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Flood risk assessment using an indicator based approach combined with flood risk maps and grid data

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ABSTRACT

The increasing frequency of tropical cyclones, such as typhoons and localized heavy rainfall, increases the risk of flood damage in urban areas around the world. Countries implementing flood prevention projects use qualitative risk assessments, such as flood risk assessments, to support decision-making. However, existing flood risk assessment methods are not able to select and reflect only the damage targets that are directly exposed to flood risk. In addition, existing indexing methods are limited in improving the skewness of the raw data distribution, which distorts the calculated flood risk index. This study conducted a flood risk assessment based on an indicator-based approach using flood risk maps and grid data utilizing indicators (buildings, road area, etc.) from 2016 to 2019 for 44 cities and counties in the Gyeongsang-do Province. The flood risk assessment in this study consists of four items (Hazard, Exposure, Vulnerability, and Capacity) and nine indicators. Instead of using statistical data, we used the overlapped grids with the flood risk map for Exposure and Vulnerability indicators to reflect the flood risk exposed targets in the risk assessment. The limitations of existing indexing methods, such as min–max normalization, were improved by dividing the distribution into ten quantiles and scoring each quantile interval when indexing the indicators. Finally, entropy weights and Euclidean distance were applied to calculate the annual flood risk index of 44 cities and counties. The annual flood risk indices for local governments were arranged in descending order and then, the rankings of flood damage amount in 2019 were compared with the calculated index rankings. The sum and mean of absolute errors were 386 and 9.897, and the root mean square error was calculated as 11.930, which showed an improvement over the existing method. Using the calculated indices, it is possible to create Hazard vs. Capacity graph, Exposure vs. Vulnerability graph, or annual flood risk index graph. These graphs can be utilized to understand the level of exposure to flood risk of local governments and to assess the level of response through the Capacity index that contributes to damage reduction. It is believed that the flood risk assessment method presented in this study not only accurately identify the flood risk for local governments but can also be used to support decision-making processes to strengthen the government's disaster prevention capabilities.

1. Introduction

According to the report of the United Nations Office for Disaster Risk Reduction (UNDRR) in 2020, 7348 cases of drought, earthquake, flood, typhoon, etc. occurred worldwide in 2000–2019. This resulted in 1.23 million deaths and economic losses amounting to $2.97 trillion (Centre for Research on the Epidemiology of Disasters (CRED) and UNDRR, 2020). In the past 20 years (1980–1999), flood events have been more than doubled from 1,389 to 3,254. Studies have showed that flooding in urban areas may cause greater damage with increasing urbanization even in developing countries. (Dewan et al., 2012; Hammond et al., 2015; Waghwala and Agnihotri, 2019).

The average annual rainfall in Korea for the last 30 years (1988–2017) was 1305.5 mm, which was 10.5 % higher than the average annual rainfall (1181.4 mm) in the previous 30 years (1958–1987) (NIMS, 2018). The increased frequency of large-scale

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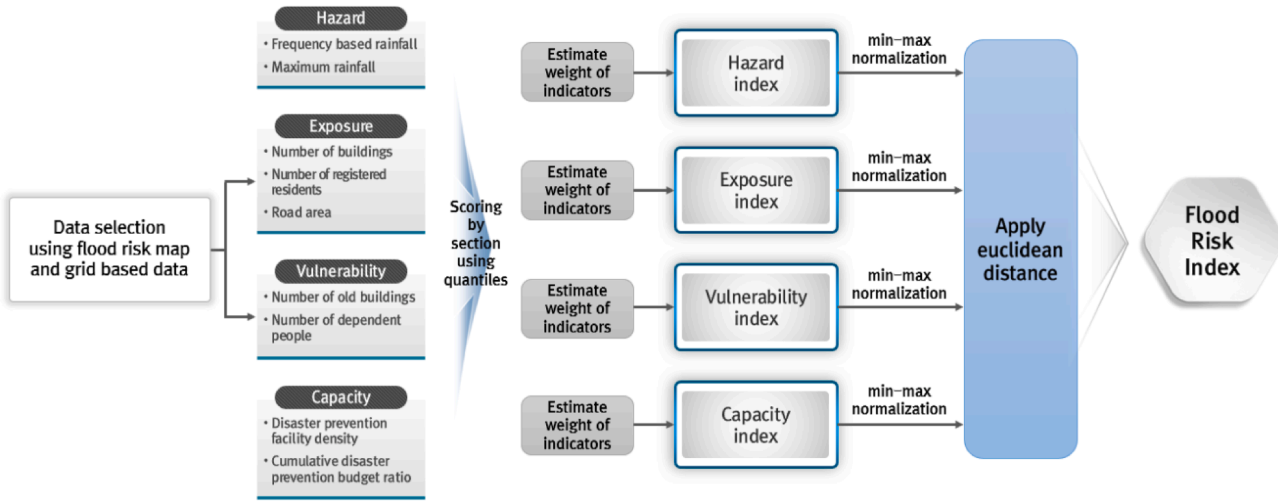


Fig. 1. Flow chart for the flood risk index calculation.

typhoons and localized heavy rainfall over the years has also contributed to the increase in average annual rainfall and in the number of rainfall over 50 mm/hr. Since the occurrence of such disasters in urban areas with concentrated population density would lead to an exponential increase in damage, the Korean government is implementing annual qualitative risk assessment, such as the Regional Safety for Natural Disaster (RSND) at the local government unit. However, RSND comprehensively evaluates the risks of only four natural disasters caused by rainfall, wind, wave height, and heavy snow but not specific disasters like floods. Moreover, RSND uses statistical data such as population density and the number of semi-underground households for evaluating disaster risk, and it cannot select and evaluate the subjects which are directly exposed to disaster risk. If statistical data such as the number of buildings and the number of semi-underground households by local governments are used without selection, buildings located on high land such as mountains or in areas without nearby rivers can be included in the assessment, resulting in an overestimation or underestimation of flood risk.

Studies conducted in Asia and Europe also have the same limitations because the risk assessments were made based on statistical data collected by administrative boundary units such as counties (Fekete, 2009; Li et al., 2014; Fernandez et al., 2016; Bakkensen et al., 2017; Choi et al., 2017; Joo et al., 2019; Chen and Alexander, 2022; Kim et al., 2022).

Generally, qualitative risk assessment of disasters is performed using a risk matrix or an indicator-based approach (IBA). The IBA calculates the risk index by combining various indicators suitable for each of the four items (Hazard, Exposure, Vulnerability, and Capacity). For risk assessment using IBA, the risk index is calculated using the statistical data of administrative boundary units for each indicator (Benouar and Mimi, 2001; NDMI, 2015; Han et al., 2015; Lee et al., 2019). However, flood risk assessments using grid data have recently been attempted (Yu et al., 2018; Amadio et al., 2019; Park and Lee, 2019; Chen et al., 2021; Hwang et al., 2021), in which various types of statistical data can be put in to individual grids along with the location information, and time series analysis is possible without spatial restrictions, e.g., administrative boundaries (European Forum for GeoStatistics, 2011; Steinnocher et al., 2011; Freire et al., 2016; Wang et al., 2020). Therefore, in flood risk assessment using grid data characteristics, only the subjects exposed to flood risk can be selected and evaluated for each city and county. However, even in the previous studies using grid data, the risk index was calculated at the grid level to assess the risk of local areas using statistical maps, and local government-level flood risk assessment using a combination of flood risk maps and indexing method was not carried out.

For risk assessment using IBA, quantitative statistical data for each indicator constituting the item are first indexed to unify the unit and range of statistical data (Lyu et al., 2018). Min-max normalization, Z-score, T-score, etc. are mainly used as indexing methods, while differences may occur in the range, distribution, mean, and standard deviation of the index depending on the application method (Cai et al., 2016; Jelinek et al., 2021). In qualitative risk assessment, risk is evaluated using the risk index, which is calculated for each analyzed subject. If there is a bias in the distribution of raw data for each analyzed indicator, the risk index is distorted. Therefore, methods that correct the bias of raw data in indexing each indicator play an important role in the risk assessment. However, because the correction methods of root and log conversions that have been used in existing studies have limitations in improving this bias, a new method needs to be developed.

In this study, to overcome the limitations of the existing flood risk assessment method, a flood risk assessment using IBA was performed for 44 cities and counties in Gyeongsang-do Province, South Korea, from 2016 to 2019. When we assess the flood risk for local government, the indicators of the Exposure and Vulnerability which are overlapped by the flood risk map and grid data were selected. This is to consider actually exposed indicators to the flood risk. The flood risk maps for the extreme rainfall event were obtained from the Ministry of the Interior and Safety and the Ministry of the Environment. There exists bias when we do indexing statistical data and the flood risk assessment can be distorted. Therefore, we applied a method of assigning scores to the divided intervals so that statistical data distribution can have the same density based on quantiles for improving the biased flood risk assessment. Finally, the flood risk index calculated for each city and county was verified with the flood damage amount to confirm the validity of the analysis method and propose the utilization of the item indices and the flood risk index.

2. Methodology

2.1. Index and indicators for IBA

IBA is a qualitative risk assessment method mainly used in the prevention stage of disaster management. It estimates the risk index for each community, local government, and country by combining Hazard, Exposure, Vulnerability, and Capacity indices (Bollin and Hidajat, 2006; Greiving et al., 2006; Van Westen et al., 2012; Kron et al., 2019; Ming et al., 2022). Each index has indicators related to their characteristics. For example, the indicators of the Exposure index have different units, such as human and material assets, which are objects that can be exposed to risk and are indexed as dimensionless values. Entropy

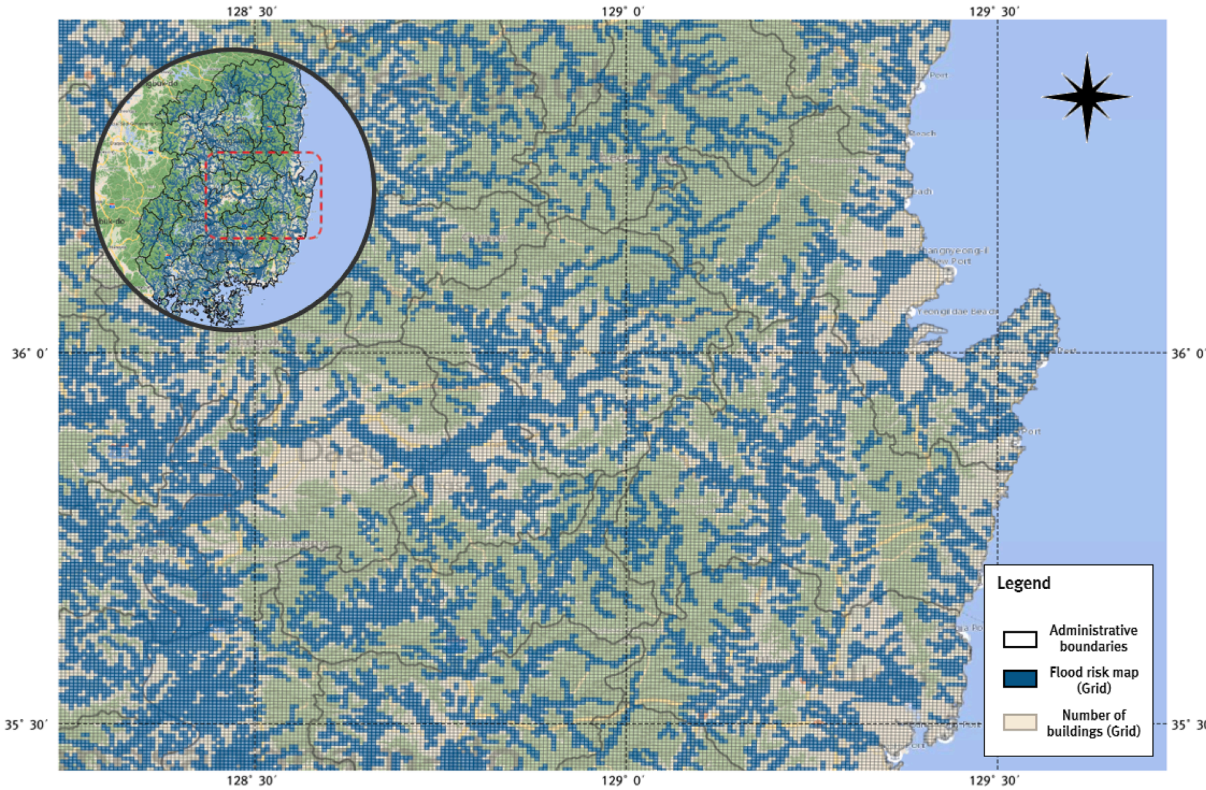


Fig. 2. Grid data of the number of buildings by city and county in the Gyeongsang-do Province and a flood risk map by grid unit.

weights are then applied to the indexed indicators, and the weighted indicators are added to obtain the Exposure index. The Hazard index consists of indicators related to disaster risk and areas of a high annual Hazard index are places in greater risk of being affected by disasters. The Vulnerability index consists of indicators that show the vulnerability of the Exposure index indicators. The Capacity index consists of indicators that contribute to reducing the target area risk. To check whether local governments are making efforts to reduce damages, verification through changes in the Capacity index can be done.

In this study, the Hazard index consisted of frequency-based rainfall (100 years frequency for 24 h, expressed in mm), maximum rainfall (in 24 h, mm). Exposure index comprised the number of buildings, registered resident population, and road area (m^2). On the other hand, the Vulnerability index consisted of the number of old buildings and the number of dependent people, while the Capacity item comprised the density of disaster prevention facilities (pcs/km^2) and the cumulative disaster prevention budget ratio (1,000 KW/km^2) (pcs: pieces, KW: Korean Won). For indicator selection, we checked not only whether the characteristics of the target item were reflected in the indicators but also whether the analysis data could be updated annually. Additionally, we comprehensively considered whether grid unit spatial analysis was possible.

Fig. 1 shows the flowchart of the flood risk index calculation procedure. Below is the detailed description:

1. Selection of statistical data for each local government by overlapping grid data for each indicator of Exposure and Vulnerability items and the flood risk map.
2. Indexing by indicators through scoring each quantile interval.
3. Calculation of an index by items by applying entropy weight to each indicator.
4. Application of min-max normalization to each item index to unify the index range from 0 to 1.
5. Calculation of the flood risk index by applying the Euclidean distance.

2.2. Selection of statistical data by indicators using grid data and flood risk map

Statistical data established by local governments were used in the previous studies for flood risk assessment, others were extracted from the spatial analysis data to be used for each indicator (e.g. number of buildings and road areas). However, statistical data cannot be used for selected subjects that are actually exposed to flood risk. Moreover, statistical data selection from spatial analysis data in a polygonal form, such as road name address electronic maps, is time-consuming. However, grid data can be analyzed in various ways without restrictions on administrative boundaries, and data processing is easy. In this study, grid data was used.

To overcome the limitations of the existing studies, the grid data for each indicator of the four indices were constructed based on the 500×500 m grid data provided by the National Geographic Information Institute. Additionally, the national, local, and small river flood risk maps of the Gyeongsang-do Province (a combination of Gyeongsangnam-do Province and Gyeongsangbuk-do Province in Korea) were overlapped with the grid data for each indicator of the Exposure and Vulnerability indices, and the grids necessary for flood risk assessment were selected. For convenience, the flood risk map was also converted into grid data. The grid unit flood risk map uses the flood damage rate as an attribute value. This is to ensure that the statistical values corresponding to the flooded area ratio can be extracted from the overlapped grid data for each indicator. Fig. 2 shows the grid data for the number of buildings distributed in Gyeongsang-do Province and the flood risk map of the grid unit. The number of buildings exposed to flood risk for each local government can be identified by applying the flood damage rate in grid units to the grid data selected from the flood risk map.

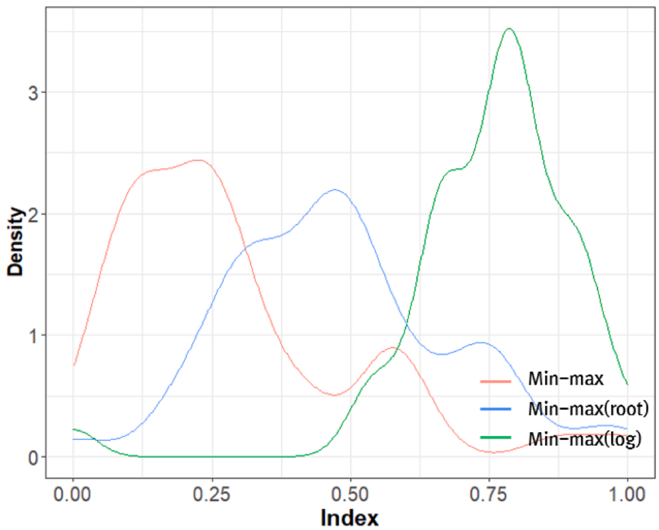


Fig. 3. The min-max normalized index of the number of buildings by cities and counties in the Gyeongsang-do Province.

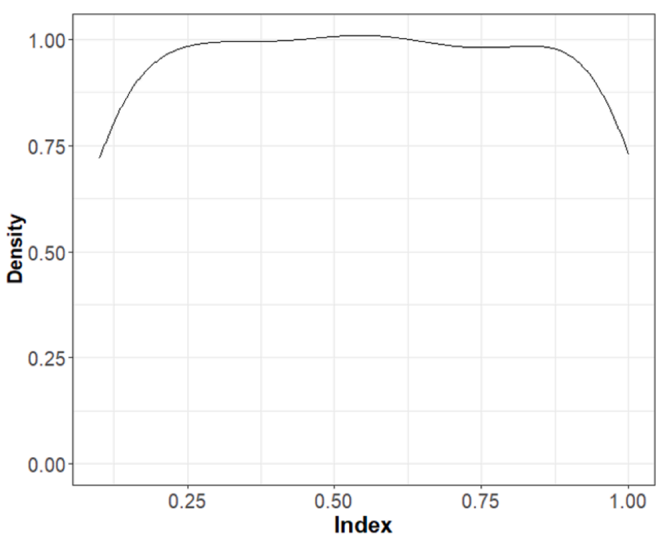


Fig. 4. Scoring each quantile interval of the number of buildings by cities and counties in the Gyeongsang-do Province.

2.3. Scoring each quantile interval

Quantitative statistical data for each indicator used in the qualitative risk assessment generally have different units for each indicator; therefore, it goes through an indexing process, e.g., min-max normalization or Z-score (Aroca-Jiménez et al., 2022). However, some statistical data do not follow a normal distribution even after indexing, leading to distribution bias in the indicators, indices, and calculated risk. To solve this problem, root or log conversion methods are applied to statistical data before indexing. However, in the case of a very large extreme value in the statistical data or low amount of data, the index does not follow a normal distribution, even after the application of root or log conversions. Fig. 3 shows the probability density function for the calculated index when simple min-max normalization is applied to the number of buildings. The same goes with when min-max normalization is applied after root transformation or log transformation. Among the 44 cities and counties in Gyeongsang-do, which include high-building density cities like Busan, Ulsan, and Daegu Metropolitan City, it can be seen that the distribution of the index is skewed to the left for the simple min-max normalized index. This bias also appeared when root or log conversions were applied. Even for the root conversion that was close to the normal distribution among the three graphs, the Shapiro-Wilk normality test resulted to a p-value of 0.00053784, which rejects the null hypothesis.

To solve this problem, this study applied a scoring of each quantile interval for calculating the index for each indicator (Wang et al., 2021). Scoring each quantile interval is a method in which the statistical data for each indicator are divided into ten equal parts based on the ten quantiles and the scores are assigned to each zone in the range of 0.1–1 at intervals of 0.1. Unlike the min-max normalization and Z-score methods, this method assigns scores for each zone with the same density, and provides indexing without distribution bias. Fig. 4 shows the application of scoring in each quantile interval on the distribution of the number of buildings in 44 cities and counties in the Gyeongsang-do Province from 2016 to 2019, and demonstrates the same density in all zones. The index for each indicator was calculated by applying the scoring for each quantile interval for nine indicators included in the four items.

2.4. Entropy weight

Analytic Hierarchy Process (AHP), Technique for Order Performance by Similarity to Ideal Solution, and entropy weight are generally applied in qualitative risk assessment to calculate the weights for each indicator and index (Chuansheng et al., 2012; Kafle and Shakya, 2018; Lee et al., 2020). Among the weight calculation methods, the entropy weight enables objective analysis because, unlike the Delphi and AHP methods that are performed through a survey, the subjectivity of the participants is excluded and only the statistical characteristics of the quantitative data are reflected (Aomar, 2010; Lee et al., 2015; Seong and Byun, 2016). Furthermore, it is possible to easily renew the weights even after updating the statistics for the latest year for each indicator. In this study, the index for each item was calculated by applying the entropy weight to the index for each indicator. Eq. (1) configures the raw data in the matrix, and Eq. (2) calculates the indices, while Eq. (3) utilizes the indexed data to calculate the entropy for each indicator. Finally, Eqs. (4) and (5) calculate the weight of each indicator using entropy.

$$D = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} (i = 1, 2, \cdots, m; j = 1, 2, \cdots n) \tag{2}$$

$$E_j = -k \sum_{i=1}^{m} p_{ij} \log p_{ij} (k = \frac{1}{\log m}; j = 1, 2, \cdots n) \tag{3}$$

$$d_j = 1 - E_j \tag{4}$$

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} (j = 1, 2, \cdots, n) \tag{5}$$

D: Matrix of raw data by indicators x_{mn}: Raw data by indicators E_j: Entropy w_j : Entropy weight.

2.5. Euclidean distance

The Euclidean distance is a method to calculate the distance between two points in the Euclidean space as defined by the mathematician Euclid. This method is often used in qualitative risk assessment instead of the equal-weight method (Mousavi et al., 2022; Ying et al., 2023). In this study, the flood risk index was calculated by applying Euclidean distance to the index was calculated. Because the four indices constitute the flood risk index, the Euclidean distance was implemented in a four-dimensional space. The calculated flood risk index ranged from 0 to 2,

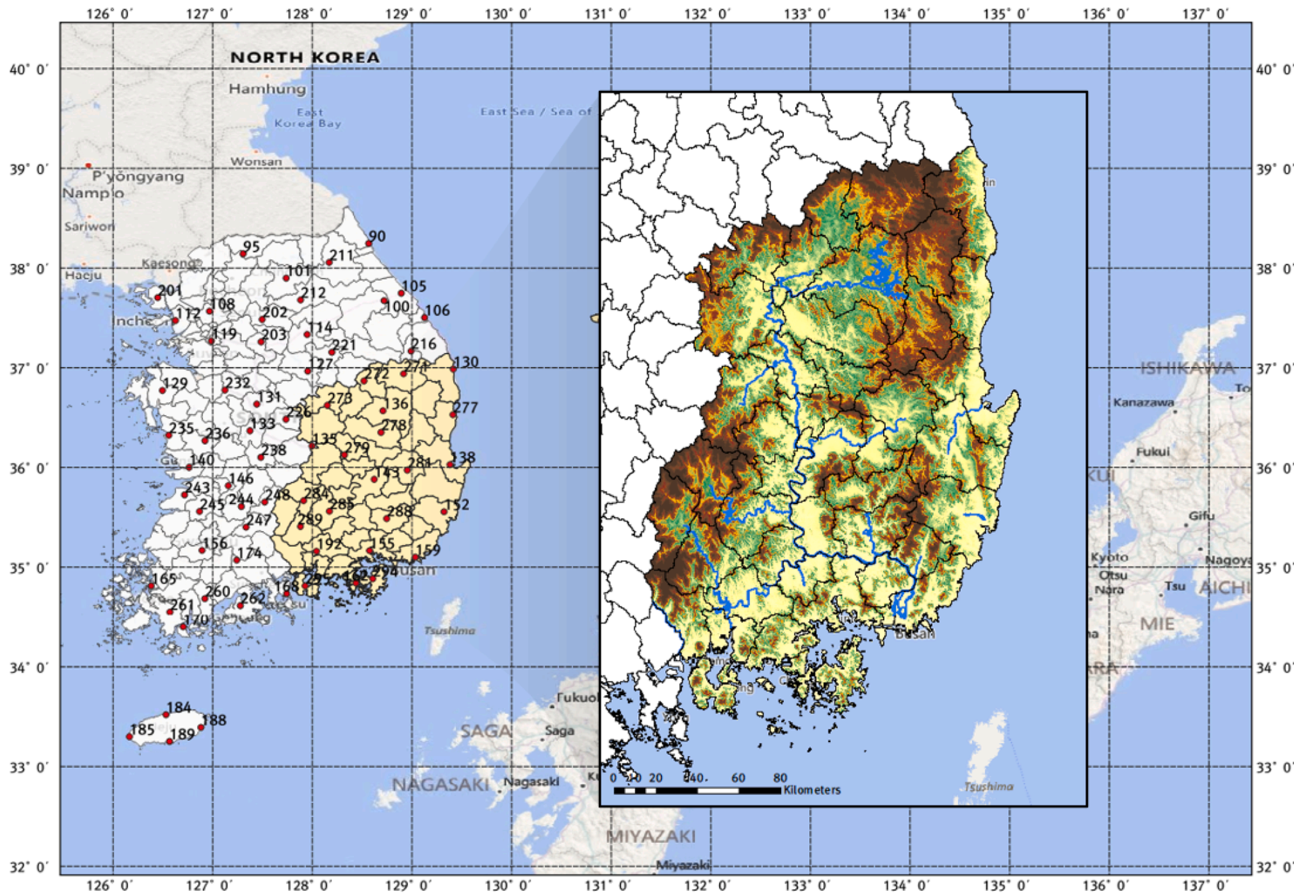


Fig. 5. Geographical characteristics of the Gyeongsang-do Province and the distribution of the Nakdong River.

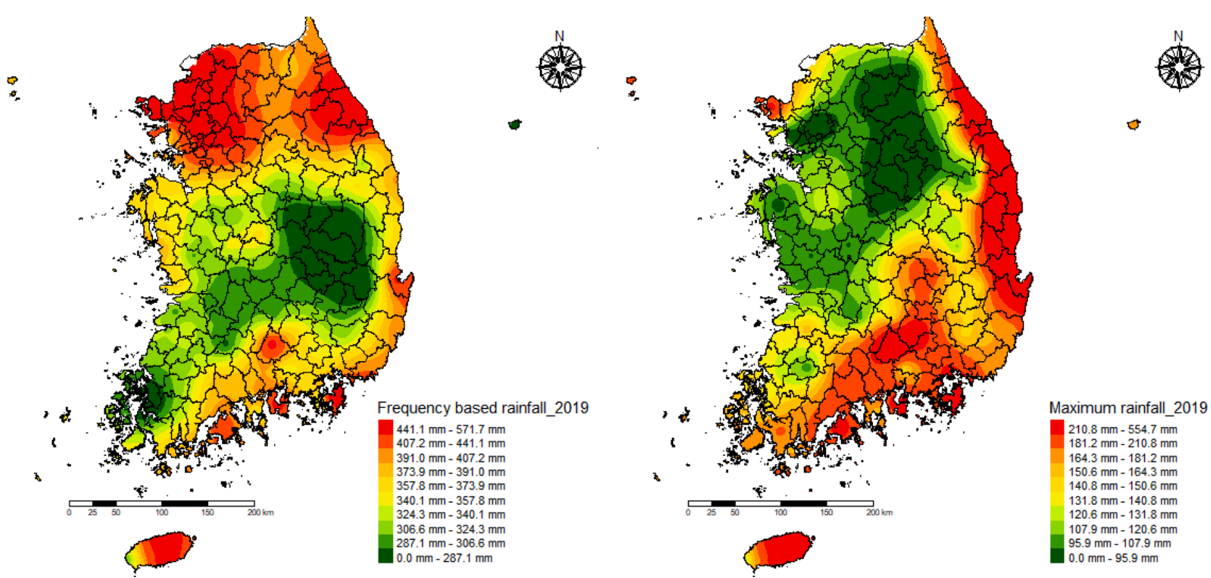


Fig. 6. 2019 National grid unit frequency-based rainfall (left) and maximum rainfall (right).

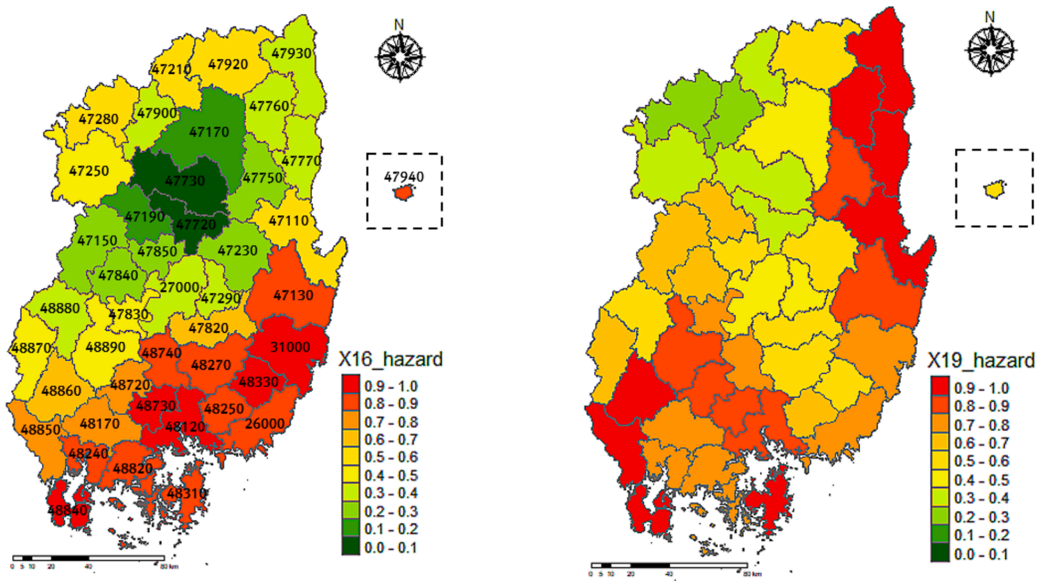
where 0 is the safest and 2 is the most dangerous. Unlike the other indices, the Capacity index is reversed in the Euclidean distance because a larger index has a positive significant value, and a smaller index has a negative significant value. Eq. (6) shows the calculation of the flood risk index by applying the Euclidean distance.

$$D = \sqrt{(Hazard)^2 + (Exposure)^2 + (Vulnerability)^2 + (1 - Capacity)^2} \quad (6)$$

3. Results

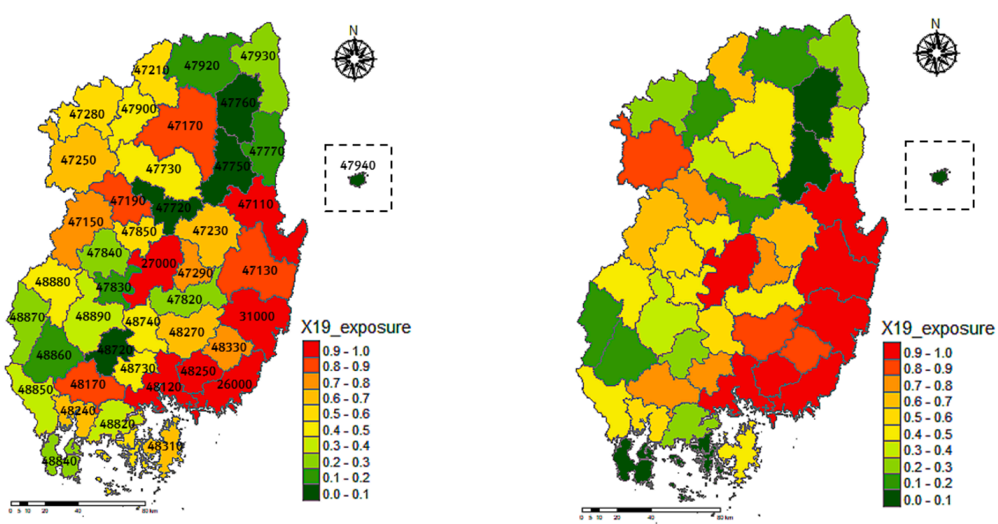
3.1. Hydrometeorological characteristics of the study area

The Gyeongsang-do Province is located in the southeastern part of the Sobaek Mountains in Korea. Excluding the Ulleung-do Island,



(a) Hazard index for 2016. (b) Hazard index for 2019.

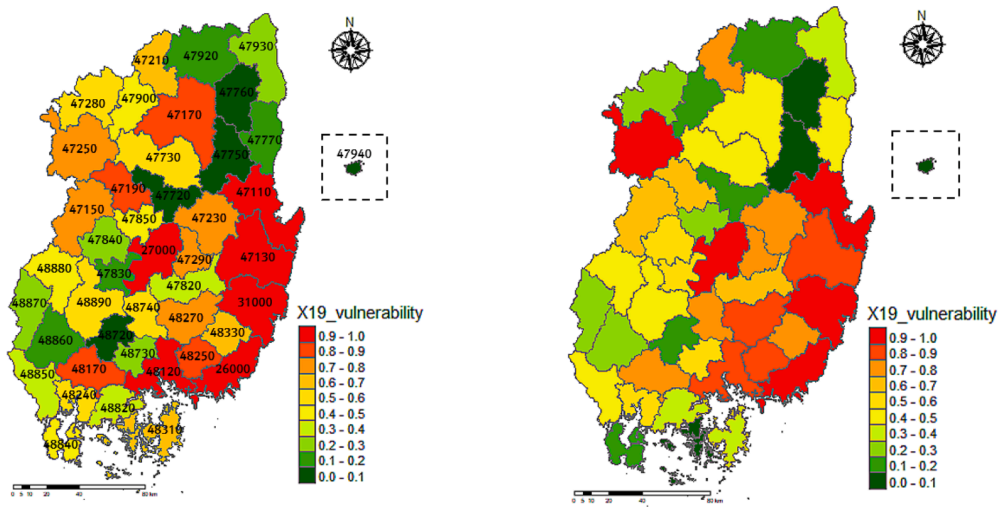
Fig. 7. Hazard index of the cities and counties in the Gyeongsang-do Province.



(a) Exposure index without overlapping the flood risk map. (b) Exposure index obtained when overlapping the flood risk map.

Fig. 8. Exposure index of the cities and counties in the Gyeongsang-do Province in 2019.

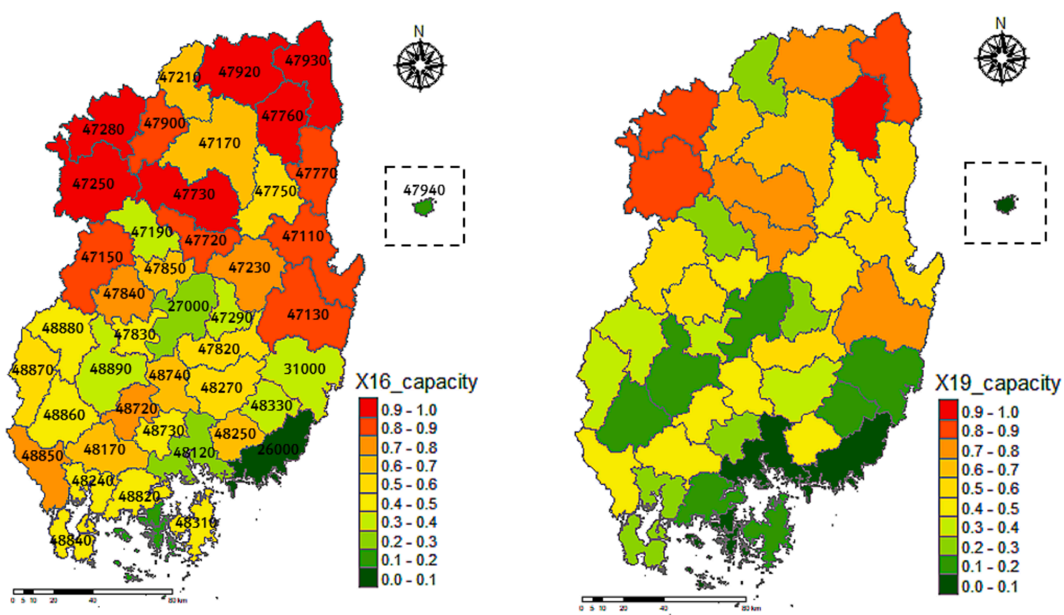
Gyeongsang-do Province is located at 127° 40′–129° 40′ and 34° 30′–37° 10′. Geographically, Gyeongsang-do Province is divided into an inland region surrounded by the Taebaek and Sobaek mountains and a coastal region adjacent to the East and South Seas. The Nakdong River, which is the longest river in South Korea, is located in this province. It has a gentle slope and a very large river regime coefficient. Therefore, before dam construction and implementation of river improvement projects, large-scale flood damage frequently occurred in the downstream cities and counties, such as Miryang, Gimhae, and Yangsan City. The Gyeongsang-do Province has 44 cities and counties, including Busan, Ulsan, and Daegu Metropolitan City, and rainfall varies with location (inland or coastal). Inland cities and counties, such as Andong, Gumi, Gimcheon, and Sangju City receive less rainfall than the national average during the rainy season. However, coastal cities and counties, such as Busan Metropolitan City, Ulsan Metropolitan City, Geoje City, and Changwon City, experience flood damage from heavy rains and typhoons each year. During the study period (2016–2019), Typhoons Chaba in 2016, Kongrei in 2018, and Mitak in 2019 affected the coastal cities and counties, causing intense flood damage. Because of the hydrometeorological characteristics of the Gyeongsang-do Province, decision-makers in each local government need accurate flood risk assessment to prepare measures to reduce flood risk. Rainfall data were gathered from the 69 nationwide automated synoptic observing systems (ASOS) as shown in Fig. 5. In the same figure, the Digital Elevation Model of the Gyeongsang-do Province and the distribution of the Nakdong River are shown.



(a) Vulnerability index without overlapping the flood risk map.

(b) Vulnerability index obtained when overlapping the flood risk map.

Fig. 9. Vulnerability index for the cities and counties in the Gyeongsang-do Province for 2019.



(a) Capacity index for 2016.

(b) Capacity index for 2019.

Fig. 10. Capacity index of the cities and counties in the Gyeongsang-do Province.

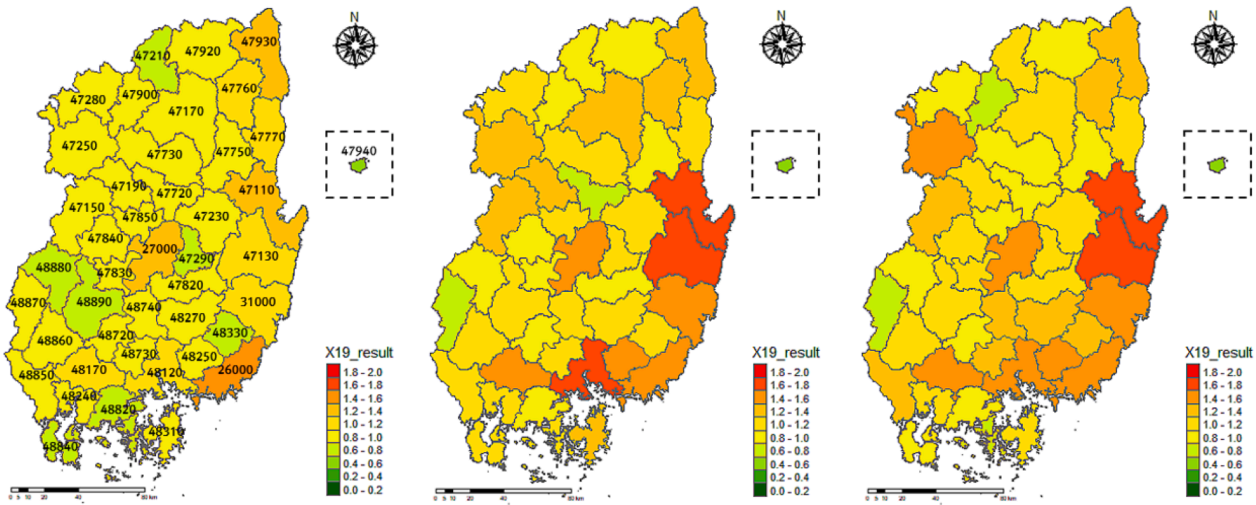
3.2. Calculation of indices

3.2.1. Hazard index

In flood risk assessment, the Hazard index is composed of frequency-based rainfall and maximum rainfall. In this study, rainfall data from the 69 ASOS provided by the National Climate Data Center were used to calculate the frequency-based rainfall and maximum rainfall for each of the 44 cities and counties in the Gyeongsang-do Province. Additionally, kriging was applied to these indicators to create grids with the same size and location as the grid data. Subsequently, the frequency-based rainfall and maximum rainfall per area were calculated during 2016–2019 by averaging the attribute values of the grids located within the administrative boundary of each city and county in the Gyeongsang-do Province. Fig. 6 shows the 2019 nationwide frequency-based rainfall and maximum rainfall in each grid unit.

After calculating the area unit frequency-based rainfall and maximum rainfall for each of the 44 cities and counties during 2016–2019, the index (0.1–1.0) for each indicator was calculated by applying scoring to each quantile interval. Subsequently, entropy weights were applied to the calculated index by indicators to obtain the Hazard index for each of the 44 cities and counties. In the case of the entropy weight, the frequency-based rainfall was calculated as 0.194, and the maximum rainfall was 0.806. Fig. 7 shows the Hazard index by city and county for 2016–2019.

The Hazard index was largely calculated for the cities and counties adjacent to the south and east coasts as the index is significantly affected by maximum rainfall, which increases owing to the annual typhoons. In 2016, the Hazard index was significantly high in the cities and counties along the southern coast, e.g., Busan Metropolitan City (26000) and Ulsan Metropolitan City (31000), which were impacted by Typhoon



(a) Min-max normalized index (Root conversion). (b) Flood risk index without the flood risk map. (c) Flood risk index with the flood risk map.

Fig. 11. Flood risk index for the cities and counties in the Gyeongsang-do Province for 2019.

Table 1
Comparison of actual damage and flood risk index for the cities and counties in Gyeongsang-do Province for 2019.

Administrative District (Code)	Actual amount of damage		Min-max normalized index (Root conversion is applied)			Flood risk index (Flood risk map isn't applied)			Flood risk index (Flood risk map is applied)		
	Damage (1000 KW)	Rank	Index	Rank	Absolute Error	Index	Rank	Absolute Error	Index	Rank	Absolute Error
Geoje City (48310)	66,305	33	0.852	23	10	1.393	9	24	1.130	22	11
Geochang County (48880)	415,307	20	0.846	24	4	0.882	34	14	0.935	34	14
Goseong County (48820)	113,230	30	0.984	8	22	0.961	31	1	0.901	35	5
Gimhae City (48250)	831,818	14	0.855	22	8	1.519	7	7	1.526	7	7
Namhae County (48840)	282,783	24	0.902	16	8	1.056	25	1	0.954	33	9
Miryang City (48270)	825,323	15	0.833	26	11	1.136	18	3	1.312	12	3
Sacheon City (48240)	172,308	27	0.900	17	10	1.116	22	5	1.085	25	2
Sancheong County (48860)	243,763	25	0.746	32	7	1.044	26	1	1.047	27	2
Yangsan City (48330)	297,462	23	0.782	31	8	1.174	17	6	1.318	11	12
Uiryeong County (48720)	463,437	18	1.169	4	14	0.947	33	15	0.988	31	13
Jinju City (48170)	162,944	28	0.943	11	17	1.559	6	22	1.407	9	19
Changnyeong County (48740)	378,959	21	0.727	34	13	1.119	21	0	1.269	15	6
Changwon City (48120)	3,321,544	6	0.657	36	30	1.659	3	3	1.536	6	0
Tongyeong City (48220)	1,116,795	11	0.930	13	2	1.133	20	9	0.781	37	26
Hadong County (48850)	231,827	26	1.104	5	21	1.134	19	7	1.205	17	9
Haman County (48730)	919,349	12	0.899	18	6	1.023	28	16	1.302	14	2
Hamyang County (48870)	69,617	32	0.872	20	12	0.791	38	6	0.776	38	6
Hapcheon County (48890)	534,968	17	1.203	2	15	1.069	24	7	1.039	28	11
Gyeongju City (47130)	12,206,593	3	0.939	12	9	1.681	2	1	1.698	2	1
Goryeong County (47830)	842,690	13	0.967	9	4	0.821	36	23	1.096	24	11
Gumi City (47190)	271	39	0.842	25	14	1.389	11	28	1.184	20	19
Gunwi County (47720)	3,482	37	1.179	3	34	0.795	37	0	0.810	36	1
Gimcheon City (47150)	2,299,977	8	0.530	39	31	1.351	13	5	1.262	16	8
Sangju City (47250)	149,834	29	1.492	1	28	1.319	14	15	1.557	5	24
Seongju County (47840)	6,579,107	4	0.831	27	23	0.952	32	28	1.169	21	17
Andong City (47170)	64,340	34	0.856	21	13	1.390	10	24	1.016	29	5
Yeongdeok County (47770)	29,379,458	2	0.684	35	33	1.104	23	21	1.195	18	16
Yeongyang County (47760)	2,203,315	9	0.822	29	20	1.311	15	6	1.311	13	4
Yeongju City (47210)	16,497	36	0.924	15	21	0.997	29	7	1.109	23	13
Yeongcheon City (47230)	1,800	38	0.622	38	0	1.180	16	22	1.194	19	19
Ulleung County (47940)	356,796	22	0.735	33	11	0.561	39	17	0.561	39	17
Uljin County (47930)	53,927,303	1	1.024	6	5	1.368	12	11	1.380	10	9
Uiseong County (47730)	73,011	31	1.006	7	24	1.035	27	4	0.995	30	1
Cheongdo County (47820)	445,115	19	0.828	28	9	0.841	35	16	1.078	26	7
Cheongsong County (47750)	555,965	16	0.802	30	14	0.963	30	14	0.962	32	16
Pohang City (47110)	5,204,992	5	0.949	10	5	1.745	1	4	1.758	1	4
Daegu (27000)	24,498	35	0.925	14	21	1.504	8	27	1.504	8	27
Busan (26000)	1,931,608	10	0.630	37	27	1.592	4	6	1.592	3	7
Ulsan (31000)	2,772,836	7	0.898	19	12	1.585	5	2	1.585	4	3
Sum of Absolute Error			576			428			386		
Mean Absolute Error (MAE)			14.769			10.974			9.897		
Root Mean Square Error (RMSE)			16.839			13.686			11.930		

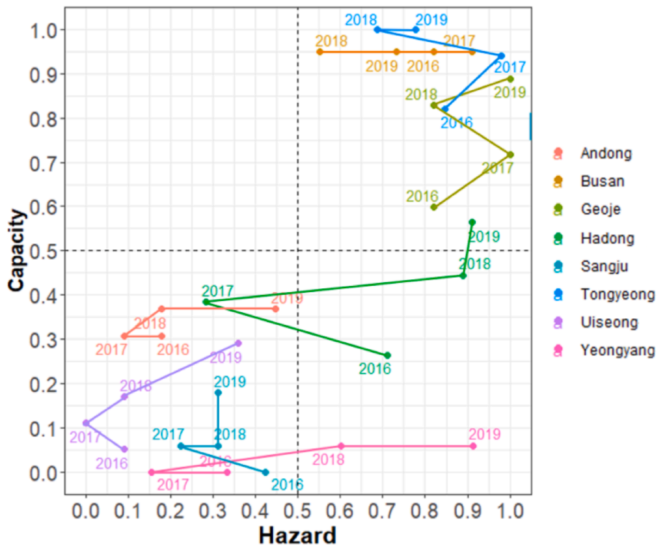


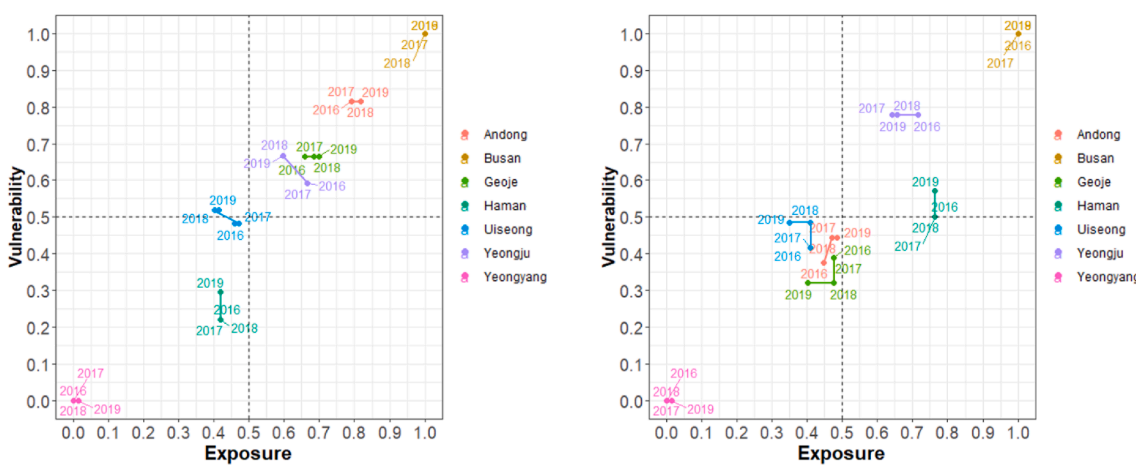
Fig. 12. Changes in annual Hazard and Capacity indices of the cities and counties in the Gyeongsang-do Province.

Chaba. Additionally, in 2019, the Hazard index was highly calculated in Pohang (47110), Uljin (47930), and Yeongdeok (47770) owing to the impact of Typhoon Mitak.

3.2.2. Exposure index

The Exposure and Vulnerability indices were calculated using statistical data selected by overlapping the grid data and flood risk maps for each indicator, rather than the statistical data of the cities and counties (See Section 2). Under Exposure, the entropy weight was 0.221 for the number of buildings, 0.656 for the registered resident population, and 0.123 for the road area. Urbanized areas tend to have a high Exposure index due to the high number of population and residential buildings compared to the rural areas. Fig. 8 shows the Exposure index of the cities and counties calculated using the statistical data of 2019 and the Exposure index calculated by selecting the grid data overlapped with the flood risk map.

Since there is no significant change in indicators such as the number of buildings and the number of registered residents in the annual statistics of cities and counties, the Exposure index does not fluctuate greatly from year to year. However, the exposure index was significantly high in major cities and counties, such as Busan (26000), Daegu (27000), and Ulsan Metropolitan City (31000), due to high building and population density. Because Busan and Ulsan Metropolitan City have a large Hazard index, the flood risk will increase in the absence of proper disaster prevention capabilities. When comparing the exposure index calculated with statistical data and flood risk map, clear differences can be found in some cities and counties. For example, for Andong City (47170), the indices of the number of buildings, registered resident population, and road area were 0.9, 0.8, and 0.9, respectively, using the statistical data of 2019. However, when grid data and flood risk maps were used, the indices for each indicator were 0.5, 0.5, and 0.8, respectively, confirming that the number of buildings and population directly exposed to flood risk was less. Since Andong City has a valley-shaped terrain structure, flood hazard maps are widely distributed in the downstream plain where agricultural land is distributed, and the area of flood risk maps is small in the downtown area of Andong City where buildings and population are densely concentrated. For this



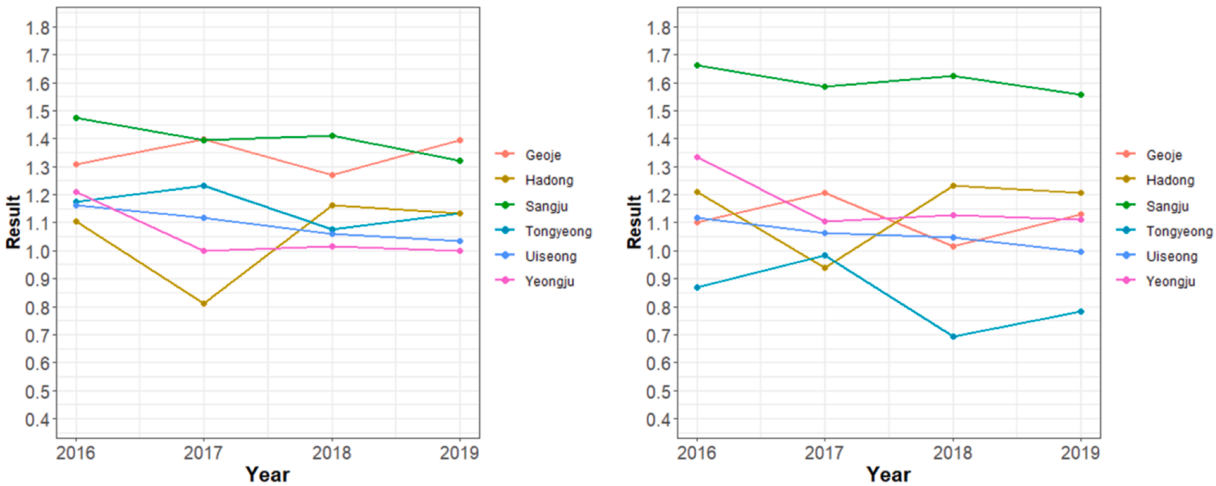
(a) Exposure and Vulnerability indices without overlapping the flood risk map.

(a) Exposure and Vulnerability indices obtained when overlapping the flood risk map.

Fig. 13. Changes in the annual Exposure and Vulnerability indices of cities and counties in the Gyeongsang-do Province.

Table 2
Comparison of the annual flood risk index of the cities and counties in the Gyeongsang-do Province.

Administrative District (Code)	Flood risk index (Flood risk map is not applied)				Flood risk index (Flood risk map is applied)			
	2016	2017	2018	2019	2016	2017	2018	2019
Geoje City (48310)	1.308	1.398	1.271	1.393	1.101	1.207	1.015	1.130
Hadong County (48850)	1.105	0.811	1.160	1.134	1.210	0.938	1.233	1.205
Sangju City (47250)	1.472	1.393	1.410	1.319	1.661	1.585	1.623	1.557
Tongyeong City (48220)	1.175	1.230	1.074	1.133	0.867	0.982	0.692	0.781
Uiseong County (47730)	1.162	1.115	1.060	1.035	1.117	1.063	1.048	0.995
Yeongju City (47210)	1.208	1	1.015	0.997	1.334	1.105	1.125	1.109



(a) Flood risk index without overlapping the flood risk map.

(b) Flood risk index with an overlapped flood risk map.

Fig. 14. Change in the annual flood risk index of cities and counties in the Gyeongsang-do Province.

Table A1
Raw data of Hazard item by indicators for 44 cities and counties in Gyeongsang-do Province.

Administrative District	Frequency based rainfall (mm)				Maximum rainfall (mm)			
	2016	2017	2018	2019	2016	2017	2018	2019
Geoje City	442	458	453	447	187	269	188	238
Geochang County	313	310	309	311	131	88	158	158
Goseong County	366	376	373	372	223	162	176	192
Gimhae City	374	381	379	374	221	143	149	180
Namhae County	436	437	434	434	242	137	244	214
Miryang City	328	331	334	330	236	77	177	157
Sacheon City	377	382	381	379	205	111	207	177
Sancheong County	411	409	408	414	161	80	227	241
Yangsan City	372	374	375	369	226	129	154	164
Uiryeong County	355	354	355	360	188	106	187	209
Jinju City	361	364	365	365	190	96	189	182
Changnyeong County	328	329	330	332	203	90	179	185
Changwon City	368	375	372	372	237	122	138	203
Tongyeong City	359	375	371	370	218	229	177	193
Hadong County	391	392	391	391	180	94	212	199
Haman County	351	354	353	355	226	98	157	199
Hamyang County	347	345	346	349	142	81	202	181
Hapcheon County	350	345	345	353	149	116	191	217
Gyeongsan City	273	274	274	274	153	81	144	145
Gyeongju City	358	352	356	366	197	95	164	213
Goryeong County	312	309	310	315	141	104	169	189
Gumi City	260	266	255	263	116	90	119	181
Gunwi County	241	261	240	245	107	85	112	153
Gimcheon City	290	284	283	290	120	93	154	176
Mungyeong City	290	281	280	278	161	127	120	113
Bonghwa County	346	343	339	345	155	91	127	160
Sangju City	296	286	283	286	147	116	134	139
Seongju County	292	290	289	296	125	94	149	183
Andong City	247	255	246	252	115	96	123	155
Yeongdeok County	304	304	316	355	132	101	222	336
Yeongyang County	299	301	304	336	130	96	171	291
Yeongju City	329	327	322	320	162	89	133	128
Yeongcheon City	254	258	255	260	132	92	133	166
Yecheon County	270	269	263	262	143	107	118	129
Ulleung County	271	268	269	274	244	95	73	169
Uljin County	318	318	321	374	134	93	166	407
Uiseong County	232	260	231	234	105	90	105	140
Cheongdo County	307	308	310	309	196	79	167	154
Cheongsong County	274	285	279	298	121	96	163	230
Chilgok County	266	272	266	272	115	83	129	174
Pohang City	360	357	362	386	163	91	192	277
Daegu	284	286	286	288	136	80	152	157
Busan	402	410	407	400	187	198	146	178
Ulsan	385	380	381	380	239	110	148	175

Table A2
Raw data of Exposure item by indicators for 44 cities and counties in Gyeongsang-do Province (Flood risk map is not applied).

Administrative District	Number of buildings				Number of registered residents				Road area (m^2)			
	2016	2017	2018	2019	2016	2017	2018	2019	2016	2017	2018	2019
Geoje City	35,563	36,077	36,452	36,663	257,183	254,073	250,516	248,276	10,723,859	10,789,828	10,787,325	10,942,981
Geochang County	28,111	28,396	28,649	28,853	63,308	62,763	62,455	62,179	11,666,741	12,024,237	12,422,720	12,464,787
Goseong County	29,662	29,907	30,007	30,212	54,703	54,060	53,243	52,276	12,840,378	12,901,605	12,931,775	13,373,304
Gimhae City	58,425	59,345	59,850	60,415	529,422	532,132	533,672	542,455	19,179,644	19,530,026	19,725,789	20,511,175
Namhae County	30,568	30,811	31,068	31,284	45,129	44,642	43,990	43,622	6,835,438	6,863,355	6,916,063	7,283,883
Miryang City	47,909	48,473	48,968	49,477	108,354	107,898	106,744	105,552	14,956,293	14,979,966	15,108,218	15,212,251
Sacheon City	33,749	34,107	34,548	34,834	114,912	114,252	113,888	111,925	11,516,009	11,780,275	11,800,018	11,753,185
Sancheong County	24,684	24,952	25,150	25,483	36,098	36,340	35,952	35,417	12,419,970	13,626,534	13,327,462	13,794,530
Yangsan City	29,211	30,135	30,750	30,958	317,037	338,535	348,639	350,759	14,210,331	14,715,905	15,024,230	15,294,699
Uiryeong County	19,371	19,477	19,602	19,676	28,111	27,849	27,667	27,168	7,788,559	7,898,887	7,905,363	8,030,806
Jinju City	62,623	63,124	63,605	64,087	346,739	346,681	345,987	347,334	21,494,960	21,543,708	21,621,400	21,716,959
Changnyeong County	35,747	36,177	36,515	36,977	63,982	64,101	63,396	62,331	10,265,750	10,317,835	10,372,635	10,474,328
Changwon City	83,640	123,691	122,991	123,257	1,063,907	1,057,032	1,053,601	1,044,740	33,519,228	33,616,356	34,080,114	36,263,563
Tongyeong City	31,580	31,675	31,820	31,631	138,160	135,833	133,720	131,404	6,419,706	6,178,604	6,172,689	6,587,383
Hadong County	29,041	29,311	29,571	29,787	49,622	48,831	47,533	46,574	11,446,989	11,452,508	11,454,407	11,770,587
Haman County	28,242	28,560	28,789	29,007	68,937	68,207	67,025	65,700	11,870,063	12,103,832	12,121,873	12,444,989
Hamyang County	23,035	23,296	23,541	23,733	40,241	40,175	40,044	39,637	11,793,747	10,908,370	10,921,506	10,973,810
Hapcheon County	32,294	32,582	32,838	33,093	48,026	47,000	45,916	45,204	14,763,629	14,948,754	14,955,969	15,705,358
Gyeongsan City	42,106	42,490	42,884	39,263	258,037	259,485	261,093	263,185	15,613,849	15,633,408	16,011,377	16,873,480
Gyeongju City	74,242	75,386	76,300	77,107	259,452	257,903	256,864	255,402	28,943,023	30,207,653	30,245,630	30,861,126
Goryeong County	18,098	18,216	18,303	18,455	34,257	33,768	32,969	32,373	7,683,369	7,823,855	7,824,316	7,914,846
Gumi City	51,285	51,962	52,533	53,230	419,891	421,799	421,494	419,742	19,515,475	19,851,366	20,940,587	21,405,123
Gunwi County	16,408	16,568	16,717	16,880	24,171	24,215	23,919	23,843	7,114,519	7,127,408	7,895,483	8,042,330
Gimcheon City	48,310	48,898	49,678	50,308	142,256	142,908	141,104	141,229	18,064,230	18,114,540	18,189,209	18,249,320
Mungyeong City	35,637	35,920	36,226	36,516	74,702	73,294	71,874	72,242	12,490,288	12,506,621	12,538,613	12,725,104
Bonghwa County	20,143	20,396	20,559	20,708	33,539	33,259	32,843	32,150	11,228,498	11,567,088	11,676,385	12,551,316
Sangju City	55,051	55,626	56,214	53,088	101,799	100,947	100,297	100,688	21,395,023	21,643,941	21,771,765	21,927,717
Seongju County	26,655	27,036	27,321	27,575	45,205	45,138	44,672	44,015	11,267,027	11,465,590	11,564,309	11,884,545
Andong City	52,064	52,657	53,091	53,605	168,798	166,272	162,180	160,052	23,337,229	24,115,851	24,253,174	24,977,668
Yeongdeok County	19,098	19,380	19,676	19,918	39,052	38,529	38,108	37,361	6,699,038	8,204,219	8,205,938	7,468,485
Yeongyang County	11,288	11,356	11,443	11,550	17,713	17,479	17,356	16,993	7,138,625	7,175,772	7,197,017	8,086,554
Yeongju City	38,364	38,396	38,764	39,040	109,247	108,371	106,801	105,067	14,656,359	14,861,972	15,815,917	15,632,928
Yeongcheon City	41,463	41,979	42,375	42,646	100,521	100,615	101,595	102,470	16,463,473	17,653,076	18,519,542	19,223,660
Yecheon County	28,059	28,373	28,627	28,919	46,166	49,253	53,274	55,100	12,803,288	13,182,683	13,208,826	13,283,062
Ulleung County	4,348	4,364	4,370	4,388	10,001	9,975	9,832	9,617	995,997	999,173	1,049,870	1,101,350
Uljin County	22,348	22,532	22,686	22,840	51,738	50,974	50,036	49,314	10,586,082	10,659,372	10,681,067	10,721,831
Uiseong County	34,385	34,565	34,730	34,929	54,014	53,474	52,944	52,595	11,329,411	12,579,640	12,688,406	13,804,111
Cheongdo County	27,310	27,704	28,074	28,352	43,564	43,346	43,057	42,910	9,749,627	9,797,893	9,842,275	9,871,485
Cheongsong County	13,596	13,834	14,041	14,315	26,301	26,006	25,678	25,416	7,328,661	7,601,638	7,638,201	9,292,817
Chilgok County	29,121	29,732	30,230	30,695	123,199	120,864	118,828	117,047	12,344,671	12,780,800	12,804,350	14,010,102
Pohang City	86,996	87,744	88,428	89,177	516,775	513,832	510,013	507,025	28,473,862	29,297,723	30,565,391	30,876,961
Daegu	253,954	254,432	252,958	250,225	2,484,557	2,475,231	2,461,769	2,438,031	56,580,799	57,394,406	57,936,666	60,172,715
Busan	372,452	369,945	366,927	361,520	3,498,529	3,470,653	3,441,453	3,413,841	57,303,032	58,424,395	58,865,289	59,533,014
Ulsan	134,152	135,575	136,645	137,385	1,172,304	1,165,132	1,155,623	1,148,019	38,678,166	44,836,992	45,634,038	46,507,635

Table A3
Raw data of Exposure item by indicators for 44 cities and counties in Gyeongsang-do Province (Flood risk map is applied).

Administrative District	Number of buildings				Number of registered residents				Road area (m^2)			
	2016	2017	2018	2019	2016	2017	2018	2019	2016	2017	2018	2019
Geoje City	4,163	4,175	4,180	4,174	21,261	20,798	19,681	19,248	4,877,304	4,927,790	4,924,802	5,034,000
Geochang County	7,246	7,267	7,045	7,061	12,961	12,795	13,114	13,099	8,130,263	8,344,430	8,620,704	8,649,702
Goseong County	8,882	8,955	8,820	8,864	8,030	7,937	7,985	7,835	8,697,361	8,732,424	8,748,250	9,088,999
Gimhae City	24,178	24,371	24,507	23,816	73,683	80,113	81,631	87,191	12,967,682	13,023,683	13,082,301	13,818,365
Namhae County	5,120	5,142	5,151	5,173	3,310	3,278	3,206	3,168	3,599,769	3,617,470	3,665,490	3,898,567
Miryang City	24,318	24,476	24,584	24,667	24,523	24,346	23,883	24,051	11,112,083	11,128,087	11,248,153	11,313,586
Sacheon City	12,306	12,196	12,070	11,866	19,451	19,380	19,134	18,407	6,788,320	6,919,736	6,928,859	6,954,450
Sancheong County	5,047	5,066	5,084	5,128	3,433	3,435	3,436	3,339	7,595,568	8,371,753	8,187,131	8,426,786
Yangsan City	11,695	11,355	11,291	11,109	104,867	111,736	115,504	116,547	10,151,127	10,371,170	10,531,166	10,682,176
Uiryeong County	9,022	9,019	9,015	8,822	7,996	7,893	8,006	7,994	5,825,322	5,920,922	5,923,021	6,024,997
Jinju City	11,864	11,930	11,953	11,989	31,170	31,326	31,145	31,221	13,086,412	13,117,539	13,148,674	13,152,590
Changnyeong County	18,263	18,417	18,121	17,557	19,728	19,846	19,749	19,237	7,987,174	8,031,657	8,073,393	8,134,513
Changwon City	25,228	25,115	24,692	24,546	66,972	66,795	66,162	65,820	20,207,562	20,255,515	20,450,098	21,130,040
Tongyeong City	1,980	1,982	1,911	1,911	4,635	4,610	4,456	4,265	1,830,397	1,765,614	1,766,352	1,940,385
Hadong County	9,790	9,839	9,842	9,804	11,614	11,350	11,289	11,183	7,907,932	7,911,127	7,913,025	8,184,125
Haman County	16,292	16,378	16,495	16,567	28,699	28,477	28,137	27,487	10,217,082	10,397,793	10,414,793	10,698,375
Hamyang County	5,389	5,339	5,321	5,274	5,350	5,348	5,309	5,136	8,729,756	8,079,998	8,089,167	8,124,532
Hapcheon County	10,078	10,103	10,103	10,026	9,288	9,100	8,963	8,814	9,865,200	9,860,658	9,865,428	10,132,123
Gyeongsan City	13,211	13,232	13,311	13,398	30,993	31,427	31,120	31,324	9,404,193	9,424,215	9,491,776	9,913,707
Gyeongju City	24,022	24,222	24,367	24,455	35,516	36,961	38,399	39,183	19,494,580	19,998,176	20,023,444	20,338,434
Goryeong County	10,156	10,222	10,265	10,317	12,983	12,790	12,616	12,372	6,602,897	6,729,649	6,729,649	6,788,657
Gumi City	13,421	13,393	13,593	13,841	19,650	20,484	21,290	20,797	10,794,181	11,038,553	11,619,695	11,867,553
Gunwi County	4,721	4,746	4,766	4,781	3,808	3,785	3,749	3,655	4,701,290	4,707,229	5,142,151	5,169,339
Gimcheon City	10,581	10,642	10,748	10,840	22,651	22,623	22,124	22,602	11,929,516	11,942,601	11,981,340	12,023,704
Mungyeong City	6,478	6,499	6,534	6,563	6,717	6,584	6,420	6,389	8,300,016	8,307,047	8,326,298	8,429,829
Bonghwa County	3,688	3,700	3,658	3,655	5,865	5,787	5,703	5,547	6,868,265	7,161,361	7,244,803	7,765,166
Sangju City	19,097	19,201	19,273	19,138	36,148	35,621	35,209	34,804	12,460,173	12,572,231	12,632,759	12,697,085
Seongju County	9,891	9,959	9,972	10,016	13,284	13,197	13,081	12,857	8,429,280	8,618,466	8,710,078	8,928,573
Andong City	8,997	9,045	9,072	9,091	11,220	10,905	10,597	10,431	9,969,013	10,362,795	10,467,004	10,800,368
Yeongdeok County	6,349	6,413	6,459	6,378	8,865	8,829	8,700	8,551	4,721,190	5,604,974	5,606,693	5,150,327
Yeongyang County	2,534	2,542	2,554	2,563	1,477	1,459	1,431	1,422	4,831,464	4,850,747	4,870,109	5,527,062
Yeongju City	11,082	10,875	10,879	10,888	23,617	23,166	22,546	21,924	10,300,679	10,376,808	11,094,116	10,843,777
Yeongcheon City	15,238	15,286	15,319	15,376	16,118	15,737	16,328	17,174	10,352,135	10,932,602	11,455,734	11,912,001
Yecheon County	5,345	5,356	5,362	5,190	4,368	4,276	4,182	4,009	7,756,209	7,990,231	8,005,584	8,049,371
Ulleung County	67	68	68	68	98	96	96	91	294,227	294,227	307,193	313,492
Uljin County	4,661	4,629	4,605	4,516	9,643	9,574	9,497	9,165	6,271,370	6,308,053	6,316,565	6,363,297
Uiseong County	10,985	10,809	10,776	10,755	8,273	8,206	8,083	7,972	9,040,816	9,730,705	9,810,351	10,518,748
Cheongdo County	13,065	13,150	13,229	13,324	10,185	10,145	9,954	9,893	7,895,867	7,932,257	7,963,340	7,986,081
Cheongsong County	2,289	2,310	2,324	2,348	2,147	2,105	2,076	2,040	5,035,570	5,261,497	5,287,501	6,053,851
Chilgok County	4,650	4,715	4,736	4,798	11,434	10,958	11,392	12,321	7,655,805	7,972,321	7,992,115	8,826,655
Pohang City	25,607	25,468	25,172	25,211	86,358	84,643	82,367	81,094	14,136,840	14,541,565	15,064,919	15,225,761
Daegu	37,678	37,721	37,767	37,679	260,354	265,272	268,483	265,528	26,677,395	27,040,236	27,365,523	27,963,468
Busan	42,880	43,022	42,706	42,602	143,189	141,122	138,544	135,482	22,497,334	22,860,936	23,194,575	23,556,407
Ulsan	26,685	26,749	26,900	27,040	167,226	167,151	167,372	164,498	20,924,809	24,617,635	24,987,958	25,392,965

reason, there is a large difference in the index by indicator depending on whether the flood risk map is applied or not in Andong City.

3.2.3. Vulnerability index

Vulnerability indicators consist of the number of old buildings and the number of dependent people. In this study, old buildings were defined as those >20 years old based on the date of approval for use of the building, and the dependent population was defined as the population under the age of 7 and over 65, ages that would need assistance in the event of a disaster. Entropy weight for the number of old buildings was 0.372, and 0.628 for the number of dependent people. Fig. 9 shows the Vulnerability index of each city and county calculated using the statistical data of 2019 and that calculated by grid data overlapped with flood risk map.

Noticeable differences were observed in the Vulnerability indices calculated using the two techniques in specific cities and counties. For example, in Tongyeong City (48220), the number of old buildings and the number of dependent population calculated using statistical data were 0.6 and 0.7, respectively, and using the flood risk map were both 0.1. The difference between the two results is due to the small number and size of rivers adjacent to the downtown area. Since Tongyeong City has a large number of islands, the number of old buildings and dependent people exposed to flood risk is small. Conversely, in the Goryeong County (47830), the indicators calculated using statistical data were both 0.2 while those calculated using the flood risk map were 0.7 and 0.6, respectively. Compared to other cities and counties, Goryeong County has fewer old buildings and dependent people but the Anrimcheon, Hoecheon, and Sogacheon Streams flow across the city center which makes them vulnerable to flood risk. Additionally, since the Nakdong River flows along the administrative boundary, the number of old buildings and dependent people directly exposed to flood risk is larger than those of the other cities and counties.

3.2.4. Capacity index

Capacity indicators include the disaster prevention facility density and cumulative disaster prevention budget ratio, which contribute to reducing flood risk. The disaster prevention facility density is the sum of river, reservoir, waterproofing, erosion control, and sea relief facilities installed by local governments through disaster prevention projects divided by the area of the local government. The cumulative disaster prevention budget ratio is calculated by dividing the cumulative sum of the [025 Disaster Prevention and Civil Defense] budget and the [141 water resources] budget for each local government divided by the area of the local government since 2012.

Unlike the other flood risk index equations, the Capacity index in Equation (6) do not have inverse relationship to the flood risk index used

Table A4
Raw data of Vulnerability item by indicators for 44 cities and counties in Gyeongsang-do Province (Flood risk map is not applied).

Administrative District	Number of old buildings				Number of dependent people			
	2016	2017	2018	2019	2016	2017	2018	2019
Geoje City	19,682	20,059	20,285	20,560	47,274	46,993	46,626	46,368
Geochang County	18,819	19,030	19,206	19,431	19,570	19,646	19,854	20,120
Goseong County	21,179	21,331	21,323	21,405	17,855	17,902	18,101	18,281
Gimhae City	28,648	29,576	30,277	31,482	91,097	92,256	93,510	97,085
Namhae County	21,224	21,681	21,948	22,088	17,764	17,702	17,686	17,902
Miryang City	29,715	30,351	30,784	31,373	32,081	32,917	33,630	34,603
Sacheon City	22,065	22,449	22,709	22,938	30,146	30,194	30,513	30,845
Sancheong County	14,380	14,771	15,055	15,320	13,601	13,731	13,930	14,201
Yangsan City	13,209	13,451	13,739	14,029	62,647	68,357	71,426	73,602
Uiryeong County	4,251	4,533	4,782	4,950	10,962	10,914	10,966	11,021
Jinju City	42,076	42,601	42,947	43,507	74,730	75,775	77,506	79,734
Changnyeong County	24,438	24,869	25,201	25,583	20,937	21,341	21,616	22,131
Changwon City	69,542	70,589	70,866	71,919	196,677	200,601	206,065	212,343
Tongyeong City	21,523	21,754	21,941	21,798	32,144	32,062	32,175	32,508
Hadong County	18,922	19,393	19,712	20,024	17,001	16,996	17,127	17,390
Haman County	5,073	5,586	5,699	5,937	18,832	18,977	19,063	19,374
Hamyang County	14,790	15,077	15,246	15,365	14,493	14,509	14,618	14,888
Hapcheon County	23,591	23,984	24,230	24,427	19,279	19,207	19,088	19,243
Gyeongsan City	23,741	24,165	24,349	22,633	56,174	57,476	58,587	60,195
Gyeongju City	44,675	45,290	45,938	46,648	65,269	66,598	67,926	69,901
Goryeong County	12,445	12,598	12,641	12,747	11,075	11,154	11,218	11,387
Gumi City	24,524	25,165	25,860	26,593	67,787	69,095	69,548	70,042
Gunwi County	10,491	10,706	10,785	10,882	9,195	9,350	9,449	9,757
Gimcheon City	25,942	26,665	27,410	27,945	38,829	39,646	40,148	40,905
Mungyeong City	23,710	24,087	24,233	24,408	24,027	24,240	24,365	24,933
Bonghwa County	13,881	14,062	14,187	14,257	12,637	12,757	12,849	13,009
Sangju City	33,637	34,481	34,934	33,277	33,650	34,040	34,508	35,247
Seongju County	15,684	16,026	16,255	16,459	15,030	15,280	15,528	15,806
Andong City	36,389	37,006	37,447	37,734	46,721	47,203	47,157	47,810
Yeongdeok County	11,773	12,088	12,413	12,610	15,023	15,191	15,322	15,514
Yeongyang County	6,616	6,718	6,785	6,843	6,201	6,283	6,386	6,502
Yeongju City	25,419	25,376	25,522	25,664	31,563	32,095	32,733	33,134
Yeongcheon City	26,459	27,080	27,429	27,756	31,228	31,803	32,495	33,654
Yecheon County	18,519	18,843	19,028	19,113	18,006	18,816	19,790	20,442
Ulleung County	3,043	3,063	3,064	3,065	2,313	2,416	2,456	2,524
Uljin County	15,959	16,166	16,355	16,466	15,958	15,976	16,063	16,197
Uiseong County	23,699	23,938	24,226	24,351	22,558	22,871	23,122	23,635
Cheongdo County	16,088	16,650	16,974	17,211	16,468	16,812	17,099	17,563
Cheongsong County	7,883	8,104	8,238	8,334	9,105	9,267	9,453	9,694
Chilgok County	12,522	12,787	12,992	13,424	25,888	25,643	25,589	25,679
Pohang City	37,565	38,726	39,531	40,557	107,636	110,432	113,530	117,617
Daegu	180,186	179,990	178,742	177,374	501,015	512,306	522,897	536,133
Busan	253,875	251,742	249,378	245,814	772,032	790,173	811,140	838,556
Ulsan	69,458	71,215	71,891	73,263	201,584	206,225	210,371	216,523

in this study (Ahmed et al., 2021). Fig. 10 shows the inverted Capacity index for cities and counties for 2016 and 2019.

Capacity index was observed to improve from 2016 to 2019 in most local governments located in the south (Fig. 10). Furthermore, among the 44 cities and counties, Tongyeong City (48220), Changwon City (48120), Ulleung County (47940), and Busan Metropolitan City (26000) had the highest Capacity index as of 2019. In particular, the Capacity index of the Yeongju City (47210) improved the most showing 0.615 in 2016 to 0.265 in 2019, indicating its efforts to strengthen disaster prevention capabilities.

3.3. Calculation and verification of flood risk index by local governments

Flood risk index for 2016–2019 was calculated by applying the Euclidean distance to the four indices calculated each year for the 44 cities and counties in the Gyeongsang-do Province. Fig. 11 shows the flood risk index by city and county in Gyeongsang-do Province as of 2019. Fig. 11(a) is the flood risk index calculated by min-max normalization after root conversion of statistical data for each indicator without overlapping the flood risk map. On the other hand, (b) is the flood risk index calculated by sectional scoring using quantiles without overlapping the flood risk map, and (c) is the result when both the flood risk map and sectional scoring were applied. The entropy weights for each indicator used in the calculation of the three flood risk indices are all the same.

Table 1 shows the absolute error between the flood damage amount rankings (excluding ship and port damage) and the flood risk index rankings calculated using the three methods.

As a result, the sum of the absolute errors of the flood risk index calculated using the proposed method is 386, the MAE is 9.897, and the RMSE is 11.930. When the min-max normalization used in the existing method was changed to the sectional scoring using quantiles, a noticeable improvement was observed. In addition, it was confirmed that the RMSE, MAE and absolute errors have improved compared to the other two methods.

Thus, it can be seen that when evaluating the flood risk in each local government, a more accurate result can be obtained by using the proposed method rather than using the min-max normalization and statistical data.

4. Discussion

4.1. Evaluation of local governments using index by item

Figs. 12 and 13 summarize the annual changes in the index by selecting representative cities and counties. When selecting

Table A5
Raw data of Vulnerability item by indicators for 44 cities and counties in Gyeongsang-do Province (Flood risk map is applied).

Administrative District	Number of old buildings				Number of dependent people			
	2016	2017	2018	2019	2016	2017	2018	2019
Geoje City	1,504	1,491	1,506	1,516	3,885	3,772	3,596	3,558
Geochang County	2,290	2,345	2,355	2,370	3,394	3,416	3,549	3,642
Goseong County	2,986	3,041	3,022	3,030	2,466	2,467	2,536	2,563
Gimhae City	5,290	5,352	5,533	5,786	14,286	15,569	15,946	16,979
Namhae County	1,673	1,661	1,690	1,706	1,291	1,302	1,298	1,315
Miryang City	6,528	6,908	7,033	7,118	7,481	7,707	7,839	8,157
Sacheon City	3,286	3,345	3,390	3,443	4,881	4,887	4,907	4,896
Sancheong County	2,377	2,420	2,426	2,466	1,229	1,251	1,288	1,280
Yangsan City	2,415	2,394	2,459	2,561	19,193	20,878	21,922	22,520
Uiryeong County	978	1,027	1,087	1,125	2,405	2,421	2,444	2,498
Jinju City	3,923	4,029	4,060	4,124	6,804	6,932	7,108	7,338
Changnyeong County	4,983	5,531	5,589	5,589	6,097	6,239	6,313	6,402
Changwon City	6,563	6,681	6,750	6,822	13,919	14,229	14,533	14,988
Tongyeong City	677	686	688	698	1,127	1,143	1,124	1,104
Hadong County	3,384	3,488	3,545	3,594	3,307	3,325	3,411	3,492
Haman County	1,799	1,823	1,863	1,943	6,677	6,703	6,802	6,877
Hamyang County	1,856	1,886	1,905	1,904	1,922	1,939	1,936	1,950
Hapcheon County	2,926	3,102	3,130	3,152	3,010	3,008	2,960	2,965
Gyeongsan City	3,960	4,078	4,132	4,194	7,140	7,328	7,362	7,615
Gyeongju City	6,082	6,221	6,311	6,428	9,306	9,840	10,417	10,919
Goryeong County	3,639	3,692	3,720	3,759	3,582	3,611	3,663	3,745
Gumi City	3,594	3,676	3,769	3,837	4,299	4,666	4,958	5,040
Gunwi County	1,433	1,450	1,475	1,503	1,200	1,222	1,237	1,250
Gimcheon City	3,609	3,807	3,941	4,023	5,820	5,966	6,091	6,390
Mungyeong City	2,070	2,262	2,285	2,310	2,208	2,259	2,281	2,332
Bonghwa County	1,312	1,552	1,574	1,591	1,857	1,890	1,905	1,904
Sangju City	6,821	7,244	7,350	7,453	9,366	9,442	9,633	9,890
Seongju County	3,023	3,145	3,208	3,274	3,549	3,631	3,738	3,824
Andong City	2,671	2,932	2,970	3,009	3,193	3,259	3,293	3,336
Yeongdeok County	2,161	2,246	2,316	2,353	3,061	3,117	3,174	3,227
Yeongyang County	486	527	530	539	557	570	570	584
Yeongju City	5,322	5,642	5,665	5,694	6,960	7,137	7,282	7,416
Yeongcheon City	4,330	4,533	4,606	4,674	5,235	5,315	5,577	5,888
Yecheon County	1,361	1,518	1,536	1,526	1,596	1,621	1,656	1,670
Ulleung County	17	33	34	34	27	27	29	29
Uljin County	2,022	2,109	2,148	2,175	2,548	2,579	2,592	2,575
Uiseong County	3,200	3,298	3,334	3,356	3,131	3,194	3,228	3,307
Cheongdo County	6,124	6,197	6,293	6,342	3,574	3,680	3,709	3,828
Cheongsong County	580	609	624	638	768	779	791	792
Chilgok County	1,538	1,545	1,558	1,589	2,590	2,578	2,718	2,938
Pohang City	10,129	10,108	10,199	10,359	18,954	19,514	20,052	20,983
Daegu	19,611	19,965	20,181	20,767	53,629	55,823	58,348	60,172
Busan	19,106	19,071	18,859	19,136	31,022	31,630	32,517	33,329
Ulsan	11,741	11,612	11,766	12,165	28,011	28,923	30,024	31,080

representative cities and counties, we prioritized local governments with distinctive features of each index and large differences in the Exposure and Vulnerability indexes depending on the application of the flood risk map. In addition, local governments with a significant increase in the Capacity index due to changes in the Hazard index were also prioritized. Fig. 12 shows the annual intensity of flood risk and the corresponding situation of the local government by setting the x-axis as the Hazard index and the y-axis as the Capacity index. The Hazard index is low in 2017, except for Geoje and Tongyeong, and is high in 2018 and 2019. In particular, cities and counties such as Geoje City and Busan Metropolitan City experienced large-scale rainfall for four consecutive years, resulting to the highest Hazard index, while Andong, Sangju, and Uiseong-gun, which have varying meteorological characteristics than the aforementioned cities and counties, were at the bottom. Furthermore, local governments' response to disaster prevention can be confirmed through the increase or decrease in the Capacity index, depending on the changes in the Hazard index.

The cities and counties in which the aforementioned characteristics are prominent are Hadong County and Yeongyang County. In the case of Hadong County, the slopes of the graphs from 2016 to 2017, 2017 to 2018, and 2018 to 2019 are proportional to the size of the annual Hazard index, suggesting that local governments adjusted the degree of reinforcement of disaster prevention capacity according to the magnitude of the annual rainfall intensity. However, the Capacity index was very low for Yeongyang County. The large Hazard index calculated in 2018 did not show any change in the slope of the graph from 2018 to 2019, which could mean that the Yeongyang County has strengthened its disaster prevention capabilities only if necessary, mainly due to fewer buildings and populations directly exposed to flood risks.

Fig. 13 shows the results obtained when the statistical data were used after setting the Exposure index in the x-axis and the Vulnerability index in the y-axis, and when the selected data in the flood risk map were used. The graphs for the representative cities and counties showed that the Vulnerability index was directly proportional to the Exposure index. Additionally, when statistical data were used in the graph, the location of Busan Metropolitan City (located at the top), and Yeongyang County (located at the bottom) were the same as when using the flood risk map. However, there is a noticeable change in the position of the graph for other cities and counties. When the flood risk map was used, the Exposure and Vulnerability indices in Yeongju City and Haman County increased significantly compared to when the statistical data was used, whereas those of Andong City, Geoje City, etc., significantly decreased. Thus, it can be said that there is a difference in the subjects actually exposed to flood risk when data are selected using a flood risk map compared to the statistical data. Furthermore, using the statistical data, the Exposure index decreased and the Vulnerability index increased for

Table A6
Raw data of Capacity item by indicators for 44 cities and counties in Gyeongsang-do Province.

Administrative District	Disaster prevention facility density (pcs/km^2)				Cumulative disaster prevention budget ratio (1000 KW/km^2)			
	2016	2017	2018	2019	2016	2017	2018	2019
Geoje City	0.1791	0.1814	0.1861	0.1861	349,263	460,945	530,984	601,745
Geochang County	0.2972	0.2972	0.2972	0.2972	252,292	280,662	322,776	367,668
Goseong County	0.6021	0.6078	0.6078	0.6078	275,014	324,784	383,501	457,342
Gimhae City	0.1344	0.1409	0.1474	0.1625	161,148	206,960	262,702	308,246
Namhae County	0.8277	0.8411	0.8411	0.5598	234,131	269,778	346,166	394,766
Miryang City	0.0249	0.0374	0.0399	0.0399	425,127	503,720	568,787	643,022
Sacheon City	0.0664	0.0836	0.091	0.0984	391,481	459,940	508,465	573,014
Sancheong County	0.3210	0.3210	0.3223	0.3223	258,069	313,890	373,598	430,579
Yangsan City	0.1277	0.1442	0.1442	0.1484	461,220	594,032	724,326	808,785
Uiryeong County	0.0228	0.0228	0.0228	0.0228	302,022	370,962	479,322	593,075
Jinju City	0.0421	0.0491	0.0491	0.0491	248,365	296,070	335,131	373,623
Changnyeong County	0.0094	0.0094	0.0094	0.0170	430,497	502,552	569,205	640,430
Changwon City	0.1766	0.1766	0.1779	0.1884	449,781	528,694	628,381	750,157
Tongyeong City	0.3573	0.3573	0.3573	0.3953	467,630	621,152	806,009	909,487
Hadong County	0.0397	0.0397	0.0456	0.0456	204,697	281,947	365,920	450,190
Haman County	0.0529	0.0529	0.0553	0.0553	402,268	517,383	590,543	662,883
Hamyang County	0.0444	0.0555	0.0582	0.0582	343,513	403,013	449,609	501,580
Hapcheon County	0.4984	0.4984	0.4944	0.5300	299,841	356,158	416,563	471,892
Gyeongsan City	0.0899	0.0948	0.0997	0.0997	393,371	482,197	607,055	718,506
Gyeongju City	0.0302	0.0347	0.0347	0.0347	128,308	177,013	229,476	261,667
Goryeong County	0.0390	0.039	0.0416	0.0416	397,229	458,711	508,369	588,289
Gumi City	0.0617	0.0617	0.0747	0.0780	488,209	637,782	737,122	825,629
Gunwi County	0.0163	0.0196	0.0196	0.0196	200,665	257,143	288,888	330,642
Gimcheon City	0.0139	0.0248	0.0248	0.0258	271,309	312,332	351,438	422,090
Mungyeong City	0.0120	0.0120	0.0120	0.0120	121,711	157,614	200,007	265,288
Bonghwa County	0.0166	0.0191	0.0199	0.0208	140,958	190,914	238,870	277,801
Sangju City	0.0119	0.0119	0.0119	0.0119	174,054	201,638	236,529	277,226
Seongju County	0.0358	0.0358	0.0358	0.0358	277,105	312,612	351,913	400,015
Andong City	0.0818	0.0818	0.0838	0.0851	133,397	170,565	203,832	231,748
Yeongdeok County	0.0254	0.0254	0.0254	0.0294	198,656	266,937	324,166	392,236
Yeongyang County	0.0109	0.0109	0.0109	0.0109	152,524	175,534	203,280	229,301
Yeongju City	0.0475	0.0504	0.0504	0.0504	294,872	399,875	495,590	598,401
Yeongcheon City	0.0284	0.0284	0.0338	0.0338	297,440	375,434	428,421	472,315
Yecheon County	0.0256	0.0361	0.0361	0.0361	216,194	271,563	310,546	342,934
Ulleung County	0.1839	0.1971	0.1971	0.1971	709,332	859,768	946,947	1,005,435
Uljin County	0.0201	0.0281	0.0281	0.0281	75,231	102,955	140,046	174,374
Uiseong County	0.0145	0.0145	0.0145	0.0145	180,676	218,693	267,865	317,327
Cheongdo County	0.0057	0.0057	0.0057	0.0057	505,486	580,835	656,364	720,482
Cheongsong County	0.1440	0.1440	0.1971	0.1971	201,842	238,495	268,044	305,648
Chilgok County	0.0775	0.0775	0.0775	0.0775	253,454	311,509	360,444	411,059
Pohang City	0.0299	0.029	0.0290	0.0290	149,049	189,418	295,376	418,903
Daegu	0.1329	0.1375	0.1318	0.1318	719,624	909,001	1,104,500	1,307,110
Busan	0.1839	0.1852	0.1890	0.1902	1,865,007	2,394,789	2,866,894	3,311,740
Ulsan	0.1234	0.1243	0.1337	0.1346	386,943	539,905	677,748	826,900

Yeongju City and Uiseong County from 2016 to 2019, indicating that a population decline, aging of buildings, and aging of the population are occurring simultaneously due to low birth rate.

4.2. Changes in the annual flood risk index

In Table 2 and Fig. 14, we compared the annual flood risk index calculated using statistical data and the selected data from the flood risk map. The flood risk index for each of the representative cities and counties showed noticeable changes in the Hazard index. Also, it showed that the cities and counties with the largest Exposure and Vulnerability indices remained at the top. Additionally, in Yeongju City and Uiseong County, where the annual Capacity index increased, the flood risk index continued to decrease, confirming that an increased Capacity index contributes to a reduction of flood risk.

Among the high-ranking cities and counties, when the flood risk map was used, the Exposure and the Vulnerability indices of Sangju City significantly increased compared to that using statistical data, and the annual flood risk index also increased significantly compared to other cities and counties. The Sangju City has mountainous terrain in the west, and a river flows across the city center in the east. Therefore, when applying the flood risk map, the city is highly exposed to flood risk, which is why the Exposure index and Vulnerability index are calculated larger than other cities and counties. Conversely, the Exposure and Vulnerability indices decreased significantly in Tongyeong City when the flood risk map was used compared to when the statistical data was used. The reason for the significant decrease in the index in Tongyeong City is that the area of the flood risk map is small due to the geographical characteristics of Tongyeong City, which is surrounded by the sea on three sides and has no developed rivers. Furthermore, significant differences were observed in the flood risk index of Yeongju City, Hadong County, and Geoje City when flood risk maps were used.

In the existing studies, the number of buildings and population by target area was compiled by general statistics, not grid data. So even if a flood risk map was used, the flooded area could not be selected and reflected appropriately in the indicators, especially in the form of population density. These studies have also used the flood depth and flooded area derived through the flood risk map for indicators in the hazard index (Zhang et al., 2022). Comparing the flood risk indices calculated by the two methods in Table 1, when the flood risk map was used, the Sum of the Absolute Errors, MAE, and RMSE were calculated to be small, which indicates better results. These observations suggest that the flood risk assessment method presented in this study accurately monitors the flood risk scenario of the local government compared to that of the existing methods and can be used to support decision-making in strengthening the disaster prevention capacity.

5. Conclusions

In this study, flood risk assessment was performed using grid-unit spatial analysis data and flood risk maps for the 44 cities and counties in the Gyeongsang-do Province from 2016 to 2019. The flood risk index was calculated using four indices (Hazard, Exposure, Vulnerability, and Capacity) and nine indicators.

Scoring each quantile interval was applied to the statistical data of the indicators to calculate the flood risk index. This is to overcome the limitations of the existing methods, such as min-max normalization and Z-score. As a result, the sum, mean of absolute errors, and RMSE for flood risk indexes by local governments as of 2019 were calculated to be 386, 9.897, and 11.930, respectively, which are significantly better than the results calculated by applying the existing min-max normalization, which were 576, 14.769, and 16.839.

Flood risk assessment was conducted using a comparison of calculation using statistical data for each local government and overlapping the flood risk map and grid data, where the combination of the latter provided a more accurate evaluation.

The cities and counties of Yeongju City and Geoje City had underestimation or overestimation issues for Exposure and Vulnerability indicators when statistical data were used. But in this study, the flood risk assessment of the aforementioned counties and cities have improved using the proposed method.

Hazard vs. Capacity graphs, Exposure vs. Vulnerability graphs, and the annual flood risk index graph helped to accurately understand the flood risk of local governments which can later support the decision-making process as well as to strengthen the disaster prevention capabilities. Because the indices constituting the graph were related to each other, the annual fluctuation of the index appeared as an organic change in the graph. Decision-makers who establish disaster prevention measures for each local government can use these results to establish appropriate measures for reducing flood risk.

In this study, the subjects exposed to flood risk were limited to buildings (residential and non-residential buildings), the population, and roads, and flood risk assessment of each local government. For future studies, a developed flood risk assessment technique can be applied to various spatial ranges such as basin units (using grid data). Agricultural land (e.g., rice paddies, fields, greenhouses, etc.) and official land values can also be added as new indicators.

CRediT authorship contribution statement

Won-joon Wang: Methodology, Software, Writing – original draft, Visualization. **Donghyun Kim:** Visualization, Resources. **Heechan Han:** Formal analysis, Resources. **Kyung Tak Kim:** Conceptualization, Software, Funding acquisition. **Soojun Kim:** Project administration, Writing – review & editing. **Hung Soo Kim:** Resources, Project administration, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Hung Soo Kim reports financial support was provided by Korea Environment Industry & Technology Institute.

Data availability

Data will be made available on request.

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Appendix A. . Raw data of indicators for flood risk assessment for cities and counties in Gyeongsang-do Province

Tables A1 – A6.

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