s data is necessary to have a more accurate result. The provided dataset is consisting of 4 different TIFF images with the resolution of 1 M x 1 M.

To properly extract the green space in Ulsan city, NDVI was calculated. NDVI uses the Red band and Near Infra-Red bands together to distinguish green areas from non-green portions. This is a handy way to analyze green space, especially for high density, mixed areas like Ulsan. The typical housing pattern in Ulsan and Korea at large is 15–20 stories apartments. This can be considered non-greenery as they are mostly covered by impervious surfaces. However, the latest construction trends enforce construction vendors to design parking spaces all underground, making the aboveground surface a completely car-free environment. This car-free space is now utilized with a large amount of landscaping providing amenities and environmental

| Table 3. Land Cover Changes in Ulsan City between 1980 and 2000. |
|-------------------------|----------------|----------------|----------------|----------------|----------------|
| (in km$^2$)             | 1980           | 1990           | 2000           | 1990–1980      | 2000–1990      | 2000–1980      |
| Urban Areas             | 54.5           | 76.5           | 114.6          | 21.9           | 40.3%          | 38.1           | 49.8%          | 60.1           | 110.2%         |
| Crop                    | 213.8          | 172.9          | 131.3          | –40.8          | –19.1%         | –41.6          | –24.1%         | –28.4          | –38.6%         |
| Forest                  | 732.1          | 681.4          | 746.3          | –50.5          | –6.9%          | 64.9           | 9.5%           | 14.3           | 2.0%           |
| Pasture                 | 42.1           | 94.4           | 30.1           | 52.3           | 124.3%         | –64.3          | –68.2%         | –12.0          | –28.6%         |
| Wetlands                | 0.2            | 1.8            | 1.1            | 1.5            | 586.6%         | –0.8           | –44.6%         | 0.7            | 280.5%         |
| Herbaceous             | 6.5            | 25.2           | 27.1           | 18.7           | 286.7%         | 1.9            | 7.6%           | 20.6           | 316.1%         |
| Open Water              | 16.1           | 13.0           | 14.8           | –3.1           | –19.7%         | 1.8            | 14.3%          | –1.3           | –8.2%          |

| Table 4. Green space Changes in Ulsan City between 1980 and 2000. |
|-------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                         | 1980            | 1990            | 2000            | 1990–1980       | 2000–1990       |
| Green space             | 190.7 km$^2$    | 200.1 km$^2$    | 189.9 km$^2$    | –9.4 km$^2$ (+4.9%) | –10.2 km$^2$ (-5.1%) | –0.8 km$^2$ (-0.4%) |
| Non-green space         | 129.4 km$^2$    | 118.9 km$^2$    | 130.2 km$^2$    | +10.5 km$^2$ (-8.1%) | +11.3 km$^2$ (+9.5%) | +0.8 km$^2$ (+0.4%) |
benefits at the same time. Using the typical land cover datasets, these changes are very hard to detect. With high resolution satellite images and NDVI calculation, however, these changes can be captured and be included as a part of green space.

Figure 3 illustrates the difference between land cover datasets and high resolution with NDVI calculation. As can be seen, high resolution satellite with NDVI calculation can capture small changes in highly dense areas. Land cover datasets are relatively in low resolution providing a coarse picture about the site. Having a higher resolution with NDVI calculation can detect minor changes in parcel levels, depicting a clearer picture about the study area.

Table 5 depicts the amount of green space and non-green space by each district. As can be seen, the North district contains the largest amount of green space and its ratio to non-green space is about 75.14%. It means that more than 2/3 of the North district is covered with green space. On the other hand, the least proportion of green space exists in the South district and its proportion is about 26.4%. This is a plausible result as the South district is a historic district, where old industrials and dated facilities still remain. Each district consists of several sub-districts for administrative purposes.

Figure 4 illustrates each district’s green space using high resolution image and NDVI calculation. Dashed line represents the boundary of sub-districts within each district. There are a total of 46 sub-districts existing in Ulsan city and each sub-district has different amount of green space.

### 4.3. Relationship between green space and flooding damages

The Ministry of the Interior and Safety (MIS) in Korea provides flooding damages in financial terms based on the reported insurance payments. Specific components are not opened to general public, but the total amount of flooding damage can be accessed based on sub-district levels. According to the MIS, Ulsan city has experienced about 30 times of flooding damages since 2010, a total of about 7,414km² affected by the flooding in 17 years (Ministry of the Interior and Safety 2018).
Figure 3. Land Cover compared to High Resolution with NDVI.

Table 5. Amount of Green space by Each District.

| District     | Green space | Non-green space |
|--------------|-------------|-----------------|
| North District | 119.50 km²  | 39.53 km²       |
| Central District | 15.57 km²   | 20.89 km²       |
| South District  | 20.00 km²   | 55.72 km²       |
| East District   | 21.48 km²   | 16.47 km²       |

Figure 4. Green space by District using NDVI.
Especially, when the Chaba hit southeast part of Korea in 2016, the total damage in financial terms was about $200 million and approximately 8 nearby cities were impacted significantly. Of $200 million, a worth of about $25 million was incurred from private facilities, whereas about $175 million worth was due to the public infrastructure damages (Ministry of the Interior and Safety 2018).

This damage is based on voluntarily reports by major insurance firms, meaning that although the numbers are apparent, they can be considered a conservative

Table 6. Green space, Non-green space, and Insurance Amount for Each Sub-District.

| Names            | Green space (km²) | Non-green space (km²) | Total Area (km²) | Amount (Million $) |
|------------------|-------------------|-----------------------|------------------|--------------------|
| Central          |                   |                       |                  |                    |
| Haksok-dong      | 0.15              | 0.80                  | 0.95             | 32.18              |
| Bangu1-dong      | 0.18              | 0.96                  | 1.14             | 38.61              |
| Bangu2-dong      | 0.07              | 0.44                  | 0.51             | 17.28              |
| Boksan1-dong     | 0.20              | 0.57                  | 0.77             | 26.08              |
| Boksan2-dong     | 0.14              | 0.49                  | 0.63             | 21.34              |
| Buljeong-dong    | 4.31              | 3.21                  | 7.52             | 254.72             |
| Okgyo-dong       | 0.09              | 0.58                  | 0.67             | 22.69              |
| Seongnam-dong    | 0.19              | 0.84                  | 1.03             | 34.89              |
| Ujeong-dong      | 0.62              | 0.90                  | 1.52             | 51.49              |
| Taehwa-dong      | 2.50              | 3.28                  | 5.78             | 195.78             |
| Daun-dong        | 2.86              | 4.76                  | 7.62             | 258.11             |
| Byeongyeong1-dong| 0.21              | 1.21                  | 1.42             | 48.11              |
| Byeongyeong2-dong| 2.22              | 1.80                  | 4.02             | 136.17             |
| Yaks-a-dong      | 1.83              | 1.05                  | 2.88             | 97.55              |
| Sub Total        | 15.57             | 20.89                 | 36.46            | 1,235.01           |
| South            |                   |                       |                  |                    |
| Sinjeong1-dong   | 0.21              | 1.30                  | 1.51             | 708.67             |
| Sinjeong2-dong   | 0.87              | 1.93                  | 2.80             | 1,314.10           |
| Sinjeong3-dong   | 0.10              | 0.91                  | 1.01             | 474.01             |
| Sinjeong4-dong   | 0.12              | 0.84                  | 0.96             | 450.55             |
| Sinjeong5-dong   | 0.04              | 0.59                  | 0.63             | 295.67             |
| Dal-dong         | 0.13              | 1.12                  | 1.25             | 586.65             |
| Samsan-dong      | 0.90              | 4.23                  | 5.13             | 2,407.72           |
| Samho-dong       | 0.37              | 2.20                  | 2.57             | 1,206.16           |
| Mugeo-dong       | 1.08              | 2.14                  | 3.22             | 1,511.23           |
| Ok-dong          | 3.10              | 8.42                  | 11.52            | 5,406.58           |
| Daehyun-dong     | 0.25              | 0.89                  | 1.14             | 335.03             |
| Suam-dong        | 0.25              | 0.34                  | 0.59             | 276.90             |
| Seonam-dong      | 8.98              | 18.21                 | 27.19            | 12,760.84          |
| Yaeumjangsaengpo-dong | 3.60 | 12.60          | 16.20            | 7,603.00           |
| Sub Total        | 20.00             | 55.72                 | 75.72            | 35,337.13          |
| East             |                   |                       |                  |                    |
| Bangeo-dong      | 0.54              | 4.07                  | 4.61             | 2,412.75           |
| Ilsan-dong       | 0.61              | 1.79                  | 2.40             | 1,256.09           |
| Hwajeong-dong    | 0.36              | 0.64                  | 1.00             | 523.37             |
| Daesong-dong     | 2.56              | 3.00                  | 5.56             | 2,909.95           |
| Jeonha1-dong     | 2.84              | 4.26                  | 7.10             | 3,715.95           |
| Jeonha2-dong     | 0.08              | 0.28                  | 0.36             | 188.41             |
| Jeonha3-dong     | 0.07              | 0.28                  | 0.35             | 183.38             |
| Nammok1-dong     | 2.52              | 0.45                  | 2.97             | 1,554.42           |
| Nammok2-dong     | 2.38              | 0.59                  | 2.97             | 1,554.47           |
| Nammok3-dong     | 9.52              | 1.11                  | 10.63            | 5,563.45           |
| Sub Total        | 21.48             | 16.47                 | 37.95            | 19,862.25          |
| North            |                   |                       |                  |                    |
| Nongso1-dong     | 9.14              | 5.92                  | 15.06            | 356.92             |
| Nongso2-dong     | 7.07              | 4.47                  | 11.54            | 273.50             |
| Nongso3-dong     | 25.52             | 6.16                  | 31.68            | 750.81             |
| Gangdong-dong    | 55.38             | 6.00                  | 61.38            | 1,454.70           |
| Hyomun-dong      | 8.21              | 8.49                  | 16.70            | 395.89             |
| Songjeong-dong   | 5.26              | 4.34                  | 9.60             | 227.52             |
| Yangjeong-dong   | 4.95              | 1.93                  | 6.88             | 163.06             |
| Yeompo-dong      | 3.97              | 2.22                  | 6.19             | 146.71             |
| Sub Total        | 119.50            | 39.53                 | 159.03           | 3,769.11           

Especially, when the Chaba hit southeast part of Korea in 2016, the total damage in financial terms was about $200 million and approximately 8 nearby cities were impacted significantly. Of $200 million, a worth of about $25 million was incurred from private facilities, whereas about $175 million worth was due to the public infrastructure damages (Ministry of the Interior and Safety 2018).

This damage is based on voluntarily reports by major insurance firms, meaning that although the numbers are apparent, they can be considered a conservative
measure. Using this measure and the amounts of green space by each sub-district, a relationship can be assessed. According to the records, the total amount of insurance paid in Ulsan city due to the reported natural disasters in 2016 was about $60.3 million. Among $60.3 million, the highest paid district was the South district and the lowest was the Central district. Looking at the insurance amount per sub-district, the East district shows the highest paid insurance amount per km², about 0.31 million higher than the Ulsan city as a total. Table 6 illustrates the overall results.

To understand a possible relationship between green space and flooding damages, a statistical analysis was applied. Using a linear regression, a possible relationship between the amount of green space and flooding damage was assessed. By implementing the payment record of 46 sub-districts as dependent variables, and using the area of green space, Non-green space, and green space in floodplain as independent variables, a regression analysis was conducted. Floodplain in this study adopted a 100-year floodplain as the study is designed to identify the effectiveness of greenspace in flooding for general circumstances. Table 7 indicates the analysis result.

The entire model came out to be statistically significant ($F = 41.714, df(3, 46): p < 0.001; R = 0.865; R^2 = 0.731$) and all the independent variables show statistically significant results at the 95% confidence level. According to the analysis, if there is 1 km² increase of green space inside sub-districts, then it would have lowered flooding financial damage by $44,099. In addition, if there is an increase of 1 km² of non-green space inside sub-districts in Ulsan city, then it would have increased the flooding damage by $691,094. Finally, if there is an increase of green space inside floodplain area, then it will reduce flooding damage by $953,755. Although this analysis is based only on Ulsan city, the result came out as statistically significant, meaning that an increase in green space could mitigate flooding impact in sub-districts.

5. Conclusions

Coastal cities are spontaneous features considering human history, and most of large cities are set on nearby water bodies. For that reason, flooding is a constant issue for urban disaster, especially under global warming and climate change. Ulsan is not so different and had experienced a harsh storm like Chaba in 2016. As a consequence, millions of dollars were estimated as flooding damage and a large number of human impacts were observed. This study was to provide a holistic view on flooding damage and its opportunity costs under such disasters.

Analysis results indicate that having a higher portion of green space inside a city could have a reduction effect on flooding damage. Using 46 sub-districts in Ulsan,
the study has identified that 1 km² of green space increase could reduce financial insurance of flooding damage by $44,099. In addition, an increase in non-green space also could have raised insurance payment by $691,094. Although this result is coming out from 46 cases, it gives a number of implications. First, green space could have a mitigation effect in flooding damage. Although many studies have articulated the importance of green space, this study gave an empirical finding with an actual case. Second, the result confirms that green space inside floodplain is more effective than its existence outside floodplain. The difference is about 21 times ($44,099 vs. $953,755), and for that reason, it could be perceived that green space inside floodplain could be a necessary and effective measure to reduce flooding impact.

The study results provide a holistic view on how flooding risks differ based on urban infrastructure planning. As can be seen, green space can mitigate flooding impact to a certain degree and for that reason, it could be used to determine how natural disaster policy in municipal level should be organized. In addition, it can also provide a foundation for claiming insurance payments to those facilities without careful considerations on environmental planning. If green space can relieve flooding impact, the most and biggest damage frequently observed in Korean society, then municipal policy guidelines and insurance company’s policy should implement such advantages in their future direction. A more thorough consideration for green space planning in a city needs to be emphasized.

This study is intended to provide a numerical understanding about flooding impact and it is meaningful in that regard. However, subsequent studies should consider a number of additional aspects. First, this study does not account for a large number of cases. The main reason is because insurance payment information relates to privacy issues, and thus, it is difficult to obtain at sub-district level. Second, although the study provided a holistic understanding on flooding damage and green space amount, it does not consider green space patterns and density. If other measurements are added, the results will become more robust. For further studies, controlling other omitted variables, such as land uses, building density, and floor-area ratio should be included to provide more detailed results. In addition, subsequent studies should also test spatial dependency to avoid any misinterpretations. Despite the fact that the study contains above limitations, the study has provided numerical evidence in flooding impact and expects to be used in green space planning studies.

Data availability statement

The data that support the findings of this study are available from the corresponding author, [Hwanyong Kim], upon reasonable request.

Disclosure statement

In accordance with Taylor & Francis policy and my ethical obligation as a researcher, I am reporting that I receive no funding. I have disclosed those interests fully to Taylor & Francis, and I have in place an approved plan for managing any potential conflicts arising from that involvement.
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