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Grid-based flood insurance rate mapping for detached houses considering flood loss frequency and severity

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ABSTRACT

This study suggests a technique for mapping grid-based flood insurance rate for detached houses using flood loss frequency and severity. The number of approved flood insurance policies and insurance claims were used to calculate loss frequency. Loss severity was estimated using flood damage ratio map that was developed by applying the equation calculating damage ratio of detached house according to flood depth to flood inundation map. Analysis results of flood insurance rate for Ulsan City, the percentage of area that flood insurance rate was less than 0.02% was 96.51%, over than 0.02% and less than 0.04% was 0.04%, over than 0.04% and less than 0.06% was 0.75%, over than 0.06% and less than 0.08% was 1.03%, and over than 0.08% was 0.53%. In particular, low lying districts near Dong Stream located in western region of Buk-gu have the highest insurance rate ranging in from 0.06 to 0.08. The low lying area near estuary of Hoeya River, Cheongryang Stream, and upstream of Taehwa River in Ulju-gun have higher insurance rate ranging in from 0.04 to 0.08. Flood insurance rate of most area in Ulsan City was calculated to be less than 0.02, which is less than existing uniform insurance rate executed by Korean government.

Keywords: Flood; Insurance; Damage ratio; Inundation; Natural disaster

1. Introduction

The advancement of science makes our life convenient and enriching. However, it has been threatening us by causing various natural phenomena such as global warming, climate change, and destruction of ecosystems [1]. According to the Ministry of the Interior and Safety (MOIS) of Korea, damage caused by natural disaster from 2008 to 2017 is recorded to be 348.6 billion USD and typhoon took the largest toll at 45.5% (158.8 billion USD) followed by heavy rainfall at 42.9%, (149.4 billion USD), heavy snowfall at 6.5% (22.6 billion USD), earthquake at 2.8% (9.6 billion USD), wind wave at 1.2% (4.3 billion USD), and strong wind at 1.1% (3.9 billion USD) [2]. The damage caused by typhoon and heavy rainfall which is related with flood disaster was 308.2 billion USD and it accounts for 88.4% of the natural disaster damage. Therefore, countermeasure for flood prevention is a necessity. Management of flooding is a major societal challenge that is only expected to worsen due to several trends including population growth and urbanization [3], sea level rise [4], intensification of precipitation extremes [5,6], and the compounding effects of sea level rise and terrestrial flooding [7,8]. Several research on flood inundation mapping with numerical analysis and identification of hazardous area for installation of flood prevention structure have been performed [9–15]. A variety of studies have been performed regarding the assessment of natural disaster risk

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and vulnerability considering indices of hazard, exposure, vulnerability, and adaptation capacity [16–24].

Studies on flood inundation mapping and flood risk assessment were utilized for structural countermeasure to prevent flood disaster at national level. The government should protect the life and property of the people in the event of a disaster. However, a change in the policy is necessary since people are availing insurance to protect their private properties like houses and cars from natural disasters. Various countries of the world are developing insurance policy and applying it as a non-structural countermeasure for flood disaster. In the United States, FEMA Flood Insurance Rate Maps (FIRM) represent an estimate of the risk of flooding in a certain area, and specifically show the extent of the floodplain affected by the base flood (100-year flood). This is the severity of flood that has a 1% chance of occurring in any given year, and the base floodplain is called the special flood hazard area. FIRM is the official map of a community on which FEMA has delineated both the special hazard areas and the risk premium zones applicable to the community [25]. Classified flood insurance rate is calculated through method of net premium according to flood return periods those are 10-, 50-, 200-, and 500-year [26]. In the case of Switzerland, they estimated insurance rate after calculating mean damage ratio and premium considering service demand [27]. Korean government has executed an insurance policy for natural disasters such as flood, wind, and snow disaster for detached houses as countermeasures to mitigate flood disaster damage. However, the problem is it applies a uniform insurance rate on all places within an administrative district without considering the regional natural disaster characteristics. Hence, natural disaster insurance mapping that incorporates various levels of insurance rates considering grid-based natural disaster damage ratio is required.

This study provides an improvement to the existing uniform insurance rate implemented by Korean government for flood, wind, and snow disaster. An equation for mean flood insurance rate was derived as a function of the following three factors: mean flood damage ratio, the number of approved flood insurance policies, and the number of reported flood insurance claims. Regional map of flood damage ratio for detached houses was developed using 100-year flood inundation map and flood depth-damage ratio curve for detached houses. The number of approved flood insurance policies and flood insurance claims were built utilizing insurance data from 2006 to 2016. Classified flood insurance rate was calculated by substituting the values of these three factors into the derived equation. After which, a 30 m grid flood mean insurance rate map was developed.

The classified flood insurance rate map is expected to be used as a basis for possible change in policy from uniform insurance rate to grid-based insurance rate, identification of hazardous region for detached houses, and establishment of scientific countermeasures for prevention, preparation, response, and restoration stages.

2. Materials and methods

2.1. Study area

Ulsan City, the selected study area, has experienced terrible flood damage due to typhoon Chaba when it hit Korea in September 2016. It is located in southeast of Korea as shown in Fig. 1. The total area is 1,056 km^2 with a population of 1.17 billion. It has five administrative districts namely Buk-gu, Dong-gu, Jung-gu, Nam-gu, and Ulju-gun. The western area of Ulsan City is a high mountain area with elevation of over El.1,000 m. The eastern part is a lowland area that is in contact with the East Sea. Most rivers are steep and short, they originate from the western highlands and flow into the East Sea. There are two national rivers in Ulsan City: Taehwa River and the Hoeya River. The length of the Taehwa River that flows through the central part of Ulsan City is 46.0 km and its watershed area is 643.9 km^2. Hoeya River flowing through the southern part is 41.0 km in length and has a watershed area of 217.9 km^2. Ulsan City's average

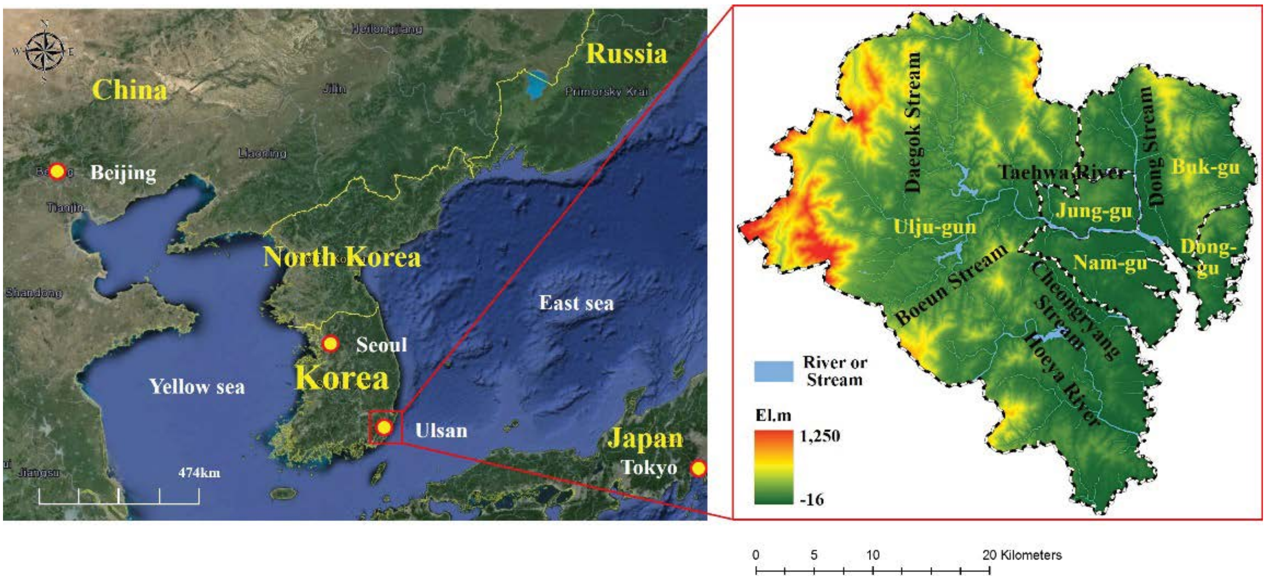

Fig. 1. Location of Ulsan City in Korea.

annual temperature is 13.8℃ with annual precipitation of 1,274.6 mm, in which 70% falls in Summer from June to September [28].

2.2. Calculation for flood insurance rate

The insurance rate (IR) is the ratio of the premium (P) to the insurable amount (IA) that determines the premium when signing the insurance (Eq. (1)). There are two methods of calculating the actuarial pricing for calculating the insurance rate: the loss ratio method and the net premium method. The loss ratio method is a method of determining premiums in accordance with changes in the actual loss resulting from the operation of the business, and adjusting the existing rate to a realistic rate level. The net premium method is a way of calculating rates regardless of the existence of past rates. The net premium method is a method of estimating the insurance premium by predicting the risk of the same group on the premise that the frequency and depth of accidents required to calculate premiums do not change over a period of time.

$$\mathrm{IR} = \frac{P}{\mathrm{IA}} \tag{1}$$

where IR, P, and IA are insurance rate, premium, and insurable amount, respectively.

The net premium method was selected to calculate the flood insurance rate in this study. Korea Insurance Research Institute presented the equation for estimating premiums using net premium method as a function of the loss frequency and the loss severity as shown in Eq. (2). The ratio of the number of insurance claims (IC) to the number of approved insurance policies (AIP) is the loss frequency, whereas the ratio of gross insurance benefit (GIB) to the number of insurance claims is the loss severity. The loss frequency can be calculated by using data from past insurance claims. However, in case of loss severity, since it is estimated using flood inundation map and flood loss data, modification of the equation for insurance rate is required. The loss severity can be expressed as the average insurance benefit (AIB) because it is the ratio of the gross insurance benefit to the number of insurance claims. Substituting Eq. (2) into Eq. (1) will result to the average insurance rate (AIR) and can be expressed as Eq. (3).

$$P = \frac{\text{No.of IC}}{\text{No.of AIP}} \times \frac{\mathrm{GIB}(\mathrm{USD})}{\text{No.of IC}} \tag{2}$$

$$\mathrm{AIR} = \frac{\text{No.of IC}}{\text{No.of AIP}} \times \frac{\mathrm{AIB}(\mathrm{USD})}{\mathrm{IA}(\mathrm{USD})} \tag{3}$$

where IC, AIP, GIB, AIR, and AIB are insurance claims, approved insurance policies, gross insurance benefit, average insurance rate, and average insurance benefit, respectively.

From the insurer's point of view, the average insurance benefit is the amount of average damage (AD) to the house, and the insurable amount is the asset value (AV) of the house. Therefore, the damage ratio (DR) can be expressed as Eq. (4) and finally the average insurance rate can be calculated using Eq. (5).

$$\frac{\mathrm{AIB}}{\mathrm{IA}} = \frac{\mathrm{AD}(\mathrm{USD})}{\mathrm{AV}(\mathrm{USD})} = \mathrm{DR}(\%) \tag{4}$$

$$\mathrm{AIR} = \frac{\text{No.of IC}}{\text{No.of AIP}} \times \mathrm{DR}(\%) \tag{5}$$

where AD, AV, and DR are average damage, asset value, and damage ratio, respectively.

3. Results and discussions

3.1. Development of flood inundation map

The flood inundation map is needed to estimate the damage ratio, which is one of the factors for estimating the average flood insurance rate. A flood damage ratio map based on a 30 m grid can be created by applying the damage rate curve to the flood inundation map. This map is used to calculate the insurance rate map. Flood scenario should be determined to create flood inundation map. U.S. Federal Emergency Management Agency (FEMA) used 100-year flood scenarios when developing flood insurance rate maps. MOIS also developed a 100-year flood inundation map separating national rivers and local rivers to map flood insurance rates and manage floods [29]. For the national rivers, HEC-RAS which is one-dimensional model and FLUMEN (FLUVAL Modeling Engine) which is a two-dimensional model were used to create inundation map. In case of local rivers, the 100-year flood level and digital elevation map were used as input data for GIS (geographic information system) and the flood inundation map was created using GIS operation. In this study, flood inundation map developed by MOIS [2] was used to map flood insurance rates. Flood inundation map analysis by administrative district of Ulsan City reveals that the average flood depth was 1.03 m and the maximum flood depth was 9.59 m. The flood area was estimated to be 26.35 km^2 which means 1.85% of the total area was flooded. The results of flood inundation analysis per administrative district are shown in Table 1. Notably, a large flood occurred at the junction of Taehwa River and Dong Stream located at the boundary of Jung-gu and Nam-gu (Fig. 2). Jung-gu and Nam-gu are densely populated administrative districts, 17.16% and 9.86% of the administrative districts were flooded, respectively.

3.2. Development flood damage ratio map

The flood damage ratio for detached houses is an important factor for calculating the average flood insurance rate, which varies according to flood depth. The Ministry of Construction of Korea calculates damage ratio by flood depth through the simple method [30] in order to predict the economic effects of the policies related to the river in 1993. This method estimates agricultural damages first and then applies the coefficient to agricultural damages to calculate other damage items. The use of this simple method posed a problem that the economic feasibility of the project was evaluated to be lower and the entire river or basin could not be considered. Subsequently, Korea revised the simple method through the project entitled "The Study on

Table 1
Flood inundation analysis per administrative district of Ulsan City

Administrative districts	Flood depth (m)		Administrative area (km^2)	Inundated area (km^2)	Inundated area ratio (%)
	Maximum	Mean			
Buk-gu	6.14	1.20	158	4.61	2.92
Dong-gu	1.48	0.47	36	0.04	0.11
Jung-gu	4.70	0.73	37	6.35	17.16
Nam-gu	2.21	0.82	71	7.00	9.86
Ulju-gun	9.59	1.07	754	1.55	0.21
Ulsan City	9.59	1.03	1,056	19.55	1.85

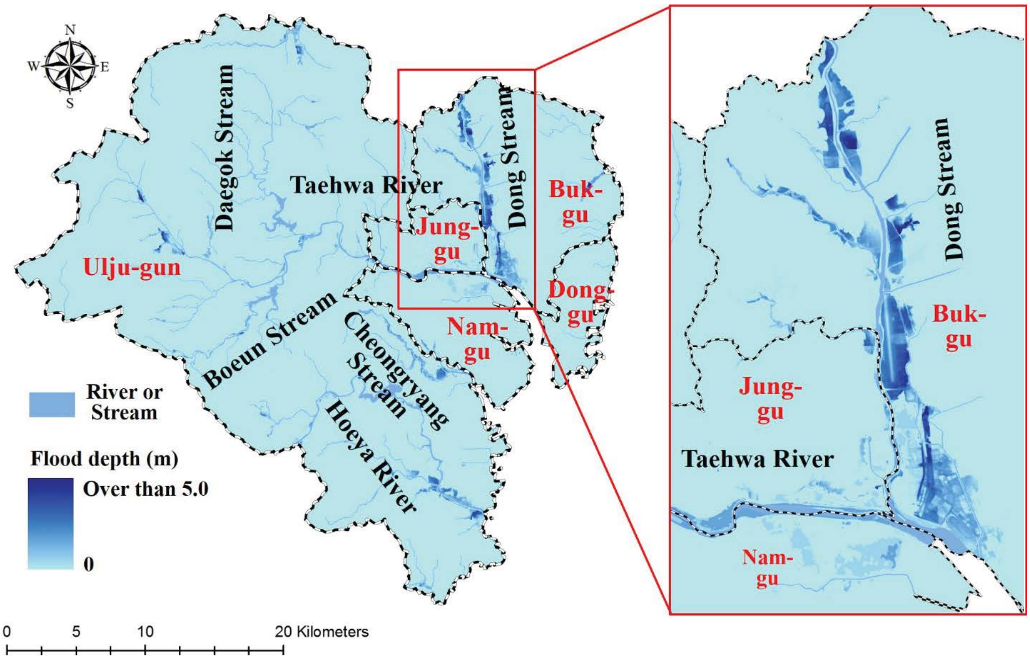

Fig. 2. Mapping flood inundation of Ulsan City.

Improvement Method of Economic Feasibility for Flood Control" [31]. In recent years, the study by Jeong and Yoon [32] has supplemented the damage ratio according to the flood depth as shown in Table 2. The correlation between the flood depth and the damage rate is expressed by the curve as shown in Fig. 3 and this can be expressed as Eq. (6).

$$y = -0.0238\,h^3 + 0.048\,h^2 + 0.3988\,h + 0.0173 \tag{6}$$

where y is damage ratio for detached house and h is equal flood depth.

The flood depth map is transformed into the flood ratio map for detached house by substituting the flood depth included in flood inundation map (Fig. 2) into h in Eq. (6) as shown in Fig. 4. The damage ratio in the Hoeya River, Dong Stream, and Cheongryang Stream, where more than 3.0 m of flood depth was observed, was estimated to be 100%. In most regions including low-lying areas near the Taehwa River at the border of Jung-gu and Nam-gu, the damage ratio was estimated to be in the range of 20%–82% (Fig. 4).

Table 2
Flood damage ratio according to flood depth for detached house

Category	Damage ratio according to flood depth (%)				
	0–0.5 m	0.5–1.0 m	1.0–2.0 m	2.0–3.0 m	Over than 3.0 m
Detached house	15	32	64	95	100

3.3. Data gathering for the number of approved insurance policies and number of insurance claims

An accurate loss frequency is essential to estimate a reasonable insurance rate. It is estimated using the number of approved insurance policies and the number of insurance

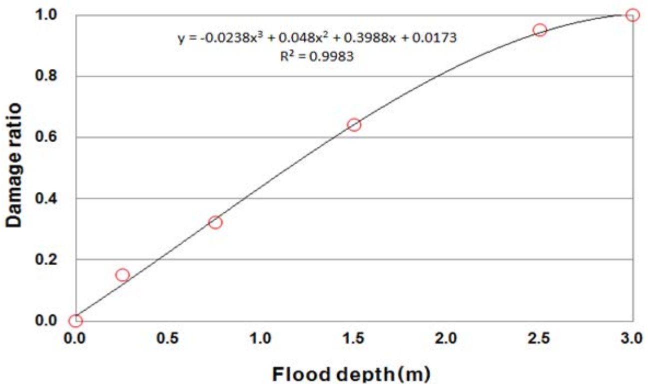

Fig. 3. Flood depth–damage ratio curve for detached house.

claims data. Therefore, the insurance statistics of accredited institutions is required to calculate accurate loss frequency. The insurance statistics was established using the data from 2006 to 2016 provided by MOIS. According to the MOIS, a total of 1,902,060 insurance policies were approved from 2006 to 2016. Among these, the number of housing insurance claims due to flood was 1,537. However, there were 480 cases of housing insurance claims due to wind disasters and 26 cases due to snow disasters. As a result, the number of approved insurance policies and the number of insurance claims for houses due flooding was 1,902,060 and 1,537, respectively.

3.4. Flood insurance rate mapping of Ulsan City

The number of approved insurance policies, number of flood insurance claims and damage ratio were substituted into Eq. (5) and the grid-based flood insurance rate map was developed as shown in Fig. 5. The flood insurance rate

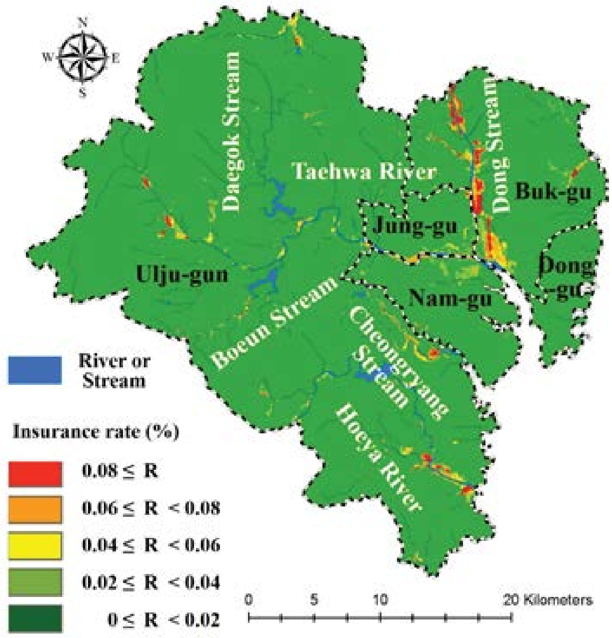

Fig. 5. Grid-based flood insurance rate map developed in this study.

of detached house for areas where flood is predicted not to occur is calculated as 0, the maximum flood insurance rate was estimated at 0.0808. The average insurance rates were as follows: 0.0054 for Buk-gu, 0.0038 for Jung-gu, 0.0026 for Nam-gu, 0.0013 for Ulju-gun, and 0.0001 for Dong-gu in descending order (Table 3). The uniform natural disaster insurance rate, which is currently applied in insurance policy of MOIS is multiplied by the flood damage rate of 65% to convert to flood insurance rate as shown in Fig. 6. The

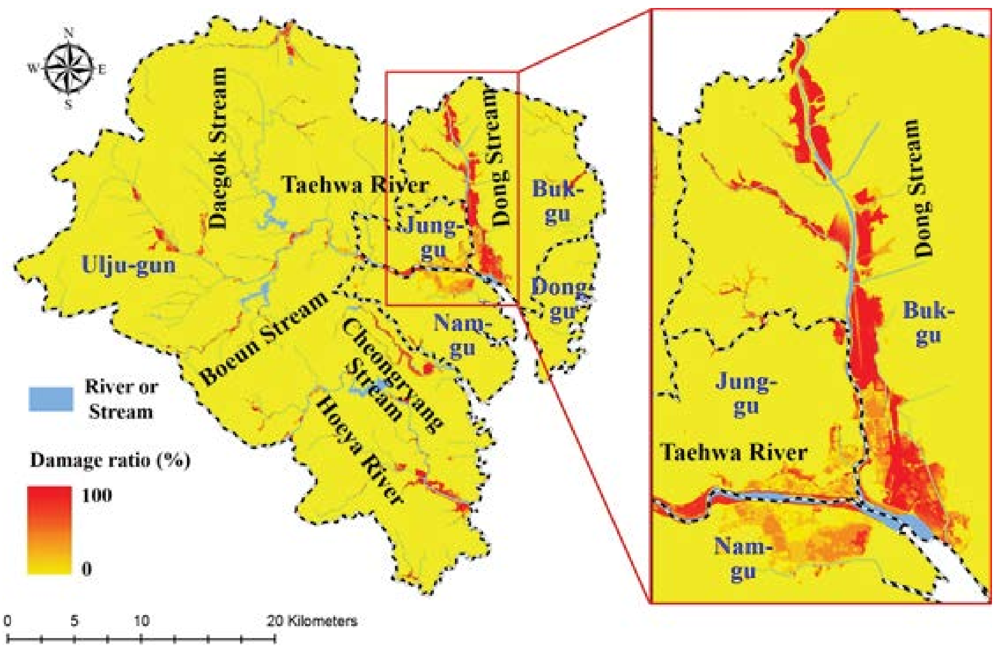

Fig. 4. Flood damage ratio map for detached house.

Table 3
Statistics of flood insurance rate calculation

Administrative districts	Calculated flood insurance rate in this study				Existing uniform insurance rate
	Minimum	Mean	Maximum	Standard deviation	
Buk-gu	0	0.0054	0.0808	1,87	0.0321
Dong-gu	0	0.0001	0.0808	9,921	0.0232
Jung-gu	0	0.0038	0.0808	30	0.0620
Nam-gu	0	0.0026	0.0808	1,862	0.0186
Ulju-gun	0	0.0013	0.0808	8,491	0.0549

existing insurance rate (Fig. 6) is based on the assumptions that each administrative district has the same insurance rate irrespective of the topography and flood characteristics. Hence, constant issues such as people living in the highlands without flood damage and those living in the lowlands with habitual flood damage paying the same premium exists. The current uniform flood insurance rate of Buk-gu is 0.0321 in all regions, but the grid-based flood insurance rate resulting from this study is calculated differently according to terrain and hydrological characteristics. In the case of Buk-gu, the flood insurance rate in the flood hazard area near the confluence of Taehwa River and Dong Stream is 0.0450–0.0808, which is higher than the uniform flood insurance rate. For the flood hazard area of high land, flood insurance rate is calculated as 0–0.0150, which is lower than current uniform flood insurance rate. Only the flood hazard area in Ulju-gun should have high insurance rate because flood damage occurs only in the Hoeya Estuary and Taehwa River. However, Ulju-gun has a uniform insurance rate of 0.0549, which is a high insurance rate for the whole region. In this study, the insurance rate was 0.04–0.0808 in low land area near the Hoeya Estuary and Taehwa River. In other highlands, the insurance rate was lowered from 0 to 0.02, which made the insurance rate more reasonable.

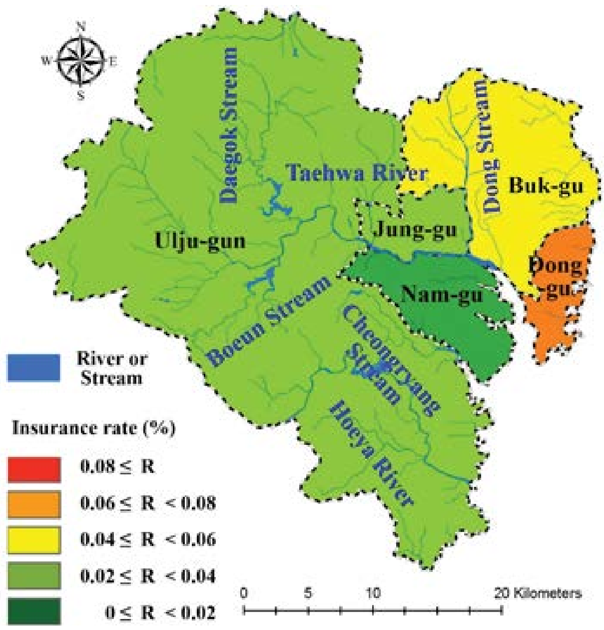

Fig. 6. Existing uniform flood insurance rate map of Ministry of Interior and Safety of Korea.

Table 4
Area according to the classification of flood insurance rate

Administrative districts		Range of flood insurance rate					Total
		$0 \le R < 0.02$	$0.02 \le R < 0.04$	$0.04 \le R < 0.06$	$0.06 \le R < 0.08$	$0.08 \le R$	
Buk-gu	Area (km^2)	143.60	3.80	2.43	4.25	3.50	157.58
	Ratio (%)	91.13	2.41	1.54	2.70	2.22	100
Dong-gu	Area (km^2)	35.77	0.01	0.00	0.00	0.01	35.79
	Ratio (%)	99.96	0.02	0.00	0.00	0.02	100
Jung-gu	Area (km^2)	34.71	0.94	0.35	0.90	0.08	36.98
	Ratio (%)	93.86	2.54	0.95	2.43	0.22	100
Nam-gu	Area (km^2)	68.32	2.11	0.12	0.84	0.04	71.43
	Ratio (%)	95.63	2.96	0.17	1.18	0.06	100
Ulju-gun	Area (km^2)	736.62	5.62	4.98	4.91	1.96	754.09
	Ratio (%)	97.68	0.75	0.66	0.65	0.26	100
Ulsan city	Area (km^2)	1,019.02	12.48	7.88	10.90	5.59	1,055.87
	Ratio (%)	96.51	1.18	0.75	1.03	0.53	100

R: Flood insurance rate.

Areas with high flood insurance rate and low rates were distinguished based on the flood insurance rate of 0.04%, which is median of flood insurance rate calculated in this study. For the whole Ulsan City, 97.69% of its area has a flood insurance rate of less than 0.04%, while the remaining 2.31% has flood insurance rate of 0.04% or more. In particular, the regions with insurance rates of 0.04% or more in Buk-gu and Jung-gu were 6.46% and 3.60%, respectively. Ulju-gun has the largest area with a flood insurance rate of 0.04% or more, which is 11.84 km^2, followed by Buk-gu with an estimate of 10.19 km^2 (Table 4).

The area near Cheongryang Stream and Taehwa River is where flood occurred during Typhoon Chaba in 2016. The flooded area during Typhoon Chaba is shown in Figs. 7 and 8. The flood insurance rate in the area where the flood occurred in the past was 0.03 or more, which is higher than other areas. Because there was insufficient previous flood mapping data available, it could not be compared with the map of flood insurance rates in all Ulsan City. However, two comparative cases (area near Cheongryang Stream and Taehwa River) have proven that the flood insurance rates calculated by this study reflect the actual flood damage well.

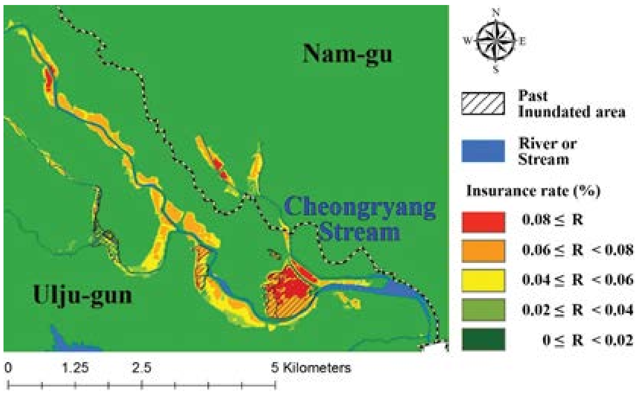

Fig. 7. Past inundated area and flood insurance rate map near Cheongryang Stream.

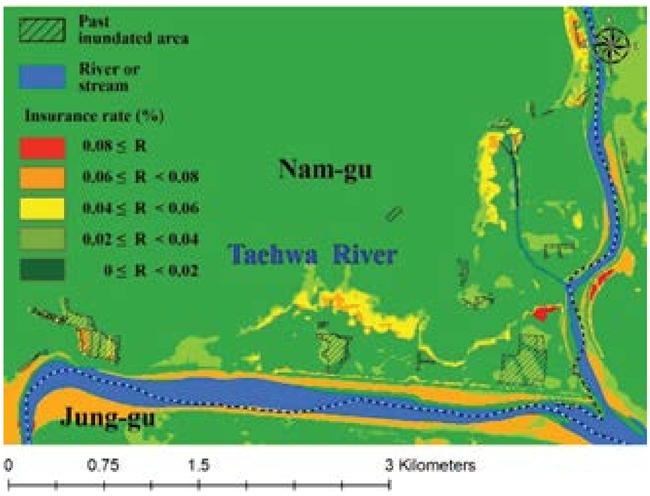

Fig. 8. Past inundated area and flood insurance rate map near Taehwa River.

4. Conclusions

In this study, the equation for flood insurance rate calculation for detached houses was derived using loss frequency and loss severity. The loss frequency was calculated using the number of approved insurance policies and the number of flood insurance claims. The loss severity was estimated through a map of flood damage ratio by applying flood depth–damage ratio curve to the flood inundation map. Using the depth and frequency of the flood, a 30 m grid-based flood insurance rate map was created. In Ulsan City, the area with flood insurance rate less than 0.02% is 96.51%, between 0.02% and 0.04% is 1.18%, between 0.04% and 0.06% is 0.75%, between 0.06% and 0.08% is 1.03%, and 0.08% or more is 0.53%. In particular, the flood insurance rates in the low-lying areas near Dong Stream in the western part of Buk-gu were the highest in Ulsan city and are also higher than the uniform insurance rate of 0.0549. In addition, the insurance rate was estimated to be 0.04–0.080 in the vicinity of the Hoeya Estuary in the Ulju-gun, the vicinity of Cheongryang Stream, the upstream of Taehwa River in the western area of Ulsan City, and the area near Taehwa River located in the border between Jung-gu and Nam-gu. In most other regions, the insurance rate is less than 0.02, which is lower than the existing uniform insurance rate. The existing uniform insurance rate has many problems. As an example, although flood disaster occurs only in some areas of the administrative district, the insurance rate of the entire administrative district is increased. The insurance rate map developed in this study can improve this problem because it has information on flood insurance rates for each 30 m grid within the same administrative districts. It is expected that the implementation of reasonable flood insurance policies will be possible through the utilization of grid-based flood insurance rate map.

Acknowledgements

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References

[1] I.S. Yu, Development of and Index based Risk Assessment Model - Focused on Flood, Wind, and Snow Disaster, Ph.D. diss., Kongju National University, Cheonan, Republic of Korea, 2017.
[2] Ministry of the Interior and Safety (MOIS), 2017 Annual Disaster Report, Sejong, Republic of Korea, 2018.
[3] L. Sundermann, O. Schelske, P. Hausman, Mind the Risk - A Global Ranking of Cities Under Threat from Natural Disasters, Techical report, Swiss Reinsurance Company, Zurich, Switzerland, 2014.
[4] S. Hallegatte, C. Green, R.J. Nicholls, J. Corfee-Morlot, Future flood losses in major coastal cities, Nat. Clim. Change, 3 (2013) 802–806.
[5] G. Lenderink, E. Van Meijgaard, Increase in hourly precipitation extremes beyond expectations from temperature changes, Nat. Geosci., 1 (2008) 511–514.
[6] D. Coumou, S. Rahmstorf, A decade of weather extremes, Nat. Clim. Change, 2 (2012) 491–496.

[7] H.R. Moftakhari, G. Salvadori, A. AghaKouchak, B.F. Sanders, R.A. Matthew, Compounding Effects of Sea Level Rise and Fluvial Flooding, Proc. Natl. Acad. Sci. USA, 114 (2017) 9785–9790.
[8] A. Luke, F.S. Brett, A.G. Kristen, L.F. David, B. Danielle, E. Ana, S. Kimberly, R. Abigail, E.S. Jochen, A. Amir, B. Victorial, A.M. Richard, Going beyond the flood insurance rate map: insights from flood hazard map co-production, Nat. Hazards Earth Syst. Sci., 18 (2018) 1097–1120.
[9] Y.H. Bae, D.K., Koh, Y.S. Cho, Numerical Simulations of Flood Inundation with FLUMEN, J. Korea Water Resour. Assoc., 51 (2015) 934–654.
[10] G.H. Lee, K.W. Park, W.S. Yu, K.S. Jung, C.L. Chang, A Study on Flood Damage Estimation Using DEM-based Flood Inundation Model and MD-FDA, J. Korean Soc. Hazard Mitig., 17 (2011) 327–336.
[11] B.H. Kim, S.Y. Choi, K.Y. Han, An analysis method of 1D hydrodynamic model based on GIS for flood inundation mapping, J. Korean Society of Hazard Mitig., 11 (2011) 227–235.
[12] S.S. Hong, D.S. Jung, E.H. Hwang, H.S. Chae, Study on the watershed analysis of the expected flood inundation area in South Han River, J. Korean Assoc. Geographic Inf. Stud., 19 (2016) 10–119.
[13] S.S. Ahn, J.S. Lee, J.H. Kim, Analysis of Flood Inundation Area Using HEC-RAS/GIS, J. Environ. Sci., 13 (2004) 19–26.
[14] C.H. Lee, T.G. Lee, Evaluation of an Applicability of HEC-RAS 5.0 for 2-D Flood Inundation Analysis, J. Korea Academia-Ind. Coop. Soc., 17 (2016) 726–733.
[15] S.M. Kang, M.J. Park, S.H. Kim, S.J. Kim, Water engineering: a study on the mitigation of inundation damage using flood inundation analysis model FLUMEN - for the part of Jinwicheon Reach, J. Korean Soc. Civil Eng., 27 (2007) 583–590.
[16] Intergovernmental Panel on Climate Change (IPCC), Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability, Third Assessment Report, McCarthy et al., Eds., Cambridge University Press, Cambridge, UK, 2001.
[17] N. Brooks, W.N. Adger, P.M. Kelly, The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation, Global Environ. Change, 15 (2005) 151–163.
[18] P.M. Kelly, W.N. Adger, Theory and practice in assessing vulnerability to climate change and facilitating adaptation, Climate Change, 47 (2000) 325–352.
[19] R.H. Moss, A.L. Brenkert, E.L. Malone, Vulnerability to Climate Change: A Quantitative Approach, Prepared for the U.S. Department of Energy, 2001.
[20] S.H. Eriksen, P.M. Kelly, Developing credible vulnerability indicators for climate adaptation policy assessment, Mitig. Adapt. Strat. Global Change, 12 (2007) 495–524.
[21] M.E. Ibarraran, E.L. Malone, A.L. Brenkert, Climate change vulnerability and resilience: current status and trends for Mexico, Environ. Dev. Sustainability, 12 (2010) 365–388.
[22] E. Romieu, C. Vinchon, Coastal Vulnerability: Climate Change and Natural Hazards Perspectives, Geophysical Research Abstracts, EGU General Assembly, Vienna, Austria, 2009, p. 12477.
[23] A. Moreno, S. Becken, A climate change vulnerability assessment methodology for coastal tourism, J. Sustain. Tourism, 174 (2009) 473–488.
[24] M.B. Wehbe, R.A. Seiler, M.R. Vincour, H. Eakin, C. Sanots, H.M. Civitaresi, Social Methods for Assessing Agricultural Producers' Vulnerability to Climate Variability and Change Based on the Notion of Sustainability, Assessments of Impacts and Adaptations of Climate Change (AIACC) Working Papers, 2005. Available at: www.ajaccproject.org.
[25] Green County Soil & Water Conservation District. Available at: https://www.gcswcd.com/maps-data/fema-firm.
[26] Munich Re, Die Versicherung weiterer Elementargefahren, 1993.
[27] Swiss Re, Natural Catastrophes and Reinsurance, 2003.
[28] I.S. Yu, T.G. Lee, L.H. Kim, S.M. Jeong, Development of natural disaster risk map as reflected in flood, wind and snow in Ulsan City, Desal. Wat. Treat., 63 (2017) 455–462.
[29] Ministry of the Interior and Safety (MOIS), Insurance Rate Making and Mapping based on Natural Disaster Risk, Sejong, Republic of Korea, 2018.
[30] Ministry of Construction (MOC), River Facilities Standards, Sejong, Republic of Korea, 1993.
[31] Ministry of Construction and Transportation (MOCT), The Study on Improvement Method of Economic Feasibility for Flood Control, Sejong, Republic of Korea, 2001.
[32] J.H. Jeong, Y.N. Yoon, Design Practice of Water Resources, Goobibook, Seoul, Republic of Korea, 2009.