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Delineation of Flood Hazard Zones by Using a Multi Criteria Evaluation Approach in Padang West Sumatera Indonesia

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Abstract

In Indonesia flood disasters constitute natural disasters that often occur and have resulted in substantial losses to human life. Mitigation is the important measure to determine hazard flood zones. To determine the weight and rate, the Analysis Hierarchy Process (AHP), Geographical Information System (GIS) are used for overlay analysis. Upon assessment by experts, the research findings reveal that elevation is the highest weight, that is 24%; flood frequency is the lowest weight, that is 7,4%. Further, the analysis result on the flood hazard level in the research area, based on the hazard level class, reveals as follows: a) an area of 8,351.6 ha (12%) includes the high hazard zone; b) an area of 11,378.7 ha (16%) is the moderate hazard zone; and c) an area of 49,738.8 ha (72%) is the low hazard zone.

Key words: delineation, harzad flood area, mitigation.

1. Introduction

Disaster is an event or a series of events that threatens and disrupts public lives and livelihoods caused either by natural and/or non-natural factors or man-made factors, and claims lives, environmental damage, loss of assets, and psychological impact (Law No. 24 of 2007). In addition, according to Wardhono *et al.* (2012), a flood disaster may result in huge damage to social and economic lives of the people. Asdak (1995) claims that there are three factors that contribute to flood, that are meteorology, watershed physical characteristics and humans. Popovska *et al.* (2010) claim that flood is caused by rainfall intensity. Furthermore, according to Penning-Rowsell (2003), flood occurs due to lack of control over land use, especially in the catchment zones and watersheds. Yüksek *et al.* (2013) claim that humans are the significant factor that contribute to disasters for their misuse of land, deforestation, urbanization, and settlements.

According to Sadyohutomo (2008) increases in population and life quality has led to the increases in needs to land use. According to Kodoatie (2013) change of land use into urban solid has posed impacts on the flood increasing because of decreased open space to act as catchment zones. Pribadi *et al.* (2006) claims that the thriving development has contributed to the change in the scheme of land use where the solid space has increasingly expanded and removed natural space to change its functions. This phenomenon commonly occurs in urban zones where changes in land use are taking place dynamically.

Jha *et al.* (2011) have observed that several cities in the world are risky to flood hazard. The current existing flood hazard level calls for urgency to prepare the flood risk management in the urban residential zones. According to Popovska *et al.* (2010) the most appropriate effort to minimize flood hazard and loss incurred is to make a flood hazard zoning map. In the research area from 1988 to 2008 land was actively covered. The urban solid (settlements) has been continuously expanding, where the catchment zones are conversely becoming shrunk from year to year. The green void space in the research areas were 66.339 ha in 1988 and has shrunk to 59.328 ha in 1998 and 52.888 ha in 2008. So, from 1988 to 2008 the green void space in cities has converted to solid space by 13,451 ha. The objectives of this research are therefore to delineate and determine the mitigation policy dedicated to flood hazard settlements.

2. Methodology

2.1. Research Site and Time

This study was conducted for six months from March 2016 to August 2016 and the location of research in Padang West Sumatera Indonesia. The research area is located by boundaries in terms of latitude and longitude geographical coordinates: 100º05'05'–100º34'09'' E and 00º44'00''-01º08'35'' S. The research area are 69496 ha. The research location can be viewed in Figure 1.

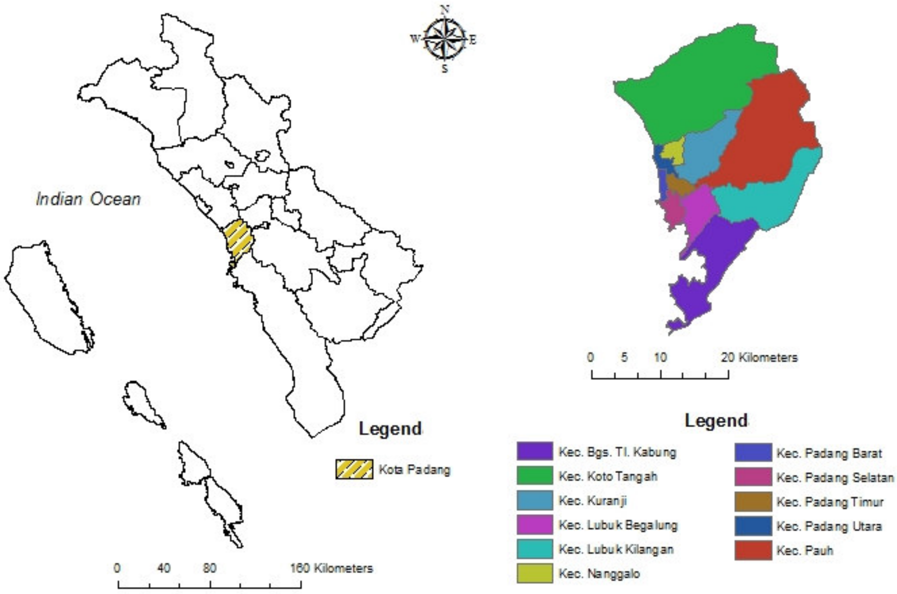

Figure 1. The Research Location in Padang West Sumatera Indonesia

2.2. Data Types and Source

This research requires some data derived from the relevant agencies. In making maps using ArcGIS 10.1 software. and for the analysis of expert opinion using Expert Choice 11 software.

Table 1. Data types, sources, and data output

Data types	Sources	Data output
Soil type	Land Research Center Bogor (1990) scale 1 : 250.000	Soil type map
Slopes	Agency Coordination of National Surveying and Mapping (1977) topographic map scale 1 : 50.000	Slopes map
Land use	Landsad ETM 7	Land use map
Rainfall data	Meteorology Climatology and Geophysics Council Tabing Padang (2013)	Rainfall map
Elevation	Shuttle Radar Topography Mission (SRTM) generated Digital Elevation Model (DEM)	Elevation map
Frequency Flood	Regional Disaster Management Agency Kota Padang	Frequency flood map
Landforms	Departements of Geography Faculty of Social Sciences UNP Padang	Landforms map

Flood hazard can be analyzed by using the Multi Criteria Evaluation (MCE) method. Weight and rank are determined based on the opinion of experts using the Analytical Hierarchy Process (AHP) method. The experts judge them on a scale of 1 to 9 using pairwise comparisons (Table 2).

Table 2. Criteria for Judgment using the AHP Method

Value	Description
1	A is equally important to B
3	A is slightly more important than B
5	A is more important than B
7	A is strongly more important than B
9	A is absolutely more important than B
2, 4, 6, 8	Intermediate values between the two adjacent judgments

Sources: Saaty (1983), Marimin dan Maghfiroh (2010)

To determine the flood hazard interval class, we use equation, that is equation 1 as introduced by Dibyosaputro (1999).

$$I = \frac{c-b}{k} \quad (1)$$

Whereby:

I : the number of distance interval class
c : the number of highest score
b : the number of lowest score
k : the number of class desired

3. Results and Discussion

3.1. Characteristics Research Area

According to the Land Research Center Bogor (1990) soil type map scale of 1: 250,000 categorizing soil types: alluvial soil (13.8%), ground andosol (39.9%), ground latosol (25.5%), ground regosol (9%), ground organosol (0.3%), and the complex of red-yellow podzolic soil (11.5%). Furthermore, the slope generated from the topographic map in the study area can be divided into four categories, namely: the slopes of 0-8% with an area of 17.613,9 ha (25%), the slopes of 9-16% with an area of 10.373,2 ha (14.93%), the slopes of 17-26% with an area of 31.559 ha (45.41%), and a slope of more than 27% with an area of 9.949,9 ha (14.32%). Distribution of soil type and slope in the study area can be seen in Figure 2.

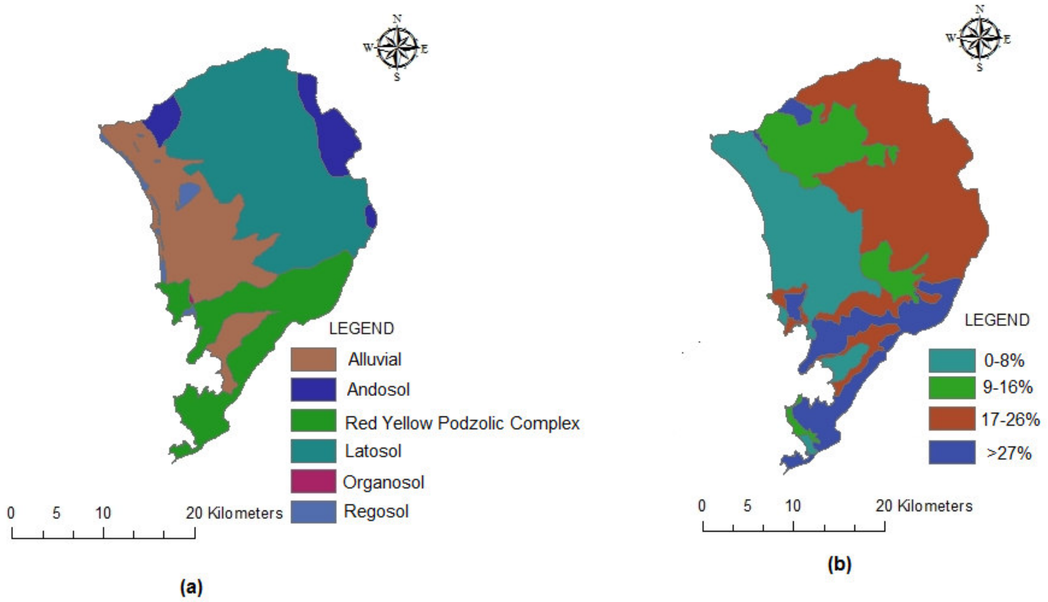

Figure . Soil type (a), and slope (b) in the study area

Geomorphological characteristics of the study area can be divided into: backswamp, coastal alluvial plain, between the beach plains, flood plains, shoals beach, sand spit, pyroclastic flow fan, fan fluvio volcanic, mountainous complex volkan, limestone hills, volcanic hills, and natural levee. Based on the landforms can be distinguished on the hills of volcanic landforms, marine complex landform, landforms tombolo, alluvial landform, landforms marsh behind, and landforms coastal alluvial plains. Volkan complex landform mountains are landforms of the most dominant area of research, which has tilted up a steep slope and the slope shape concave, convex, and complex. Rainfall is a climate that is very important element in influencing the occurrence of floods. Rainfall data from five stations rainfall in the study period 1975 - 2012 the average amount of rainfall that is 3,683 mm/year. The average amount of the highest rainfall occurs in November, while the lowest amount of rainfall occurs in February. Based on the map of rainfall in the study were mostly rainfall intensity 3500 - 4000 mm/year. Rainfall data of the average area of research the period 1975 - 2012 showed decreased over time. Average rainfall area of research the period 1975 - 2012 which is 3.789,8 mm/year. The highest rainfall intensity 6054,26 mm/year in 1981, while rainfall intensity terentah amounted to 2065,5 mm/year in 1997. Fluctuating rainfall in the period 1975 -2012 research can be seen in Figure 3, and distribution of rainfall is shown in Figure 4.

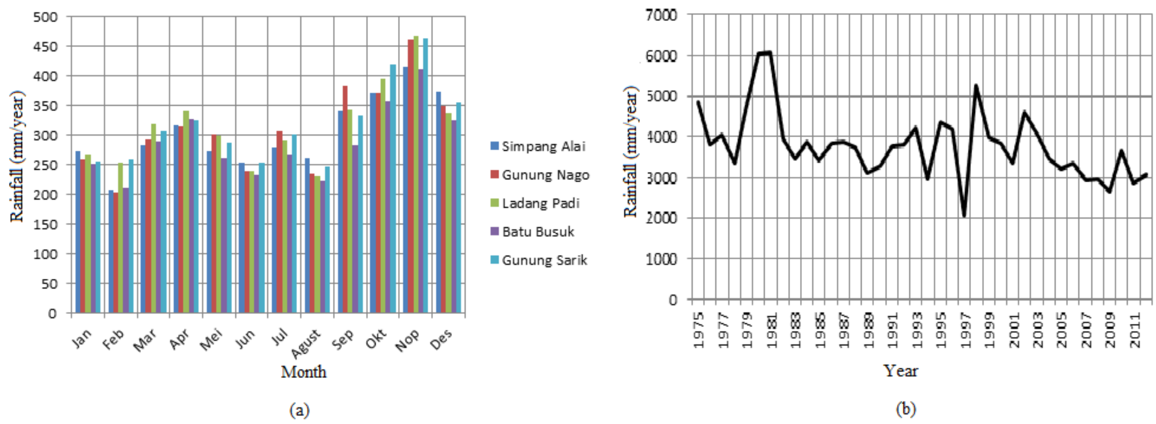

Figure 3. Graph average rainfall (a), and graph fluctuating rainfall period 1975-2012 (b) in the study area

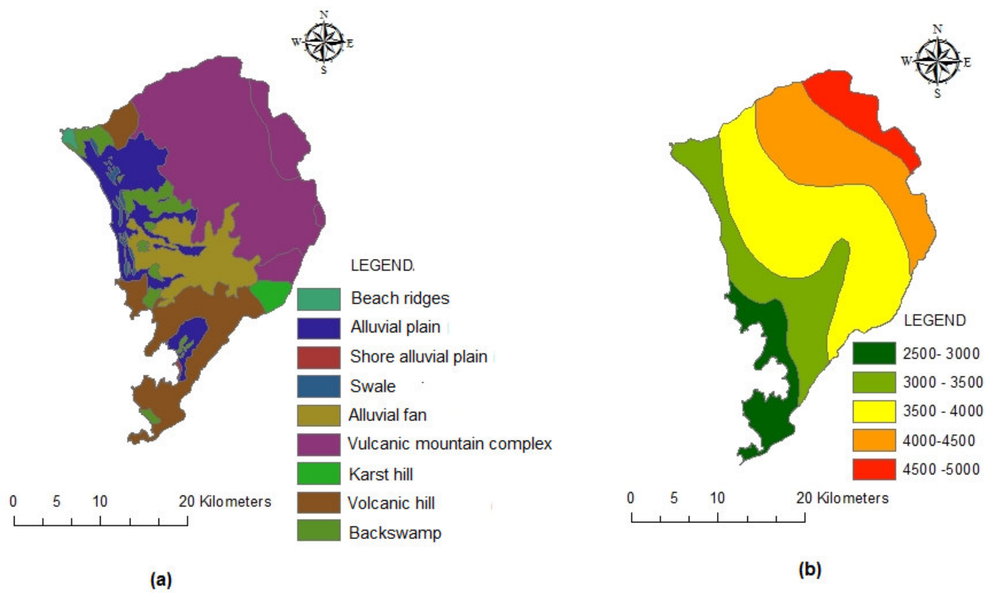

Figure 4. Landform (a), and distribution of rainfall (b) in the study area

Using imagery Shuttle Radar Topography Mission (SRTM) generated by Digital Elevation Model (DEM) and form the elevation map in the study area. Elevation region distinguished research on seven categories: 0-10 meters above sea level (12,5%), 10-30 meters above sea level (8,5%), 30-50 meters above sea level (3,8%), 50-150 meters above sea level (10,7%), 150-450 meters above sea level (21,6), 450-1000 meters above sea level (25,8%), and> 1000 meters above sea level (17,1%). Regional Disaster Management Agency Kota Padang fields described the frequency of flooding in the area of research in three categories: 3,3% of the study area is always flooded (more than 6 times a year), 2,6% are region of frequent flooding (4-6 times a year), 1,4% are rarely flooded area (less than 4 times a year), and 92.7% are areas without flooding. Furthermore, land use resulting from the research area Landsad ETM image interpretation in 2014 and distinguished six types of uses were: residential (16,5%), paddy (9,3%), mixed farms (3,8%), shrubs (0,6%), vacant land (0,6%), and forests (69,3%). Distribution of elevation, the frequency of flooding and land use in the study area can be seen in Figure 5.

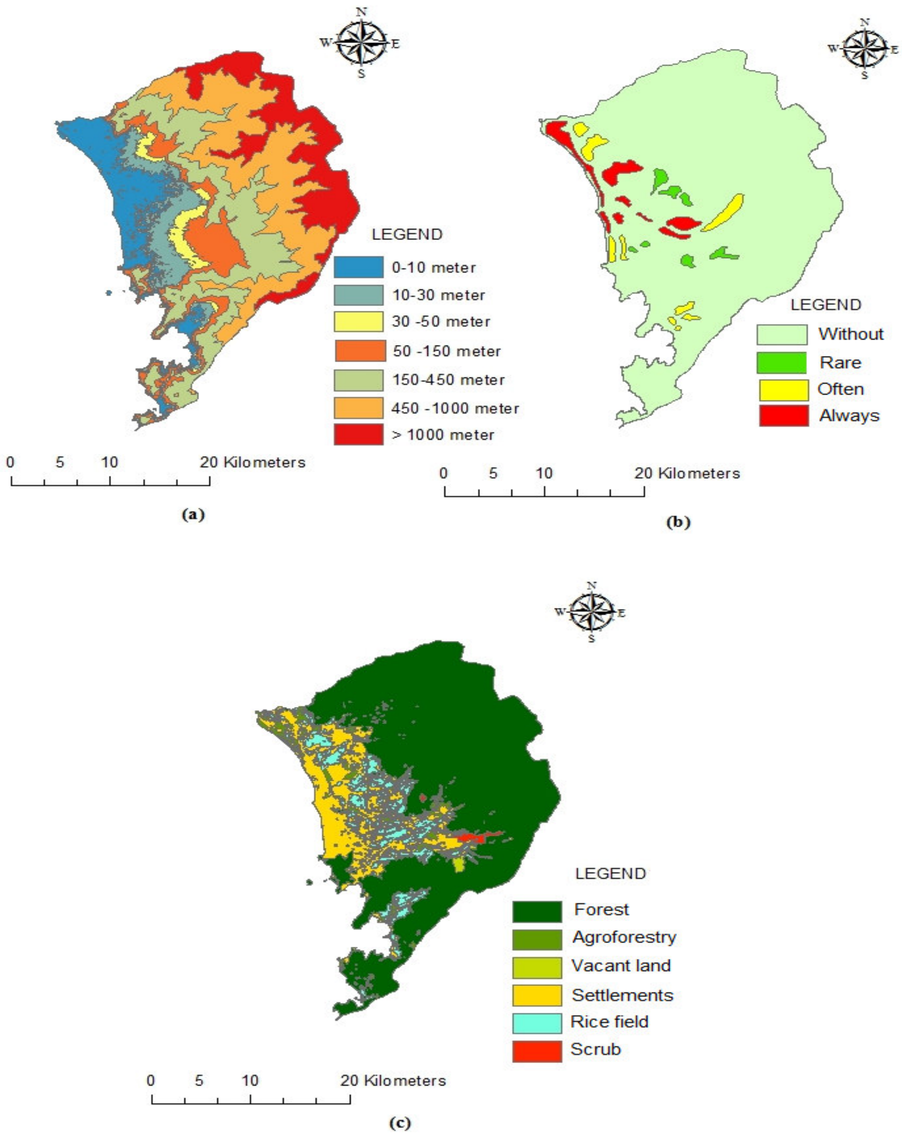

Figure 5. Elevation (a), frequency of flooding (b), and land use (c) in the study area

3.2. Flood Hazard Analysis

The result of the experts' assessment in factors that determine risks to flood hazard in the research area as analyzed by method of pairwise comparisons is that the highest weight value is the elevation / height of the sea level. The elevation weight value according to the assessment of experts in determining flood hazard area are 24%. It means that the higher the location in the research area is, the less possible the location is to be hit by flood. In addition, the slope has a weight value of 20.6% to determine the delineation of flood hazard. It means that flatter the morphology of the research area is, the riskier the zone is to be hit by flood. Furthermore, Rainfall, type of soil, form of soil, land use and flood frequency constitute factors that contribute to determine flood hazard zones. The weight value of each factor are: rainfall/precipitation level (11.3%), type of soil

(10.1%), form of soil (15.9%), and land use (10,7%). The lowest weight value is flood frequency by 7.4%. The distribution of experts' assessment in determining the weight value can be viewed in Figure 6.

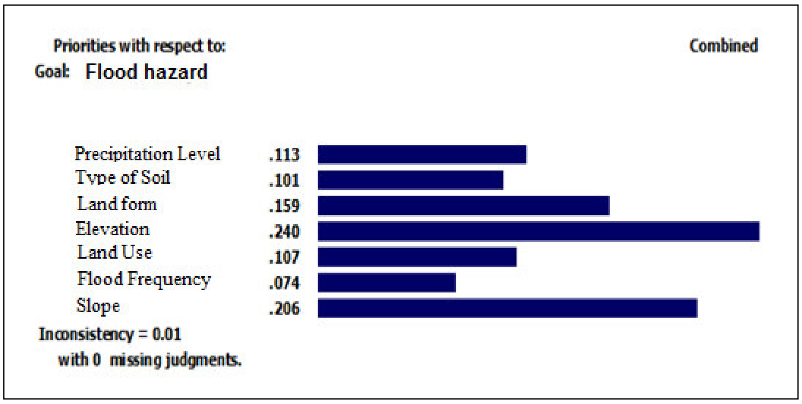

Figure 6. The result of experts' assessment in determining the weight of flood hazard

The result of expert's assessment (Figure 7) shows that the more intense the rainfall is, the riskier the location is to be hit by flood. The highest rate are is 37% with intense rainfall being more than 5000 mm/year. Meanwhile, the lowest rate is 5.2% with intense rainfall be 2500-3000 mm/year. On the type of soil, Organosol soil has 36.3%, which is the highest rank in the flood hazard. Meanwhile, the latosol soil has the lowest rank by 7.6% in contribute to delineation of flood hazard in the research area. The land form contributes to 15.4% in determining flood hazard zones. The result of experts' assessment shows that a backswamp has the highest rate of 21.2%. Meanwhile, a volcanic hill has 3%, which is the lowest rank. Elevation has the biggest contribution value in determining a flood hazard zone in the research area. The result of experts' assessment shows that the riskiest height against flood is 0-10 meters dpl, which is 38.5%. Meanwhile, height of more than 1000 meters dpl is relatively safe, with a value of 4.1%. Additionally, the result of experts' assessment in the rank of land use shows that land use for settlements and urban solid has the highest value of 33.3%. Meanwhile, the forest area has the lowest value of 4.8%. It means that the more the solid land use is, the riskier the area is to be hit by flood. The rank of flood frequency shows that the rate of flood frequency which is more than 6 months' flood in one year (always) is 56.9%, as the highest rank. Meanwhile, the value of area without flood throughout the year is 7.5%. This means that the more frequent the flood is, the riskier the area is. The result of experts' assessment of the rank of slope shows that the highest rank of slope of 0 – 8% is 53.5%, conversely, the lowest value of slope of more than 27% is 7.5%.

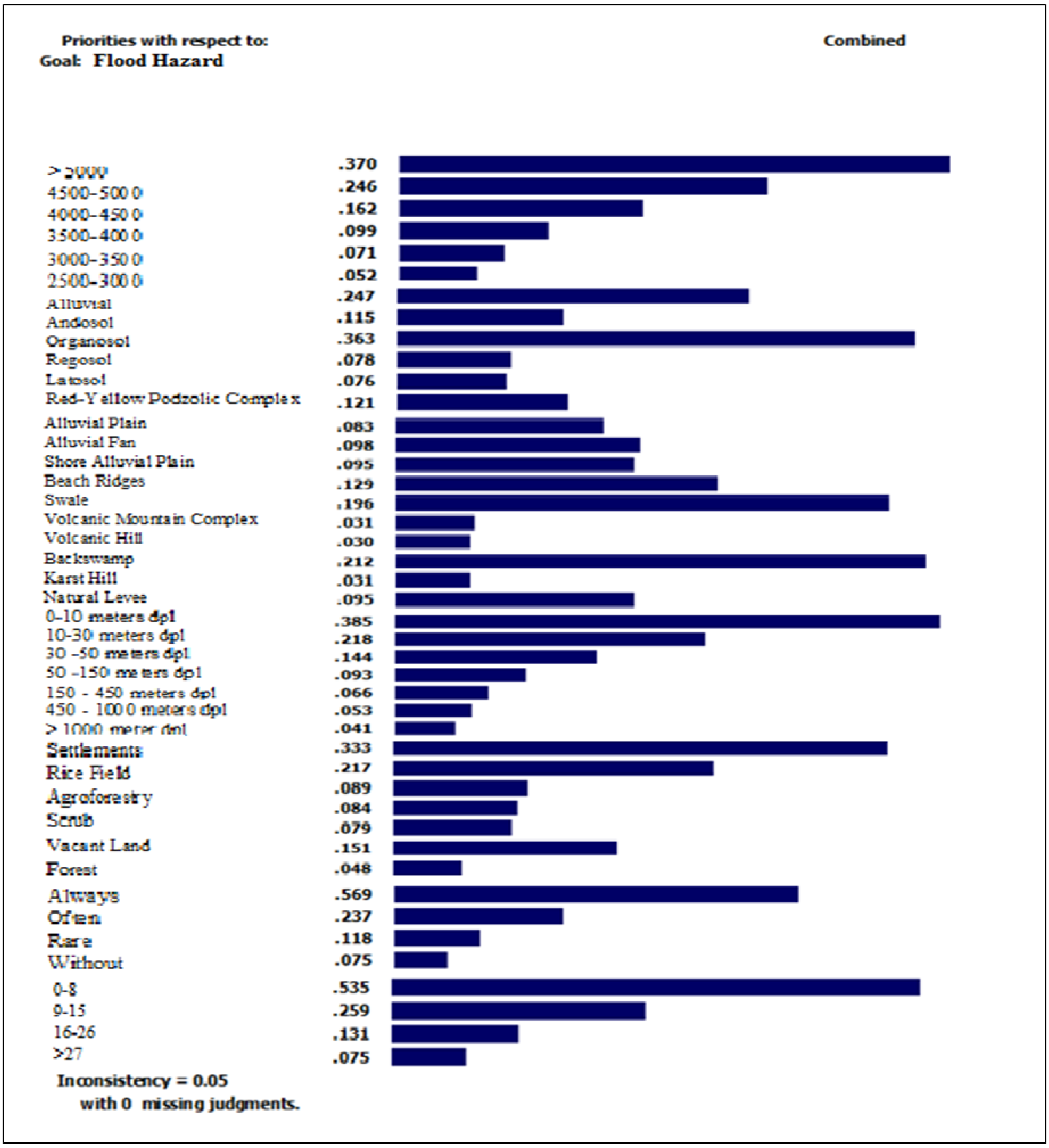

Figure 7. The result of experts' assessment of the rank of the flood hazard zones

Table 2. Flood Hazard Indicators

Indicator	Sub-indicator	Area (ha)	Weight	Rank	Score
Type of Soil*	Alluvial	9,612.3	10.1	24.7	249.5
	Andosol	27,709.3		11.5	116.2
	Organosol	196.3		36.6	369.7
	Regosol	6,225.0		7.8	78.8
	Latosol	17,732.9		7.6	76.8
	Red-Yellow Podzolic Complex	8,019.6		12.1	122.2
Slope (%) **	0-8	17,617.2	20.6	53.5	1102.1
	9-15	10,375.8		25.9	533.5
	16-26	31,558.1		13.1	269.9
	>27	9,951.8		7.5	154.5
Land form **	Alluvial Plain	9,097.0	15.9	8.3	132.0
	Alluvial Fan	8,485.5		9.8	155.8
	Shore Alluvial Plain	69.5		9.5	151.1
	Beach Ridges	291.9		12.9	205.1
	Swale	708.9		19.6	311.6
	Volcanic Mountain Complex	33,691.7		3.1	49.3
	Volcanic Hill	11,772.6		3	47.7
	Backswamp	3,857.0		21.2	337.1
	Karst Hill	1,209.2		3.1	49.3
	Natural Levee	0		9.5	151.1
Rainfall *	> 5000	0	11.3	37	418.1
	4500-5000	5,274.7		24.6	278.0
	4000-4500	16,046.6		16.2	183.1
	3500-4000	27,520.4		9.9	111.9
	3000-3500	13,822.8		7.1	80.2
	2500-3000	6,831.5		5.2	58.8
Elevation **	0-10 meters dpl	8,687.0	24	38.5	924.0
	10-30 meters dpl	5,900.2		21.8	523.2
	30 -50 meters dpl	2,633.9		14.4	345.6
	50 -150 meters dpl	7,415.2		9.3	223.2
	150 - 450 meters dpl	15,004.2		6.6	158.4
	450 - 1000 meters dpl	17,964.7		5.3	127.2
	> 1000 meter dpl	11,890.8		4.1	98.4
Land Use *	Settlements	11,477.7	10.7	33.3	356.3
	Rice Field	6,436.2		21.7	232.2
	Agroforestry	2,614.7		8.9	95.2
	Scrub	424.1		7.9	84.5
	Vacant Land	403.9		15.1	161.6
	Forest	48,139.4		4.8	51.4
Frequency	Always	2,279.5	7.4	56.9	421.1
	Often	1,779.1		23.7	175.4
	Rare	945.1		11.8	87.3
	Without	64,492.3		7.5	55.5

Sources: * MAFF-Japan (Zain 2002, Hermon 2012), ** Haryani *et al.* (2012), and *** Hardjowigeno dan Widiatmaka (2007)

Table 2 is the flood hazard indicators that used to determine delineation of flood hazard zone in the research area. Further, to determine the flood hazard interval class rate, we use equation 1. The total highest score is 3,661.3, whereas the total lowest score is 543. The equation has resulted interval of 1039.4, and flood interval class can be viewed in Table 3.

Table 3. Flood Hazard Interval Class

Hazard Class	Interval Class	Hazard Index
Low Class	543 - 1582,4	Low Hazard Zone
Moderate Class	1582,5 - 2621,8	Moderate Hazard Zone
High Class	2621,9 - 3661,3	High Hazard Zone

According to Stoica dan Iancu (2011) flood hazard zones can be determined by using the geospatial model with the GIS system. Karmakar *et al.* (2010) use data on land use, morphology, and urban infrastructure as input data to produce flood hazard. According to Miharja et al. (2013) to determine a flood hazard zone, several maps must be overlaid, including: a) type of soil map; b) slope map; c) land form map; d) rainfall map; e) elevation or height map; f) land use map; and g) flood frequency map.

The result of analysis of flood hazard level in the research area based on the flood hazard class shows that: a) an area of 8,351.6 ha includes a high hazard zone; b) an area of 11,378.7 ha includes a moderate hazard zone; and c) an area of 49,738.8 ha includes a low hazard zone. Distribution of flood hazard zones in the research area may be viewed on the flood hazard level map (Figure 8).

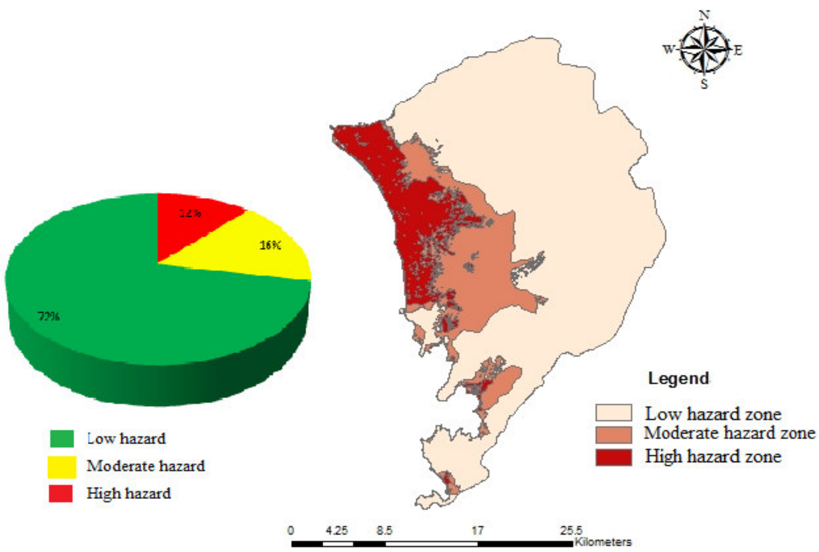

Figure 8. Flood hazard level map in study area

4. Conclusion

From the foregoing, it is concluded that the result of experts' assessment in determining the weight of hazard shows the highest weight is elevation (24%), whereas the lowest weight is flood frequency (7.4%). Further, the result of analysis of flood hazard level in the research area based on flood hazard class shows: a) an area of 8,351.6 ha (12%) includes the high hazard zone; b) an area of 11,378.7 ha (16%) is the moderate hazard zone; and c) an area of 49,738.8 ha (72%) is the low hazard zone.

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