

A case study of regional risk assessment of river restoration projects: Nakdong River Basin, South Korea

Jong-Suk Kim, Sun-Kwon Yoon, Minha Choi and Young-II Moon

ABSTRACT

An integrated approach to risk assessment that can pose significant challenges to mitigation and adaptation at the local or regional levels in the context of climate change was developed. First, a conceptual framework for flood risk analysis was developed based on the hydrologic hazard and the socioeconomic vulnerability of a region. Second, weighting factors for each indicator were estimated using the modified Delphi approach based on the results of a survey of an expert group. Third, geographic information system analysis described the hydrologic risk at the regional level before and after completion of the Four Major Rivers Restoration Project at the Nakdong River Basin, South Korea. Finally, sensitivity analysis was conducted to evaluate the extent of the resilience of the Nakdong River Basin based on climate change scenarios to extend the existing research. It was found that the effect of the river restoration project in the future would be insignificant in terms of risk control over regions where floods are likely to increase upon climate change. We believe that this study provides useful information for the development of scientific, effective risk management tools for consistent application in a time of changing climate.

Key words | climate change scenarios, Four Major Rivers Restoration Project, hazard, hydrologic risk, vulnerability

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INTRODUCTION

Climate change can be defined as a change in the average climatic conditions of a certain region over an extended period (IPCC 2007). Evidence of recent climate change is seen all over the world in such changes as the reduction in the volume of the Alpine glaciers and the increase in the average global temperatures (Thomas *et al.* 2006; Hegerl *et al.* 2007). Rainfall discontinuity, seasonal fluctuation, and changes to periodicity due to climate change may be significant factors contributing to recent uncertainty concerning the security and sustainability of stable water supplies (Hegerl *et al.* 2007; Bae *et al.* 2008; Kim *et al.* 2012).

A large body of published research concerns the management of risk to global water resources related to climate change and the evaluation of the extent of vulnerability of water resources to climate change (Anselmo *et al.* 1996; Kasperson *et al.* 2005; Zheng *et al.* 2009; Wang *et al.* 2011). These studies suggest a variety of impact

evaluation and management measures that can be used to respond and adapt to climate change. Despite the growing body of research that predicts and evaluates the potential effects of climate change on water resources, it is, in fact, difficult to precisely predict hydrometeorological phenomena. The challenge partly arises from the high level of uncertainty involved and the ambiguity of the standard of overall evaluation.

Watson *et al.* (1996) investigated the international research trends in risk analysis vulnerability evaluation related to climate change. They proposed that climate change is a multi-dimensional phenomenon in which vulnerability, defined as the extent to which climate change may cause damage to systems, consists of sensitivity, adaptation, and exposure. Connor & Hiroki (2005) also argued that climate change vulnerability is multi-dimensional and proposed a meteorological and hydrologic index, a socioeconomic

index, and a countermeasures-related index to evaluate and analyze the risk and vulnerability associated with climate change. Rygel *et al.* (2006) supported these ideas and argued that the most important factor in the analysis of climate change risk and vulnerability evaluation is the selection of adequate indices to measure it. Balica *et al.* (2009) estimated and evaluated the flood risk and vulnerability of three resolutions (river basin, sub-catchment, and urban area), and Fekete (2009) factored the flood risk and social vulnerability index into fragility, socioeconomic condition, and region.

There are other notable analytical approaches to the evaluation of the effects of climate change on water resources. For example, Jung *et al.* (2010) analyzed long-term runoff with the precipitation runoff modeling system using a multipurpose dam inflow rate and climatic data to analyze the resilience of river discharge against climate change in Korea. Son *et al.* (2011) developed a flood vulnerability index that reflects elements of climate change and applied this measure to evaluate six medium-sized regional areas in the Han River Basin, Korea. In addition, Lee *et al.* (2011) suggested evaluation techniques for flood risk and the vulnerability to flood due to climate change that rely on the Multi-Model Ensemble scenario and applied these to analysis of the five river basins in Korea. Yoon *et al.* (2014) performed a case study to develop a flood risk index including ecological components in the Korean Han River Basin, where flood disasters frequently occur. Most recently, Jung *et al.* (2014) deconstructed the vulnerability-resilience index of climate change into exposure, sensitivity, and adaptive capacity and then analyzed the four major watersheds in Korea. However, studies of the generalized hydrologic integrated risk index of regional basins still lack efficient frameworks that meet the demands of diverse stakeholder groups. Therefore, further standardization research that constructs conceptual factor categories for analyzing the impact of regional climate change and evaluating regional vulnerability to climate change is necessary.

This study aims to add to the body of research on generalized hydrologic integrated risk indexes at the regional level by estimating an integrated regional risk index (IRRI) and then examining its applicability. The use of a conceptual system for the computation of IRRI is advantageous because: (1) it effectively evaluates the change in the regional hydrologic risk; (2) it presents the hydrologic risk

due to climate change as a standardized and quantified value; (3) it can serve as a template to be used whenever local level governments try to establish strategies for dealing with the effects of climate change; and (4) it can serve as a standard measure for the permanent evaluation of a district's ability to recuperate from climate change.

The structure of the paper is as follows: the next section describes the data and methodology followed by the results of the analysis; and the final section presents the summary and conclusion.

DATA AND METHODOLOGY

Study area

The Nakdong River Basin is located between 35°03' and 37°13' north latitudes and between the 127°29' and 129°18' east longitudes. It is South Korea's longest and second most important river. The water stream length is about 511 km and its basin area is 23,702 km², accounting for about 24.1% of South Korea's total geographical area.

According to the Korean Water Management Information System (WAMIS), during the 42 years from 1966 to 2007, the annual average precipitation in the Nakdong River Basin was about 1,179.8 mm. In that period, about 67.1% of the yearly precipitation (approximately 791.3 mm), occurred during the summer months (June–September). The annual cost of flood damage during the 37 years from 1970 to 2007 was, on average, 113 million dollars. The cost of flood damage in the Nakdong River Basin was 32.5% of the total cost of flood damage from all four rivers (Han, Nakdong, Geum, and Yeongsan) during that period. The annual average flood area of the Nakdong River Basin was 15,854.8 ha, which was 41.7% of the four rivers' total flood area. Thus, of the four rivers, the Nakdong River Basin was the most hydrometeorologically vulnerable basin with the greatest risk of flooding.

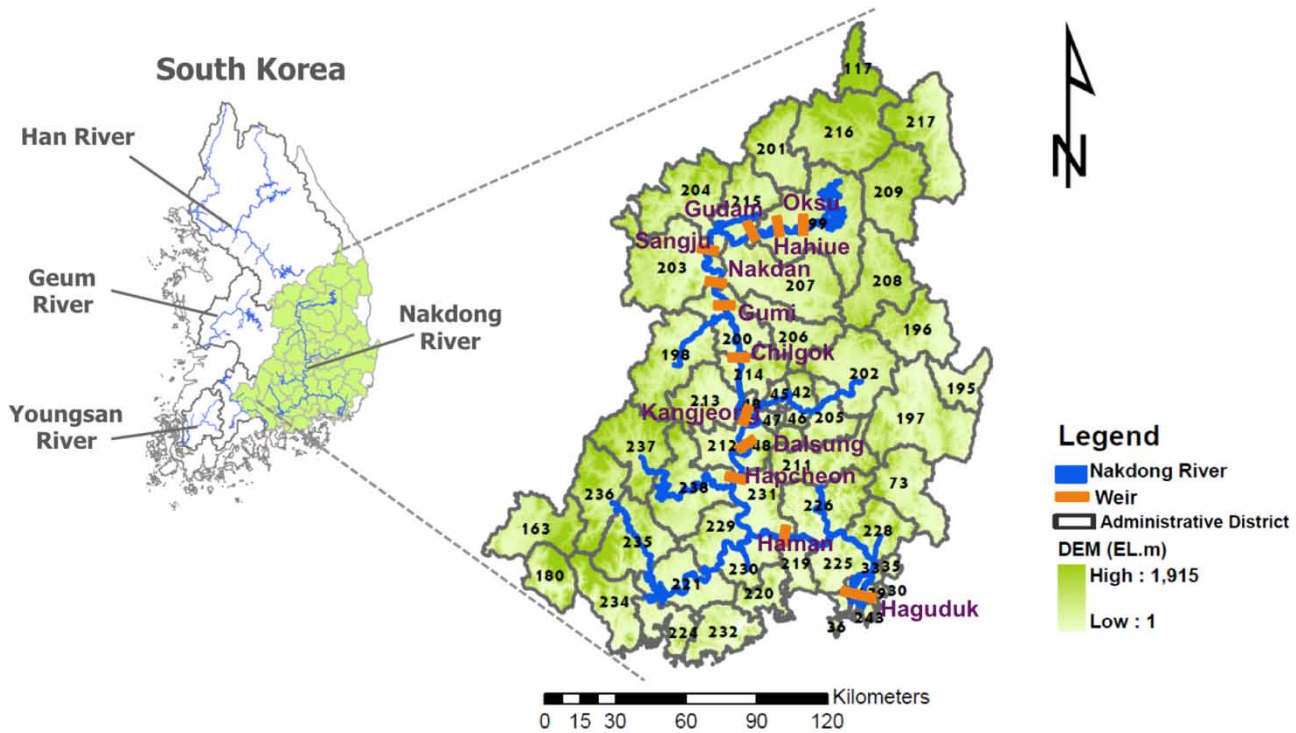
In addition, the Nakdong River Basin flows through 58 administrative districts, including Busan, Ulsan, and the Daegu metropolitan cities. According to the Nakdong River Basin survey conducted by WAMIS in 2005, the total population in the Basin was 5,900,609 and the population density was 248.95 people/km². The gross domestic

product varied by industry; for example, the manufacturing industry was worth 118 trillion dollars and the mining industry was valued at 213.8 billion dollars. The survey found that there were 1,922,824 houses, 1,252 kindergarten schools, 923 elementary schools, 504 middle schools, 348 high schools, 34 colleges, and 29 universities in the Basin.

During the 5 years between 2008 and 2012, inclusive, project-related dredging of the river floor and the installation of 16 barrages across the basin changed the shape of the riverbed and drastically altered the hydrologic environment. Therefore, a hydrologic risk assessment accounting for socioeconomic factors needs to be conducted. Figure 1 shows the location of the Nakdong River Basin and the newly installed barrages after the project was completed in 2011.

Methodology of the integrated risk assessment and factor classification

Hazard is a condition of risk occurrence, and vulnerability and it is the basic state of risk occurrence (Maskrey 1989). To assess the impacts of climate change, Kasperson et al. (2005) defined the factors of socioeconomic vulnerability. This study analyzes the factors of vulnerability and risk in local or regional basins due to the effects of climate change using the Nakdong River Basin as typical of that size of basin. The analysis applies the concept of risk proposed by Maskrey (1989) and Kasperson et al. (2005), where risk was defined as a function of the hydrologic risk factor and the socioeconomic vulnerability factor, as



ID	Name	ID	Name	ID	Name	ID	Name	ID	Name
26	Jungu, Busan	44	Namgu, Daegu	196	Bukgu, Pohang	206	Gunwi	217	Uljin
27	Seogu, Busan	45	Bukgu, Daegu	197	Kyungju	207	Uideong	219	Changwon
30	BusanJingu	46	Suseonggu	198	Kimcheon	208	Cheongsong	220	Happogu, Changwon
33	Bukgu, Busan	47	Dalseogu	199	Ahdong	209	YeongYang	221	Jinju
35	Keumjeonggu	48	Danseong	200	Gumi	211	Cheongdo	224	Sacheon
36	Kangseogu	73	Ulju	201	Yeongju	212	Goryeong	225	Kimhae
39	Sasanggu	117	Taeback	202	Yeongju	213	Seongju	226	Miryang
41	Jungu, Daegu	163	Namwon	203	Sangju	214	Chilgok	228	Yangsan
42	Donggu, Daegu	180	Gurye	204	Munhyung	215	Yecheon	229	Uiryeong
43	Seogu, Daegu	195	Namgu, Pohang	205	Kyungsan	216	Bonghwa	230	Hanan
								231	Changnyeong
								232	Goseong
								234	Hadong
								235	Sancheong
								236	Hamyang
								237	Geochang
								238	Hapcheon
								243	Sahagu, Busan

Figure 1 | Location of the study area (Nakdong River Basin).

shown in Equation (1).

$$\text{Risk} = f(\text{hydrologic hazard, socioeconomic vulnerability}) \tag{1}$$

Therefore, if the integrated risk index is generalized to include the vulnerability and the hazard related to the hydrologic risk, Equation (2) can be derived

$$\text{IRR}(j) = \sum_{i=1}^m h_i \times H_i + \sum_{j=1}^n v_j \times V_j \tag{2}$$

Here, IRR_i is the integrated risk index, h_i and v_j are the weights of each factor, H_i is the hydrologic risk index, and V_j is the socioeconomic vulnerability index.

In this study, the reliability of applying the initial weights to each factor was verified through the Delphi method (Jung & Choi 2012) in which a survey of experts in each administrative district was conducted (Kim et al. 2011). In addition, to avoid extreme weighting, this study applied the entropy-based bootstrap resampling method (Ripley 1987; Becker et al. 1988), which is a statistical generation method. Figure 2 shows the results on the radar chart of applying the modified entropy-based weighting to each factor.

The conceptual model that provided the framework for the analysis is shown in Table 1. It shows the basic structure of the IRRi that was developed for the computation of

hydrologic risk in the Nakdong River Basin. To compute the IRRi of small- to medium-sized basins (such as the Nakdong River Basin), the IRRi is composed of two distinct dimensions: the hydrologic hazard dimension and the socioeconomic vulnerability dimension. Each dimension consists of three determinants. The determinants of hydrologic hazard are Trigger, Condition, and Response. The socioeconomic vulnerability determinants are Exposure, Susceptibility, and Resilience (Adger & Kelly 1999; Cutter et al. 2003).

Each of the six determinants is, in turn, measured by two or more factors. Regarding the hydrologic hazard determinants, Trigger is indicated by the number of days when the daily amount of precipitation exceeds 150 mm and the daily precipitation factor during every 100 years in each administrative district. The historical precipitation data used in this study are the daily rainfall for each region provided by the Korea Meteorological Administration (KMA) and the future climate change simulation data are from the Regional Climate Model A1B scenario from KMA. Condition is derived from the length of the river in each administrative district, the ratio of the region with no river improvement, and the slope of the basin. Response is measured by the change in the water level at the confluence of the main stream and the branch, the newly calculated backwater impact area, and the observed scale of past flood damage.

For the analysis of socioeconomic vulnerability, Exposure is measured by the number of people under

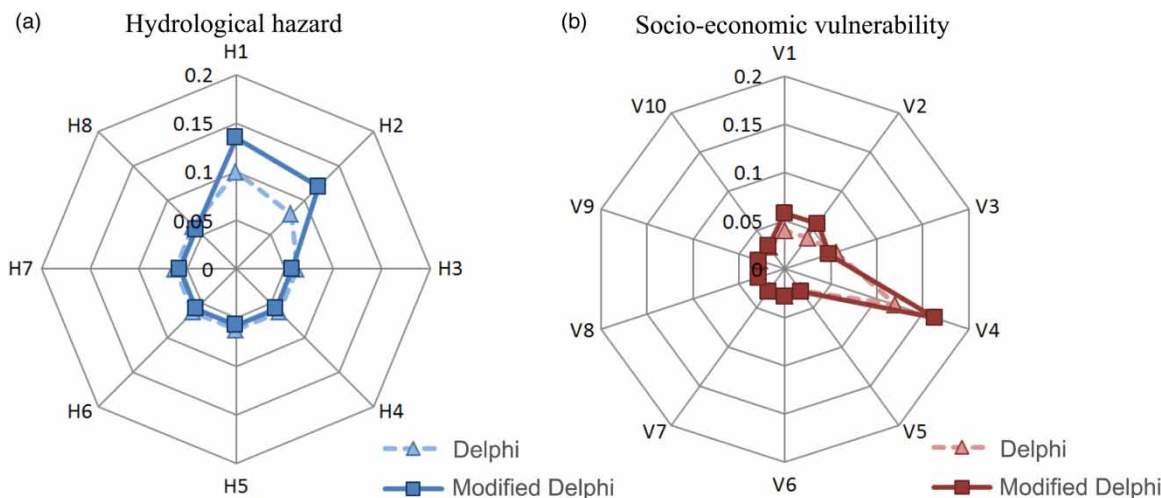


Figure 2 | Modified Delphi weighting factors for the risk assessment.

Table 1 | Conceptual framework for analyzing the IRRI in the Nakdong River Basin, Korea

Goal	Components	Determinants	Indicators
IRRI	Hydrologic hazard	Trigger	Number of days over 150 mm rainfall per day: H₁ Daily rainfall probability of 100 years storm: H₂
	Socio-economic vulnerability	Condition	River length (km): H₃ Area rate of un-refurbished area (%): H₄ Slope of watershed: H₅
Response		Water level changes at the connection of mainstream and tributaries: H₆ Effective area of backwater from newly installed dams: H₇ Historical flood damage amount: H₈	
		Exposure	Number of people over 61 and less than 15 years old: V₁ Population density (number of people/km ²): V₂ Town area near river: V₃
		Susceptibility	Property density (\$/m ²): V₄
		Resilience	Sewer ratio (%): V₅ Prevention results of local governments: V₆ Financial independence (%): V₇ Number of government employees: V₈ Number of hospital per million people: V₉ Hazard mitigation system: V₁₀

Indicators used here are obtained from the national achievements of Korea National Emergency Management Agency.

15 years of age plus the number of people over 61 years of age in each administrative district, the population density (the number of people in every 1 km²), and the size of the geographical area of the towns near the basin. Susceptibility is indicated by the density of real estate, calculated as (\$/m²). Resilience consists of six factors: (1) sewer ratio of each administrative district, (2) prevention results of local governments, (3) financial independence, (4) the number of government employees, (5) the number of hospitals per million people, and (6) the hazard mitigation system.

The procedure of regional risk assessment can be summarized as follows: First, a conceptual factor classification system was developed by estimating the IRRI for small and medium-sized basins among the applicable administrative districts after the Four Major Rivers Restoration Project. Second, we applied a weighting factor to each factor using the modified Delphi technique based on the results of a survey of an expert group. Third, we conducted a climate change hydrologic risk analysis using data before and after the Project. The applicability of the IRRI was evaluated by applying the suggested integrated risk analysis method to the Nakdong River Basin in Korea. Finally, to extend the existing research, a climate change sensitivity analysis was conducted to evaluate the extent of the resilience of the Nakdong River Basin. Changes to six resilience factors were

analyzed to assess the climate change resilience-based adaptation ability of the Nakdong River Basin as typical of small and medium-sized basins.

ANALYSIS AND RESULTS

Rainfall pattern with climate change

This study analyzed the influence of climate change in the Nakdong River Basin according to the projected characteristics of precipitation in the Basin. The analysis found that the overall average number of days with precipitation greater than 150 mm in a year in the Nakdong River Basin was 0.358 (days/year) at present; the maximum value was 0.706 (days/year) in the Hadong region and the minimum value was 0.132 (days/year) in the Youngcheon region. In addition, the average projected value for the future was 0.484 (days/year); Sancheong was projected to have the maximum precipitation of 0.963 (days/year) and the minimum projected precipitation was 0.177 (days/year) in the Youngcheon region. The heavy rainfall experienced in the Nakdong River Basin was expected to increase by 35.3% in the future and the rates of projected increase appear to be relatively higher in the coastal regions adjacent to the

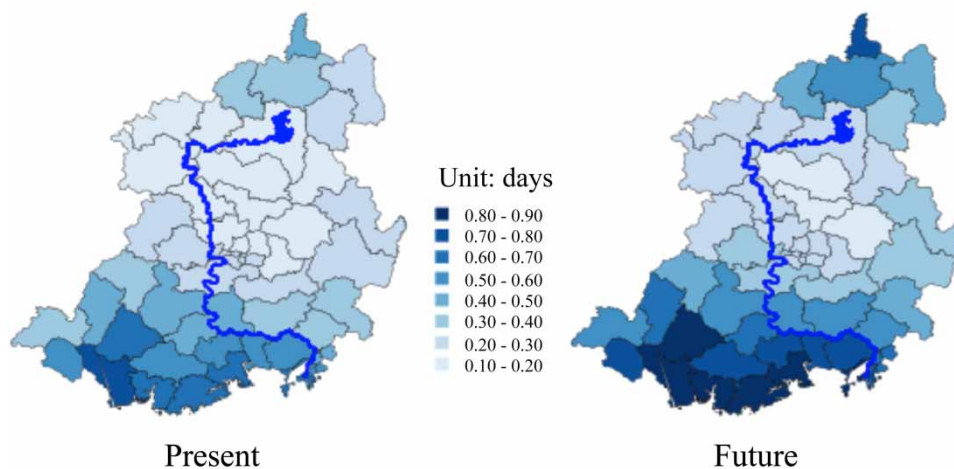
southern sea and the East Sea and relatively lower in the interior of the central part of the Nakdong River Basin.

In addition, the analysis of the 100-year frequency of rainfall in each administrative district in the Nakdong River Basin found that the overall average rainfall in the Nakdong River Basin was 302.5 mm. Sancheong had the maximum amount of 373.2 mm and the Euseong region had the minimum amount of 226.7 mm.

In the projections, the overall average rainfall in the Nakdong River Basin was 321.1 mm. The maximum was 384.3 mm, projected for the Sancheong region; the minimum was 246.9 mm, projected to occur in the Euseong

region. The 100-year frequency rainfall in the Nakdong River Basin was projected to increase by 6.15% in the future, and the rates of increase were projected to be higher in the southern and eastern coastal regions, a pattern similar to the pattern of number of heavy rain days; the projection for the inland area of the central part of the Nakdong River Basin was relatively low. Figure 3 illustrates the number of heavy rain days due to climate change in the Nakdong River Basin at present (2010) and for the future (2070–2100) as well as the projected geographical distribution of the 100-year frequency of precipitation in each administrative district.

(a) Number of days over 150mm rainfall per day



(b) Daily rainfall probability of 100 years storm

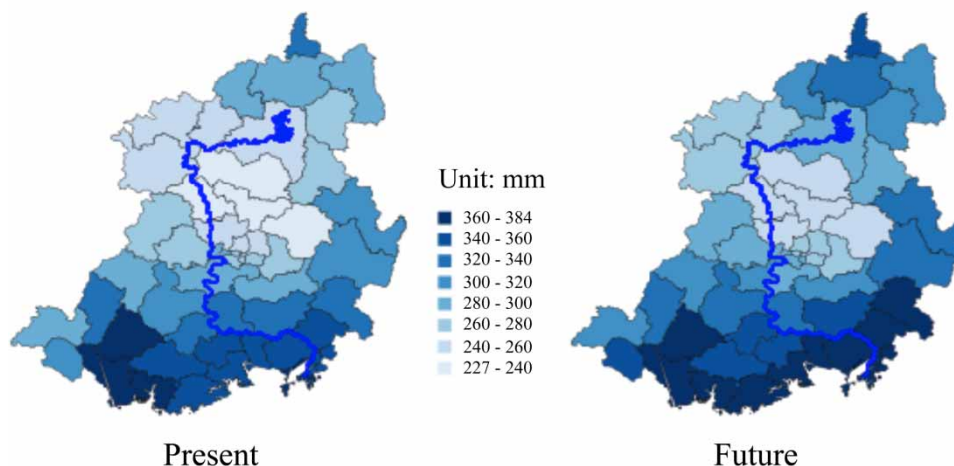


Figure 3 | Rainfall pattern for the current and future climate conditions in the Nakdong River Basin, South Korea.

Effects of the Four Major Rivers Restoration Project on climate change

To determine the hydrologic risk and socioeconomic vulnerability indexes, an additional analysis was conducted in addition to the analysis of the effects of climate change on the integrated regional risk before and after the Project. Figure 4 presents the results of the calculation of the IRRI for 58 cities and counties in the Nakdong River Basin according to the classification system suggested above under Methodology of the integrated risk assessment and factor classification.

The results show that the average IRRI in the Nakdong River Basin before and after the Project was 0.1915 and 0.1945, respectively, indicating that the average IRRI after the Project increased by 1.5%. A change of risk was not present in most regions except for some river channel areas. The region with the highest IRRI was Changwon; Namgu, Daegu had the lowest IRRI. In addition, the region with the most change in IRRI was Sangju and the region with the least change was Saha-gu, Busan (Figure 4(a)).

After the completion of the Project, the average IRRI in the Nakdong River Basin due to climate change was 0.2290, suggesting that the average IRRI will increase 19.6% over the IRRI that existed before the Project due to climate change. Furthermore, the IRRI demonstrated an increase in most of the regions except for some of the river channel sections. The region with the highest IRRI was Changwon and the region with the lowest IRRI was Namgu, Daegu. In addition, the region with the greatest change in the

integrated regional risk was Sangju and the region with the least amount of change was Jung-gu, Daegu (Figure 4(b)).

Sensitivity analysis for risk assessment in a changing climate

To determine the extent of sensitivity to climate change after the Project, the extent to which the IRRI of each administrative district varied was assessed when the resilience was increased by 10, 25, and 50%. When the resilience was increased by 10%, the average IRRI was 0.2185, which was an average decrease of 4.58%. In addition, the minimum value was 0.070 in the Namgu, Daegu region and the maximum value was 0.392 in Changwon. When the resilience was increased by 25%, the average IRRI was 0.206, which was an average decrease of 9.99%. The minimum value was 0.061 in the Namgu, Daegu region and the maximum value was 0.372 in Changwon. Finally, when the resilience was increased by 50%, the average IRRI was 0.197, which was an average decrease of 14.05%. The minimum value was 0.057 in the Gunwi region and the maximum value was 0.355 in Changwon. Figure 5 shows the analysis result of the sensitivity of climate change to the change in resilience.

Table 2 shows the means, standard deviations, and coefficients of variation (CV) before and after projected changes in the IRRI for the main factors in 58 cities and district administrative regions. The average of the sewage system ratio in each administrative district was 67.50%, the average for the prevention results of local governments was 84.15%, the average financial independence was 22.18%, the average

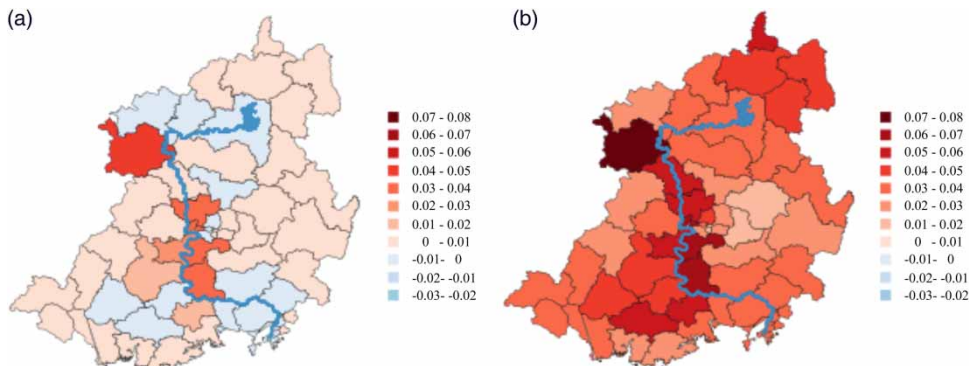


Figure 4 | Risk difference before and after the restoration project and risk changes associated with climate change in the Nakdong River Basin, South Korea.

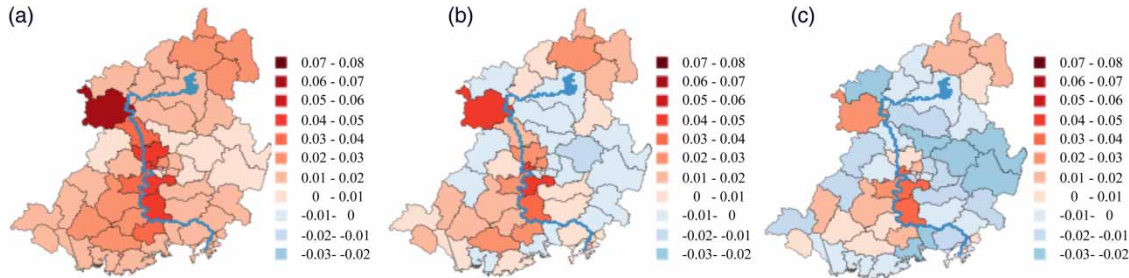


Figure 5 | Sensitivity analysis for risk assessment in a changing climate. (a) 10% increase, (b) 25% increase, (c) 50% increase.

Table 2 | Summary of resilience in the Nakdong River, Korea

Indicators statistics	Sewer ratio (%)	Prevention results of local governments (%)	Financial independence (%)	Number of government employees (Person)	Number of hospital per million people	Hazard mitigation system (%)	IRRI	
Mean	Pre	67.50	84.15	22.18	814.2	2.0	79.86	0.2290
	+10%	70.75	85.74	24.40	895.7	2.2	81.87	0.2185
	+25%	75.63	88.11	27.72	1,017.8	2.5	84.89	0.2061
	+50%	83.75	92.08	36.59	1,343.5	3.4	89.93	0.1968
STDEV	Pre	30.25	15.35	11.45	342.0	1.829	8.19	0.0746
	+10%	27.22	13.82	12.59	376.2	2.012	7.37	0.0741
	+25%	22.68	11.52	14.31	427.4	2.286	6.14	0.0737
	+50%	15.12	7.68	18.89	564.2	3.017	4.10	0.0737
CV	Pre	0.448	0.182	0.516	0.420	0.898	0.103	0.3256
	+10%	0.385	0.161	0.516	0.420	0.898	0.090	0.3390
	+25%	0.300	0.131	0.516	0.420	0.898	0.072	0.3574
	+50%	0.181	0.083	0.516	0.420	0.898	0.046	0.3743

*STDEV, standard deviation; CV, coefficient of variation (CV = STDEV/Mean).

number of government employees was 814.2 employees, the average number of hospitals per million people was 2.0 hospitals, and the average of the hazard mitigation system was 79.86%. Analysis of the IRRI found that when the six resilience factors of socioeconomic vulnerability were increased by 10, 25, and 50%, the resilience to climate change increased by 4.8, 10.0, and 14.0%, respectively. These results suggest that future climate change can be handled effectively by increasing the basin resilience of each administrative district.

SUMMARY AND CONCLUSION

In this study, the risk due to climate change was defined as the combination of hydrologic hazard and socioeconomic

vulnerability. The risk was separated into eight hydrologic factors and 10 socioeconomic factors to develop an IRRI. In addition, weights were applied to these factors through a modified Delphi approach that included data from a survey of experts. The main findings of this study are as follows:

1. The results suggest that a conceptual system of factor categorization to evaluate the quantitative extent of risk and to analyze the vulnerability of regional-sized basins due to climate change is useful. This study conducted an analysis of the IRRI before and after the project and the associated effects of climate change in the Nakdong River Basin to verify its applicability.
2. Application of the conceptualized risk analysis method to the Nakdong River Basin found that the IRRI increased

by 1.5% after the project; it was further found that the IRRRI would increase by an additional 19.6% due to climate change after the project. Compared to the current status, risks over some regions in the Nakdong River basin were expected to decrease upon large-scale river restoration projects, and higher risks were expected over some regions upon climate changes in the future. However, it turned out that the effect of river restoration project in the future would be insignificant in terms of risk control over regions where floods are likely to increase upon climate changes.

- The IRRRI was calculated by mathematically increase six resilience factors know to relate to basin resilience by 10, 25, and 50% to analyze the region's sensitivity to climate change. The analysis found that the resilience of the Nakdong River Basin increased by 4.8, 10.0, and 14.0% with increases of 10%, 25%, and 50%, respectively. The results strongly suggest that: (a) future climate can be handled effectively by increasing basin resilience in each administrative district; and (b) it is feasible to use structural/non-structural measures as basin characteristics.

This study is advantageous because it evaluates hydrologic risk due to climate change using standardized and quantitative factors. Specifically, this study provides a measure with the potential to obtain basic information to efficiently evaluate the changes to regional hydrologic risk over a river area affected by the Four Major Rivers Restoration Project as well as a method for assessing systematic water resource management and climate change vulnerability.

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