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ARTICLE

Estimation of flood risk index considering the regional flood characteristics: a case of South Korea

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Abstract Global warming is increasing the variability of climate change and intensifying hydrologic cycle components including precipitation, infiltration, evapotranspiration, and runoff. These changes increase the chance of more severe and frequent natural conditions, and limit ecosystem function and human activities. Adaptation to climate change requires assessment of the potential disaster risk. The objectives of this study were to estimate the flood risk index (FRI) considering regional flood characteristics at the national level and to prioritize the factors affecting flood risk through principal component analysis. FRI was estimated based on the Delphi survey results from 50 water resources experts in South Korea. The potential risk analysis was conducted for 229 local governments in South Korea. The results showed that natural and social factors were more influential flood risk factors to South Korea than administrative and economic and facility factors. Specifically, natural, social, administrative and economic, and facility factors were, respectively, highest at Jindo-Gun in Jennam-Do, Gumi-Si in Kyongsanbuk-Do, Dong-Gu in Incheon-Si, and Suwon-Si, Kyonggi-Do. Overall, the highest FRI is shown in Anyang-Si, Kyongggi-Do. The spatial distribution of the FRI was high in the southeastern coastal region and basins of the two biggest rivers in South Korea, and normalized flood frequency followed spatial patterns similar to FRIs. This study provided information on the relative flood risk index among administrative units for investment prioritization in flood risk management. In this regard, the suggested FRI is expected to significantly contribute to methodical and economic improvements in budget allocations for flood risk management.

Keywords Flooding · Flood risk index · Delphi survey · Principal component analysis · Risk indicator · Regional flood characteristic

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Introduction

Climate change is a critical issue in water resources management in terms of ecosystem function and human activities. For example, disastrous events like river depletion, flood, soil loss, and landslide related to changing climate are occurring more often globally. In particular, floods are one of the most severe and frequent globally occurring natural hazards. Mitigation of flood damage is a global concern that has been increasing mainly due to urbanization and climate change (Trenberth et al. 2007; Theobald et al. 2009).

Many studies have used various approaches to mitigate these damages based on the susceptibility of the system to risks of water shortage or flood, as well as hydrologic and meteorological situations (Zhang et al. 2002; Green 2004; Rao et al. 2005; Fedeski and Gwilliam 2007; Ferreira et al. 2007; Dawson et al. 2008; Jonkman et al. 2008; Morita 2008; Van Alphen et al. 2009; Vojinovic and Tutulic 2009; Koivumaki et al. 2010; Lamb et al. 2010; Harvey et al. 2012). Zhang et al. (2002) assessed flood risk resulting from heavy rainfall on the basis of the macro-zonation concept considering regional macro information, such as the contributions of meteorological triggering factor, natural and socioeconomic factors to flood damage, and historical flood damages in Yamaguchi Prefecture of Japan. Rao et al. (2005) suggested a vulnerability index on the basis of remote sensing (RS) and geographic information system (GIS) technology to predict and mitigate the flood risk caused by cyclones in the Bay of Bengal in the east coast of India where approximately 80 % of all local cyclones have occurred. Fedeski and Gwilliam (2007) proposed an assessment of the risk to buildings due to hydrological and geological hazards in the United Kingdom in terms of the cost of damage from data collected by a combination of physical survey and GIS techniques on three elements of risk: exposure, hazard, and vulnerability. Jonkman et al. (2008) suggested an integrated hydrologic and economic model to predict and assess the damage due to catastrophic flooding in The Netherlands, where more than half of the country could be permanently threatened by flooding. This model provided an integrated framework for the assessment of both direct hazard-induced damages and indirect economic damages such as interruption of production flows outside the flood affected area, as well as loss of life due to flooding. Van Alphen et al. (2009) emphasized the need for uniform approaches through multi-national cooperation in flood risk assessments in Europe, given that many European rivers are part of transboundary water systems.

However, it is difficult to directly apply these methods to the regions like Korea in which physical conditions of climate and topography are so varied spatially. A comprehensive index considering various indicators influencing flood risk is required. Several studies in Korea have focused on deriving one index presenting the degree of flood damage recently. In Water Vision 2020 (2000), the index of potential flood damage (PFD) was introduced and used to analyze the potential flood risk in 1,500 administrative units for water management. Lee et al. (2006) presented modified PFD as a multiplication of damage, damage potential, and vulnerability. Choi et al. (2006) estimated the expected amount of flood damage by applying the damage rate based on the damage scale and flooded depth in expected damage regions. This study was somewhat useful in analyzing the flood risk in certain region, but is not realistic in developing one representative index for nationwide flood risk assessment, since hydraulic analyses must be done beforehand for the possibly affected regions. Lee et al. (2006) also suggested a watershed evaluation index, such as PFD, potential streamflow depletion (PSD), and potential water quality deterioration (PWQD) for integrated watershed management. Lee et al. (2007) assessed the regional relative safety considering flood risk and qualitatively evaluated flood risk using GIS.

Most studies to date have been limited to a certain watershed for water management and scientific research, making it difficult to directly the findings for water management on the basis of administrative units at a nationwide level. It is necessary to determine an index of flood risk at a nationwide level in countries with local governments. In South Korea, local governments are divided by administrative units including Si (City), Gu (County), Gun (Subprovince), and Do (Province) (Park et al. 2009). Determinations of investment priorities by the central government of South Korea in the face or budget restrictions require knowledge of water management among the various governing units. Natural, social, administrative and economic, and facility factors for flood risk vary among local governments, which compound the difficulty and uncertainty of PFD assessment. In addition, the prediction methods and logical basis for relative indicators between administrative units in South Korea are unclear.

Flood risks depends on the conditions of nature, society, economy, and facility. However, such condition gives different and complex contribution to the flood risk in the individual administrative units. From this reason, the central government of South Korea has concerned on the allocation of the limited budget for flood risk management to the local government. Therefore, budget allocations for flood risk management needs a rational method to consider characteristics of individual administrative units; In this regard, the twin objectives of this study are to (1) estimate an integrated index (the Flood Risk Index, FRI) consisting of natural, social, administrative and economic, and facility factors for administrative units at the nationwide level in South Korea; and (2) prioritize flood risk management by representing the relative flood risk of 229 administrative units. To achieve these objectives, a FRI was estimated based on the Delphi survey from experts participated in flood risk management of South Korea. FRI is estimated for entire local governments in South Korea (229 administrative units).

Materials and methods

Determination of indicators for estimating flood risk index

At a national level, FRI can be a useful method to compare the degree of flood damage risk in 229

Table 1 The selection of 11 of 25 indicators for the four main factors

Factor	Source	Indicator	Periodical measurability	Quantifiability	Predictability	Availability
Natural	Climate	Daily rainfall (DR)	Good	Good	Poor	Average
		Hourly rainfall (HR)	Good	Good	Poor	Average
		Annual average rainfall (AAR)	Good	Good	Poor	Good
	Topography	Average watershed slope (AWS)	Average	Good	Good	Poor
		River density (RD)	Average	Good	Good	Good
Social	Population	Population (P)	Good	Good	Average	Good
		Population density (PD)	Good	Good	Average	Good
	Asset growth	Number of total employee (NTE)	Average	Good	Average	Good
		Manufacturing Output (MO)	Average	Good	Average	Good
	Development in upstream watershed	***Area of developed region (ADR)***	Good	Good	Good	Good
		Flood inundation area (FIA)	Average	Good	Good	Poor
Administrative and economic	River management	***Number of experts for river management (NERM)***	Average	Good	Good	Good
	Budget	***Self-supporting financial degree (SFD)***	Good	Good	Average	Good
	River improvement	***Levee belongings (LB)***	Average	Good	Average	Good
Facility	Public facility	***Number of public facilities(NPF)***	Good	Good	Good	Good
		Length of Paved Road (NPR)	Good	Good	Average	Good
		Length of pipe line for water supply (LPWS)	Good	Good	Average	Good
		Number of educational facilities (NEF)	Good	Good	Average	Good
	Private facility	***Number of total housing (NTH)***	Good	Good	Average	Good
		Number of farming and fishing housing (NFFH)	Good	Good	Poor	Good
		Number of total livestock (NTL)	Average	Good	Poor	Good
	Flood detention facility	Capacity of pumping stations (CPS)	Good	Good	Average	Poor
		Length of pipe line for drainage (LPD)	Good	Good	Average	Good
		Flood control storage (FCS)	Good	Good	Good	Average
		Area of pervious region (APR)	Good	Good	Good	Good

Italicized and bold texts show 11 selected indicators for estimating FRI in the administrative units

administrative units of South Korea. Potential indicators to represent flood risk for each administrative unit are necessary to consider regional flood characteristics. In this context, Park et al. (2010) suggested that 25 potential indicators categorized into four factors were introduced to develop a comprehensive index representing various regional characteristics of flood risks in South Korea (Table 1). The selected indicators were normalized using *Z*-score method. Administrative FRI was combined and estimated (Fig. 1) by multiplying normalized indicators and weights of indicators calculated by water resource experts. To estimate FRI, indicators of flood risk were selected on the basis of the reason of flood risk and damage specification, and the representing indicators were derived. Causes of flood risk can be classified as hydrological, meteorological, structural (e.g., risk of failure of dam, levee, and embankment), and non-structural (e.g., topography and soil permeability). Damage specification can be narrowed down to casualty and property damage. Thus, major influences of flood damage can be categorized as natural, social, administrative and economic, and facility factors. Finally, 11 major contributors among 25 potential indicators were determined based on periodical measurability, quantifiability, predictability, and availability for data collection (Table 1). Here, 4 main factor, 25 potential indicators, and 11 selected indicators are described in Table 1. Since the 11 indicators differed in their degree of influence on flood risk, different weights are assigned to the indicators to reflect their significance (Nardo et al. 2005).

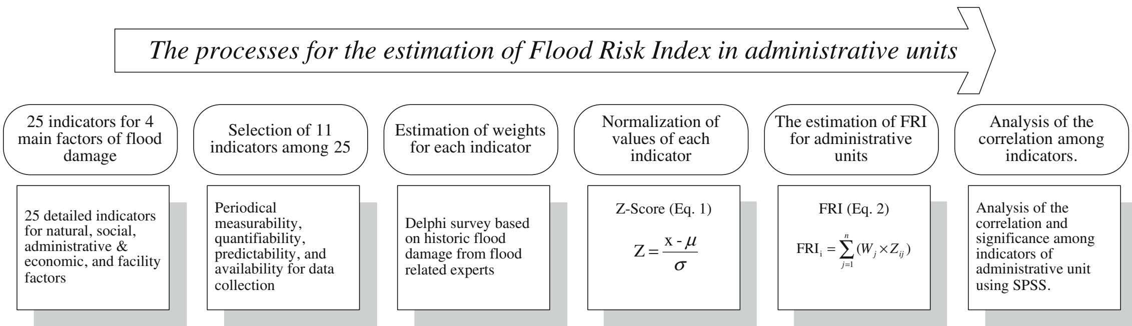

Fig. 1 The process for the estimation of flood risk index

Table 2 Major indicators and their weights influencing flood damage

Factors	Natural factors		Social factors			Administrative and economic factors				Facility factors		Total
Weights	0.32		0.24			0.24				0.20		1.00
Representative indicators	AAR	RD	PD	MO	ADR	NERM	SFD	LB	NPF	NTH	APR	Total
Weights	0.20	0.13	0.09	0.08	0.07	0.09	0.07	0.09	0.06	0.06	0.08	1.00

Estimation of indicator weights

Delphi is a consensus method first introduced in studies by the RAND Corporation in the 1950s. The main objective of the Delphi survey is to obtain effective consensus of a group in decision-making (Dalkey and Helmer 1963). The Delphi survey method was applied to weight indicators based on the opinion of water resource experts working on the mitigation of flood risk and damage in various communities (Brown and Halmer 1964; Brown 1968; Canter 1996; Taylor and Ryder 2003; Elmer et al. 2010). This method is advantageous to understand the relative significance between indicators, can be easily prepared, and estimates balanced weights quickly. However, it is difficult to assign weights if the numbers of indicators are too big. From this reason, in this study, water resources experts including water researchers, governmental officers, and professors weighed indicators on the basis of relative significance, with the total sum of these weights being 1. For the questionnaire, the Delphi technique was used to select 50 experts in water resources through purposive sampling. The weights of all indicators are shown in Table 2.

Natural factors, in particular annual precipitation, were most influential factor to flood risk. Administrative and economic factors and social factors were similar in significance, and facility factor was the least influential. The 11 indicators in Table 2 could be aggregated and compared, given their differing measurement units and data ranges (Nardo et al. 2005) Therefore, the indictors needed to be standardized by transforming them in dimensionless numbers before the aggregation stage (Nardo et al. 2005). The score method was used. It is the most commonly used because it converts all indicators to a common scale and average of zero and standard deviation of one (Eq. 1):

$$Z = \frac{x - \mu}{\sigma}, \quad (1)$$

where Z is the normalized value, x is the value of indicator, μ is the indicator average, and σ is the standard deviation (Nardo et al. 2005). Typically, a high Z-score indicates a high flood risk, with a score of 1 indicating the most extreme flood risk.

Estimation of flood risk index

Eleven indicators were selected as described in the preceding section according to the administrative units in Korea, and were normalized by their Z-scores. Normalized indicators are multiplied by the weights in Table 2 and summed into FRI (Eq. 2):

$$\mathrm{FRI}_i = \sum_{j=1}^{n} (W_j \times Z_{ij}), \quad (2)$$

where FRI is the flood risk index on i administrative units in Korea, W is the weight on j indicator, and Z is the normalized value on i administrative unit and j indicator.

The estimated FRI of 229 administrative units in Korea followed a normal distribution (Park et al. 2010). Even though the estimated indices generally vary according to the purpose and indicators, mostly they are differentiated and organized for different levels (Kim 2001; Park et al. 2010). However, there is no clear definition of the flood risk levels. Due to this reason, the risk level in this study was defined by five groups based on cumulative density probability: very low (less than 10 %); low (10–30 %); middle (30–70 %); high (70–90 %); and very high (more than 90 %). For example, if FRI of an administrative unit is 60 % among 229 administrative units of Korea, the level of flood risk will be middle.

Principal component analysis (PCA) was used to determine factors that were most significant to the potential risk of flood damage (Eq. 3):

$$P_i = a_{i1}X_1 + a_{i2}X_2 + \cdots + a_{ik}X_k, \tag{3}$$

where, X_1, X_2,⋯, X_k are k variables measured on a sample of n subjects, a_{ik} is the weight, and P_i is ith principal component, which can be written as a linear combination of the original variables (X).

PCA is a multivariate statistical method to reveal how different variables are associated with each other (Nardo et al. 2005; Choi et al. 2007). The main purpose of a PCA is to reduce many variables into fewer uncorrelated components (Rygel et al. 2006). It describes the variance–covariance structure of many variables by a fewer linear combinations of given variables (Choi et al. 2007). The maximum quantity of variance is accounted by the first principal component. This method has also been applied for several studies on climate change research to suggest appropriate criteria for weighting among those indices (i.e., Nardo et al. 2005; Rygel et al. 2006). In this study, PCA was used to quantify the relative contribution of four categorized factors to the potential risk of flood damage.

Results and discussion

Analysis of flood risk index by factors and principle component

Natural factors were highest at Jindo-Gun in Jeonnam-Do (FRI 0.77), followed by Busan Jin-Gu in Busan-Si (FRI 0.68) (Table 3). FRIs were generally higher in northern Gyeonggi-Do, southern Gangwon-Do, and southern coastal regions of Korea. Among the indicators in natural factor, AAR was hightest in Jeonnam-Do, Jingdo-Gun, and the RD was highest at Busanjin-Gu in Busan-Si. Natural factors were more influential than social factors on the basis of the Delphi survey method. However, natural factors were the second principal component on the basis of PCA results, and explained 61.4 % of potential risk (Table 4). These results indicated that evaluation by Korean water resources experts who considered natural factors including AAR and RD was more significant than the other three factors, but weights applied for selected indicators were possibly subjective. For this reason, Rygel et al. (2006) presented a method of aggregating indicators that avoids the problems associated with assigning weights on the basis of Pareto ranking method. Further studies are required to determine which method is more appropriate in Korea: weight assignment based on the Delphi survey or the Pareto ranking method, without weighting of indicators.

Social factors were highest at Gumi-Si in Kyungbuk-Do (FRI 0.53), followed by Nam-Gu in Ulsan-Si (Table 3). Regionally, FRIs were highest in the western capital territory and southeast coast of Kyungnam-Do. Among the social factor indicators, PD was highest at Yangcheon-Gu in Seoul-Si, MO was highest at Gumi-Si in Kyungbuk-Do, and ADR was highest at Pohang-Si in Kyungbuk-Do (PD 0.34, 0.45, and 0.24, respectively). PCA results indicated that social factors were the first principal component and explained 44.7 % of potential risk (Table 4). Social factors including PD and ADR in this study were also considered as important indicators in other studies (Adger et al. 2004; Rao et al. 2005; Rygel et al. 2006). Rao et al. (2005) regarded PD as one of the five major indicators in their flood vulnerability index. Rygel et al. (2006) also mentioned the importance of social factors, especially in metropolitan region in developing countries. They suggested that an administrative unit may be more vulnerable to flood damage if the values of indicators, such as population density and number of very young children, are high.

The administrative and economic factor was highest at Dong-Gu in Incheon-Si followed by Yeongdo-gu in Busan-Si (FRI 0.23 and 0.22, respectively; Table 3). FRIs for administrative and economic factor were highest in Incheon-Si, east coast of Gangwon-Do, and inland area of Chungbuk-Do. NERM was highest at Yeongam-Gun in Jeonnam-Do, SFD was highest at Jangheung-Gun in Jeonnam-Do, and LB was highest at Dong-gu, Gwangju-Si (all 0.09). Facility factor was highest at Suwon-si, Gyeonggi-Do (FRI 0.54), followed by Cheongju-Si, Chungbuk-Do (FRI 0.48) (Table 3). FRIs were highest in the capital territory and southern coast of Kyungnam-Do. Among the indicators, NPF was highest Jeonju-Si, Chungbuk-Do (0.28), NTH was highest at Suwon-Si, Gyeonggi-Do (0.27), and APR was highest at Dong-Gu in Busan (0.08) (0.28, 0.27, and 0.08, respectively).

Even though administrative and economic factors and facility factors seemed to be less influential than natural and social factors, considering the Delphi survey and PCA results (Table 4), these two factors cannot be ignored. Individual indicators in these factors are still closely related to adaptive capacity and exposure (IPCC 2007). Moreover, these two factors may be very efficient for the direct

Table 3 Results from FRI estimation by factors (the most two highest areas for each factor)

Factors	Highest		2nd Highest	
	Location	FRI	Location	FRI
Natural	Jindo-Gun, Jeollanam-Do	0.77	Busanjin-Gu, Busan-Si	0.68
Social	Gumi-Si, Kyongsangbuk-Do	0.53	Nam-Gu, Ulsan-Si	0.45
Administrative and economic	Dong-Gu, Incheon-Si	0.23	Yeongdo-Gu, Busan-Si	0.22
Facility	Suwon-Si, Kyonggi-Do	0.54	Cheongju-Si, Chungcheongbuk-Do	0.48
Overall	Anyang-Si, Kyonggi-Do	0.87	Koyang-Si, Kyonggi-Do	0.85

Table 4 Results from principal component analysis on four factors

Principal component	Variance explained	Natural factor	Social factor	Politic factor	Facilitative factor
1st PC	44.690	−0.050	0.508	−0.430	0.348
2nd PC	71.018	0.614	0.033	0.214	0.123
3rd PC	89.582	−0.230	0.106	0.474	0.143

application in establishing countermeasures against flood risks mainly due to typhoons and intensive rainfall in the summer season in Korea (Park et al. 2009, 2010).

Distribution of flood risk index

The spatial distribution of normalized flood risk in South Korea is shown in Fig. 2. FRIs were highest in Northern Gyeonggi-Do and the southern and eastern coastal regions of South Korea. FRIs were lowest in northern inland areas, such as Inje-Gun in Gangwon-Do and Ongjin-Gu in Incheon-Si (FRI for both, −0.75). More details on the FRI values and individual indicators can be found in Park et al. (2010).

The applicability of FRI was investigated by comparing the results of this study with those of another study on actual occurrence frequency of flood damage (Park et al. 2009). Figure 3 presents the spatial distribution of normalized flood

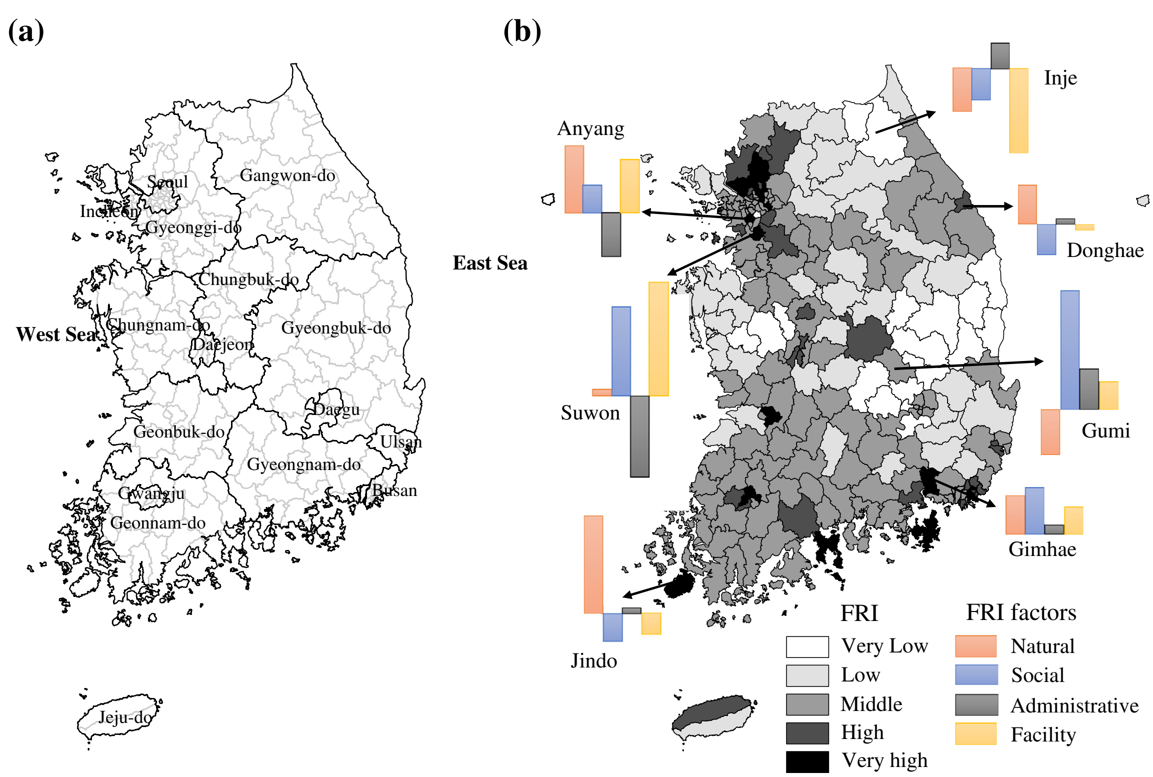

Fig. 2 The estimated FRIs for individual administrative units of Korea. **a** Administrative units of Korea. **b** FRIs by four factors

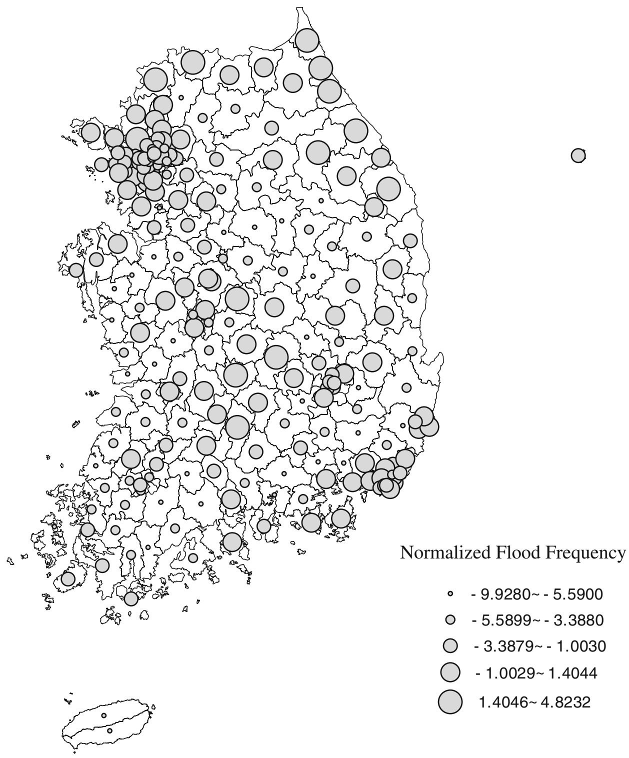

Fig. 3 The spatial distribution of normalized flood frequency in South Korea

frequency in South Korea, which was highest at Dalseo-Gu in Daegu-Si and lowest at Yeonsu-Gu in Incheon-Si (4.82 and −1.69, respectively). In addition, normalized flood frequency was generally higher in the eastern coastal area of Gangwon-Do, northern inland region of Gyeonggi-Do, and the Han River and Nakdong River basins.

FRI suggested by this study is an index to represent the potential risk of flood damage. It may be different from actual regional distribution of restoration cost for flood damage. For example, the actual dimensionless cost for flood damage restoration was relatively high in Gangwon-Do Inje-Gun, but FRI was underestimated in the same area. Gangwon-Do Inje-Gun is located in agricultural inland area with low RD (Park et al. 2010). Natural, social, and facility factors were underestimated (FRI −0.32, −0.14, and −0.38, respectively). Indicators in social and facility factors are vulnerable when flooding occurs, but costs for flood damage restoration in agricultural areas result mainly from damage to croplands and roads. This kind of index studies might vary with location, methods, and research objectives (Rygel et al. 2006).

Limitations

Although indicators and indices proposed in this study are useful to establish a governmental water resource management plan, these results may have to be carefully interpreted due to some inherent limitations of the indices and assumptions made during the analyses. The limitations include the following.

(1) A weight value for each indicator could comprehensively explain the spatial variations of indicators for entire South Korean region. However, weighting values are generally a function of location, and more studies are needed to develop sophisticated weighting values, especially given the heterogeneous land cover and complex topography in Korea.
(2) In Delphi method, the selected 50 experts in water resources through purposive sampling gave the weights of FRI, but purposive sampling involves the subjectivity in determining the weights of FRI. Also, small target population can be an uncertainty source in the determination of weights.
(3) Defining the risk level based on the proposed FRI involves subjectivity because there is no clear definition to determine risk level.
(4) The impacts of extreme events capable of substantial damage, such as typhoon or severe drought, were not included in this study.
(5) The proposed FRI did not include the adaptive capacity and vulnerability of a system.
(6) The proposed FRI was estimated based on the historic flood damage for each administrative unit. Therefore, it should be regularly updated for the changed flood information with a specific period (i.e., 5 or 10 years).
(7) The definition of indicators for flood risk is subjective because the given conditions (natural, social, administrative and economic, and facility factors) are different in the target area. Therefore, standardization of flood risk indicators is required.

The FRI can be accurately estimated in a data-rich environment, and even developed countries strive to obtain more flood information. Although the FRI suggested in this study has limitations to represent the accurate potential of flood risk, this index can be useful for flood risk management in underdeveloped or developing countries due to its simplicity; the suggested index is expressed as one value consisting of regional flood characteristics (Eq. 3). In addition, it is likely that a more reasonable index can be derived if the spatial and temporal flood risk trends of influential indicators are understood according to the administrative units.

Conclusion

This study attempted to estimate FRI considering regional flood characteristics at the national level. For estimating FRI, weights were obtained throughout Delphi survey by

50 water resources experts. FRI was estimated for 229 administrative units of South Korea. PCA was used to identify the most significant factor among four categorized factors influencing the potential risk of flood damage. The results show that high FRI was distributed in the southeastern coastal region and basins of the two biggest rivers in Korea. Also, natural and social factors were more influential than administrative and economic, and facility factors.

Historical flood damage and frequency at nationwide level were compared and normalized to estimate the relationship with the FRI, which can be a useful method to compare the degree of flood damage risk in administrative units of South Korea, since it is provided as one numerical value considering regional flood characteristics for each administrative unit.

The FRI proposed in this study was effective in reflecting regional reasons and characteristics of flood risk by comparing relative differences among factors or indicators. As an example, a specific countermeasure against flood risk is required for the region where FRI is high (Fig. 2b) through analyzing concrete reason with on-site examination. The estimated FRIs were high in southeastern coastal region and basins of the two biggest rivers in South Korea (Fig. 2).

The study is significant for several reasons. It estimated the flood risk index at nationwide level using a simple method. It identified the elements inducing flood risk at each administrative unit. It provided information on the relative flood risk index among administrative units for investment prioritization in flood risk management.

The results can be utilized as fundamental data for comparison of potential flood risk among administrative units, determination of investment priorities for water management among governing units, and for the reasonable allocation of water management budgets on the basis of quantitative comparison and analysis of the degree of predictable flood damage. If the influential indicators in a given administrative unit are appropriately predicted by temporal and statistical analyses, the FRI suggested in this study will contribute to the systematic and economic improvement with reasonable allocation of budgets in water management. In addition, understanding the regional trends of flood indicators for individual administrative unit will help to predict accurate regional flood risks as climate change continues.

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