A STUDY ON WATER RESOURCES FACILITIES MANAGEMENT STRATEGY BASED ON CLIMATE CHANGE RISK ASSESSMENT

By

SONG, Woo Jin

CAPSTONE PROJECT

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF PUBLIC MANAGEMENT

2018

A STUDY ON WATER RESOURCES FACILITIES MANAGEMENT STRATEGY BASED ON CLIMATE CHANGE RISK ASSESSMENT

By

SONG, Woo Jin

CAPSTONE PROJECT

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF PUBLIC MANAGEMENT

2018

Professor Dongseok KIM

A STUDY ON WATER RESOURCES FACILITIES MANAGEMENT STRATEGY BASED ON CLIMATE CHANGE RISK ASSESSMENT

By

SONG, Woo Jin

CAPSTONE PROJECT

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF PUBLIC MANAGEMENT

Committee in charge:

Professor Dongseok KIM, Supervisor ______________________

Professor Junesoo LEE ______________________

Professor TaeJong KIM ______________________

Approval as of December, 2018

EXECUTIVE SUMMARY

Due to climate change, extreme weather events have been rampant and serious. Worldwide water-related disasters such as droughts and floods have been continuously occurring.

The purpose of this study is to assess the risk of climate change on water related facilities by looking into three selected multipurpose dam – Hoengseong Dam, Miryang Dam and Buan Dam. These dams are used for various purposes like flood control, water supply and power generation. In order to provide a basis for creating a climate change adaptation plan, a climate change risk assessment was conducted for each dam.

Climate Change Risk was assessed by estimating the likelihood of climate impact factors (heavy rain, drought, great heat, freezing, strong wind, and heavy snow) by multiplying the climate index values to the magnitude of the expected impact. The assessment results were analyzed using the climate change risk matrix. According to the position on the matrix, the response level is divided into the categories: acceptable, focus on prevention, focus on response, focus on prevention and response.

Results of the risk assessment show that the risk of drought poses the highest likelihood and regarded as very dangerous in all three dams. Due to this, prevention and response focused adaptation measures are necessary. Heavy rain is less likely to occur but the magnitude of the impact is large so the adaptation measure should be focused on response. In terms of great heat, the measure focused on response is applicable. The rest of the factors – freezing, strong wind, and heavy snow – were evaluated as relatively safe and having acceptable levels of risk.

TABLE OF CONTENTS

I. Introduction

A. Background of the study

Due to climate change, extreme weather events have been rampant and serious. Worldwide water-related disasters such as droughts and floods have been continuously occurring. The western part of Korea's Chungcheongnam-do has experienced droughts and floods have occurred in Cheongju and Incheon areas in the summer of 2017. The Intergovernmental Panel on Climate Change's (IPCC) 2014 report on climate change warns about urban flood leading to widespread damages to infrastructure and water shortages due to drought in Asia, including the Korean Peninsula. These risks are expected to increase in the future. Droughts and floods are not the only risks of climate change seasonal concentration of precipitation, resulting to poor water supply stability and increasing water management difficulties, is also a challenge.

Infrastructure damage is also a climate change risk. There are dams and multi-regional water supply facilities in the water sector. These are public facilities that prevent floods and drought and control the water supply. If these infrastructures fail to function or are destroyed, people's lives are hugely affected.

Policies covering national water resources and climate change adaptation like the National Water Resources Plan and National Climate Change Adaptation Plan have already been established and implemented to better manage water resources. In addition, dam design standards were revised three times – in 2001, 2005 and 2011 – to cope global issues such as abnormal flooding and increasing frequency of earthquakes. However, the detailed management plan for each water facility has been discussed only recently by the Ministry of Environment (ME) when it implemented the Guideline for Establishing Climate Change Adaptation Plan in Public Organizations in 2016. According to this document, public organizations should establish a climate change adaptation plan.

B. Purpose of the study

The purpose of this study is to provide a basis for preparing future management plans for each water related facility and establishing a climate change adaptation plan in the water sector to overcome water management difficulties arising from climate change. Furthermore this study also aims to provide some recommendations to the national water management policy and climate change adaptation policies.

II. Literature Review

A. Brief summary of the purpose

The difficulties of water management due to climate change are intensifying. Thus, it is needed to detail a climate change adaptation plan for each water facility that affects people's lives. Therefore, this study will assess the climate change risks to water facilities to provide a basis for preparing climate change adaptation measures.

B. Review of related research and national plan

1. Difficulty in managing water resources due to climate change

Kim Nam-Sung, et al. (2015) analyzed rainfall data from 1976 to 2010. His results showed that the drought in the Korean Peninsula was further intensified in the spring season. The analysis of the hydrological risk of the five major river basins in the Korean Peninsula showed that drought-poor areas in the watershed would be increasing as a result of climate change forecasts for short- and medium-term droughts.

Kim Cho-Rong, et al. (2013) found that the average future water shortage in the Korean Peninsula is predicted to increase up to 10-30% in the 2020s, anticipating climate change effects. In the case of the four major river basins, the amount of water during the non-flood season (October-June) is predicted to decrease gradually in the far future, while the average water shortage in the 2080s (2070-2099) is expected to grow by up to 97% (about 516.5 million m^3).

According to the National Water Resources Plan (2016), the frequency and intensity of drought increased due to climate change. The Boryeong Dam experienced a 200-year frequency drought for several years since 2015. During droughts in areas without tap water are vulnerable to water shortage. In addition, climate change has altered rainfall characteristics, cause frequent and excessive floods and deteriorating water quality increased water temperature, heavy rainfall and floods.

In the recent Wonju River Dam Construction Feasibility Study conducted by the Korean Development Institute (2017), it was found that the reservoir planning flood level should be for the frequency of 200 years in order to estimate the annual average flood damage amount and the optimal flood control amount before and after dam construction to estimate the dam size.

2. National water related policies and plans

a. National Water Resources Plan

The National Water Resources Plan has been drafted four times since the original plan in 1965 and revised thrice. The second revised version of the fourth plan created in 2011 included the establishment of a safe homeland for climate change as one of the basic goals. The plan was again revised in 2008 because the River Law was amended to incorporate measures securing national water resources as a response to climate change. This version of the plan estimated precipitation, runoff and duration of drought by considering the impact of climate change.

b. Dam design standard

The fifth Dam Design Standard was revised in 2011 as the need to improve the durability and stability of dams arises. This is in preparation for natural disasters, considering the extreme floods and droughts caused by frequent abnormal climate and earthquake cases in Japan. The amended standard specified the flood calculation process, to align with the goal of mitigating climate change effects. Estimating the flood control design is now based on the 200-year flood frequency, which also determines the spillway size.

c. Preliminary feasibility study (water resources sector)

Dam construction, one of the major projects in the water resources sector, is a large-scale and comprehensive construction project that has great impacts on the environment. When planning a dam, the feasibility of the project must be evaluated through sufficient investigation. Flood damage analysis is carried through a flood control economical survey then the amounts of flood by frequency and the amount of damage by frequency are estimated.

d. National Waterworks Plan and the Guideline for Establishing a Master Plan for the Development of Water Supply

National Waterworks Plan (2016) and the Guideline (2016) deal with the need to stabilize water supply facilities due to climate change. However, these do not cover the impacts of climate change on water demand forecasts, and water supply prospects.

e. National Climate Change Adaptation Measures

Korea has established the National Climate Change Adaptation Measures in 2008 in accordance with the Framework Act on Low Carbon, Green Growth (No. 48) and its enabling law, Enforcement Decree (No. 38), to minimize the impacts of climate change and to ensure the protection of the people and their properties.

In 2010, the First National Climate Change Adaptation Measures (2011-2015) were established. This was then revised and supplemented in 2012, giving birth to the Second National Climate Change Adaptation Measures (2016-2020) in 2015. The Second Measures is designed to establish a climate change risk assessment system through scientific climate change risk analysis for public facilities. Accordingly, the Guideline for Establishing Climate Change Adaptation Plan in Public Organizations was also created in 2016 and the Guideline for Establishing Measures to Adapt to Climate Change in Public Organizations and Tools to Support Establishment followed the year after.

3. Definition of climate change risk

Climate change risk is defined as the combination of the likelihood and magnitude of the events that will occur as a result of climate change impacts (Pearman 2008cited in Chae, 2013p.12). According to the Guideline for Establishing Measures to Adapt to Climate Change in Public Organizations and Tools to support Establishment (2017), climate change risk is the likelihood of future loss occurring from the event caused by climate change. The high climate change risk means that the likelihood of occurrence of the event is high, or the damage caused by it is big, or both.

4. Research of climate change risk assessment

Kim Suyoung, et al. (2015) selected three indicators of climate change risk in the urban area of Incheon Metropolitan City: hazard, vulnerability, and exposure based on the risk concept of the IPCC (2014) for the assessment of climate change risk. The research derived concerned areas with the hazards, multiplied by vulnerability and the degree of exposure. Then after, the research derived the climate change impact factors.

Kim, Dong Hyun (2015) applied the qualitative risk assessment techniques used in the United Kingdom’s climate change adaptation policy to the basic parts of domestic adaptation policy and suggested the implications of its establishment. The extent of the impact on the economy, the environment, and society, as well as the possibility of occurrence, and the urgency were selected as indicators of the research. Analysis results show that the increase in flood damage due to floods and typhoons is the most important risk to be managed urgently in terms of the impact level and urgency. The degree of impact of this risk is above average and urgency level is high. This means that there is an increased possibility of repetitive damage to the infrastructure due to extreme climatic events.

The Guideline for Establishing Measures to Adapt to Climate Change in Public Organizations (2017) explained the risk assessment method. The first step is to check the level of public organization's response to climate change. The next step is to calculate the risk occurrence likelihood multiplied by the magnitude of influence. After that, the risk will be assessed using a matrix to derive its ranking. The guideline suggests five types of climate impact factors: great heat, cold wave, heavy rain, heavy snow, and strong wind. Drought is one of the most important risk impact factors in water-related facilities but it is not included in the guideline.

Ⅲ. Research Methods

A. Selection of facilities to be assessed

Dams are the water facilities selected for risk assessment they are directly related to the increase in damage caused by floods and typhoons, which are the most important risks to be managed in the water sector (DH. Kim, 2015). Among the dams in Korea, this study selected three multi-purpose dams used for flood control, water supply and power generation. Out of 19 multi-purpose dams, three dams except Boryeong Dam were finally selected among Hoengseong Dam where the recent concentrated precipitation and Miryang Dam, Buan Dam and Boryeong Dam where drought was serious. Boryeong Dam, which suffered the most severe drought between 2016 and 2018, has already been focused on national measures and excluded from risk assessment.

Table 1. Multi-purpose dams in Korea

River basin	Han River basin	Nakdong River basin	Geum River basin	Seomjin River basin	Other basins
Total(19)	3	9	2	2	3
The name of the Dam	Soyanggang	Andong	Daecheong	Seomjingang	Buan*
	Chungju	Imha	Yongdam	Juam	Boryeong
	Hoengseong*	Hapcheon			Jangheung
		Namgang			
		Miryang*			
		Gunwi			
		Gimcheon Buhang			
		Seongdeok			
		Bohyeonsan			

* Selected in this paper

B. Method to assess the climate change risk

Climate change risk assessment is conducted for each dam. Climate Change Risk is assessed by estimating the likelihood of a climate impact factor multiplied wiht the extreme climate index values by the magnitude of the expected impact.

Extreme climate index values for each climate impact factor were computed using the explained below, given a value from 1 to 5.

C. Data for analysis

1. Likelihood of occurrence

a. Data source

The likelihood of occurrence is estimated using the future climate impact information for each location where the facility is located. The Korea Meteorological Administration (KMA) estimates the extreme climatic factor value based on the climate change scenarios RCP 4.5[1], RCP 8.5[2]. This study uses the value of RCP 8.5, which is more pessimistic scenario.

This research uses the data of the extreme climatic index value provided by the Guideline for Establishing Measures to Adapt to Climate Change in Public Organizations and Tools to Support Establishment for each of the RCP municipalities of the KGAWC (Korea Global Atmosphere Watch Center) of the KMA (Korea Meteorological Administration). The extreme climatic index values are days of great heat, days of freezing, days of heavy rain, days of

[1] RCP 4.5 means that the global Green House Gases (GHG) mitigation policy is realized fairly, and the extreme climate index value according to RCP 4.5 is used to solve the problem of excessive response and budget.

[2] RCP 8.5 means the emission of GHG with current trends (without mitigation) and utilizes the value of the extreme climate index by climate change factors according to RCP 8.5 for active climate change adaptation.

heavy snow, and days of strong wind. Each value uses a moving average of the climate change forecasts for a 30-year period (2021-2050).

Table 2. The extreme climatic index values

Index	**Definition**
Days of heavy rain	Number of days in a year when the daily precipitation is more than 80mm
Days of drought	Frequency of occurrence defined as extreme drought based on Standardized Precipitation Evapotranspiration Index(SPEI)
Days of great heat	Number of days in a year when the maximum daily temperature is above 33^{o}C
Days of freezing	Number of Days in a year when the minimum daily temperature is below -12^{o}C
Days of strong wind	Number of Days in a year when the maximum wind speed is more than 14m/s
Days of heavy snow	Number of Days in a year when the daily snowfall is more than 5cm

(Sources: Korea Adaptation Center for Climate Change (KACCC), Korea Environment Institute (KEI))

Days of drought will also be assessed for climate change risk because it is an important climate factor in the operation and management of water resources facilities. However, since there is no forecast data in the Guideline, the data of drought days in the K-water's research will be used. Drought values for 25-year forecast (2026-2050) were used in this study.

b. Data standardization

The value of the extreme climate index goes through a process of standardization that converts it to a value from 1 to 5.

<Standardization formula of the extreme climate index>

$$Y = 4 * \frac{X - (\text{Min value of extreme climate index values})}{(\text{Max value of extreme climate index values}) - (\text{Min value of extreme climate index values})} + 1$$

(X: Value of extreme climate index, Y: likelihood of the climate change impact factor)

c. AHP analysis for weighting values

There would be a problem despite using the standardized value of extreme climatic index value. For instance, days of heavy rain, damage of heavy rain is serious but the number of heavy rain days itself is lower than the other factors such as days of great heat. To reduce the gap between the standardized value and the actual impact value, the weight of the climate factors affecting the water facilities is estimated. After that, the weight is multiplied by the standardized value to be used as the final likelihood of occurrence. This study will survey experts to come up with the estimates and analyze the weights using the AHP (Analytic Hierarchy Process) method. The weighted values by AHP analysis are standardized again with values 1- 5.

2. Data of the expected impact magnitude

This study makes a checklist of impacts by climate impact factors. After that, the survey is carried out for each facility. The objects affected by climate impact factors are classified into facilities, facility managers, and services for citizens. Each of the three factors consist of several checklists and the magnitude of impact is calculated for each of the three. The range of the survey scores is the same as the range of the likelihood outcome value 1 to 5.

Table 3. Classification of the affected objects

Impact factors	**Checklists**
Facilities	- Main dam - Intake facilities - Power generating facilities
Facility managers	- Labor productivity - Safety of work condition
Services for citizens	- Services - Public health and property

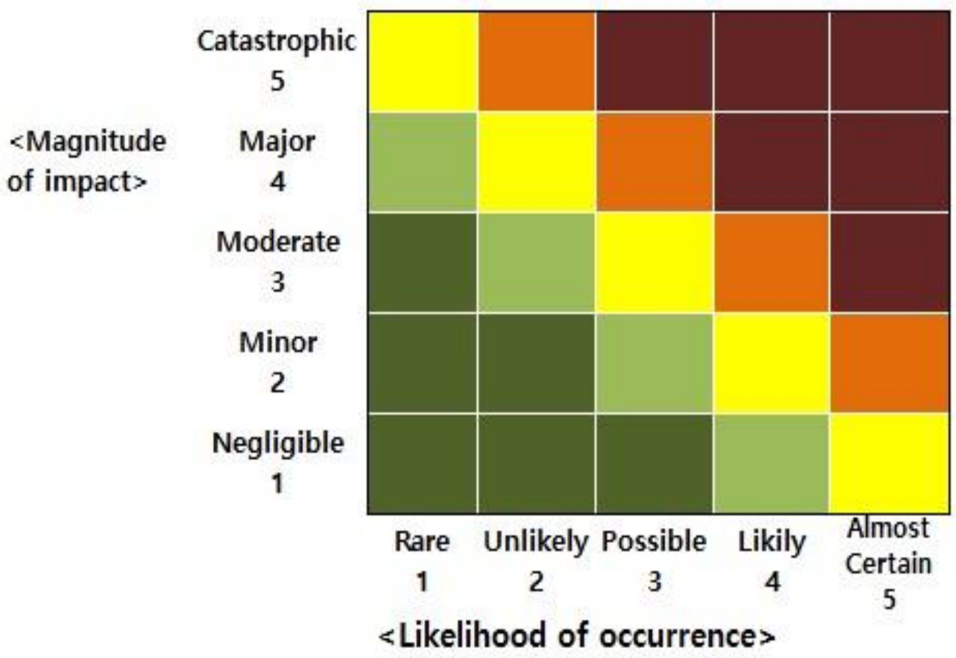
(Sources: Report on Measures to Adapt Climate Change to K-water Main Facilities)

D. Analysis of assessment results

1. Matrix analysis

The assessment results are analyzed using the climate change risk matrix. The likelihood of occurrence for each climate impact factor is on the horizontal axis and the magnitude of impact is on the vertical axis. The location on the matrix is used to analyze the response level of each climate impact factor. The value of occurrence likelihood is used as the final value by standardizing the extreme climate index value for each of the five climate impact factors. This is followed by the analysis of the AHP results and standardizing the values according to the checklist. The magnitude of impact is the average value of the items in the checklist.

Figure 1. Climate change risk matrix



(Source: The Guideline for Establishing Measures to Adapt to Climate Change in Public Organizations)

The scale of the likelihood of occurrence is shown in Table 4 and the scale of the magnitude of impact is shown in Table 5.

Table 4. Likelihood of occurrence

Measures		**explanation**
1	Rare	It can only happen in very exceptional case
2	Unlikely	Someday it can happen
3	Possible	Someday it may happen
4	Likely	It is likely happen in most situations
5	Almost certain	It will almost happen in most situations

(Source: The Guideline for Establishing Measures to Adapt to Climate Change in Public Organizations and Tools to Support Establishment (2017))

Table 5. Magnitude of impact

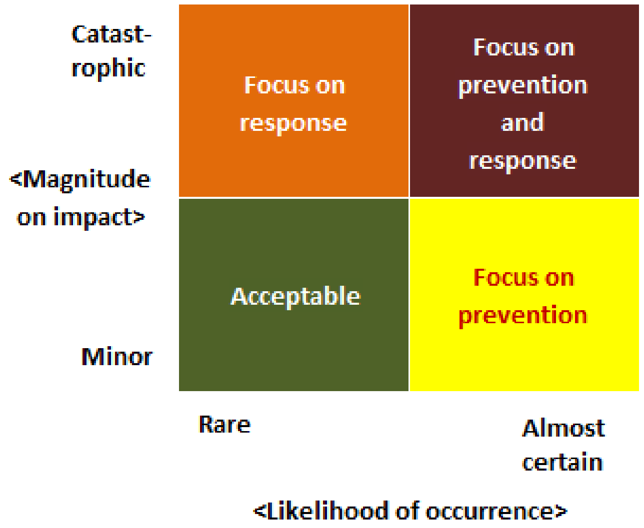
Measures		Explanation		
		Facilities	Facility managers	Services for citizens
1	Negligible	Almost no impact	Almost no impact	Almost no impact
2	minor	No impact on functionality, but need maintenance	Workers need simple medical care, and can work without difficulty	A slight impact on service delivery process, and public health and property, but does not interfere with the provision of services
3	Moderate	No impact on functionality, but some maintenance or reinforcement is necessary	Workers need simple medical care, Work environment becomes uncomfortable, and affecting daily work	Service may be provided but problems and inconveniences may arise in the process of providing services, and medium damage may occur to public health and property
4	Major	Major facilities are defective and require urgent repair	Difficulty in carrying out major work due to serious injury of workers and safety threat of work environment	Some restriction on the provision of services and significant damage to public health and property
5	Catastrophic	Immediately prohibit the use of facilities and reinforce or reconstruct	Impossible to work or die	Service cannot be provided at all, and causes severe damage to public health and property

(Source: Report on Measures to Adapt Climate Change to K-water Main Facilities revised)

2. Interpretation of the results

The risk score is computed by estimating the likelihood of occurrence and the magnitude of impact. Larger risk score means greater risk of climate change. The response will be determined according to the score’s position in the matrix and the response level is divided into the following 4 categories: acceptable, focus on prevention, focus on response, focus on prevention and response.

Figure 2. The response level according to climate change risk assessment



(Source: The Guideline (2017)

Adaptation measures according to the level of response for each of the four categories are detailed in Table 6.

Table 6. Adaptation measures according to the response level

Categories	**Adaptation measures**
Focus on prevention and response	High priority climate change risk requires active prevention and response activities
Focus on response	Establish response measures based on the likelihood of occurrence
Focus on prevention	Develop preventive activities to reduce the likelihood of occurrence
Adaptable	Minimal monitoring to prevent transitions to other climate change risks

Source: The Guideline (2017))

E. Suggest implications for establishing water resources facilities management plan

After the results are obtained, this study would suggest implications for establishing a specific adaptation plan for each facility such as dam reinforcement based on the level of response, advancement of the management of water reserve rates, etc.

Ⅳ. Results

A. Survey and analysis overview

1. Likelihood of occurrence

The likelihood of occurrence was calculated by standardizing the extreme climate values provided by the ME. These values were multiplied by the weighted values of the AHP analysis based on the survey of 10 experts who have been working in dam sector in K-water for more than 10 years. The standardized values were calculated afterwards.

2. Expected impact magnitude

This study surveyed 36 staff members, who have experiences in the management of K-water's dam facilities, to measure the impact of six extreme climate factors on three dams.

Table 7. The checklist items of the survey

Impact factor / Extreme climate	Facilities	Facilities managers	Service for citizens
Heavy rain	Main Dam, intake facilities, power generating facilities	Labor productivity, safety of work condition	Service
Drought	"	Labor productivity	"
Great heat	"	Labor productivity, safety of work condition	"
Freezing	"	"	-
Strong wind	"	"	-
Heavy snow	"	"	-

(Source: Report on Measures to Adapt Climate Change to K-water Main Facilities revised)

3. Climate change risk

Climate change risks were assessed by multiplying the final values of likelihood of occurrence by the values of the expected impact magnitude.

B. Analysis of risk assessment results of each three dams

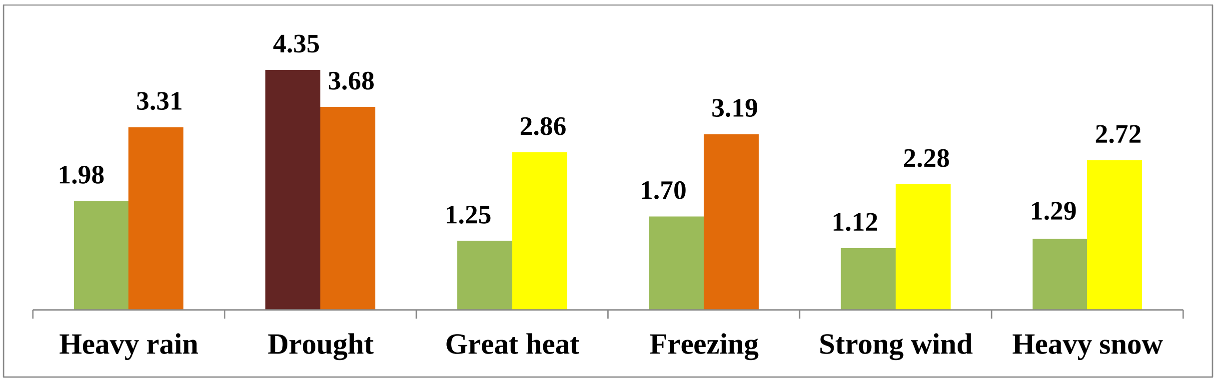
1. Hoengseong Dam

Table 8. Results of climate change risk score calculation of Hoengseong Dam

Extreme climate	Impact factors	Checklist		Likelihood of occurrence	Expected impact magnitude	Total Risk
A. Heavy rain	a. Facilities	a-1. Main Dam	A-a-1	2.01	3.25	6.53
		a-2. Intake facilities	A-a-2	2.01	3.00	6.03
		a-3. Power generating facilities	A-a-3	2.01	2.33	4.69
	b. Facility managers	b-1. Labor productivity	A-b-1	2.02	3.50	7.07
		b-2. Safety of work condition	A-b-2	2.02	3.50	7.07
	c. Service for citizens	c-1. Service	A-c-1	1.90	3.58	6.81
B. Drought	a. Facilities	a-1. Main Dam	B-a-1	4.05	3.79	15.34
		a-2. Intake facilities	B-a-2	4.05	3.50	14.16
		a-3. Power generating facilities	B-a-3	4.05	3.58	14.50
	b. Facility managers	b-1. Labor productivity	B-b-1	4.01	3.67	14.71
	c. Service for citizens	c-1. Service	B-c-1	5.00	3.75	18.75
C. Great heat	a. Facilities	a-1. Main Dam	C-a-1	1.15	2.42	2.79
		a-2. Intake facilities	C-a-2	1.15	2.92	3.36
		a-3. Power generating facilities	C-a-3	1.15	2.42	2.79
	b. Facility managers	b-1. Labor productivity	C-b-1	1.20	2.89	3.45
		b-2. Safety of work condition	C-b-2	1.20	2.92	3.49
	c. Service for citizens	c-1. Service	C-c-1	1.41	3.08	4.34
D. Freezing	a. Facilities	a-1. Main Dam	D-a-1	1.62	2.42	3.91
		a-2. Intake facilities	D-a-2	1.62	3.42	5.53
		a-3. Power generating facilities	D-a-3	1.62	3.00	4.86
	b. Facility managers	b-1. Labor productivity	D-b-1	1.77	3.36	5.96
		b-2. Safety of work condition	D-b-2	1.77	3.50	6.21
E. Strong wind	a. Facilities	a-1. Main Dam	E-a-1	1.24	2.00	2.48
		a-2. Intake facilities	E-a-2	1.24	2.17	2.69
		a-3. Power generating facilities	E-a-3	1.24	1.75	2.17
	b. Facility managers	b-1. Labor productivity	E-b-1	1.00	2.50	2.50
		b-2. Safety of work condition	E-b-2	1.00	2.67	2.67
F. Heavy snow	a. Facilities	a-1. Main Dam	F-a-1	1.09	2.33	2.55
		a-2. Intake facilities	F-a-2	1.09	2.58	2.83
		a-3. Power generating facilities	F-a-3	1.09	2.25	2.46
	b. Facility managers	b-1. Labor productivity	F-b-1	1.48	3.00	4.43
		b-2. Safety of work condition	F-b-2	1.48	3.08	4.55

In the Hoengseong Dam, drought is predicted to be the largest and catastrophic in the likelihood of occurrence with a score of 4.35. This is followed by heavy rain. The third risk is freezing due to the local characteristics of the dam, followed by heavy snow, great heat and strong wind. The magnitude of impact is largest in drought with 3.68, followed by heavy rain with 3.31. Freezing is reached more than 3 because of the of the colder temperature in the northern part of the country. Great heat, strong wind, heavy snow came after, respectively.

Figure 3. Likelihood of occurrence (L) and magnitude of impact (R) of Hoengseong Dam



	Rare, Negligible (x<1)		Unlikely, Minor (1<x≤2)		Possible, Moderate (2<x≤3)		Likely, Major (3<x≤4)		Almost certain, Catastrophic (x>4)

The climate change risk is measured to be the largest for drought. Heavy rain, freezing, great heat, heavy snow, strong wind had significantly lower levels of risk.

Figure 4. Climate change risk by climate impact factor of Hoengseong Dam

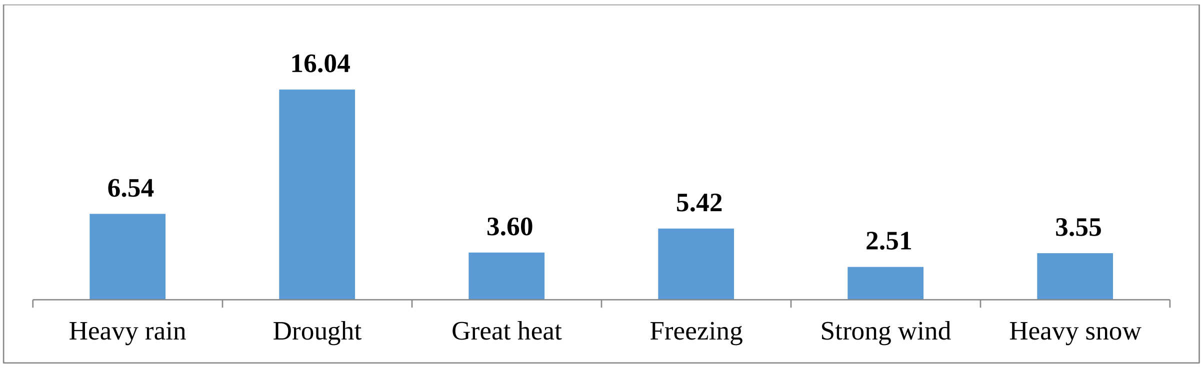
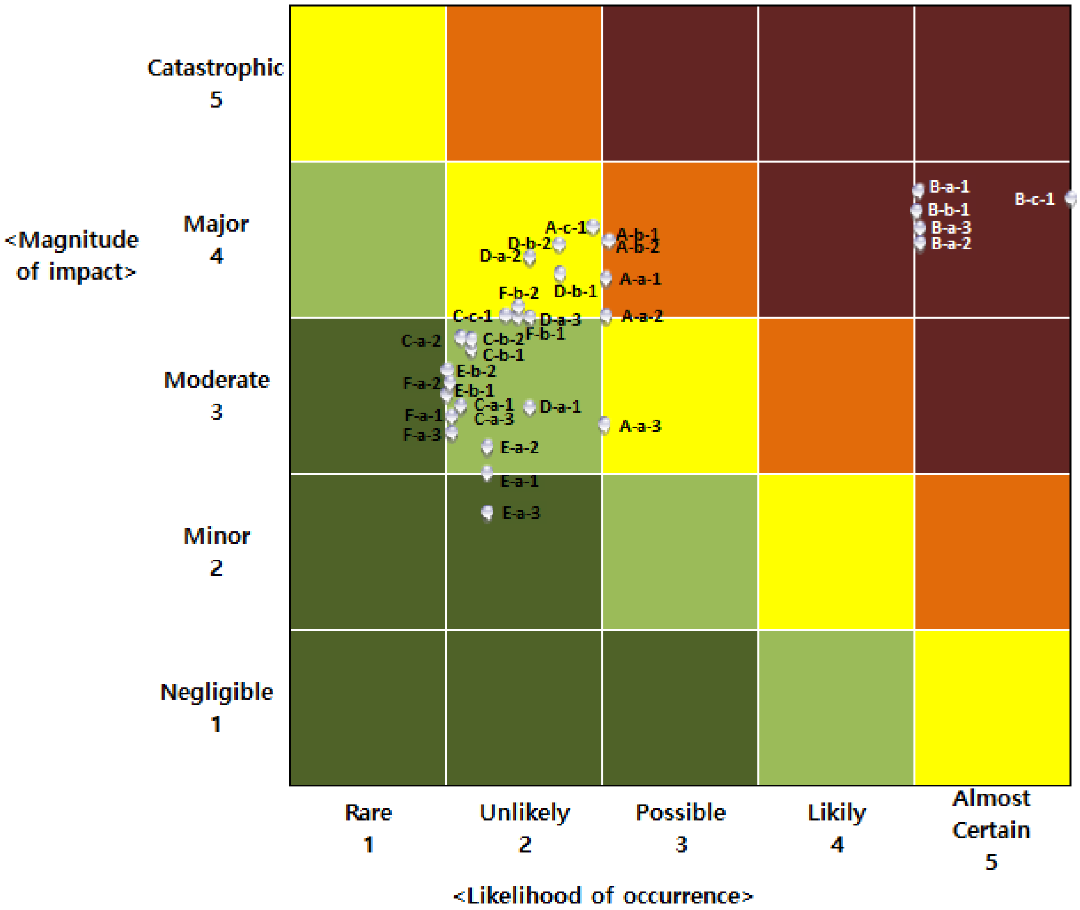


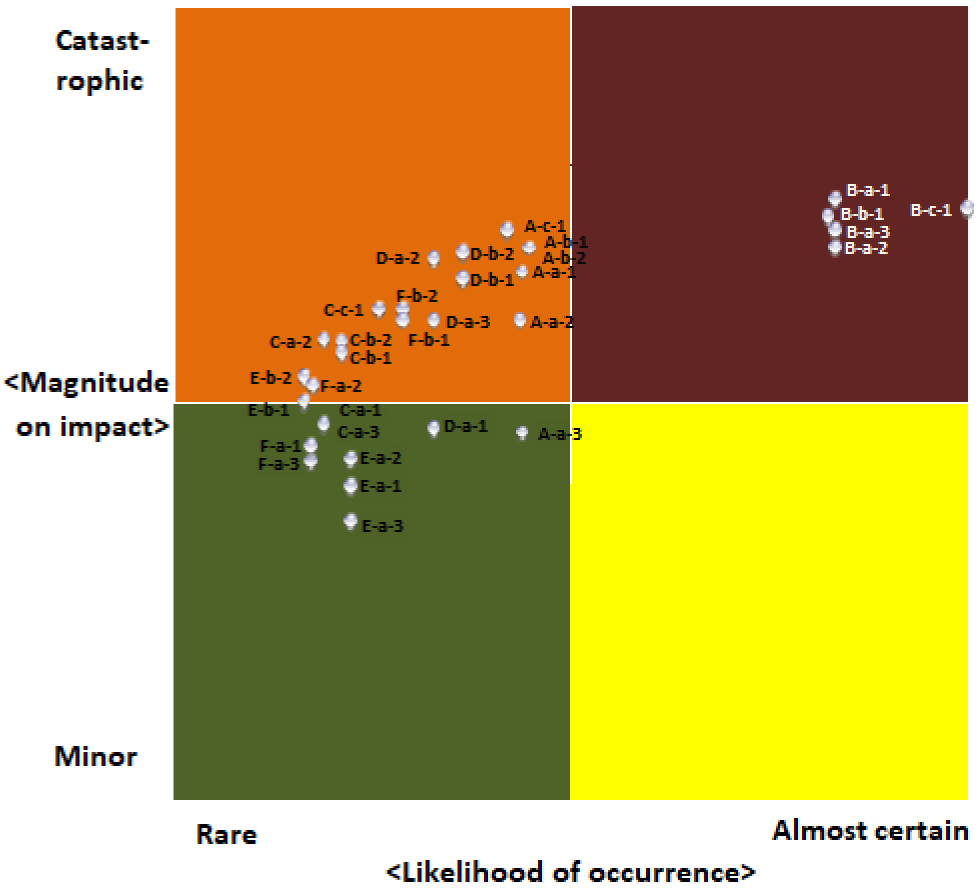
Figure 5. Matrix of climate change risk assessment of the Hoengseong Dam



A: Heavy rain, B: Drought, C: Great heat, D: Freezing, E: Strong wind, F: Heavy snow	
a: Facilities	1: Main Dam, 2: Intake facilities, 3: Power generating facilities
b: Facility managers	1: Labor productivity, 2: Safety of work condition
c: Service for citizens	1: Service
Very safe, Safe, Moderate, Dangerous, Very dangerous	

Drought is evaluated as very dangerous. Among the items in the heavy rain checklist, service for citizens was determined to be the most dangerous. Most of heavy rain falls in the dangerous grade except for power generating facilities and service for citizens. Freezing got a moderate grade while great heat, strong wind and heavy snow were found be at either safe or very safe levels.

Figure 6. Results of climate change risk matrix analysis of Hoengseong Dam



<table>
<tr><td colspan="8">A: Heavy rain, B: Drought, C: Great heat, D: Freezing, E: Strong wind, F: Heavy snow</td></tr>
<tr><td colspan="2">a: Facilities</td><td colspan="6">1: Main Dam, 2: Intake facilities, 3: Power generating facilities</td></tr>
<tr><td colspan="2">b: Facility managers</td><td colspan="6">1: Labor productivity, 2: Safety of work condition</td></tr>
<tr><td colspan="2">c: Service for citizens</td><td colspan="6">1: Service</td></tr>
<tr><td></td><td>Acceptable</td><td></td><td>Focus on prevention</td><td></td><td>Focus on response</td><td></td><td>Focus on prevention and response</td></tr>
</table>

The Hoengseong Dam needs to focus on prevention and response against drought risks in all aspect of facilities, facility managers, and service for citizens. Other five extreme climate events such as heavy rain, great heat, freezing, strong wind, and heavy snow require climate change adaptation measures focusing on response or the risks are evaluated as acceptable.

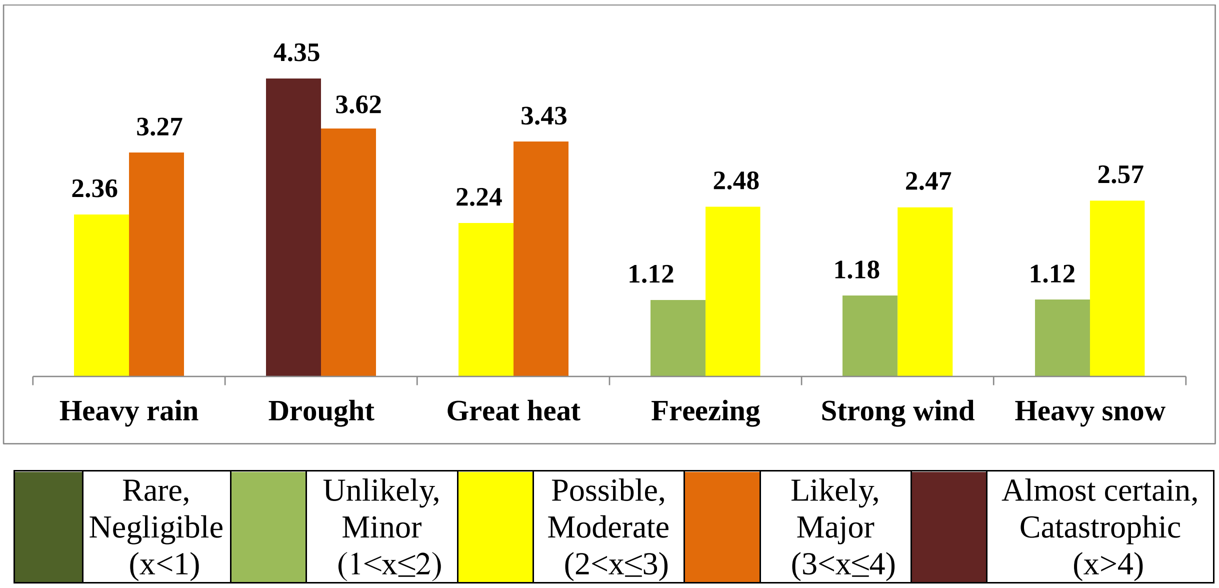
2. Miryang Dam

Table 9. Results of climate change risk score calculation of Miryang Dam

Extreme climate	Impact factors	Checklist		Likelihood of occurrence	Expected impact magnitude	Total Risk
A. Heavy rain	a. Facilities	a-1. Main Dam	A-a-1	2.41	3.08	7.43
		a-2. Intake facilities	A-a-2	2.41	3.04	7.33
		a-3. Power generating facilities	A-a-3	2.41	2.33	5.62
	b. Facility managers	b-1. Labor productivity	A-b-1	2.42	3.33	8.08
		b-2. Safety of work condition	A-b-2	2.42	3.42	8.29
	c. Service for citizens	c-1. Service	A-c-1	2.26	3.60	8.15
B. Drought	a. Facilities	a-1. Main Dam	B-a-1	4.04	3.67	14.83
		a-2. Intake facilities	B-a-2	4.04	3.33	13.48
		a-3. Power generating facilities	B-a-3	4.04	3.58	14.49
	b. Facility managers	b-1. Labor productivity	B-b-1	4.01	3.58	14.37
	c. Service for citizens	c-1. Service	B-c-1	5.00	3.75	18.75
C. Great heat	a. Facilities	a-1. Main Dam	C-a-1	1.87	2.92	5.46
		a-2. Intake facilities	C-a-2	1.87	3.67	6.87
		a-3. Power generating facilities	C-a-3	1.87	2.75	5.15
	b. Facility managers	b-1. Labor productivity	C-b-1	2.03	3.50	7.10
		b-2. Safety of work condition	C-b-2	2.03	3.50	7.10
	c. Service for citizens	c-1. Service	C-c-1	2.82	3.67	10.33
D. Freezing	a. Facilities	a-1. Main Dam	D-a-1	1.09	2.00	2.18
		a-2. Intake facilities	D-a-2	1.09	2.50	2.73
		a-3. Power generating facilities	D-a-3	1.09	2.25	2.46
	b. Facility managers	b-1. Labor productivity	D-b-1	1.14	2.58	2.94
		b-2. Safety of work condition	D-b-2	1.14	2.83	3.23
E. Strong wind	a. Facilities	a-1. Main Dam	E-a-1	1.33	2.08	2.78
		a-2. Intake facilities	E-a-2	1.33	2.25	3.00
		a-3. Power generating facilities	E-a-3	1.33	1.75	2.34
	b. Facility managers	b-1. Labor productivity	E-b-1	1.02	2.75	2.81
		b-2. Safety of work condition	E-b-2	1.02	3.08	3.15
F. Heavy snow	a. Facilities	a-1. Main Dam	F-a-1	1.00	2.29	2.29
		a-2. Intake facilities	F-a-2	1.00	2.50	2.50
		a-3. Power generating facilities	F-a-3	1.00	2.25	2.25
	b. Facility managers	b-1. Labor productivity	F-b-1	1.24	2.67	3.30
		b-2. Safety of work condition	F-b-2	1.24	2.92	3.61

Drought was found most likely to occur in theMiryang Dam. This is followed by heavy rain and great heat. The remaining risks – strong wind, freezing, and heavy snow – are less likely to occur. The magnitude of impact is the largest in drought, and the second largest is great heat unlike in the Hoengseong Dam. Heavy snow, freezing, and strong wind recorded lower scores and was assessed to have unlikely minor impact.

Figure 7. Likelihood of occurrence (L) and magnitude of impact (R) of Miryang Dam



Drought has the largest estimated climate change risk. The succeeding risk priority is great heat, heavy rain, heavy snow, strong wind, and freezing, respectively.

Figure 8. Climate change risk by climate impact factor of Miryang Dam

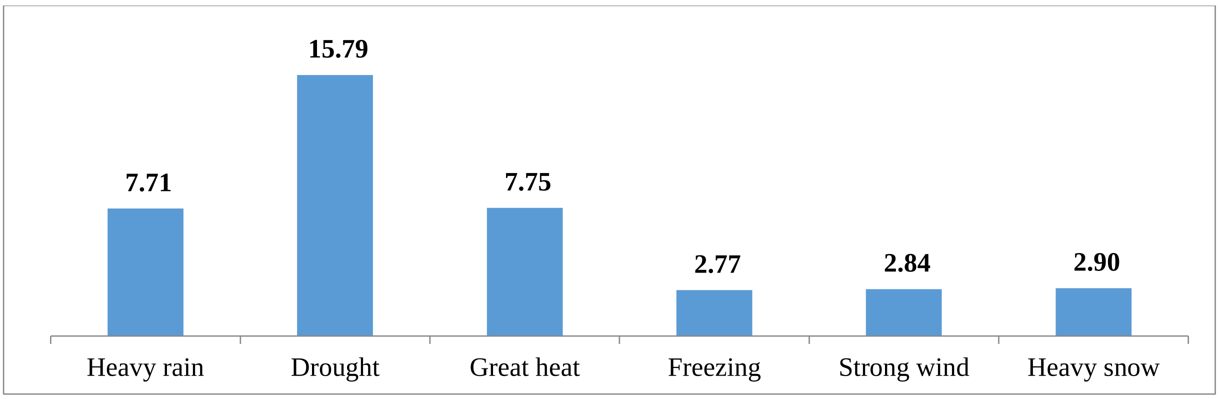
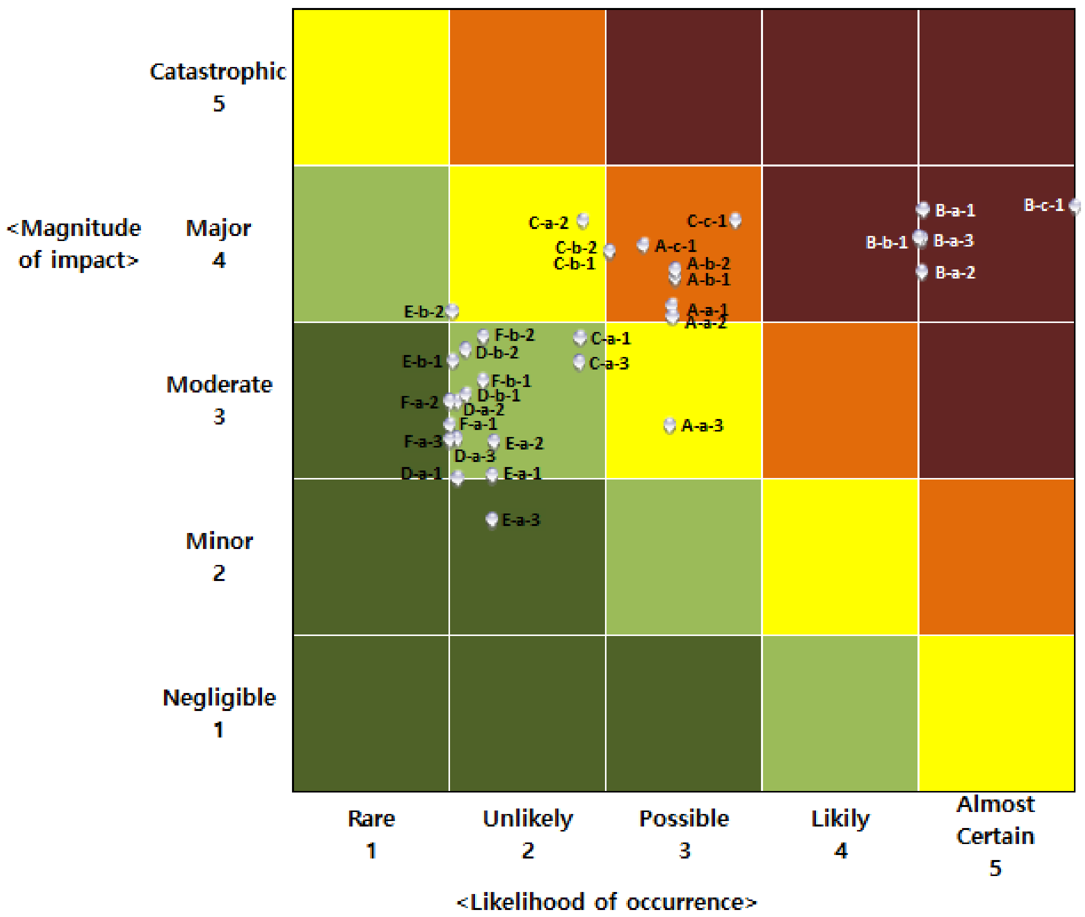


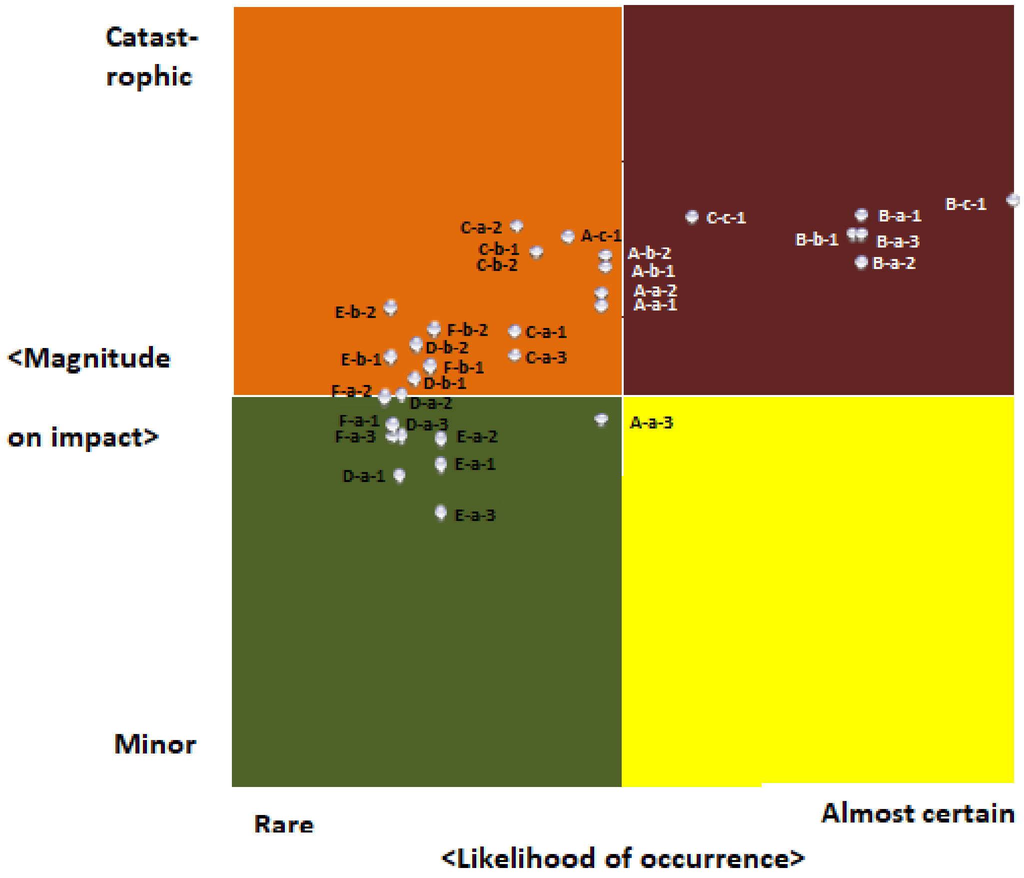
Figure 9. Matrix of climate change risk assessment of Miryang Dam



A: Heavy rain, B: Drought, C: Great heat, D: Freezing, E: Strong wind, F: Heavy snow	
a: Facilities	1: Main Dam, 2: Intake facilities, 3: Power generating facilities
b: Facility managers	1: Labor productivity, 2: Safety of work condition
c: Service for citizens	1: Service
Very safe, Safe, Moderate, Dangerous, Very dangerous	

As in the Hoengseong Dam, drought in the Miryang Dam was also predictedto be very dangerous. Most of the items in the heavy rain checklist fell in the dangerous grade, except for power generating facilities. For thegreat heat checklist, service was assessed to be at the dangerous grade. Most of other climate impact factors such as freezing, strong wind and heavy snow were at the safe grade.

Figure 10. Results of climate change risk matrix analysis of Miryang Dam



A: Heavy rain, B: Drought, C: Great heat, D: Freezing, E: Strong wind, F: Heavy snow							
a: Facilities	1: Main Dam, 2: Intake facilities, 3: Power generating facilities						
b: Facility managers	1: Labor productivity, 2: Safety of work condition						
c: Service for citizens	1: Service						
(green)	Acceptable	(yellow)	Focus on prevention	(orange)	Focus on response	(dark red)	Focus on prevention and response

The Miryang Dam needs to focus on prevention and response against drought risks in all aspects of facilities, facility managers, and service for citizens. Service for citizens for great heat risk is also the same. Although the likelihood of occurrence of heavy rain is low, the magnitude of impact on all aspects except power generating facilities is large, so adaptation measures against heavy rain need to focus on response. Adaptation for great heat should be the same with heavy rain.

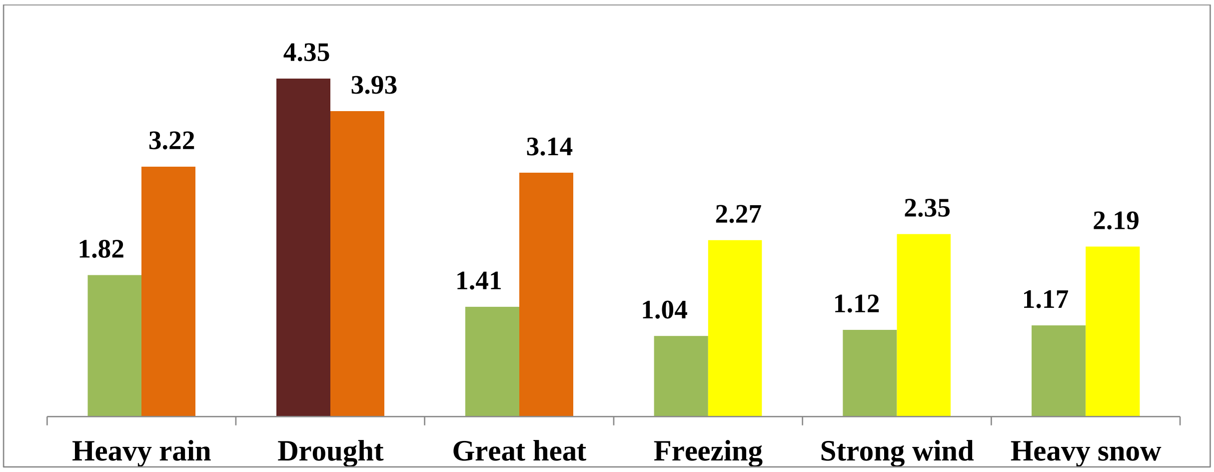
3. Buan Dam

Table 10. Results of climate change risk score calculation of Buan Dam

Extreme climate	Impact factors	Checklist		Likelihood of occurrence	Expected impact magnitude	Total Risk
A. Heavy rain	a. Facilities	a-1. Main Dam	A-a-1	1.85	3.03	5.60
		a-2. Intake facilities	A-a-2	1.85	2.96	5.47
		a-3. Power generating facilities	A-a-3	1.85	2.17	4.01
	b. Facility managers	b-1. Labor productivity	A-b-1	1.86	3.46	6.43
		b-2. Safety of work condition	A-b-2	1.86	3.42	6.35
	c. Service for citizens	c-1. Service	A-c-1	1.76	3.50	6.15
B. Drought	a. Facilities	a-1. Main Dam	B-a-1	4.05	4.17	16.86
		a-2. Intake facilities	B-a-2	4.05	3.83	15.51
		a-3. Power generating facilities	B-a-3	4.05	3.83	15.51
	b. Facility managers	b-1. Labor productivity	B-b-1	4.01	3.88	15.55
	c. Service for citizens	c-1. Service	B-c-1	5.00	3.98	19.90
C. Great heat	a. Facilities	a-1. Main Dam	C-a-1	1.27	2.75	3.50
		a-2. Intake facilities	C-a-2	1.27	3.33	4.24
		a-3. Power generating facilities	C-a-3	1.27	2.67	3.39
	b. Facility managers	b-1. Labor productivity	C-b-1	1.33	3.17	4.22
		b-2. Safety of work condition	C-b-2	1.33	3.17	4.22
	c. Service for citizens	c-1. Service	C-c-1	1.64	3.33	5.46
D. Freezing	a. Facilities	a-1. Main Dam	D-a-1	1.02	1.88	1.92
		a-2. Intake facilities	D-a-2	1.02	2.33	2.39
		a-3. Power generating facilities	D-a-3	1.02	2.00	2.05
	b. Facility managers	b-1. Labor productivity	D-b-1	1.05	2.36	2.49
		b-2. Safety of work condition	D-b-2	1.05	2.58	2.72
E. Strong wind	a. Facilities	a-1. Main Dam	E-a-1	1.24	2.08	2.57
		a-2. Intake facilities	E-a-2	1.24	2.17	2.68
		a-3. Power generating facilities	E-a-3	1.24	2.00	2.47
	b. Facility managers	b-1. Labor productivity	E-b-1	1.00	2.42	2.42
		b-2. Safety of work condition	E-b-2	1.00	2.82	2.82
F. Heavy snow	a. Facilities	a-1. Main Dam	F-a-1	1.04	2.08	2.16
		a-2. Intake facilities	F-a-2	1.04	2.08	2.16
		a-3. Power generating facilities	F-a-3	1.04	1.83	1.90
	b. Facility managers	b-1. Labor productivity	F-b-1	1.31	2.17	2.84
		b-2. Safety of work condition	F-b-2	1.31	2.58	3.39

As with the other two dams, the Buan Dam, drought was also found to have the highest likelihood of occurrence with a score of 4.35. Likelihoods of occurrence of other event are lower than 2. The magnitude of impact is also the highest in drought, followed by heavy rain, great heat, strong wind, heavy snow, and freezing.

Figure 11. Likelihood of occurrence (L) and magnitude of impact (R) of Buan Dam



	Rare, Negligible (x<1)		Unlikely, Minor (1<x≤2)		Possible, Moderate (2<x≤3)		Likely, Major (3<x≤4)		Almost certain, Catastrophic (x>4)

Climate change risk is estimated to be the largest of drought. The risk priority order is as follows: drought, heavy rain, great heat, strong wind, heavy snow, and freezing.

Figure 12. Climate change risk by climate impact factor of Buan Dam

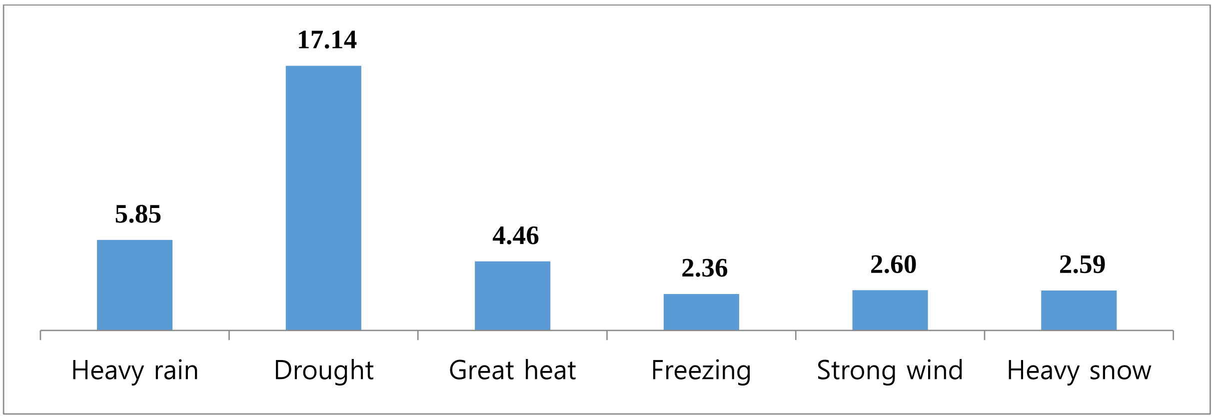
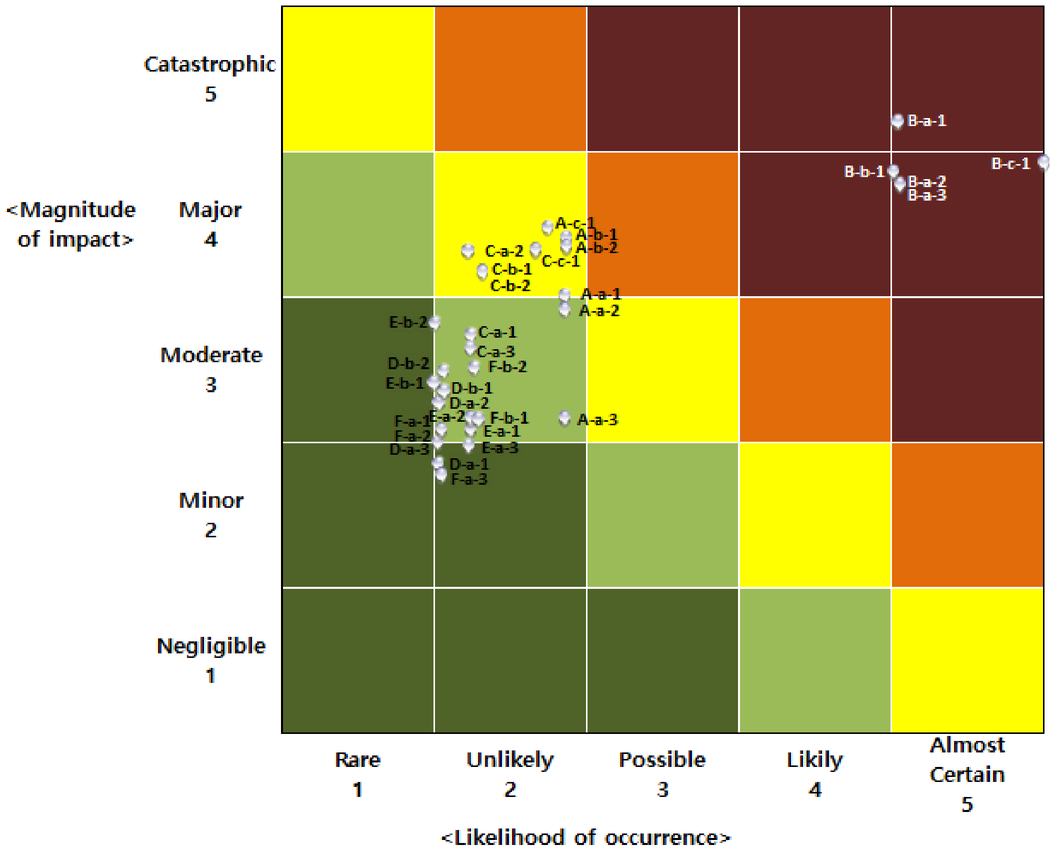


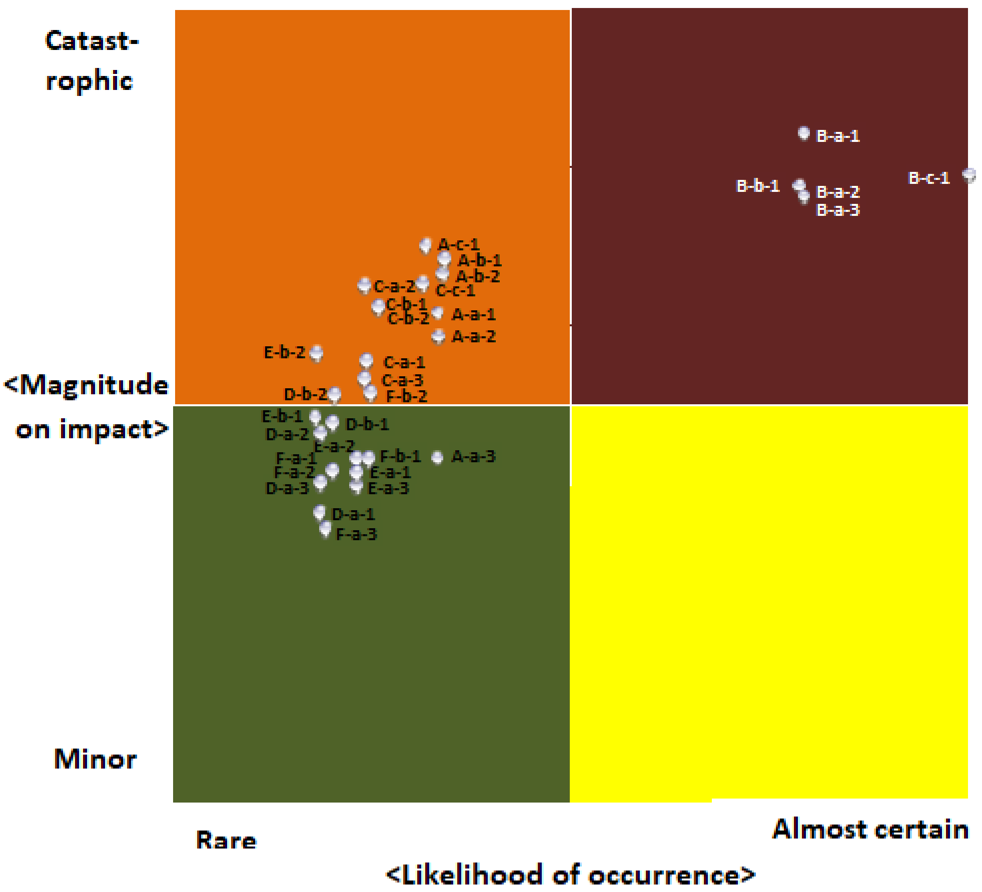
Figure 13. Matrix of climate change risk assessment of Buan Dam



A: Heavy rain, B: Drought, C: Great heat, D: Freezing, E: Strong wind, F: Heavy snow	
a: Facilities	1: Main Dam, 2: Intake facilities, 3: Power generating facilities
b: Facility managers	1: Labor productivity, 2: Safety of work condition
c: Service for citizens	1: Service
Very safe, Safe, Moderate, Dangerous, Very dangerous	

In the Buan Dam, drought is evaluated to be very dangerous. Among the items in the drought checklist, service shows almost certain in likelihood of occurrence and major in magnitude of impact. Unlike the two dams, there is no dangerous grade recorded for this one. For the heavy rain, main dam of facilities, facility managers, and service for citizen had a moderate grade. For the great heat checklist, intake facilities facility managers and service for citizen also received a moderate grade

Figure 14. Results of climate change risk matrix analysis of Buan Dam



A: Heavy rain, B: Drought, C: Great heat, D: Freezing, E: Strong wind, F: Heavy snow							
a: Facilities	1: Main Dam, 2: Intake facilities, 3: Power generating facilities						
b: Facility managers	1: Labor productivity, 2: Safety of work condition						
c: Service for citizens	1: Service						
	Acceptable		Focus on prevention		Focus on response		Focus on prevention and response

Similar to the Hoengseong Dam and the Miryang Dam, the Buan Dam also needs adaptation measures focused on prevention and response for all facilities, facility managers, and service for citizens for drought risk. For heavy rain, all checklist items except power generating facilities, it is necessary to focus on response. The same results turned out for great heat.

C. Summary of results of the climate change risk assessment

As a result of averaging the risk values for each climate impact factor of three dams, the drought is found to be the highest in terms of the likelihood of occurrence and the expected impact magnitude, followed by heavy rain, great heat, freezing, heavy snow, and strong wind.

Table 11. Risk value for each climate impact factor of three dams

	Hoengseong Dam			Miryang Dam			Buan Dam		
	LOO	EIM	CCRV	LOO	EIM	CCRV	LOO	EIM	CCRV
Heavy rain	1.98	3.31	6.54	2.36	3.27	7.71	1.82	3.22	5.85
Drought	4.35	3.68	16.04	4.35	3.62	15.79	4.35	3.93	17.14
Great heat	1.25	2.86	3.60	2.24	3.43	7.75	1.41	3.14	4.46
Freezing	1.70	3.19	5.42	1.12	2.48	2.77	1.04	2.27	2.36
Strong wind	1.12	2.28	2.51	1.18	2.47	2.84	1.12	2.35	2.60
Heavy snow	1.29	2.72	3.55	1.12	2.57	2.90	1.17	2.19	2.59
LOO: Likelihoods of occurrence EIM: Expected impact magnitude CCRV: Climate Change Risk Value = LOO * EIM									

The risk of heavy rain of three dams recorded the highest in the Miryang Dam, followed by the Hoengseong Dam and then the Buan Dam. Drought risk is highest in the Buan Dam, which recently suffered drought. It was followed by the Hoengseong Dam and the Miryang Dam, as shown in Figure 4. The risk of great heat is the highest in the Miryang Dam and the lowest in Hoengseong Dam, which islocated in the northernmost region. On the other hand, the freezing risk is the highest in the Hoengseong Dam and lowest in the Buan Dam, as shown in Figure 5.

Figure 15. Risk value of heavy rain (L) and drought (R)

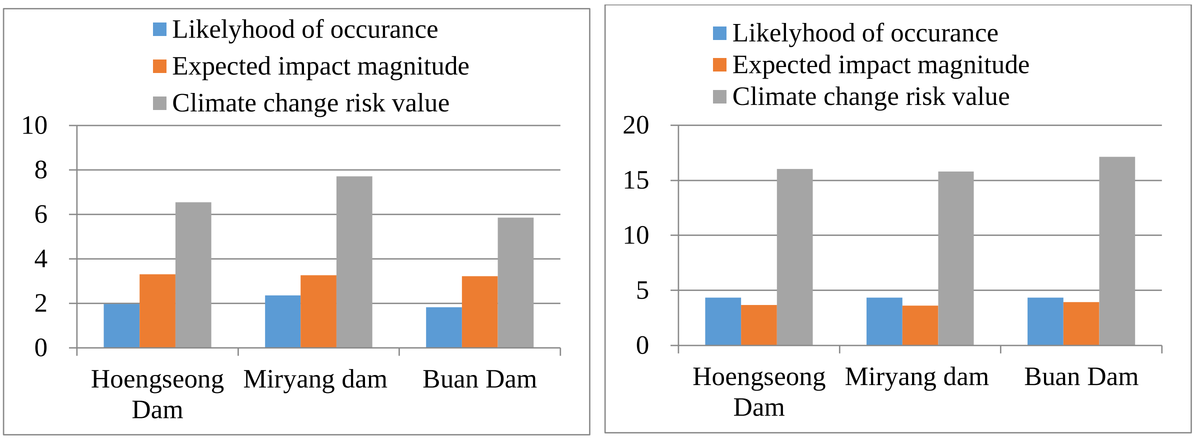
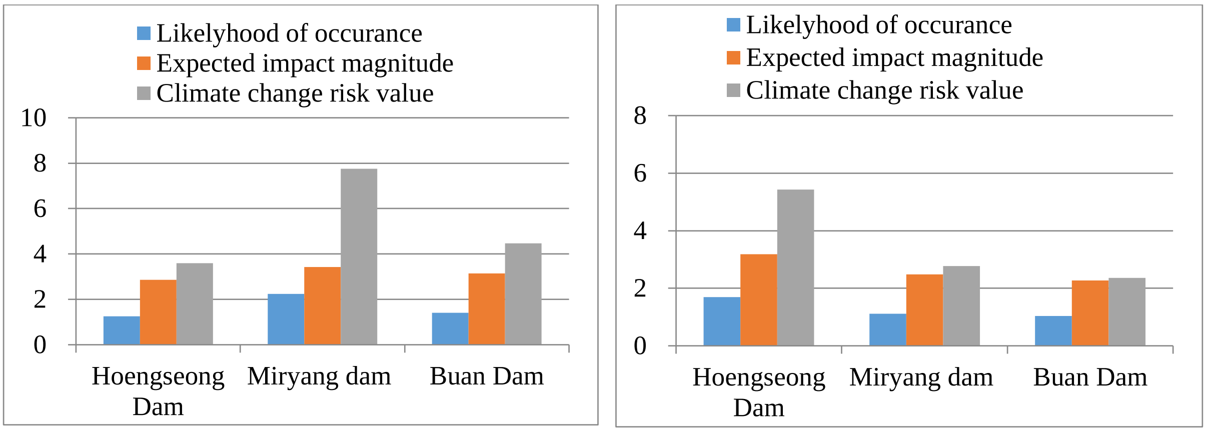
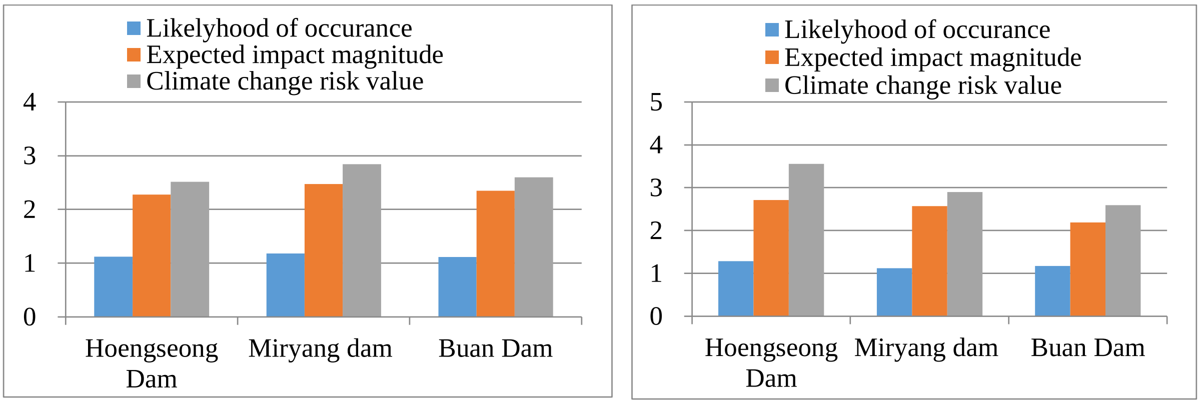


Figure 16. Risk value of great heat (L) and freezing (R)



The risk of strong wind is highest in the Miryang Dam, followed by the Buan Dam and the Hoengseong Dam. The risk of heavy snow is highest in the Hoengseong Dam, which is located in Gangwon Province. The Miryang Dam and the Buan Dam follows.

Figure 17. Risk value of strong wind (L) and heavy snow (R)



Drought had the highest likelihood of occurrence and high magnitude of impact score as the matrix analysis of all the three dams showed it is very dangerous for facilities, facility managers, and service for citizens. Therefor prevention and response adaptation approach is necessary for adaptation measure against drought.

Heavy rain was rated as the second highest risk. Although the likelihood of occurrence of heavy rain is low, the magnitude of impact score is as high with a score of three or more in all the dams. The matrix analysis found that heavy rain is moderate or dangerous to the main dam, intake facilities, facility managers and service for citizens, except for power generating facilities. Therefore, measure that focused on response is more appropriate than prevention against heavy rain.

Great heat was found to be very dangerous in terms of service to citizen for the Miryang Dam. An adaptation policy focused on prevention and response was assessed to be the appropriate measure. The other items in the checklists for the Miryang Dam and the other two dams were analyzed to be of higher risk and the measure focused on response is more appreciate.

The other three climate impact factors such as freezing, strong wind, and heavy snow had a moderate risk level in terms of safety of work condition of all dams, labor productivity of some dams, and intake facilities. An adaptation-focused response was suggested after the analysis.

The rest of the checklist items of freezing, strong wind, and heavy snow showed to be either safe or very safe and do not require prevention or response measures because the risks are at an acceptable level.

Table 12. Overall results of climate change risk assessment

	Focus on prevention and response	**Focus on response**
(Likelihood of occurrence)	(Almost certain/likely)	(Unlikely/possible)
(Magnitude of impact)	(Catastrophic/major)	(Catastrophic/major)
Drought	- Hoengseong Dam, Miryang Dam, Buan Dam: all facilities, Labor productivity, Safety of work condition, service	
Heavy rain		- Hoengseong Dam, , Miryang Dam, Buan Dam: Intake facilities , labor productivity, safety of work condition, service - Miryang Dam: labor productivity, safety of work condition - Buan Dam: safety of work condition
Great heat	- Miryang Dam: service	- Hoengseong Dam: intake facilities , labor productivity, safety of work condition, service - Miryang Dam: all facilities, labor productivity, safety of work condition - Buan Dam: all facilities, labor productivity, safety of work condition, service
Freezing		- Hoengseong Dam: intake facilities , labor productivity, safety of work condition - Miryang Dam: labor productivity, safety of work condition - Buan Dam: safety of work condition
Strong wind		- Hoengseong Dam: safety of work condition - Miryang Dam: labor productivity, safety of work condition - Buan Dam: safety of work condition
Heavy snow		- Hoengseong Dam: intake facilities, labor productivity, safety of work condition - Miryang Dam: labor productivity, safety of work condition - Buan Dam: safety of work condition

(Acceptable: excluded as not urgent, focus on prevention: excluded as there is nothing)

Ⅴ. Conclusion and policy suggestion

According to the results of the climate change risk assessment, risk varies from time to time and for every specific location. Total risk score of drought for all three dams ranged from 13.48 to 19.90. Other than that, there is no total risk of more than 10 among the six climate impact factors except for Miryang Dam, the score 10.33 of service for citizen of great heat. Among the total risk of 96 items, the 32 checklist items per one dam, the lowest total risk are from Buan Dam. The total risk score of main dam of freezing is 1.92 and the total risk score of power generation facilities of heavy snow is 1.90.

As above, for all three dams, drought turned out to be the highest risk, which is very risky to facilities, facility managers, and services for citizens. Prevention and response-based adaptation measures are needed for this climate change risk. Drought affects water quality and power generation becomes limited. Ultimately, it stops the supply of clean water, causing great danger to the people. Results indicate that drought has persisted in the southern part of Korea. The Boryeong Dam has reached the limited water level and reduced water supply and this situation is likely to continue in the future, and the impact of water supply disruption will be large. Both prevention and response policies are essential.

In the case of heavy rain, the likelihood of occurrence is relatively low but the magnitude of impact is large. The magnitude of impacts score of heavy rain is higher than 3.0 in all three dams except for power generation facilities. Unlike the drought, which causes gradual damage over a long period of time until the drought is resolved, floods cause serious damage in a short period of time. Therefore, respond focused adaptation measures are needed.

In order to adapt to climate change, it will be difficult to build new dams. Existing dams should be able to adapt to climate change. It is then necessary to unify the actual water management by optimizing their flood and drought control capacity. This can be enhanced by linking the dam operations and by reinforcing the capacity of reservoirs that can be used for flood control in surrounding agricultural reservoirs.

Climate change adaptation measures in the checklists for the dams should enhance their productivity and safety of facility managers. The measures should be designed to provide uninterrupted water supply, prevent water related disasters in the surrounding areas, and provide safe and sustainable supply of clean water through improved water quality.

Implementation of climate change adaptation measures for dams can be ensured by adopting the results of this study. In addition to establishing adaptation measures, continuous monitoring and review of changes in climate change risk status should be conducted as part of risk management.

BIBLIOGRAPHY

Bae, Deg-Hyo. 2009. Climate change impact assessment and adaptation strategy on water resources. *Planning and Policy*, 333, 34-45.

IPCC. 2014. Climate change 2014: Impacts, adaptation, and vulnerability. IPCC WGⅡ.

Kim, Cho-Rong, et al. 2013. Water balance projection using climate change scenarios in the Korean peninsula. *Journal of Korea Water Resources Association*, 46(8), 807-819.

Kim, Dong Hyun. 2015. Risk sssessment and classification for climate change adaption: application on the method of climate change risk assessment in the UK. *Journal of Environmental Policy Research*, 14(1), 53-83.

Kim, Nam-Sung, et al. 2015. Hydrologic risk analysis based on extreme drought over the Korean peninsula under climate change. *Journal of Korean Society of Hazard Mitigation*, 15(4), 45-52.

Kim, Suyoung, CS. Park and BS. Byun. 2015. Urban management strategies based on climate change risk assessment. *The Geographical Journal of Korea*, 49(4), 479-490.

Kore Development Institute. *A Study to Revise and Complement the Standard Guidelines for Preliminary Feasibility Studies of Water Sector Projects (4th edition)*. Seoul: KDI, 2008.

___. *Wonju River Dam Construction Feasibility Study*. Sejong: KDI, 2017.

K-water. *Report on Measures to Adapt Climate Change to K-water Main Facilities.* Daejeon: K-water, 2018.

Ministry of Environment. *National Waterworks Plan.* Seoul: ME, 2016.

___. *The First National Plan for Response to Climate Change*. Seoul: ME, 2016.

___. *The Guideline for Establishing Master Plan for Development of Water Supply*. Seoul: ME, 2016.

___. *The Guideline for Establishing Measures to Adapt to Climate Change in Public Organizations.* Seoul: ME, 2016.

___. *The Guideline for Establishing Measures to Adapt to Climate Change in Public Organizations and Tools to Support Establishment.* Seoul: ME, 2017.

___, et al. *Second National Climate Change Adaptation Measures (2016-2020).*

Ministry of Land, Infrastructure, and Transport. *2011, Dam Design Standard.* Seoul: 2015.

___ . *National Water Resources Plan (2001-2020)*. Seoul: ME, 2016.

Pearman, G. *Climate Change: Risk in Australia under alternative emissions futures, Department of Treasury.* Canberra: Australian Government, 2008. Canberra.

Chae, Yeo Ra et al. 2013. Development of a Climate Change Risk Management Framework to Minimize National Risks, *KEI*.

Climate Change Information Center. n.d. RCP Scenario. http://www.climate.go.kr/index.html.