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Dynamic Model of Land Use Change in Landslide Hazard Zones in Tanah Datar District, West Sumatra

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Abstract

Population growth has an impact on land resource needs, pressure on land use will have an impact on environmental degradation. As an effort to reduce pressure, policy efforts in land use are needed. This study aims to develop dynamic models in land use and develop land use policy direction. The method used in dynamic modeling uses system analysis and land change policy direction using ISM analysis. In dynamic modeling, land use change uses three scenarios, namely: optimistic scenario, murder scenario, and pessimistic scenario. In determining the direction of the policy involving all stakeholders as many as 15 experts. The results of dynamic model analysis show that forest area changes from time to time of 1.6 percent per year. Changes in forest areas will have an impact on increasing environmental disasters. As an effort to save the environment, there is a need for law enforcement and strict sanctions against perpetrators of forest area destruction.

Keywords: Dynamic model, Landslide, Hazard

Introduction

Landslides are a natural phenomenon that is influenced by many factors, uncontrolled land use can cause landslides (Hermon, 2009; Flentje and Chowdhury, 2016; Oktorie, 2017). In addition, the high intensity of rainfall causes the soil cavity to be filled with water, and forms a sloping area (Hermon, 2001; Mai and Smith, 2018). Today, landslides often occur in various parts of Indonesia, and landslides have caused property losses and loss of life (Hermon, 2010; Hermon, 2011; Abuzeinab, 2017; Hermon, 2017). Landslide disasters have caused the destruction of settlements and other facilities and infrastructure, so that it is necessary to restructure the settlements of the population into areas without landslides. During recent decades, the study of land use change has become a prominent research topic (Hermon, 2011; Hermon, 2012; Hermon, 2014; Hermon, 2015; Hermon, 2016), as change in land use has been recognized as one of the most important factors of environmental modification in the world. The land use refers to objects that represent human activities that results in the production of goods and services for society (Hermon, 2016).

Uncontrolled population growth affects land use. Built area will increase, but the water catchment area will be even faster (Utoyo *et al*., 2001; Umar, 2016; Umar and Dewata, 2017; Kristian and Oktorie, 2018; Hermon *et al*., 2018). Unbalanced and supported by the amount of water absorbed in the soil will encourage landslides during the rainy season (Harun, 1992; Canuti *et al*., 2013; Hermon, 2014; Umar *et al*., 2017). The dynamics of land use change for settlements are influenced by human movements in building settlements and the movement of regional functions, such as education, industry, trade, etc (Kustiawan, 1997; Virdin, 2001; Syahrin 2003; Suryani and Marisa, 2005; Martono *et al*., 2015; Oktorie, 2018). Furthermore, the rapid development will lead to changes in land use patterns, where built space increasingly dominates and urges natural spaces to change function. In addition, and explained that changes in land use patterns resulted in fluctuations in the carrying capacity of land resources, resulting in landslides (Sitorus, 2005; Xiao *et al*.,

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2006; Mendoza *et al*., 2011; Hermon *et al*., 2019). Land use change has been recognized throughout the worldwide as one of the most important factors influencing the occurrence of landslides hazard around the world. Kaur *et al*., (2004) and Pribadi *et al*., (2006) explain that landslides are essentially caused by the inability of the soil to withstand loads above it because the soil has undergone degradation of soil properties.

Tanah Datar District has experienced an increase in landslides from both frequency and area affected in the period 2000-2017 (Glade, 2003). According to BPBD (2017); Huang and Zhao (2018), landslides can cause serious casualties dan severe damage to property. Furthermore,[22], explained the death toll caused by landslides worldwide is large. Disaster mitigation that can be done to minimize the impact of risk by determining the area of landslide hazard. Tanah Datar District based on physical characteristics has areas that are very prone to landslides, including: a) morphologically, around 55 percent of the area is relatively steep (<27%); b) around 70 percent of the Limapuluh Kota District area primary forest area is converted into a secondary forest area; c) increasing rainfall intensity in the upper watershed area; and d) the development of the developed area. The growth of world population is currently increasing every year and requires a shorter period of time. The faster the growth of the world's population has an impact on increasing the need for land, especially for the development of residential areas. Limitations of the earth's surface space to support land needs for settlements have an impact on the use of land that is not in accordance with its designation. Tanah Datar District has a population growth rate of around 1.3 percent per year. High population growth increases the need for land for residential areas. While the physical characteristics of the Tanah Datar District area have many limiting factors to be used for residential areas, namely: a) relatively steep morphology, b) around 70 percent are primary forest areas, and c) are hazard to landslides and volcanic eruptions .

Method

The type of data used in this study is categorized into two types, namely primary data and secondary data. Primary data is generated from measurements and collection from the field, while secondary data is obtained from official documents, information and records from various relevant agencies. According to [13,3,14] stated that some map needs in the dynamic model of land use in landslide hazard zone research are land use sourced from Landsat 7+ ETM imagery in 2010 and Landsat 8+ ETM imagery in 2017. When dynamic systems there is often a need to use assumption because; data may not exist for variables and we don’t have empirical data about the future [23]. In the study of dynamic models of land use in the landslide hazard area a comparative analysis of land use was carried out with different interpretations of the time. The results of interpretation of changes in land use are analyzed using dynamic system approach. In the dynamic system approach there are several stages, including: needs analysis, problem identification, problem formulation, system identification, validation, model supplementation, and model evaluation.

To determine the direction of the policy using the Interpretative Structural Modeling (ISM) method. ISM is an established qualitative tool which can be applied in various disciplines [24]. The ISM method is effective enough to structure complex issues because it can be used to define and clarify issues, assess impacts and identify relationships between policies. Broadly speaking, the stages of the ISM method are as follows:

a) Decomposition of each element into several sub elements.
b) Determination of the contextual relationship between sub-elements in each element that shows pairwise comparisons there / no contextual relationships are used by expert opinions.
c) Structural Self Interaction Matrix (SSIM) using symbols V, A, X and O.
d) Making the Reachability Matrix (RM) table, replacing the symbols V, A, X and O with numbers 1 or 0.
e) Perform calculations based on transivity rules where the SSIM matrix is corrected until a closed matrix occurs.
f) Perform sub element level on each element according to vertical or horizontal levels. Preparation of the Power Dependence Driver (DPD) matrix for each sub element. Element classification is divided into four, including:
   1) Quadrant I: Autonomous consists of sub elements that have driver power (DP) value ≤ 0.5 X and dependence value (D) ≤ 0.5 X. Where X is the number of sub elements in each element. Sub elements in quadrant I are generally not related to the system.

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2) Quadrant II: Dependent consists of sub elements which have a power driver (DP) value ≤ 0.5 X and dependence value (D) ≥ 0.5 X. Where X is the number of sub elements in each element. Sub elements in quadrant II are sub elements that depend on elements in quadrant III.
3) Quadrant III: Link (Linkage) consists of sub elements that have driver power (DP) value ≥ 0.5 X and dependence value (D) ≥ 0.5 X. Where X is the number of sub elements in each element. Sub elements that enter the third quadrant need to be studied carefully, because every action on one sub element will affect the other sub elements in quadrants II and IV.
4) Quadrant IV: Independent consists of sub elements that have a power driver (DP) value ≥ 0.5 X and dependence value (D) ≤ 0.5 X. Where X is the number of sub elements in each element.

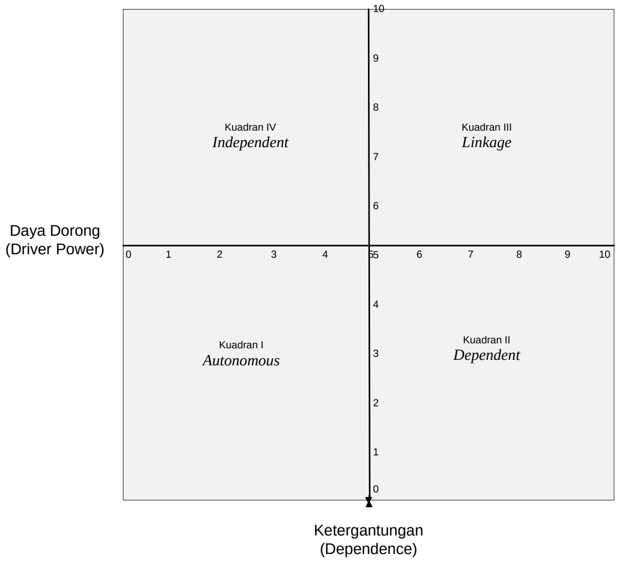

Figure 1. Driver Power and Dependence Matrix

Result and Discussion

Tanah Datar District has around 45 percent of the landslide hazard area. High population growth (1,6 percent) causes the use of land that is not suitable to be used or developed for settlements [3]. The study area has the characteristics of the area around 70 percent of the morphology of the hills. Based on the geology of the research area, it is an area of Bukit Barisan and Semangko faults.

Table 1. Land Use Change for The Period 2010-2017 in Tanah Datar District

Land Use	Forest	Farm	Intercropping	Sattlement	Paddy	Swamp	Clearing	Total (ha)
Forest	**75,864**	1	0	0	0	0	0	75,865
Farm	0	**12,678**	7,717	1,507	9,004	0	62	30,968
Intercropping	0	10,201	**589**	273	902	21	8	11,994
Settlement	0	0	0	**5,371**	0	0	0	5,371
Paddy	0	1,022	966	294	**6,406**	0	0	8,688
Swamp	13	71	0	11	111	**182**	0	388
Clearing	0	0	0	0	0	0	**0**	0
Total (ha)	75,877	23,973	9,272	7,456	16,423	203	70	

Source : Analysis (2018)

In Tanah Datar District the period of 2010-2018 has experienced changes in land use.In 2010 around 70 percent were forest areas, but this region experienced a reduction of 0.4 percent/year. Although the changes have no significant effect on landslides, this condition will be a threat to the future.

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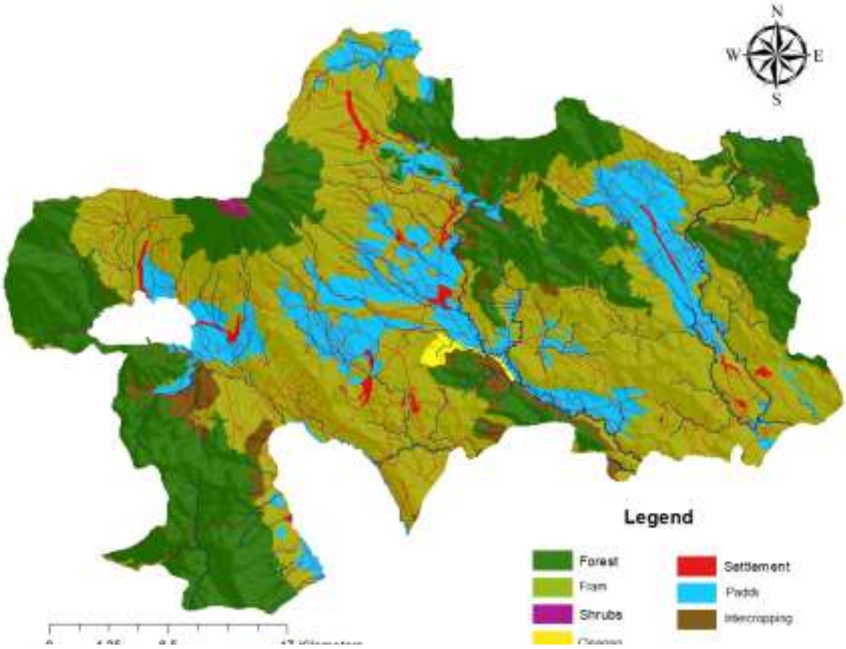

Figure 2 . Land use in Tanah Datar District (2010)

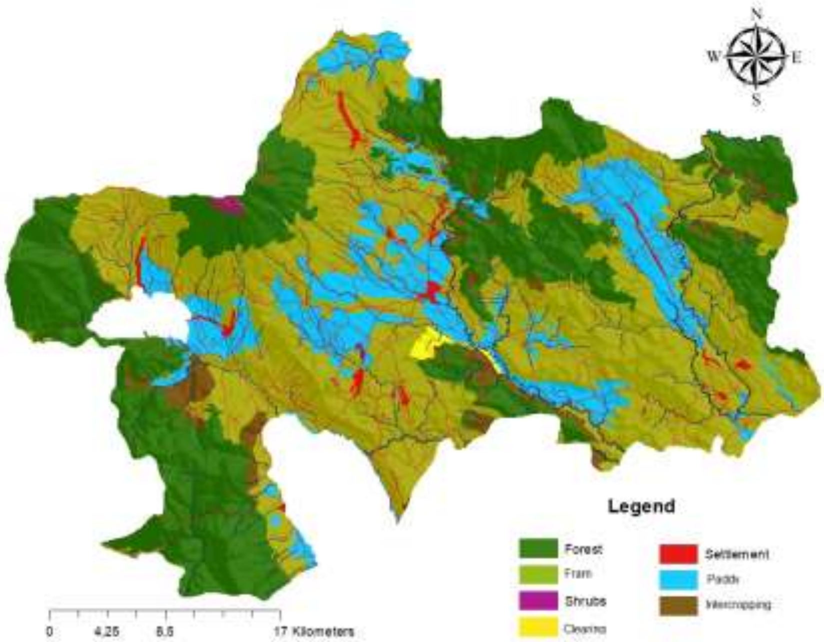

Figure 3. Land Use in Tanah Datar District (2017)

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The results of problem identification have four causal relationships, including: population growth, land use change, land needs, and policies. Population growth in the study area increased about 1 percent/year, and this problem caused land change about 1,4 percent/ year.

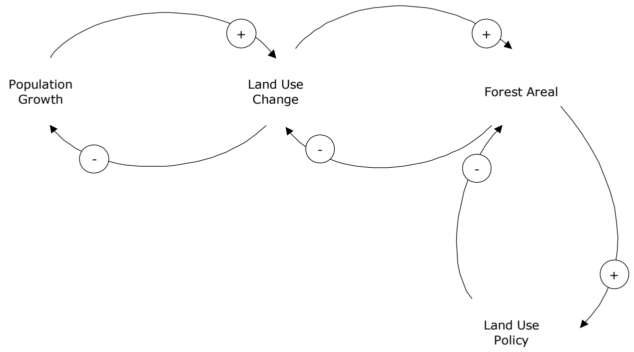

Figure 4. Causal Loop Dynamic Model Land Use Change in Tanah Datar District

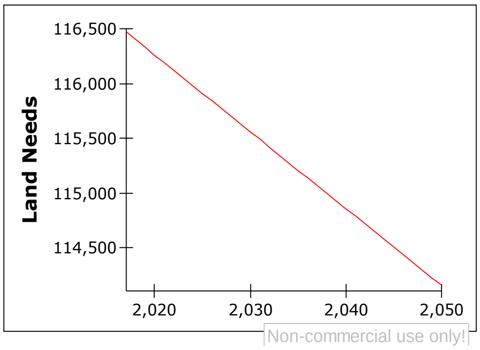

Figure 5. Graph Land Needs Impac Population Growth in Tanah Datar District

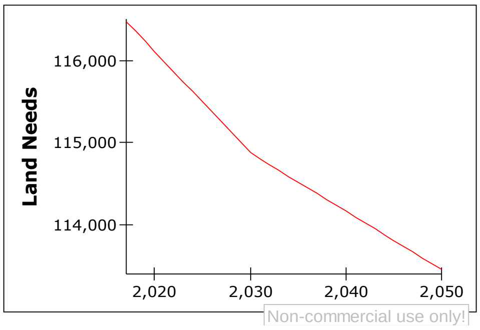

Figure 6. Graph of Land Needs for Government Policy Scenarios in Reducing Population Growth

The results of an analysis of 10 sub elements for the direction of spatial policy in Tanah Datar Regency indicate that two elements belong to the independent category (quadrant IV), and eight sub-elements are in quadrant III. Figure 8 presents that sub-elements of E7 consistency in the implementation of spatial plans and sub elements of E8 law enforcement in spatial violations have a high thrust (drive power). In addition, both sub elements have a low dependency value on other sub elements.

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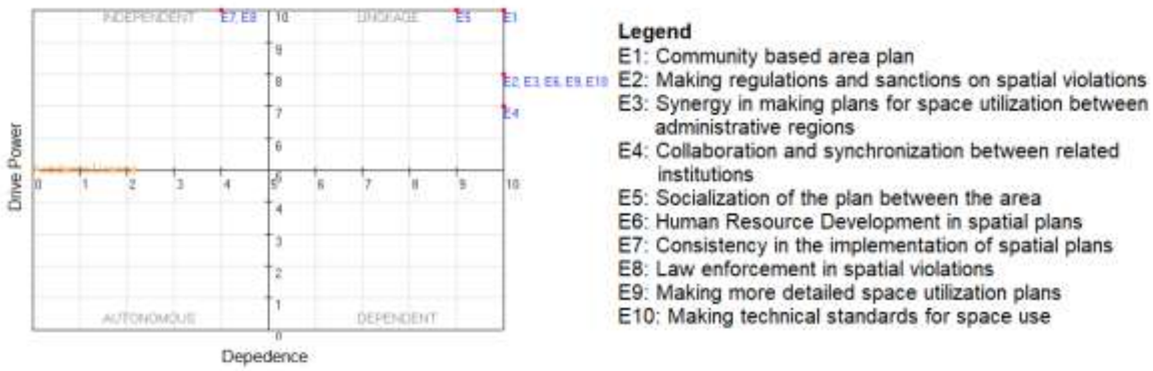

Figure 7. Quadrant Drive Power and Dependence

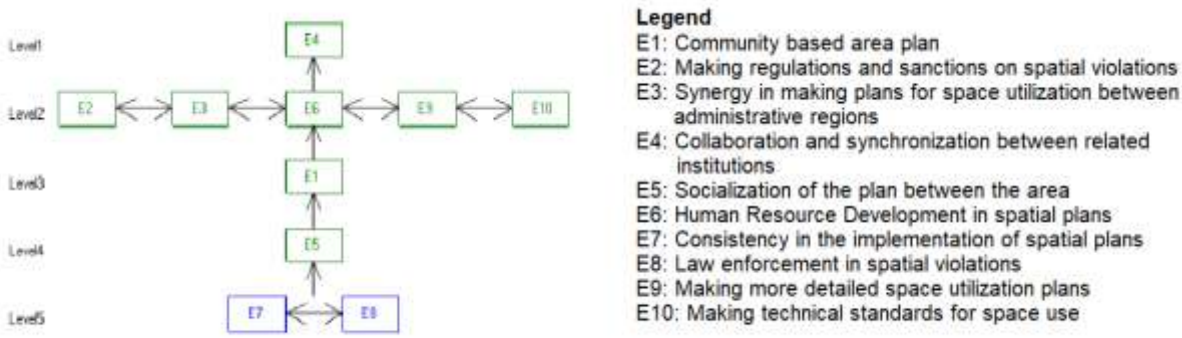

Figure 8. Land Use Policy Structure in Tanah Datar District

Figure 7 presents the implementation structure of the Tanah Datar District space utilization plan, there are five levels. At the highest level (level 5) there are two sub elements are sub elements of E7 consistency in the implementation of spatial plans and sub elements of E8 law enforcement in spatial violations. As a sub element of the summit, the two sub elements become the main policy in the direction of the implementation of spatial planning in Tanah Datar District.

Conclusion

The population growth of around 1.6 percent in Tanah Tanah District has an impact on land use. Settlement areas have increased every year, thus reducing water catchment areas. The implementation structure of the Tanah Datar District space utilization plan, there are five levels. And than the highest level there are two sub elements are sub elements of E7 consistency in the implementation of spatial plans and sub elements of E8 law enforcement in spatial violations.

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