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SOCIO-ECOLOGICAL VULNERABILITY ASSESSMENT AND THE RESULTING IN SPATIAL PATTERN: A CASE STUDY OF SEMARANG CITY

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Abstract: The aim of this paper is to examine the socio-ecological vulnerability and the resulting in spatial pattern on a city scale. The assessment methods for vulnerability-resilience in the social and ecological have been broadly examined, such as the Environmental Vulnerability Index (EVI) and disaster risk assessment by the BNPB (*Badan Penanggulangan Bencana Nasional*). However, in some cases, these methods are suitable only in disastrous vulnerability and on a larger scale. The assessment method of socio-ecological systems in this paper has been modified to a city-scale and per the data availability. By using spatial data, this paper analyses the connection between vulnerability-resilience of socio-ecological systems and land coverage pattern. Based on the case study, the finding shows that almost 28% of Semarang city areas are socio-ecologically vulnerable. Most of the land use of the vulnerable areas is currently used for urban built-up area and agriculture. For future research, this method can be used for vulnerability assessment of the socio-ecological system in other cities and as a consideration for decision making in spatial planning.
Keywords: socio-ecological system, spatial pattern, vulnerability assessment

A. Introduction

The vulnerability and resilience level of the social and ecological system affects the spatial pattern and land use, which also become one of the challenges for spatial planning in a developing country. Human and the environment are two components that cannot be separated from each other. Interactions between human social conditions and the ecology of their environment will result in some outcomes that will then affect those interactions all over again (Ostrom 2009). This cycle is known as a socio-ecological system (SES).

SES framework compiled by Ostrom (2009) to analyse the connection between social, economic and political aspects and how it can be related to the ecological life. Azizul (2016) argued that in the ecological system, the dimension of the place plays a role in changing environmental values, which then affect the processes, functions, and ecological patterns. The assessments of physical, ecological and environmental vulnerability are still not enough to determine the welfare of the people who live in a certain area. The socio-ecological system vulnerability is also closely related to the stakeholders contained in it (De Chazal et al., 2008). There are many opinions and frameworks about environmental vulnerability; however there is still no general agreement on vulnerability indicator guidelines (Beroya-Eitner, 2016). This fact is indicated by the usage of different methods and variables in each study on environmental vulnerability. Beroya-Eitner (2016) argued that the specific concept of vulnerability for environmental systems is needed to process to the socio-ecological system.

The assessment methods for vulnerability-resilience in the social and ecological system have been broadly examined, such as the environmental vulnerability index (EVI) and disaster risk assessment by the Disaster Management Agency. EVI is an assessment compiled by the South Pacific Applied Geoscience Commission (SOPAC), the United Nations Environment. According to the EVI Manual (Pratt et al. 2004), the EVI function is a guide to determine the level of environmental vulnerability at the national level or in certain regions.

Badan Nasional Penanggulangan Bencana (BNPB) in the document of *Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012* divides the vulnerability map into social, economic, physical and ecological/environmental. The variables include human life (social vulnerability), economic territory, physical structure, and ecological/environmental areas. In the exposure compositions, the information includes population density, sex ratio, poverty ratio, the ratio of disabled people and age group ratio. However, the guideline in this regulation only encompasses in disastrous vulnerability assessment, not in general socio-ecological vulnerability.

Several studies that combine the spatial method and modified EVI have been conducted (Choudhary et al. 2018; Zou & Yoshino 2017; Grigio et al. 2006). The differences in the assessment methods in each study are influenced by the availability of data, the situation, and the conditions of the research location. Some vulnerability assessments in ecology and socio-ecology have several characteristics in common, namely dependence on expert judgment, stakeholder involvement, ranking and mapping methods, and quantitative methods (De Lange et al. 2010). The assessment of socio-ecological vulnerability in this paper has been adjusted for city scale and data availability for a case study in the city of Semarang. To analyse the connection between the vulnerability of socio-ecological systems and the spatial pattern, the assessment method uses spatial and statistical data.

The socio-ecological vulnerability assessment in this paper is modified based on the environmental vulnerability index (Pratt et al. 2004) and socio-ecological system framework (Ostrom 2009). The variables need to be prepared to do the socio-ecological vulnerability assessment, and each of them will be scored. In this assessment, the scoring will be in the range of one to five, where one is the most vulnerable, and five is the most resilient (figure 1).

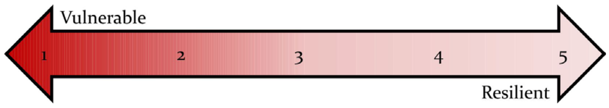

Figure 1. Socio-ecological vulnerability scoring

The vulnerability assessment is divided into social and ecological. The framework for the socio-ecological vulnerability assessment can be seen in figure 2. After the variables are scored, the number will be summed up and scored based on the rank from one to five by using the interval method.

$$Interval = \frac{Highest\ number - lowest\ number}{total\ score\ (5)}$$

Upper-class limit 1: lowest number + interval
Upper-class limit 2: upper-class limit 1 + interval
Upper-class limit 3: upper-class limit 2 + interval
Upper-class limit 4: upper-class limit 3 + interval
Upper-class limit 5: highest number

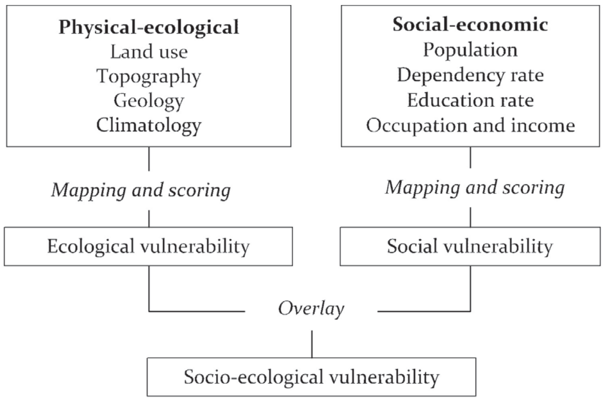

Figure 2. Socio-ecological vulnerability assessment framework

a) Social vulnerability

Social vulnerability is assessed with social and economic variables. Classification in the social and economic aspects will be assessed by the lower level of administration to find out which district is the most vulnerable. The variables for social vulnerability assessment are population density, dependency ratio, education rate, and economic condition.

Population Density

Population or population density is also one of the variables in EVI. Population density plays an important role by affecting the interaction number with the environment. The score of population density is based on the classification of population density per kilometre stipulated in the document of *Peraturan Kepala Badan Pusat Statistik Nomor 37 Tahun 2010*. Population density is calculated with the following formula:

$$Population\ density = \frac{Total\ population}{Total\ Area}$$

Table 1. Population density scoring

No	Density (population/km²)	Score
1	<500	5
2	500-1249	4
3	1250-2499	3
4	2500-3000	2
5	>3000	1

Dependency ratio

In the socio-ecological system, a dependency figure is affecting the ability of the community to meet their needs. The more people who depend on one individual, the greater the dependents imposed on them. A dependant is someone who has economic, time and energy burden. These large dependents indirectly increase the level of social vulnerability. Dependency ratio is calculated with the following formula.

$$Dependency\ ratio = \frac{people\ aged\ 0\ to\ 14 + people\ aged > 65}{people\ aged\ 15\ to\ 64} \times 100$$

Table 2. Dependency ratio scoring

No	Dependency ratio (%)	Score
1	>80	1
2	60-79	2
3	40-59	3
4	20-39	4
5	<20	5

Education rate

Education is one of the variables that affect the socio-ecological vulnerability. People with a higher level of education have higher environment sensitivity and knowledge, so they are better in processing the environmental risk (Muttarak & Lutz 2017). The highly educated people are the people that have graduated from high school, college and university. The education rate is calculated with the following formula.

$$Education\ rate = \frac{highly\ educated\ people}{total\ population} \times 100$$

Table 3. Education rate scoring

No	Education level (%)	Score
1	>80	5
2	60-79	4
3	40-59	3
4	20-39	2
5	<20	1

Economic

The economic ability of the community depends on their jobs and incomes. The poor have a higher vulnerability to changes in their environment, especially those whose main income comes from agriculture, livestock and fisheries (UNEP, 2003).

In this assessment, the economic scoring is assessed by calculation based on the average income estimation. The labour farmer, fisher, and construction labour are in the lowest score as this group is considered to have income below the average. The industrial labour group is the second lowest score with average industrial labour income is on the minimum wage. The same applies to the field owner-farmers who manage their agricultural activities without profit sharing. Judging by the transportation demands and facilities in most areas of the city, the transportation workers get the medium score (3). Workers in the business and merchant sectors have higher score (4) since they are assumed to have the capability in business and high economic competitiveness. The highest score belongs to the category of a civil servant and Indonesian armed forces due to their consistent salaries, health insurance facilities, and pension costs. The score for each occupation can be seen in the following table.

Table 4. Economic scoring

No	Occupation	Score
1	Labour farmer	1
2	Fisher	1
3	Construction labour	1
4	Industrial labour	2
5	Field owner-farmer	2
6	Retirement	2
7	Transportation	3
8	Service/etc.	3
9	Business	4
10	Merchant	4
11	Civil servant/Indonesian Armed Forces	5

From the results of this scoring, the average according to each sub-district will be calculated using the following formula:

$$\text{Economic score} = \sum \frac{score\ \times\ total\ workers}{total\ population}$$

b) Ecological vulnerability

Ecological vulnerability is assessed with physical and ecological variables. The physical aspects are included in the assessment because the physical appearance of the area is considered a cause of ecological vulnerability. The variables on ecological vulnerability assessment are land use, topography, geology, and climatology.

Land use

Land use types and ecosystem structures are strongly associated with natural and environmental vulnerability (Choudhary et al., 2018). In the concept of vegetation, the loss of green areas will have an impact on changing the structure and function of the ecosystem which will then affect all components in it (Pratt et al., 2004). In this assessment, the land use will be specified into five categories. Each category has the scoring based on the vulnerability level.

Table 5. Land use scoring

No	Land use	Score
1	Industry	1
2	Urban area	2
3	Vacant land	3
4	Agriculture/aquaculture	4
5	Green area	5

The industrial area is considered as the highest vulnerability due to the activities and pollution that has caused environmental issues. The second most vulnerable is the urban area, which includes the settlement, housing, trade, and services. Urban areas get 2 for the vulnerability score because the communities also contribute to household waste and affect the environment. While in vacant lands, there is no human activity that contributes to environmental damage. Therefore, vacant lands get a medium score of 3. Physically, agriculture and aquaculture are resilient as they do not affect the environment negatively. Agriculture and aquaculture areas are possible to change due to the high demand for new developments. The green area, such as mangrove and city forests, has the highest score as the highest resilient level is in physical land cover.

Topography

Analysis of topographic variables on vulnerability is based on the slope. Areas with steep slopes have a higher vulnerability to disasters, especially landslides (Badan Nasional Penanggulangan Bencana, 2016). The topographic is scored based on the document of *Surat Keputusan Menteri Pertanian Nomor 837 Tahun 1980*.

Table 6. Topography scoring

No	Slope	Score
1	>40%	1
2	25-40%	2
3	15-25%	3
4	2-13%	4
5	0-2%	5

Geology

Geological information is one of the main data necessary to assess environmental vulnerability (Pratt et al., 2004). In geological variables, each soil types have their level of soil sensitivity to erosion. The scoring for each soil types is based on the document of *Surat Keputusan Menteri Pertanian Nomor 837 Tahun 1980*.

Table 7. Soil type scoring

No	Slope	Score
1	>40%	1
2	25-40%	2
3	15-25%	3
4	2-13%	4
5	0-2%	5

Climatology

In climatology, the annual rainfall has an important role in controlling the vulnerability to the water supply, drought, and flooding risk. The climate variable is scored based on the EVI manual (Pratt et al., 2004) for rainfall in wet periods. The score is modified since the EVI manual is using a 1-7 scale, while this assessment is only using a 1-5 scale.

Table 8. Average rainfall scoring

No	Average rainfall (mm/year)	Score
1	<15.0	1
2	15.0-25.0	2
3	25.0-35.0	3
4	35.0-45.0	4
5	>45.0	5

B. Spatial pattern analysis

One of the follow-up studies from the socio-ecological vulnerability assessment analysis is to analyse the correlation with spatial patterns. This phase analyses land use in areas that are considered vulnerable so that in the future, spatial plan or the provision of facilities can be focused on these areas. For example, if an area that has a high vulnerability score is industrial, it is necessary to consider if industries in the area are planned to expand.

In this paper, we use the overlay method to analyse the relationship between socio-ecological vulnerability and the spatial pattern. The output is presented in the form of visual data showing areas that have high vulnerability and the current land use. The framework of the socio-ecological vulnerability and spatial pattern analysis can be seen in figure 3.

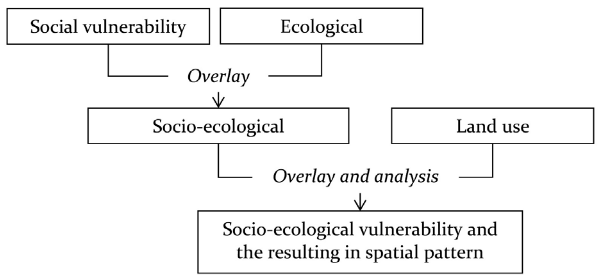

Figure 3. Socio-ecological vulnerability and the resulting in spatial pattern framework

C. Semarang city

Semarang is the capital city of Central Java province. This city is located in the North part of Java Island and directly borders the Java Sea. The total areas of Semarang city are 373.70km^2, divided into 16 districts and 177 sub-districts. Four districts are directly located next to the Java Sea; Tugu district, West Semarang district, North Semarang district and Genuk district; with the total coastline length is approximately 13.6km. As a coastal city, Semarang is burdened with environmental risk as well as rapid urban growth. In 2016, the total population in Semarang city was 1,729,428 and continued to grow each year.

We chose Semarang city as a case study for socio-ecological vulnerability assessment since the city has various social and ecological types. In its development, Semarang city experiences suburbanisation; where urbanisation development is not only happening in the city centre (Handayani & Rudiarto, 2014). Rapid urbanisation is indeed able to bring benefits to the development and economy of a city, but there are still consequences of these activities. In the Southern area of Semarang city, changes in land use in Gunungpati district have brought several negative impacts, namely increased landslide vulnerability, reduced water catchment areas, and pollution of community water sources (Kumala Dewi & Rudiarto, 2014). Meanwhile, in the downtown area (Semarang Tengah district), the micro climates in some areas are described as 'uncomfortable', especially in the middle of the day due to lack of green vegetation and green open space (Setyowati, 2008).

The data sources for each variable for socio-ecological vulnerability assessment in Semarang city are obtained from the Central Bureau of Statistics and Development Planning Agency. After following the mapping and scoring phase, the outputs are social and ecological vulnerability maps (figure 4). The final result is the overlay between two outputs: the socio-ecological vulnerability map (figure 5).

The socio-ecological assessment in Semarang city shows that one out of 16 districts in is very vulnerable (Genuk district). From the result in socio-ecological vulnerability map, it can be seen that the social vulnerability can increase or decrease the vulnerability level of the area. Genuk district gets the lowest resilience number in social vulnerability along with Gayamsari, Semarang Barat and Tembalang district.

Seen from the socio-ecological vulnerability map, most of the very vulnerable areas are located in the downtown and coastal areas of the city. The total vulnerable area in Semarang city is 107.36km² or 27.94% of Semarang city areas. The number is counted from the vulnerability score 1 and 2. The spatial pattern analysis also shows that the highest number of land use is in urban area and agriculture or aquaculture. The high number in the urban area explains how the high density could be a threat to a city. Meanwhile, the vulnerable area in agriculture or aquaculture faces social and sustainability problems. The detail about the land use and vulnerability scores of Semarang city can be seen in table 9.

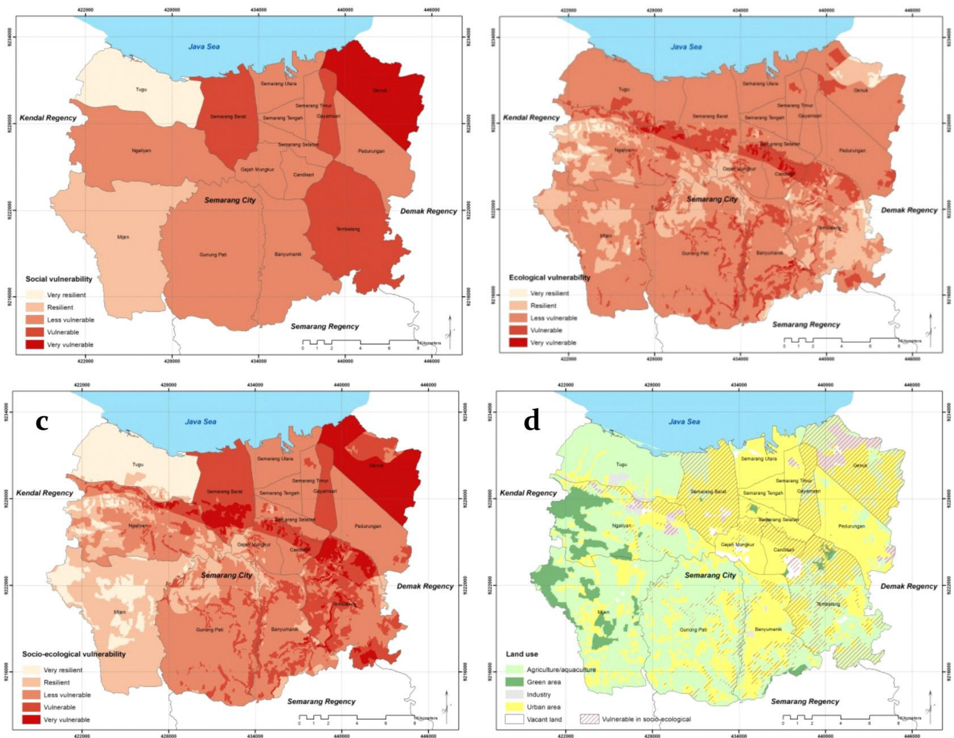

Figure 4. (a) Social vulnerability; (b) Ecological vulnerability
(c) Socio-ecological vulnerability (d) Spatial pattern in vulnerable area

Table 9. Land use in vulnerability score

Vulnera-bility	Land use	Area (km²)	Total Area (km²)	Percen-tage
Very vulnerable	Urban area	21.25	34.72	9.04
	Agriculture/aquaculture	10.26		
	Industry	2.8		
	Vacant land	0.41		
Vulnerable	Urban area	43.1	72.64	18.90
	Agriculture/aquaculture	22.54		
	Industry	5.51		
	Vacant land	1.11		
	Green area	0.38		
Less vulnerable	Urban area	88.49	163.78	42.62
	Agriculture/aquaculture	70.4		
	Vacant land	2.43		
	Green area	1.43		
	Industry	1.03		
Resilient	Agriculture/aquaculture	46.18	71	18.48
	Urban area	15.31		
	Green area	7.29		
	Industry	1.61		
	Vacant land	0.61		
Very resilient	Agriculture/aquaculture	28.33	42.14	10.97
	Green area	11.32		
	Urban area	2.42		
	Vacant land	0.07		

D. Conclusion and recommendations

The socio-ecological vulnerability assessment in this paper is a compilation and modification from previous studies about vulnerability assessment. The method used in this study is considered to be more suitable to analyse social and ecological vulnerability levels in a city scale compared to EVI assessment method due to the output of the data. Using the spatial tools and analysis in GIS, the output of this study is visualised in a vulnerability map form. Meanwhile, with EVI methods, the output is presented in a graphic form.

As a case study in Semarang city, most of the vulnerable areas are located in the coastal and downtown areas of the city. At least 27.94% area of the city has a vulnerable score of 1 and 2. The land uses of the vulnerable areas are mostly urban area and agriculture or aquaculture. Regarding social and ecological factors, these areas are the most vulnerable due to the high density and low social resilience.

From the analysis in the assessment process, it is concluded that the diversity of the output results depend on the diversity of conditions in the study area. Thus, there is a possibility that certain variables have a higher impact on the vulnerability score. In other words, the more homogeneous the region, the less detailed the results are. However, this study has several limitations. Data novelty affects the accuracy of the assessment output. The data used to analyse socio-ecological vulnerability in Semarang city are taken in 2011 for physical conditions, and in 2017 for socio-economic conditions. Urban physical conditions, in general, will continue to change following land requirements as well as demographic, economic and population density. Therefore, the accuracy of the assessment can be improved by the presence of the latest data for the source input.

The variables in the vulnerability assessment may vary for each city or area. For smaller areas (e.g. district scale), the variables should be more detailed for better accuracy in the result. The characteristics of other areas can also make it possible for the addition of other variables to support the accuracy of the assessment. For example, the shoreline erosion variable can be added to an area with a wide coastline, and the density of road usage variable can be added to an area with dense traffic.

For future research, this assessment can be useful to analyse the vulnerability level of the socio-ecological system in other cities as consideration for decision making in spatial planning. It can also be used to analyse the social adaptation and living sustainability in the socio-ecological vulnerable areas. However, the vulnerability and resilience levels cannot be determined only by the mapping analysis. This assessment is focused on the relationship between the human condition and the environment so that it excludes the possibility of vulnerability factors originating from natural disasters or social conflicts. Therefore, field observations are still needed to determine the details of the problems in the study area.

Acknowledgement

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