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Predictions of Vulnerability Flood and Flood Prone Areas in Watershed West Sumatra Province using Arc-GIS and Category Value

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Abstract: WestSumatra is an area of west coast of Sumatra; the topography is hilly to steep. It consistsof 20 small watersheds with the area from 20 km^2 to 690 km^2. The annual rainfall is approximately 4950 mm / year or 340 mm / month(BWS,2008). The area along the coast and estuaries are often vulnerable by flooding. Based on this phenomenon, it can be predicted thatthe flooding in the west Sumatra is caused by the combination of extremely heavy rainfall, length of the rivers which are mostly short and tides. The morphologically rivers that are relatively straight with many branches on the upstream side of the river also cause the situation getting more vulnerable. Flood vulnerability assessment and areas prone to flooding assessment was performed using the results of the land area of the satellite image map, Arc-GIS and hydrological data. The analysis was conducted by using quantitave approarch to categorize and give dignity/values for each parameter that causes flooding. Data were collected from local government and field measurements. The classification of vulnerability was divided into five categories. According to the three watersheds, it was obtained the value that shows the characteristic with rather vulnerable and medium level to flooding and flood-prone areas. It is more dominant determined by rainfall, land use, specific discharge, and the influence of the coast and the existence of waterworks. If the rain occurs at the upstream of watershed at the same time with the rising of sea levels (tide), then there will be inudation due to the stagnant of drainage network systems where the city crosses. It happened for those watersheds of West Sumatra, for small watershed with area more vulnerable in the appeal of a large watershed. Therefore, an integrated flood management plays important role on this particular areas.

Keywords: *Vulnerability, Watershed, Flood, Category, Value*

1. Introduction

West Sumatera is a hilly area bounded in the east and western part of the Indonesian ocean. This area extends from the North to the South. As a result, this area is located on a steep slope up to the ramps. Steep terrain in the upstream rivers and estuaries are in the plains and partly below sea level. Therefore, there are many tributaries flow area and the river that is relatively straight. It is only at the upper which has many tributaries that merges with the main river (BWS V 2008).

Almost all rivers flowing from East to West with great discharge flow occur in the afternoon or tidal conditions. The tide generally occurs twice, that is in the evening and morning. The tides and discharge peaks occur at the same time, as a result, puddle happened at the confluence area (estuary). The phenomenon of flood oftern occured in the last few years (Daoed, Bambang, Abdul, 2014). This flood was also caused by the growth of residential areas in the coastal region in which the changeof the land use occured from swamp into residential areas and public facilities. It was also as a result of climate change and changes of functions of forest area (BWS V 2008).

Based on the facts, it is essential to predict the vulnerability of flood and flood-prone land in the watershed. Therefore, it can be a reference for decision makers.

1.1 Area of the Study

The research is located in the province of West Sumatra, the north of the province of North Sumatra, the south of the province of Jambi and Bengkulu, also the Eastern of the province of Riau. This area is managed for agricultural land, plantation and residential area. The residential area is dominant along the coast. The agriculture is mostly farms of rice, pulses, oil palm and rubber and cocoa (Bakosurtanal 2011 and BWS 2008). In the picture below, it can be seen the limit of location of the provinces and area of the study. There are several watersheds, included small watershed and all of them used for irrigation, fishery and tourism.

The small watershed is the catchment area has an area smaller than 100 km^2. Besides, it was also found that the length of the river is less than 30 km. (Daoed, 2014),The statement is almost the same is also disclosed in another paper.(Azmeri 2016, Modrick, 2015).

The irrigation has been managed by the government and supported by the community through farmer groups since the first.

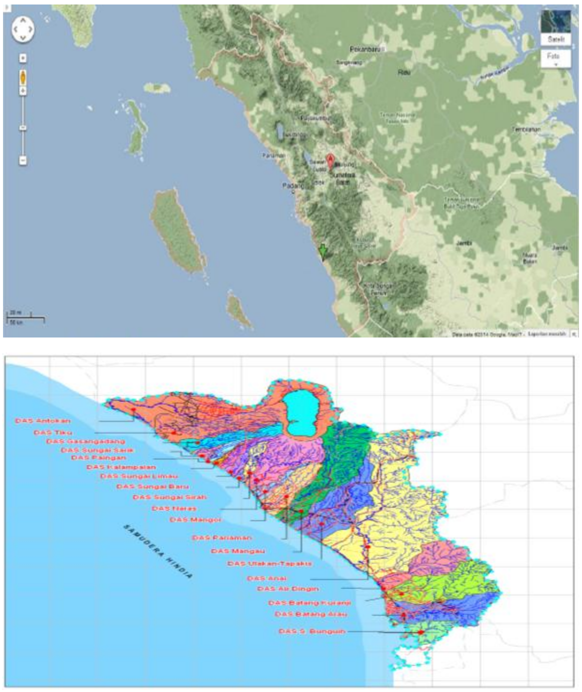

Figure1. *Region of West Sumatra - Indonesia and small watersheds*

1.2 Watershed Management Pattern

The general pattern in managing the watershed is by analyzing the biophysical and socio-cultural characteristics. The characterization results can be used to determine the classification of watershed in the supportability of restored or maintained category.

Characterization is a series of activities or procedures to determine the character of each watershed, while the characteristics are as specific features of watershed that are shown by parameters depending on the circumstances morphometry, topography, soils, geology, vegetation and land use, hydrology and human (Seyhan, 1977, Paimin 2010).

To obtain the characteristics of the watershed, procedures that are arranged in a formulation which can provide a value that distinguishes one another are needed. The formulation is used as a basic in arranging the pattern of watershed management.

1.2.1. Characterization of Watershed

Watershed Characterization will be compiled in a typology of watershed formula (Paimin, 2013), where the typology of watershed will indicate the degree of vulnerability and potential of watershed. The typology of watershed will show the vulnerability and the potential of the watershed that consist of land typology, socio-economic typology which form the typology of catchment areas. The interaction betweena catchment area of physical typology and the rain which falls on it will indicate the flood potential and as a reflection of the input characteristic of rain and land. The interaction between the flood potential and flood-prone areas show the typology of flood in the watershed.

1.2.1.1 Typology of Land

A catchment area is a place of the rain to fall that includes watersheds and resource areas for human life.

The catchment area is cosidered as the processor of the rain that falls on it, then the characteristics of the land can be determined from the natural character and the characters that are managed by humans as natural resources, where the characters can be changed based on local community activities. The characteristics of the land are composed by natural parameters that make up the land, such as geology, slope and climate, while the parameters that are processed by the human are the land cover, such as agricultural areas.

1.2.1.2 Typology of Flood

Rain that falls in the catchment area will flow on the surface and it is partially saturated into the soil. Based on water system in the watershed, the flood potential is a reciprocal relationship between the typology of land and rain, which can be formulated between rainfall (R) and the vulnerability. Here rainfall (R) and land are grouped into five (5) categories.Table-1 Typologyformula of flood water supply

Table1.*Typologyformula of flood water supply*

Rainfall(R) (mm)	Category-Value	score
<20	Very low	1
21-40	Low	2
41-75	Medium	3
76-150	High	4
>150	Very high	5

Source: Paiman, Planning Systems and Watershed Management, BPTKPDAS, 2013 and modifications

The flood-prone area is characterized by its land systems. The classification of the form of theland in table-2 can be used to express the vulnerability of flood area. The interaction rateofvulnerable areas of flood andthe flood water supplies will lead to the degree of vulnerability of flood (flood typology) of a catchment area or watershed.

Tabel 2 *System of vulnerable flood land*

Land form	Category-Value	score
Mountains and hills	Very low	1
Fans and lava, terraces	Low	2
Plain	Medium	3
Alluvial plains, alluvial valleys	High	4
Swamps, coastal, pathways bends	Very high	5

Source: Paiman, Planning Systems and Watershed Management, BPTKPDAS, 2013 and modifications

1.2.2 Classification of the Level of Land and Flood Vulnerability

Land and flood vulnerability are grouped into five (5) categories. Each category is given a score from 1 to 5. To easy in determining the level of vulnerability, each category is completed by interval value that is derived from dividing of the difference between the highest and the lowest scores and it is divided by the number of category, or

$$IN = \frac{(Highest\ score - lowest\ score)}{(the\ number\ of\ category)}$$

In table -3, it can be seen the interval value for each category and the degree of vulnerability of flood and flood land that will be used as a reference in determining the classification of each watershed that is reviewed.

Tabel 3 *Classification of typology or the vulnerability of land to erosion*

Category	Interval Value	Level Vulnerability
Very high	$IN \geq 4.2$	Very vulnerable / very degraded
High	$3.4 \leq IN < 4.2$	Vulnerable / Degraded
Average	$2.6 \leq IN < 3.4$	Medium
Low	$1.8 \leq IN < 2.6$	Rather prone / Rather degraded
Very Low	IN <	Not vulnerable / not degradable

1.2.3 Changes of Qualitative Value into Quantitative Form

Natural parameters of flood potential that are taken more tend to be qualitative, for examples, the form of watersheds, the slope and the density of the river, as well as management parameters that are only types of closure/ the use of land, which are observed by satellite imagery maps. However, the value of the maximum daily rainfall average wet month and river morphology arein the form of quantitative values. Therefore, it is necessary to do an approach by converting the percentage of each parameter into a quantitative value in the terms of value, weight and score category.

2. Research Methods

In this study, classification of flood and flood-prone areas vulnerability by a qualitative approach that was changed into the quantitative one by giving value or score category was conducted. Then, it was described by using an approach of Arc-GIS version 10.3 software. The flood vulnerability or flood potential was observed on the parameters of natural effects (60%), namely: rainfall, the shape of watershed, the gradient of the streams, the density of the drainage, the average slope of the watershed. Moreover, for the parameter of natural effect (40%), the specific discharge was regarded. Meanwhile, the flood-prone areas that were observed on the parameters of natural effect (55%), namely: the terrain, meandering, damming / branching river / tide. The percentage of left-right slope drainage of land and management effect (45%) was from the existence of waterworks.

3. Vulnerability Prediction of Flood and Flood Prone Areas

At the river basin areas in West Sumatra, it wasdiscovered 20 watersheds which havevariouswide of catchment areas, namely, there are two watersheds above 500 km^2, and seven watersheds are under 300 km^2 and the rest are even under 100 km^2(BWS V 2008).

Also,it has the land topography that is relatively the same, namely the steep and ramp hills near the coast. Due to the slope that is almost similar and the limitation ofthe rainfall observation post, then it was selected three watersheds that were representative, that is the watershedswhich have small and large areas.

The watersheds which were studied entered into the territory of Padang city administration, such as, Kuranji watershed; and Tiku and Gasan Gadang watersheds that cross the city of Padang Pariaman.

3.1 Prediction of Watershed Vulnerability

Each parameter that was reckoned the watershed vulnerability to flood was weighted in advance. In the estimation of section (A),the weighting of the natural effect is 60% and management is 40%. In the natural weighting, the parameters consisted of35% of rainfall, 5% of the watershed forms, 10% of the gradient ofthe streams, 5% of the drainage density, and 5% of the average of watershed slope. The weighting for the management parameter was 40% of the land use. In the estimation of section (B), a measurement parameter was in the form of 100% of a specific discharge. (Paimin-2013).

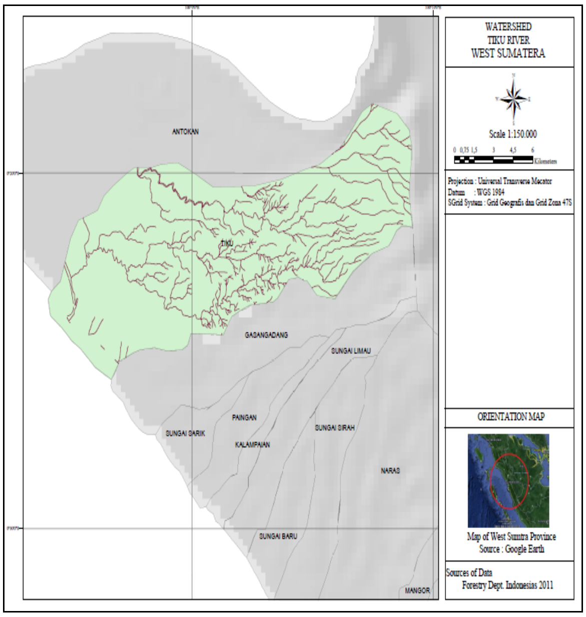

Figure 2. *Description of river flow in watershed Tiku*

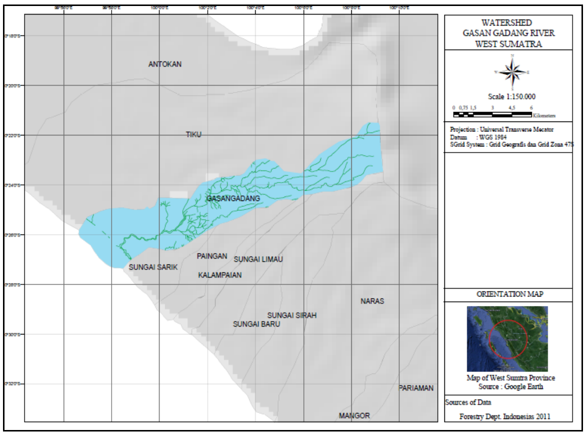

***Figure 3.** Description of river flow in watershed Gasan Gadang*

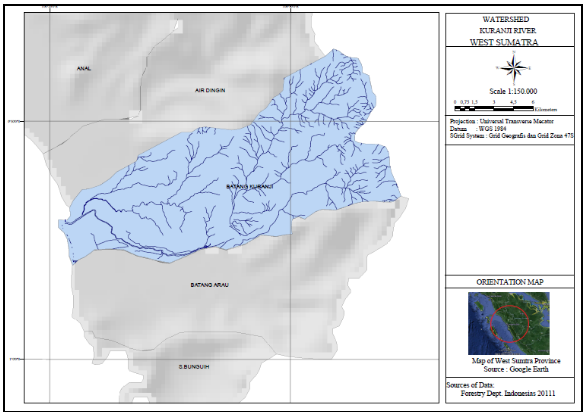

***Figure4.** Description of river flow inwatershed Kuranji*

In estimating the vulnerability value of some parameters onflood was done by estimating the area of each parameter by using Arc-GIS software. For example, forthe stream gradient is approximated by the land slope through the percentage of land area. The percentage of land area was calculated by using the ratio of the slope of the ecosystem per segment that were divided by the watershed area and multiplied by 100% . It was also for the average slope of watershed. Furthermore, for the specific discharge, monthly water discharge was used during the observation was divided by the watershed area. Then all the parameters in section (A) and (B) were summed.

To determine the classification of the typology of land vulnerability level against flood and flood-prone areas, then it was used a comparison which was similar with Rod, JK, Berthling, I., Lein, H., Lujala, P., Vatne, G., Bye, LM, 2012) did, in which it was to select an integrated vulnerability index. Thus, the typology classification was calculated by the average value of the flood vulnerability (VF) with the vulnerability of flood-prone areas (VA), ie

$$VR = \frac{1}{2}\,VF + \frac{1}{2}\,VA$$

VR = the value of vulnerability

In thetable -4, it can be seen the results of the prediction of the flood vulnerability value (VF) also the category and level of the vulnerability. In the table-5, it was shown the results of the prediction of the vulnerability value of flood-prone area also the category and the degree of vulnerability of each watershed.

***Table 4.** Vulnerability to flood for each watershed*

Watershed	Area (Km^2)	Value Flood (VF) A	B	$\bar{R}$	Category	Vulnerability level / Degradation
Kuranji	207.83	2.09	3	2.54	Low	Rather Vulnerable / Rather degraded
Tiku	117.60	2.05	2	2.02	Low	Rather Vulnerable / Rather degraded
Gasan Gadang	74.25	2.03	2	2.01	Low	Rather Vulnerable / Rather degraded

3.2 Discussion

In the predicted results of flood vulnerability, Table-4, it can be seenthe effects of natural parameters and parameter measurements of annual specific water discharge nearly equal value. While the prediction of the vulnerability of land flood was strongly influenced by the effect of damming parameter in this case due to the tides, waterworks, the slope of drainage on the left and right. This was caused bythe river is fairly straight and the downstream meets the sea (tidal conditions), so the effect of meandering was not so dominant.

***Table 5.** Vulnerabilities of flood prone areas of each watershed*

Watershed	Area (Km^2)	Value (VA)	Category	Vulnerability level/ Degradation
Kuranji	207.83	3.18	Average	Medium
Tiku	117.60	3.24	Average	Medium
GasanGadang	74.25	3.24	Average	Medium

To determine the classification of the typology of the vulnerability of flood and erosion-prone land, it was done by adding up the value VF and VA and divided by two. It is assumed that the influence of these two values are equal. The prediction of the three Watersheda, as shown in table -6 below:

***Table 6.**Classification of typology flood vulnerability*

Watershed	Value VF	VA	VR	Category	The Vulnerability/ degradation
Kuranji	2.54	3.18	2.86	Average	Medium
Tiku	2.02	3.24	2.63	Average	Medium

Gasan Gadang	2.01	3.24	2.63	Average	Medium

It is seen that the value of the vulnerability to flood potentialis in a fairly vulnerable position (Table 4), while the vulnerability to the land of the floodis still in medium position. However, in the classification value of the typology of flood vulnerability, they are all in medium position. It shows that all Watersheds provide the same vulnerability indication. The effect of the vulnerability that causes some areas experienced the flood can be seen below.

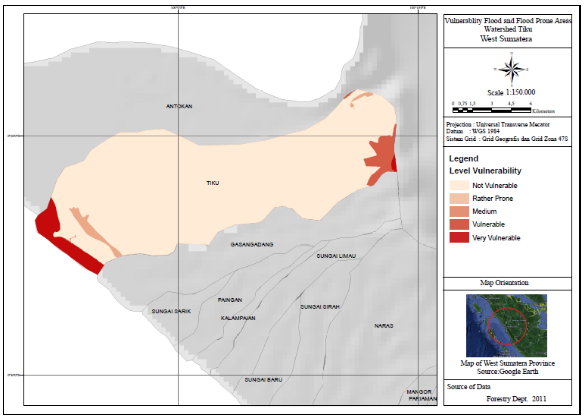

Figure 5. *The level of vulnerability of flood prone areas in Tiku watershed*

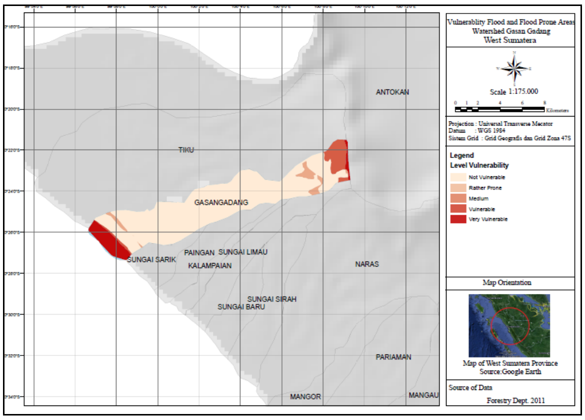

Figure 6. *The level of vulnerability of flood prone areas in Gasan Gadang watershed*

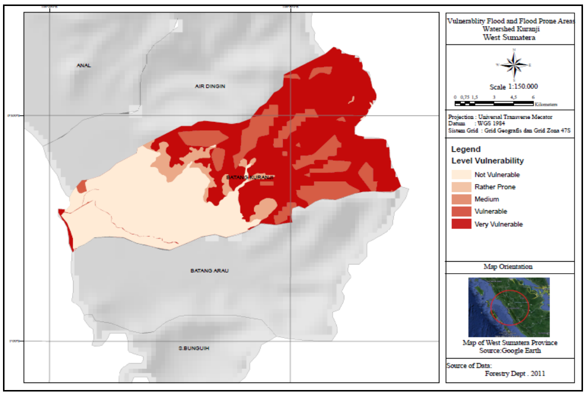

Figure 7. *The level of vulnerability of flood prone areas in Kuranji watershed*

In figure 5, it shows that predictions ofTiku watershed that will be inundated by water and the degree of vulnerability is classified as high susceptible to floodthat is on the edge of the beach. Meanwhile, others are not in the vulnerable condition . For figure 6, in the area of GasanGadang watershed,the floodis dominant in the areas along the coast with the level of vulnerability is very vulnerable, while others are included in invulnerable and somewhat vulnerable categories in the upstream. Then,if the figure 7 is seen carefully, it is different from the two previous pictures, where the areas with very high levels of vulnerability remain in the area of the seaside and in the upstream and the level of the vulnerability of upstream area is very degraded. This result is closely match with the phenomenon of flash floods on 24 July 2012 and 13 September 2012 (Abdul Hakam -2012). In which the debris flow that occurred brought catastrophic in the upstream and the huge material loss.

3.3 Conclusion

1) From the calculation of the value of watershed vulnerability to flood, it can stated that the smaller watersheds are more vulnerable than large watersheds. Although, the final result is the value of watershed vulnerability typologies included in the avarage category and vulnerability for all watersheds.
2) All of the seaside areas are at a very high level of flood vulnerability. Whereas, other regions are not at a vulnerable level of flood vulnerability.
3) EspeciallyKuranji watershed has a level of vulnerability to flood-prone areas is very high or very likely to be degraded. It is specifically at the seaside areas and the upstream.

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