sustainability

MDPI

Article

A Flood Risk Assessment Model for Companies and Criteria for Governmental Decision-Making to Minimize Hazards

Jieun Ryu [1], Eun Joo Yoon [2], Chan Park [3], Dong Kun Lee [4,*] and Seong Woo Jeon [5,*]

1. Ojeong Eco-Resilience Institute Environmental GIS/RS Center, Korea University, Seoul 02841, Korea; ulygajok@gmail.com
2. Interdisciplinary Program in Landscape Architecture, Seoul National University, Seoul 08826, Korea; youn01@snu.ac.kr
3. Department of Landscape Architecture, University of Seoul, Seoul 02504, Korea; chaneparkmomo7@uos.ac.kr
4. Department of Landscape Architecture and Rural System Engineering, Seoul National University, Seoul 08826, Korea
5. Department of Environmental Science and Ecological Engineering, Korea University, Seoul 02841, Korea

* Correspondence: dklee7@snu.ac.kr (D.K.L.); eepps_korea@korea.ac.kr (S.W.J.); Tel.: +82-2-880-4885 (D.K.L.); +82-2-3290-3043 (S.W.J.)

Received: 16 August 2017; Accepted: 30 October 2017; Published: 1 November 2017

Abstract: Flood risks in the industrial sector and economic damages are increasing because of climate change. In addition to changes in precipitation patterns due to climate change; factors that increase flood damage include infrastructure deterioration and lack of storage facilities. Therefore; it is necessary for companies and the government to actively establish flood management policies. However; no evaluation method is currently available to determine which items should be invested in first by small and medium-sized enterprises that have limited finances. Because the government should make comprehensive and fair decisions; the purpose of this study is to propose priority investment risk items and an assessment method to decide which companies should be invested in first in flood risk management due to climate change. The multispatial scale of the method takes both the location and characteristics of the company into account. Future climate change scenarios were used to evaluate the changing patterns of flood risks. We developed the relative Flood Risk Assessment for Company (FRAC model) methodology to support the government's policymaking. This method was applied to four companies belonging to four different industries and three risk items were derived that are likely to harm the company owing to flooding.

Keywords: risk; risk assessment; floods; industrial parks; climate change; SMEs (small and medium-sized enterprises)

1. Introduction

Climate change affects various industrial sectors, such as climate-sensitive industrial facilities and raw materials as well as the climate change policies of the government [1]. Industrial parks have a better ability to adapt to climate change than other types of social infrastructure because of their high safety design standards. Most studies have focused on proposals for greenhouse gas emissions reduction to comply with government regulations [2]. However, climate change has affected storm patterns, dramatically increasing the frequency and magnitude of precipitation, and increasing the damage caused by floods in many countries [3]. In fact, heavy rains in South Korea flooded roads and factories in Ulsan-Mipo National Industrial Park and Cheongwon-Noksan Industrial Park in 2009, Bupyeong Industrial Park in 2010, and Gumi National Industrial Park in 2012. The Elbe flood in Germany in 2002 had a large direct and indirect impact on the local economy [4]. Consequently, flood disaster recovery costs were high [5]. In the U.K., flood-related industrial disruptions are on the rise; floods in 2013 and 2014 damaged approximately 21% of industry, amounting to losses worth $271–365 million [6]. In Thailand, five intense typhoons occurred in 2011, resulting in 815 deaths and $45.7 billion in economic damage. Seven out of 60 existing economic zones in Thailand suffered flood damage due to heavy rainfall; 451 companies, more than half of the 804 multinational corporations in the country, also suffered flood damage and economic losses [7]. As these examples illustrate, floods are more frequent than other natural disasters, and their frequency and magnitude are increasing because of climate change. These cause direct and indirect damage to people and infrastructure, and increase the cost of recovering from flood damage [8,9].

Floods are not the problem of an individual company but a social problem that can have a significant impact on the national economy [2,10]. Therefore, it is necessary for the government and enterprises to prepare for floods through "top-down" and "bottom-up" approaches. However, small and medium-sized enterprises (SMEs) usually do not have the financial capacity to invest in research on preventing flood damage. Government investments are therefore needed to mitigate the flood risk for SMEs with respect to the long-term stabilization of the economy. In South Korea, the government supports SMEs with over 40 projects, including subsidies for flood relief and transfer of information and investment between researchers and industries [11]. This "top-down" approach has direct implications for SMEs to improve their adaptive capacity through the establishment of various measurements. On the other hand, in the U.K., where the industrial sector is actively adapting to climate change at the government level, the government provided the Business Areas Climate Assessment Tool [12], which allows companies to self-check risks directly on the Internet. The Environment Agency also provides guidance and training courses such as the Climate Ready program and Climate U.K. to support companies' adaptation to climate change [13]. This "bottom-up" approach focuses on raising awareness of the adaptation of the industrial sector to climate change and providing tools to assess its own risks related to natural disasters.

Linking "bottom-up" and "top-down" approaches, known as a two-way approach, means combining government investments based on cross-company comparisons with adaptation plans of individual companies based on disaster risk. This not only has the advantages of both approaches but also enables smooth communication between governments and companies on climate change adaptation. The study of floods accounts for the largest portion of natural disaster research, but there is little support for two-way approaches. Most studies adopt costly methodologies to elaborate the extent of damage from flood. These measures may be suitable for bottom-up approaches, but it is difficult to apply to top-down approaches that require cross-company comparisons. In other words, a two-way approach requires a very compact and low-cost evaluation tool while providing reliable results that facilitate intercompany comparisons.

Therefore, the purpose of this study is to develop an evaluation method to address two questions: (1) Which industrial parks or companies should have priority for government investments to reduce overall flood risk in industrial sectors? (2) How should the government support companies to reduce the country's overall flood risk? To answer these two research questions, we developed a simple decision-making model, namely the relative Flood Risk Assessment for Companies (FRAC) model, using the indicators and risk matrix derived from a number of interviews with corporate stakeholders.

2. Method

2.1. Related Works

The flood risks of industrial complexes and enterprises can be evaluated using three methods. The first method involves the use of a physical model that can quantitatively determine the degree of flooding based on location, although the cost to the enterprise is high. The second method involves a rough evaluation of the degree of vulnerability to floods, using indicators based on the area in which the firm is located. The third method is based on a survey to derive and evaluate risk items through interviews with company stakeholders.

In previous research, many physical flood risk assessment tools have been suggested to reduce the physical damage caused by floods; they are based on the possibility of physical flooding and damaged areas obtained through physical models or statistical analyses of big historical data. Although these methods can predict the occurrence and damage of floods relatively accurately, they are also time consuming and expensive [14]. In addition, most of the studies target regional and urban units rather than individual companies. In Japan, the economic evaluation model for floods was established using a stage/depth damage curve based on historical data [15]. A Hazard U.S. Multi-Hazard (HAZUS-MH) (Federal Emergency Management Agency, Washington, DC, USA) flood loss estimation methodology was developed to predict flood damage by the Federal Emergency Management Agency [16–18]. The U.K. has also used the HAZUS-MH 2.1 (FLO-2D Software, Inc., Nutrioso, AZ, USA), which allows for larger-scale data analysis and statistical inferences [17,18]. In The Netherlands, which is particularly vulnerable to inundation owing due to geographic specificities, researchers assessed flood risk by taking into account the extent, depth, and frequency of flooding due to climate change. They also regularly update strong adaptation measures based on assessment results and the "Water Law" [19,20]. In Vietnam, flood hazard, flood risk assessment, and mapping have been carried out using the two-dimensional flood routing model FLO-2D. Unlike the above regional model, the input–output and computable general equilibrium models can directly calculate business losses due to disasters [21].

On the other hand, some studies have used indicators for flood risk assessment. Such studies are cost-effective because they do not require large amounts of statistical data or sophisticated simulation analysis. These methods can evaluate the location environment easily using indicators at the regional scale and enterprises in the industrial sector [22]. However, this approach is limited because the information it provides on individual companies is not sufficient to identify and assess the specific risks to the enterprise and rely government support. In South Korea, vulnerability assessment to floods is carried out in industrial parks by integrating industrial and social indicators, such as infrastructure, land cover ratio, and budget for disasters as well as other factors [4,10]. In the German federal state of Baden-Württemberg, the vulnerability of 16 industrial sectors to natural disasters was evaluated by the administrative district [23]. Sun et al. [24] proposed a comprehensive evaluation method using hazard, exposure, vulnerability, and restorability indicators and applied it to the Ahmad region of China. The weights for each indicator were determined using entropy and fuzzy concepts. These studies can be used to identify areas to invest in for the reduction of flood damage; however, they are not practical for individual enterprises because they only include infrastructure and location indicators.

The questionnaire method can identify factors pertinent to flood risk through in-depth interviews with business stakeholders, and evaluate the impacts and possibility of occurrence. The risk evaluation results are likely to change according to the subjective opinions of corporate stakeholders. Rodrigues et al. [25] derived acceptable risk levels in the furniture industrial sector using 147 questionnaires from the accident statistics and database of the Portuguese Authority for Work Conditions. Ahn [26] used the expert questionnaire to create a list of possible risks in construction projects. Lee et al. [27] also derived risk items likely to occur through consultation with experts in disaster management systems with respect to mining limestone.

Therefore, in this study, we developed the FRAC model, which combines the survey method and the indicator-based flood risk assessment method for the environment in which the company is located. Doing so enhances the evaluation results, which can be used by the government to extend support to companies.

2.2. The FRAC (Relative Flood Risk Assessment for Company) Model

Risk analysis is a useful method to assess the impact and likelihood of an event when an event occurs in a variety of areas [23,28,29], such as disasters [30], health [31], pollution [32], corporate profit and loss [33,34], and safety [35]. The Fifth Report of the Intergovernmental Panel on Climate Change describes climate-related risks as, "the impact of climate-related impacts on climate change" [36]. Risk assessment methods vary, but the most frequently used methods involve multiplying (a) the likelihood of a hazard event and the consequence of the hazard [23,28,29,37], (b) the probability of an event with its impact [27,28,38], (c) the hazard with the vulnerability [24,39,40], or (d) the probability of an event occurring with its consequence [41,42]. Likewise, risk has been assessed in a variety of contexts and needs to be clearly defined according to the purpose of the assessment.

The purpose of this study is to evaluate flood risk by considering the industry, size, process, and geographical environment of enterprise. This study is the first to present the FRAC model, which consists of three evaluation models. We use the concepts of hazard and vulnerability to assess flood risk ($\text{Risk}_{Location}$ model), evaluate a company's flood risk based on the probability and consequence ($\text{Risk}_{Company}$ model), and evaluate each result as a risk matrix. Vulnerability was evaluated by using sensitivity and adaptive capacity as a measure of system vulnerability when floods occur [43]. The results of each evaluation were combined into a risk matrix to derive the final flood risk of the company (Risk_{Flood} model). This method uses a top-down approach to assess the geographic and climatic factors of industrial parks nationwide, which is based on the bottom-up approach of selecting risk items and actively reflecting the results of the company. Therefore, it is useful for identifying companies and industrial complexes that need government support, or for determining the risk items that the government should support. In particular, when assessing the hazards of $\text{Risk}_{Location}$, we considered changes in flood risk due to future climate change, taking into account scenarios in the 2030s (2025–2034) and 2050s (2045–2054).

Risk_{Flood} is a step of synthesizing and grading the evaluation results of the $\text{Risk}_{Location}$ model and $\text{Risk}_{Company}$ model using a 5-by-5 risk matrix. The FRAC model refers to the entire process of deriving the $\text{Risk}_{Location}$ model, $\text{Risk}_{Company}$ model, and Risk_{Flood} result that combines the two (see Figure 1). Expressing this as a formula, the FRAC model can be written as a function of $\text{Risk}_{Location}$, $\text{Risk}_{Company}$, and Risk_{Flood} as shown in Equation (1). In this equation, i denotes the risk item of an individual company, and j denotes an industrial park in which the company is located.

$$\text{FRAC model} = f\ \{\text{Risk}_{Location\ j}, \text{Risk}_{Company\ i}, \text{Risk}_{Flood\ i}\} \tag{1}$$

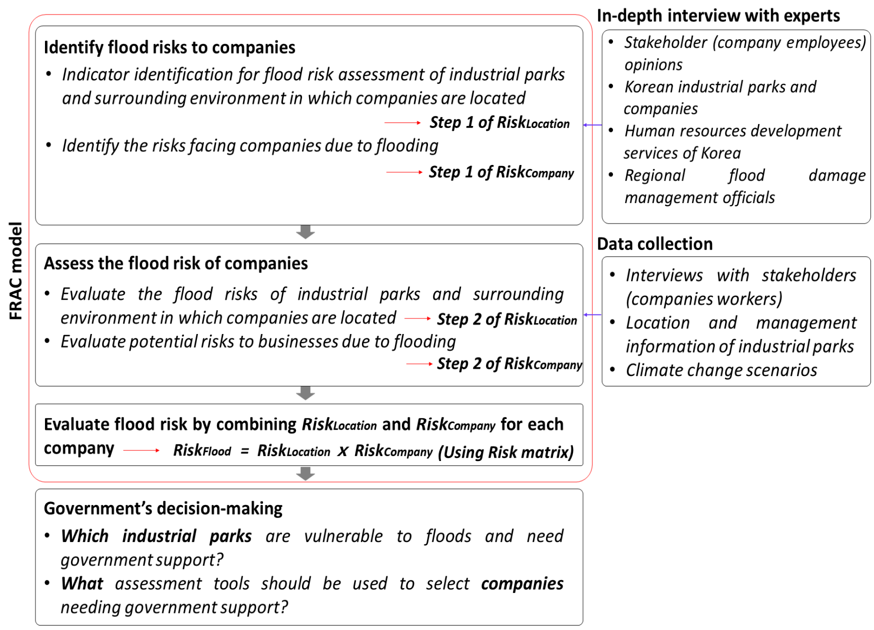


Figure 1. Study-flow of flood risk assessment (FRAC) model for a company.

In this model, the first step is the risk identification phase. Then, the inventory and risk items of $\text{Risk}_{Location}$ and $\text{Risk}_{Company}$ are listed and screened to evaluate flood risk. The second step is to evaluate the $\text{Risk}_{Location}$ by constructing data using information on the industrial parks based on the selected indicators and evaluate the $\text{Risk}_{Company}$ by building data on each risk item through in-depth interviews with corporate stakeholders. The third step is to aggregate the results of the $\text{Risk}_{Location}$ and $\text{Risk}_{Company}$ ratings for each company.

2.2.1. $\text{Risk}_{Location}$

For the evaluation of the $\text{Risk}_{Location}$ model, we used the indicator-based evaluation method, which enables the easy collection of data by considering various social and physical phenomena. The evaluation method can be divided into two steps. The first step is to screen the indicators of risk assessment, and the second step is data collection, evaluation, and grading of flood risk.

In the first step, we determined the indicators for the company's location risk assessment based on a literature review and in-depth interviews with industrial partners (Table 1). These interviews included two employees from of six companies, three climate change experts, five officials from the Industrial Parks Corporation, and three civil servants from the department of damage caused by winds and floods in local government (September to October 2013). To complement the interviews, analysis of flood damage cases in South Korean companies and industrial parks (from 2002 to 2014) was also conducted.

Table 1. Indicators used for $\text{Risk}_{Location}$.

Categories	Indicators	Index	Flood Risk List (Sub-Indicators)	Score Scale	Source
Hazard	Hazard	Precipitation	More than 100 mm of daily rain per year	Total number of days	Representative Concentration Pathways (RCP) scenario (Korea Meteorological Administration)
			five-day maximum rainfall period	Total number of days	
Vulnerability	Sensitivity	Infrastructure	Water ratio in industrial parks	%	Land cover data (Ministry of Environment)
			Outdated facilities	Year of construction	Industrial parks information (Korea Industrial Parks Corporation)
		Characteristics of industrial sectors	Ratio of vulnerable business types [1]	%	
		Location of industrial parks	Slope	Degree	Digital Elevation Model (DEM) Geographic Information System (GIS) data
			Industrial park area within 100 m of mountains	m^2	Land cover data (Ministry of Environment)
			Soil characteristics within 100 m of mountains [2]	1–6	Soil characteristics map (Korean Soil Information System)
			Coastal landfill location	Landfill: 1 Out of landfill: 0	Industrial parks information (Korea Industrial Parks Corporation)
			Number of roads	Total number	Google Maps
			Distance from coast and river (within 1 km)	Meters	Google Maps

Table 1. *Cont.*

Categories	Indicators	Index	Flood Risk List (Sub-Indicators)	Score Scale	Source
	Adaptation	Infrastructure	Emergency power supply facilities	Yes: 1/No: 0	Industrial parks information (Korea Industrial Parks Corporation)
			Number of fire stations in city	Total number	Internet search
			Number of medical facilities in city	Total number	Internet search
			Green space ratio (green space area/industrial area)	%	Land cover data (Ministry of Environment)
			Flood reduction facilities	Total number	Contact local government
		Technical skills and funds for climate adaptation	Investment in facilities	Total amount	Industrial parks information (Korea Industrial Parks Corporation)

[1] Vulnerable business ratio: We defined energy-consuming industries (e.g., petrochemicals, refineries, textiles, and automobiles) as vulnerable sectors because they depend strongly on power supply and transportation, and consequently will be more adversely affected than other industries because of climate change impacts on related infrastructure. Examples of such impacts include water shortages or insufficient supply of high-temperature water to power stations [44,45]. In addition, these companies have high greenhouse gas emissions and are likely to be impacted negatively by government emissions regulations. The "ratio of vulnerable business types" is calculated by dividing the number of companies from vulnerable sectors by the total number of companies operating in industrial complexes; [2] Soil characteristics within 100 m of the mountains are based on the boundary of the industrial complex. A 100-m buffer was created using the GIS tool and the soil characteristics of land within the boundaries were analyzed. By using the soil map, the average drainage degree of the buffer was graded around the land in the industrial park in which the company is located. Depending on the drainage, the values ranged from 1 to 6, very poor to very good.

After selecting indicators to assess vulnerability and hazard, and before the standardization of these indicators, we collected flood damage data to determine the threshold of each indicator. If a threshold can be derived from damage data, a good value (safe) and bad value (dangerous) can indicate the start of a flood. In this study, information was gathered from the Industrial Complex Management Corporation, which mines data on companies' flood damage information. Then, to find the threshold value of each indicator, statistical analysis of indicators and the weather and infrastructure conditions at the time of flood damage was performed. Based on flood damage cases, the indicator "100 mm per year" was selected after a relation analysis using SPSS ver. 12.00 (IBM, Seoul City, Korea) (P = 0.01, *coefficient of correlation* > 0.4). After setting the flood assessment indicators for hazard and vulnerability, the data were constructed and standardized for all industrial complexes nationwide and used for the analysis.

Second, to evaluate the risk, the collected data that were standardized by indicators were used to calculate and grade hazard and vulnerability. These results were re-assessed using the 5-by-5 risk matrix. To collect data on assessment indicators, statistical data of each industrial park published on the homepage of the Industrial Complex Management Corporation and geographic information system (GIS) data were used. Additionally, for unavailable information, direct field visits or telephone calls were required.

Based on the data indicators, the standardized values of each sub-indicator were totaled and standardized again for each indicator to evaluate the values of hazard and vulnerability. Because all indicators have different units and properties [4,46], the raw values of each sub-indicator must be standardized with values from 0 to 1. Equation (2) represents the standardization method for each sub-indicator. Norm N_i is the result of standardization of a sub-indicator using raw data (N_i) from the 42 industrial parks (n (N_i) = 42) and i is the number of sub-indicators that consist of the indicators.

$$\text{Norm } N_i = \frac{N_i - N_i^{min}}{N_i^{max} - N_i^{min}} \tag{2}$$

$$\text{with } 0 \leq \text{Norm } N_i \leq 1$$

To calculate hazard and vulnerability, indicator values (hazard, sensitivity, and adaptation ability; *j*) are required. The standardized value of the indicator is Norm I_j that can be expressed using the value of Norm N_i, which is the standardized value of the sub-indicator, as shown in Equation (3). This equation shows how to standardize sub-indicators for each indicator based on the sum of indicators.

$$\text{Norm } I_j = \frac{\sum_1^i \text{Norm } N_{i_j} - \left(\sum_1^i \text{Norm } N_i\right)_j^{min}}{\left(\sum_1^i \text{Norm } N_i\right)_j^{max} - \left(\sum_1^i \text{Norm } N_i\right)_j^{min}} \tag{3}$$

$$\text{with } j \in \{\text{Hazard, Sensitivity, Adaptation ability}\}$$

To evaluate hazard and vulnerability, we calculated vulnerability using Equation (4).

$$\text{Norm } I_{Vulnerability} = \text{Norm } I_{Sensitivity} - \text{Norm } I_{Adaptation} \tag{4}$$

$$\text{with } 0 \leq \text{Norm } I_{Sensitivity} \text{ and Norm } I_{Adaptation} \leq 1 \qquad ()$$

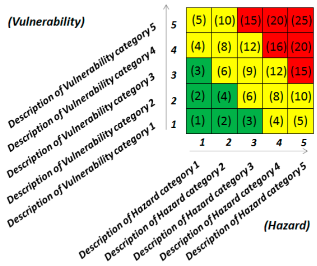
The values of Norm I_{Hazard} and Norm $I_{Vulnerability}$ were ranked according to the evaluation criteria in Table 2. The $\text{Risk}_{Location}$ was then evaluated based on the values of the two categories using the 5-by-5 risk matrix evaluation method in Equation (5). The values calculated for each category were normalized again to the values of Norm I_{Hazard} and Norm $I_{Vulnerability}$ to calculate the values of the other units. Thus, Norm I_{Hazard} and Norm $I_{Vulnerability}$ range between 0 and 1. The levels can be classified in equal intervals of 0.2 based on the characteristics of the data because the values are already standardized (see "range of raw data" in the second column of Table 2) [47–50]. Hazard and vulnerability are categorized into five levels based on the criteria in Table 2. The level of $\text{Risk}_{Location}$ is based on the multiplication of hazard and vulnerability, which is the result of using the 5-by-5 risk matrix classification. Equation (5) shows the evaluation method for $\text{Risk}_{Location}$ using the levels of hazard and vulnerability. The value of $\text{Risk}_{Location}$ was derived for the 42 industrial parks; *i* represents each national industrial park in this study.

$$\text{Risk}_{Location\ j} = \text{Hazard}_j \times \text{Vulnerability}_j \tag{5}$$

$$\text{with } \text{H}_j \in \{1, 2, 3, 4, 5\}, \text{V}_j \in \{1, 2, 3, 4, 5\} \text{ and } 1 \leq j \leq 42$$

The levels of hazard (H) and vulnerability (V) are scored from 1 to 5 according to the criteria of Table 2; thus, the multiplied value of hazard and vulnerability ranges between 1 and 25. According to Table 2, if the value of H multiplied by V is between 1 and 3, and H and V are between 1 and 3, $\text{Risk}_{Location}$ is level 1. The value obtained by multiplying H by V is 4 when H and V are both 2; $\text{Risk}_{Location}$ is level 1. However, if H and V are not equal, it is evaluated as level 2. When H and V are greater than 4 but less than 12, and H and V values range between 1 and 5, they are evaluated as level 2. If the value of H multiplied by V is 15 or more and 25 or less, and H and V are 3, 4, or 5, it is evaluated as level 3.

Table 2. Hazard and vulnerability criteria for the calculation of $\text{Risk}_{Location\ j}$.

	Range of Hazard (H) and Vulnerability (V)	$\text{Risk}_{Location\ j}$			Risk Matrix
Grade	**Range of Raw Data**	**Range of H and V Level**	**$\text{Risk}_{Location\ j}$ Value (H × V)**	**$\text{Risk}_{Location\ j}$ Level**	
1	0–0.2	H ∈ {1, 2, 3}, V ∈ {1, 2, 3}	1–3	1	
2	0.2–0.4	H ∈ {2}, V ∈ {2}	4		
3	0.4–0.6	H ∈ {1, 2, 3, 4, 5}, V ∈ {1, 2, 3, 4, 5}	4–12	2	
4	0.6–0.8	H ∈ {1, 2, 3, 4}, V ∈ {1, 2, 3, 4}	4		
5	0.8–1.0	H ∈ {3, 4, 5}, V ∈ {3, 4, 5}	15–25	3	- Green color: Relative safe level ($\text{Risk}_{Location}$ level is 1) - Green color: Relative safe level ($\text{Risk}_{Location}$ level is 1) - Yellow color: Relative normal level ($\text{Risk}_{Location}$ level is 2) - Red color: Relative dangerous level ($\text{Risk}_{Location}$ level is 3) - The value in parentheses is the product of the value corresponding to the horizontal axis (Hazard) and the value corresponding to the vertical axis (Vulnerability) in the risk matrix.

2.2.2. $\text{Risk}_{Company}$

The evaluation process for $\text{Risk}_{Company}$ is divided into two stages. First, screening the risk items of possible flood risks for the companies' risk assessment is needed. Second, in-depth interviews with the companies' stakeholders and data on damages caused by floods are collected for each item to rank the probability and consequence by risk item. The interviews are necessary because the companies' employees are knowledgeable about actual flood damage [51].

First, we investigated the cases of flood damage to companies and industrial parks, listed the possible flood risk items of companies based on the literature survey, and then determined the risk items through in-depth interviews with business stakeholders [52–55]. The 31 risk items were derived from literature reviews considering transportation logistics, productivity levels of workers, location of the companies, companies' financial situation, and the market impact of the flood (whole flood risk items in Table 3). Afterwards, in-depth interviews with companies' stakeholders were used to evaluate the risk that the actual damage would likely create for the companies and the consequences. They selected risks with high probabilities and that would be the most affected by flooding based on criteria of probability in Table 4 and consequences in Table 5. From July to August 2015, interviews for each company were conducted with three employees who had more than 10 years of work experience in the company (see Appendix A for the questionnaire used). Through discussions with five business stakeholders from each company, the final risk items were determined based on the risk items that were damaged by flood. Table 3 provides an example of a company's flood risk assessment list. For example, Risk 1 includes flooding and destruction of production facilities, Risk 2 involves increased humidity that degrades raw materials and final products, and Risk 3 is power supply interruption due to power station or substation damage that leads to production system paralysis. These are commonly identified risk items for companies in various industrial sectors.

Secondly, we evaluated the probability of occurrence and the consequences of the risk of the three derived final risk items. The probability of occurrence is judged from 1 to 5 using the evaluation criteria based on the flood damage cases by risk item (see the second column of Table 5). The consequences of the risk from 1 to 5 was assessed based on questionnaires and in-depth interviews with five employees who worked for more than 10 years in the environmental management and safety management departments of each company between September and October 2015 (refer to Appendix B for the questionnaire). In order to review employees' thoughts on the magnitude of risk in the second in-depth interview, we prepared risk assessment data and made an on-site visit from October to November 2015.

In the interviews, workers assessed the consequences of risk items (Table 4) in the questionnaire based on previous flood damage to their company. The results of the consequence evaluation were compared with those of the interviewees who participated in the in-depth interviews, along with details of the damage caused by the production process and the flood. The average values were adjusted in the third in-depth interview held in November 2015, which mainly focused on the magnitude of the difference between risk items. Owing to the large variation in risk assessment values, there were inconsistencies in the data; therefore, a third interview was conducted with two employees who had worked at their respective companies for more than 10 years. The consequence grade was adjusted based on the third interview.

Table 3. Flood risk assessment of company's risk list for $\mathrm{Risk}_{Company\ i}$.

Categories	Flood Risk List	Final Flood Risk to Be Assessed Considering Both Probability and Consequence
Transportation & Logistics	Road flooding and collapse	
	Road slope collapse and sediment discharge	
	Inundation and damage to transportation vehicles due to typhoons and heavy rain	
	Loss of raw materials and damage in case of heavy rainfall	
	Impassable roads	
	Damage to product transportation facilities	
	Significant increase in traffic accidents (railways, roads)	
Production	Flooding and collapse of production facilities	○ (Risk 1)
	Concerns about the destruction and overturning of various and large equipment	
	Increased possibility of building collapse due to strong winds and heavy rain	
	Power supply interruption due to power station and substation damage (production system paralysis)	○ (Risk 3)
	Unsafe roads due to flooding	
	Damage to water treatment facilities	
	Increase of polluted water outflow due to flooding	
	Increase in energy consumption for maintaining constant temperature and humidity when the outside temperature is lowered due to prolonged, heavy rains	
	Increased humidity degrading raw materials and final products	○ (Risk 2)
	Increased possibility of mixed discharge of waste due to flooding	
	Damage and collapse of waste treatment facilities due to typhoons and floods	
Workers	Increased worker mortality caused by factors such as facility collapse and electrocution	
	Increased worker injury due to lightning, etc.	
	Increased possibility of workers' mental health problems (posttraumatic stress)	
	Outdoor workers inability to work due to flooding	
Location	Increased probability of flood damage due to heavy rainfall and high tide overlap	
	Increased probability of flood damage due to aging domestic water exclusion facilities	
	Increased probability of flooding within the workplace and nearby coasts	
Finance	Increase in personal and material insurance costs due to floods	
	Increased cost of repairing damaged facilities	
	Added transportation costs due to disruption in infrastructure supply and demand	
	Difficulties in shipping products and with respect to the costs of claiming damages due to the flood	
Market	Increased possibility of supply chain damage in other companies related to product manufacturing	
	Decrease in the quality of products	

Table 4. Consequence criteria of risks according to risk items.

Profit-Making	**Accomplishment**	**Supply of Materials and Tools**	**Human Resources**	**Process**	**Consequence Grade (C)**
No profit	Did not achieve the goal	Supply is interrupted	Manpower vacuum	Suspended	5 (very risky)
Goal not achieved	Did not achieve the goal	Supply is delayed for a long period of time	Not sufficient for a long period of time	Supply is delayed for a long period of time	4 (risky)
Goal achieved	Achieved the goal	Supply is delayed	Not sufficient for a short period of time	Process is delayed	3 (normal)
Achieved, partially exceeding the goal	Achieved, partially exceeding the goal	Supply is delayed for a short period of time	Slight problem	Process is delayed for a short period of time	2 (not very risky)
Achieved, exceeding the goal	Achieved, exceeding the goal	Stable supply	Smooth	Achieved the process	1 (not risky)

We used the concept of consequence and probability to obtain the $\text{Risk}_{Company}$ rating. Each risk item can be evaluated according to the method defined in Equation (6) by multiplying consequence (c) with probability (p) to determine the $\text{Risk}_{Company}$ level (Table 5). The consequences along the x-axis are graded from 1 to 5 and the probabilities along the y-axis are graded from 1 to 5. Therefore, the multiplied values ranged between 1 and 25, which can be classified as 1 to 3 using a 5-by-5 risk matrix with three different categories (green, yellow, and red). The classification criteria are shown in Table 4. The $\text{Risk}_{Location}$ level can be assigned to each risk item.

$$\text{Risk}_{Company\ i} = \text{Consequence}_i \times \text{Probability}_i \quad (6)$$

$$\text{with } i \in \{1, 2, 3\}, i \text{ is a risk item}$$

2.2.3. Risk_{Flood}

To determine the Risk_{Flood} rating, the $\text{Risk}_{Location}$ and $\text{Risk}_{Company}$ results were multiplied to assess the Risk_{Flood} level of each risk item. Each level of $\text{Risk}_{Location}$ and $\text{Risk}_{Company}$ was classified into three categories (dangerous, normal, and safe) based on the grading method using the 3-by-3 risk matrix. The Risk_{Flood} level was obtained by multiplying $\text{Risk}_{Location\ j}$ with $\text{Risk}_{Company\ ji}$, as seen in Equation (7). The j value ranges from 1 to n, which represents the number of companies participating in the case study. There are three risk items for each company; i ranges from 1 to 3. Three Risk_{Flood} values for each risk item should be calculated for each company. Since $\text{Risk}_{Company}$ has one value for each risk item, $\text{Risk}_{Company}$ has three values in total. However, there is onlyaone $\text{Risk}_{Location}$ value for each company, and the value of $\text{Risk}_{Location}$ is repeatedly used for the three risk items. Because a company's Risk_{Flood} rating can be assessed with a risk-by-risk matrix, a company can assess the Risk_{Flood} rating for three risk categories (dangerous, level 3; normal, level 2; and safe, level 1). The classification criterion can be expressed as Equation (7). If $\text{Risk}_{Location\ j}$ multiplied by $\text{Risk}_{Company\ j}$ equals 1 or 2, then it is classified as level 1. If the product is 3 or 4, it is classified as level 2. Otherwise, it is classified as level 3.

$$\text{Risk}_{Flood\ ji} = \text{Risk}_{Location\ j} \times \text{Risk}_{Company\ ji} \quad (7)$$

$$\text{with } j \in \{1, 2, 3, \ldots, n\}, j \text{ is an industrial park number}; i \in \{1, 2, 3\}, i \text{ is a risk item}$$

According to the underlying concept of this study, the FRAC model represents the whole flood risk assessment process in which the Risk_{Flood} level is described as being equal to the FRAC level. The results of the FRAC model evaluation with the three risk items (i = 1, 2, 3) of enterprise j are expressed in the risk matrixes for each risk item (Table 6).

Table 5. Probability grading criteria based on the risk items and rating of $\text{Risk}_{Company}$.

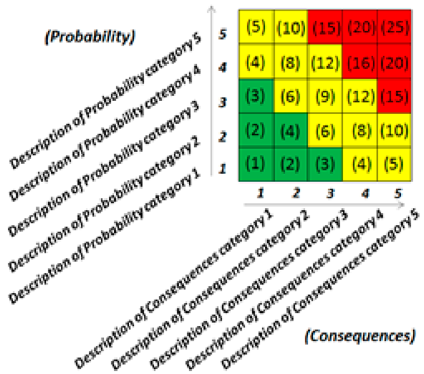
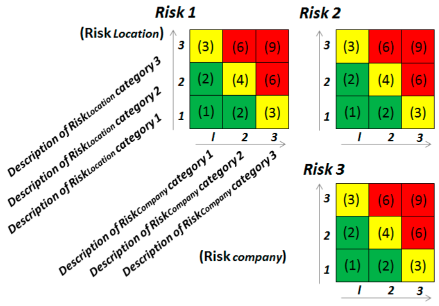
Grade of P	Evaluation Standard of the Risk Probability for Each Risk Item (P)		$\text{Risk}_{Company\ i}$		Risk Matrix
	Range of Raw Data Value	Range of C and P Level	$\text{Risk}_{Company\ i}$ Value ($C \times P$)	$\text{Risk}_{Company\ i}$ Level	
1	No damage occurred in the past and the probability is very low	$C \in \{1, 2, 3\}$, $P \in \{1, 2, 3\}$	1–3	1	
2	Damage was not recorded in the past; however, considering the location's physical features, the probability of risk is moderate to low	$C \in \{2\}$, $P \in \{2\}$	4		
3	Damage was recorded in the past; considering the geographical location and environment, the probability is high to extremely high	$C \in \{1, 2, 3, 4, 5\}$, $P \in \{1, 2, 3, 4, 5\}$	4–12	2	
4	Actual damage (various cases within the last 10 years), no damage and recovery costs	$C \in \{1, 2, 3, 4\}$, $P \in \{1, 2, 3, 4\}$, $C \neq P$	4		
5	Actual damage (various cases within the last 5 years), damage and recovery costs are incurred	$C \in \{3, 4, 5\}$, $P \in \{3, 4, 5\}$	15–25	3	- Green color: Safe level ($\text{Risk}_{Company}$ level is 1) - Yellow color: Normal level ($\text{Risk}_{Company}$ level is 2) - Red color: Dangerous level ($\text{Risk}_{Company}$ level is 3) - The value in parentheses is the product of the value corresponding to the horizontal axis (Consequences) and the value corresponding to the vertical axis (Probability) in the risk matrix.

Table 6. FRAC (relative Flood Risk Assessment for Company) grading criteria.

$\text{FRAC}_{ji} = \text{Risk}_{Flood\ ji}$		Risk Matrix
$\text{Risk}_{Location\ j} \times \text{Risk}_{Company\ ji}$	Level	
1, 2	1	
3, 4	2	
6, 9	3	- Green color: Relative safe level (Risk_{Flood} level is 1) - Yellow color: Relative normal level (Risk_{Flood} level is 2) - Red color: Relative dangerous level (Risk_{Flood} level is 3) - The value in parentheses is the product of the value corresponding to the horizontal axis ($\text{Risk}_{Company}$) and the value corresponding to the vertical axis ($\text{Risk}_{Location}$) in the risk matrix.

3. Case Study

3.1. Study Context

South Korea has the 11th largest economy in the world [55]. The country boosted national growth by intensively constructing industrial parks since the 1960s and offering various tax incentives and infrastructure for their creation [56]. As a result, 68.6% of companies are located in industrial parks nationwide and 80.7% of the manufacturing sector is located in industrial parks.

For this study, four companies were selected for FRAC evaluation: (1) a thermal power plant (TP); (2) an expanded polystyrene manufacturer (EPSM); (3) an electric parts manufacturer (EC); and (4) a pulp and paper manufacturer (PP). The above four companies sought to participate in the evaluation, and their awareness of climate change was higher than other companies. Therefore, we selected the above four firms among the companies that the researchers wanted to participate in the evaluation. In this study, $\text{Risk}_{Location\ j}$ was used to assess the environmental conditions of companies in order to assess the flood risk posed by the location of the company. The geographic locations of the evaluated companies are shown in Figure 2. These four companies were selected because they are located in national industrial parks and represent their respective industry type in South Korea. The four types of companies were selected to identify risk items that affect both SMEs and large companies, representing the entire industry that should be prioritized in the country. The four companies are located in different industrial parks.

TP is South Korea's largest thermal power plant built on the western shore to supply domestic power. TP has eight power generation facilities located within the industrial park, occupying a total area of 231,000 m^2; 42 companies depend on TP for their operation. EPSM is located in a national industrial park that houses approximately 48% of the manufacturing companies in the mechanical and petrochemical industries. This industrial park (total area of 17,760,000 m^2) was constructed on a landfill partly built on the sea; thus, the ground is relatively low. EC, one of South Korea's leading electronic component manufacturers, is located in an inland national industrial park which was established to develop the electronics industry. The industrial park covers a total area of 4.6 km^2 and is located in a relatively hilly region. PP is a paper and pulp manufacturing company located in a national industrial park adjacent to the southern coast, which mainly supports the nonferrous metal industry, refineries, oil stockpiling, and chemical pulp industries.

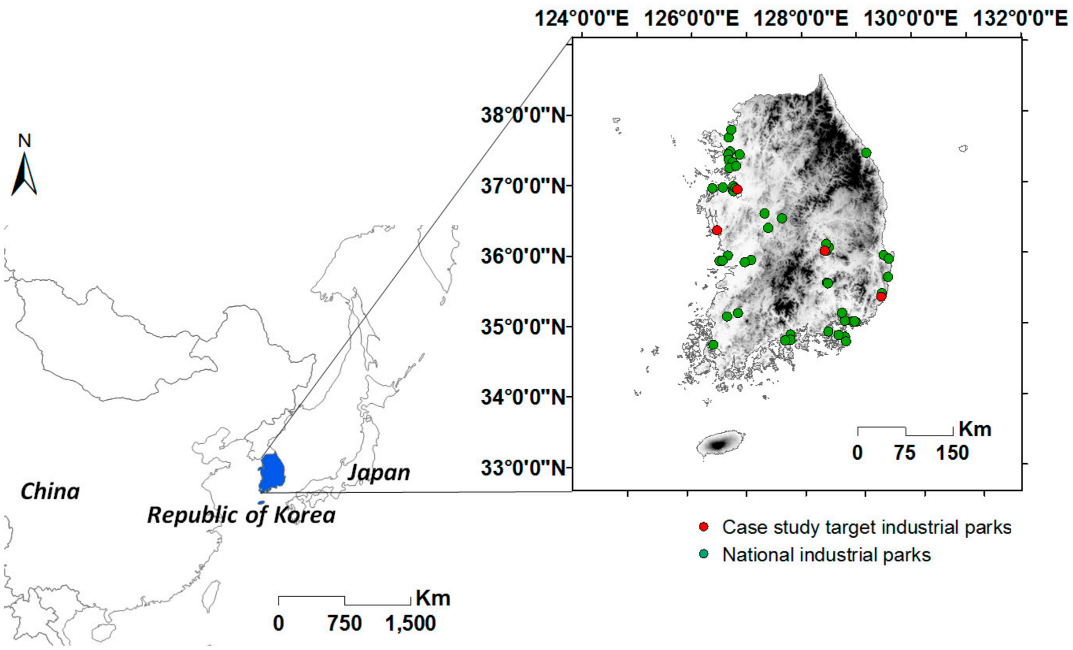


Figure 2. Study context.

3.2. Results of the Case Study Using the FRAC Model

The evaluation results can be utilized as data for decision-making in two areas: (1) Which industrial parks are vulnerable to floods and need government support? (2) For what risk items do companies need government support in order to reduce the country's overall flood risk?

3.2.1. Which Industrial Parks Are Vulnerable to Floods and Need Government Support

The hazard value of each company's location was evaluated according to climatic exposure using indicators. Each indicator was standardized as shown in Equation (2), and ranged from 0 to 1.0 (Figure 3A). Gwangyang National Industrial Park (No. 2) had the highest rated value (0.64) and average grade (3.60). The average grade was derived by considering both baseline and future (for the 2030s and the 2050s, respectively) hazard grades. The industrial park currently belongs to the fifth highest hazard grade. However, it is predicted that the risk grades of the location will somewhat decrease in the future, to the third and fourth grade. On the other hand, Gumi High Tech Valley (No. 5) was rated the lowest value and grade. The average future hazard level of this industrial park was 1.20. Currently, the hazard is grade 2, but in the future, the hazard will be further reduced to grade 1. High-hazard areas are regions with a high probability of flooding.

Risk$_{Location}$ levels were calculated by multiplying hazard and vulnerability grades and classified into three levels using a 5-by-5 risk matrix. In Figure 3 below, the graph at the bottom is multiplied by the grade of each hazard and vulnerability. The average level of current and future Risk$_{Location}$ was largest at the Sam-Il Resource Reserve Park (No. 20) at 15.00, because the hazard grade has a rating of 2 to 4, but the vulnerability grade has a rating of 5. This means that the risk is significantly higher than in other industrial parks. Daegu Science Park (No. 10) had the lowest average risk level of 1.02 for the present and future because hazard is at the second and third grade in the present and future, respectively, and the vulnerability is very low (grade 1). The Gwangyang National Industrial Park (No. 2) and Jin-Hae National Industrial Park's (No. 34) Risk$_{Location}$ showed the highest average level (2.40). On the other hand, Daegu Science Park (No. 10), Light Green Industrial Park (No. 19), and

Chang-Hang National Industrial Park's (No. 31) Risk$_{Location}$ showed very low average levels (1.00). When the Risk$_{Location}$ level of evaluation is high, the hazard and vulnerability grades are also high (No. 2, No. 34). However, if the level of Risk$_{Location}$ is normal or low, there are two reasons—the hazard grade is high but the vulnerability grade is low (Nos. 19, 35) or vice versa (Nos. 5, 13, 21). Hazard and vulnerability grades were all low (Nos. 10 and 31). The Figure 3B shows the final grade determined by the multiplication of the hazard grade and vulnerability grade, and translated into three levels as indicated by the three colors in the 5-by-5 risk matrix. The results clearly indicate the range of Risk$_{Location}$ for each industrial park.

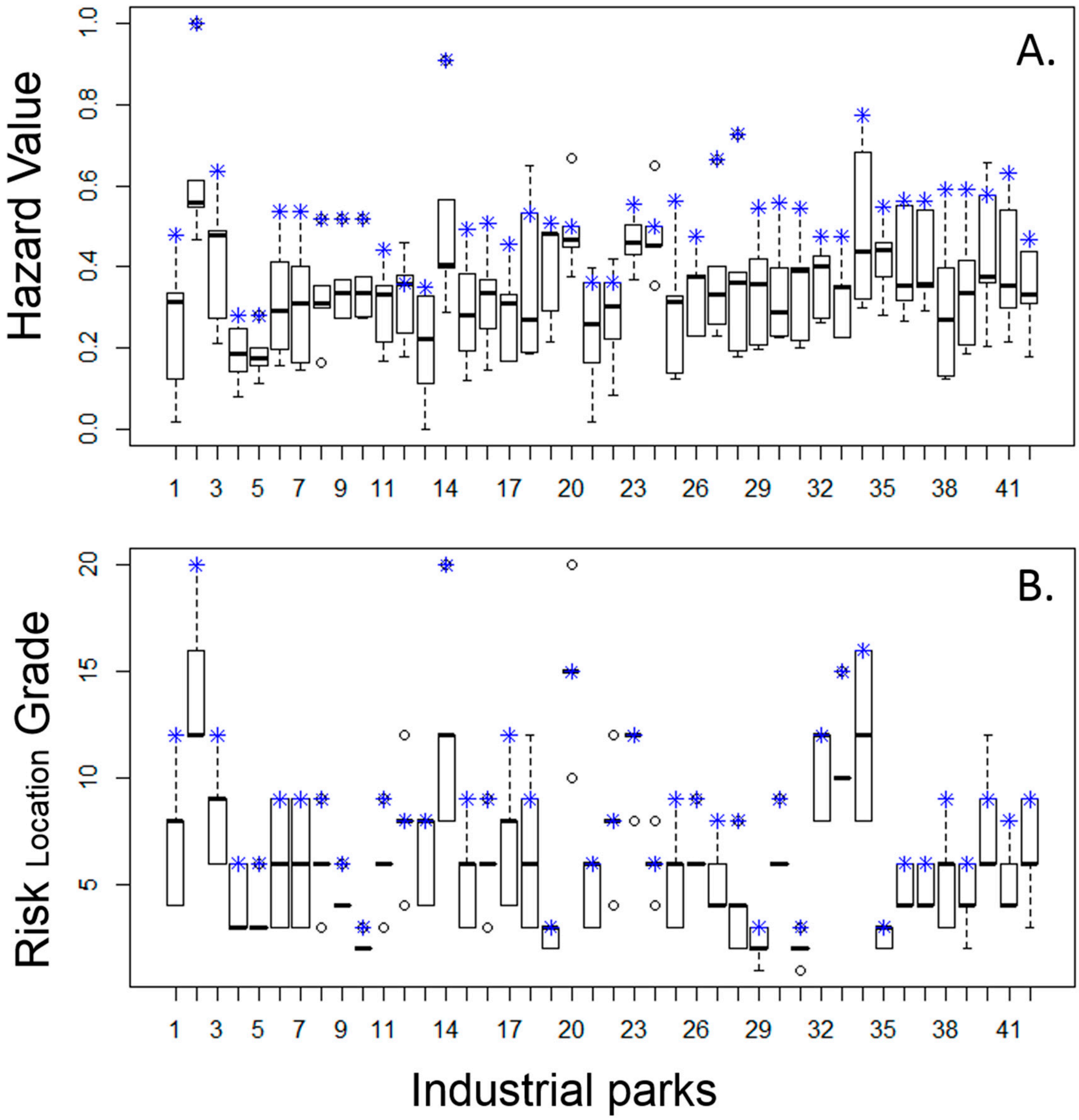


Figure 3. The blue asterisks indicate the current level of hazard (Max = 1) and Risk$_{Location}$ grade (Max = 20). The lines in the box plots show the median values, and the ranges represent the uncertainty ranges of future hazard and risk. We considered the 2030s and the 2050s to see future uncertainty with representative concentration pathways (RCP) of 4.5 and 8.5, respectively.

The Risk$_{Location}$ evaluation results were based on the degree of vulnerability to floods and the possibility of floods (hazard) occurring in industrial parks in which the target companies are located. In this study, the flood risk level of a national industrial park in the southern region was high (red circle, dangerous level) and most inland and eastern industrial parks were assessed at a safe level (green circle), as seen in Figures 4–6. In other studies, the vulnerability of the southern region was high owing to high sensitivity and low adaptive capacity [57–59]. The results of this study show that the industrial parks in the southern region, similar to previous studies, had high flood risk; however, the risk level decreased gradually according to climate change scenarios [58,59]. Construction of industrial parks in South Korea began in the early 1960s. In the 1970s, the government began to develop heavy chemical industry sectors, such as steel, petrochemicals, and non-ferrous metals, in industrial parks [60]. At that time, industrial parks were mainly located in metropolitan areas in the central and southern coasts of South Korea to ensure accessibility for the transportation of raw materials for importation and exportation. Therefore, most industrial parks built during the early industrialization phase were rated with vulnerability grade 5 (dangerous) (see first image in Figure 4). Hazard grades were highest in the southern coast, where vulnerability is currently high, but is being graded lower over time (Figures 4–6). As a result, the risk is classified as safe (green color, level 1) and normal (yellow color, level 2) at the baseline. In the 2030s, most areas except for the western and southern coasts are expected to change from normal to safe. In the 2050s, most of the southern inland areas were graded as safe, whereas the majority of the remaining areas were normal, suggesting a potential decreasing trend compared to the current level. The uncertainty of climate change scenarios and increasing variations in annual precipitation could be the main reasons for the reduction of hazard levels in the future.

To understand this trend, we compared annual precipitation deviation data in the 2030s and 2050s for the 42 industrial parks based on the five-day cumulative maximum rainfall in the hazard index. The cumulative maximum rainfall on the 5th day decreased on average in the future, but in the 2030s in the RCP 4.5 scenario, the average regional standard deviations of the 42 industrial complexes is 58.2, with the highest value of 125.1. Therefore, the difference was very large. For the same RCP 4.5 scenario in the 2050s, the average regional standard deviation was 95.9, with the highest value of 404.4 and minimum value of 0. The maximum five-day cumulative rainfall of the baseline was found to be the highest at 235 mm among the 42 industrial parks. However, in the RCP 4.5 scenario, the maximum value of 532 mm in the 2030s, and 1518.3 mm in the 2050s, gradually increased. Thus, the difference in annual precipitation increased greatly in one region but the average precipitation decreased.

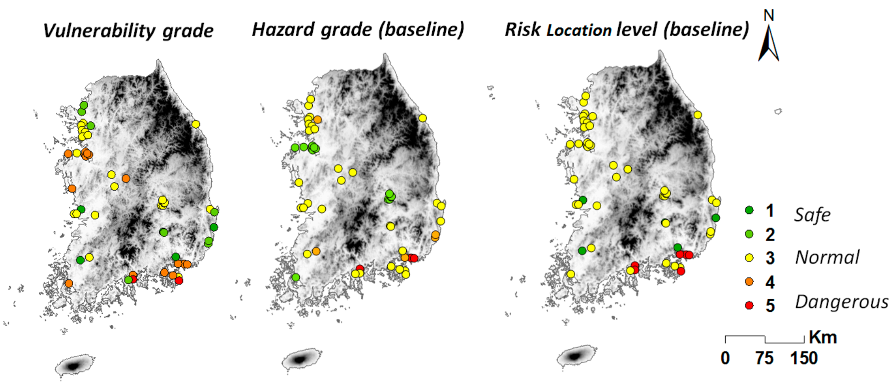


Figure 4. Comparison of vulnerability and hazard grades and $\text{Risk}_{Location}$ levels in national industrial parks at the baseline.

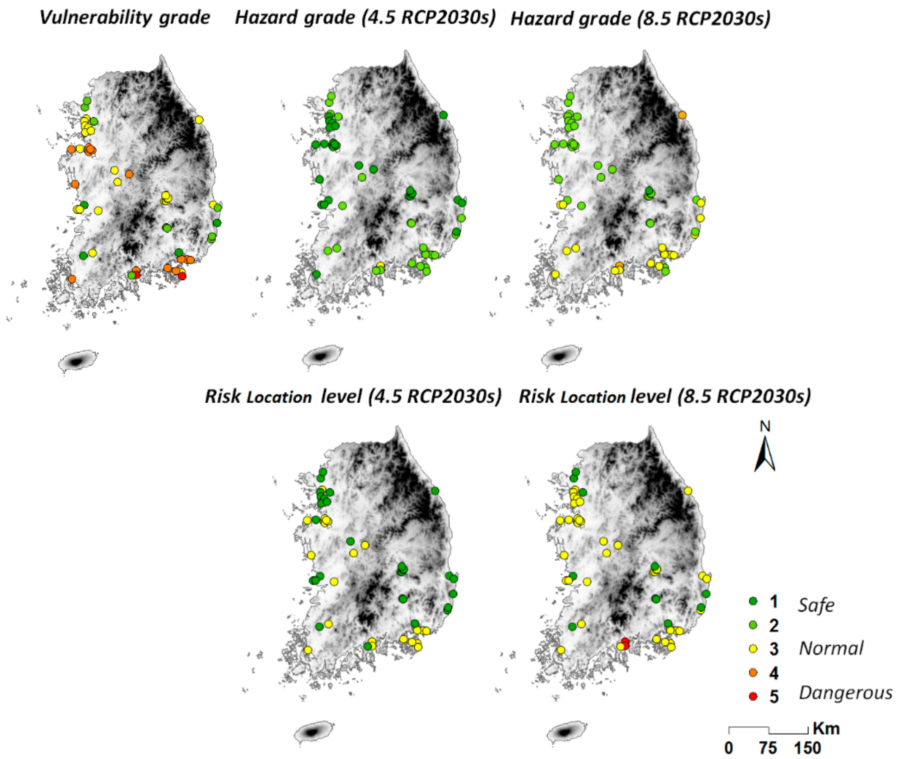


Figure 5. Comparison of vulnerability and hazard grades and Risk$_{Location}$ levels in national industrial parks in the 2030s.

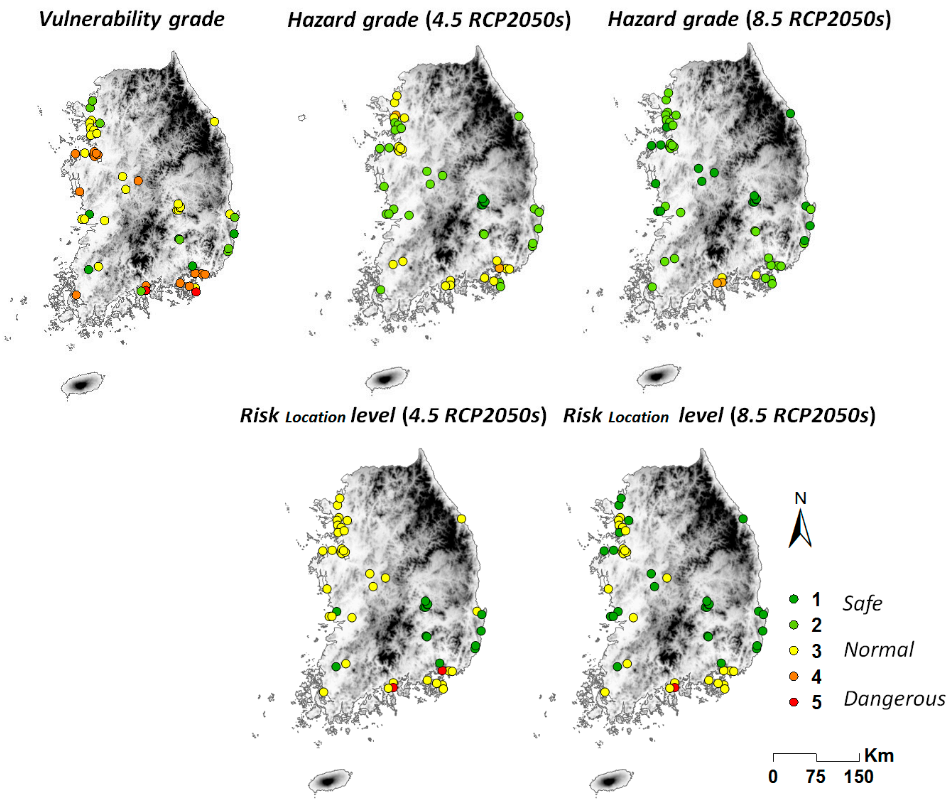


Figure 6. Comparison of vulnerability and hazard grades and Risk$_{\mathrm{Location}}$ levels in national industrial parks in the 2050s.

3.2.2. What Risk Items of Companies Should the Government Support to Reduce the Country's Overall Flood Risk

The final FRAC level, which includes the $\text{Risk}_{Location}$, $\text{Risk}_{Company}$, and Risk_{Flood} levels, can be used to support the government's decision-making. The three risk items in Table 3, derived from $\text{Risk}_{Company}$, can be used to determine the types of support that should be provided to each company. Depending on the risk category or the average risk rating of the risk category, the companies that need federal support may be different.

Based on in-depth interviews with company stakeholders about the possible risks for companies, there are three risks caused by floods that have a great influence on the production activities of parks. Risk 1 is the flooding and destruction of production facilities; Risk 2 is the damage caused by increased humidity that degrades raw materials and final products; and Risk 3 is the interruption of power supply due to power station and substation damage, which leads to production system paralysis. Therefore, the government should support these risk items.

However, in the case of insufficient funds, risk items must be prioritized. After further comparison of the three chosen risk items, the one with the highest level should receive support. Risk 2 presented the highest average level among the four companies, whereas Risk 1 presented the highest FRAC level for TP. The average level of Risk 1 for the four companies was 1.50, Risk 2 was 1.75, and Risk 3 was 1.50 (Table 7). In the case of Risk 1, TP was evaluated as having a risky level (level 3); however, the average rating of the four companies was 1.5. If the government decides to prioritize risk item funding to reduce the overall flood risk for all companies, it should focus on Risk 2. However, if the aim is to reduce the greatest risk of flooding among all companies, Risk 1 should be prioritized for funding. In the table below (Table 7), ① indicates the risk level of the location of companies, and ② indicates the risk level of a company's risk lists. Risk_{Flood} level is the result of multiplying the values of ① and ② using the 3-by-3 risk matrix.

To analyze the evaluation results of the three possible risk items of TP (the highest risk company), we investigated cases of the company's flood damage, its production process, and flood prevention measures. TP is a coal-fired power plant that produces electricity. It has a steam power plant using bituminous coal and a combined cycle power plant using liquefied natural gas as raw material. The power plant is located on the coast because it requires a large amount of cooling water. On 15 August 2012, several sections of the power plant were flooded and damaged due to local heavy rainfall. The rainfall per hour was 68 mm for 3 h, and the cumulative rainfall was 218 mm. The heavy rains and high tide overlapped, and the flood damage occurred largely because the rainwater was not able to flow to the sea. As a result, the cutoff area of the power plant collapsed and the 345 kV underground power plant of the combined power plant was submerged. Several facilities in the power plants were flooded, including the sump pit, cable room, and 345 kV tunnel. Most of these facilities flooded because they were located in the basement. After TP was damaged, three sump pumps were purchased to prevent flooding, resulting in recovery costs of approximately 43,802 USD. The average level of Risk_{Flood} in TP was 2.00, and $\text{Risk}_{Company}$'s Risk 1 was assessed as level 3, Risk 2 as 2, and Risk 3 as level 1. In other words, the Risk 1 item of flooding and collapse of production facilities was found to be the most dangerous. The risk level of Risk 1 for TP is a risky level that does not change in the present and future. Based on the results of the FRAC, enterprises need to invest in facilities to prepare for flooding and the destruction of production facilities due to floods. By improving the ability of the company to deal with floods, such as buying new drain pumps after flood damage, the level of Risk 1 is expected to decrease, and this adaptive measure will reduce the probability of Risk 1. In addition, a decrease in the hazard grade from the FRAC model and the company's flood risk adaptation plan will result in lower risk levels in the future.

Table 7. Comparison of FRAC levels evaluated with company risk items.

		①					②	① × ②				
		Risk$_{Location\ j}$ (Level)					Risk$_{Company\ i}$ (Level)	Risk$_{Flood}$ (Level)				
		Baseline	2030s		2050s			Baseline	2030s		2050s	
			RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5			RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
TP	Risk 1						3 (1.50)	3	3	3	3	3
	Risk 2	2 (2.00)	2 (1.40)	2 (1.79)	2 (1.79)	2 (1.48)	2 (1.75)	2	2	2	2	2
	Risk 3						1 (1.50)	1	1	1	1	1
EC	Risk 1						1 (1.50)	1	1	1	1	1
	Risk 2	2 (2.00)	1 (1.40)	2 (1.79)	1 (1.79)	1 (1.48)	2 (1.75)	2	1	2	1	1
	Risk 3						2 (1.50)	2	1	2	1	1
EP SM	Risk 1						1 (1.50)	1	1	1	1	1
	Risk 2	2 (2.00)	2 (1.40)	2 (1.79)	2 (1.79)	2 (1.48)	2 (1.75)	2	2	2	2	2
	Risk 3						2 (1.50)	2	2	2	2	2
PP	Risk 1						1 (1.50)	1	1	1	1	1
	Risk 2	2 (2.00)	1 (1.40)	2 (1.79)	1 (1.79)	1 (1.48)	2 (1.75)	2	1	2	1	1
	Risk 3						1 (1.50)	1	1	1	1	1

Note: The highest value of the risk assessment result of Risk$_{Flood}$ was highlighted in gray.

In order to analyze the evaluation results of the three possible risk items of EC, we investigated cases of flood damage, data related to the characteristics of the company, and measures by the company to reduce flood damage. EC produces camera modules and package substrates, which are parts of electronic devices. For both product lines, the manufacturing process should maintain a temperature of 22 ± 2 °C and humidity of 50 ± 5%. In order to maintain the proper temperature and humidity, EC manufactures products in a Clean Room equipped with advanced temperature, humidity, and particle control functions. It is a space necessary for precise work with products such as semiconductors, because these are shielded from pollution and the external environment [61]. However, if rain is constantly falling, the number of equipment and operating rate can be changed to adjust the humidity of the Clean room. In addition, since EC uses ultrapure water for product manufacturing, defective products are possible when the water treatment process is defective. For this reason, EC is located in an industrial park near the Nakdong River where many electronic component manufacturers are located. However, because of the existence of well-maintained drainage facilities, the enterprises in this industrial complex are less likely experience flooding and are more likely to avoid damage to their production facilities. In the past, neighborhood businesses and roads were flooded for approximately 5 h because of a hurricane in September 2012. However, EC did not directly suffer from flood damage considering the overall climatic damage. This company was graded as low risk for Risk 1, as it was not severely damaged by flooding. Risk 2 and Risk 3 items were evaluated at the normal or safe levels in present and the future. However, not all of the production of EC is safe because of the sensitivity to humidity and high consumption of electricity. EC's electricity consumption is over 70% higher than that of other companies; therefore, production can cease if flooding were to interrupt its power supply. The company has experienced a change in electric power supply due to actual typhoons, floods, and lightning, and some production lines have been shut down three to four times a year. However, because there is reserve power in EC, a power outage does not have a significant impact on the production process itself, resulting in only a partial interruption. Therefore, since EC is at a normal or safe level, it is not a priority to establish adaptation measures.

EPSM produces expanded polystyrene (EPS) foam and expanded polypropylene. We analyzed the production process and gathered cases of flood damage to product manufacturing and interpreted the results of Risk_{Flood}. The production process of this company involves pasteurization, maturation, and plastic processing steps. pasteurization is a process that softens raw materials using water, air, and steam, and then expands them for processing. Maturation is a process in which raw materials are aged to penetrate various chemicals in the air when internal gas is released to into the environment as the pressure inside the material decreases while passing through the pasteurization process. In the plastic process step, raw materials go through pasteurization and maturation, then aged and dried again, and then put into a product-shaped frame and steamed to produce final product. EPS, in particular, is sensitive to temperature and humidity changes because high temperature and proper humidity must be maintained during the manufacturing process. During the pasteurization step, high temperatures must be maintained, while constant humidity (30–50%) at room temperature is required during maturation. Thus, when floods caused by heavy rainfall occur, the humidity may increase and temperature may decrease. To reduce the unintentional manufacturing of defective products, it is necessary to maintain a certain temperature and humidity. The Risk_{Flood} level of Risk 1 was at the safe level, and the Risk 2 and Risk 3 levels were at the normal level, because there was no evidence of flood damage to the enterprise because of good drainage in the area where EPSM is located. There are no cases yet of flood damage, and flood risk mitigation measures are not necessary at the normal level. However, it is necessary to pay careful attention because the products are manufactured through processes that are sensitive to temperature and humidity.

In order to analyze the evaluation results of the three possible risk items of PP, we examined cases of flooding, data on the characteristics of the enterprise, and adaptation measures by the company to minimize flood damage. A pulp-making process from wood pulp raw materials and a paper sheet-making process are performed at the PP plant. PP uses domestic pine and some imported wood chips to make pulp and paper that is stored outdoors. Wood chips are transferred to a digester to separate lignin and cellulose, and then washed and bleached, which consumes a large amount of water. During this time, the temperature of the water is between 80 and 90 °C and 65,000 tons of water per day are consumed. Paper fibers are bleached, compressed, dehydrated, and then coated and cut to produce paper. In order to make pulp and paper, most of the raw materials are made from domestic pine wood as thinning enables the production of many woods domestically. In addition, the use of domestic pine can reduce the risks associated with importing raw materials affected by natural disasters such as floods. However, owing to the lack of raw materials, PP has to import wood chips. Raw materials are imported once every two to three weeks to prevent the possibility of a suspension in supply due to heavy rains and strong winds. If the weather deteriorates, the materials will be shipped again in a few days. The raw materials are supplied in large quantities domestically and internationally once or twice a week. The company stores the raw wood chips and paper and pulp products outside in a field without proper protective measures. Therefore, flooding can reduce the quality of raw materials and final products. Although PP has its own measures for preventing flood damage, it has no clear adaptation plan, and the raw materials and products are very sensitive to moisture. However, because of the high level of awareness and lack of damage from large floods, Risk 1 and Risk 3 were evaluated at safe levels. Some of the current and future Risk 2 items were rated at the normal level because the products and raw materials are sensitive to humidity. Also, because the company stores and produces large quantities of raw materials, there is likely to be some impact from floods. In the case of Risk 2 items, the damage will not increase greatly because the likelihood of hazard occurrence is lower in the future and the degree of vulnerability is low. Therefore, it was determined that the company does not need to adopt measures against flood damage.

3.3. Use of Evaluation Results in Government Decision-Making

South Korea seeks to reduce the damage caused by floods in the industrial sector as a way for the government to support companies using top-down and bottom-up approaches for national economic development. In line with this objective, this project was carried out with financial support from the central government. This study was evaluated using indicators based on the age and flood vulnerability of industrial complexes, and the results can be used as a basis to identify future renovation projects. The evaluation method presented in this study can provide guidelines for selecting companies that need support.

First, this study can be a reference for decision-making in allocating taxes and infrastructure building in high-risk industrial parks in the country. The number of industrial complexes has been increasing since the 1960s [62,63]. Among the 42 national industrial parks, 28 are considered outdated. Consequently, the physical environment is poor and production volume is reduced because of remodeling rather than the construction of new industrial complexes; policies to meet the demand of new industries are emerging with respect to renovating old industrial complexes [64,65]. However, not all old industrial parks are vulnerable to flooding. This study showed that some older industrial parks were less prone to hazards and the risk of flooding was low. Some industrial parks are expected to have a lower risk rating owing to the possibility of hazards based on future climate change scenarios. The results of this study can be used for government decision-making on which industrial parks to prioritize for the purpose of reducing flood damage. To increase the productivity of enterprises and industrial complexes, provisions concerning the designation of revitalizing business districts are included in this law [66]. In 2016, a council for business revitalization was established in Ansan City in Gyeonggi Province, Boseong County in Jeollanam Province, and Gumi City in Gyeongsangbuk Province. Thus, planning for the regeneration of industrial complexes is underway.

Second, the evaluation model suggested in this study can be used for decision-making when the government establishes tax benefits and policies to improve the flood adaptability of SMEs with high flood risks. Based on estimates, the precipitation patterns and some risks are going to shift in the future because of climate change. The FRAC levels of EC and PP will change in the future. Of the four evaluated companies, TP is at a dangerous level (level 3) with respect to both current and future FRAC ratings of Risk 1. Risks 2 and 3 were evaluated as normal and safe, respectively. EC has been assessed as level 1 for both Risk 1 and FRAC values in the present and future (2030s, 2050s), but the FRAC values for Risks 2 and 3 are normal at present and in the 2030s (RCP 8.5), and safe in the 2030s (RCP 4.5) and 2050s (RCP 4.5 and 8.5). No dangerous levels are indicated; therefore, it is not an investment priority to prevent damages caused by floods. However, if the variability in precipitation patterns becomes more severe owing to climate change, companies might face increasing damages; therefore, it is necessary to regularly check and invest in facilities over the long-term. Because this method reflects the companies' and workers' opinions based on numerical values from a detailed evaluation, it can be used to offer reliable support for decision-making. The results show that the government could decide to give some support to stabilize the national economy and reduce flood damage. Among the risks, three were selected based on the results of the risk assessment and discussions with employees with sufficient working experience; however, the average risk levels of each company varied. Risk 1 was evaluated as a risky level (level 3) but the average rating was the highest for Risk 2. Therefore, the government might prioritize investment objectives to reduce the risk of one company or that of several companies.

4. Conclusions

We proposed the FRAC model to be used for decision-making by the national government and governments in various countries to support national industries. The FRAC model is a flood risk assessment method that can reflect the status of a company. Based on the concepts of hazard and vulnerability, $\text{Risk}_{Location}$ was assessed for 42 industrial parks by considering environmental conditions, meteorological phenomena, and infrastructure. For the assessment of $\text{Risk}_{Company}$, we used the concepts of probability and consequence and presented the evaluation results using three levels for each of the three risk items. The FRAC level was then evaluated by plotting it on a 3-by-3 risk matrix.

However, since the industrialization period the level of growth of firms and industrial complexes differ on an international scale; hence, the FRAC model proposed in this study aims to compare companies and industrial complexes within one country rather than among multiple countries. In addition, since precipitation patterns, precipitation levels, urbanization rates, and industrialization periods vary greatly among countries, evaluation indicator data should be developed for each country and evaluated on a local scale. Therefore, rather than presenting absolute evaluation criteria that can be applied to the same standards in various countries worldwide, the decision-making tool presented herein can be used to determine the government and industrial complex support to reduce damage caused by industrial flooding within a country. The Republic of Korea has a total area of approximately 100,188.1 km^2, about 2/3 of the total area of Japan (377,915 km^2). Given that Korea represents an area approximately 1/98th the total area of the United States (9,826,675 km^2), countries with large variations in area or climate can apply this method by adjusting the scale of the evaluation. This further underlines the difficulty in comparing flood risks among countries.

We evaluated four Korean companies using the FRAC model. According to predicted climate change, the increase and decrease of precipitation in the 2030s and 2050s were large. However, owing to the large interannual deviation in precipitation, we found that risks need to consider these factors. In addition, since the results were derived from the opinions of company personnel, and are relatively reliable and consistent with past cases, it is necessary to consider them in the context of differences between each company, such as production process, plant size, location, and working environment. It should be reiterated that one interview did not provide extensive data; three in-depth interviews were needed to select indicators, assess risks, and verify the results.

The results of this study are significant with respect to three areas. First, because of the use of the concepts of hazard and vulnerability to evaluate floods in a number of industrial parks, it is possible to identify which of the national industrial parks was at risk or vulnerable to flooding by considering climate change. This evaluation can be used as a decisive factor when remodeling industrial parks based on the indicators after quantitatively evaluating industrial parks that are vulnerable to flooding in future regeneration projects. Second, the three risk categories derived from this study are important risk items regardless of the type of industry; other industries can focus on these items and manage risks. The results are useful in deciding what items the government should invest in first. Third, the government can decide which company to invest in according to a standardized priority basis for the stabilization of the national economy. The results of this study, which is based on the FRAC model, can be used as criteria for this prioritization.

However, the evaluation method proposed in this study is subject to limitations. First, this FRAC model can only evaluate companies located in industrial parks within this study's spatial scope. Since there are many companies located outside these areas, evaluation methods considering these types of companies should be proposed in the future. Second, the average values for the 2030s and 2050s were used to derive the hazard values but deviations in precipitation are increasing, which mean that the maximum and minimum values also have to be considered. Third, the data used to evaluate the FRAC model in this study are variable, which can be both disadvantageous and advantageous. The disadvantage is that it is difficult to present the absolute threshold of the indicators by country. Conversely, the advantage is that the risk assessment is very flexible. If conditions such as government and enterprise climate change adaptation policies and infrastructure renewal change, then the effects driven by such changes on conditions can be confirmed. Moreover, the value of the infrastructure of the industrial complex in which a company is located can change as a result of renovations and repairs, and the hazard (i.e., climate) changes continuously owing to increases in greenhouse gas emissions. In addition, the evaluation results are not always the same because of changes in corporate adaptation policies, upgrading of existing industrial complexes, and creation of new industrial complexes. If the value of an indicator changes because of various factors such as the construction of a new industrial complex or new construction in an industrial complex, remodeling, etc., then the value of $\text{Risk}_{Company}$ can be determined after evaluation of $\text{Risk}_{Location}$ by reflecting this value in the evaluation database. It should be noted that the accuracy of the evaluation results can be improved as the number of industrial complexes to be evaluated increases owing to the characteristics of the relative evaluation method. Therefore, in this study, all national industrial complexes in South Korea were evaluated. The Republic of Korea develops 5-, 10-, and 20-year long-term plans each time it establishes government policies. This is because new governments focus on different administrative components, and the current economy and environment are constantly changing as new policies are implemented. Therefore, this study can be used to provide feedback on changes once the government provides support to the industrial complexes and enterprises that must prepare for flood risks.

The hazards and vulnerabilities used in the FRAC model are based on the relative standardization and combination of individual indicators. Some of the hazard indicators are based on real flood damage cases that are applicable nationwide. However, other indicators have a relatively high vulnerability, and even if they are standardized for all national industrial complexes in the Republic of Korea, the possibility of indirect flood damage remains. Therefore, further research is required to determine the threshold value of each evaluation indicator. Floods occur frequently worldwide and are the most damaging of natural disasters; thus, the government's decision-making system should adapt to the overall climate change risks of industries, including SMEs.

Acknowledgments: This study was supported by the BK 21 Plus Project in 2016 (Seoul National University Interdisciplinary Program in Landscape Architecture, Global Leadership Program toward innovative green infrastructure), the Korea Environment Industry & Technology Institute (KEITI) through "The Chemical Accident Prevention Technology Development Project" Project, funded by Korea Ministry of Environment (MOE) (No. 2016001970001) and Supported by a Korea University Grant.

Author Contributions: Jieun Ryu conceived the entire study, analyzed the data, and wrote the paper. Eun Joo Yoon, Chan Park, Dong Kun Lee, and Seong Woo Jeon discussed the structure and content of the thesis. All authors substantially revised the first draft after discussion of the structure and results of this paper.

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

Appendix A. Questionnaire Assessing the Impact of Floods on Companies

1. How long have you worked for the company? ( )
2. Has there been a case in which the output of the plant changed due to humidity change? If yes, please describe it here. ( )
3. Do you consider water management when constructing and expanding process facilities? Is there a process that requires water? If yes, please describe it here.
4. Please indicate the risks for your company in the event of a flood (using V).

(This item is evaluated by major processes.)

		1	2	3	4	5	
Profit creation	Exceeded			V			No profit
Stable demand of production	Exceeded			V			Goal not achieved
Supply of raw materials	Stable supply	V					Interruption of supply
Human resources	Stable supply			V			Interruption of supply
Process	Exceeded	V					Process stop

Was the process stopped due to the lack of water? If so, what are the costs and time of recovery or what are the costs of the damage? (Please fill out the following items for each of your company's major processes.)

Occurrence date	(Date)		
Occurrence condition	Air temperature (°C)	Seawater temperature (°C)	Precipitation (mm)
Process stage in which facility damage or damage occurred			
Damage intensity (downtime or cost of the facility)			

5. Please fill in the numbers for your company below.

Categories	Indicator	Scale	Value
Equipment	Percentage of facility area affected by floods in company	%	
	Inspection period for equipment or devices affected by flooding	Day	
	Average energy efficiency in company		
Products	Percentage of products affected by flooding	%	
	Percentage of warehouse area of the company in which flooding could be avoided		
Raw materials	Percentage of raw materials affected by floods	%	

Appendix B. Questionnaire Example of Assessing the Mesoscale Flood Risk

- Please evaluate the degree of risk that can be caused by drought on a scale from 0 to 5.
  - Assuming that the additional costs for various industries and production activities will sharply rise due to flood.
  - Assuming that the flood is severe and it is difficult to receive water from other areas.

Risk items	Evaluate the degree of danger on a scale from 0 to 5 for each item. If it does not occur, it is 0; it is closer to 1 when it is not dangerous.				
	Profit creation	Stable demand of production	Supply of materials	Human resources	Process
Collapse of road slope and soil discharge					
Inundation and destruction of transportation vehicles due to typhoon or storms					

References and Notes

1. Pinkse, J.; Kolk, A. Challenges and trade-off in corporate innovation for climate change. *Bus. Strategy Environ.* **2010**, *19*, 261–272. [CrossRef]
2. Ministry of Knowledge Economy. *Research of Climate Change Vulnerability on Industrial Sector*; Ministry of Knowledge Economy: Sejong, Korea, 2012; pp. 1–90.
3. Rizzi, J.; Gallina, V.; Torresan, S.; Critto, A.; Gana, S.; Marcomini, A. Regional risk assessment addressing the impacts of climate change in the coastal area of the Gulf of Gabes (Tunisia). *Sustain. Sci.* **2016**, *11*, 455–476. [CrossRef]
4. Khazai, B.; Merz, M.; Schulz, C.; Borst, D. An integrated indicator framework for spatial assessment of industrial and social vulnerability to indirect disaster losses. *Nat. Hazards* **2013**, *67*, 145–167. [CrossRef]
5. Mechler, R. *Natural Disaster Risk Management and Financing Disaster Losses in Developing Countries*; Verlag für Versicherungswissenschaft: Karlsruhe, Germany, 2004.

6. UKCIP. *UK Climate Change Risk Assessment 2017: Evidence Report*; UKCIP: Oxford, UK, 2017; p. 23.
7. Hagiwara, Y.; Kuribayashi, D.; Sawano, H. Enhancement of Flood Countermeasures of Japanese-Affiliated Firms Based on the Lessons Learned from the 2011 Thai Flood. *JDR* **2016**, *11*, 1176–1189. [CrossRef]
8. Gaume, E.; Bain, V.; Bernardara, P.; Newinger, O.; Barbuc, M.; Bateman, A.; Blaskovicova, L.; Bloschl, G.; Borgy, M.; Dumitrescu, A.; et al. A compilation of data on European flash floods. *J. Hydrol.* **2009**, *367*, 70–78. [CrossRef]
9. Komolafe, A.A.; Adegboyega, S.A.A.; Akinluyi, F.O. A review of flood risk analysis in Nigeria. *Am. J. Environ. Sci.* **2015**, 157–166. [CrossRef]
10. Ryu, J.; Lee, D.K.; Park, C.; Ahn, Y.; Lee, S.; Choi, K.; Jung, T.Y. Assessment of the vulnerability of industrial parks to flood in South Korea. *Nat. Hazards* **2016**, *82*, 811–825. [CrossRef]
11. Jang, J.; Lee, B.H. Problems of technology support to small business enterprises: Focusing on industry-academy-laboratory collaboration. *Korea Gov. Rev.* **2006**, *13*, 223–245.
12. UCKIP, BACLIAT Vulnerability Assessment. UK. 2014. Available online: http://www.ukcip.org.uk/wizard/future-climate-vulnerability/bacliat/ (accessed on 30 May 2017).
13. Committee on Climate Change, UK Climate Change Risk Assessment 2017: Evidence Report. 2017, pp. 28–103. Available online: https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Chapter-6-Business-and-industry.pdf (accessed on 30 May 2017).
14. Vu, T.T.; Ranzi, R. Flood risk assessment and coping capacity of floods in central Vietnam. *J. Hydrol. Environ. Res.* **2013**, *14*, 44–60. [CrossRef]
15. Dutta, D.; Herath, S.; Musiake, K. A mathematical model for flood loss estimation. *J. Hydrol.* **2003**, *277*, 24–49. [CrossRef]
16. FEMA. *Flood Map Modernization Mid-Course Adjustment*; FEMA: Washington, DC, USA, 2006.
17. FEMA. *CRS Coordinator's Manual Changes*; FEMA: Washington, DC, USA, 2012.
18. Scawthorn, C.; Flores, P.; Blais, N.; Seligson, H.; Tate, E.; Chang, S.; Mifflin, E.; Thomas, W.; Murphy, J.; Jones, C.; et al. HAZUS-MH flood loss estimation methodology, II. Damage and loss assessment. *Nat. Hazards Rev.* **2006**, *7*, 72–81. [CrossRef]
19. Klijn, F.; de Bruijn, K.M.; Knoop, J.; Kwadijk, J. Assessment of The Netherlands' Flood Risk Management Policy under Global Change. *AMBIO* **2012**, *41*, 180–192. [CrossRef] [PubMed]
20. Vergouwe, R.; Sarink, H. *The National Flood Risk Analysis for The Netherlands*; Rijkswaterstaat VNK Office: Roermond, The Netherlands, 2016; pp. 1–120.
21. Yang, J.S.; Park, J.H.; Kim, N.K. Development of drought vulnerability index using trend analysis. *KSCE* **2012**, *5*, 185–192.
22. Birkmann, J. Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications. *Environ. Hazards* **2007**, *7*, 20–31. [CrossRef]
23. Merz, M.; Hiete, M.; Comes, T.; Schultmann, F. A composite indicator model to assess natural disaster risks in industry on a spatial level. *J. Risk Res.* **2013**, *16*, 1077–1099. [CrossRef]
24. Sun, Z.; Zhang, J.; Zhang, Q.; Hu, Y.; Yan, D.; Wang, C. Integrated risk zoning of drought and waterlogging disasters based on fuzzy comprehensive evaluation in Anhui Province, China. *Nat. Hazards* **2014**, *71*, 1639–1657. [CrossRef]
25. Rodrigues, M.A.; Zrezes, P.M.; Leao, C.P. Defining risk acceptance criteria in occupational settings: A case study in the furniture industrial sector. *Saf. Sci.* **2015**, *80*, 288–295. [CrossRef]
26. Ahn, S. A case study of the risk identification in construction project. *KJCEM* **2015**, *16*, 15–23. [CrossRef]
27. Lee, S.M.; Kim, S.M.; Lee, Y.H. Introduction of the $B_{(i,j,k)}$ BCP and risk assessment of underground limestone mine. *Tunn. Undergr. Space* **2012**, *22*, 383–392. [CrossRef]
28. Smith, K. *Environmental Hazards: Assessing Risk and Reducing Disaster*, 2nd ed.; Routledege: London, UK; Philadelphia, PA, USA; Winnipeg, MB, Canada, 1996.
29. Brooks, N. *Vulnerability, Risk and Adaptation: A Conceptual Framework*; Tyndall Centre Working Paper; Tyndall Centre: Norwich, UK, 2003.
30. Anbalagan, R.; Singh, B. Landslide hazard and risk assessment mapping of mountainous terrains: A case study from Kumaun Himalaya, India. *Eng. Geol.* **1996**, *43*, 237–246. [CrossRef]
31. Hamidin, N.; Yu, O.J.; Connell, D.W. Human health risk assessment of chlorinated disinfection by-products in drinking water using a probabilistic approach. *Water Res.* **2008**, *42*, 3263–3274. [CrossRef] [PubMed]

32. Zhang, K.; Pei, Y.; Lin, C. An investigation of correlations between different environmental assessments and risk assessment. *Procedia Environ. Sci.* **2010**, *2*, 643–649. [CrossRef]
33. Torabi, S.A.; Soufi, H.R.; Sahebjamnia, N. A new framework for business impact analysis in business continuity management (with a case study). *Saf. Sci.* **2014**, *68*, 309–323. [CrossRef]
34. Torabi, S.A.; Giahi, R.; Sahebjamnia, N. An enhanced risk assessment framework for business continuity management. *Saf. Sci.* **2016**, *89*, 201–218. [CrossRef]
35. Xin, Z.; Xiaohu, X.; Kaili, X. Study on the risk assessment of the Tailings Dam Break. *Procedia Eng.* **2011**, *26*, 2261–2269. [CrossRef]
36. 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; Core Writing Team, Pachauri, R.K., Meyer, L.A., Eds.; IPCC: Geneva, Switzerland, 2014; p. 151.
37. Winsemius, H.C.; Van Beek, L.P.H.; Jongman, B.; Ward, P.J.; Bouwman, A. A framework for global river flood risk assessments. *Hydrol. Earth Syst. Sci.* **2013**, *17*, 1871–1892. [CrossRef]
38. Kang, H.W.; Min, B.J.; Kim, Y.S. A study on the Costs Variation Range through the Risk Factors for Overseas Plant Projects. *J. Architect. Inst. Korea* **2010**, *7*, 139–146.
39. Hay, J.; Mimura, N. The changing nature of extreme weather and climate events: risks to sustainable development, Geomatics. *Natl. Hazards Risk* **2010**, *1*, 3–18. [CrossRef]
40. Foudi, S.; Oses-Eraso, N.; Tamayo, I. Integrated spatial flood risk assessment: The case of Zaragoza. *Land Use Policy* **2015**, *42*, 278–292. [CrossRef]
41. Renn, O. The role of risk perception for risk management. *Reliab. Eng. Syst. Saf.* **1998**, *59*, 49–62. [CrossRef]
42. Renn, O. Three decades of risk research: Accomplishments and new challenges. *J. Risk Res.* **1998**, *1*, 49–71. [CrossRef]
43. UNDP. *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Polices, and Measures*; Cambridge University Press: Cambridge, MA, USA, 2005.
44. Jiang, F.; Tatano, H.; Kuzuha, Y.; Matsuura, T. *Economic Loss Estimation of Water Supply Shortage Based on Questinaire Survey in Industrial Sectors*; Report of the National Institute; National Research Institute for Earth Science and Disaster Prevention: Tsukuba, Japan, 2005.
45. Rose, A.; Lim, D. Business interruption losses from natural hazards: Conceptual and methodological issues in the case of the Northridge earthquake. *Environ. Hazard* **2002**, *4*, 1–14.
46. Chen, Y.; Song, G.; Yang, F.; Shushen, S.; Zhang, Y.; Liu, Z. Risk assessment and hierarchical risk management of enterprises in chemical industrial parks based on catastrophe theory. *Int. J. Environ. Res. Public Health* **2012**, *9*, 4386–4402. [CrossRef] [PubMed]
47. Kim, J.; Sung, H.H.; Choi, G. Spatial patterns of urban flood vulnerability in Seoul. *J. Korean Assoc. Reg. Geogr.* **2013**, *19*, 615–626.
48. Hamdani, Y.; Setyawn, D.; Setiawan, B.; Affandi, A.K. Mainstreaming adaptation climate change into Strategic environmental assessment case study Banyusain District, South Sumatra Province. *J. Sustain. Dev.* **2015**, *7*, 8–17.
49. Kaliraj, S.; Chandrasekar, N.; Peter, T.S.; Selvakumar, S.; Magesh, N.S. Mapping of coastal aquifer vulnerable zone in the south west coast of Kanyakumari, South India, using GIS-based DRASTIC model. *Environ. Monit. Assess.* **2015**, *187*, 4073–4099. [CrossRef] [PubMed]
50. Bing, G.; Yi, Z.; Fingeng, Z.; Wenliang, L.; Futao, W.; Litao, W.; Fuli, Y.; Wang, F.; Guang, Y.; Wei, L.; et al. Spatial patterns of ecosystem vulnerability changes during 2001–2011 in the three-river source region of the Qinghai-Tivetan Plateau, China. *J. Arid Land* **2016**, *8*, 23–35.
51. Kim, D.H. Risk assessment and Classification for climate change adaptation: Application on the Method of climate change risk assessment in the UK. *J. Environ. Policy* **2015**, *14*, 53–83.
52. DEFRA. *The UK Climate Change Risk Assessment*; Evidence Report; DEFRA: London, UK, 2012.
53. Joint Ministry of Republic of Korea. *Reviewed First National Climate Change Adaptation Policy*; Joint Ministry of Republic of Korea: Seoul, Korea, 2015; pp. 9–147.
54. Ministry of Environment. *Climate Change Vulnerability Map for Detailed Government Adaptation Policy*; Ministry of Environment: Gwacheon, Korea, 2012.
55. International Monetary Fund. *World Economic Outlook Database*; International Monetary Fund: Washington, DC, USA, 18 April 2017.
56. Ministry of Environment. *Water Demand Forecast Manual*; Ministry of Environment: Gwacheon, Korea, 2014.

57. Bae, D.H.; Lee, M.W. Flood vulnerability assessment and case analysis based on climate change. *Plan. Policy* **2010**, *344*, 20–31.
58. Lee, M.W.; Kim, T.W.; Moon, G.W. Assessment of flood damage vulnerability considering regional flood damage characteristics in South Korea. *J. Korean Soc. Hazard Mitig.* **2013**, *13*, 245–256. [CrossRef]
59. Hong, J.H.; Hwang, J.H. Analysis on the change of regional vulnerability to flood. *Environ. Policy Res.* **2006**, *5*, 1–18.
60. Huh, M.; Lim, C. A study on the competitiveness reinforcement based on the analysis of industrial complexes using vital index. *Reg. Dev. Stud.* **2012**, *44*, 75–96.
61. Oh, M.D. Clean Room Air Conditioning and Environmental Control System. *Facil. Soc.* **1991**, *20*, 391–408.
62. Chung, J.; Kim, J.; Baek, S. The strategy of innovation fund raising for the old industrial complex. *Constr. Econ. Ind. Res.* **2014**, *5*, 67–92.
63. Industrial Sites and Development Act. No. 14480. Directive 29 December 2009, Professional Revision 4 August 2011. Republic of Korea.
64. Kim, T.H.; Lim, D.I. The regeneration policy of deteriorated industrial complexes: The case study of Ulsan industrial complex. Wonju City. *KDI* **2014**, *26*, 159–180.
65. Jang, C.S.; Jung, C.J.; Na, J.M.; Shin, W.J.; Jung, W.G.; Jung, J.W. Status and Tasks of Regeneration of old industrial complex. *UEIS* **2015**, *397*, 4–20.
66. Act on Special for Promoting Vitality and Strengthening Competitiveness of Old Industrial Park. Ministry of Trade, No. 13879. Directive 27 January 2016, Apply 28 January 2017. Republic of Korea.