

Analyzing the Association between Heavy Snowfall Risks and Disaster Effects in South Korea

Geun Young Kim[#], Hee Jae Kim⁺, Sun Young Kim

Department of Urban Planning, Kangnam University, 40 Kangnam-ro, Gigeung-gu, Yongin, Korea

Abstract

The risk of heavy snowfall has increased in Korea due to global climate change, but the local governments' tasks of estimating such risks would be complex. The tasks include a number of methods and techniques for risk assessment handling relevant data sets. They also require the decision-making process of identifying heavy snowfall hazards, computing the vulnerable likelihood of heavy snowfall events, and analyzing consequential impacts of heavy snowfalls. The objective of this research is to analyze the association between heavy snowfall risks and disaster effects for local governments. This research evaluated risks using the point-based heavy snowfall risk assessment method developed by previous studies. The technique was applied to identify the association between 7 point-based snowfall risks and 52 heavy snowfall disaster loss datasets.

Key words: heavy snowfall, snow hazard, disaster risk map, statistical analysis, GIS(Geographic Information System)

1. Introduction

The vulnerability of heavy snowfall events in South Korea has recently been greater due to the climate change caused by global warming. Transportation systems of the heavy snowfall regions can be immobilized by heavy snowfall disasters. Vulnerable buildings and facilities including vinyl greenhouses, arcade roofs, or tinplate roof houses can be risked by the winter disasters. Heavy snowfall casualty and disaster losses raise the issues of community

preparedness to heavy snowfall hazard. The increasing elderly communities in farmland areas intensifies the weakness of elderly person isolation with blocked roads, insufficient heating fuel, foods shortage, and electricity cut off in rural aging society.

Determining heavy snowfall risks to persons, property, operations or business activities is a complex task that contains a number of methodologies and techniques for risk assessment. It requires relevant data sets for heavy snowfall disaster events

[#] The 1st author: Geun Young Kim, Tel. +82-31-280-3765, e-mail. gykim@kangnam.ac.kr

⁺ Corresponding author: Hee Jae Kim, Tel. +82-31-899-7174, Fax. +82-31-280-3937, e-mail. irex1@naver.com

and impacts. A decision-making process is needed to be developed in order to identify heavy snowfall hazards, compute the vulnerable likelihood of heavy snowfall occurrence, and analyze consequential impacts.

The objective of this research is to analyze the association between heavy snowfall risks and snowfall disaster losses for better prepared regional disaster management policies of local governments. This research evaluates snowfall risks computed from a point-based heavy snowfall risk assessment method. Point-based snowfall risks are obtained from the previous risk assessment research computed using cumulated snowfall data sets of the Korea Meteorological Administration by Lee(2009). Winter storm disaster loss data sets are collected from natural disaster yearbooks published by the Ministry of Public Safety and Security(MPSS) of the Korean central government. The GIS method is used to understand geographical distributions of heavy snowfall disaster losses in local governments of South Korea. The correlation analysis method of statistical analysis technique is applied to identify the association between seven point-based snowfall risk data sets and fifty-two heavy snowfall disaster loss data sets.

II. Developing the Heavy Snowfall Risk Assessment

1. Understanding the Risk Assessment

Various types of threat or danger exist in our daily life activities. Risk is the estimated impact that a potential hazard would have on persons, services, facilities, and structures in a community

during a particular time period. Risk is the expected magnitude of losses in order to control the uncertainty of our daily activities by applying a complex procedure to potential threats. Risk emphasizes the estimation and quantification of threat or harm in order to determine appropriate levels of safety or the acceptability of a technology or course of action(Cutter, 2001). Risk is widely defined as the product of a hazard and its consequences in the academic field(Petak & Atkinson, 1982; Ansell & Wharton, 1992; Clarke, 1999; Kron, 2002; Galloway, 2007; DHS, 2007).

Risk computation is the potential for realization of unwanted, adverse consequences to human life and properties based on the expected result of the conditional probability of the event occurring times the consequence of the event given that it has occurred(Gratt, 1987). It makes a quantitative estimate of damage, injuries, and costs likely to be experienced within a specified geographic area over a specific period of time(Deyle, *et. al.*, 1998). Risk assessment can be related to three components: the change of loss, the magnitude of loss, and the exposure of loss(MacCrimmon & Wehrung, 1986). Kron (2002) determines the risk using three risk assessment components:

- 1) The hazard, i.e. the threatening natural event including its probability of occurrence;
- 2) The exposure, i.e., the values/humans that are present at the location involved;
- 3) The vulnerability, i.e. the lack of resistance to damaging/destructive forces. Benouar & Mimi (2001) provide the following risk assessment function:

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability} / \text{Disaster Management} \quad (1)$$

where

Hazard is the 'Punch of Nature' (external forces), Vulnerability is the weakness/strength of the element at risk, and Disaster Management is the comprehensive strategy based on a set of activities to reduce the risk.

This research applies the idea of Benouar and Mimi's risk assessment function with the concept of Kron's three risk assessment components. The conceptual function of risk assessment for any hazard during a particular time period is developed in this research:

$$\text{Risk} = \text{Probability of Hazard} \times \text{Disaster Consequence} / \text{Disaster Management} \quad (2)$$

where,

Probability of Hazard is the occurrence probability of the damaging event,

Disaster Consequence is the expected degree and type of damage, and

Disaster Management is the distribution of costs and benefits by the endeavor of a community to reduce the risk.

The function (2) is the modified version of Benouar and Mimi's function (1). Lee(2009) provided outcomes of heavy snowfall risks based on the point-based heavy snowfall risk assessment method using Kron's function (2). The applicability of Lee's snowfall risk assessment using property type-wise wind fragility functions can be improved by performing the association analysis between snowfall risk assessment outcomes and actual heavy snowfall disaster loss data sets.

2. The Heavy Snowfall Risk Assessment Framework and Research Data

Heavy snowfall events are severe winter disasters in which large amounts of falling or blowing snow are driven for an extended period of time. This study uses the decomposition approach that sequentially computes the probability of heavy snowfall disaster, average snowfall losses by disaster damage categories, and non-scale disaster management indices within the framework of snowfall risk assessment.

The likelihood of heavy snowfall disaster is computed using heavy snowfall disaster events. The average snowfall losses are computed by fifty-two

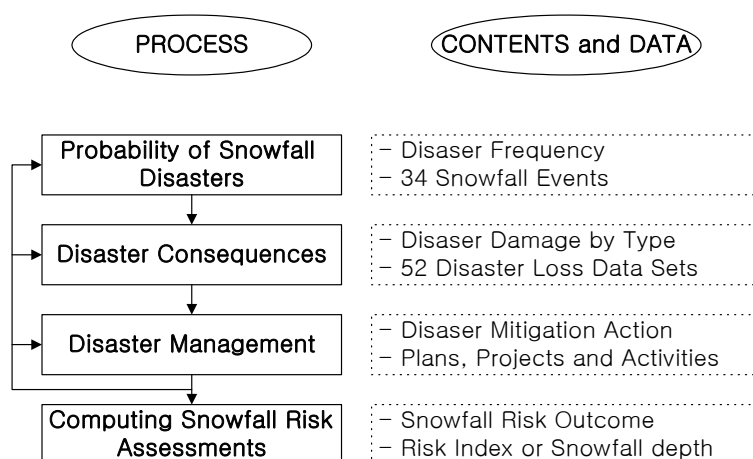


Figure 1. Heavy snowfall risk assessment framework and research data

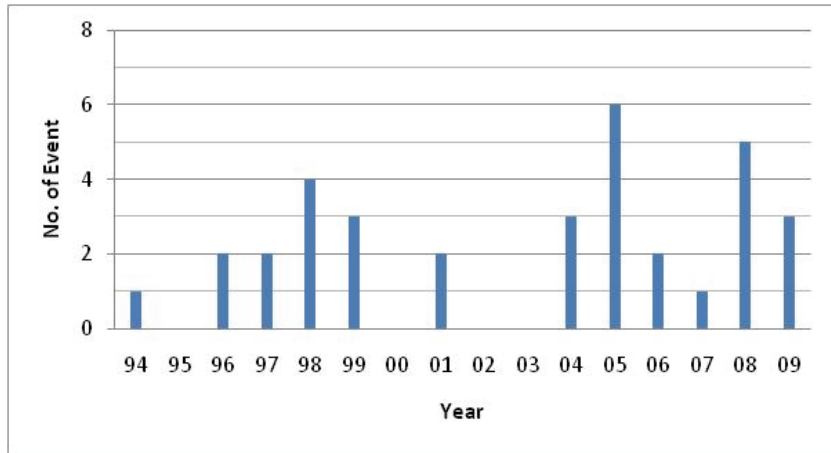


Figure 2. Heavy snowfall events by year in South Korea

disaster damage categories. The heavy snowfall event and disaster loss data sets are obtained from the Natural Disaster Yearbook published by the Ministry of Public Safety and Security during the period of 1994 to 2009. The heavy snowfall policy evaluation index introduced by Kang, *et. al.*(2005) can be applied as the non-scale disaster management indices for the heavy snowfall risk assessment. The heavy snowfall risk assessment framework and research data sets are presented in <Figure 1>.

III. Heavy Snowfall Events and Disaster Losses

1. Heavy Snowfall Events

Thirty-four heavy snowfall disasters are identified from the Natural Disaster Yearbooks during the period of 1994 to 2009. The probability of annual occurrence of heavy snowfall disaster in South Korea is 2,125, computed by thirty-four divided by sixteen. The annual event of heavy snowfalls in South Korea is shown in <Figure 2>. The monthly distribution of heavy snowfall events is presented in <Figure 3>.

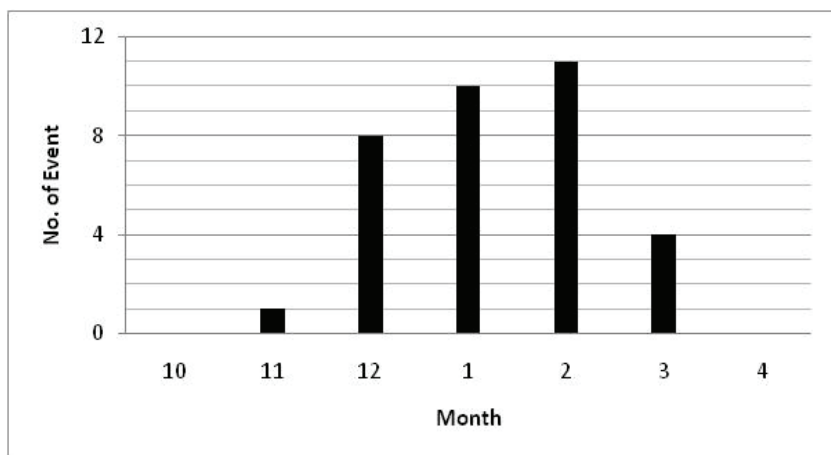


Figure 3. Monthly distribution of heavy snowfall events

The occurrence of heavy snowfall disasters is high during the period of December to February. The total probability of the three winter months reaches to 0.853, while the probability of snowfall occurrence in March is relevant(0.118).

2. Analysis of Heavy Snowfall Disaster Losses

This study obtains fifty-two disaster loss data sets for heavy snowfalls during the period of 1994 to 2009. Twenty-three data sets out of the fifty-two snowfall disaster loss data sets are monetary losses with the unit of Korean Won. These data sets are converted to present values of the 2009 standard year by applying the 2009 monetary

value index provided by the Bank of Korea. Average values and standard deviations of the fifty-two disaster loss data sets are computed and presented in <Table 1>.

The total number of 1,326 correlation coefficients between two average data sets out of the fifty-two snowfall disaster loss data sets is analyzed using the Statistical Analysis Software (SAS) 9.1.3 version. The total number of 410 correlation coefficients is statistically significant within the 0.05 significance level, including 336 correlation coefficients within the 0.01 significance level. The correlation coefficients between total economic loss variable and one of the fifty-one remaining

Table 1. Mean and standard deviation of disaster damage variables

(Unit: Number, 1000 KWN)

Variable		Mean	STD	Variable		Mean	STD
Disaster victim	Housing Household	2.58	11.42	Public Facility (Econ. Loss)	Fresh Water Facility	120.9	1,103
	Housing Person	8.79	41.05		Port	1,742	26,651
	Other Household	0.86	5.78		Fishery Facility	1,344	8,403
	Other Person	3.79	26.36		School	1,727	11,893
	Total Household	3.44	13.82		Railroad	7.76	98.91
	Total Person	12.58	53.14		erosion control	7.61	116.42
Casualty	Death	0.00	0.04	Small Facility	1,061	6,810	
	Missing	0.01	0.06	Military Facility	2,572	9,802	
	Wounded	0.00	0.02	Other Public Facility	5,170	25,137	
Building	Total	0.02	0.08	Total	14,034	43,648	
	Total Collapse	0.04	0.15	Number	0.01	0.12	
	Half Damage	0.13	0.51	Econ. Loss	14.44	168.72	
	Total	0.18	0.63	Number	2,813	10,261	
Damaged Vessel	Econ. Loss	2,823	9,915	Livestock	Econ. Loss	135.88	849.61
	No. of Ship	0.02	0.36	Cattle	Number	9.85	20.47
	Tons of Ship	194.6	2,125	Shed	Econ. Loss	209,859	513,329
Agricul. Land	Econ. Loss	1,324	6,436	Fishery Damage	Number	1.84	14.00
	Rice(ha)	17.41	175.2	Econ. Loss	16,590	81,919	
	Barley(ha)	261.6	2,734	Number	9.07	76.23	
	Total	279.0	2,889	Econ. Loss	2,848	18,479	
Agricul. Product	Rice(ha)	1.31	5.70	Number	2.95	6.19	
	Barley(ha)	0.28	2.36	Econ. Loss	227,964	565,391	
	Other(ha)	0.81	2.97	Number	12.52	27.43	
	Total(ha)	2.40	6.95	Econ. Loss	209,179	426,746	
Public	Econ. Loss	0.03	0.50	Sub-total Economic Loss	666,590	1,262,383	
	Road	281.4	2,987	Total Economic Loss	684,772	1,273,995	

variables are presented in <Table 2>. Thirty-one correlation coefficients are identified to be statistically significant within the 0.05 significance level, including twenty-eight correlation coefficients within the 0.01 significance level. About sixty-one percent of fifty-one correlation coefficients using the total economic loss variable present the association between the total economic loss variable and the remaining variable, though thirty-one percent of correlation coefficients among fifty-two variables are revealed to have the association between the two variables. This result provides the

usefulness of the total economic loss variable in the heavy snowfall risk assessment.

This study examines the geographical distribution of the fifty-two heavy snowfall damage data sets by applying the GIS technique using the GIS software. The geographical distributions of average values of total disaster victim, building economic damage, public facility economic damage, and total economic damage during the period of 1994 to 2009 are shown in snowfall disaster risk maps of <Figure 4>. The first three GIS distribution case studies are selected based on the relatively significant

Table 2. Correlation coefficients of fifty-one variables with total economic loss variable

Variable		Corr. Coef.	P-value	Variable		Corr. Coef.	P-value
Disaster victim	Housing Household	0.580**	<.0001	Public Facility (Econ. Loss)	Fresh Water Facility	0.021	0.7496
	Housing Person	0.577**	<.0001		Port	0.028	0.6752
	Other Household	0.096	0.1441		Fishery Facility	-0.015	0.8144
	Other Person	0.090	0.1690		School	0.135*	0.0392
	Total Household	0.519**	<.0001		Railroad	-0.028	0.6755
	Total Person	0.490**	<.0001		erosion control	0.021	0.7501
Casualty	Death	-0.002	0.9717	Small Facility	-0.004	0.9501	
	Missing	-0.053	0.4193	Military Facility	0.167*	0.0106	
	Wounded	0.199**	0.0023	Other Public Facility	0.172**	0.0084	
Building	Total	0.013	0.8388	Total	0.185**	0.0046	
	Total Collapse	0.426**	<.0001	Walls	Number	-0.030	0.6430
	Half Damage	0.297**	<.0001	Econ. Loss	-0.032	0.6256	
	Total	0.337**	<.0001	Livestock	Number	0.507**	<.0001
Damaged Vessel	Econ. Loss	0.457**	<.0001	Cattle	Econ. Loss	0.012	0.8598
	No. of Ship	0.049	0.4542	Shed	Number	0.832**	<.0001
	Tons of Ship	0.235**	0.0003	Fishery	Econ. Loss	0.844**	<.0001
Agricul. Land	Econ. Loss	-0.022	0.7430	Damage	Number	0.077	0.2386
	Rice(ha)	0.254**	<.0001	Econ. Loss	0.187**	0.0041	
	Barley(ha)	0.237**	0.0003	Fishing Gear	Number	0.024	0.7107
	Total	0.238**	<.0001	Econ. Loss	0.025	0.6997	
Agricul. Product	Rice(ha)	0.469**	<.0001	Vinyl House	Number	0.736**	<.0001
	Barley(ha)	0.439**	<.0001	Econ. Loss	0.801**	<.0001	
	Other(ha)	0.162*	0.0128	Number	0.617**	<.0001	
	Total(ha)	0.603**	<.0001	Other	Econ. Loss	0.842**	<.0001
Public	Econ. Loss	0.199**	0.0022	Sub-total Economic Loss	0.999**	<.0001	
	Road	-0.034	0.6085	-	-	-	

The symbol of **** stands for the 0.01 significance level.
 The symbol of ** stands for the 0.05 significance level.

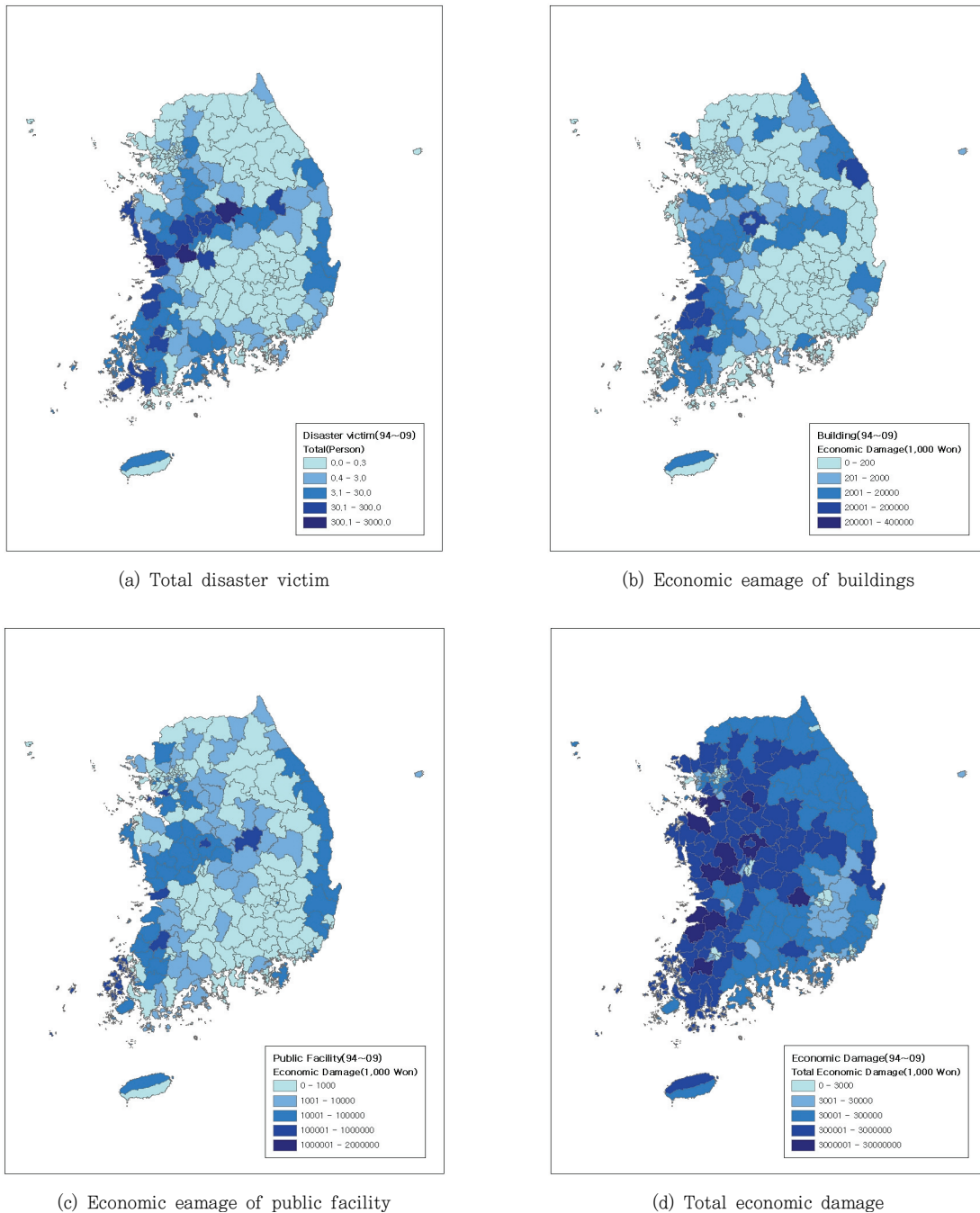


Figure 4. Disaster risk maps of four average values during 1994 to 2009

correlation coefficients with total economic loss variable. They can be causes of snowfall-related economic damage. The last GIS case study is the geographical distribution of total economic damage of heavy snowfall disasters that provides vulnerable areas.

The geographical distributions in <Figure 4>

present that both southwest coastal areas and east coastal areas are vulnerable to heavy snowfall disasters.

IV. Results

The Korean government presented snowfall risks

Table 3. Correlation coefficients between snowfall risks and disaster loss variables

Variable	Annual Maximum Snowfall	Annual Minimum Snowfall	Annual Average Snowfall	30-Year Snowfall	50-Year Snowfall	100-Year Snowfall
Building Half Collapse	0.360** (0.0032)	0.199 (0.1120)	0.291* (0.0185)	0.296* (0.0168)	0.295* (0.0169)	0.295* (0.0169)
Building Total	0.316* (0.0105)	0.208 (0.0967)	0.260* (0.0368)	0.259* (0.0371)	0.259* (0.0375)	0.258* (0.0378)
No. of Walls	0.380** (0.0018)	-0.070 (0.582)	0.208 (0.0968)	0.261* (0.0354)	0.265* (0.0329)	0.269* (0.0303)
Econ. Loss of Walls	0.370** (0.0024)	-0.061 (0.6280)	0.205 (0.1011)	0.256* (0.0394)	0.259* (0.0369)	0.263* (0.0341)
Econ. Loss of Cattle Shed	0.066 (0.5995)	0.295* (0.0171)	0.103 (0.4163)	0.073 (0.5643)	0.071 (0.5762)	0.068 (0.5892)
Sub-total Econ. Loss	0.017 (0.8913)	0.266* (0.0322)	0.027 (0.8298)	-0.003 (0.9810)	-0.005 (0.9672)	-0.008 (0.9512)
Total Econ. Loss	0.019 (0.8837)	0.264* (0.0333)	0.025 (0.8422)	-0.004 (0.9743)	-0.006 (0.9611)	-0.009 (0.9455)

computed from the point-based heavy snowfall risk assessment method developed by a governmental R&D project. The Point-based snowfall risks are obtained from the risk assessment research computed using cumulated snowfall data sets of the Korea Meteorological Administration by Lee(2009). The study provides seven relevant variables including the three annual data sets of maximum, minimum and average snowfalls, and the four estimated values of 30-year, 50-year, 100-year and 200-year snowfall. This research investigates the association between Lee's snowfall risks and heavy snowfall disaster losses.

Results from the correlation analyses show that seven snowfall loss data sets are associated with Lee's snowfall risks. Only twenty-five out of 364 correlation coefficients are proven to be statistically significant within the 0.05 significance level, including three correlation coefficients within the 0.01 significance level. This result presents that the association between Lee's snowfall risk indices and snowfall losses is weak. The current snowfall risk association method based on only snowfall

depth is needed to be improved by including economic losses or other snowfall factors. The annual maximum snowfall data set is relatively better than other snowfall risk indices in terms of statistical significance with snowfall loss data sets.

V. Conclusion

This research analyzed the association between NEMA's snowfall risks and heavy snowfall disaster loss data sets. Heavy snowfall disasters occurred high during the period of December to February. The total probability of the three winter months reaches to 0.853. This explains the seasonality of heavy snowfall disaster risks. The statistical analysis results show that the total economic loss variable is important in the heavy snowfall risk assessment. Thirty-one correlation coefficients are identified to be statistically significant with the total economic loss variable, including twenty-eight correlation coefficients within the 0.01 significance level. The results of these associations reveal the usefulness of the total economic loss data

in the heavy snowfall risk assessment. The association between NEMA snowfall risks and snowfall losses seems to be weak. The improvement of the current snowfall risk association method is needed for better snowfall disaster policies of local governments.

The geographical distributions of heavy snowfall losses represent regional difference in heavy snowfall impacts to life, property, and infrastructure of local governments. The geographical distributions of average values of total disaster victim, building economic damage, public facility economic damage, and total economic damage during the period of 1994 to 2009 provide strong locality of heavy snowfall effects. This proves that causes and economic effects of heavy snowfall disasters are different from those of other natural disasters including typhoons or heavy rainfalls.

Local governments of South Korea are needed to develop heavy snowfall disaster management policies and plans different from traditional natural disaster management policies and plans. Their policies and plans should be improved based on updated information of thirty-one snowfall-related damage variables to total economic losses. GIS-based regional difference outcomes can be also used for the heavy snowfall disaster management policies and plans of South Korean local governments.

감사의 글

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우리나라의 대설 위험도와 대설재난 영향간 연관성 분석

국문초록 세계의 기후변화 현상으로 인하여 한국에서도 대설의 위험도 증가하고 있다. 한국의 지방자치단체에서 대설의 위험을 이해하는 것은 복잡한 업무이다. 이러한 업무에는 대설재난 사건 및 영향과 관련된 자료뿐만 아니라 위험성 평가를 위한 여러 방법론과 기술을 포함한다. 따라서 대설의 위험을 파악하고, 대설 재난의 취약수준을 계산하여 대설 영향을 분석하는 의사결정 프로세스가 필요하다. 본 연구는 한국 지방자치단체의 잘 준비된 재난관리 정책을 위하여 대설 위험도와 대설재난 영향간 연관성을 분석하는 것을 목적으로 한다. 본 연구에서는 이전의 연구에서 개발된 점적 대설 위험도 평가 방법을 사용한 대설 위험도에 대해 평가하였다. 본 연구에 사용된 통계 분석 기법은 7개 지점 기반의 강설 위험 데이터와 52개 대설재난 피해 데이터 사이의 연관성을 분석하기 위하여 사용되었다.

주제어 : 대설, 강설위험, 재난위험지도, 통계분석, 지리정보시스템

Profiles **Geun Young Kim** : He received his B.S in Korea University. He received M.Pl., Ph.D. from University of Southern California, USA in 1997. He is a professor of the Department of Urban Planning at Kangnam University, in which he has taught since 1999. His research interest is urban planning, transportation planning, and disaster & emergency management (gykim@kangnam.ac.kr).

Hee Jae Kim : He received his B.S., M.A., and Ph.D. from Chung-Ang University, Korea in 2016. He has been a research fellow at the Multi-disciplinary Center for Ubiquitous Cities(MDCUC) of Kangnam University since 2016. His research interest is urban planning, real estate analysis, and disaster & emergency management(irex1@naver.com).

Sun Young Kim : She received her B.S. from Kangnam University, and M.S from Hongik University, Korea. She is a Ph.D. candidate in Gachon University. She has joined as a research fellow at the Multi-disciplinary Center for Ubiquitous Cities(MDCUC) of Kangnam University since 2016. Her research interest is urban planning and disaster & emergency management(ggsunny@naver.com).