J. Comput. Struct. Eng. Inst. Korea, 27(6)
pp.485~492, December, 2014
http://dx.doi.org/10.7734/COSEIK.2014.27.6.485

pISSN 1229-3059 eISSN 2287-2302
Computational Structural
Engineering Institute of Korea

메라피 화산재해에 대한 지역단위의 사회적 취약성 평가

이 승 수[1†] · Yohana Noradika Maharani[2] · 이 원 호[3]

[1]충북대학교 토목공학부, [2]충북대학교 토목시스템공학과, [3]광운대학교 건축공학과

Assessment of Local Social Vulnerability in Facing Merapi Volcanic Hazard

Sungsu Lee[1†], Yohana Noradika Maharani[2] and Waon-Ho Yi[3]

[1]*School of Civil Engineering, Chungbuk National Univ., 361-763, Cheongju, Korea*
[2]*Department of Civil Systems Engineering, Chungbuk National Univ., 361-763, Cheongju, Korea*
[3]*Department of Architectural Engineering, Kwangwoon Univ., 138-701, Seoul, Korea*

Abstract

In regards to natural disasters, vulnerability analysis is a component of the disaster risk analysis with one of its objectives as a basis for planning priority setting activities. The volcano eruption raises many casualties and property in the surrounding area, especially when the volcano located in densely populated areas. Volcanic eruptions cannot be prevented, but the risk and vulnerability can be reduced which involve careful planning and preparations that anticipate a future crisis. The social vulnerability as social inequalities with those social factors can influence the susceptibility of various groups to harm and govern their ability to respond. This study carried out the methods of Social Vulnerability Index (SoVI) to measure the socially created vulnerability of the people living in Merapi proximal hamlets in Central Java, Indonesia that refers to the socioeconomic and demographic factors that affect the resilience of communities in order to describe and understand the social burdens of risk. Social vulnerability captured here, using a qualitative survey based-data such as interviews to local people with random ages and background to capture the answer vary, also interviews to stakeholders to help define social vulnerability variables. The paper concludes that by constructing the vulnerability index for the hamlets, the study reveals information about the distribution and causes of social vulnerability. The analysis using SoVI confirms that this method works well in ensuring that positive values indicating high social vulnerability and vice versa.

Keywords : *social vulnerability, social vulnerability index (SoVI), Merapi volcano eruption*

1. Introduction

Social vulnerability is difficult to quantify, therefore Cutter *et al*. (2003) proposed the construction of Social Vulnerability Index (SoVI) as a basis for local officials, emergency managers, and planners to add to their action plan on disaster response in order to allocate the necessary resources in the events of disasters to the right targets at the right location (Cutter *et al*., 2003; UCHSC, 2004; Boruff *et al*., 2005; Boruff *et al*., 2007).

The similar study also conducted by the work of Pungky Utami (2009) with unit of analysis in village district and analysis census-based data without a qualitative survey based-data. However, this study carried out analysis on the level of hamlet, instead of village district, since a village may be located in several hazard zones (observation by Sagala and Okada). Also, social vulnerability captured here is using a qualitative survey based-data such as interviews to local people and stakeholders to help define social vulnerability variables by conducted fieldwork which

† Corresponding author:
Tel: +82-43-276-3344; E-mail: joshua@chungbuk.ac.kr
Received October 25 2014; Revised November 10 2014
Accepted November 11 2014

consisted of one and a half weeks during September 2-11, 2013. It was covering of two trips, first was surveyed the environment and residential building and interviews to the local people in Turgo and Kaliurang Barat hamlet, Pakem District, Sleman Regency related to vulnerability. Second, interviews and collecting data from stakeholders such as BPPTKG, Yogyakarta and BPBD Sleman (Regional Disaster Management Board).

2. Case Study Area

According to Suryo and Clarke (1985), the most common hazards following a volcanic eruption in Indonesia are lava flows, volcanic blocks and bombs, pyroclastic flows, lahars, and ash plumes, which commonly occur in Merapi volcano. Merapi has high volcanic activity and it is the most active of least 129 active volcanoes in Indonesia, located in Java Island which has been responsible for thousands of deaths in the region. Since AD 1000, Merapi has erupted more than 80 times. Merapi eruption in 2010 was the biggest (VEI 4), compared with the same disaster in five occurrences in the past 1994, 1997, 1998, 2001, 2006 and caused death loss around 400 people.

The focus of this study was in Turgo hamlet in Purwobinangun village and Kaliurang Barat hamlet in Hargobinangun village, Pakem District, Sleman Regency, Special Region of Yogyakarta, as shown in Fig. 1. The study areas are involved as Hazard Zone III (KRB III). Hazard Zone III is a disaster-prone areas often pounded by hot clouds, lava flows (avalanches /burst of incandescent material), toxic gases.

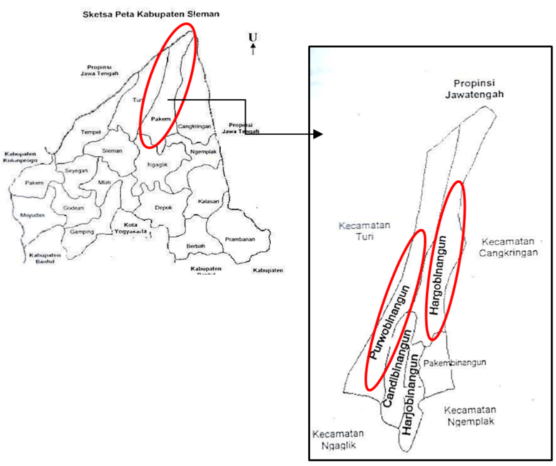

Fig. 1 The map of study area location

3. Social Vulnerability Index (SoVI) Analysis

The study runs Statistical Package for Social Science (SPSS) to process the data set and using Principal Component Analysis (PCA) analysis.

Tabachnick and Fidell (2007) explained several steps in running PCA, which include selecting a set of variables, preparing correlation matrix, extracting a set of components from the correlation matrix, determining the number of components to extract by Kaiser's criterion as well as scree plot, rotating the components to increase its interpretability, and interpreting the results.

In the early stage, the calculation for this study was only for two hamlets as case study i.e. Turgo and Kaliurang Barat hamlets. The initial dataset for those two cases study were proved invalid as the number of cases was less than the number of variables, thus PCA would not produce reliable results. Due to that reason, other hamlets were added to perform the calculation, which using the statistical data obtained from the website of Sleman Regency statistical office.

Statistical identification is very important in terms of engineering field (Yang *et al.*, 1993). In this case, the statistical data obtained from Pakem District in Figures 2007 and Sleman Regency in Figures 2010. Due to the limited and availability of data, the assumption was taken in this study. The unit analysis in this study was at the hamlet level; therefore all indicators in this research were then calculated at the hamlet level. Data obtained were derived and adjusted according to the amount of population in each hamlet to get numbers in statistical data in the level of hamlet.

The vulnerability index is constructed from nine socio-economic concepts which collectively represent a universal concept of social vulnerability. A Principal Component Analysis (PCA) is used to reduce

Table 1 Social vulnerability variables, concepts and rationale

Label	Vulnerability variables	Concept of vulnerability	Vulnerability rationale
PRCTFEM	Percentage of females	Gender	Correlated with lack of resources
BBTDLR	Number of baby and toddler	Age	May require more assistance during a hazard event
UNDER19	Number of under 19 years old		
ELDRY	Number of elderly		
EMPLYLS	Unemployment	Employment loss	Contributing to a slower recovery from disaster
POPDNSTY	Population density	Rural / urban	High population will increase the social vulnerability
MOVEPPL	Movement of people who come		
AGRCLTR	Number of people who works in agriculture(farmer)	Livelihood	May be more vulnerable due to lower incomes and more dependent on locally based resource economies
MINQUAR	Number of people who works in mining and quarrying		
MIDSCHL	Number of people who has education until middle school	Education	Lower education constrains the ability to understand warning information and access to recovery information
DISBLD	Disable people(blind, deaf, physical handicapped, chronically sick, double)	Disability	Require additional support and assistance in coping with the hazard impacts
VEHCMT	Number of vehicle motorized	Transport	Enable to evacuate
VEHCNNMT	Number of vehicle non-motorized		Lack of mobility
FAMNUMB	Families number	Household	Large family number will increase the social vulnerability

the number of variables into fewer components that are uncorrelated with all others (Lattin *et al*., 2003). After observing the vulnerability variables relevant to the case study, there were 14 variables (Table 1) available for further analysis.

The research identifies the underlying factors which increase the social vulnerability by assessing the variables used to measure social vulnerability. To obtain the SoVI, two steps of analyses will be carried out. The first step is variable reduction and then followed by the calculation of social vulnerability index, as explained in the following section.

3.1 Variable reduction

The Principle Component Analysis was taken to reduce correlated variables into several uncorrelated appropriate components using varimax rotation and the eigenvalues greater than 1. The component which has eigenvalues greater than 1 will extract, and then used to measure the social vulnerability of each hamlet. The statistical steps explained as following section.

Because of the value and unit of each variable is different, then the raw data need to be performed using data standardization Z-score. Z-scores are expressed in terms of standard deviations from their means. Resultantly, these z-scores have a distribution with a mean of 0 and a standard deviation of 1. The formula for calculating the standard score is given below

$$z = \frac{X-\mu}{\sigma} \tag{1}$$

Where μ is mean, X is score, and σ is standard deviation. The value of z is positive when the value is greater than the mean, and z is negative when the value is less than the mean.

For the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy (MSA) presented in Table 2 tests that the partial correlation among variables are small. KMO's statistic Kaiser (1974) recommends a bare minimum of 0.5 and that values between 0.5 and 0.7 are mediocre, values between 0.7 and 0.8 are good, values between 0.8 and 0.9 are great and values above 0.9 are superb (Hutcheson *et al*., 1999). For any variables with values below 0.5 then it should consider excluding from the analysis and repeat the analysis without them. The KMO's equation is,

Table 2 KMO and Bartlett's test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.804
Bartlett's Test of Sphericity	Approx. Chi-Square	330.813
	df	66
	Sig.	0.000

$$KMO = \frac{\sum_i \sum_{i \neq k} r_{ik}^2}{\sum_i \sum_{i \neq k} r_{ik}^2 + \sum_i \sum_{i \neq k} a_{ik}^2} \quad (2)$$

Where r_{ik} is coefficient of simple correlation between variable i^{th} and k^{th}, and a_{ik} is coefficient of partial correlation between variable i^{th} and k^{th}. Measure of Sampling Adequacy (MSA) equation is,

$$MSA = \frac{\sum r_{ij}^2}{\sum r_{ij}^2 + \sum pr_{ij}^2} \quad (3)$$

Bartletts test of sphericity measure tests the null hypothesis that the original correlation matrix is an identity matrix. A significant test tells us that the R-matrix is not an identity matrix; therefore, there are some relationships between the variables we hope to include in the analysis. For these data, Bartlett's test is highly significant if $p<0.001$. The Bartletts's equation is,

$$X^2 = -\left[(N-1) - \frac{(2p+5)}{6}\right] \ln|R| \quad (4)$$

Where N is the amount of observation, p is the amount of variable and $|R|$ is determinant matrix correlation.

According to the process calculation as explained in above steps, the two variables i.e. POPDNSTY and AGRCLTR have to be removed because do not meet the requirements. After removing POPDNSTY and AGRCLTR variables, it shows from the results in Table 2, the KMO value is 0.804; means the value is great since correlations between pairs of variables can be explained by the other variables. Bartlett's test is 0.000, means highly significant if $p<0.001$. Hence, the samples could be analyzed further without AGRCLTR and POPDNSTY variables.

In this calculation, the result of Measure of Adequacy Sampling (MSA) for all variables is more than 0.5, then it can be analysed further. Only those with eigenvalues >1 (Kaiser criterion, Kaiser 1960) which need to be considered. As factors with eigenvalues <1 can be said to be not significant, as shown in Table 3. An eigenvalue represents the amount of variance accounted for by a factor. Because the variance that each standardized variable contributes to a principal factor extraction is 1, a factor with an eigenvalues less than 1 is not as important, from a variance perspective, as an observed variable. Variance factor is formed of the % of Variance on Extraction Sums of Squared Loadings.

An extraction procedure is usually accompanied by rotation to improve the interpretability and scientific

Table 3 Initial Solution

Component	Initial Eigenvalues			Extraction Sums of Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.999	66.659	66.659	7.999	66.659	66.659	6.999	58.329	58.329
2	1.784	14.866	81.525	1.784	14.866	81.525	2.784	23.196	81.525
3	0.913	7.611	89.136	-	-	-	-	-	-
4	0.688	5.734	94.840	-	-	-	-	-	-
5	0.322	2.687	97.557	-	-	-	-	-	-
6	0.147	1.225	98.783	-	-	-	-	-	-
7	0.058	0.479	99.262	-	-	-	-	-	-
8	0.045	0.376	99.638	-	-	-	-	-	-
9	0.035	0.292	99.930	-	-	-	-	-	-
10	0.007	0.055	99.985	-	-	-	-	-	-
11	0.001	0.012	99.997	-	-	-	-	-	-
12	0.000	0.003	100.000	-	-	-	-	-	-

Extraction Method: Principal Component Analysis utility of the solution. The purpose of rotation is to achieve a simple structure in which each factor has large loadings in absolute value for only some of the variables, making it easier to identify (Nourusis, 2003). In this case, choose the most common orthogonal rotation method known as varimax was developed by Kaiser (1958).

For varimax a simple solution means that each factor has a small number of large loadings and a large number of zero (or small) loadings. This simplifies the interpretation because after varimax rotation, each original variable tends to be associated with one (or a small number) of factors, and each factor represents only a small number of variables.

$$V=\Sigma\left(q_{j,l}^{2}-\bar{q}_{j,l}^{2}\right)^{2} \quad (4)$$

Where $q_{j,l}^{2}$ being the squared loading of the j^{th} variable on the l factor and $\bar{q}_{j,l}^{2}$ being the mean of the squared loadings.

Following in the Table 4 are derived components which are used to construct the social vulnerability index for each hamlet. Factor with the greatest values are classified into Factor 1 with variance on extraction sums of square loadings is 66.659% and Factor 2 is 14.866%.

Table 4 Component and loading used to construct the social vulnerability index

Component (concept of vulnerability)	Label (vulnerability variables)	
Gender	PRCTFEM	FACTOR 1, variance on extraction sums of square loadings is 66.659%
Age	BBTDLR	
	UNDER19	
	ELDRY	
Livelihood	MINQUAR	
Education	MIDSCHL	
Disability	DISBLD	
Transport	VEHCMT	
	VEHCNNMT	
Household	FAMNUMB	
Employment loss	EMPLYLS	FACTOR 2, variance on extraction sums of square loading is 14.866%
Rural / urban	MOVEPPL	

3.2 Calculation of Social Vulnerability Index (SoVI)

The next step is derived the components which are used to construct the social vulnerability index for each hamlet. The total components' score is summed to create the social vulnerability index score. The score is classified into levels ranging from the value <-1.5 indicating low social vulnerability to the value >+1.5 indicating high social vulnerability.

From the results of PCA analysis, factor score values obtained for each hamlet and the factor 1 score and factor 2 score are summed to create the total social vulnerability index score (SV score), shown in Table 5.

As the case study in Pakem District, Turgo hamlet has - 0.53 score and Kaliurang Barat hamlet has - 0.56. It means that Turgo hamlet is more vulnerable than Kaliurang Barat hamlet. It is also shown that Juwangan hamlet in Kalasan District with 3.75 score is the most vulnerable than others.

The next step is to map the social vulnerability score derived from the statistical analysis. The social vulnerability map and the Merapi's volcanic hazard

Table 5 Ranking of Social Vulnerability Index (SoVI)

Hamlet	Factor 1 score	Factor 2 score	SV Score	Rank
Sonokulon	-0.84	-0.51	-1.35	1
Pagerjurang	-0.75	-0.43	-1.18	2
Kragan	-0.85	-0.22	-1.07	3
Mlesen	-0.42	-0.55	-0.97	4
Sambi	0.03	-0.95	-0.92	5
Jurangjero	-0.44	-0.38	-0.82	6
Mancasan	0.08	-0.79	-0.71	7
Kaliurang Barat	0.04	-0.6	-0.56	8
Turgo	-0.42	-0.12	-0.53	9
Jambeyan	-0.22	-0.24	-0.46	10
Ngentak	-0.14	-0.13	-0.26	11
Tepus	0.52	-0.72	-0.21	12
Ngepos	0.81	-0.45	0.36	13
Sambirejo	-0.67	1.64	0.97	14
Pucung	-0.05	1.4	1.35	15
Glondong	-0.15	2.77	2.62	16
Juwangan	3.46	0.28	3.75	17

Pakem District
Kalasan District
Tempel District

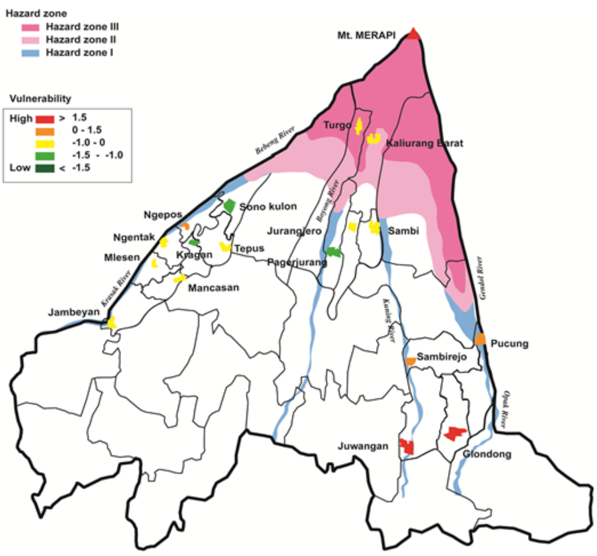

Fig. 2 Social vulnerability map overlaid with Merapi volcanic hazard map 2010

map 2010 (BPPTK) are overlaid together. According to the social vulnerability map in Fig. 2, the finding is that the high socially vulnerable people do not necessarily reside within hazard zone III or II, taking the example of Juwangan and Glondong hamlets reside within hazard zone I that has highest socially vulnerable than others where these two hamlets located near the river. Juwangan hamlet located near to Kuning River and Glondong hamlet located near to Opak River.

3.3 Dominant influence of individual variables

In order to predict which individual variables give significant contributions to the total score, the study

Table 6 Dominant social vulnerability variables rank based on standardized beta coefficient(β)

Standardized variables	β	Sig.(<0.05)
Number of vehicle non-motorized	0.461	0.000
Families number	0.412	0.000
Number of unemployment	0.232	0.001

applies the stepwise regression method. The standardized beta coefficients in the stepwise regression indicate the strength independent variables (vulnerability variables) with the dependent variable (social vulnerability score). As shown the result in Table 6, shows the number of vehicle non-motorized is the most important contributor of social vulnerability in all hamlets. According to the result of interviews with the people in study area, transport was the initial list of vulnerability variable that most frequently mentioned as they are lack of transportation, since they need quick access during evacuation. The result is followed by the families' number and the number of unemployment.

The removed variables shown in Table 7 which are grouped in a separate table below show that their significance values (Sig.) do not meet the requirement ($p<0.05$), therefore the hypothesis that the variables do not demonstrate strong relationship with the dependent variable is accepted. To interpret the results, only the first few columns are relevant to this study, namely the beta value (Beta In), t-statistic (t) and the significance value (Sig.). The beta value and t-statistics show the degree to which each predictor

Table 7 Exclude variables

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
3	Zscore(ZPRCTFEM)	0.250c	1.670	0.121	0.434	0.050
	Zscore(ZBBTDLR)	0.040c	0.897	0.387	0.251	0.665
	Zscore(ZUNDER19)	0.208c	1.469	0.168	0.390	0.058
	Zscore(ZELDRY)	0.247c	1.899	0.082	0.481	0.062
	Zscore(ZMOVEPPL)	0.086c	1.521	0.154	0.402	0.359
	Zscore(ZMINQUAR)	0.162c	1.839	0.091	0.469	0.138
	Zscore(ZMIDSCHL)	0.221c	1.777	0.101	0.457	0.071
	Zscore(ZDISBLD)	-0.026c	-0.429	0.675	-0.123	0.369
	Zscore(ZVEHCMT)	0.058c	0.927	0.372	0.258	0.332

a. Predictors in the Model:(Constant), Zscore(VEHCNNMT)
b. Predictors in the Model:(Constant), Zscore(VEHCNNMT), Zscore(FAMNUMB)
c. Predictors in the Model:(Constant), Zscore(VEHCNNMT), Zscore(FAMNUMB), Zscore(EMPLYLS)
d. Dependent Variable: totsovi

affects results if the effects of other predictors are held constant (Field, 2005).

4. Conclusion

The creation of vulnerability index is a useful starting point when trying to capture vulnerability. This approach depends much on the quality, availability of the data and the unit of analysis that are dealing with. This study carried out analysis on the level of hamlet, instead of village district, since a village may be located in several hazard zones. The finding from the analysis using SoVI confirms that this method works well in ensuring that positive values indicating high social vulnerability and vice versa. The small number of cases has created few difficulties in processing the dataset since PCA requires large sample size. In addition, according to the interviews to the local people, found that experiences of disaster in the past eruption might make the people more prepared for future scenarios. Most interviewees understand that children, baby, elderly, pregnant mother are the most vulnerable group. Most people in both study areas have a good understanding of the dangers of volcano, as they received education and socialization from government such as BPPTKG and BPBD Sleman.

Acknowledgments

This research was supported by a grant (NEMA-BAEKDUSAN-2012-4) from the Volcanic Disaster Preparedness Research Center sponsored by National Emergency Management Agency of Korea.

References

Abdi, H., William, J.L. (2010) Principal Component Analysis, *Wiley Interdisciplinary Reviews: Comput. Statistics,* 2.

Cutter, S.L. (1996) Vulnerability to Environmental Hazards, *Prog. Hum. Geogr.,* 20(4), pp.529~539.

Cutter, S.L., Boruff, B.J., Shirley, W.L. (2003) Social Vulnerability to Environmental Hazards, *Soc. Sci. Q.,* 84(2).

Cutter, S.L., Emrich, T.C. (2006) Moral Hazard, Social Catastrophe: The Changing Face of Vulnerability along the Hurricane Coast, *The Annals of the American Academy of Political and Social Science.*

Cutter, S.L., Mitchell, J.T., Scott, M.S. (1997) *Handbook for Conducting a GIS-Based Hazards Assessment at the County Level,* South Carolina Emergency Preparedness Division Office of the Adjutant General.

Cutter, S.L., Mitchell, J.T., Scott, M.S. (2000) Revealing the Vulnerability of People and Places: A Case Study of Georgetown County, South Carolina, *Ann. Assoc. Am. Geogr.*, 90(4), pp.713~737.

Field, A. (2005) Factor Analysis on SPSS, *lecture notes distributed in the topic C8057 Research Methods II,* University of Sussex, dated 10/12/2005. Available from www.sussex.ac.uk/Users/andyf/factor.pdf.

Kabupaten, S.D.A. (2010) (Sleman Regency in Figures 2010). Katalog BPS: 1102001.3404. Kerjasama Badan Pusat Statistik dengan BAPPEDA Kabupaten Sleman.

Kecamatan, P.D.A. (2007) (Pakem District in Figures 2007). Katalog BPS: 1403 34 04 160. Kerjasama BPS dan BAPPEDA Kabupaten Sleman.

Lattin, J.M., Carroll, J.D., Green, P.E. (2003) Analyzing Multivariate Data, *Toronto: Thomson Brooks/Cole.*

Lowe, C.J. (2010) Analysis Vulnerability to Volcanic Hazards: Application to St. Vincent, Thesis of Doctor of Philosophy at University College London.

Suryo, I., Clarke, M.C.G. (1985) The Occurrence and Mitigation of Volcanic Hazards in Indonesia as Exemplified at the Mount Merapi, Mount Kelut and Mount Galunggung Volcanoes, *J. Eng. Geol. & Hydrogeol.,* 18, pp.79~98.

Tabachnick, B.G., Fidell, L.S. (2007) 5th Edn. using Multivariate Statistics, *Boston: Pearson International Edition.*

Utami, P., Sagala, S., Mariany, A. (2009) Assessment of Regional Disaster Resilience by using Social Vulnerability Index, *A paper for International Conference on Regional Development,* Environment and Infrastructures Institute of Technology Bandung (ITB).

Yang, K.T., Chol, K.S. (1993) Representation of Dynamic Stiffness Matrix with Orthogonal Polynomials, *Comput. Struct. Eng.,* 6(2), pp.95~102.

요 지

자연재해에 있어서 취약성 분석계획의 우선순위 설정활동을 위한 기초자료로서 재해 위험분석의 주요한 요소이다. 화산폭발은 화산이 인구밀도가 높은 지역에 위치하고 있는 경우 많은 사상자와 재산피해를 야기한다. 화산폭발을 막을 수 없지만, 위험도와 취약성은 미래의 위기를 예측하는 신중한 계획과 준비작업을 통해 저감될 수 있다. 사회적 불평등으로서 사회적 취약성은 다양한 사회 구성원이 재해에 대응 능력에 민감한 영향을 미친다. 본 연구에서는 인도네시아 중부 자바에 위치한 메라피 화산 인근 지역주민들의 사회적 취약성을 평가하기 위하여 사회적 취약성 지수(SoVI) 기법을 활용하였다. SoVI는 사회적 위험부담을 이해하고 정량화하기 위하여 지역사회의 복원탄력성에 영향을 미치는 사회 경제적 및 인구 통계학적 요인을 이용하여 평가된다. 본 연구에서 사회적 취약성은 이해 관계자와 지역주민과의 설문조사를 통해 평가되었다. 연구결과로 도출된 취약성 지수는 사회적 취약성의 분포와 원인에 대한 정보를 반영함을 확인하였다.

핵심용어 : 사회 취약점, 사회 취약도 지수(Social vulnerability index - SoVI), 메라피 화산분화