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Land Stability Model for Sustainable Spatial Planning in Padang City-Indonesia based on Landslide Disaster

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Abstract

The main objectives of this research are to evaluate and formulate land stability level zone and to formulate spatial planning in Padang city. Evaluation and formulation of land stability level in Padang city conducted using Geographic Information System (GIS) technique and MAFF-Japan Model for spatial planning in Padang city. The research result, show that there were four land stability zone levels in Padang city i.e zone of high land stability (18.613 ha), zone of medium land stability (15.256 ha), zone of low land stability (27,614 ha), and zone of very low land stability (7.633 ha). The land area that has been built-up in zone A (A1) (9.062 Ha) and the total area of zone A (18.613 Ha), so that zone A (A2) can still be developed for the built-up land is 9.551 Ha. The land area that has been built-up in zone B (B1) (2.080 Ha) and the total area of zone B (9.551 Ha), so that zone B (B2) can still be developed for the built-up land is 8.923 Ha. While the zone C that has been built-up is 5.465 Ha. The unsuitable characteristics of zone C as the built-up land and potentially large enough to occur landslides, then all development in zone C (C1, C2, C3 and C4) (5.462 Ha) need in relocated gradually to zone A or B.

Keywords: Model, Land Stability, Spatial Planning, Landslide, Padang.

1. Introduction

The Regional Spatial Plan (RTRW) in each administrative regions (Regency, City and Province) in Indonesia basically functions as a controlling tool for land use change [1]. Control of land use change is very important because the area of land in an area is permanent while the need for land becomes increasingly high as a result of the development and progress of a region. [2] adds that along with the development and progress of a region, the insistence on changes in natural spaces that are ecologically belonging to the buffer zone will also be higher. This results in a decrease in land stability so that during the rainy season the potential for landslides will also be large.

Landslides are a natural phenomenon that is always associated with the arrival of the rainy season, occurs suddenly in a relatively short period of time at a certain place with a very heavy level of damage, even losing the lives of the people who live nearby [3]. According to [4] [5] [6] [7] [8] [9], landslide disasters other than caused by regional characteristics, are also caused by human activities in terms of meeting their needs without regard to the sustainability of natural resources. Today, landslides occur and destroy settlements and other facilities and infrastructure. This causes loss of property and souls of residents who live in the area, so it is necessary to rearrange the resettlement of residents to areas that are landslide-free.

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Based on data from Welfare Agency the Social of Disaster and Flood Management (BKSPBB) Padang City 2007 year shows that in the span of 1980-2007 there had been + 30 landslides that hit the city of Padang which caused a lot of loss to wealthy, property and lives. Location of landslide events is in the area of Bukit Barisan hills, i,e at Bukit Lantiak, Bukit Gado-Gado, Bukit Mata Air, and Bukit Air Manis. In addition, landslides also occurred in Bukit Gaung, Lubuk Minturun, Sitinjau Laut, Indarung, and Bungus Teluk Kabung. Landslide disasters that occurred in Bukit Lantiak in 1999 resulted in 67 deaths and dozens of houses destroyed. In 2000 and 2001 landslides again occurred on Bukik Lantiak which killed dozens of lives. The disaster is classified as a severe landslide disaster, so it is considered as a disaster in the National [10].

Padang City is the capital of West Sumatra which has a relatively dynamic topography condition, especially in the eastern and southern parts of Padang City, which has a relatively high potential for landslides. As a result of the pressure for space for settlements and urban activities, resulting in "natural spaces" in the eastern and southern parts of the city already being used for settlements, thus reducing the function of space in maintaining ecological functions and buffer zones. Based on the foregoing, the goal to be achieved is to formulate zones of land stability to prevent landslides and formulate Padang City spatial zones based on landslides disaster.

2. Method

The analytical approach used an approach to *the Power Sim* analysis tool. The types of digital data used i.e: 1) Landsat images OLI (*Operational Land Imager*) 8 2017 and Landsat images ETM+ (*Enhanced Thematic Mapper Plus*) 1997 and 2007; 2) Map of Indonesian Earth (RBI) sheets 6444 - 6447 scales 1:100,000 in 2008, 3) Map of Padang City Spatial Plan (RTRW) 2010-2030; 4) Map of Padang City Soil; 5) Map of Padang City Geomorphology, (6) Map of Padang City Slope; 7) Map of Padang City Geological; and 8) Data and map of Padang City rainfall. Analysis methods of land stability natural ability for prevention of landslide are done through a spatial approach with the model simulation of MAFF–Japan [11] [5], i.e with the formula:

$$\mathbf{KL = P + 3\,(LU) + 2\,(S) + 2\,(ST) + G + LF}$$

Where:

KL : land stability
P : rainfall
LU : land use
S : slope
ST : soil
G : geology
LF : landform

Model simulation results are correlated spatially with land suitability maps to obtain sustainable spatial planning zones in Padang city based on landslide disaster. Analysis of overlay the land planning maps with land use maps is to identify the distribution of land stability for spatial planning in Padang City, i.e by division [10] [12] [13] [14] [15] in modification.

Zone A: the planning zone for the development of urban spatial with land characteristics *suitable* for sustainable spatial planning allocation based on landslide disasters with *low* categories. Zone A is divided into:

Zone A1: the zone for sustainable spatial planning in Zone A has been utilized.

Zone A2: the zone for sustainable spatial planning in Zone A which has not been utilized.

Zone B: the planning zone for the development of urban spatial with land characteristics *suitable* for sustainable spatial planning allocation based on landslide disasters with *medium* categories. Zone B is divided into:

Zone B1: the zone for sustainable spatial planning in Zone B has been utilized.

Zone B2: the zone for sustainable spatial planning in Zone B which has not been utilized.

Zone C: the planning zone for the development of urban spatial with land characteristics *suitable* for sustainable spatial planning allocation based on landslide disasters with *medium - very high* categories. Zone C is divided into:

Zone C1: the zone is *not suitable* for sustainable spatial planning with the level of landslide disasters for *medium* categories in Zone C has been utilized.

Zona C2: the zone is *not suitable* for sustainable spatial planning with the level of landslide disasters for *high* categories in Zone C has been utilized.

Zone C3: the zone is *not suitable* for sustainable spatial planning with the level of landslide disasters for *very high* categories in Zone C which has not been utilized.

Zone C4: the zone C without spatial planning utilization.

3. Result and Discussion

Based on the results of the implementation of the model of land stability analysis in prevention landslides in Padang City in 2017 (Fig 1), it is known that there are 4 zones of land stability in its function of preventing landslides, i.e: 1) *high* land stability zones (18.613 Ha) with very stable soil conditions so the region is safe from landslide disasters, including the sub-districts of Padang Timur, Padang Utara, Padang Barat, Nanggalo, Koto Tangah in the west part, Kuranji in the west part, Lubuk Begalung in the north part, Bungus Teluk Kabung in the west part; 2) *medium* land stability zones (15.256 Ha) with less stable soil conditions so that landslides have a chance to occur once a year in regions with slopes > 15 %, covering the sub-district of Koto Tangah in the centre part, Kuranji in the centre part, Pauh in the west part, Lubuk Kilangan in west and east part, Padang Timur in the east part, and Bungus Teluk Kabung in the centre part; 3) *low* land stability zones (27.614 ha) with unstable soil conditions so landslides have the potential to occur between 1-2 years, include the sub-distict of Koto Tangah in the north part, Kuranji in the east part, Pauh in the north part, Lubuk Kilangan in the east part, Padang Selatan in the south part, and Bungus Teluk Kabung in the east part; and 4) *very low* land stability zones (7.633 ha) with soil conditions experiencing frequent landslides due to long landslide and new landslides that are still active due to high rainfall and strong erosion, so that the chance of landslides > 2 times in 5 years, includes the sub-district of Koto Tangah in the east part, Kuranji in the north part, Pauh in the east part, and Lubuk Begalung in the west part.

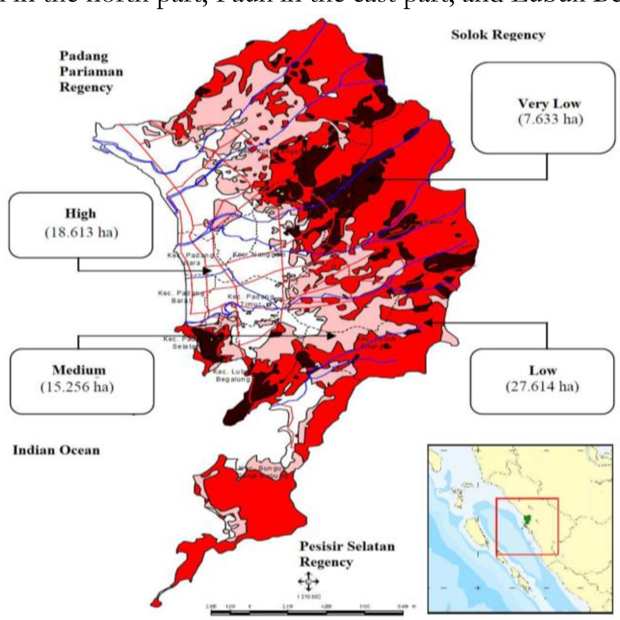

Figure 1. Map of land stability zones in Padang city in preventing landslide disaster.

Based on the analysis of Landsat images OLI 8 2017, and Landsat images ETM+ 7 1997, 2007, the regions with *low* land stability experienced the growth of land for built-up space, especially for settlements and urban infrastructure which continues to grow from 1997 until the year 2017 in Padang City. In 1997, the area of land built-up in the region of *high* land stability is 4.720 Ha, in 1995 increased become 6.945 ha, and the year 2017 continues to increase to 9.062 Ha (Fig 2).

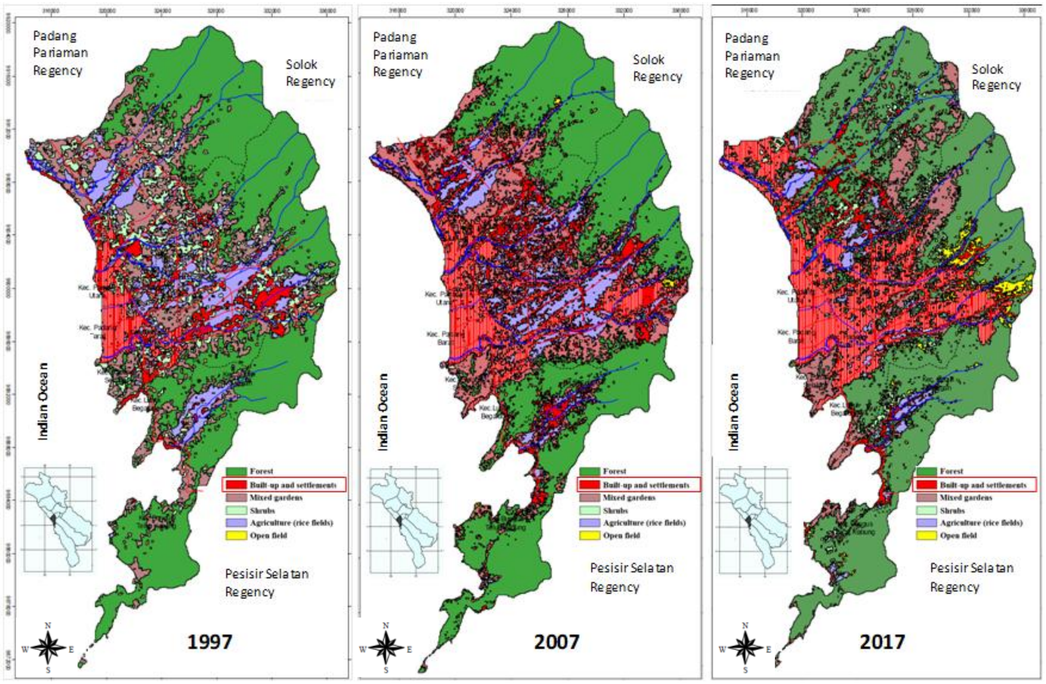

Figure 2. Map of land use change in 1997, 2007 and 2017 in Padang City.

The land was built-up in the region of *medium* land stability in 1997 was 874 Ha, in 2007 it increased to 2.085 Ha, and in 2017 increased to 2.894 Ha. In 1997 the area of land built-up in the region of *low* land stability is 714 Ha, in 2007 increased to 2.125 Ha, and the year 2017 continues to increase to 2.895 Ha. Whereas the land built-up in the region of very low land stability in 1997 was 248 Ha, in 2007 it increased to 930 ha, and in 2017 continues to increase to 1.757 Ha. [5] [16] adds the increase in land area was built-up in the regions with *low* and *very low* land stability in Padang City, cause by weak government control in controlling urban spatial policy (RTRW) in Padang City.

The results of land stability analysis with land suitability level in 3 zone regions, i.e: 1) Zone A is the region that is suitable to be a built-up land with high land stability; 2) Zone B is the region that is suitable to be a built-up land with medium land stability; and 3) zone C ia the region that is *not suitable* for built-up land (Fig 3[a]).

The area of land that has been built-up in zone A (A1) is 9.062 Ha and the total area of zone A is 18.613 Ha, so that zone A (A2) that can still be developed for the built-up land is 9.551 Ha. The area of land that has been built-up in zone B (B1) is 2.080.58 ha and the total area of zone B is 11.004 Ha, so that zone B (B2) that can still be developed for the built-up land with several actions to increase land stability in landslide prevention is 8.923.42 Ha. Whereas zone C that has been built-up land is 5.465, 42 Ha. The characteristics of zone C that are *not suitable* as a built-up land and potentially large enough for landslides, then all development in zone C (5,462.42 Ha) needs to be relocated gradually to zone A or zone B. Directives to improve land stability for an attempt landslide prevention efforts in Padang City can be seen in Table 1 dan Fig 3[b] below.

Table 2. Spatial planning and directives for enhancement of land stability in landslide prevention efforts.

Zone		area (Ha)	directives of spatial planning	directives for enhancement of land stability in landslide prevention efforts
A	**A1**	18.613	Construction of settlements and urban infrastructure	-
		9.062	Has been used	-
	A2	9.551	Development recommendations	1. Region supervision 2. Control of region utilization
B	**B1**	11.004	Construction of settlements and urban infrastructure is limited	-
		2,080.58	Has been used	1. Region supervision 2. Control of region utilization
	B2	8,923.42	Conditional development recommendations	1. Geological analysis and slope stability 2. Technical for engineering minimize slope slopes 3. Applying *vegetative* techniques 4. *Terraces* 5. The tight drainage system
C	**C1**	39.499	Protected forest	-
		813.42	Has been used for the construction of settlements	Relocation
	C2	2.895	Has been used for the construction of settlements	Relocation
	C3	1.757	Has been used for the construction of settlements	Relocation
	C4	34,033.58	Protected forest	Strict supervision and control of the government

Source: Results of Research Data Analysis (2017).

Information:

A1, zone A which has been used for development

A2, zone A which has not been used for development

B1, zone B which has been used for development

B2, zone B which has not been used for development

C1, zone C (*not suitable*, moderate landslide) has been used for development

C2, zone C (*not suitable*, high landslide) has been used for development

C3, zone C (*not suitable*, *very high* landslide) has been used for development

C4, zone C (*not suitable*, moderate to *very high* landslide) has not been used for development.

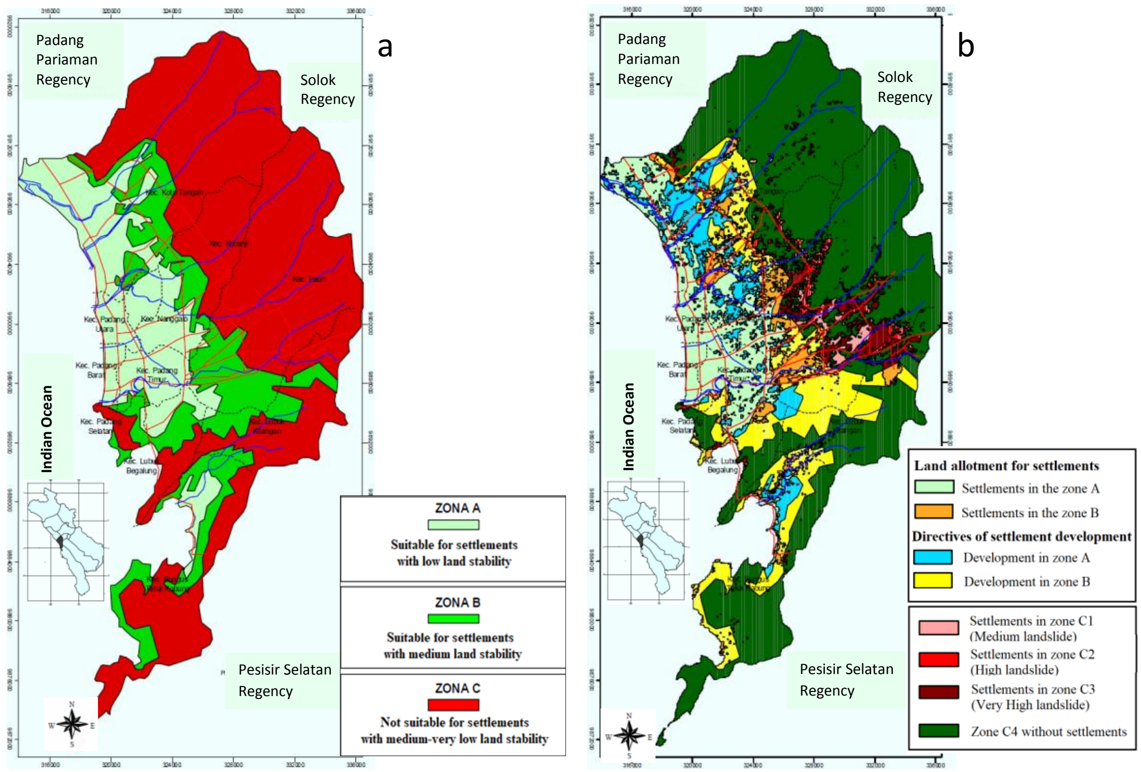

Figure 3. a Map of the land stability with level of land suitability; and b) City Space Allocation Zone Based on Ecological Sustainability of Land Stability for Landslide Prevention.

Zone A is required to supervise the region and control the utilization of the region used for development. The directives of increasing of land stability in zone B is also more focused in terms of region supervision and control of the utilization of the area used for development. [18] [19] [20] adds, besides that it needs to be done geological analysis and slope stability, the technique of engineering to minimize slope, with apply vegetative techniques, terracing, and proper drainage systems. Directives for enhancement of land stability in zone C are for protected forests and lands that have been used for development must be relocated because they are *not suitable* with the spatial planning for settlements development and infrastructure in Padang City.

3. Conclusion

Model of land stability for the spatial planning in Padang City is a positive linear type, where happen an increase in land area that is used especially for built-up lands (settlement) from 1997, 2007, until 2017, both at landslide disaster levels (*low, medium, high* and *very high*). Where the development of land area built-up on low landslide disaster levels is 4.720 Ha (1997) increased to 6.945 Ha (2007) and again increased to 9.062 Ha (2017) with an average acceleration of change the land stability area for land of built (settlement) at a *low* landslide disaster levels is 217.10 Ha/year. The factors that influence the change of land use to built-up land in Padang City are quite varied and varied in each land use, both in the range of 1997-2007, and in the range of 2007-2017. Factor that consistently affect changes in all land use to were built-up land is the period of 1997-2007. The policy priority for the spatial planning in landslide disaster regions in Padang City is prioritized on: 1) prevent of settlement development in regions that are not intended for settlements, especially in the zone of *high* landslide disaster and *very high* landslide disaster; 2) arrange the level zones of landslide disaster to develop early warning systems; 3) do empowering to landowners society who carry out agricultural activities in the landslide disaster zones for *high* and *very high* categories;

4) arrange of land use zones for spatial planning for the built-up land (settlement) based on landslide disaster levels; and 5) relocated society of gradually and continuous on the society living in the regions with landslide disaster levels of high and *very high* to regions that destined for settlements.

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