Analysis on Natural Disaster Risk based on Flood, Snow and Wind Damages

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Abstract
This study developed each flood, wind and snow risk map and integrated natural disaster risk map. On a 100-year flood basis of an Inundated flood map for the elucidation of flood risk, a 15.31m maximum depth of water was shown which is 1.8% or 670 km^2 of the whole study area that is inundated at 36,860 km^2, while a 100-year frequency return period mapping for wind velocity resulted to a range from 19.3 m/s to 59.9 m/s and snow load ranging from 0.31 kN/m^2 to 7.53 kN/m^2. Four levels of risk were determined from the usage of flood inundation map to identify the flood risk namely: safe, warning, dangerous and severely dangerous water depth. These levels symbolize the degree of damage caused by flood to buildings and people lives. The determination of wind and snow risk showed same classifications of result for areas that are lower that the designed wind velocity and snow load. Integrated natural disaster risk map was developed by applying weight calculated based on flood, wind and snow damage according to administrative districts to each risk map.

Keywords
Flood risk, snow risk, wind risk, natural disaster, integrated disaster risk

INTRODUCTION

Recently, natural disasters such as flood, wind, snow and earthquake damages have occurred frequently all over the world. From January 22–24, 2016, a major blizzard produced up to 91 cm of snow in parts of the Mid-Atlantic and Northeast United States (Chicago Tribune 2016 ; The Washington Post 2016). The governors of the eleven states and the mayor of Washington, D.C. declared a state of emergency due to the extreme snowfall and blizzard conditions. Approximately 103 million people were affected by the storm and of which 33 million people were under blizzard warnings and more than 13,000 flights were cancelled in relation to the storm’s rippling effects. The total economic losses were estimated ranges from $500 million to $3 billion (Wikipedia 2016). Also, extreme flooding has occurred in Thailand at the end of March 2011, which normally takes place on the latter part of the dry season of the country. Heavy rain fell in the southern region, with over 120 centimeters (47 in) of rain falling in certain areas (NASA Earth Observatory 2011). It was said that at least 53 people have died and almost 9 million people have been affected by the floods after localized heavy rains and has affected 50 of Thailand's 76 provinces. (New Zealand Herald 2011) Close to 160,000 ha (400,000 acres) of land have been submerged (Bernama Malaysian National News Agency 2011). Around 5,000 households have been evacuated, (MCOT 2011) with the inclusion of hundreds of tourists (The Nation 2011). Typhoon Haiyan, known as Super Typhoon Yolanda in the

Philippines, devastated portions of Southeast Asia, particularly the Philippines, on November 8, 2013 (NPR 2013). According to the Philippine Government, a total of 16 million people were directly affected by the super typhoon and of which 6,300 were killed, 4.1 million were displaced and 1.1 million houses were damaged or destroyed. It is also recorded as the strongest typhoon on the planet which sustained a wind speed of 315 kph (195 mph), some say it was a “monster”, because of its winds tremendous power. The super typhoon is so large in diameter that clouds from it are affecting two thirds of the country, which stretches more than 1,850 kilometers (1,150 miles). Recovering from this typhoon will take time to recover due to its adverse effects and since the country lacks the finance to rebuild easily the damages brought about by the monster typhoon haiyan. Typhoon Maemi, known in the Philippines as Typhoon Pogi, was the most powerful typhoon in 2003 to strike South Korea since record-keeping began in the country in 1904. It was reported that death and disappearance were 132, victims were 61,000, and damage was about 3.9 billion won caused by Typhoon Maemi. In terms of snow, there was a 50 cm wet snowfall with a density of about 300kgf/㎥ in February, 2014 in Gyeongju of Korea. The snowfall caused a resort hall’s roof to collapse killing 10 people and 128 people sustained severe wounds from the accident. Typhoon took a largest toll at 26% among all types of natural disasters followed by torrential rain at 52% and heavy snow at 20% in Korea for the last decade and this requires urgent countermeasures (NEMA 2003-2012).

Assessment of regional natural disaster risk is very important to prevent and mitigate such natural disaster. Disaster risk assessment is considered an effective means of solving natural disaster (Stephane et al. 2013), and therefore has been widely applied to natural disaster insurance, floodplain management, disaster warning systems, and evacuation planning, proving to be an important scientific reference for flood disaster risk management and relevant decision-making (Zou et al. 2013). Various researchs have been performed to evaluate natural disaster risk. In order to assess natural disaster risk, numerous systematic methods such as the analytic hierarchy process (AHP) (Fernández and Lutz 2010; Stefanidis and Stathis 2013; Yang et al. 2013), set pair analysis (SPA) (Zou et al. 2013; Guo et al. 2014), and fuzzy comprehensive evaluation (FCE) (Jiang et al. 2009; Li 2013; Lai et al. 2015) have been applied to this field, with mixed results(Wang et al. 2015). Federal Emergency Management Agency released HAZUS-MH that can estimates four types of hazard risk : flooding, hurricanes, coastal, surge, and earthquakes. A variety of research on disaster vulnerability were studied to analyze natural disaster risk (Connor and Hiroki 2005 ; Barroca et al. 2006 ; Rygel et al. 2006 ; Balica et al. 2009 ; Fekete, 2009). The studies of developing flood inundation map, wind speed and snowfall map and their risks have been continuously performed (Lee et al. 2011, Shin et al.2014, NEMA 2009, Yu et al. 2014].

The analysis for the recently studied research, which is related to flood such as developing flood inundation map, flood risk map and development of flood early warning system has been studied thoroughly, however the study on wind damage and snow damage has not yet been studied enough. Several research regarding flood, wind and snow have already taken place however, an integrated natural disaster risk for each disaster has not been researched yet.

In this study, each risk: flood, wind and snow that occupies the majority of the natural disaster damage in Korea are analyzed and an integrated natural disaster risk map was developed. Each is expected to detect an area vulnerable to various natural disasters. Policymakers could come up with proper countermeasures against these sorts of natural disasters using the each natural disaster risk map. Therefore, when using integrated natural disaster risk map; policymakers, researchers and government officials could make decision for priorities of countermeasures for mitigating and preventing natural disaster. Regional natural disaster risk is going to be also used to calculate reasonable natural disaster insurance rate for restoration.

RESEARCH METHOD

Study Area

Daegu, Gyeongbuk and Gangwon are located on the northeastern part of Korea see Fig. 1.They are the chosen study areas for this research. These places were divided according to their area in km^2, population, average precipitation in mm, average temperature in Celsius, an average wind speed in m/s and average snow fall in cm, see Table 1 for the analysis of risk and development of mapping.

Table 1. Selected Regions for Data Analysis of Risk

Division	Daegu	Gyeongbuk	Gangwon
Area(km^2)	881	19,056	16,923
Population	2,529 thousand	2,697 thousand	1,760 thousand
Average precipitation (mm)	1,064	1,133	1,462
Average temperature (°C)	14.1	12.2	11.0
Average annual maximum wind speed (m/s)	2.7	2.0	2.5
Average annual maximum snowfall (cm)	16.9	6.6	28.3

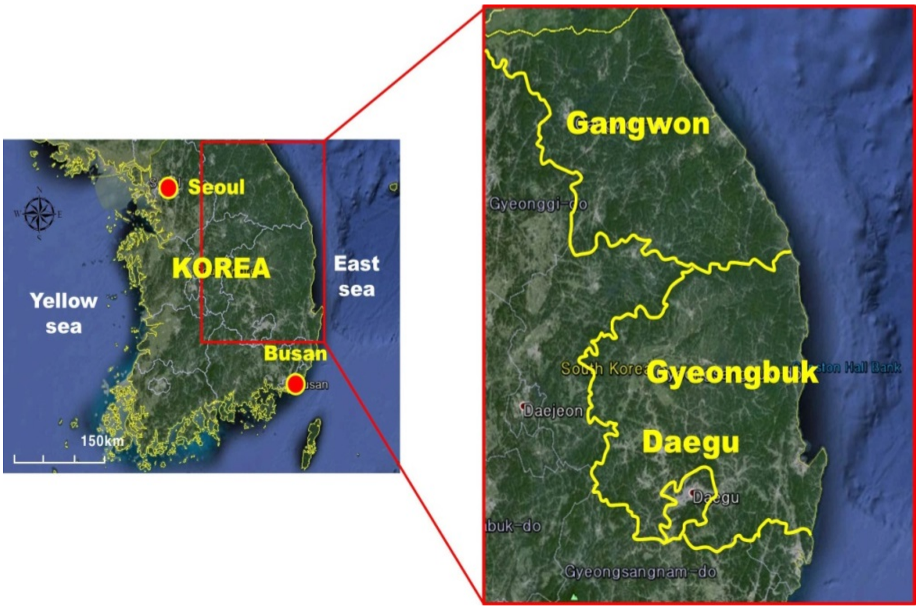

Figure 1. Location of study area

Method for the Development of Flood Risk Map

A requirement of having a flood inundation map first, before developing a flood risk map should be done. In this research, the inundation map refers to those submerged areas due to inundating rivers. Damage incurred to the structures and human life with the use of the four categories that is illustrated in the flood risk map is developed.

Flood Inundation Map

There are various ways to develop the flood inundation map such as the use of numerical analysis models and GIS program through flood level and topographic data (NEMA 2014). A comparison between the numerical analysis model and GIS program is that in numerical analysis, even if it is more accurate, it is limited to small range of areas, while the GIS program can cover a wide range of areas, but a little less accurate than numerical analysis. However, GIS program has the edge for evaluating the total study area of 36,860 km^2 and a river as long as 8,486.87 km^2 as shown in Table 2 for the development of an inundation map. Therefore, shape file format was made based from the data of the flood inundation map of the 810.52 km national rivers and was produced from Hec-Ras (one-dimensional) and FLUMEN (two-dimensional) models that came from the Ministry of land, Transport and Maritime Affairs as shown in Fig. 2. It also shows a converted 10-m grid-based raster for the improvement of the map. However, for the 7,676.35 km long Local River, the determination and inclusion of the flood inundation map was made through the GIS program which has the areas lower than the 100-year level of river. A Digital Elevation Map (DEM) of both the study area and level of flood that is calculated within the 100-year flood level of the river is needed to develop an inundation map using the GIS program. Areas where flood level DEM is higher than that of the topographic DEM are used to get the inundation depth.

Table 2. Scopes of National and Local River

Division	National river	Local river	Sum
Number	13	635	648
River length(km)	810.52	7,676.35	8,486.87

(a) Numerical Analysis Model (b) Flood Inundation Map

Figure 2. Inundation map of Taehwa River in shape and raster format

Flood Risk Map

The inundation grade where the risk map is based and where flood risk grade is found, serves as a unique contract term of the present storm and wind insurance policy of Korea. Table 3 below shows the classifications of flood risk map that states that for a depth of 0 it is considered safe, a range of 0.0 - 0.5 indicates warning, 0.5 - 1.0 signifies dangerous and more than one implies severely dangerous intensity.

Table 3. Classification of flood risk

Legend	Zone	Intensity	Inundation depth(m)
	Ⅰ	Safe	0
	ⅠⅠ	Warning	0.0 to 0.5
	ⅠⅠⅠ	Dangerous	0.5 to 1.0
	ⅠV	Severely dangerous	more than 1.0

Method for the development of wind risk map

The wind risk map was developed from the application of the design wind velocity calculation method which was suggested by the Korean Building Code of Ministry of Land, Infrastructure and Transport [MLIT (2009)] and the wind velocity estimation method that was described in the Development of Risk Assessment Technique for Strong Wind and Heavy Snowfall of National Emergency Management Agency [NEMA (2009)]. The first model to develop the wind risk map was the Homogeneous Wind Model. This model provides the value of the velocity when the elevation and roughness are not applicable. The same goes to the surface roughness and topographical effect model. Also, for the Homogeneous Wind Model, the surface roughness and topographical effect models were applied to it to develop a wind velocity map which has the same four classifications as the previous table mentioned.

Homogeneous Wind Model

This model, through the use of velocity frequency analysis was developed without the use of surface roughness and topographical effect. The velocity frequency analysis uses an annual maximum wind velocity data that is older than 20 years while the Gumbel distribution uses the probability distribution for analysis. Also, for the parameter estimation it used the moment method for investigation. Gumbel's cumulative probability distribution is shown in Eq. (1), while the calculation for x and the inverse function of F(x) are revealed on Eq. (2).

$$\mathrm{F(x)} = e\left[-e\left(-\frac{x-x_0}{a}\right)\right] \tag{1}$$

$$x_t = x_0 - a\, ln[\ln T - ln(T-1)] \tag{2}$$

Where, x, x_0 and a are variance, positional parameter and shape parameter, respectively. The calculation of the wind velocity using Eq. (2) does not anymore need or take into account the usage of surface and topography parameters on the Homogeneous Wind Model.

Surface Roughness Model

Usually the earth's surface roughness is affected by the velocity of wind. Here, the Surface Roughness Model signifies that the weight on the surface roughness depends on the unpredictable change of the wind velocity. Korean Building Code [MOLIT (2009)] categorizes the surface roughness with regards to the height of the structure or land. If the region has a building with a height greater than 10-storey then the roughness result is 0.58, for those that are at a height of 3.5 m the roughness is 0.81, a height of 1.5 m produces a 1.0 roughness and the last category which is the coast, grassland and aerodrome regions has a surface roughness of 1.13. All are dimensionless.

Topographical Effect Model

The in betweens of hills and slopes which are a topographic feature has a higher wind velocity than the rest of the features. The model estimates the increasing rate of velocity which depends upon the features of topography. To assess the growing rate quantitatively, Korean Building Code [MOLIT (2009)] recommends that the use of topographic factors is dependent on the topography of hills, slopes, mountains and lands. The factors which ranges from 1.05-1.27 is applicable for sloped lands, on the other hand, a range of 1.11-1.61 is for hills and mountains. The speed that is supplemented by topography can be estimated by multiplying the velocity of the homogeneous wind model to the topographic factors.

Wind Risk Map

In this study, a comparison of the 100-year velocity frequency developed from the homogeneous wind, surface roughness and topographical effect models are required for the development of a wind risk map. It is based on the Korean Building Code [MOLIT (2009)] which states that the velocity frequency is mad as a standard for designing structures. Table 4 shows that when the wind risk is equivalent to 0, the intensity is on a safe zone, for those which are on the range of 0 but less than 1, a warning status is indicated. A wind risk ranging from 1 but less than 1.5 declares a dangerous sign and greater than 1.5 has a mark of severely dangerous status.

Table 4. Classifications of Wind Risk

Legend	Zone	Intensity	WR
	Ⅰ	Safe	WR = 0
	Ⅱ	Warning	0 < WR ≤ 1.0
	Ⅲ	Dangerous	1.0 < WR ≤ 1.5
	Ⅳ	Severely dangerous	1.5 < WR

※WR(Wind Risk) = wind velocity estimated in this study/design wind speed according to districts

Method for the Development of Snow Risk Map

The use of an annual maximum snowfall which was observed by the meteorological station is required for frequency analysis to develop a snow risk map of the study area. A 10-m grid based snowfall map is created through the application of the unit weight of snow fall and the frequency analysis.

Snowfall Frequency Analysis

In computing for the probability of snowfall, a snowfall frequency analysis is done. The construction of an annual maximum snowfall data that is at least 20 years or more should be made for snowfall frequency, probability distribution and parameter estimation method. This will help in selecting the best fit for the analysis of snowfall. Various probability distributions for extreme and ordinary frequency analysis are present nowadays. One is the Snow load frequency analysis which applies the Generalized Extreme Value, Type-Ⅰ(Gumbel), Type-Ⅱ(Log-gumbel) and Type-Ⅲ(Weibull), Log-Pearson Type-Ⅲ. The most fitting for snowfall frequency analysis is the usage of the Generalized Extreme Value, while the most frequently used in Korea is the Probability weighted moment method [Yu et al. (2014)]. This research also used GEV from the moment method to execute snowfall frequency analysis, wherein the probability density function of GEV is Eq. (3) and Eq. (4) is the variance that depends on the return period.

$$F(x) = e^{-\left[1-b\left(\frac{x-x_0}{a}\right)\right]^{\frac{1}{b}}} \tag{3}$$

$$x_t = x_0 + \frac{a}{b}\left[1 - \left\{-ln\left(1-\frac{1}{T}\right)\right\}^{b}\right] \tag{4}$$

Where, a is the scale parameter, b is the shape parameter, x_0 is the positional parameter and T is the return period.

Snow Load

Snowfall frequency analysis is made through the multiplication of unit weight of snow with the 100-year snowfall. On Fig. 3, it shows that the relation of first 50 cm snowfall with the 100 kg/m^3 unit weight has a horizontal and constant line, however as both parameters increases until 200cm for snowfall and 250 kg/ m^3 for the unit weight it indicates a diagonal increasing movement, then maintains a straight horizontal line after the 200 cm mark for the snowfall.

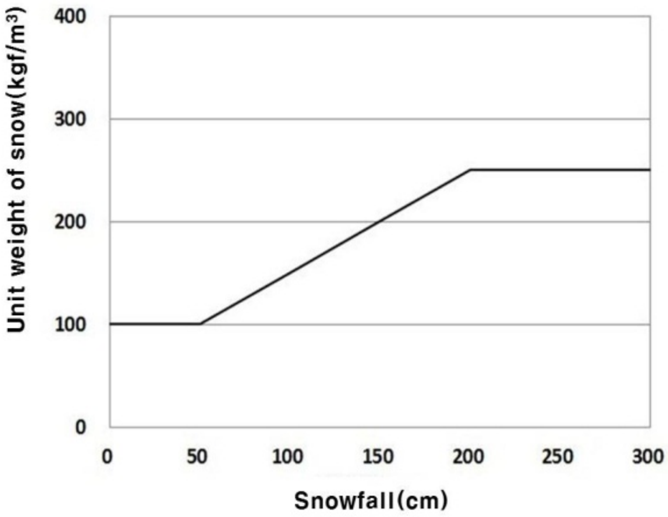

Figure 3. Unit weight of snow according to snowfall

Snow Risk Map

An assessment connecting the 100-year snowfall through the use of snowfall frequency analysis and the design of snow load of the study area is required to develop a snow risk map. Table 5 shows four classification of snow risk for the awareness of the public. A value of 0 for the snow risk indicates a safe zone, a range between 0 to 1.0 signifies a warning, while a range of 1.0 but less than 1.5 symbolizes a status of dangerous and last but not the least a snow risk higher than 1.5 results for a severely dangerous area and is not fit.

Table 5. Classifications of Snow Risk

Legend	Zone	Intensity	SR
(blue)	Ⅰ	Safe	SR = 0
(yellow)	Ⅱ	Warning	0 < SR ≤ 1.0
(orange)	Ⅲ	Dangerous	1.0 < SR ≤ 1.5
(red)	Ⅳ	Severely dangerous	1.5 < SR

※SR(Snow Risk) = Snow load estimated in this study/design snow load according to districts

RESULTS AND DISCUSSION

Results from the Development of Flood Risk Map

A 10m grid-based flood risk map as shown in Fig. 4 was made and for the development of flood inundation map of Daegu, Gyeongbook and Gangwon, numerical and GIS model was used. Out of the total study area of 36,860 km^2, only 670 km^2 was found to be submerged and the remaining area of 36,190 km^2 was founded to be safe. This also showed that a 125 km^2 area was associated with the second level which is on a warning zone with depths ranging from 0m to 0.5m, an area of 163 km^2 for the dangerous zone with depth range of 0.5m to 1.0m and lastly an area of 382 km^2 for the severely dangerous with range of 1.0m or more.

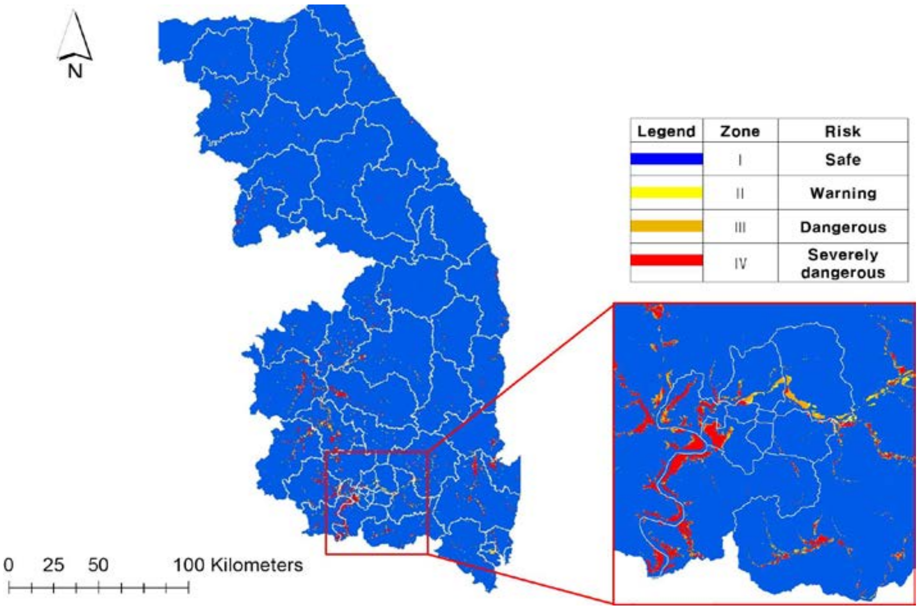

Figure 4. Flood Risk Map

Results from the Development of Wind Risk Map

The three models namely: Homogeneous wind, Surface roughness and Topographical effect are used to develop the wind risk map. The 10m grid-based wind risk map is shown in Fig. 5 where in the maximum and minimum velocity is 19.3 m/s and 59.5 m/s, respectively also elucidated that there were no safe areas and that for the warning sign it has a total area of 12,095 km^2, the dangerous indicated an area of 24,510 km^2 and lastly the severely dangerous incurred a total of 255 km^2 of the total study area.

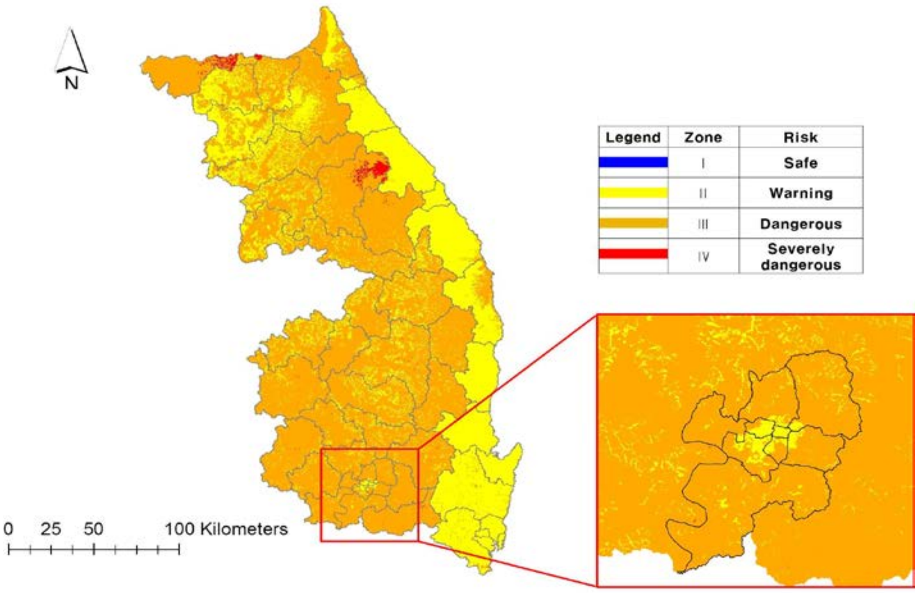

Figure 5. Wind Risk Map

Results from the Development of Snow Risk Map

A 100-year snow load map by the snowfall frequency analysis was developed and the 10m grid-based snow risk map is shown in Fig. 6 which has a minimum and maximum snow load of 0.31kN/m^2 and 7.53kN/m^2, respectively. In this result, there were also no safe areas. The warning sign made a total of 27,785 km^2, while the dangerous zone incurred an area of 7,678 km^2 and lastly the severely dangerous got a total of 1,397 km^2 from the whole study area.

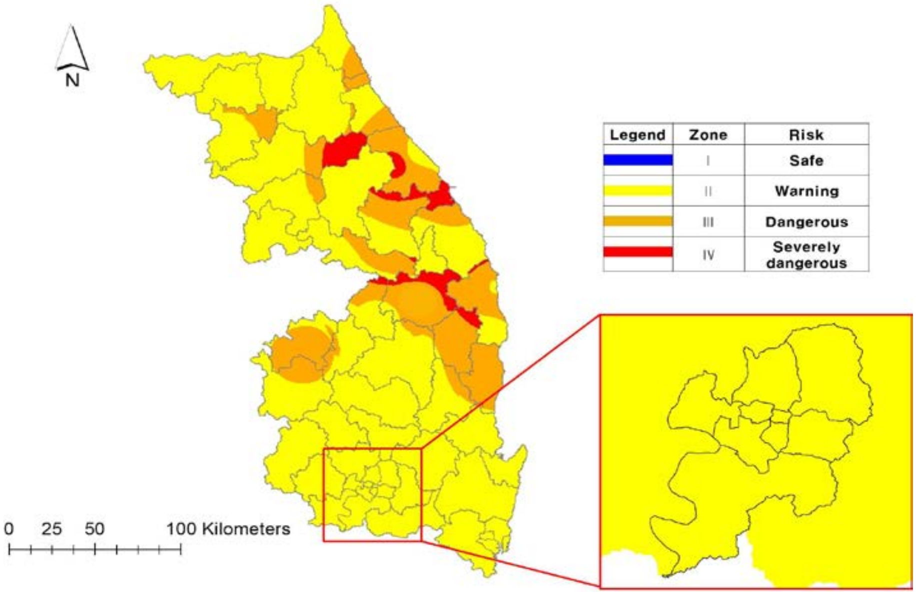

Figure 6. Snow Risk Map

Results from the Development of Integrated Natural Disaster Risk Map

Table 6 explains the weights given per region and per damage for 2006-2014 it belongs to and all of which must sum up to 1. The Daegu region, for example only contains the flooding damages, while for the Gyeongbuk and Gangwon area, there exists all three damages. In the table 6, it is also noticeable that the most weight comes from the Flood damage making it the most dominant or prominent among the three. In Fig. 7 which is the integrated natural disaster risk map, where all the three risks: flood, wind and snow were combined, it is said that for the 4 different zonal risks the following areas were computed and calculated: safe summing up to 36,177 km^2, warning having 261 km^2, dangerous with 374 km^2 and severely dangerous with 48 km^2. It may then be concluded that a lot of areas or places are still under safe zones and from the other areas where threats have been determined specifically, a counter-measure or preventions can be made for the safety of the lives of the people around those areas.

Table 6. Weight of flood, wind and snow damage for integrated natural disaster risk map

Region	Flood damage	Wind damage	Snow damage
Daegu	1.00	0	0
Gyeongbuk	0.83	0.11	0.06
Gangwon	0.68	0.14	0.18

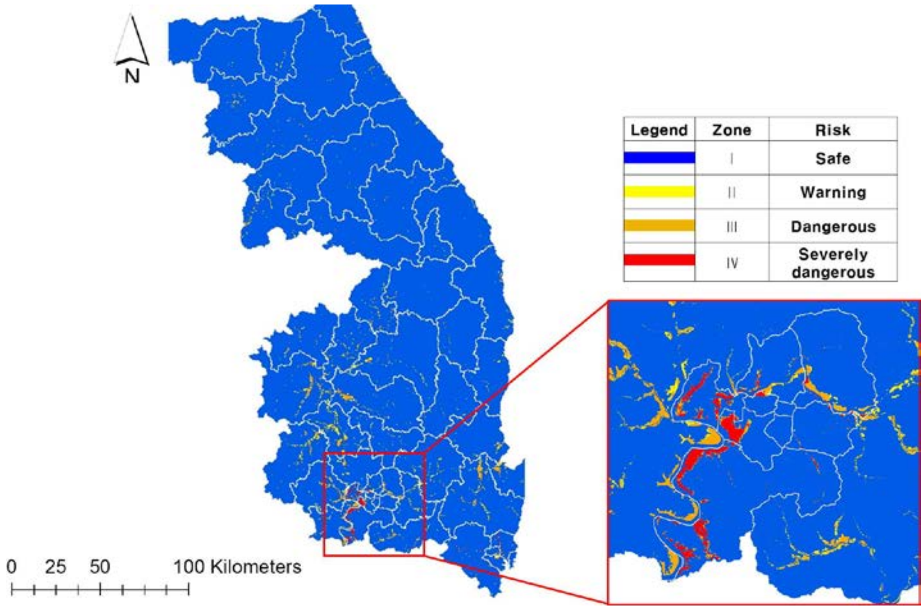

Figure 7. Integrated natural disaster risk map

CONCLUSION

This study developed the flood, wind and snow risk map of Daegu, Gyeongbuk and Gangwon. One-dimensional and two-dimensional numerical modeling was applied to national rivers while GIS technique that used flood level was applied to local rivers to develop the flood inundation map. It was analyzed that 670 km^2 (1.8%) of the city were submerged out of the total 36,860 km^2 and the remaining 36,190 km^2 (98.1%) were classified as safe areas. The study also showed that, warning area with a depth of 0m to 0.5m shows an area of 125 km^2 (18%), dangerous area at 0.5m to 1.0m was 163 km^2 (48%) and severely dangerous at more than 1.0m was 382 km^2 (34%) from the inundated area of 670 km^2.

For developing the wind risk map, the wind velocity estimation method suggested by Korean Building Code (2009) was applied to develop homogeneous wind model, surface roughness model and topographical effect model and develop the wind velocity map of Daegu, Gyeongbuk and Gangwon. The 100-year minimum and maximum wind velocity of the study area were estimated to be 19.3m/s and 59.9m/s, respectively. It also showed that there were no safe areas and that on a warning zone, the area covered was 12,070km^2, for the dangerous zone an area of 24,535 km^2 and for the severely dangerous it had incurred a total of 255 km^2.

On the other hand, snowfall frequency analysis was performed to develop 100-year snow load and snow risk maps. The minimum and maximum snow loads of the study area were estimated to be 0.31kN/m^2 and 7.53kN/m^2, respectively. There were also no safe areas. A warning zone got an area of 11,795 km^2, the dangerous got a total of 14,744 km^2 and the last one which is the severely dangerous had acquired an area of 10,321 km^2.

Integrated natural disaster risk map of Daegu, Geongbuk and Gangwon was developed by combining flood, wind and snow risk applying each weight that is calculated from monetary damage for 2006-2014. The map has 4 different zonal risk :

safe summing up to 36,177 km^2, warning having 261 km^2, dangerous with 374 km^2 and severely dangerous with 48 km^2. It may then be concluded that a lot of areas or places are still under safe zones and from the other areas where threats have been determined specifically, a counter-measure or preventions can be made for the safety of the lives of the people around those areas.

Each risk map is expected to detect an area vulnerable to various natural disasters. Policymakers could come up with proper countermeasures against these sorts of natural disasters using the each natural disaster risk map. Therefore, when using integrated natural disaster risk map; policymakers, researchers and government officials could make decision for priorities of countermeasures for mitigating and preventing natural disaster. Regional natural disaster risk is going to be also used to calculate reasonable natural disaster insurance rate for restoration.

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REFERENCES

Balica, S. F., Douben, N., Wright, N. G. 2009 Flood vulnerability indices at varing spatial scales. *Water Science & Technology* **60**(10), 2571-2580.

Barroca, B., Bernardara, P., Mouchel, J. M., Hubert, G. 2006 Indicators for Identification of urban flooding vulnerability. *Natural Hazards and Earth System Sciences* **6**, 553-561.

Bernama Malaysian National News Agency 2011 Death Toll in Thailand Floods Reaches 41. Retrieved 3 April 2011.

Chicago Tribune 2016 Potentially historic blizzard looms over D.C., more than 2 feet of snow projected. January 21, 2016. Retrieved January 22, 2016

Connor, R. F., Hiroki, K. 2005 Development of a method for assessing flood vulnerability *Water Science & Technology* **51**(5), 61-67.

Fekete, A. 2009 Validation of a social vulnerability index in context to river-floods in Germany *Natural Hazards and Earth System Sciences* **9**, 393-403.

Fernandez, D.S., Lutz, M.A. 2010 Urban flood hazard zoning in Tucuman Province, Argentina, using GIS and multicriteria decision analysis. *Eng. Geol* **111**(1–4), 90–98.

Guo, E.L., Zhang, Z.Q., Ren, X.H., et al. 2014 Integrated risk assessment of flood disaster based on improved set pair analysis and the variable fuzzy set theory in central Liaoning Province, China. *Nat. Hazards* **74**, 947–965.

Jiang, W.G., Deng, L., Chen, L.Y., Wu, J.J., Li, J. 2009 Risk assessment and validation of flood disaster based on fuzzy mathematics. *Prog. Nat. Sci.* **19**, 1419–1425.

Lai, C.G., Chen, X.H., Chen, X.Y., Wang, Z.L., Wu, X.S., Zhao, S.W. 2015 A fuzzy comprehensive evaluation model for flood risk based on the combination weight of game theory. *Nat. Hazards* **77**, 1243–1259.

Lee, J. H., Jun, H. D., Park, M. J., hak, J. J. 2011 Flash Flood Risk Assessment using PROMETHEE and Entropy Method. *Journal of Korean Society of Hazard Mitigation* **11**(3), 151-156.

Li, Q. 2013 Fuzzy approach to analysis of flood risk based on variable fuzzy sets and improved information diffusion methods. *Nat. Hazards Earth Syst. Sci.* **13**, 239–249.

MCOT 2011 Thailand's flood death toll reaches 40. 3 April 2011. Retrieved 3 April 2011.

Ministry of Land, Infrastructure and Transport (MOLIT) 2009 Korean Building Code

National Emergency Management Agency (NEMA) 2003-2012 Annual disaster report.

NASA Earth Observatory 2011 Unseasonal Heavy Rain Floods Thailand. 2 April 2011.

National Emergency Management Agency (NEMA) 2009 Development of Risk Assessment Technique for Strong Wind and Heavy Snowfall

National Emergency Management Agency (NEMA) 2014 Insurance Rate Making and Mapping Based on Natural Disaster Risk

New Zealand Herald 2011 Tourists stranded as Thai flood death toll passes 120. 1 April 2011. Retrieved 3 April 2011.

NPR 2013 Why Typhoon Haiyan Caused So Much Damage. November 11, 2013. Retrieved April 21, 2014.

Rygel, L., O'Sullivan, D., Yarnal, B. 2006 A method for constructing a social vulnerability index: An application to hurricane storm surges in a developed country, mitigation and adaptation strategies for global change. *Earth and Environmental Science* **11**, 741-764.

Shin, J. Y., Park, Y. J., Kim, T. W. 2014 Evaluation of Inland Inundation Risk in Urban Area using Fuzzy AHP. *Journal of Korea Water Resources Association* **47**(9) 789-799.

Stefanidis, Stefanos, Stathis, Dimitrios 2013 Assessment of flood hazard based on natural and anthropogenic factors using analytic hierarchy process (AHP). *Nat. Hazards* **68**, 569–585.

Stephane, H., Colin, G., Robert, J.N., et al. 2013 Future flood losses in major coastal cities. *Nat. Climate Change* **3**(9), 802–806.

The Nation 2011 Rescue efforts underway to save survivors of destroyed Krabi village; 100 still missing; Emergency evacuation in Trang, Phatthalung, Nakhon Si Thammarat and Phuket. 1 April 2011. Retrieved 6 April 2011.

The Washington Post (Washington, D.C.) 2016 Eastern Seaboard braces for potentially historic winter storm. January 22, 2016. Retrieved January 22, 2016

Wikipedia 2016 United States blizzard

Wang, Z.L., Lai, C.G., Chen, X.H., Yaing, B., Zhao, S.W., Bai X.Y. 2015 Flood hazard risk assessment model based on random forest. *Journal of Hydrology* **527**, 1130-1141.

Yang, X.L., Ding, J.H., Hou, H. 2013 Application of a triangular fuzzy AHP approach for flood risk evaluation and response measures analysis. *Nat. Hazards* **68**, 657–674.

Yu, I. S., Kim, H. Y. Imee, V. N., Jeong, S. M. 2014 Assessment and Improvement of Snow Load Codes and Standards in Korea. *Journal of the Korean Society of Civil Engineers* **34**(5), 1421-1433.

Zou, Q., Zhou, J.Z., Zhou, C., Song, L.X., Guo, J. 2013 Comprehensive flood risk assessment based on set pair analysis-variable fuzzy sets model and fuzzy AHP. *Stoch. Environ. Res. Risk Assess*. **27**, 525–546.