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Assessment of Social Vulnerability to Floods in Java Island, Indonesia

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Assessment of Social Vulnerability to Floods in Java Island, Indonesia

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Abstract

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Indonesia is constantly at risk of floods, earthquakes, and landslides. Java, which is the most populous island in Indonesia, has a high risk of loss of life and property damage from natural hazards.

Social vulnerability is known as a factor that reduces or increases the extent of damage from natural hazards. In light of this, this study conducted empirical analyses of the factors affecting the social vulnerability of Java Island. First, a set of social vulnerability indicators were selected and aggregated into two indices; Socio-economic Vulnerability Index (SEVI) and Built Environment Vulnerability Index (BEVI). Second, the two indices were mapped to identify the most vulnerable communities and examined in their spatial patterns. The distribution of the SEVI and BEVI revealed communities

with high scores, thereby identifying the communities that should be given the most attention. The SEVI map showed that the communities located in central and eastern Java and the clusters of the small islands including Kepulauan Seribu and Madura Island have high levels of socio-economic vulnerability while the urban communities and its surroundings showed relatively low levels of socio-economic vulnerability. The BEVI map revealed high built environment vulnerability along the communities located in the southwest coast of Java. Also, cluster analysis of each index showed HH, LL clusters and LH space outliers.

Third, the relationship between the economic losses from floods and the vulnerability indicators were analyzed using the Ordinary Least Squares (OLS) regression. It has revealed that socio-economic status and accessibility to basic infrastructure were associated with the economic losses from floods. From the socio-economic aspect, illiterate variables indicating education level, poverty variable indicating income level, and fishery population variables showed a significant positive influence on flood losses. Among the built environment variables, communities lacking access to electricity had a significant positive influence on flood losses, but communities lacking sewage disposal facility showed a significant negative influence. The sewage disposal facilities in Indonesia are outdated or not properly maintained. The result can be interpreted as flood loss caused by sewer overflow due to poor maintenance of the facilities.

This study compared the socio-economic and built environment vulnerability levels at the community level, thereby identifying vulnerable communities that need the most support for emergency planning and response. It also empirically demonstrated the influence of selected vulnerability indicators on economic losses from floods in Java, which provides grounds for effective resource allocation and more strategic and informed decisions to build resilient communities.

Keyword: Social vulnerability, Cluster analysis, OLS Regression analysis, Natural hazard, Flood

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Chapter 1. Introduction

1.1 Research Background and Objectives

Climate change has brought more frequent and intense extreme weather events such as floods, heat waves, and earthquakes, which pose significant threats to human lives and property (IPCC, 2014). While climate change poses multiple environmental threats to the whole world, research has found that the extent of damages and losses from disasters is related to vulnerability. Vulnerability, which is the tendency to be adversely affected, has been defined and understood by sensitivity or susceptibility to harm and the lack of capacity to cope and adapt (IPCC, 2014), and by diverse thematic dimensions including social, economic, physical, environmental, and political aspects (Adger, 1999; UNISDR, 2017). Therefore, the concept of vulnerability can be said to encompass various aspects of society and hence should be integrated into policy formation and strategic planning for disaster preparedness.

Assessment of social vulnerability has received attention in both research and practice because it provides answers as to which regions should be prioritized for policy intervention and how government budget could be allocated to effectively reduce disaster risk. Therefore, it enables decision-makers and planners to make more strategic and informed decisions to build

resilient communities. From the social vulnerability perspective, disaster losses are not solely determined by the magnitude or intensity of natural hazards, but largely influenced by the social characteristics that make people vulnerable (Birkmann, 2006). People who are not equipped to disasters hold the most propensity to receive damage. For example, those who are less educated or living in marginalized conditions are more prone to be affected by natural hazards (Cutter et al., 2003). In light of this, emerging literature focused on measuring and understanding social vulnerability to identify the communities most exposed to disaster risks (Rygel et al., 2006; Holand et al., 2011; de Loyola Hummell et al., 2016) and to understand the factors that lead to the different impacts of natural hazards (Zahran et al., 2008; Schmidtlein et al., 2011; Jeong & Yoon, 2018; Török, 2018).

Indonesia is one of the world's most disaster-prone countries that experience multiple natural hazards including floods, landslides, tsunamis, and earthquakes. After the devastating Sumatra earthquake and tsunami in 2004 that claimed the lives of more than 165,000, the government of Indonesia enacted the Disaster Management Law No. 24/2007 and established the National Agency for Disaster Management (BNPB) (BNPB, 2007). Despite increased budget and manpower, frequent natural hazards cause considerable damage and economic losses and pose an enormous obstacle to sustainable growth of Indonesia.

Hence, this paper aims to quantify social vulnerability to floods in Java

Island by constructing a Socio-economic Vulnerability Index (SEVI) and Built Environment Vulnerability Index (BEVI) at the community level with the context-specific indicators. Then, spatial patterns of the indices are examined utilizing cluster analysis. This study also analyzes the relationship between the vulnerability indicators and the actual economic losses from floods. This study contributes to the understanding of the various indicators constituting social vulnerability and identifying the communities that should be considered as top priority in disaster management policy.

1.2 Research Structure

This research is organized into 5 chapters including this chapter, which describes the research background and objectives.

Chapter 2 starts by exploring the core concepts. It introduces the concept of vulnerability, disaster risk, and disaster management cycle. The second part of the chapter presents the literature review on attempts to assess social vulnerability. Last part of this chapter brings out the implications of the literature review and discusses the contributions of this study.

Chapter 3 introduces the research methods used in this thesis, including constructing Socio-economic Vulnerability Index (SEVI) and Built Environment Vulnerability Index (BEVI), cluster analysis, and the OLS regression analysis. It also describes the study area and sources of data.

Chapter 4 presents the results of the methods adopted to understand social

vulnerability by presenting the SEVI and BEVI maps, then analyzes how vulnerability indicators are associated with the economic losses from floods. It also details the interpretations of the results based on the research hypothesis.

Chapter 5 recaps the research findings and provides policy implications based on the analysis results. It also discusses challenges and opportunities of the research findings.

Chapter 2. Literature Review

2.1 Concepts

2.1.1 Vulnerability

The concept of vulnerability has been understood from various perspectives such as psychology, ecology, economics, and geography. In the context of hazard discourse, the concept of vulnerability has evolved in its definition from different perspectives.

From the IPCC definition, vulnerability is the tendency to be adversely affected, and it understands the vulnerability from the perspectives of sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2014). Vulnerability can also be understood as "The conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards" (UNISDR, 2017).

Dessai & Hulme (2004) understood the vulnerability with the top-down *biophysical* and the bottom-up *social* approaches and suggested that social vulnerability approach is more relevant to near-term policy interventions while biophysical approach provides useful information for the long-term planning based on probability (Fig. 2-1). However, these two approaches are not opposing, but rather interact with each other to produce the overall place

vulnerability (Cutter et al., 2003; Holand et al., 2011). Overall, the viewpoints to understand vulnerability are divided into thematic dimensions of human and non-human factors, and the vulnerability determines the degree in which the social group is affected and overcome to external impacts.

2.1.2 Disaster Risk

Understanding the concept of risk is important to understand disaster risk. Disaster risk can be understood as the probability of occurrence of hazardous events produced by the interactions among the vulnerability, exposure, and hazard (Crichton, 1999; IPCC, 2014). (Table 2-1).

Table 2-1 Disaster Risk Components (IPCC, 2014).

Vulnerability
"The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt."
Exposure
"The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected."
Hazard
"The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause losses of life, injury, or other health impacts, as well as damage and losses to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources."

The vulnerability can be understood as s progression. One of the most widely accepted conceptual framework to understand risk is the disaster Pressure and Release (PAR) model that defines risk as a product of vulnerability and hazard (Blaikie et al., 1994; Wisner et al., 2004). This model recognizes the vulnerability as a progression starting from the root causes and dynamic pressures, which result in unsafe conditions of groups of society. PAR model does not explicitly identify exposure in the model, but it's an unsafe condition in the vulnerability progression involve exposure component of risk (Cutter, 1996).

One of the insights from the definitions of disaster risk is that while controlling the occurrence of natural or human-induced events is very difficult or even impossible to prevent from happening, we are able to reduce disaster risk by elaborating on vulnerability and exposure.

2.1.3 The Disaster Management Cycle

The Disaster Management Cycle has four integrated components: mitigation, preparedness, response, and recovery. Mitigation and Preparedness are proactive actions, so these components are about what we can do prior to a disaster event. On the other hand, Response and Recovery are reactive actions, which focuses on post-disaster activities (Fig. 2-1).

According to UNISDR (2017), Mitigation mainly focuses on reducing or avoiding possible impacts of hazards by the adoption of structural or non-

structural measures. Examples of structural measures include man-made structures such as dams, levees, sea walls, etc. Non-structural measures involve land-use planning, disaster insurance, public awareness programs, etc. Preparedness process aims to build the capacity to manage all types of contingencies in an efficient way. It includes contingency planning, evacuation, and public information, training, etc. Mitigation and Preparedness put emphasis on disaster reduction related capacity building in advance of a disaster event. Response is immediate and short-term action such as disaster relief. Recovery is about restoring back to normalcy or improving disaster-affected livelihoods and assets. Recovery process is important in that it could reduce the future disaster risk and better equip the affected community or city to future hazards.

Fig. 2-1 The Disaster Cycle (adapted from Cutter (2003)).

2.2 Assessment of Social Vulnerability

2.2.1 Indicator-based Analysis

The vulnerability is largely affected by societal conditions and socio-economic pathways (IPCC, 2014). That is, different populations have different vulnerability level according to their socio-economic factors (Wisner et al., 2004). Social vulnerability is a multidimensional concept, which can be broadly defined as "the possession of factors that determine the degree to which someone's life and livelihood are put at risk" (Zahran et al., 2008). According to Cutter et al. (2003), social vulnerability is shaped by social inequalities and place inequalities. Specifically, attributes of individuals (gender, age, income, and employment) and built environment and regional characteristics (urbanization, population density, and basic infrastructure) contribute to social vulnerability.

Quantification of social vulnerability has been recognized as a valuable reference index to identify socially marginalized groups and plan for hazard risk mitigation (Dwyer et al., 2004). By quantifying relative social vulnerability to natural hazards, we are able to identify where to put the most mitigation or adaptation efforts. As one of the pioneering works, Cutter et al. (2003) developed the Social Vulnerability Index (SoVI) by aggregating indicators that influence social vulnerability. This method was applied across the U.S. counties to compare the relative levels of social vulnerability to

natural hazards. The constructed indices have been applied to assess social vulnerability to different hazard types (Rygel et al., 2006; Balica et al., 2012; Armaș & Gavriș, 2013) at different regional scales (Birkmann, 2007).

Even though there is still no academic consensus on a set of indicators of social vulnerability, commonly used indicators to assess social vulnerability include age, education, income, and employment (Adger, 1999; Cutter et al., 2003; Kubal et al., 2009; de Loyola Hummell et al., 2016). Those who are highly educated are more likely have low risk, while others with low education level have a lack of access to disaster-related information, during the evacuation or recovery process (Cutter et al., 2003). Built environment indicators such as basic infrastructure, population density, and medical capacity also influence social vulnerability (Cutter et al. 2003; Prashar et al., 2012; de Loyola Hummell et al., 2016). Limited access to infrastructure and lifeline could serve to compound potential disaster losses (Cutter et al. 2003; Prashar et al., 2012). However, one of the limitations of quantitative measurement of social vulnerability is that indicators may not fully represent the situation of the place. Thus, it is crucial to incorporate place-specific indicators that are specific to the context of place (Adger, 2006; Frazier et al., 2013; Wood et al., 2015). Some of the most widely used indicators are presented in Table 2-2.

Table 2-2 Indicators and expected influence on disaster damage.

Indicator	Expected Influence	Literature
The elderly, children	(+)	(Cutter et al., 2003; Kubal et al., 2009)
Foreign population	(+)	(Cutter et al. 2003)
Female	(+)	(Cutter et al. 2003)
Poverty	(+)	(Adger, 1999; Cutter et al. 2003)
Per capita income, GDP	(−)	(Adger, 1999; Cutter et al. 2003)
Little education	(+)	(Cutter et al. 2003; Norris et al., 2008; Holand & Lujala, 2011)
House ownership (rented)	(+)	(Cutter et al. 2003)
Unemployment	(+)	(Cutter et al., 2003; De Loyola Hummell et al., 2016; Prashar et al., 2012)
Illiteracy	(+)	(Cutter et al. 2003)
Lack of basic infrastructure (electricity, water, sanitation, sewer, etc.)	(+)	(Cutter et al. 2003; Prashar et al., 2012)
Population density	(+)	(Cutter et al., 2003; de Loyola Hummell et al., 2016)
Medical capacity (hospitals, doctors, etc.)	(−)	(Cutter et al. 2003)

Age is one of the most influential social vulnerability indicators. Cutter et al. (2003) argued that children under the age of 5 and the elderly age above 65 are particularly vulnerable to hazards due to lack of physical capacity to respond quickly during emergency situations.

For gender, the female population has been recognized more vulnerable than male in terms of physical strength, resources, and information (Cutter et

al., 2003). However, some researchers argue that the level of vulnerability can be determined coupled with other characteristics such as gender or health (Yumarni et al., 2014; Tomio et al., 2014).

Financial capacity also influences social vulnerability. Poor people are likely to reside in slum areas that might put restrictions on coping strategies during a disaster (Adger, 1999). Similarly, poverty directly/indirectly affects social vulnerability as both of them put constraints on coping capacity in disaster events (Adger, 1999). On the contrast, income level and GDP are recognized as variables that could reduce social vulnerability (Adger, 1999; Cutter et al. 2003) because wealthy individual or community are likely to have better chance to prepare for and recover from disaster events.

Education level also determines the level of social vulnerability and is linked to socio-economic status, employment opportunities, and health (Holand et al., 2011). Those who are highly educated are more likely have low risk, while the others who are little educated have lack of access to disaster-related information, which increases vulnerability (Cutter et al., 2013). Low education constraints understanding information during evacuation or recovery process.

Also, those who are living in the rented house are likely to have insufficient financial resources to own house, which also reveals weak economic status. Renters might not have enough choices to reside at a safe place without high

risk of disaster (Cutter et al., 2003).

Securing a job is related to securing assets for disaster recovery (De Loyola Hummell et al., 2016), so it has been argued by the previous studies that people who are unemployed might suffer more and lack recovery capacity. Even employed, people might suffer more than others depending on the type of occupation. Lower-wage occupations including personal service are known to have a negative influence on social vulnerability compared to other occupations (Cutter et al., 2003).

Limited access to basic infrastructures such as power, structures, or resources could serve to compound potential disaster losses (Cutter et al. 2003; Prashar et al., 2012). In addition to lack of infrastructures, old age of sewer lines or water pipelines were also indicated as determinants of the level of vulnerability (Holand et al., 2011).

On the other hand, medical factors such as a number of hospitals or the number of doctors could contribute to reducing damage from disaster events.

Lastly, population density also poses a negative influence on potential hazard risk (Holand et al., 2011; De Loyola Hummell et al., 2016). This is also linked to the rural and urban characteristics of the location. High population density poses constraints on travel during emergency situations. Furthermore, expected disaster losses is larger than rural area due to buildings, people, vehicles, etc. (Kropp et al., 2006).

2.2.2 Regression Analysis

While many researchers have contributed to analyzing the relationship between the social conditions and vulnerability, research on the relationship between vulnerability indicators and actual disaster damage has not progressed much (Schmidtlein et al., 2011). Vulnerability and disaster studies in recent years attempted to examine the driving factors that affect adverse harm from natural hazards. Zahran et al. (2008) examined the social vulnerability and built environment factors to flooding casualties using zero-inflated negative binomial regression models, which provides useful insights when there are numerous zeros that also need to be taken into consideration. Jeong & Yoon (2018) revealed significant vulnerability factors on economic losses from floods using the OLS and the spatial autoregressive models. Schmidtlein et al., (2011) utilized the OLS regression analysis to determine the relationship between social vulnerability and modeled losses from earth earthquake events. Other statistical method such as Geographically Weighted Regression (GWR) was also utilized to examine the variables that influence on people affected from flood hazards (Török, 2018). Other researchers focused on validation of social vulnerability indicators that composite social vulnerability index (Tate, 2003; Heß, 2017).

2.3 Summary and Implications

Previous studies on social vulnerability have attempted to understand the social vulnerability to natural hazards by the composite index of relevant indicators or by statistical analysis to examine contributing factors to natural hazards.

Indicator-based analysis has been widely applied in social vulnerability research. SoVI, which is developed by Cutter et al. (2003), numerous studies have been measured social vulnerability at different scale and various types of disaster types. Also, recent studies have applied different types of statistical analysis models to examine vulnerability factors that contribute to disaster damages. Depending on the nature of the variables used in the analysis, models such as GWR and OLS regression can be used.

The results of the above-mentioned analysis methods can be used as a basis for establishing policies to reduce disaster risk. The implications of existing research on social vulnerability can be summarized as follows;

First, one of the limitations of quantitative measurement of social vulnerability is that indicators may not fully represent the characteristics or the context of place. Thus, it is crucial to incorporate place-specific indicators (Adger, 2006; Frazier et al., 2013; Wood et al., 2015).

Second, the directionality of the indicators used to construct the SVI may not always be the same. Therefore, it is necessary to confirm whether the same

effect (positive/negative) exists in the designated study area.

The strength of this study is that it used context-specific indicators considering the characteristics of Java Island. Also, this study divided social vulnerability into socio-economic and built environmental aspects and constructed the SEVI and BEVI rather than as a single index, which enables a richer discussion of regional characteristics. Lastly, it has empirically verified the relationship between selected indicators and the flood losses using statistical analysis.

Chapter 3. Methodology

3.1 Study Area

Indonesia is one of the world's most disaster-prone countries that experience multiple natural hazards including floods, landslides, and earthquakes (Fig. 3-1). Being located on the Pacific Ring of Fire with active volcanoes, Indonesia is also at risk of earthquakes and volcanic eruptions. After the devastating Sumatra earthquake and tsunami in 2004 that claimed the lives of more than 165,000, the government of Indonesia enacted the Disaster Management Law No. 24/2007 and established the National Agency for Disaster Management (BNPB) (BNPB, 2007). Despite increased budget and manpower, frequent natural hazards cause considerable damage and economic losses and pose an enormous obstacle to sustainable growth of Indonesia.

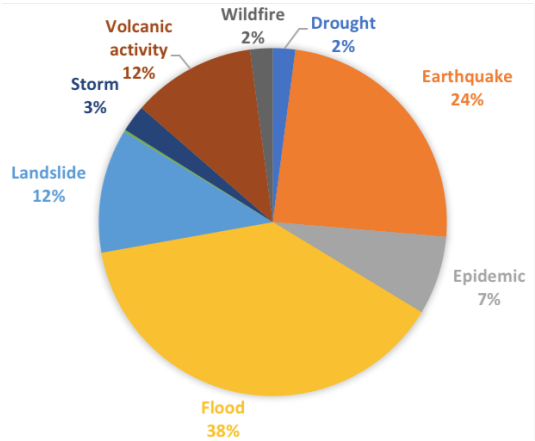

Fig. 3-1 The frequency of disasters in Indonesia (1900-2016) (source: EM-DAT)

From a hazard perspective, Java is a disaster-prone island (Fig. 3-2) and has the largest number of people exposed to natural disasters with more than 55% of the Indonesian population (BPS, 2016). At the same time, Java is undergoing a mega-urbanization process, which brings challenges for the local and central government to manage its urban growth (Firman, 2017). Urban population is steadily increasing as more people come to urban areas seeking better economic opportunities, which makes Java at high risk of disaster impacts.

Java is an Indonesian island bordered by the Indian Ocean in the south and the Java Sea in the north. It consists of six provinces; Banten, West Java, Central Java, East Java, Special Capital Region of Jakarta, and Special Region of Yogyakarta (BPS, 2010). City and regency are administered under province. McLaughlin & Cooper (2010) emphasized the spatial scale for developing vulnerability indices. In an attempt to assess social vulnerability, determining geographic scale (global, national, sub-national, household/individual) is important since indicators that are significant at the national level might not be the same. For the analysis, 118 communities (84 regencies and 34 cities), a second-level administrative subdivision, were chosen as study units.

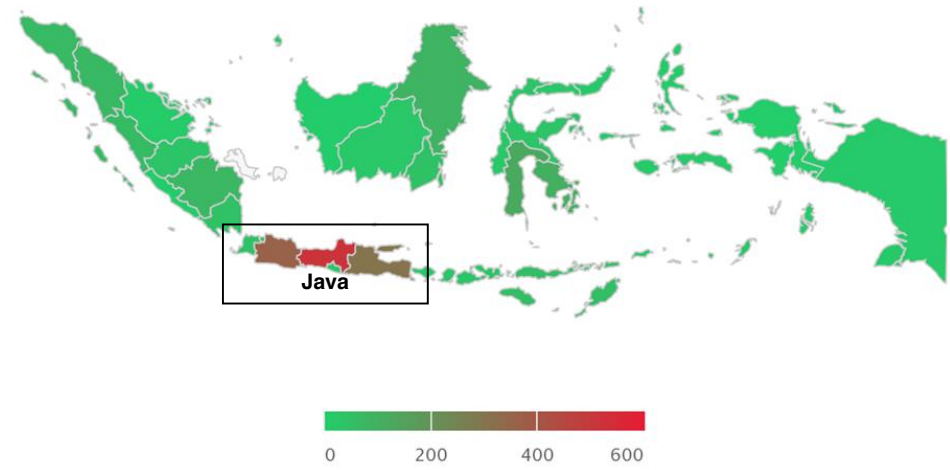

Fig. 3-2 The number of disaster events in Indonesia (2010).
(source: BNPB, bnpb.go.id)

3.2 Selection of Variables

Variables were selected based on previous studies, relevance, and data availability. Firstly, indicators and variables identified as important in the previous literature were employed (Adger, 1999; Cutter et al., 2003; Kubal et al., 2009; Prashar et al., 2012; de Loyola Hummell et al., 2016). Secondly, the author considered Indonesia's situation to choose the appropriate indicators. Context-based indicators were selected to reflect the characteristics and situation of the study area. For example, poverty and inequality are major challenges in Indonesia. Even though strong economic growth led to poverty reduction, about 10% of the total population still live

below the poverty line and a large population is barely above the poverty line (Worldbank, 2018). Similarly, population employed in fisheries was selected as a variable considering because coastal communities in Java Island that are dependent on fisheries are prone to be affected by potential natural hazards.

Data sources for the study include Statistics Indonesia (BPS), the National Socio-economic Survey (SUSENA), and Village Census (PODES). Selected year of analysis was 2010, which is the latest census year. However, the selected year of the hospital density variable was 2011 due to data unavailability.

Table 3-1 summarizes the selected variables and sources of data.

Table 3-1 Social vulnerability indicators and selected variables.

Concept	Variable	Year	Source
Female	% female population	2010	BPS
Age	% age under 5 and over 65	2010	BPS
Low Education	% population aged 25 or older with no high school diploma	2010	BPS
	% of illiterate population aged 15 and above	2010	SUSENAS
Poverty	% population living below the poverty line	2010	BPS
Employment	% unemployed population	2010	BPS
	% population employed in fisheries	2010	BPS
Housing Type	% of population living in rentals	2010	BPS
Infrastructure	% households with no sewage disposal facility	2010	SUSENAS
	% households with no electricity	2010	SUSENAS
	% households with no access to safe water	2010	SUSENAS
	% households with no access to sanitation facility	2010	SUSENAS
	Hospital density (# of hospitals/ km^2)	2011	PODES
Population Dispersion	km^2 of land area per individual	2010	BPS

* BPS: Statistics Indonesia, SUSENA: National socio-economic survey, PODES: Statistics Indonesia, Village Census

3.3 Data Analysis

3.3.1 Socio-economic Vulnerability Index (SEVI) and Built Environment Vulnerability Index (BEVI)

In an attempt to better understand the social vulnerability of Java Island, this part focused on the development of the relevant indices to quantify the social vulnerability with a spatial scale of community level. A total 14 variables representing socio-economic and built environment characteristics of Java were transformed into Z-score (1): $Z = \frac{score - mean}{standard\ deviation}$. In case where variables have different units, it is essential to transform the value into standardized form so that units could be compatible (Zahran et al., 2008). Several relevant variables were excluded due to the multi-collinearity problem.

This study considered that social vulnerability consists of socio-economic and built environment vulnerability aspects. Some scholars measured social vulnerability by separating it into two sub-groups: Socio-economic Vulnerability Index (SEVI) and Built Environment Vulnerability Index (BEVI). This study also constructed the SEVI and BEVI based on the previous studies (Borden et al., 2007; Holand et al., 2011; Zhou et al., 2014).

As a combination method to create SEVI and BEVI, this study calculated the sum of the standardized values divided by the number of variables for

each index. Alternatively, previous studies employed principal component analysis (PCA), which can be used to reduce the dimensions of the variables (Cutter et al., 2003; Fekete, 2009; Holand et al., 2011). While PCA is a useful tool when the number of variables is very large or highly interrelated, the selected variables in this study did not show high correlations among the variables.

3.3.2 Cluster Analysis

Notably, when spatial observations are large in numbers, local patterns may appear depending on the type of variables. Local patterns in spatial data with spatial autocorrelation can be explored using cluster analysis. For the additional analysis of SEVI and BEVI, this research attempted to identify the clusters and outliers. Anselin (1995) proposed Local Indicator of Spatial Association (LISA), which is the spatial analysis technique for measuring spatial association. One of the advantages of this spatial statistics method is that it provides a cluster and outlier analysis, identifying the localities having similar and dissimilar scores.

3.3.3 Ordinary Least Squares (OLS) Regression

The disadvantage of the constructing an index is that the selected variables are scored, making it difficult to know the characteristics of each variable. However, the OLS method has the advantage of knowing significance and the influence of the variables constituting the index on the economic losses

caused by floods.

For the dependent variable, the total normalized economic losses from floods over 10 years (2001 to 2010) was selected for this research. The values were inflation adjusted to 2010. Economic loss data were collected from the Indonesian Disaster Data and Information (DiBi) database compiled by the National Disaster Management Agency (BNPB) of the Republic of Indonesia (available online at http://dibi.bnpb.go.id).

For the independent variables, the variables used to construct the SEVI and BEVI were selected to examine the effects of selected variables on disaster loss. Then, flood frequency variable was added as a control variable. It is clear that locations suffered from intense or frequent natural hazard are likely to have larger disaster damage. By including control variable(s), it is possible to observe more accurate influence of the variables of interest.

The equation for the OLS regression can be noted as (2), where flood-induced economic damage (FED_i) of community i is dependent on the standardized regression coefficient (β) times J vulnerability indicators (*VI)* and the error term ϵ.

$$ln(FED_i) = \beta_0 + \sum_{j=1}^{J} \left(\beta_{ij} \cdot VI_{ij}\right) + \epsilon_i \qquad (2)$$

Chapter 4. Results and Discussions

4.1 Descriptive Statistics of Data

The sample size of this study was 118 communities in Java Island, Indonesia. In terms of demography, 50.14% was female and 49.86% was male. The elderly and children – who are particularly vulnerable to natural disasters – accounted for 14.22%. With regard to educational achievement, those without a high school diploma over the age of 25 occupied more than 60%, and illiterate people who do not have easy access to information accounted for 14%. The average percentage value below the poverty line was 1.5%, but the gap between the minimum and maximum values was over 40%. which implies financial inequality in Java. Unemployed people are known to be vulnerable to natural disasters due to lack of resources. The average percentage value was 6.69%. According to previous studies, not only the employment status but also the types of occupation influence vulnerability to natural hazards. Due to its geographical location surrounded by the sea, fishing is one of the major economic sources in the coastal communities of Java. Island. As sea-level rise is threatening Java, those who are engaged in fisheries are likely to suffer from potential natural hazards. The average percentage of people engaged in fisheries was 3.28%. However, there is a big difference between the maximum and minimum values.

With regard to build environment factors, the portion of households

without sewage disposal facility and electricity was relatively low, with 7.49% and 0.56% respectively. On the other hand, there is a larger portion of households with no access to safe water and sanitation. The lack of basic resources and infrastructures is indicative of a low socio-economic status and insufficient capacity to respond to and recover from disaster events. Medical capacity such as the number of hospitals or doctors greatly reduces adverse impacts from natural hazards, especially during the response and recovery process. The average density of hospital was $0.05/\mathrm{km}^2$. Population sparsity is proxy for rural characteristics of the location. Population density variable is more frequently used, but it was transformed into reciprocal value because it did not meet the normal distribution.

Table 4-1 summarizes the descriptive statistics.

Table 4-1 Descriptive statistics of the variables.

Variable	Mean	SD	Min	Max
% female population	50.14	0.93	48.31	52.44
% age under 5 and over 65	14.22	1.70	11.00	19.32
% population aged 25 or older with no high school diploma	41.60	9.43	20.79	55.53
% of illiterate population aged 15 and above	13.94	7.85	1.70	47.72
% population living below the poverty line	1.50	4.49	0.03	47.08
% unemployed population	6.69	1.74	3.35	11.42
% population employed in fisheries	3.28	4.25	0.29	22.62
% of population living in rentals	8.45	6.48	0.37	34.33
% households with no sewage disposal facility	7.49	6.98	0.53	39.22
% households with no electricity	0.56	0.90	0.00	5.08
% households with no access to safe water	66.25	14.77	26.64	99.07
% households with no access to sanitation facility	65.96	13.88	19.87	93.13
Hospital density (# of hospitals/ km^2)	0.05	0.10	0.00	0.60
km^2 of land area per individual	0.00	0.00	0.00	0.00

Note: N = 118 communities

4.2 The SEVI and BEVI Maps

A set of 14 variables were grouped into SEVI, including gender, age, education, poverty, employment, and housing type. These 8 variables were all positively loaded on the SEVI score. BEVI consists of 6 variables, which encompasses accessibility to basic infrastructure and population density. Infrastructure variables (sewage disposal facility, electricity, safe water, and sanitation facility) were positively loaded and hospital density and population dispersion variable were negatively loaded on the BEVI score. Figure 3 is the resulting maps showing the community-level socio-economic and built environment vulnerability in Java Island.

The SEVI scores ranged from -0.88 (least vulnerable) to 0.80 (most vulnerable). Map of the relative socio-economic vulnerability showed the most vulnerable communities in central and eastern parts of Java (Fig. 4-1). Smaller islands that are not attached to the main island such as Kepulauan Seribu, a cluster of 105 islands, and Madura Island showed the highest SEVI scores. These islands are known to have infertile land and hence heavily relies upon fisheries for sustenance. Another distinctive feature observed was that the cities such as Jakarta, Semarang, and Surabaya– where more education and job opportunities exist – have low SEVI scores. Communities located near the big cities also showed low SEVI scores.

For the BEVI map, communities along the southwestern coast of Java were

found to be the most vulnerable regarding built environment. The most vulnerable community scored 1.54 and the least vulnerable community scored -1.16. Similar to SEVI map, communities that are not attached to the main Island had high built environment vulnerability. While communities around Jakarta showed low or moderate relative level of socio-economic vulnerability, relative level of built environment vulnerability in the same area was higher.

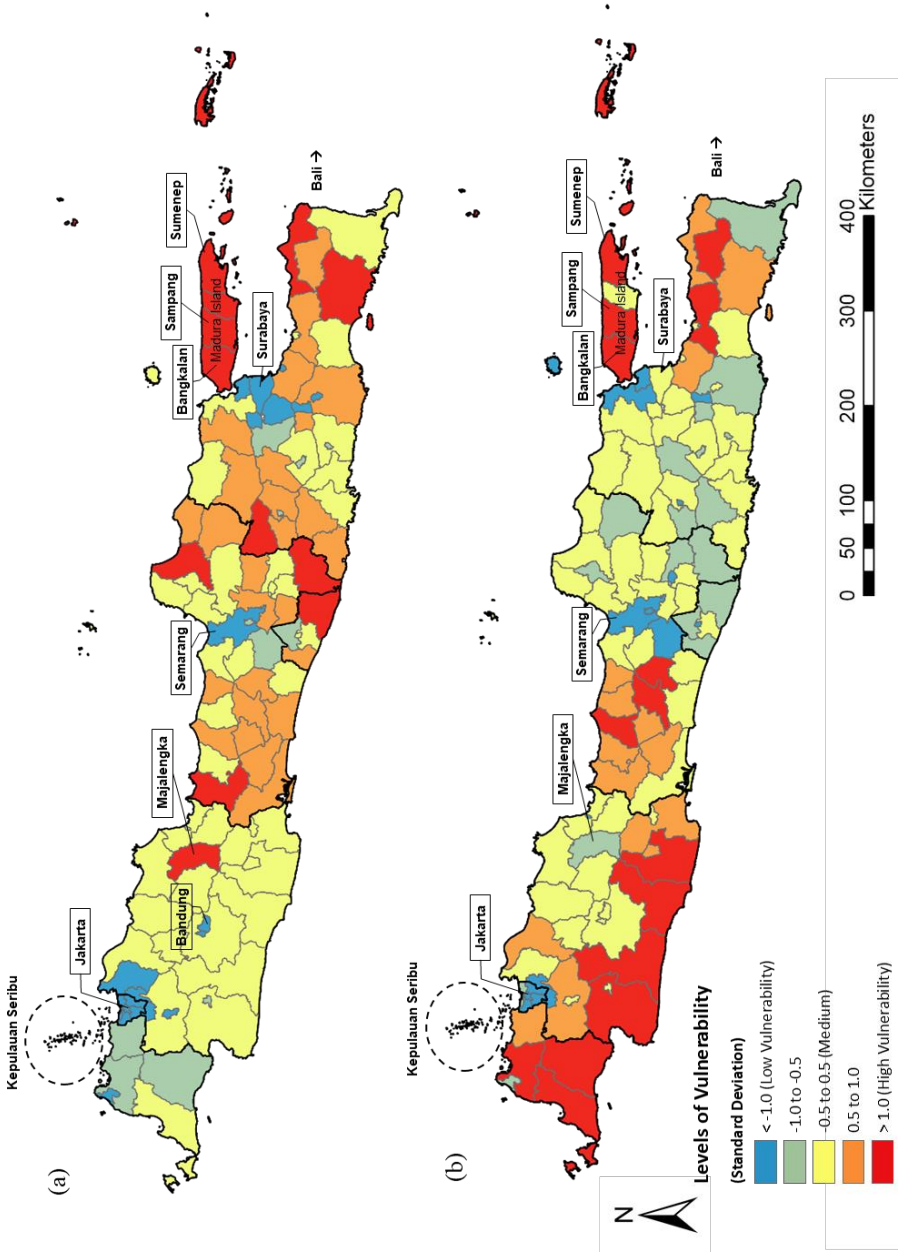

Fig.4-1 Map of the (a) relative socio-economic vulnerability (b) and relative built environment vulnerability in Java

Table 4-2 Ten communities with the highest SEVI and BEVI scores.

No	Name	SEVI score	Name	BEVI score
1	Sumenep, Kab.	0.81	Cianjur, Kab.	1.54
2	Bangkalan, Kab.	0.77	Tasikmalaya, Kab.	1.36
3	Sampang, Kab.	0.75	Lebak, Kab.	1.35
4	Majalengka, Kab.	0.75	Pandeglang, Kab.	1.34
5	Gunung Kidul, Kab.	0.70	Sumenep, Kab.	1.12
6	Kepulauan Seribu, Kab.	0.70	Garut, Kab.	1.04
7	Wonogiri, Kab.	0.57	Sukabumi, Kab.	0.96
8	Pamekasan, Kab.	0.54	Bondowoso, Kab.	0.95
9	Pati, Kab.	0.52	Banjarnegara, Kab.	0.93
10	Ngawi, Kab.	0.51	Probolinggo, Kab.	0.92

4.3 Local Indicators of Spatial Association (LISA) Map

The Spatial Autocorrelations of the SEVI and BEVI scores were tested with Moran's I. The distribution of both scores were found to have positive spatial autocorrelation, so the Local Indicator of Spatial Autocorrelation (LISA) analysis was conducted. (Fig. 4-2).

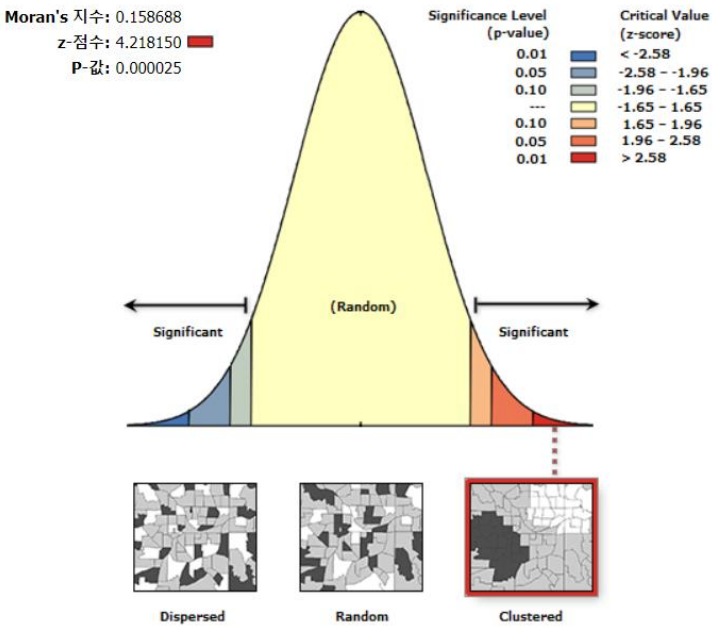

Fig. 4-2 Anselin Local Moran's I.

According to the Fig. 4-3, the LISA map of SEVI scores identified LL clusters around Jakarta, the capital city of Indonesia. It can be interpreted that Jakarta and the surrounding communities have sufficient human and physical resources to prepare for natural hazards. There are several HH clusters in the central and eastern part of Java. HH clusters are where the Indonesian government could invest in order to reduce the level of socio-economic vulnerability. Sukoharjo regency was identified as the LH outlier. The LISA map of BEVI scores identified LL clusters in Jakarta, but HH clusters were evident in West Java and East Java, particularly the area below Jakarta. It shows there exists large disparities or inequalities around the capital city.

Purwakarta and Banyuwangi were identified as LH outliers where low built environment vulnerability score is surrounded by the high scores.

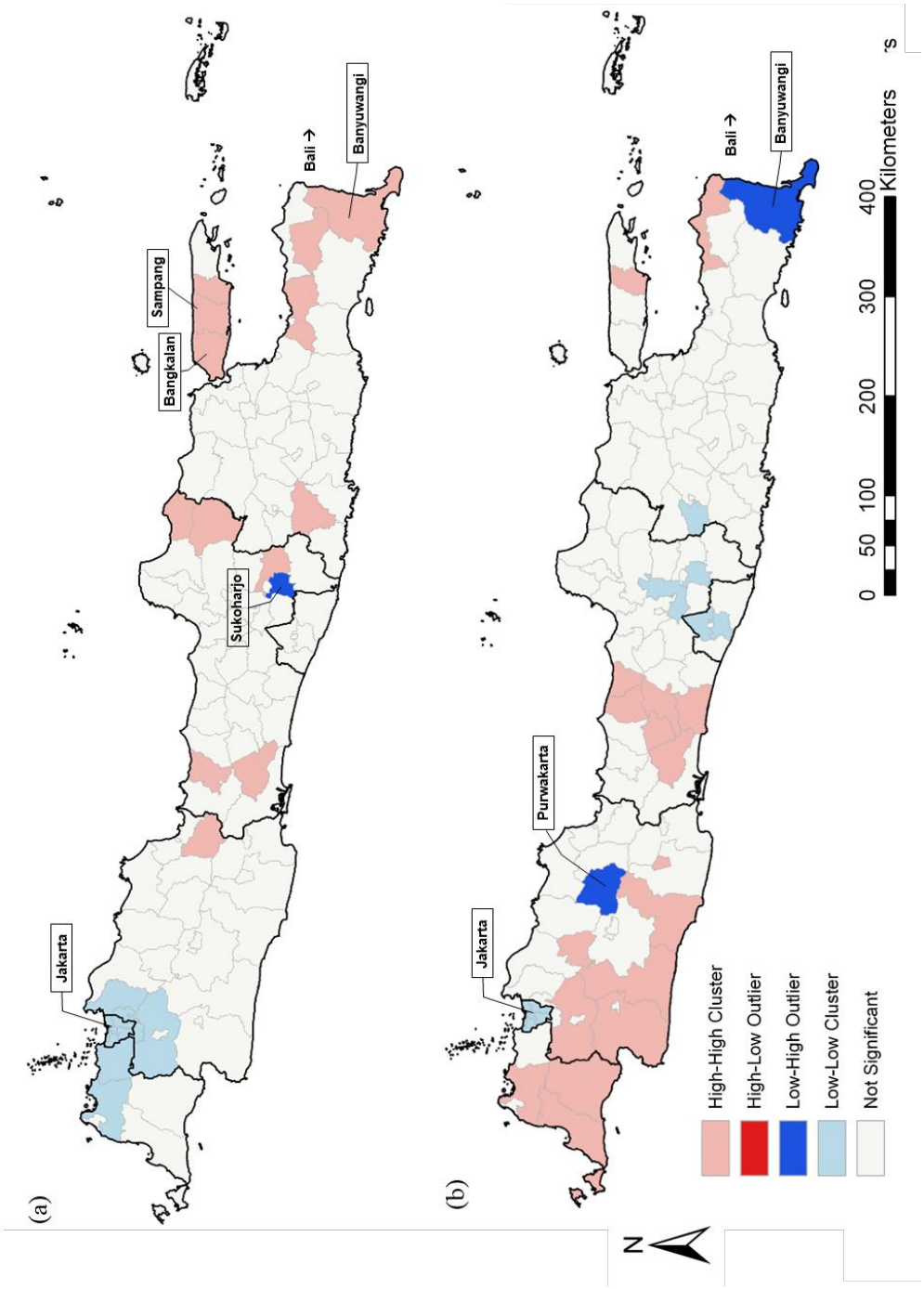

Fig. 4-3 LISA cluster maps of (a) the SEVI scores (b) and BEVI scores.

4.4 Factors Contributing to Economic Losses from Floods

The variables used to construct the indices were adopted for the OLS regression. Additionally, the flood frequency variable was included to act as a controlling variable. Table 4-3 shows the result of the OLS regression analysis.

With regard to the socio-economic aspect of variables, previous studies have found that unstable or lower economic status compounds the possibility being adversely affected by natural hazards. The illiterate population coefficient (+0.276) reaffirmed the result from previous studies that people who are not able to fully receive information during the crisis are more likely to experience high economic losses (Cutter et al., 2003). The population that lives below the poverty line had a positive significance at a 99% confidence level. This result showed that although the poverty rate is declining, people in extreme poverty are still likely to be severely impacted by natural hazards. In this study, the fishery-related variable was included to consider the geographical specificity of Java Island. According to the analyzed result, those engaged in fisheries were more vulnerable to flooding impacts with a positive significance at a 95% confidence level.

Regarding built environment factors, households with no sewage disposal facility and electricity showed a significant relationship with the economic losses from floods. However, the direction of influence was found to be the

opposite. The result demonstrated that no sewage disposal facility has a negative relationship with economic losses. This result can be attributed to the poor sewage system in Indonesia. A number of communities in Indonesia have not equipped with a proper sewage disposal facility except for the big cities, and hence intense or severe floods could lead to overflow, causing more damage (Nilsen et al., 2011; Matthews, 2015). Also, no access to electricity had a positive relationship with the economic loss from floods. The absence of electricity means that the housing environment cannot afford this basic infrastructure, and therefore the socio-economic status of the households is likely to be low.

Table 4-3. Results of OLS regression model.

Factor	Independent Variable	B	SE	β	P-value
Environmental	Flood frequency	0.361	0.125	0.322	0.006***
Socio-economic	% female population	-0.164	0.193	-0.146	0.4
	% age under 5 and over 65	0.005	0.197	0.005	0.979
	% population aged 25 or older with no high school diploma	0.135	0.264	0.121	0.611
	% of illiterate population aged 15 and above	0.095	0.190	0.276	0.040**
	% population live below the poverty line	0.309	0.147	0.403	0.001***
	% unemployed population	0.140	0.172	0.125	0.421
	% population employed in fishery	0.452	0.128	0.384	0.045**
	% of population living in rentals	0.430	0.209	0.085	0.619
Built Environment	% households with no sewage disposal facility	-0.435	0.148	-0.388	0.005***
	% households with no electricity	0.276	0.152	0.246	0.076*
	% households with no access to safe water	0.172	0.187	-0.154	0.361
	% households with no access to sanitation facility	0.244	0.179	-0.218	0.177
	Hospital density (# of hospitals/km^2)	-0.049	0.165	-0.044	0.767
	Population dispersion (km^2 of land area per individual)	-0.029	0.174	-0.026	0.869

a. Dependent Variable: Economic losses from floods over 10 years
b. $F(15, 52) = 3.208$
c. R-square: 0.481, Adjusted R-square: 0.331

Chapter 5. Conclusion

5.1 Summary

The primary focus of this research was to compare the levels of social vulnerability of 118 communities in Java Island and analyze the influence of vulnerability factors on economic losses from floods. Since the subjective selection of indicators can pose misleading effects on the results, data were selected following the selection criteria. At the same time, context-specific variables that reflect geographic and socio-economic characteristics of Java Island were taken into consideration.

From the map of SEVI and BEVI scores, high levels of social vulnerability appeared in the eastern part and small Islands of Java. Furthermore, cluster analysis revealed that Jakarta and the surrounding communities show relatively low level of social vulnerability. On the other hand, the BEVI map showed that the adjacent communities located below Jakarta have high social vulnerability.

Then, the OLS regression was conducted to identify which variables have significant effects on economic losses from floods. Significant variables were identified from environmental, socio-economic, and built environment aspects. The result that low education and income level is positively associated with the flood damage was consistent with previous studies. It is

worth noting that lacking sewage disposal facility was negatively associate with the flood loss.

5.2 Discussions

As the risk of natural hazards is expected to become more severe in the future due to climate change, emerging literature on vulnerability to natural hazards has focused on social characteristics that increase vulnerability. This study empirically identified communities with high socio-economic and built environment vulnerability by constructing SEVI and BEVI. This paper also has managed to analyze the effect of the vulnerability indicators on flood-induced economic losses using the OLS model.

Due to rapid urbanization in Java Island, socio-economic disparities and built environment inequality have deepened. Therefore, government policy and planning should be prepared in the direction of reducing this gap. The main findings of this analysis provide decision-makers and planners with four evidence-based insights.

First, the SEVI map shows that most of the big cities such as Jakarta, Surabaya, Semarang and the surrounding localities have a low level of socio-economic vulnerability. It can be interpreted that a better socio-economic situation in a larger city has a positive impact on the surrounding area as well. The Sukoharjo region, the LH outlier (i.e. low level socio-economic vulnerability surrounded by the high vulnerability) can be a good place to

give attention to because government's investment can effectively lower the socio-economic vulnerability of the surrounding communities. Clusters of communities with high socio-economic vulnerability – particularly Kepulauan Seribu and Madura Island apart from the main island – can also be considered areas where government intervention should be given a priority.

Second, it is worth noting that the communities located in southwestern part of Java show high level of built environment vulnerability and largely clustered. In order to lower the BEVI scores, the government should not only build infrastructure such as sanitation facility but also maintain these facilities. While communities in Central and Eastern Java show high built-environment vulnerability, the Banyuwangi community located at the eastern end of Java was identified as the LH outlier. That is, this community has a low built environment vulnerability unlike the surrounding communities. Banyuwangi is known for its tourism with well-preserved nature, and it also serves as a port between Java and Bali. It can be inferred that the built environment vulnerability of this community is low due to its proximity to the sea and its abundant tourism resources. Given the East Java's reputation as one of the most vulnerable regions in Southeast Asia, further research is needed on the specific reason why the area has a low BEVI (Yusuf & Francisco, 2009).

Third, from the OLS regression analysis, indicators pertaining to illiteracy, poverty, and fisheries from the socio-economic dimension demonstrated positive relationship with economic losses. Poverty directly and indirectly

affects social vulnerability as both place constraints on coping strategies (Adger, 1999). Therefore, disaster risk education for marginalized people is crucial. Education for children is effective in that they can spread information to their families at home. It is also important to increase public participation by a provision of training for disaster preparedness and dissemination of disaster supply kits. Another significant variable associated with the flood loss was population employed in fisheries. In addition to training, early warning system and disaster preventive measures can be expanded along the coastal line.

Fourth, households with disposal facilities installed were found to have more influence on the amount of flood loss compared to ones with no disposal facility. The sewage disposal facilities in Indonesia are mostly outdated and have not been properly managed. This causes sewage to easily overflow during flood events. Therefore, there is a need for the government to replace old infrastructure and maintain it continuously. In addition, households that do not have access to electricity were also found experience higher flood loss. Households that do not have the access to resources such as electric lighting are likely to have low socioeconomic status. Moreover, emergency response may be difficult in the absence of electricity. Therefore, there is a need for a policy to expand supply to areas that lack basic infrastructures such as electricity and water supplies. For those who lack access to basic infrastructure, the government can take measures such as providing disaster

supply kits along with the expansion of the basic infrastructure in areas with high built-environment vulnerability.

The findings of this study provide a useful reference for decision-makers and planners to better prepare for flood events. However, limitations of this study arise due to limited access to reliable local-level data. Data that are not periodically collected or not properly measured cannot guarantee the robustness of an index. At the same time, different methodologies in constructing an index such as different weighting mechanisms or dimension-reduction methods may lead to different results.

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홍수에 대한 사회적 취약성 평가

- 자바섬을 대상으로 -

국문 초록

김 주 리

인도네시아는 홍수, 지진 및 산사태와 같은 여러 자연재해의 위험에 가장 심각하게 노출되어 있는 나라 중 하나이다. 특히 본 연구의 대상지인 인도네시아 자바섬은 전체 인구의 55% 이상이 거주하는 인구 과밀 섬인 동시에, 자연 재해가 가장 빈번하게 발생하는 섬이기도 하다.

사회적 취약성은 자연재해의 피해 정도를 완화하거나 가중시키는 주요 요소로 알려져 있다. 따라서, 본 연구는 자바섬의 사회적 취약성의 영향 요인에 대한 실증적인 분석을 시행하였다. 우선 사회적 취약성을 측정하기 위해 인도네시아의 특성을 고려하여 취약성 지표들을 선정하고 이를 사회경제적 및 건조환경적 차원으로 분류하였다. 이후 선정된 지표를 기반으로 하여 지역사회 (커뮤니티)별 사회경제적 취약성 지수 (SEVI)와 건조환경 취약성 지수 (BEVI)를 산출하고 높은 취약성 수준을 보이는 지역사회를 도출하였다. 사회경제적 취약성 지수 분석 결과 중부 및 동부 자바에 위치한 지역사회와 해안가에 위치한 소규모 섬이 높은 사회경제적 취약성을 보인 반면, 도시와 그 주변 지역사회는 사회경제적 취약성이 낮은 것으로 평가 되었다. 건조환경 취약성 지수는

자바의 남서쪽 연안에 위치한 지역사회에서 높게 나타났다. 이어서 각각의 지수에 대한 클러스터 분석을 통해 HH, LL 클러스터와 LH 공간 아웃라이어 패턴을 보이는 지역사회를 도출하였다.

그 다음으로 사회적 취약성을 구성하는 지표들이 실제 홍수 피해에 어떠한 영향을 미치는지 알아보았다. 분석 결과 사회경제적 변수 중 교육 수준을 나타내는 문맹 변수, 소득 수준을 나타내는 빈곤층 변수, 어업 종사자 변수가 홍수 피해에 유의한 정(+)의 영향을 미치는 것을 확인했다. 건조환경적 측면에서는 기반 시설인 전기가 공급이 원활하지 않은 지역사회의 경우 홍수 피해에 유의한 정(+)의 영향을 미치는 것으로 나타났다. 하지만 하수처리시설이 부족한 지역 사회는 유의한 부(−)의 영향이 나타났다. 인도네시아의 하수관거 및 하수처리시설은 오래되거나 적절한 관리·보수가 이루어지지 않는 열악한 상황이다. 분석 결과는 열악한 시설의 배수 능력 한계로 오히려 물이 넘쳐서 홍수 피해를 가중시키는 것으로 해석할 수 있다.

본 연구는 사회경제 및 건조환경적 취약성이 지역사회별로 어떻게 나타나는지 살펴보았으며, 취약성 지표들이 자바섬의 홍수 피해에 미치는 영향을 실증적으로 증명하였다.

주요어: 사회적 취약성, 클러스터 분석, OLS 회귀모형, 자연재해, 홍수
학 번: 2016-25774