Integrating Tsunami Disaster Risk Assessment into Coastal Spatial Planning for Sustainable Development in Sukabumi District

Taufiq (Ministry of Marine Affairs and Fisheries, Indonesia)
Koji ASAI (Division of Civil and Environmental Engineering)

This research is designed based on the Crunch Model which formulates tsunami disaster risk as the multiplication between the level of hazard and vulnerability. The analysis results show that the most dangerous areas of tsunami are obtained. Based on the analysis results, the allotment of space utilization for buffer zones (coastal and river set back zones) are still not acquired, additionally the level of community preparedness for future disaster events is still low. Therefore, coastal spatial planning must consider the balance between the opportunities and constraints (tsunami) that exist in the region and involves the interaction between humans and the environment.

Key Words : *typhoon tide hazard map, questionnaire survey, evacuation behavior*

1. INTRODUCTION

Sukabumi district, located in the southwestern West Java province Indonesia, is a disaster prone area. It has a coastline which stretches to the length of about 114 km and is adjacent to the Indian Ocean. Potential earthquakes originate from the movement of the Indian-Australian Plate which moves northward with a speed of ± 7 cm/year and Eurasia Continental Plate that moves relative to the south with a speed of ± 0.4 cm/year (Minster and Jordan, 1978).

Several tectonic earthquake events around the Indian Ocean which are scattered under the shallow seabed as a result of collision activities between two plates can lead to damage and the aftershock hazard which is Tsunami. Tsunamis have occurred nine times in Indonesia within 15 years. The last one occurred in July 2006 around the coast of Pangandaran-West Java province due to a 7.7 magnitude earthquake at a depth of 34 km causing the death of 668 people and a financial loss of US$ 44.7 million (Muhari et al., 2007).

Previous disasters have taught us that these natural events pose a permanent threat to the surrounding environment as well as the community living in coastal areas. Almost all of major cities in Indonesia are located at coastal areas which function as residential area, trading, industrial and other sectors of development (MMAF, 2009). Since Sukabumi district is located in disaster prone area, disaster mitigation based on risk assessment should be done to minimize the negative impacts of disaster whenever it occurs in the future time.

Our research goal is to know the level of risks and to reduce the impacts of tsunami disaster in

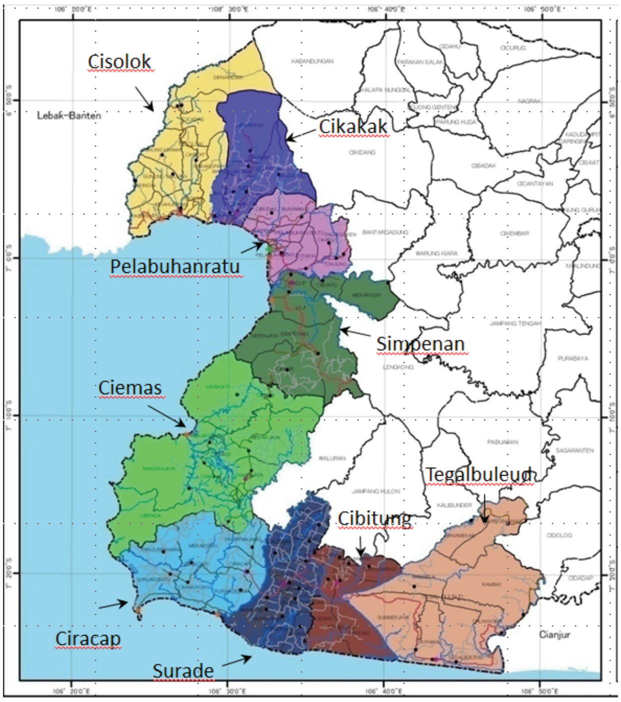

Fig.1 Sukabumi district and 9 sub-districts

order to achieve the sustainability of development in Sukabumi district. The research objectives of this study are as follows;

1) To identify the level of tsunami hazard.
2) To define the vulnerability of various exposed elements on the coastal environment.
3) To assess the level of tsunami risk.
4) To work with the risk level in estimating the impacts of tsunami hazard, recommending the coastal spatial planning and developing the disaster mitigation strategies.

The main target of this study is to develop a planning tool, which will be benefit and help the decision makers to establish coastal spatial planning that integrated with disaster mitigation principles.

2. RESEARCH METHODOLOGY

The study area is located in Sukabumi district - West Java province shown in Fig,1. There are nine sub-districts which categorized as tsunami hazard prone areas: Cisolok, Cikakak, Pelabuhanratu, Simpenan, Ciemas, Ciracap, Surade, Cibitung and Tegalbuleud sub-districts. Data collection category is divided into: (1) primary data obtained from field observations and interviewing some stakeholders who are chosen based on their knowledge, expertise and position and (2) secondary data which are collected from government institution's documents and comprehensive literatures.

The spatial multi criteria decision (SMCDA) analysis framework enables the integration of goals, objectives, spatial data and stakeholder preferences in a systematic method (Strager, 2006). There are four type methods that can be used to achieve the research purpose:

a) Benefit Criterion Method

Every criterion of hazard and vulnerability under consideration is arranged in order of the decision maker's preference. There are several methods to get numerical weights from rank-order information (e.g. rank sum, Malczewski, 1999). Then, benefit criterion is used as new values to standardize the entire number of attributes.

b) Pairwise Comparison Method

Somewhat more complex method is the pairwise comparison method from the Analytic Hierarchy Process (AHP) developed by Saaty (1977). The AHP, which is a method of measurement to formulate and analyze multi-criteria decision making, become a significant methodology to solve engineering problems (Wang and Raz, 1991) and some of the industrial engineering applications of the AHP include its use in integrated manufacturing (Putrus, 1990).The method of AHP is used in this research in order to determine the weight of vulnerability criteria before the overlaying analysis of thematic layer with the evaluation factors when GIS conducts this work. The AHP has a unique superiority in multi factor comprehensive evaluation and it just needs less quantitative data that can make clearly comparative analysis on the complex decision problems. Moreover, it is applicable to decision situations involving subjective judgment and can be used for both qualitative data and quantitative data (de Steiguer, J.E., 2003).

c) GIS Based Spatial Analysis Method

The SMCDA is associated with geographical entities and relationships between entities and therefore can be represented in the form of maps. Meanwhile, the occurrence of geological disaster related with the lithology, slope, topography, hydrological condition and so on as the fundamental factors are under the identical coordinates system and become the basis that GIS is used in disaster research (Liang et. al, 2010).

The overlay process is used to relate all mentioned parameters. This study uses raster-based overlay which is often to rank attribute values by suitability or risk and then assign a relative importance weight value before being summed to produce an overall rank for each cell (ESRI, 2011). This research only used hypothetical model, hence the accuracy of the model cannot be validated.

d) Pseudo Evaluation Method

Public policy evaluation is used to evaluate the effectiveness and provide guidance and recommendation on the implementation of spatial planning based on disaster mitigation principles. Policy evaluation is a way for producing information about the values or benefits of the policy results (Dunn, 2009). The determination of indicators and benchmarks which are based on literature as well as formal rules is called Pseudo evaluation method.

3. RESULTS AND DISCUSSION

3.1 Vulnerability Equation

This research is designed based on the Crunch Model scheme which formulated risk (R) as the multiplication between the level of hazard (H) and vulnerability (V) (Blaikie et al., 1994).

$$R = HV \quad (1)$$

Equation (2) is the vulnerability equations for each criteria groups (ADPC, 2004) .

$$V(a,A) = \sum_{i=1}^{i=n} S_i(w_i, e_i) \quad (2)$$

Where, *V(a,A)* is vulnerability level of the element a (e.g: geology), belonging to the vulnerability criteria A (e.g. physic), w_i is weighting coefficient, e_i is vectorial value estimated for the impact element, n is total number of impact elements related to the criteria A.

3.2 Preliminary Analysis

Various spatial data and attributes data which collected as the previous step are prepared and used to build hazard and vulnerability model. In this study, a topographical map scale 1:25,000 (Bakosurtanal, 2000) and administrative area map scale 1:10,000 (Bappeda Kabupaten Sukabumi, 2006) are used as base maps where the spatial precision and validation were done by each institutions. The spatial data have to be digitized from an original topographic map or an air photograph in a scale that will allow the user to identify open spaces.

3.3 Tsunami Hazard Analysis

Tsunami hazard assessment is aiming at assessing the geographical extent of the tsunami affected area, the intensity of the tsunami impact and the probability of the occurrence (Strunz et al., 2011). There are many criteria related to tsunami hazard that can determine the tsunami hazard impact i.e. inundation, run-up height, tsunami intensity, likelihood of tsunami, damage observed in earlier tsunami, coast adjacent to tsunamigenic source, and reef damage (Shankar, R., 2005). Many Japanese scientists have examined those correlations such as; estimation of fluid force acting on individual structures (Iizuka and Matsutomi, 2000), moving velocity and collision force of floating objects (Matsutomi, 1999), inundation flow velocity of tsunami on land (Shuto et al, 2007).

The evaluation of criteria involves specifying (1) a comprehensive set of objectives that reflects all concerns relevant to the decision problem, and (2) measures to achieve those objectives.

The SMCDA which apply in GIS requires both data on criterion values and the geographical locations of alternatives (Malczewski, 1999). Consequently, the discrete alternatives criteria which typically involve decision making processes have to be determined. According to Malczewski (1999), the technique for selecting criteria may be developed through an examination of the relevant literature, analytical study and opinions.

The tsunami parameters that impacted the study area were possible to identify by collecting such above information and catalogues of historic tsunami in Indonesia and earthquake hazard around Sukabumi coastal region. The data used for this stage were acquired from the previous studies of tsunami hazard zones (Bappeda Jawa Barat, 2007 and Oktariadi, 2009), which classified the hazard parameters into several types: 1) run-up height, 2) beach morphology, 3) beach roughness, and 4) earthquake intensity, consequently, those data generated four hazardous zones as shown in Table 1.

Table 1 The Level of Tsunami Hazard Zones

No	Zone	Information
1	High	High level of hazard
2	Medium	Moderate level of hazard
3	Low	Low level of hazard
4	Very low/Safe	Very low level of hazard

Every criterion under consideration is arranged in the order of the decision maker's preference. Rank sum weight method is used in this step as follows:

$$w_j = \frac{n - r_j + 1}{\sum_{k=1}^{n}(n - r_k + 1)} \quad (3)$$

where w_j is the normalized for the j-th criterion, n is the number of criteria, and r_j is the rank position of the criterion. Either strait ranking (the most important = 1, second important = 2, etc.) or inverse ranking (the least important = 1, next least important = 2, etc.) can be used. The following step

Table 2 The Classification of Weight Value

Score	Information	Weight	Benefit Criterion
1	High importance	0.4	1
2	Moderate importance	0.3	0.667
3	Low importance	0.2	0.333
4	Very low importance	0.1	0

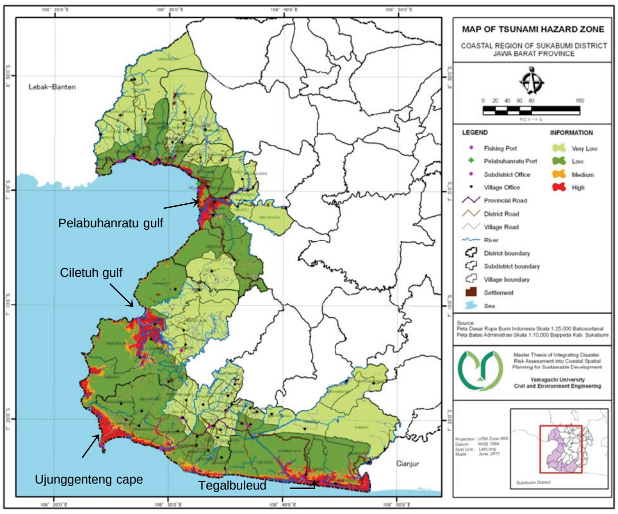

Fig. 2 Tsunami hazard zone

is assigning new values with Benefit Criterion where the higher score (score = 1) represent the highest performance, and contrary (score = 0) is the lowest performance (Malczewski, 1999).

$$x'_{ij} = x_{ij} / x_{i\max} \tag{4}$$

where x'_{ij} is standardized score for the i-th alternative and j-th attribute, x_{ij} is the row score and x_{imax} is the maximum score for the j-th attribute. For instance, the table 2 represents the classification of weight value for tsunami hazard zones modeling.

Based on the table 2 after defining the importance of weight value, these data are simulated in raster based by using the GIS-spatial analyst feature. Fig.2 shows that red color represents the highest hazard level as the most concern area in this research.

Statistical estimations depict that the tsunami hazard area of the highest level of hazard in Pelabuhanratu sub-district is about 21.46% (8.4×10^6 m^2) and described it as one of the most dangerous areas compare to the adjacent administrative areas. Meanwhile, it has developed urban infrastructure, a wide economic base and is an important center of government and tourist activity.

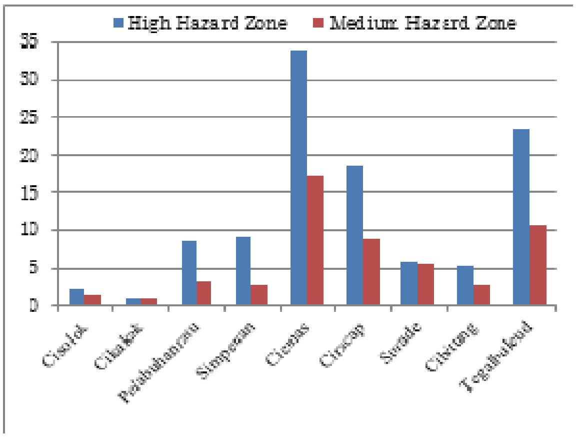

Fig. 3 Area of Tsunami hazard zone (m^3)

Table 3 The Details of Vulnerability Criteria

No	Criteria	Subcriteria	Reference
1	Physic	- Slope	PVMBG (2009)
		- Geology	PVMBG (2009)
		- Building density	ISDR and Davis et al. (2004)
		- Substandard house	ISDR and Davis et al. (2004)
2	Social	- Population density	Papathoma (2003)
		- Children & elderly	Davis et al. (2004)
		- Low education	Davis et al. (2004)
3	Economy	- Land use	Papathoma (2003)
		- Poor inhabitant	ISDR (2004)
		- Prone occupation	ISDR (2004)
4	Environment	- Vegetation type	USDA-NRCS (1986)

Vulnerability is characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard (ISDR, 2009). Vulnerability criteria processing is very important in this research and it is not easy to obtain due to many terms and definitions from the expert groups, and the discussions are still continue and could not obtain the result precisely. Criteria should be closely related to the decision model and the problem situation and due consideration also needs to be given to the number of criteria

Table 4 Details of Physical Criterion Value

No	Subcriteria	Information	Score	Weight	Normal value
1	Slope	Flat	1	0.333	1
		Sloping	2	0.267	0.75
		Quiet steep	3	0.200	0.5
		Steep	4	0.133	0.25
		Very steep	5	0.067	0
2	Geology	Alluvial	1	0.333	1
		Quarter	2	0.267	0.75
		Tertier	3	0.200	0.5
		Pretertier	4	0.133	0.25
		Hard rock	5	0.067	0
3	Building density	Very dense	1	0.333	1
		Dense	2	0.267	0.75
		Quiet dense	3	0.200	0.5
		Less dense	4	0.133	0.25
		Low dense	5	0.067	0
4	Substandard house	Very high	1	0.333	1
		High	2	0.267	0.75
		Quite high	3	0.200	0.5
		Less high	4	0.133	0.25
		Low	5	0.067	0

Table 5 Details of Social Criterion Value

No	Subcriteria	Information	Score	Weight	Normal value
1	Population density	High	1	0.5	1
		Medium	2	0.333	0.498
		Low	3	0.167	0
2	Children and elderly	High	1	0.5	1
		Medium	2	0.333	0.498
		Low	3	0.167	0
3	Low education	High	1	0.5	1
		Medium	2	0.333	0.498
		Low	3	0.167	0

Table 6 Details of Economic Criterion Value

No	Subcriteria	Information	Score	Weight	Normal value
1	Land use	Built up	1	0.333	1
		Food crop	2	0.267	0.75
		Plantation	3	0.200	0.50
		Forestry	4	0.133	0.25
		Shrub	5	0.067	0
2	Poor inhabitant	High	1	0.5	1
		Medium	2	0.333	0.498
		Low	3	0.167	0
3	Occupation at risk	High	1	0.5	1
		Medium	2	0.333	0.498
		Low	3	0.167	0

(Malczewski, 1999). Taking small number of criteria (oversimplification) which more suggested has a purpose to reach data availability and quality.

After examining the relevant vulnerability literatures, comprehensive relations between model and problems situation, and considering about data availability and quality, there are four vulnerability criteria chosen for this research, which are physic, social, economy and environment as shown in Table 3.

The data required for spatial analysis are based on village level. Unfortunately, several data released by statistical institutions could not match the requirement. Thus, those data can be developed by using sub-district administrative unit to simplify and meet the requirement of analysis processing, for instance data of number of children and elderly people and education level. Data for low income condition are the number of small scale farm households and data for occupation at risk are the number of farmers and fishermen. Those data are preferred because these groups of people will not have enough resources to survive and to prepare if tsunami hazards occur. In addition, land use data which obtained from topographic map scale 1:25,000 (Bakosurtanal, 2000) are divided into five classes based on Sukabumi government's annual revenue report to perform the weight of economic importance level.

The following step is to provide ranking value for the attributes of each criteria of vulnerability in order to observe the level of importance with Benefit Criterion method as previous step guidance. For instance, the tables 4, 5 and 6 represent the classification of weights for each vulnerability criteria.

In addition, the AHP method as a part of spatial multi criteria decision making analysis is also used to determine the weight of each sub criteria before the spatial analysis process. It is usually offered with the pair-wise comparison technique that simplifies preference ratings among decision criteria.

Based on the decision makers, this method comes to decompose the decision problem into elements, according to their common characteristics, and levels, which correspond to the common characteristic of the elements (Berrittella, 2007). The topmost level is the focus of the problem or

Table 7 Details of Environment Criterion Value

No	Subcriteria	Information	Score	Weight	Normal value
1	Vegetation type	Food crop	1	0.333	1
		Shrub/grass	2	0.267	0.75
		Plantation	3	0.200	0.50
		Forestry	4	0.133	0.25
		Non vegetation	5	0.067	0

ultimate goal. The intermediate levels correspond to criteria and sub-criteria, while the lowest level contains the decisions alternatives or the weight of importance degree. If each element of each level depends on all the elements of the upper level, then the hierarchy is complete, otherwise it is defined incomplete. The vulnerability equation can be formulated as follows;

$$V_P = w_1(w_3P_S + w_4P_G) + w_2(w_5P_{BD} + w_6P_{SH}) \tag{5}$$

$$V_S = w_7S_{PD} + w_8S_{CE} + w_9S_{LE} \tag{6}$$

$$V_{Ec} = w_{10}E_{LU} + w_{11}(w_{12}E_{PI} + w_{13}E_{OR}) \tag{7}$$

$$V_{total} = V_P + V_S + V_{Ec} + V_{En} \tag{8}$$

where,

- V_P = physical vulnerability
- V_S = social vulnerability
- V_{Ec} = economic vulnerability
- V_{En} = environmental vulnerability
- P_S = physical slope
- P_G = physic geology
- P_{BD} = physic building density
- P_{SH} = physic substandard house
- S_{PD} = social population density
- S_{CE} = social children and elderly number
- S_{LE} = social low education
- E_{LU} = economy land use
- E_{LI} = economy poor inhabitant
- E_{OR} = economy occupation at risk
- w_{1-13} = individual weight of each subcriteria

In this stage, all of the weights are defined by pairwise comparison approach except for environmental vulnerability criteria since it just offers a single parameter which is type of vegetation. In addition, physical and economic criteria have to follow multiple weight analysis processing because its sub-criteria do not have precise correlation between each other.

$$\begin{array}{cc|ccccc|} & & \multicolumn{5}{c}{\underline{\textbf{Criterion}}} \\ & \underline{\textbf{Alt.}} & C_1 & C_2 & C_3 & \dots & C_N \\ \cline{3-7} & A_1 & a_{11} & a_{12} & a_{13} & \dots & a_{1N} \\ & A_2 & a_{21} & a_{22} & a_{23} & \dots & a_{2N} \\ A \Rightarrow & A_3 & a_{31} & a_{32} & a_{33} & \dots & a_{2N} \\ & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ & A_N & a_{N1} & a_{N2} & a_{N3} & \dots & a_{NN} \\ \cline{3-7} \end{array}$$

Figure 4 Pairwise Comparison Matrix

Table 8 The AHP Pairwise Comparison Scale

Importance Intensity	Verbal Scale	Explanation
1	Equal importance	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgement favour one element over another
5	Strong importance of one element over another	An element is strongly favoured
7	Very strong importance of one element over another	An element is very strongly dominant
9	Extremely importance of one element over another	An element is favoured by at least an order of magnitude
2,4,6,8	Intermediate values	Used to compromise between two judgements
Reciprocals of above nonzero	If acitivity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

The structure of the decision problem is generated for computing the priorities of the elements as matrix A. Where a_{ij} represents the pairwise comparison rating between the element *i* and element *j* of a level with respect to the upper level. The entries aijare governed by the following rules: $a_{ij} > 0$; $a_{ij} = 1/a_{ij}$; $a_{ij} = 1$.

Table 8 reports the relative importance scale that used in the pairwise comparison of AHP (Saaty, 1977). Following Saaty (1980, 2000), the priorities of the elements can be estimated by finding the principal eigenvector w of the matrix **A**.

$$\mathbf{AW} = \lambda_{\max}\mathbf{W} \tag{9}$$

When the vector **W** is normalized, it becomes the vector of priorities of elements of one level with respect to the upper level. $\lambda_{\max}$ is the largest eigen value of the matrix **A**. In the cases where the pairwise comparison matrix satisfies transitivity for all comparisons, it is said to be consistent and it verifies the following relation;

$$a_{ij} = a_{ai} a_{kj} \quad \forall i, j, k \tag{10}$$

The AHP allows inconsistency, but provides a measure of the inconsistency in each set of judgments. The consistency of the judgmental matrix can be determined by consistency ratio (*CR*).

$$CR = CI / RI \tag{11}$$

where *CI* (consistency index) for a matrix of order *n* is

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{12}$$

and random index (*RI*) as average consistencies of randomly generated matrices as follows:

Table 9 The Average Consistencies of Random Matrices

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table 10 Composite Matrix of Physical Criteria

	P_I	P_E	Norm P_I	Norm P_E	Weight	V_1	V_2		CI	CR
P_I	1.00	0.33	0.25	0.25	0.250	0.50	2	2	0	0
P_E	3.00	1.00	0.75	0.75	0.750	1.50	2			

Recomposite Matrix of env physical (P_E) subcriteria (S=slope,G=geology)

	S	G	Norm S	Norm G	Weight	V_1	V_2		CI	CR
S	1.00	5.00	0.83	0.83	0.833	1.67	2	2	0	0
G	0.20	1.00	0.17	0.17	0.167	0.33	2			

Recomposite Matrix of infrastructure physical (P_I) subcriteria (Bd=building density, Sh=substandard

	Bd	Sh	Norm Hn	Norm Sh	Weight	V_1	V_2		CI	CR
Bd	1.00	2.00	0.67	0.67	0.667	1.33	2	2	0	0
Sh	0.50	1.00	0.33	0.33	0.333	0.67	2			

For instance, the table of matrix pairwise and consistency ratio determination for physical criteria can be shown in tables 10~12.

Table 11 Composite Matrix of Social Criteria

(P_D= population density, C_E=children and elderly, L_E= low education)

	P_D	C_E	L_E	Norm P_D	Norm C_E	Norm L_E	Weight	V_1	V_2
P_D	1.00	2.00	3.00	0.55	0.62	0.38	0.512	1.62	3.16
C_E	0.50	1.00	4.00	0.27	0.31	0.50	0.360	1.13	3.13
L_E	0.33	0.25	1.00	0.18	0.08	0.13	0.128	0.39	3.04
		CI	CR						
	3.11	0.05	0.09						

Table 12 Composite Matrix of Economic Criteria

	V_G	L_U	Norm V_G	Norm L_U	Weight	V_1	V_2		CI	CR
V_G	1.00	0.33	0.25	0.25	0.250	0.50	2	2	0	0
L_U	3.00	1.00	0.75	0.75	0.750	1.50	2			

Recomposite matrix of vulnerable group economic criteria (P_I= poor inhabitant, O_R= occupation at risk)

	P_I	O_R	Norm P_I	Norm O_R	Weight	V_1	V_2		CI	CR
P_I	1.00	0.33	0.25	0.25	0.250	0.50	2	2	0	0
O_R	3.00	1.00	0.75	0.75	0.750	1.50	2			

Just as the physical factor, the weighting processing of economic vulnerability performed separately for land use criteria and the criteria of vulnerable population groups (poor inhabitant and occupation at risk). It was done because the criteria of each group had no direct relationship to the intensity of interest. All of the weights are defined by pairwise comparison approach except for environmental vulnerability, therefore, weight values of environmental vulnerability factor are determined by normalized ranking of the benefit criterion approach which described in the previous section (table 7). In general, a consistency ratio of 0.1 or less is considered to be acceptable, but if the value is higher, the judgments may not be reliable and should be elicited again.

The ArcGIS based spatial analysis will significantly useful in this section, while as a part of general strategy of this study that is Spatial Multi Criteria Decision Analysis (SMCDA). Thus, this strategy requires not only multi criteria analysis for obtaining decision maker's preferences but also spatial analysis and modeling. Visualization techniques based on GIS are of major importance in presenting and communicating the results to the

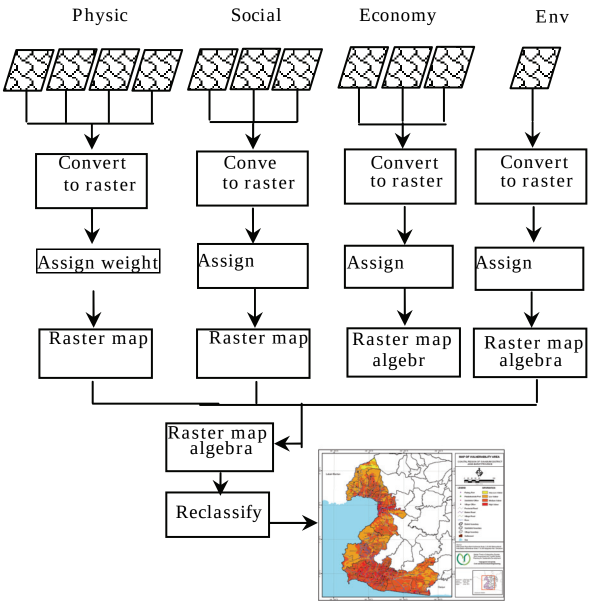

Figure 5. Vulnerability Modeling Process

users.

The total level of vulnerability is obtained from summation process of physical, social, economic and environmental vulnerability factors. Determination of vulnerability levels is performed using raster map of each vulnerability factors. Afterward, all of the maps are superimposed through Spatial Analyst Tools - Raster calculator features. Based on these analysis results through weighting and overlay processes, the vulnerability levels can be classified into four classes:

a) High vulner (index value > 0.60)
b) Medium vulner (index value 0.40-0.60);
c) Low vulner (index value 0.20-0.40)
d) Very low vulner (index value 0.00-0.20)

The combination of several vulnerability factors is given in figure 5 as color gradients that represent the gradual reduction of vulnerability value. The dark red color represents the highest level of vulnerability, whereas light yellow depicted as the lowest. The important point in here, Pelabuhanratu city, the capital of Sukabumi district is also categorized into high vulnerability area. It is fulfilled by the high level of several vulnerability criteria such as; the number of house and building, population density, low land morphology, the number of farmers and fishermen, and agricultural area which briefly contributed to Sukabumi district annual income.

The following figure (figure 5) describes the GIS based schematic procedures which utilized raster technique to obtain vulnerability model of the study area.

4. TSUNAMI DISASTER RISK ANALYSIS

A tsunami disaster risk assessment is a good tool to investigate and establish comprehensive disaster mitigation system (Port and Airport Research Institute of Japan, 2010), since it provides necessary graphical information to manage tsunami disasters and minimize damage in the region as well as regional tsunami hazards and vulnerability. Risk assessment combines the outputs of the hazard and the vulnerability assessments.

For the estimation of the "tsunami disaster risk" area, a GIS based approach has been developed and applied. The basic principle of disaster risk assessment is to define the high risk areas that are characterized by the high level of zone of being hit by tsunami and the high level of vulnerability in the study area, which refer to equation 1.

In accordance with the Crunch Model scheme, to obtain a map of disaster risk, the next process is multiplying step between Potential Tsunami Hazard and Vulnerability. In this case, the raster map of tsunami hazard must be superimposed (overlay) on the total vulnerability raster map by using Spatial Analyst Tools - Raster Calculator features. Subsequently, the risk map should be classified into several items through Reclassify feature as the following:

a) High risk (index > 0.60)
b) Medium risk (index 0.40-0.60)
c) Low risk (index 0.20-0.40)
d) Very low risk (index 0.00-0.20).

The risk map provides an overview on the overall risk for the respective coastal region. The proportion of high risk area that spread widely can be found around coastal areas of:

1. Pelabuhanratu gulf, its natural morphology can collect huge energy of tsunami wave whereas high urbanization and many important facilities are located around here;
2. Ciletuh gulf, its narrows and sharp type, directly overlooking to Indian Ocean, and also the beach with sloping contours may increase

the tsunami wave energy;

3. Ujunggenteng foreland, its open beach type which facing Indian Ocean and the occurrence of coastal vegetation degradation for public interests;
4. Tegalbuleud coastal region, its long straight beach that facing through Indian Ocean and the coastal forest that have been reduced by illegal sand mining. In addition, the high risk areas can be identified as the areas with low land morphology, a high population density, valuable land use types, and sensitive to tsunami hazard.

5. IMPACT OF TSUMANI DISASTER

Risk analysis and economics in the management of coastal environments can be done by inserting an active geological process that can lead to disaster (Mathewson and Piper, 1975). Management of the physical environment, spatial and other supporting infrastructure facilities that utilize the coastal area as a center of economic activity will become more expensive and risky if done without regard to geological processes that are ongoing and predicted to occur on the coastal morphology.

Based on the analysis results of tsunami risk mapping in the study area, the amount of damages that may occur could be obtained. This section discusses the economic effects that may occur either directly or indirectly in a more detail. Direct losses happen during the hazard's impact or immediately after. In this study, direct losses may be determined by analyzing existing land use type in the study area, especially at the high tsunami hazard zones, so that the damaged area by the tsunami inundation process can be acquired. Furthermore, that information may inform such kind of important assets that can be damaged in a flooded area.

GIS spatial analysis required again in this case, based on the analysis result of the tsunami hazard zones map (figure 2) and the map of the existing land use type in the study area, after that those maps are combined by the overlay process through Arctoolbox - Overlay - Intersect features. Moreover, the previous analysis results grouped on the basis of land units that contribute towards the revenues of Sukabumi district (GDP) to determine the extent of damage to critical assets that owned by each administrative area. Group of land units can be distinguished as follows: a) forestry (forest and swamp forest), b) fisheries (fish pond), c) settlement (house and building), d) food crop (irrigated rice field and rain fed rice field), and e) plantation (field crop and mixed farm). Figure 6 depicts the direct losses estimation of existing settlement area in the high risk zones.

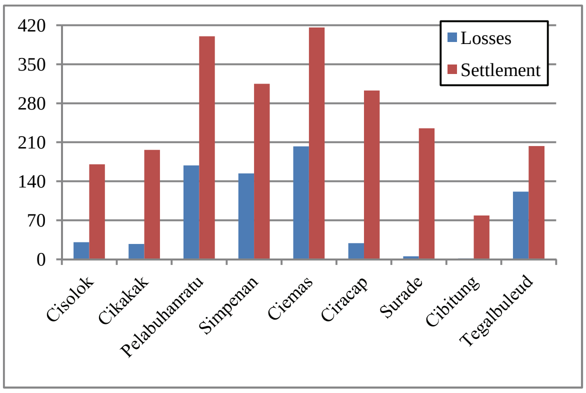

Figure 6 Direct Losses Estimation of Settlement

From figure 6, settlement assets at Pelabuhanratu, Simpenan, Ciemas and Tegalbuleud sub-districts are experiencing badly direct impacts from tsunami disaster comparing to other regions. Residential areas that affected by the tsunami waves are generally located around the coast at a distance of between 0-500 m and spread throughout the coastal sub-districts (741.36 ha). Moreover, the condition of residential structures in coastal areas that do not fit the standard of building regulation and absolutely not resistant to the tsunami waves are also scattered throughout the coastal sub-districts region.

6. INITIATIVE FOR TSUNAMI DISASTER RISK REDUCTION AND COASTAL SPATIAL PLANNING

6.1 Tsunami Disaster Risk Reduction

There are four parallel and complementary lines of actions that can be considered to reduce exposure to tsunami disasters and achieve a more sustainable approach to development.

a) Community/Stakeholder Participation

Based on other countries experiences, some of the most successful risk reduction initiatives have closely involved communities/stakeholders in understanding risks and designing appropriate response plans. Community-based disaster management is able to transforms vulnerable groups into disaster-resilient communities. As one of the main stakeholders, communities understand the socio-environmental constraints that define vulnerability and the parameters that determine the success of risk reduction policies and actions. They also have perceptions that may or may not be based on reality, but nonetheless are important to consider and incorporate in the development of risk reduction initiatives.

Sukabumi district coastal region are identified as rural areas, therefore, successes in community participation will be obtained more easily in rural areas instead of urban environments. In rural areas, individuals rely more heavily upon local communities and mechanisms for engaging communities in the decision-making process.

b) Public Policy Action

Disaster risk reduction policy deals with the course of action adopted by government and civil society to understand hazards, assess vulnerability, evaluate risk and adopt measures for risk reduction. Examples or risk reduction policy include legal and institutional arrangements that govern land use, urban planning, enactment and enforcement of regulations of constructions and risk financing.

Learning from developed countries experiences, policy making for disaster risk reduction requires a clear understanding of issues, scientific consensus and packaging of scientific knowledge in a way that can be translated into policy. Hence, other more dynamic mechanisms to impact disaster reduction policy are needed. These include grassroots advocacy groups, stakeholder partnerships, and knowledge and risk dissemination. Linkages among civil society actors have the potential to go over bureaucratic hurdles and trigger action. Moreover, collaboration between government, civil society and external agents provides excellent opportunities to create policies and processes that integrate disaster management and development. In the face of complex and competing demands, success is strongly correlated with two factors. First, the ability of government to put in place legislation and administrative arrangements that reduce hazard risk and secondly, the ability of government and civil society to work together around a common agenda aimed at avoiding catastrophic losses from natural and technological hazards.

c) Safer Rural-Urban Planning and Construction

In many ways, urbanization issues lie at the heart of safer cities and sustainable development. Unplanned urbanization, caused by population growth and migration, is a key factor in vulnerability and environmental degradation. In a more growth region, for instance Pelabuhanratu City, sustainable development and disaster risk reduction goals are often in conflict with pressure to provide housing, employment, social services and education. City attracts new inhabitants because they offer better prospects for employment and access to social services and education. Because city is not able to keep up with housing needs, a significant portion of urban growth takes place in an unplanned manner, resulting in illegal construction and a lack of compliance with safety standards.

In order to establish safer environment and construction in the tsunami hazard zones, therefore, useful means of reducing the likely impact on a community of a tsunami by:

- Prohibiting development in high risk zones
- Imposing regulations on developments in high risk zones, i.e. by banning buildings that represent high vulnerability, important facilities, hazardous facilities and important infrastructure (main roads) in the most hazard-prone areas
- Linking criteria in spatial planning, local building codes or designated laws to project development in tsunami hazard prone areas
- Planning physical water barriers for protection
- Planning functional networks of escape routes and safe places

d) Development of Prevent Culture

Developing a culture of prevention to reduce the vulnerability of society to natural and man-made hazards constitutes the foundation of disaster risk reduction. Cultural factors dictate how people perceive risk and their motivation to enhance resilience or aggravate vulnerability.

Developing a culture of prevention develops human potential which provides a community with the skills, knowledge and confidence to cope with the impacts of hazards to proactively reduce the negative consequences of future events. Human potential capacity translates into sustainable livelihood actions and infuses its influence into sustainable human development and sustainable resource use.

6.2 Implementation of Coastal Spatial Planning

a) Spatial Planning of Coastal Area

The availability of rules and regulations regarding the handling of natural disasters are expected to support the implementation of spatial planning which takes into account aspects of disasters. Specifically in Sukabumi district associated with the interests of development and mitigation of natural disasters, it is necessary to establish a legislation (local regulation) in order to organize and manage disasters in a systematic way, as a consequence this effort will has the force of law and inline with the programs of spatial planning. Thus, disasters aspect especially tsunami in the district of Sukabumi can be considered as an important aspect in spatial planning.

The existing spatial planning of Sukabumi district which has been conducted seems not to take into account the aspects of disaster risk. At this moment, this can be seen from the actual conditions of the built areas i.e: residential areas, economic centers and other, are legalized at tsunami high risk zones. This condition should be a deep concern for the policy makers in the arrangement of space specifically for coastal spatial planning in the region of Sukabumi district.

A review of the existing of Sukabumi district should be conducted to evaluate and repair any deficiencies that had been developed, so improvements to spatial planning can be account for and implemented consistently. In this case, improving spatial planning should consider the locations of tsunami hazard. It would be nice for public facilities-settlements, the central government, educational facilities, health facilities, market and worship facilities-located outside the high risk area of tsunami hazard in further planning. Meanwhile, the relocation is something that should be clearly prioritized in the program of spatial planning and mitigation. Thus, the spatial planning of Sukabumi district must consider the condition of coastal areas which have heterogeneous characteristic and at risk of tsunamis.

b) Space Utilization of Coastal Area

The existence of land use changes in the coastal area of Sukabumi district, especially in the various areas that have low plain morphology and at risk of tsunami should be considered seriously, especially the enhancement of residential areas along the coast and river set back zones which empties towards the coast. Physically control efforts can be done by establishing the artificial barrier building/wave energy absorber (sea walls, breakwaters, and river gates). These activities were motivated in large part by knowledge of potential inundation zones, and damage from past tsunamis. Meanwhile, development of natural barriers such as protective vegetation and maximizing the function of mangroves in coastal areas are some mitigation efforts that very beneficial in reducing the impacts of tsunami hazard in the future. In addition, mangroves have important role in coastal and marine ecosystem because they able to provide organic materials for coastal ecosystems. Mangroves are often referred to the coastal forest or tidal forest, are distinctive type of tropical forests that grow along the coast or in estuaries which influenced by the tides.

An importance in regarding spatial utilization analysis based on disaster mitigation principles should be public safety which can be assured through proper planning and land utilization. Development policies and decisions on public safety must be based on a comprehensive disaster risk assessment of all environmental hazard impacts that may be unique to a region. Proper spatial utilization policies must prohibit urban development in zones that the disaster assessment study identified as potentially vulnerable and may put parts of the population at risk.

Furthermore, the government agencies must designate evacuation procedures, post signs and provide proper instructions to the public. Strategies for spatial planning based on mitigating tsunami risk have generally involved space utilization for evacuating to areas of naturally occurring high ground outside of the tsunami inundation zone. In some location, high ground may not exist, or tsunamis triggered by local events may not allow sufficient warning time for communities to evacuate to high ground. A potential solution to solve these problems is vertical evacuation planning.

Based on the results of this disaster risk assessment study, government planners must construct appropriate transportation systems or modify existing ones, to facilitate the rapid evacuation of people out of vulnerable zones. This should be part of spatial analysis and contingency planning. In addition, government policies must encourage low intensity uses for sites that are most susceptible to a given hazard or other similar socially and economically non-disruptive land utilization. Such considerations of proper spatial planning are particularly significant in developing infrastructure and industrial facilities - since their destruction or damage could compound the effects of a disaster by other indirect means such as leakage or spilling of flammable or hazardous materials. Thus, decisions on development must be made carefully to protect a community's infrastructure.

For the purposes of long-term program, the sustainability of optimal utilization of space must be considered. Sustainability of initiatives is critical to overcome difficulties, survive administrative turnovers, and start impacting socioeconomic structures and parameters associated with disasters. Sustainability requires commitment in providing long-term funding, human resources and institutional support and backing. Thus, sustainability of spatial utilization should be reviewed by the local government and considering various aspects of life and regional interests, so that the impacts of the tsunami disaster on economic, humanitarian, and ecology can be minimized.

c) Spatial Control

Control of space utilization is a stage in the implementation of spatial planning to manage space utilization. According to Law No 26 about Spatial Planning, the control of space utilization is an attempt to create an orderly spatial plan that form as zoning regulations, incentives and disincentives, and punishments. In accordance with the previous explanation, zoning regulations are established as the control guidelines of space utilization.

The general functioning of the coast requires sufficient spaces. The entire coast has different varieties of ecosystems of which few are sensitive and the needs of protection. Coastal regulation zone can help to reduce risk arising due to natural hazard such as tsunamis. Zoning regulations for tsunami prone areas regulate some guidance which is able to identify a safe area or not recommended area for residential and environmental design that responds to the tsunami. In addition, zoning regulations should also consider other aspects such as economic, social and infrastructure aspects.

According to Law No. 26 year 2007 on Spatial Planning, the utilization of space can be divided according to its main function, for instance: protected areas and cultivation areas. Protected areas are areas that defined by the main function of protecting the environmental sustainability which cover natural resources and man-made resources. In this case, the protected areas which have important roles related to spatial control in the tsunami risk areas are:

- Coast setback zones

Coast setback zones include land located in urban and rural areas. The establishment of coastal buffer zone becomes one of the most important features regarding coastal spatial planning, stated clearly in the national regulation above that coastal buffer zone has to be set arbitrary depend on the coastal condition with minimum range of 100 meters from the highest high water level (HHWL).

- River setback zones

The criteria of river setback zones are as the following (RTRWN (PP 47/1997), UU 22/1999, PP 25/2000, Keppres 32/1990): 1) in urban areas, width of the river setback zone is 10 meters, 2) in rural areas, width of the river setback zones are: a. 15 meters for river with vary depth of 3-20 meters, and b. 30 meters for river with a depth >20 meters. For the role preservation of the river setback zones, then the utilization of river setback zones needs to be controlled through the permitting process and environmental control.

7. CONCLUSIONS

1) The ArcGIS based spatial-multi criteria analysis approach which is demonstrated in

this research is very useful for tsunami disaster risk assessment. The principle advantage of using this approach is that a dynamic database is generated rather than a series of static maps. This primary database may be used in a number of different ways according to the requirements of the end user. Furthermore, each attribute may be analyzed individually or in any combination which should help to identify problematic areas.

2) The most dangerous areas of tsunami are: along the coasts of research area, especially the area with sloping sea floor, sandy beaches and located around the Pelabuhanratu and Ciletuh gulfs); broadly low-land area (Ujunggenteng cape); open coastal areas with straight and elongated beach profile (Tegalbuleud beach); and along estuaries and river areas, especially for wide river and perpendicular to the direction of the beach (Cimandiri, Cidadap, Ciletuh, Cikaso rivers).
3) The areas that have a high degree of vulnerability are influenced by the high number of parameters, such as: low land morphology, built area, population density, occupation at risk (farmers and fishermen), and valuable area (i.e. infrastructure and agricultural area) which briefly contributed to the annual income of research area.
4) The high risk area lies in high tsunami hazard area which has a high degree of vulnerability. The calculation results of direct losses estimation in the high risk zones consist of: settlement (741.36 ha), plantation (2,233 ha), food crop (3,411.28 ha), and forestry (2,178.74 ha). These estimations can benefit coastal planners to use safe sites for future land use planning and engineers to design proper structures that will sustain no damage and will continue to operate in the post disaster period.
5) Based on the analysis results of coastal spatial planning in the research area, the allotment of space utilization for buffer zones (coastal and river border demarcation) are still not acquired, additionally the level of community preparedness for future disaster events is still low. Thus, residential areas, public and social facilities which are located in the danger zones will become very risky. Designing and constructing important infrastructure facilities must always take into consideration all potential forces associated with a natural disaster. Therefore, planning of coastal areas must consider the balance between the opportunities and constraints (tsunami) that exist in the region and involves the interaction between humans and the environment.

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