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# Dynamic model of forest area on flood zone of Padang City, West Sumatra Province-Indonesia

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# Dynamic model of forest area on flood zone of Padang City, West Sumatra Province-Indonesia

**Indang Dewata[1], Iswandi U[2]**
[1]Departement of Environmental Science, State University of Padang
[2]Department of Geography, Faculty of Social Science, State University of Padang

Email : i_dewata@yahoo.com

**Abstract**. The flood disaster has caused many harm to human life, and the change of watershed characteristic is one of the factors causing the flood disaster. The increase of deforestation due to the increase of water causes the occurrence of flood disaster in the rainy season. The research objective was to develop a dynamic model of forest on flood hazard zone using powersim 10.1. In model development, there are three scenarios: optimistic, moderate, and pessimistic. The study shows that in Padang there are about 13 percent of high flood hazard zones. Deforestation of 4.5 percent/year is one cause that may increased the flooding intensity in Padang. There will be 14 percent of total forest area when management policy of forest absence in 2050.

## 1. Introduction

Indonesia is a wet tropical climate country with relatively high rainfall intensity throughout the year. The high intensity of rainfall caused flood disaster in many regions in Indonesia [1]. The factors causing the flood that the high bulk factor or the decreasing factor of forest area in the upstream river [2]. Furthermore, changes in land use to built up area will increase the rate of surface water and reduced water absorption causing an increasingly wide area of flood risk [3-5].

That there are three factors causing the occurrence of flood disasters: meteorological factors, factors of watershed characteristics, and human factors. Meteorological factors that cause the occurrence of floods that rainfall intensity and distribution of rainfall. There is great opportunity of flood disaster in high rainfall intensity area. Other than that watershed characteristics including slope, altitude, landform, and soil type contribute to the occurrence of floods. Furthermore, human behavior is an important factor for the occurrence of flood disasters. Forest encroachment and land cover change into built up area is a driving factor for flood disaster [6].

The human factor is the big role in causing flood. Increasing deforestation and conversion of forest areas into other uses as well as improper in land use are factors causing the expansion of floods [5]. Mudelsee *et al*. (2003) explains that the impact of deforestation on climate change globally accelerate with hydrological cycle. With the acceleration of the hydrologic cycle resulted in the emergence of flood disasters [7].

Mitigation is a series of efforts and or actions to reduce disaster risk [8]. Measures to safeguard and preserve forest areas are one of the non-structural forms of flood mitigation [9,10]. Therefore, prediction and simulation of flood is needed to prevent the disaster. The research objective was to develop a dynamic model of forest on flood hazard zone using powersim 10.1.

## 2. Research Method

This research was conducted in Padang City, West Sumatera Province of Indonesia. Geographically, the research area is located on $100^0$ 05' 05"-$100^0$ 34' 09" E and $0^0$ 44' 00"-$1^0$ 08' 35" S with research area of 69.496 ha. The location of the study is presented in Figure 1.

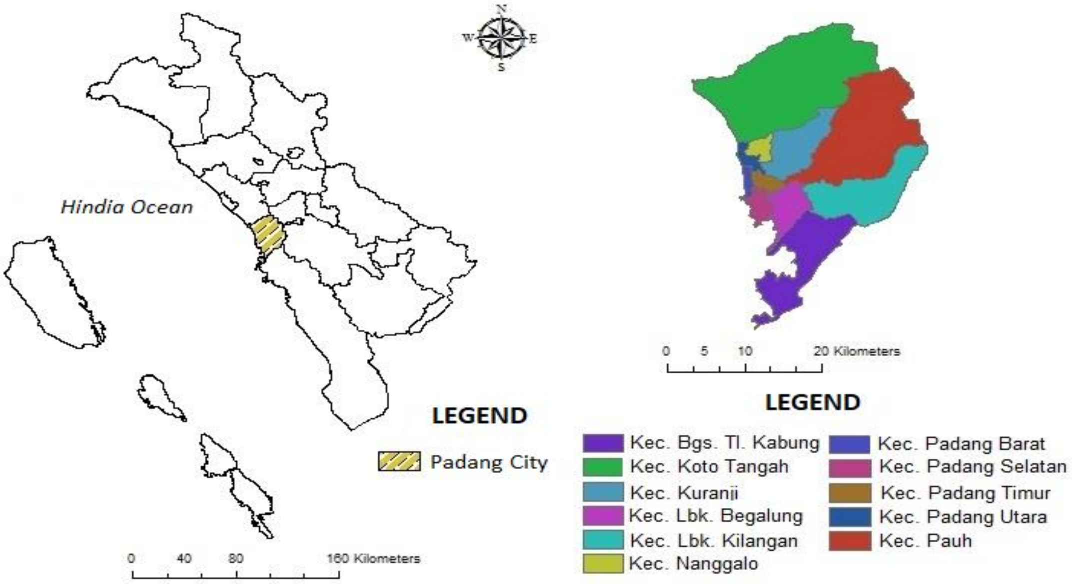


**Figure 1**. Location of research.

To determine the flood-prone zones, seven indicators are used: soil type, slope, elevation, rainfall, landform, land use, and flood frequency. The land use map is derived from 1: 250,000 scale. Slope maps are generated from the 1: 50,000 scale of Earth Map (RBI). The elevation maps are generated from the Digital Elevation Model (DEM) using the Shuttle Radar Topography Mission (SRTM) image. The land cover of Padang City resulted from Landsat ETM 7+ image interpretation in 2016 and soil type. The rainfall map is produced from interpolation of rainfall data from 1975-2012 period. Flood fraction map resulted from data analysis of Regional Disaster Management Agency (BPBD) of Padang City. Land use maps result from Landsat ETM 7+ image interpretation in 2016.

The indicator of determination of flood-prone zones used is presented in Table 1. For making the value of the flood prone interval class using equation 1. The highest total score is obtained at 3,661, while the lowest total score is obtained at 543. The desired interval class is three classes i.e. low vulnerability zone, moderately prone zones, and high-risk zones. There are many indicator with different weight, sub-indicator as specific parameters of indicator, ratings and score is important to built the model based on previous study (mention in source of table).

Here is equation 1.

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

Information:

I = large distance interval
c = highest score
b = lowest score
k = number of classes to be selected

**Table 1**. Flood zone prone indicator.

| Indicator/weight | Sub. Indicator | Ratings | Score |
|---|---|---|---|
| Type of soil/10,1 | Aluvial | 24.7 | 2495 |
| | Andosol | 11.5 | 116.2 |
| | Organosol | 36.6 | 369.7 |
| | Regosol | 7.8 | 78.8 |
| | Latosol | 7,6 | 76.8 |
| | Complexs podsolik red yellow | 12.1 | 122.2 |
| Slope (%)/20,6 | 0-9 | 53.5 | 1,102.1 |
| | 9 -16 | 25.9 | 533.5 |
| | 16-27 | 13.1 | 269.9 |
| | >27 | 7.5 | 154.5 |
| Form of land/15,9 | Aluvial plans | 8.3 | 132.0 |
| | Aluvial fan | 9.8 | 155.8 |
| | Plans aluvial beach | 9.5 | 151.1 |
| | Beting gisik | 12.9 | 205.1 |
| | Depresion between Beting | 19.6 | 311.6 |
| | Vulcanic mountain complexs | 3.1 | 49.3 |
| | Vulcanic hills | 3.0 | 47.7 |
| | Rear swamp | 21.2 | 337.1 |
| | Karst hills | 3.1 | 49.3 |
| | Natural embankment | 9.5 | 151.1 |
| Rainfall(mm/years) /11,3 | > 5000 | 37 | 418.1 |
| | 4500-5000 | 24.6 | 278.0 |
| | 4000-4500 | 16.2 | 183.1 |
| | 3500-4000 | 9.9 | 111.9 |
| | 3000-3500 | 7.1 | 80.2 |
| | 2500-3000 | 5.2 | 58.8 |
| Elevation (mdpl)/24 | 0-10 | 38.5 | 924.0 |
| | 10-30 | 21.8 | 523.2 |
| | 30-50 | 14.4 | 345.6 |
| | 50-150 | 9.3 | 223.2 |
| | 150-450 | 6.6 | 158.4 |
| | 450-1000 | 5.3 | 127.2 |
| | > 1000 | 4.1 | 98.4 |
| Land use/10,7 | Settlement | 33.3 | 356.3 |
| | Rice fields | 21.7 | 232.2 |
| | Mixed garden | 8.9 | 95.2 |
| | Shurbs | 7.9 | 84.5 |
| | Empty land | 15.1 | 161.6 |
| | Forest | 4.8 | 51.4 |
| Frequency/7,4 | Always | 56.9 | 421.1 |
| | Often | 23.7 | 175.4 |
| | Rarely | 11.8 | 87.3 |
| | Without | 7.5 | 55.5 |

Source: Iswandi (2016), Iswandi *et al.* (2016), and Iswandi *et al.* (2017)

Using the equation 1 we get the interval of 1,039. The distribution of flood hazard interval classes can be seen in Table 2. Prone class divided into three category with different interval class and and prone index. The interval class described the value of model and will be have prone index for each values.

**Table 2**. Interval class of flood prone.

| Prone class | Interval class | Prone Index |
|---|---:|---|
| Lowest class | 543 – 1,582 | Lowest prone zone |
| Moderate class | 1,583 – 2,621 | Moderate prone zone |
| Highest class | 1.1.– 3,661 | Highest prone zone |

Source: Iswandi (2016)

Dynamic modeling that will be developed in the flood prone areas of upper watershed conservation area. That human behavior due to misuse of land, deforestation and development is a driving factor for floods [7,5,13]. The Landsat 1994, 2007 and 2016 image used for analysis the land use change. Based on the three images can be described the change of forest area that will be modeled in dynamic system. In dynamic modeling using software powersim 10.1. Figure 2 shows the causal loop and dynamic model structure of flood prone zones in Padang City. After all of the process and result well done, the three scenarios have to examine.

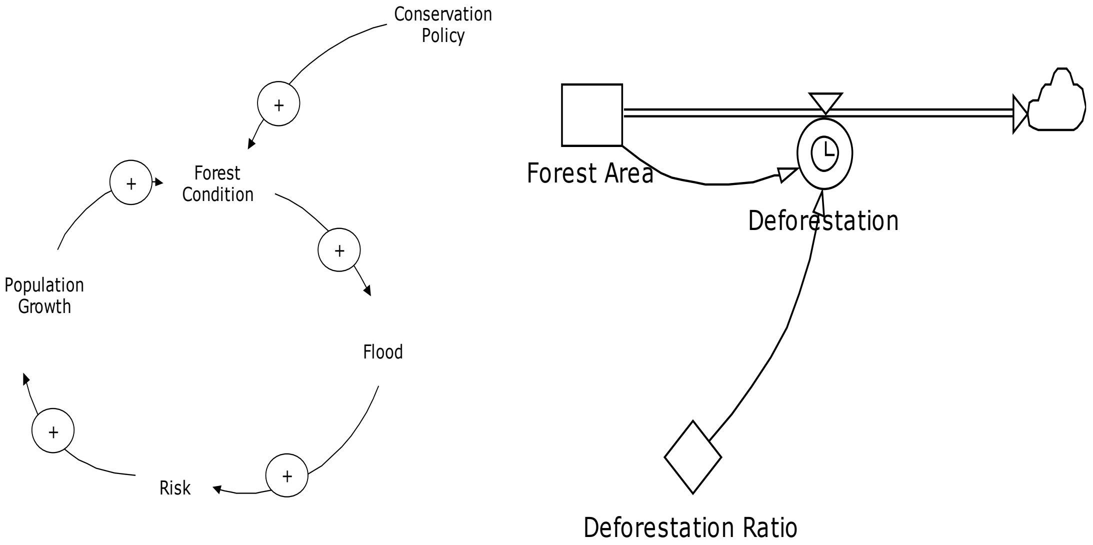


**Figure 2**. The relationship of causal loop (a), and model structure (b) flood prone areas.

## 3. Result

Padang city is the central government of West Sumatra Province. Geomorphologically the area is formed by three processes namely the fluvial origin, the process of volcanic origin, and the process of structural origin. The origin region of the fluvial process is a region with relatively flat slopes. In the research area based on the results of the zonation analysis the flood level showed that 13 percent were high vulnerable zones, 14 percent were moderately prone, and 73 percent were low-risk zones. Figure 3 presents the flood-prone zones in Padang City.

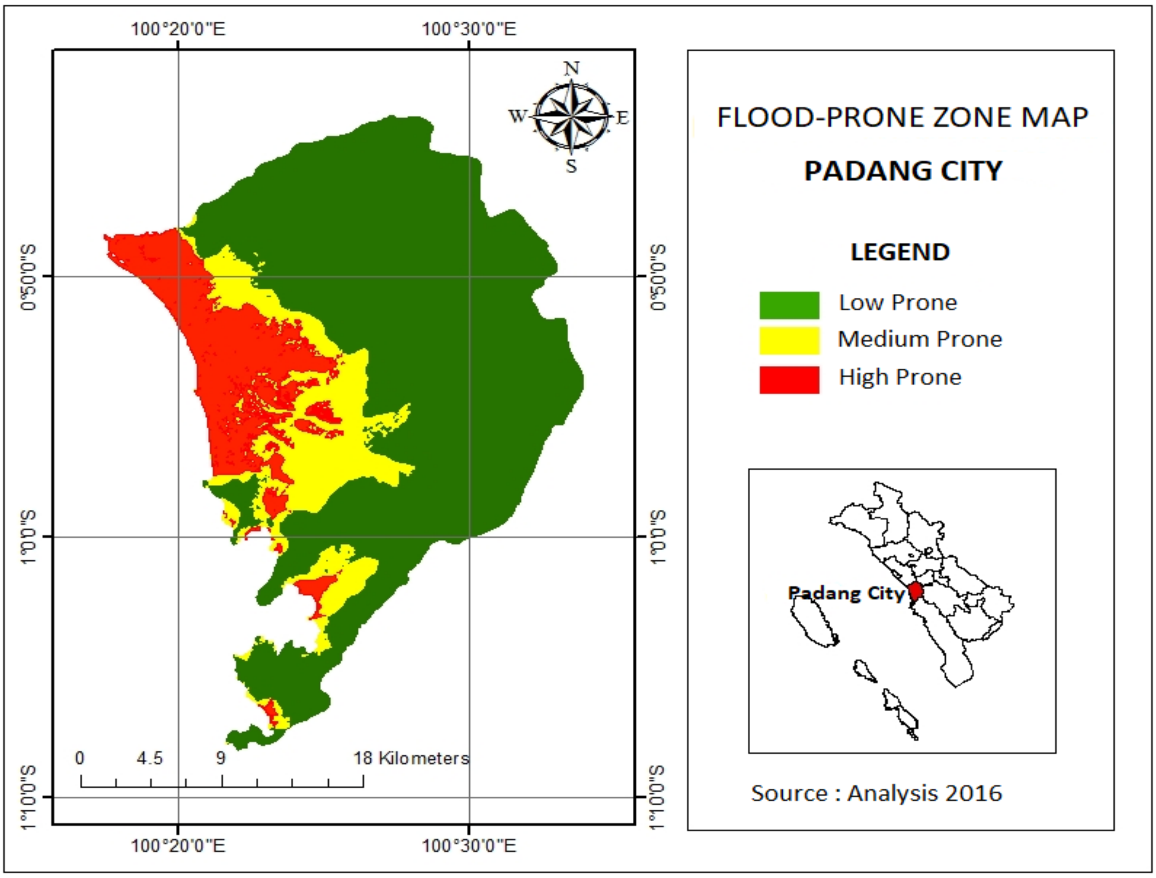
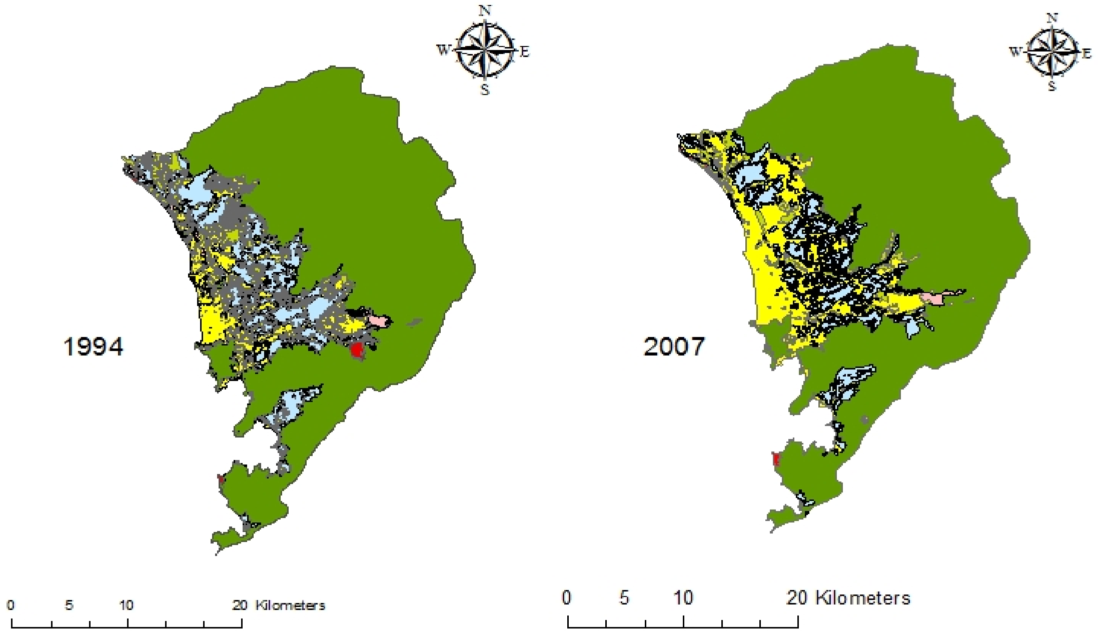


**Figure 3**. Flood-prone zone in Padang City.



(a)

(b)

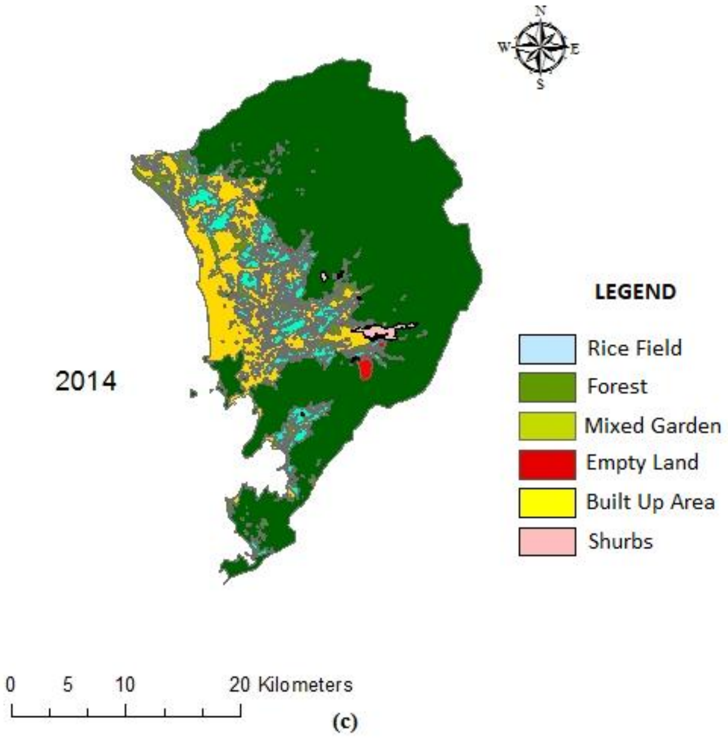


**Figure 4**. Land Use Change in Padang City.

Padang have four major rivers are Kandih steam, Airdingin steam, Kuranji steam, and Arau steam. The high intensity of rainfall in the upstream area caused the overflow of river water which resulted in the occurrence of flood disasters. Based on BPBD Padang City in the period 2000-2017 there was an increase and extent of flood disaster. Deforestation and conversion into bum land is considered as the causal factor of flood disaster in Padang City. That uncontrolled deforestation and land conversion into built up area will cause floods [4,5,14]. That forests have an important role in storing water during rain and preventing floods, it is necessary to maintain a minimum of 30 percent of the forest's upstream function [2].

**Table 3**. The dynamics of land use in Padang City.

| **Type of use** | **Large (ha)** | | |
|---|---|---|---|
| | **1994** | **2007** | **2016** |
| Settlement | 7.316,8 | 11.287,6 | 16.608,0 |
| Rice fields | 7.794,8 | 6.823,8 | 6.706,0 |
| Mixed garden | 3.589,1 | 1.506,1 | 1.214,7 |
| Bush | 938,6 | 479,2 | 424,1 |
| Forest | 49.392,9 | 48.976,8 | 44.139,4 |
| Empty land | 463,9 | 422,4 | 404,0 |
| Total | 69.496 | 69.496 | 69.496 |

Source : Citra *landsat ETM 7+* 1994, 2007, 2016

Table 3 presents land use in Padang City in 1994, 2007 and 2016 analyzed using Landsat ETM 7+ imagery. The period of 1994-2016 in Padang City has been a reduction of forest area of 5.253.5 ha, and annually forest area is reduced by 4.5 percent. Forest areas can be presented in dynamic modeling for periods up to 2050. Figure 5 shows that if the government does not intervene in controlling deforestation, then by 2050 it is estimated that the forest area will only be 9659 ha.

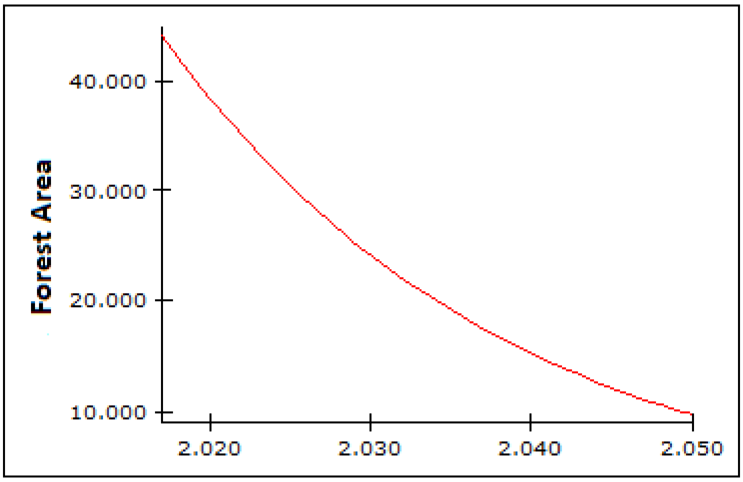


**Figure 5**. Forest area modeling without policy.

The importance of forest areas in the groundwater storage system in the rainy season will be impact on the disruption of the hydrological cycle [7]. That on the edge of the forest, the increase of number people affected destruction of forest area. Without strict supervision and law enforcement, the impact on deforestation by the forest community increases [13]. That to describe the future state can be explained by dynamic system modeling with three scenarios namely pessimistic, moderate, and optimistic [15,16].

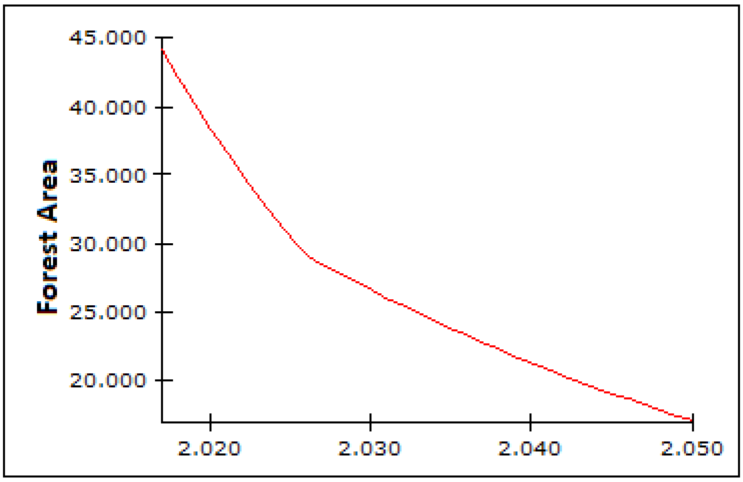


**Figure 6.** Pessimistic scenario of forest area modeling.

Under a pessimistic scenario that the rate of forest destruction can be reduced to half of the reality condition (2.3 percent) by 2050 forest area in the study area will remain 16,685 ha. Figure 6 presents a pessimistic scenario in reducing forest destruction.

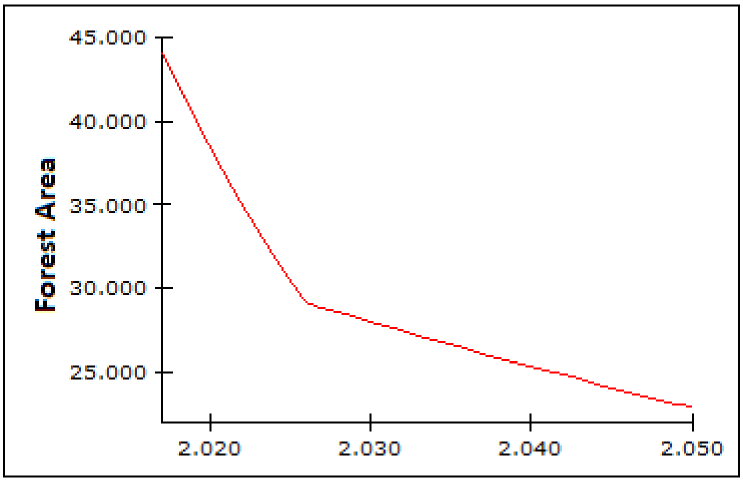


**Figure 7.** Moderate scenario of forest area modeling.

Moderate scenario with deforestation rate of 1 percent in 2050 forest area in Padang city will increase to 22,119 ha. Indicators of success in the moderate scenario include: implementation in law enforcement in forest encroachment, consistency in the utilization of spatial pattern, and implementation of synchronization of usage between government institutions.

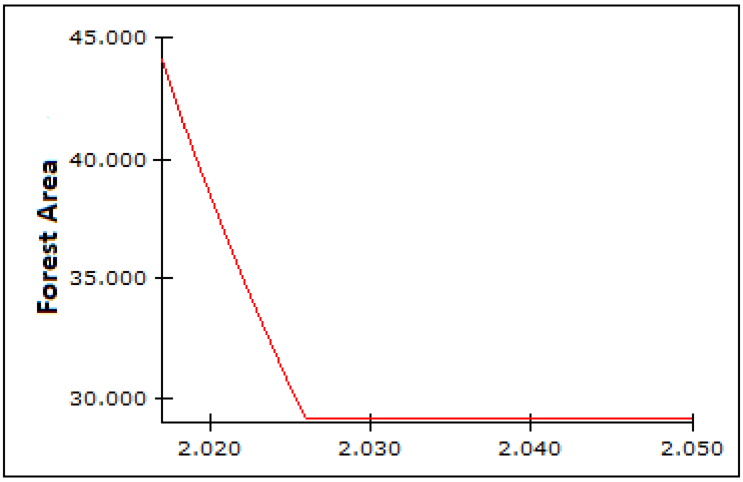


**Figure 8.** Optimistic scenario of forest area modeling.

Optimistic scenario with deforestation rate of 5 percent in 2050 forest area in Padang city will increase to 28,512 ha. Indicators of success in the optimistic scenario include: implementation in law enforcement in forest encroachment, consistency in the utilization of spatial pattern, and implementation of synchronization of usage between government institutions.

## 4. Conclusion

Padang City has about 13 percent of the area is very vulnerable (high vulnerability) to flood disaster. Approximately 50 % settlements built in the region is very prone to flooding. The model utilization success to present what will be happen to flood if there is deforestation. Deforestation is one of the factors causing flood disaster in Padang city, about 4.5 percent of forest area lost every year. In dynamic modeling is estimated in 2050 the forest area of Padang City is only 9659 ha remaining. It suggest that the regulation for sustainable environmental management should be apply well.

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