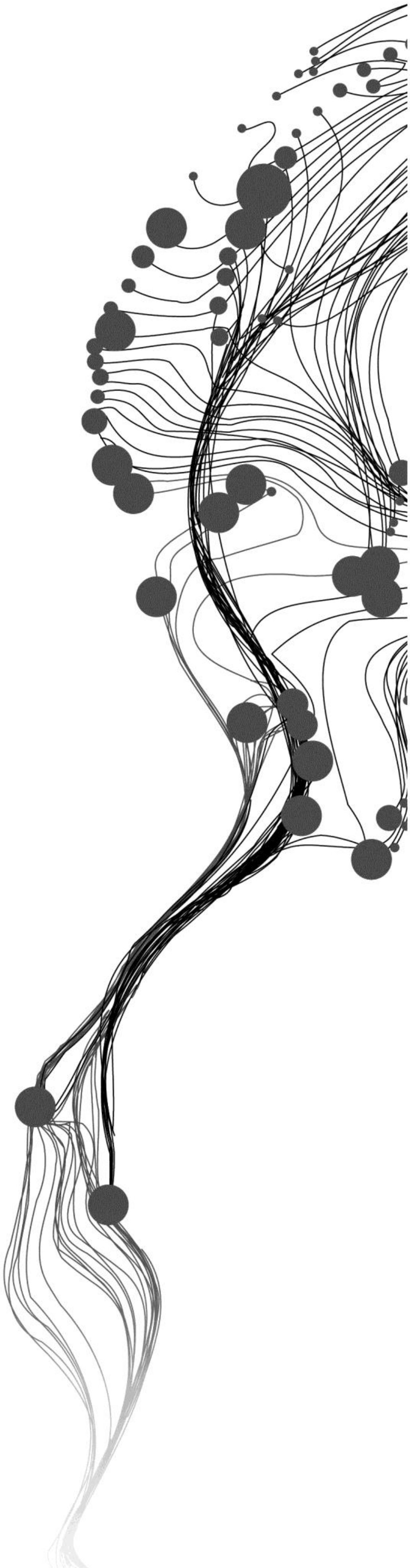
Modeling of Tropical Forest Conversion to Oil Palm Expansion Using Area Production Model

(A Case Study of Nyuatan Watershed, Indonesia)

Hidayah Hamzah
February, 2012

SUPERVISORS:
Drs. R.G. (Raymond) Nijmeijer
Dr. Y.A. (Yousif) Hussin



Modeling of Tropical Forest Conversion to Oil Palm Expansion Using Area Production Model

(A Case Study of Nyuatan Watershed, Indonesia)

HIDAYAH HAMZAH
Enschede, The Netherlands, February, 2012

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Natural Resources Management

SUPERVISORS:
Drs. R.G. (Raymond) Nijmeijer
Dr. Y.A. (Yousif) Hussin

THESIS ASSESSMENT BOARD:
Dr. (Alexey) Voinov (Chair)
Dr. J.F. (Joost) Duivenvoorden (External Examiner, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam)

Blessed is he who eats from his own sweat, rejoice from his own efforts,
and advanced from his own experiences
(Pramoedya Ananta Toer)

ABSTRACT

The development of oil palm plantation in Indonesia, particularly in Kalimantan, has been increasing dramatically and the areas assigned for oil palm plantations had increased by 900,000 hectares in the past 13 years. Modeling has been used frequently to determine where forest conversion occurs and; when and how much forest is being converted. The Area Production Model (APM) is one of the predictive models focusing on modelling forest conversion due to agriculture expansion. In this study the conversion of tropical forest conversion into agriculture land in which oil palm plantations are integrated is simulated for the Nyuatan watershed. The oil palm plantation has a concession area of more than 18,000 ha, which was established in 2010 and in 2011 was in the stage of growing oil palm seedling.

Based on the analysis of the land use maps periods of 2000, 2005 and 2009, the total amount of forest decreased with 17,416 ha leading to a deforestation rate of 1.23% per year. With the current trend and the establishment of oil palm plantation, the forest conversion in this area may still continue. The APM was used to simulate conversions for the period of 2000 – 2009 and the modeling outcome was compared with land use change map of 2000 – 2009. This validation resulted in a numerical accuracy of 86% and spatial accuracy of 65%. However, there is an overestimation in the prediction of location of deforested area. The overestimation by the model was influenced by factor maps which are access related maps such as slope, distance to roads, settlement and rivers. Furthermore, there are locations of observed deforestation not being predicted by APM simulation due to the forest conversion areas may be influenced by mining activities and activities from outside of the study area.

The scenarios developed are business as usual, moderate and sustainable scenarios. The scenarios used growth factors which follow the trend of population growth, GDP growth and agriculture trend on province level. Furthermore, the establishment of oil palm plantation in the study area will also influence the growth factors. The business as usual scenario assumed that the economy growth increase and the practices of agriculture expansion to forest are continuing. The moderate scenario assumed that the agriculture expansion was set to forest and scrub. While sustainable scenario aimed at prioritizing the expansion of agriculture to degraded land. The simulation by APM predicted that in 50 years the forest will decrease 129,524 hectares when trend that the forest is being converted to agriculture land continues. While the forest can be reduced by 78,536 ha if the agriculture land agriculture land was being prioritized to scrub.

The oil palm plantation is situated in an area that consists of 58% forest and 41% scrub. The results of APM simulations show that the prediction of forest conversion in 2040 for scenario moderate 78% is within the concession area. While for the business as usual scenario the prediction is 74% within the concession area and sustainable scenario 62% is within the concession area.

Keywords: area production model, spatial model, oil palm, agriculture expansion, East Kalimantan

ACKNOWLEDGEMENTS

Praise Allah SWT for the countless blessings and for leading me to the path where I am now.

Drs. Raymond Nijmeijer, this work will not be completed without your supervision. I thank for all the discussions, patience and guidance throughout the process of the research. I also would like to express my gratitude to Dr. Youssif Housin for his inputs and directions in this research.

I would like to send my gratitude to STUNED for giving me the chance to pursue study in The Netherlands.

I am thankful for Willem Niewenhuis for his guidance in ILWIS software. I am also grateful for the support from Dr. Michael Weir throughout the study. During the fieldwork Hunggul Yudono has given me learning experience and taught me how to interact with the local agencies, and I am thankful for his guidance and suggestions.

I would like to express my gratitude to Petrus Gunarso, Ph.d for the support in this research. Many thanks to the staff in Tropenbos Bogor for the assistance in spatial data and the staff in Tropenbos Balikpapan for the assistance during fieldwork. I also thank the staff in Forestry Agency for the assistance during the fieldwork, Bureau of Statistics and Estate Agency in Kutai Barat for the assistance in spatial data.

The support from my friends Rani, Fitri, Idham, Arie, Fesly, Tiur, Doddy, and Debi, thank you for the journey through thick and thin in Enschede. For my cluster mates Pema, Sajana, Fateme, Moon, Ameya, and all the NRM students batch 2010 thank you for your friendship.

Bang Bakti Siahaan, the so called my mentor, I would like to give my deepest gratitude for your wisdom and life learning experience throughout my journey in Aceh. My being in The Netherlands will not happen if not from your kind recommendation and I am thankful for that. To Dr. Matthew Linkie and Helimah Barnes, my gratitude for the kind letter of recommendation when I was applying for MSc course.

Lastly, I present this thesis to my family. For "Babeh" and "Bu I" who gives me strength, letting me catch my dreams and built me into who I am now and for my sisters who is always there for me.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

ADB	:	Asian Development Bank
APM	:	Area Production Model
ALOS	:	Advanced Land Observing Satellite
Badan Pusat Statistik	:	Statistics Agency
CPO	:	Crude Palm Oil
DEM	:	Digital Elevation Model
Dinas Perkebunan	:	Estate Agency
Dinas Kehutanan	:	Forestry Agency
EU	:	European Union
FAO	:	Food and Agriculture Organization of the United Nations
GDP	:	Gross Domestic Product
GHG	:	Green House Gas
GIS	:	Geographical Information System
ILWIS	:	Integrated Land and Water Information System
ITC	:	International Institute of Geo-Information and Earth Sciences
LUCC	:	Land use Cover Change
PRISM	:	Panchromatic Remote-sensing Instrument Stereo Mapping
RED	:	Reducing Emission from Deforestation
REDD	:	Reducing Emissions from Deforestation and forest Degradation
SRTM	:	Shuttle Radar Topography Mission
TCSSP	:	Tree Crops Smallholder Sector Project
UNFCC	:	United Nations Framework Convention on Climate Change
USA	:	United States of America
USDA	:	United States Department of Agriculture

1. INTRODUCTION

1.1. Forest conversion and oil palm expansion

In the last decade forest conversion rates have been alarming, reaching 13 million hectares per year (FAO, 2011). In 2010, the highest forest conversion rate occurred in South America reaching to 4 million ha/year, followed by Africa (3.4 million ha/year), Oceania including Australia (700,000 ha/year) and Asia (600,000 ha/year) (FAO, 2010) Furthermore, on country level the highest annual forest loss in the period 2000 – 2010 occurred in Brazil (2,642,000 ha/year), followed by Australia (562,000 ha/year) and Indonesia (498,000 ha/year) (FAO, 2010). According to the Food and Agriculture Organization of the United Nations (2010). Indonesia has lost more than 24 million hectares of forest from 1990 to 2010 (Figure 1.1).

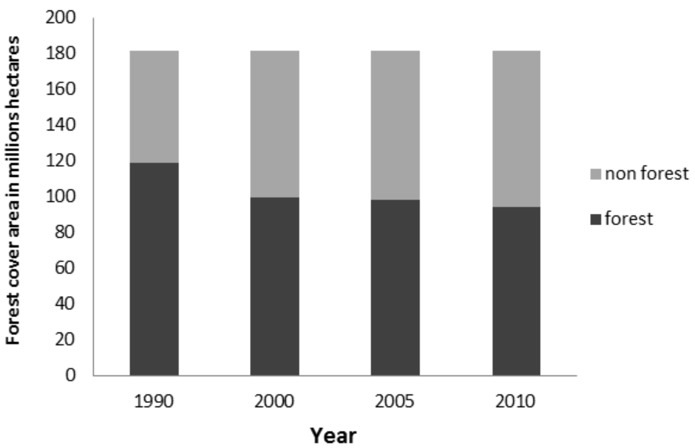


Figure 1.1 Forest cover state in Indonesia, modified after (FAO, 2011)

Forest conversion contributes between 25% and 30% of the greenhouse gases released into the atmosphere each year, estimated around 1.6 billion tons (Corley, 2009). Furthermore, tropical forest conversion is a significant contributor to climate change, causing between 12% and 17% of total anthropogenic carbon emissions (Rignot et al., 1997).

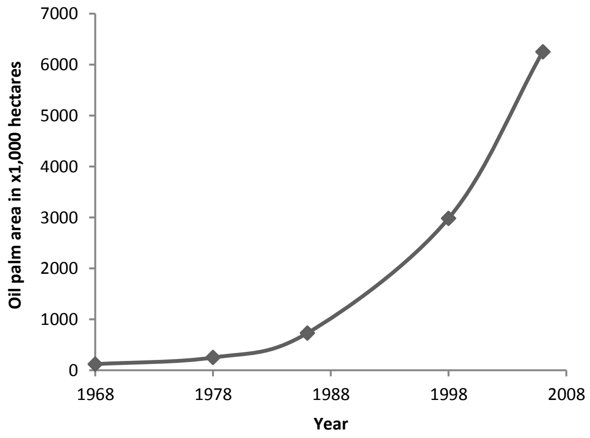
Since forest conversion contributes around 18% of global emission, reducing emissions from deforestation and forest degradation (REDD) has become a potential mitigation strategy (Angelsen et al., 2009). United Nations Framework Convention on Climate Change (UNFCC) started to adopt Kyoto Protocol to set binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions (UNFCC, 2011). In 2007, Bali Action Plan and Bali Road Map was made to commit countries to address global climate challenges. Reducing Emission from Deforestation (RED) scheme first developed to reduce emission which limits to deforestation only. However, REDD has been dicussed within parties of UNFCC since 2005 to include forest degradation (Angelsen, et al., 2009). Then REDD expanded to REDD+ which further consider forest conservation, sustainable forest management, and enhancement of forest carbon stocks.

The causes of forest conversion are complex and vary in different countries. However, main causes of forest conversion are timber logging, large scale plantation, small-scale agriculture, forest clearing for residential, forest fire, grazing, and fuel wood gathering. One of the booming crops for large scale agriculture is oil palm.

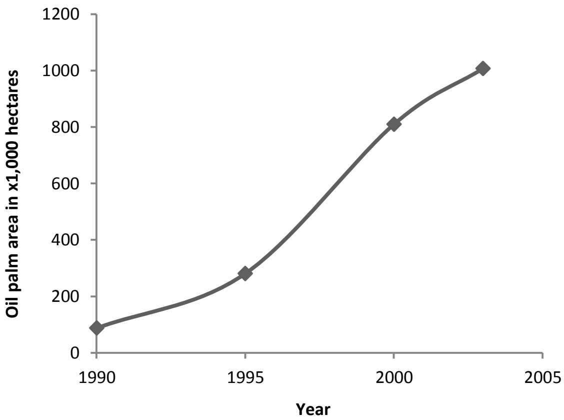
Oil palm, originating from Africa was introduced into other tropical countries in the 19th century. In 1848, oil palm was introduced in Java which the seeds became a source of income for the Southeast Asian plantations. Since the early 19th century palm oil has been used in making soap and candles and later on it founds it use as cooking oil and margarine.

Palm oil has been widely used for cosmetics, cooking oil and food products, and recently for biofuel. According to USDA (2007) cited in Corley (2009) vegetable oil consumption in 2006/2007 was 121 Mt, including 37 Mt palm oil and the rest are soybean, rapeseed and sunflower oil. Countries with high consumption of palm oil are EU reach to 45.8 kg/head and USA 39.3 kg/head (Corley, 2009).

In 1966, Indonesia and Malaysia began to ruled palm oil trade, taking over from Nigeria and Zaire. In 1967, Indonesia produce 168,000 tons of oil palm on 105,808 hectares (Sheil et al., 2009). This number drastically increase to 2.98 million hectares in 1998 and continue increase to 6.2 million hectares in 2006 (Cholhester et al., 2006; Sheil, et al., 2009). While Malaysia produces 15.8 million tons of CPO from 4.3 million hectares in 2007 (Malaysian Palm Oil Board, 2008).



a. Oil palm expansion in Indonesia modified after (Indonesian Palm Oil Board, 2007)



b. Oil palm expansion in Kalimantan modified after (Cooke, 2006)

Figure 1.2 Oil palm expansion in Indonesia and Kalimantan

Expansion of oil palm plantation in Indonesia has occurred in expense of natural forest (Koh et al., 2008). It is estimated during period of 1990-2005 from 3.1 million hectares of oil palm plantation 56% may contribute to conversion of natural forest (Koh, et al., 2008). Oil palm started to grow in Sulawesi and Sumatera and recently have spread rapidly to Papua and Kalimantan.

According to Potter (2005) cited in Cooke (2006), between 1985 and 1997 in Kalimantan approximately 8.5 million hectares of forest areas were lost to agricultural development, especially oil palm estates, grassland, scrub, and shifting cultivation. In 2003, of the 5.25 million hectares of land under oil palm in Indonesia, approximately 19% was located in Kalimantan with a 1,056 % increase from 87,092 ha to 1,006,878 ha between 1990 and 2003 (see Figure 1.2b) (Cooke, 2006). Furthermore, from 2.5 million ha cleared for oil palm in East and West Kalimantan, only 20% had been planted by 2005 (Wakker, 2006).

1.2. Conceptual framework of tropical forest conversion

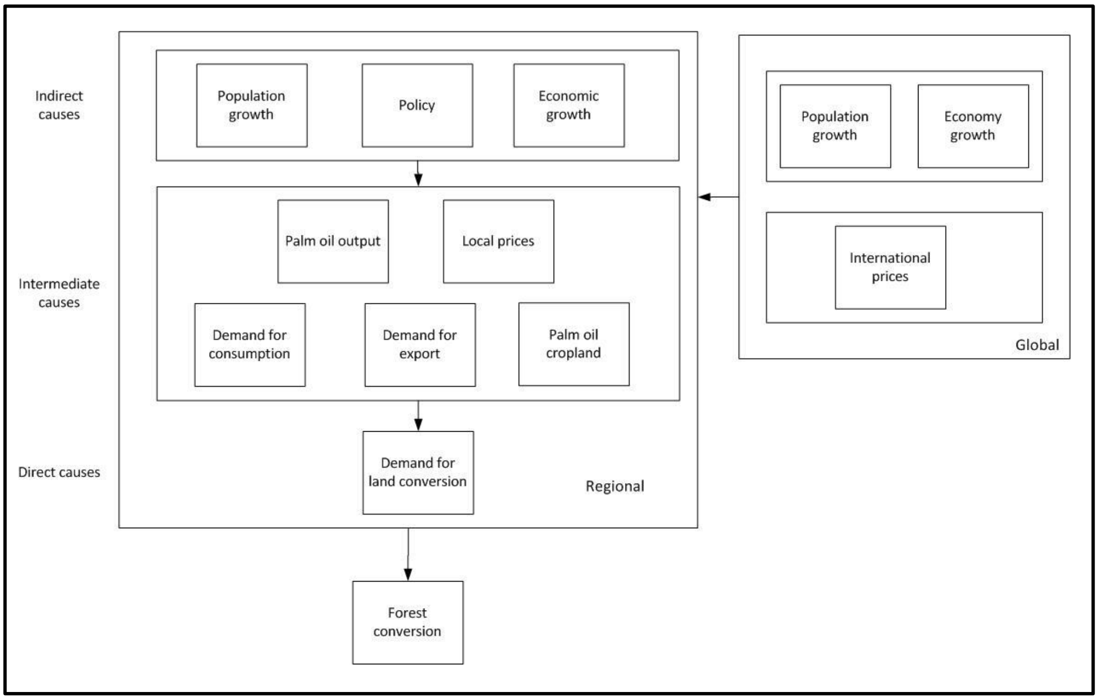


Figure 1.3 Conceptual framework of deforestation, modified after (Zikri, 2009)

1.2.1. Indirect causes of forest conversion

On global and regional level population growth has a significant role in increasing forest conversion. Particularly in the oil palm context an increase in population results in an increased demand of palm oil based products. In addition, a larger population will lead to more people in cultivating agriculture or palm oil plantations. Rapid economic growth on regional level as well as global may also contribute to higher forest conversion rates. Policy in regional and country level is also influence the forest conversion in Indonesia. Lack of law enforcement and monitoring of forest utilization can contribute to forest conversion.

1.2.2. Intermediate causes of forest conversion

The high palm oil price on the global market influences the price at regional level. An increase of the palm oil price stimulates forest conversion since more people will plant palm oil. Palm oil production output is related to the population growth. As the number of people increase, countries feel the need to increase the production of palm oil based food and products. This will lead to an expansion of oil palm as a cropland. In addition, an increase in palm oil production is based on the consumption and local and global demand for export.

1.2.3. Direct cause of forest conversion

Direct causes of forest conversion are conversion of forest to other land uses, timber cutting, slash and burn activities, fuel wood gathering and forest fires. Due to the high demand of palm oil, demand of land for palm oil plantation increases significantly and often forests are sacrificed and converted to oil palm plantation.

1.3. Problem statement

Since the introduction of forest conversion to oil palm plantation has increased significantly in Indonesia from 105,808 hectares in 1967 to 6.2 million hectares in 2006 (Indonesian Palm Oil Board, 2007) and this number will increase more because the government plan to assign another 20 million hectares for plantation expansion by 2020 (Cholhester, et al., 2006). This puts Indonesia's forest in an alarming state. Large forest being converted will lead to loss of biodiversity and livelihood.

Increase use of models to predict forest conversion has greatly expanded among experts in order to determine and understand the causes of forest conversion. Prediction of forest conversion can be used as a base for policy making and stimulate discussion among stakeholders involved. Fuller et al., (2011); Linkie et al., (2004); Pontius et al., (2008) are examples of studies using models to predict forest conversion. Challenges facing these models are lack of model's assessment and model's capability in predicting forest conversion. Furthermore, there are limited studies in modeling forest conversion due to oil palm. Sandker et al., (2007) applied a model to assess the oil palm plantation impact, but used it merely as a tool for dialog with stakeholders and not as a tool for prediction. This study will include validation to assess the model performance in predicting forest conversion due to oil palm.

1.4. Research objectives

The main objective of this study is to employ and to assess the capability of Area Production Model (APM) in modeling the conversion of tropical forest to oil palm plantations.

1.5. Specific objectives

1. To model conversion of tropical forest to oil palm plantations
2. To assess the performance of the APM model in modeling conversion of tropical forest to oil palm

1.6. Research questions

- How large is the conversion of forests to oil palm plantation?
- Where do the conversions of tropical forest to oil palm plantation occur?
- How accurate is APM in modeling forest conversion due to oil palm?

1.7. Research approach

In order to analyse and model forest conversion in the study area, these steps were taken:

1. Analysis of forest cover change in period 2000 – 2009
2. Calibration using regression models
3. Modeling forest conversion
4. Validation of the modeling results

The general research approach is presented in
Figure 1.4. Furthermore, these approaches were combined to carry out the study:

- Forest cover state in the periods of 2000 – 2009 was analysed using GIS. The result of forest cover area would be used as one of the variables in the regression
- Regression was used to calibrate the model. Variables used for regression were forest area and demand of agriculture land

- Forest conversion 2000 – 2009 was modelled using Area Production Model, which were divided into numerical APM and spatial APM
- To determine how well APM in predicting forest conversion, the prediction of deforestation map was validated using land use map 2009.

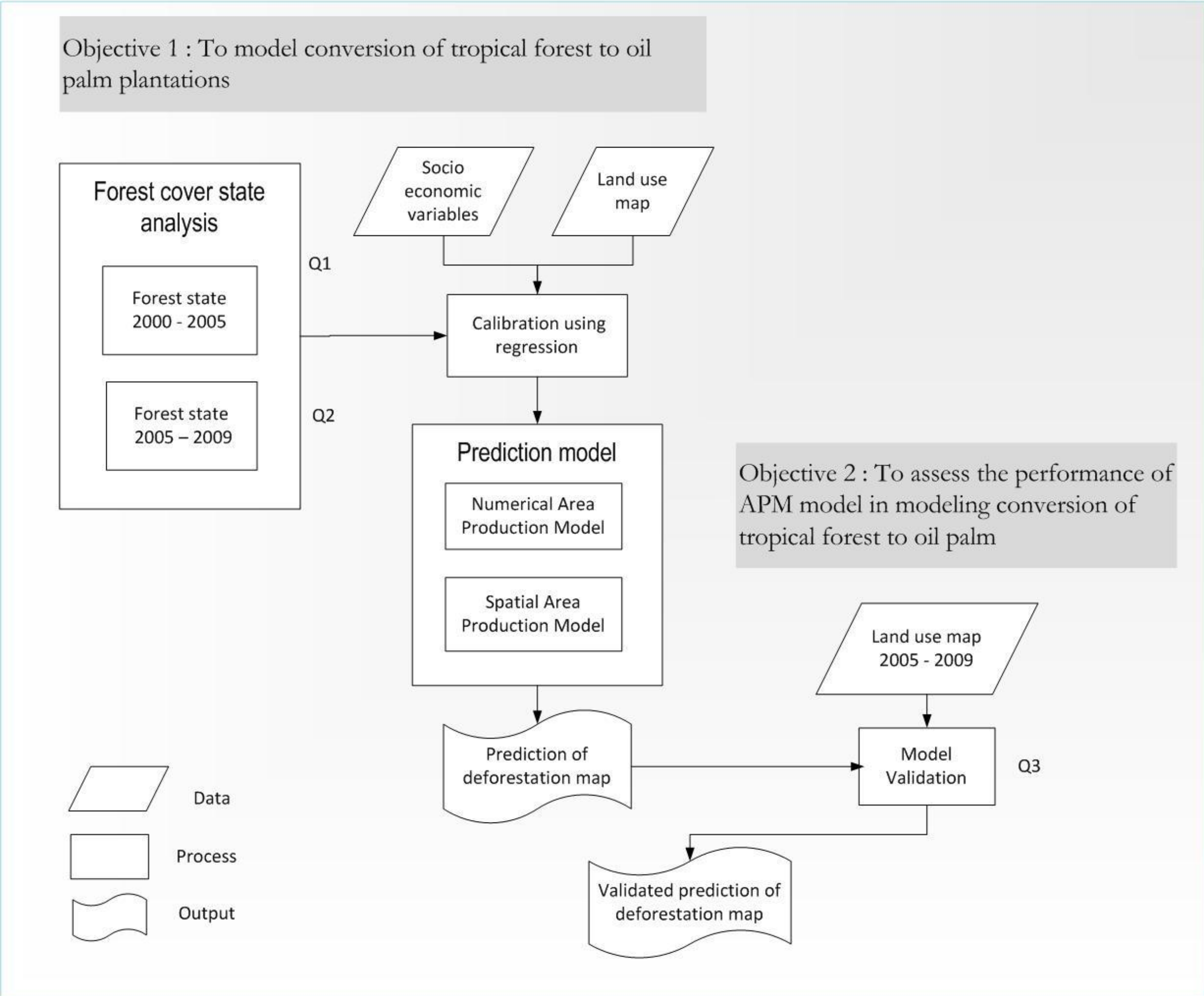


Figure 1.4 General research approach

2. STUDY AREA

2.1. Description of the Nyuatan Watershed

Nyuatan watershed is located in Kutai Barat District. Geographically Kutai Barat District, the western parts of the province of East Kalimantan, covers an area 31,628.70 km^2 and lies between 113^0 48'49" - 166^0 32'43" East Longitude and 1^0 31'05" North Latitude – 1^0 09'33" South (Badan Pusat Statistik Kutai Barat, 2008). Kutai Barat spans an area of approximately 16% of East Kalimantan's total land area and is bordered by Central Kalimantan and Malaysia.

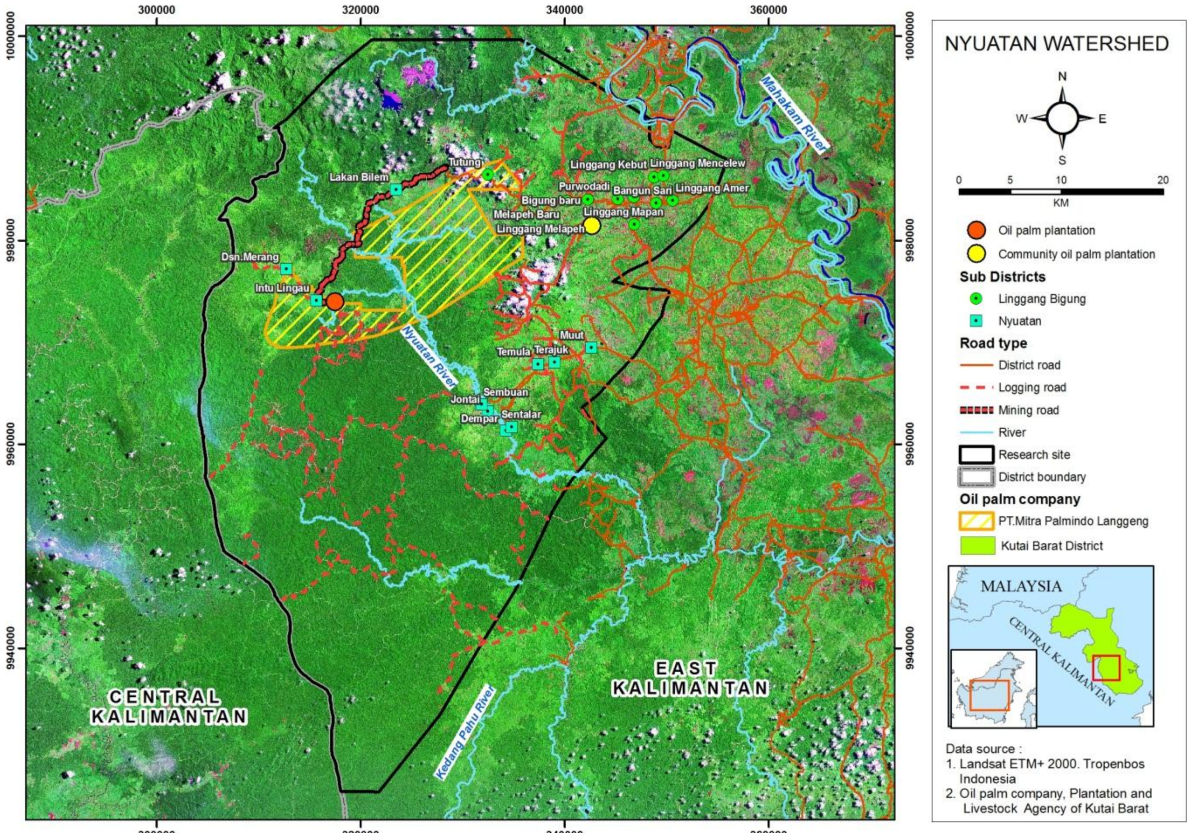


Figure 2.1 Map of study area

Land cover

From the total area of Kutai Barat District, approximately 60% is forest and this area can be divided into: protection forest, natural reserves forest, limited production forest, and production forest (Table 2.1). Forest is an important property for the local community, dominated by indigenous Dayak people, which is utilized for common and household properties (Joshi et al., 2004). The livelihood of the local community is annual slash and burn agriculture for upland rice combined with extraction of forest resources.

The Mahakam River, the biggest river in East Kalimantan, flows 980 km from the Sub District of Long Apari in the northern part of Kutai Barat District, to Kutai Kartanegara District and the city of Samarinda.

Nyuatan River is connected to Mahakam River. Mahakam is very important for most inhabitants in the three districts as sources of drinking water, and transportation corridor since some areas are only accessible by river.

Table 2.1 Forest status in Kutai Barat, source (Badan Pusat Statistik Kutai Barat, 2010)

Forest Function	Forest Zone Area (Ha)	% of Total Forest Zone	% of total Land
Protection Forest	745,140	24.3	23.6
Natural Reserves Forest	5,500	0.2	0.2
Production and Limited Production Forest	1,481,066	48.3	46.8
Convertible Production Forest	832,853	27.2	26.3
Total Forest Zone	*3,064,559*	*100*	*96.89*

Drainage network

The study area is located in Nyuatan watershed and River Nyuatan runs through this watershed area. Initially districts were divided into sub districts based on watershed boundary (Dewi et al., 2005). The boundary of the study area was determined by combining two sub districts in this watershed. Nyuatan sub district is located in the edge of forest and consists of 10 villages. Villages in Nyuatan sub district were formerly included in Damai sub district. But after the expansion of Kutai Barat district in 2004 Damai sub district was divided into Nyuatan sub district and Damai sub district. Linggang Bigung sub district consists of 11 villages, which is located outside of forest (see Figure 2.1).

2.2. Socio economic conditions

2.2.1. Population

In 2009, Linggang Bigung has population of 13,657 inhabitants and Nyuatan has population of 5,443 inhabitants. Linggang Bigung sub district has an area of 70,000 hectares with forest area of 53%. While Nyuatan has an area of 174,000 hectares with forest area of 84%.

Population growth in Nyuatan watershed is provided in Figure 2.2. Population in Nyuatan sub district was not available prior to 2004, since the sub district is formed in 2004. Therefore estimation of the number of population was conducted using the growth formula below:

$$P_t = p_o\ ((1 + i)\ \hat{}^{t})$$

Where P_t = population at year t
P_o = population at initial year
i = growth rate (%)
t = number of years

To calculate growth rate this formula was used:

$$GR = ((V_t - V_o)/V_o) \times 100$$

Where GR = growth rate (%)
V_t = population in present time
V_o = population in previous time

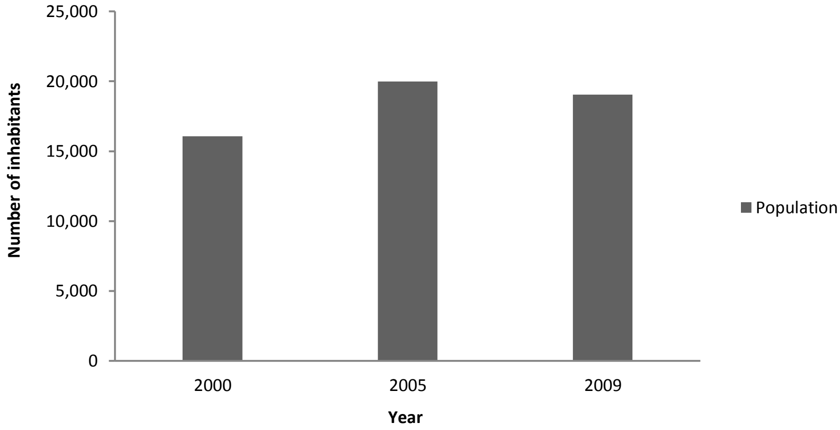


Figure 2.2 Population growth in Nyuatan watershed

2.2.2. Economic growth

Gross Domestic Product (GDP) growth of the two sub districts was not available. However, GDP growth was available in district level. The GDP is presented in US$ with conversion of $1 conversion is Rp. 9,075. GDP of Kutai Barat in 2009 was $337.8 million, increase more than 100% compared to the year of 2000 ($166.5 million).

The highest contributing sectors for GDP growth in 2005 were mining (54.43 %) and agriculture (14.58%). In 2009, GDP per capita of Kutai Barat District was $2.1 billion and annual income per capita was $1.6 billion. While GDP per capita without mining sector was $1.0 billion and annual income per capita was $497.3 million. This showed that Kutai Barat district was heavily relying on natural resources exploitation.

Kutai Barat District has experienced large scale coal extraction, large scale timber logging and forest fires (Dewi, et al., 2005). Furthermore, this area will still have to face interested sectors such as coal extraction, large scale plantation and timber logging.

The APM simulation is focusing on the agricultural expansion; therefore it will use GDP per capita without mining since the GDP should not be influenced by mining activities. The GDP growth is presented in Figure 2.3.

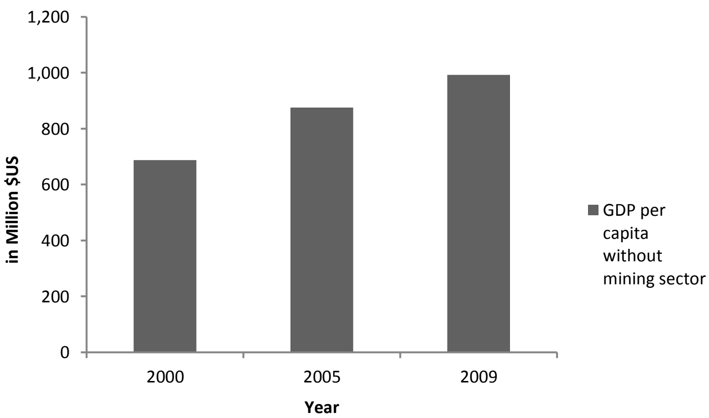
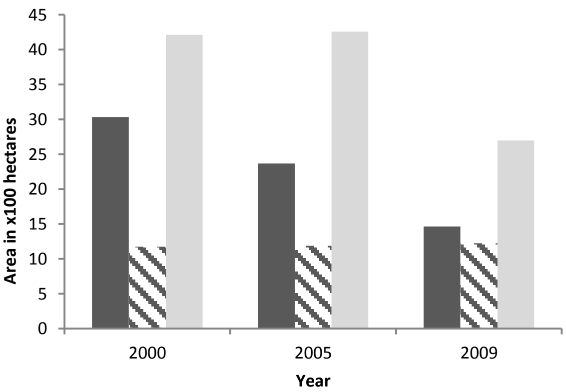


Figure 2.3 GDP per capita growth in Kutai Barat District

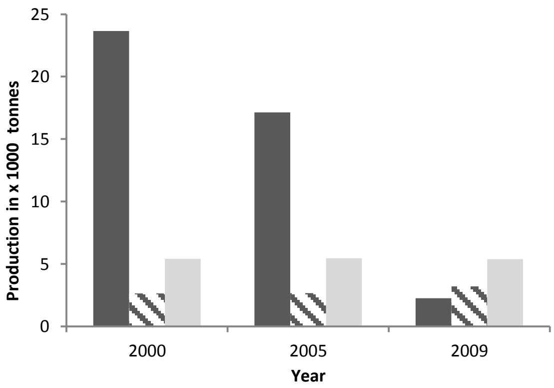
2.2.3. Agriculture

Nyuatan and Linggang Bigung sub districts rely mostly on the agricultural sector. The top agricultural products in Nyuatan are candlenut, ginger and rice paddy while in Linggang Bigung the top agricultural products are rubber, coffee and palm sugar. Information on area and production of oil palm was available in district based. While information for other agricultural sectors are available in sub district based. Agriculture condition in Nyuatan watershed according to Statistics Agency is presented in Figure 2.4.

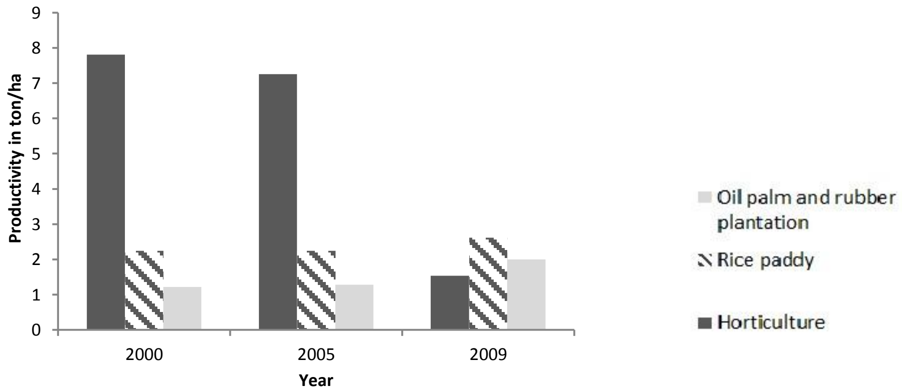
Nyuatan sub district is one of the areas which have high production of rice paddy. Furthermore this area also experiencing the increase of cash crops production. In Kutai Barat district the rubber trees planting had started in 1980's but increasing in the 1990's during the project of the Tree Crops Smallholder Sector Project (TCSSP) from Asian Development Bank (ADB). According to Estate and Plantation Agency of Kutai Barat District, the area of rubber plantation had increased from 1,205 ha in 1980 to more than 10,000 ha in 1998. By 2011 the rubber trees in Kutai Barat district had been planted in more than 34,000 ha with 17.3 million tree stands. On the other hand oil palm had started planting in 2007 and by 2011 had already planted to more than 95,000 trees stands.



a. Agriculture area in Nyuatan watershed



b. Agriculture production in Nyuatan watershed



c. Agriculture productivity in Nyuatan watershed

Figure 2.4 Agricultural condition in Nyuatan watershed for the periods of 2000, 2005 and 2009

When Figure 2.4a is observed, the area of horticulture experienced a sharp decrease. This may be caused by incomplete data in the period of 2009. However, for the other agriculture class the data is reliable. This agriculture condition will be used in the creation of growth factors.

During fieldwork in September 2011, two oil palm plantations were visited in Nyuatan watershed. One was in Linggang Malepeh village, Linggang Bigung sub district and the other one was in Intu Lingau village, Nyuatan sub district (Figure 2.1). In Linggang Malepeh village the oil palm plantation covering an area of around 5 hectares was mature and based on field observation aged around 5 years old (see Figure 2.5a). Furthermore, the surrounding area around this oil palm plantation was rubber plantation.

On the other hand oil palm trees on the plantation in Intu Lingau village were still in seedling stage around 1 year old (see Figure 2.5b). The area of oil palm seedlings was around 10 hectares. This plantation is owned by Estate Company called P.T. Mitra Palmindo Langgeng which has concession area of more than 18,000 hectares. The concession area is still covered by forest although according to Forest Function classification falls in the non-forest area.

a. Mature oil palm in Linggang Malepeh village

b. Oil palm seedling in Intu Lingau village

Figure 2.5 Photos of two oil plantation locations from field observation

2.3. Accessibility

One of the problems of villages in Kalimantan is accessibility from district city to the villages around it via roads. Based on (Dewi, et al., 2005), roads in the study area were divided into 3 classes (see Figure 2.1):

(i) district roads, which were roads layered by asphalt, some of which were built in conjunction with transmigration projects, including roads within settlement area
(ii) mining roads, built by mining companies, which were non-asphalt roads with rocks and gravel but mostly in good quality to accommodate heavy equipment
(iii) logging roads, which were poor quality roads built by companies, and often not accessible during rainy season.

Villages in Linggang Bigung were located around 30 km to 60 km from Sendawar, the main city of Kutai Barat District. Road quality in Linggang Bigung was district roads. On the other hand villages in Nyuatan were located around 30 km to 250 km from Sendawar with various qualities of roads. Intu Lingau was the farthest village in Nyuatan and only accessible through logging roads. However, roads from this village going to the forest area were logging roads.

3. MATERIALS AND METHODS

This section described the methods to reach objectives of the study. This section was divided into:
3.1 *Materials,* describing the materials used during this study
3.2 *Methods*, which consists of:

3.2.1 *General description*, where the general method and model is described
3.2.2 *Input data preparation,* where methods to prepare input data for the model are explained
3.2.3 *Monitoring forest state,* in which measuring forest state is described
3.2.4 *Modeling forest conversion*, explaining the model used in this study

3.1. Materials

Data used in this study was divided into two categories, spatial and non-spatial. Spatial data used were:

- Landsat image 2000
- Landsat image 2005
- Landsat image 2009
- ALOS PRISM image 2009
- Land use maps of 2000, 2005 and 2009 from Landsat ETM+ image interpretation. The source of the land use maps are from Tropenbos Indonesia
- Administrative map
- Slope map
- Road map
- Settlement map
- River map

All the spatial data was converted to raster datasets. Raster datasets were set to pixel size 50 x 50m. The raster was first set to pixel size 30 x 30 and 40 x 40. However, there are a number of roads or river network missing. The road and river network was visible in 50 x 50 m.

While non-spatial datasets used in the study are:

- Population of the years 2000, 2005, 2009
- GDP of the years 2000, 2005, 2009
- Crop productivity of 2005 and 2009

The tools used for fieldwork are GPS Ipaq, diameter tape, measuring tape, compass, densiometer spherical, and HAGA clinometer. This research used ILWIS 3.3 software, ArcGIS for GIS operations and Microsoft office software (word, excel, visio and powerpoint).

3.2. Methods

3.2.1. General description

In order to predict forest conversion, Area production Model (APM) was applied in the study area. This study was focusing on predicting deforestation in period 2000 – 2009, where oil palm plantation started and rubber plantation already spreading in the study area. General approach for the method was described in Figure 3.1, while a detailed description of numerical and spatial APM process will be explained in section 3.2.4.

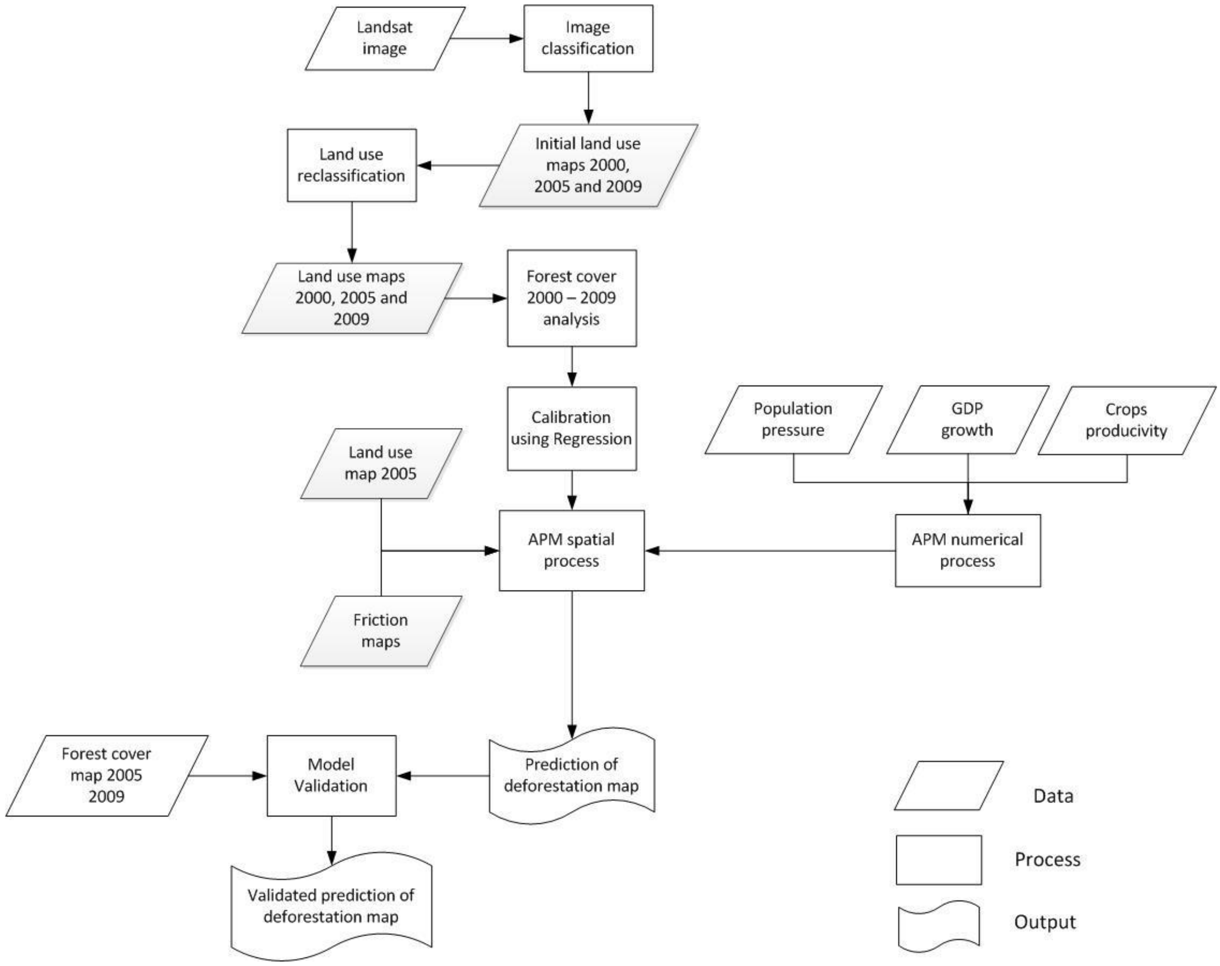


Figure 3.1 Flowchart of general research method

The land use maps 2000, 2005 and 2009 were used to determine the amount and location of forest conversion occur in the study area. The rate of deforestation will also be determined. The amount of forest and agriculture area in 2000, 2005 and 2009 needed to be acquired to develop the regression for APM calibration. This calibration will produce equation to predict the amount of deforestation and will be put to APM script to run the model.

In order for the APM model to run, first the amount of agriculture areas had to be projected. The input data to project agriculture area are population growth, GDP growth and crops productivity growth. Then, the projected agriculture area will be run using APM spatial.

The spatial model was used to know the location of forest being converted to accommodate agriculture areas. Land use map 2000 was used as initial land use in running the spatial model. The land use was first reclassified to meet the requirement of the model input. The road, river, slope and settlement will be processed and combined to produce one friction map. The friction map will determine where the deforestation will spread.

In order to validate the model, the result of APM run for period 2005 – 2009 will be compared to forest cover map 2005 – 2009.

3.2.2. Input data preparation

3.2.2.1. Field work

During the fieldwork the data collected were different land use type in the study area. The location of oil palm and rubber plantation also was observed. The approximate age of oil palm trees and rubber trees were recorded. Roads and village points were also surveyed during the fieldwork.

3.2.2.2. Land use classification

The land use maps provided were land use maps of 2000, 2005 and 2009. The land use map 2000 was used as an initial year for the model simulation. Land use maps were derived from Landsat imagery using visual interpretation and digitizing.

The land use maps were classified to these classes below:

- Undisturbed forest: Natural forest with dense canopy, highly diverse species and high basal areas. It has no logging roads, indicating that it has never been logged, at least under large scale operation, and in some areas in Indonesia this type of forest is located in areas with rough topography. Canopy cover of undisturbed forest is usually >80%
- Disturbed forest : Natural forest area with logging roads and degraded forest cover or logged spots
- Scrub: non-tree-based system consists of non-tree vegetation usually less than 5-6 meters (15-20 feet) tall. Usually scrub can be found in areas with resulted from swidden agricultural activities or logging area that has been left for 2-3 years as part of the fallow/rotational systems
- Agriculture: open area characterized by herbaceous vegetation such as rice paddy field that has big probability that it is managed by human. These features are usually associated with settlement or irrigation structure
- Mixed tree crops: mixed tree based system with more than 30% of the area consisting of various species of trees. Several examples of agro forest are the rubber agroforestry system, coffee agro forest and home garden. Mixed gardens are usually located in 0.5 - 1 km distance to a settlement or road. Tree canopy cover can reach 5% - 60%.
- Plantation area: a homogenous plantation system, usually rubber or oil palm
- Settlement: characterized by settlements including homestead, urban, rural, harbour, airports, industrial area and open mining. This unit is associated with road networks or constructed materials
- Mining : Open area with mining activities
- Water body

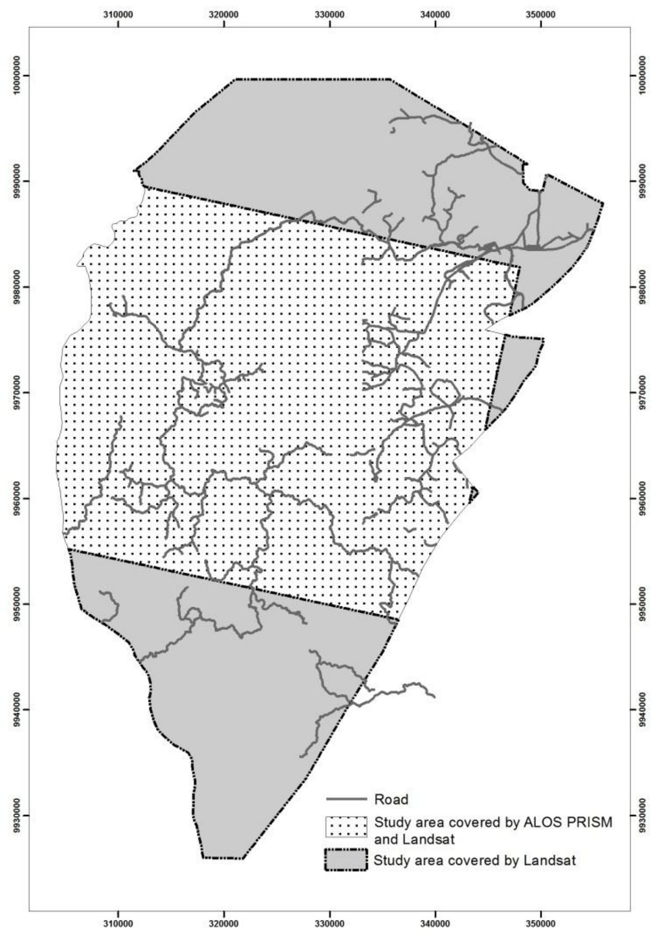


Figure 3.2 Extent of ALOS PRISM and Landsat image for updated land use map 2009

Land use map of 2009 was produced using combination of ALOS PRISM and Landsat data. The combination was done to overcome the problem of Landsat image which has gaps due to instrument malfunction.

The area which was covered by PRISM and Landsat is shown in Figure 3.2. The date of recording of ALOS PRISM image was July 2009, while Landsat image was recorded in June 2009.

The land use covered by ALOS PRISM was determined using visual interpretation and on screen digitizing. The land use map resulted from ALOS PRISM then combined with land use resulted from Landsat 2009. This combination then called updated land use map 2009.

3.2.2.3. Land use reclassification

APM land use was classified into 5 land use groups. Land use classification for APM model described below (Yanuardi, 1999):

- Agricultural land which are divided into subsistence food, market food and cash crops. Subsistence food crops are agricultural crops cultivated to satisfy the basic needs of the people, while market food crops are food crops cultivated by the community for local marketing. Cash crops are agricultural crops grown for industries or export
- Forest land for farm : forestry where the main purpose of management is to provide the farmer with fuel wood, fodder, fruit and tree products for their own consumption (community forestry, village forestry, social forestry, subsistence forestry)
- Industrial forestry: forestry where the main purpose of management is to produce industrial wood such as sawn timber and pulpwood
- Environmental forestry: forestry where the main purpose of management is environmental protection and conservation
- Other land which are divided into potential agricultural/forestry land and unproductive land. Potential agricultural/forestry land is not used as such, but with the potential for agricultural/forestry development. Unproductive land consists of land that cannot be used for agriculture or forestry for example urban areas, deserts, high mountains, lakes, etc.

Due to the indifference of land use classification in land use map and in APM input data, reclassification of the land use map was needed. The reclassification was applied to land use map 2000 which was used as an initial year of the model simulation. The reclassification result was described in Table 3.1.

Table 3.1 Land use 2000 reclassification based on APM land use classes

Model land use categories	Current land use	Area (x1000 ha)
Agricultural land		
Subsistence food (11)	Agriculture	1.867
Market food (12)	n.a.	
Cash crops (13)	Oil palm plantation and rubber plantation	2.515
Forest Land – Farm		
Natural forest (21)	n.a.	
Plantation 1 (22)	Mixed tree crops	2.248
Plantation 2 (23)	n.a.	
Forest land – Industrial		
Natural forest (31)	n.a.	
Plantation 1 (32)	n.a.	
Plantation 2 (33)	n.a.	
Forest Land – Environmental		
Natural forest (41)	Forest	166.302
Plantation 1 (42)	n.a.	
Plantation 2 (43)	Scrub	51.145
Other Land		
Potential agriculture (51)	n.a.	
Potential forest (52)	n.a.	
Unproductive land (53)	Mining, Built up, River	2.543

3.2.2.4. Preparation of factor maps

Four factor maps were used to produce friction map for the APM. Slope, distance to road, river and settlement were used as factors that contribute to forest conversion. According to Fuller et al., (2010) these access related factors are considered the most closely related proximate causes of deforestation.

Slope map

Slope map was derived from DEM (Digital Elevation Model) of SRTM (Shuttle Radar Topography Mission) 90 m. DEM map was converted to slope map (see Appendix 6a).

Distance to road

Main road in the study area was produced by tracking the road during survey. In addition, small road and logging road was produced by using the available road from topographic map and by digitizing using Landsat image. Afterwards the vector map was converted to raster map. Then the road map was calculated the distance using distance calculation function (see Appendix 6b).

Distance to river
River map was derived by digitizing river and streams in Landsat 2000 image using visual interpretation. Then the river map was subjected to distance calculation (see Appendix 6c).

Distance to settlement
The settlement map was derived by digitizing settlement in ALOS PRISM 2009 image using visual interpretation. Then settlement was subjected to distance calculation (see Appendix 6d).

3.2.2.5. Determining weights in factor maps

In order to put factor maps into the friction, weight must be added to each of the factor maps. The higher the weight in the factor maps the higher the probability that forest conversion will occur.

First a deforestation map is produced by overlaying the land use maps of 2005 and 2009. The deforestation map was then reclassified into two classes. Deforested areas were given a value of 1, while non-deforested areas were given a value of 0. After reclassification the deforestation map was crossed with the factor maps individually to determine where the deforestation occurs in a specific factor map and the deforestation density was calculated with the equation based on Ato (1996):

$$D_{area} = Npix(SX_i)/Npix(X_i)*100$$

Where: D_{area} = deforestation density (%)
$Npix(SX_i)$ = number of pixel where deforestation occurred
$Npix(X_i)$ = number of pixel in each factor maps

The next step was giving relative weight to each of the factor maps. Relative weights were given to be able to compare the calculated density of each factor map with the overall deforestation density of the total area. This was conducted by first calculating the average deforestation of the total area and then subtracting it from the individual density of each density class.

$$W_{area} = D_{area} - \sum Npix(SX_i)/\sum Npix(X_i)*100$$

Where: W_{area} = relative weight
D_{area} = deforestation density
$\sum Npix(SX_i)$ = total number of pixel where deforestation occurred
$\sum Npix(X_i)$ = total number of pixel

Afterwards the class weights for each factor maps need to be determined that serves as a basis for the friction map. The formula below is used to determine the temporary class weight.

$$WT = (W_{area} - W_{low}) - 1$$

Where : WT = temporary class weight
W_{area} = relative weight
W_{low} = the lowest relative weight

The final class weight was determined by using equation below (see Appendix 7).

$$W_{class} = WT_{low}/WT$$

Where : W_{class} = class weight

WT_{low} = the lowest temporary class weight

WT = temporary class weight

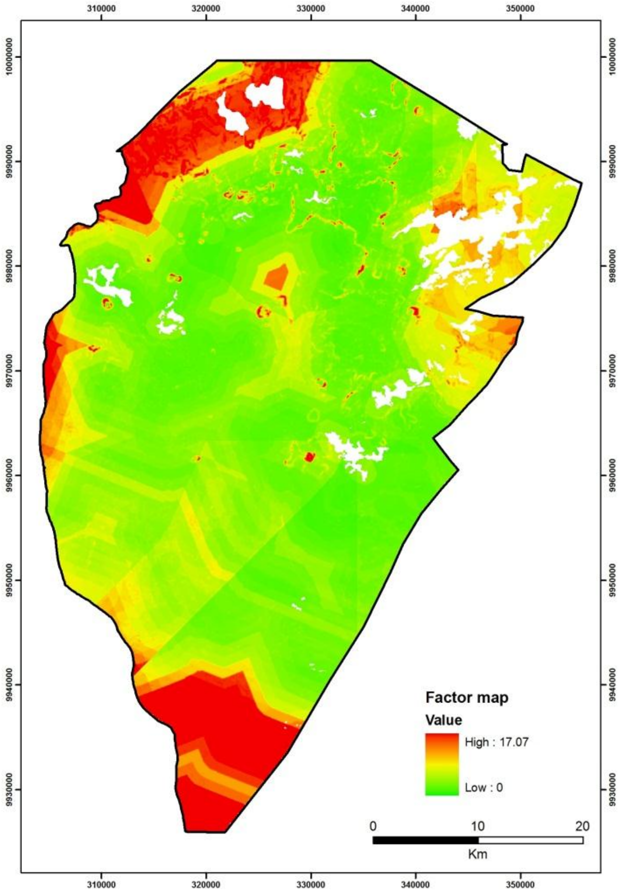


Figure 3.3 Map of suitability of deforestation

The result of the class weight showed that the lowest class weight value has the highest density and vice versa. The class weight was added to the each factor maps which would be processed to create friction map.

The higher the class weight values the higher the chance that deforestation occurs at a certain location. So in fact the weight class weight is a predictor for the location of deforestation.

Then the weights of factor maps were combined to create a suitability map of deforestation (Figure 3.3). A value of 0 refers to the land use class which showed unproductive land, like existing agriculture land, settlement and mining. The lower the value showed the higher threat to deforestation.

3.2.3. Monitoring forest state

Monitoring forest cover was done by overlaying land use maps of 2000, 2005 and 2009 using GIS analysis. The results then analysed to determine the amount and the location of forest conversion and also the rate of forest conversion. The rate of forest conversion for period 2000 – 2009 was calculated using formula by Puyravaud (2003) :

$$\text{Deforestation Rate} = \left(\frac{1}{t2-t1}\right)\ln\left(\frac{A2}{A1}\right)$$

Where: t_2 = final time

t_1 = initial time

A_2 = forest cover at time t_2 (ha)

A_1 = forest cover at time t_1 (ha)

3.2.4. Modeling forest conversion using Area Production Model

General public, decision makers and experts are all concerned about the amount of forest conversion. This has led that experts use models to determine causes, time, location and the extent of forest conversion. The purpose of models vary widely, from understanding phenomena to analysing the effect of engineering actions using detailed realistic applications (Sandewall et al., 2001). According to Lomulder

(2004) the most appropriate model should have a minimum complexity and still produce such a level of accuracy that it is possible to distinguish the results of the computations made for different measurements.

According to Lambin (1994) models for forest conversion should meet at least one of these criteria : 1) Which variables contribute the most to a forest conversion phenomenon and what are the dominant ecological and socio economic processes behind forest conversion; 2) How much is the rate of forest conversion; 3) Where are the areas of forest conversion likely to occur.

Fuller et al., (2011) compared 3 (three) Land Use Cover Change (LUCC) models and two different scenarios to predict forest conversion. The assessment of validation using figure of merit resulted in a range of different outcomes from 1% to 27% with a median of 17%. Pontius et al., (2008) also applied 13 different land use change models and showed that the validation using figure of merit ranged from 1% to 59% with a median value of 21%.

Other model to predict forest conversion is Area Production Model (APM). This model first developed in 1982 by the FAO to simulate land use changes. The model takes three main causes of forest conversion into consideration: population growth and migration, economic development and the influence of agricultural land productivity (de Gier et al., 1999). This model is designed to simulate long-term land use changes and prediction of yields from agriculture and forestry.

APM is used in this research due to the model's capability to estimate forest conversion resulting from agriculture expansion which is one of the main causes of deforestation in developing countries. In addition, this study will also determine whether or not palm oil plantation contributed to the forest conversion. One assumption in APM is that forest conversion only occurs from agriculture expansion. This simulation will predict how much area will be converted to accommodate agriculture expansion. APM is already integrated with ILWIS, which is PC-based remote sensing and GIS software package developed by ITC.

APM has three simulation phases: 1) land use development; 2) biomass energy balance simulation; and 3) forest resource development. Hargyono (1993) divided these 3 phases into five parts:

1. Land use simulation including deforestation and agricultural development
2. Supply and demand balance of biomass
3. Plantation development and management alternatives to deal with simulated conditions of biomass energy balance
4. Simulation of the present forest resources under projected land use change and management policy
5. Integration of results from part one to four

In this study only part 1 of APM is used to simulate deforestation in the study area.

3.2.4.1. Numerical APM

In order to predict deforestation APM was divided into a numerical APM and a spatial APM. Numerical APM is one of the steps that complement the spatial APM. The numerical APM was used to account for the demand of agricultural land needed as a result of growth of GDP, population and crops productivity which are the main pressures of deforestation in APM (Figure 3.4). While spatial APM was used to simulate deforestation spatially to determine which land use and where the deforestation would likely occurred.

The two driving parameters of agricultural development that trigger agriculture activity expansion on forest land are demand and production. In this study we use three assumption, which are: 1) demand for subsistence crops is considered depend only on population growth ; 2) the demand for local market food crops and industrial /export crops is assumed to be influenced by economic factors, such as Gross Domestic Product (GDP); and 3) production depends on productivity and area cultivated (Hargyono, 1993).

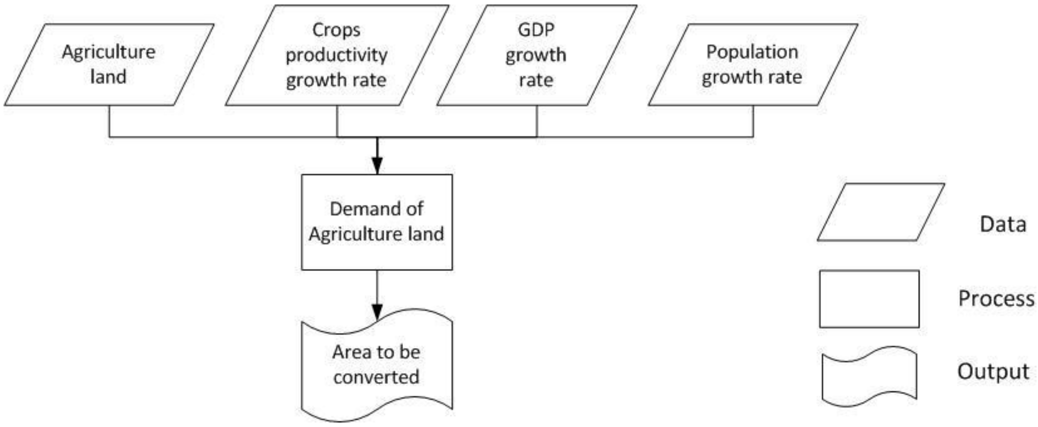


Figure 3.4 Flowchart of Numerical APM

The growth factors are determined for 2 periods which are 2000 – 2005 and 2005 – 2009. These periods then compared with observed changes occurred during the same periods. The growth factors for these two periods are presented in Table 3.2:

Table 3.2 Growth factors for periods 2000 - 2009

Period	Year	Growth of population	Growth of GDP	Growth of Productivity	
				Subsistence crops	Cash crops
1	2000-2005	1.021	1.045	1.008	1.0062
2	2005-2009	1.024	1.045	1.004	1.0050

In numerical APM, projected agriculture land was calculated using this equation (Hargyono, 1993)

$$D_{proj} = A_{sc} * (G_{pop}/G_{prod})^n + A_{mc} * (G_{GDP}/G_{prod})^n + A_{cc} * (G_{GDP}/G_{prod})^n$$

Where:

	D_{sc}	=	demand for new land for subsistence crops (ha)
	D_{proj}	=	projected agriculture land (ha)
	A_{sc}	=	present area of subsistence crops (ha)
	A_{mc}	=	present area of market crops (ha)
	A_{cc}	=	present area of cash crops (ha)
	D_{mc}	=	demand for new land for market crops (ha)
	D_{cc}	=	demand for new land for cash crops (ha)
	G_{pop}	=	growth rate of population (%)
	G_{GDP}	=	growth rate of GDP (%)
	G_{prod}	=	growth rate of crops productivity (%)

n = year projected

3.2.4.1. Model calibration

Calibration is the estimation and adjustment of parameters which affect the model and the factors that restricts the model in order to improve consensus between the output and data used in the model (Pontius Jr et al., 2004). The APM calibration is based on the assumption that growth factors of APM which are controlling the trend of agricultural development, also controlling the tendency of rural people to convert forest (Hargyono, 1993). The regression models describe the relationship between the agricultural land and the forest area. The variables of forest cover and agriculture land area used in these models came from of land use map 2000, 2005 and 2009. In this study, the model was calibrated by curve fitting using 3 regression models, which are:

Model 1 : $Y = a + bX$

Model 2 : $Y = a + bX + cX^2$

Model 3 : $Y = a + b/X$

where : Y = Forest cover area (ha)
X = Agriculture land (ha)

The regression models used above are based on a previous study by Bode (1995) cited in Ato (1996) which linked the regression model developed in the calibration phase for the prediction of forest degradation in Kali Konto. The best regression model would be used as formula to predict the amount of forest conversion in APM simulation.

3.2.4.2. Spatial APM

The APM applies the basic rules in determining the process of land use change. It uses priorities for land use. In other words which land use category should be used first before the other land use category can be used. The method for spatial APM is visualized in Figure 3.5. The result of one study by de Gier, et al., (1999) in Kali Konto, East Java indicated that the spatial component of APM significantly improve the model's behaviour.

The village boundary was determined by digitizing settlement map using ALOS PRISM image. Then the boundary was determined by using the Thiessen map function in ILWIS based on the settlement map. The village boundary will be combined with population growth during the spatial APM process to produce population pressure.

In addition, population density in each village was also calculated using this formula:

$$Pop_{dens} = A_{vil} / N_{pop}$$

Where : Pop_{dens} = Population density (inhabitants/hectares)
A_{vil} = Area of village (hectares)
N_{pop} = Number of inhabitants

The village factor was calculated by multiply population density with population growth. Then the weight was determined by classifying the village factor (Table 3.3). The lower the weight, the higher the pressures of the population on the current land use. The village weight would be linked to village boundary during the running of spatial APM.

Table 3.3 Classification for village factor weight

Class of village factor	Weight
0 - 10	5
11 - 20	4
21 - 30	3
31 - 40	4
>41	1

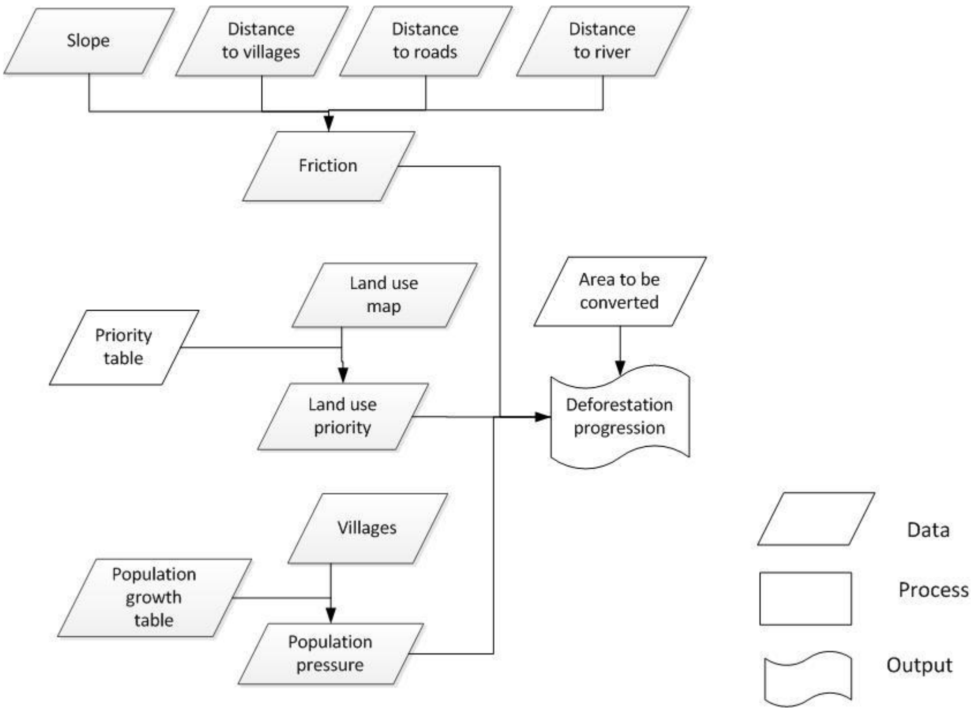


Figure 3.5 Flowchart of spatial APM

The first simulation was run for 2 periods, which are 2000 – 2005 and 2005 - 2009. Then the result was compared with observed land use change in the same periods. The growth factor used for this simulation is presented in Table 3.2. The growth factors are based on data by Statistics Agency of Kutai Barat.

Priority rules were applied as a part of spatial APM. The APM needed several rules to be determined: 1) the order which demands are to be satisfied. It is generally assumed that food production is to be satisfied in the first place; 2) the order of transfer of land classes when new land is needed for food production (or when land is no longer needed for that purpose) (Sandewall, et al., 2001). The transfer and priority of land use for the spatial APM is presented in Table 3.4.

Table 3.4 Transfer of land between classification and priority

Transfer options		Priority order of the transfer of land into agriculture	
From code	To code	Priority	Land class
11 (Subsistence crops)	43 (Scrub)	1	Forest
13 (Cash crops)	41 (Forest)	1	Scrub

The following assumption are made in the spatial APM (de Gier et al., 1993) cited in (Department of Natural Resources, 2004):

- Higher population density, resulted to faster forest degradation and forest conversion
- Higher population growth, resulted to faster forest degradation and forest conversion
- Steeper slope, resulted to slower forest degradation and forest conversion
- Greater distance, resulted to slower forest degradation and forest conversion
- Lower priority, resulted to slower forest degradation and forest conversion

The outputs of APM are:

- Projected agricultural area
- Predicted future forest area
- Forest conversion rate

3.2.4.3. Model validation

Validation can be referred to as techniques in determining a satisfactory range of accuracy in a model which is consistent with the purpose of the model application (Rykiel, 1996). The model is validated by comparing the forest cover 2005 – 2009 as reference map with the result of APM prediction for period 2005 – 2009. The validation included numerical and spatial validation. Numerical validation was done to compare the amount of forest conversion in the APM simulation with the observed change. Spatial validation was used to validate the locational accuracy resulted from the model simulation with the location of the observed change. The spatial validation of the model is done using a pixel by pixel comparison.

3.2.4.4. Development of scenarios

The model was used to predict agriculture expansion using 3 scenarios. The scenarios were business as usual, moderate and sustainable scenario. Business as usual scenario was based on the assumption that productivity growth of subsistence and market crops would continue to increase since government was focusing to develop crops sector as alternative to mining sector. The business as usual scenario assumes that land use change will continue following the trend in the past, which expanded to forest (Wicke et al., 2011) (Table 3.5). The prediction of forest conversion would be based on growth factors presented in Table 3.6.

Assumptions of growth factors for scenario BAU:

- The growth of population was assumed to follow the average rate of population growth at provincial level. The population growth was assumed to increase after period 2 due to employment by oil palm companies. In this scenario the oil palm company was assumed to employ people from outside the area (Sandker, et al., 2007)

- The growth of GDP without mining sector was assumed to increase following the trend of the agriculture sector
- The growth productivity of subsistence crops was assumed to increase due to the increase of population. The growth productivity of market crops would continue to increase, due to the establishment of oil palm plantation.

Table 3.5 Transfer of land between classification and priority for scenario business as usual

Transfer options		Priority order of the transfer of land into agriculture	
From code	To code	Priority	Land class
11	43	1	Forest
13	41	2	Scrub

Table 3.6 Growth factors for Business as usual Scenario

Period	Year	Growth of population	Growth of GDP	Growth of Productivity	
				Subsistence crops	Cash crops
1	2000-2005	1.0210	1.0450	1.0080	1.0062
2	2005-2010	1.0240	1.0450	1.0040	1.0150
3	2010-2015	1.0240	1.0430	1.0180	1.0280
4	2015-2020	1.0240	1.0430	1.0180	1.0280
5	2020-2025	1.0240	1.0430	1.0180	1.0280
6	2025-2030	1.0260	1.0400	1.0200	1.0300
7	2030-2035	1.0260	1.0400	1.0200	1.0300
8	2035-2040	1.0260	1.0400	1.0200	1.0300
9	2040-2045	1.0260	1.0400	1.0200	1.0300
10	2045-2050	1.0260	1.0400	1.0200	1.0300

Scenario moderate was implemented based on the regional development of province level. This scenario assumed that the expansion of agriculture was done in forest and scrub with the same priority (Table 3.4). The growth factors for this scenario were presented in Table 3.7.

Assumptions for growth factors after 2009:

- The growth of population was assumed to follow the average rate of population growth at provincial level. According to Regulations of East Kalimantan Province Number 15/2008 on Long-term regional development plan of East Kalimantan Province 2005 – 2025, growth rate of population was increased 2.24 % (Badan Perencanaan Pembangunan Daerah Provinsi Kalimantan Timur, 2008). This condition followed by the decrease of population growth for the next 5 periods to 2.0%
- The growth of GDP without mining sector was assumed to increase following the trend of the agriculture sector
- The growth productivity of subsistence crops was assumed to follow the average rate of productivity in provincial level which was 1.1% for period 3 to 5. While for the next 5 periods, the growth of productivity continued to increase 1.12%. The growth productivity of market crops would continue to increase, since the provincial government planned to expand oil palm and

rubber plantation to reach 1 million hectares (Badan Perencanaan Pembangunan Daerah Provinsi Kalimantan Timur, 2008). The growth productivity of market crops was assumed to increase for the period 3 to 5 at rate of 1.25% following the rate in provincial level. While for the next 5 periods the growth rate increase 1.015%

Table 3.7 Growth factors for scenario moderate

Period	Year	Growth of population	Growth of GDP	Growth of Productivity	
				Subsistence crops	Cash crops
1	2000-2005	1.0210	1.0450	1.0080	1.0062
2	2005-2010	1.0240	1.0450	1.0040	1.0150
3	2010-2015	1.0224	1.0400	1.0100	1.0250
4	2015-2020	1.0224	1.0400	1.0100	1.0250
5	2020-2025	1.0224	1.0400	1.0100	1.0250
6	2025-2030	1.0200	1.0200	1.0120	1.0150
7	2030-2035	1.0200	1.0200	1.0120	1.0150
8	2035-2040	1.0200	1.0200	1.0120	1.0150
9	2040-2045	1.0200	1.0200	1.0120	1.0150
10	2045-2050	1.0200	1.0200	1.0120	1.0150

Sustainable scenario was based on the assumptions that subsistence crops and market crops was decrease due to increasing awareness to protect the forest. This meant that there would be limitations in opening new area for plantation. The sustainability scenario assumes that deforestation is stopped and new crops plantations are required to expand to degraded forest, in this case is scrub (Wicke, et al., 2011) (Table 3.8). The growth factors for this scenario were presented in Table 3.9.

Assumptions of growth factors for scenario sustainable:

- The growth of population was assumed to follow the average rate of population growth at provincial level. The population growth was assumed to increase following the trend in the province level. In this scenario the oil palm company was assumed to employ local people from surrounding the plantation area (Sandker, et al., 2007)
- The growth of GDP without mining sector was assumed to increase following the trend of the agriculture sector
- The growth productivity of subsistence crops was assumed to increase following the trend in the province level. It was assumed since the oil palm company hired local people, there were small portion of agriculture expansion in this area. The growth productivity of market crops would continue to increase, due to the establishment of oil palm plantation.

Table 3.8 Transfer of land between classification and priority for scenario sustainable

Transfer options		Priority order of the transfer of land into agriculture	
From code	To code	Priority	Land class
11	43	1	Scrub
13	41	2	Forest

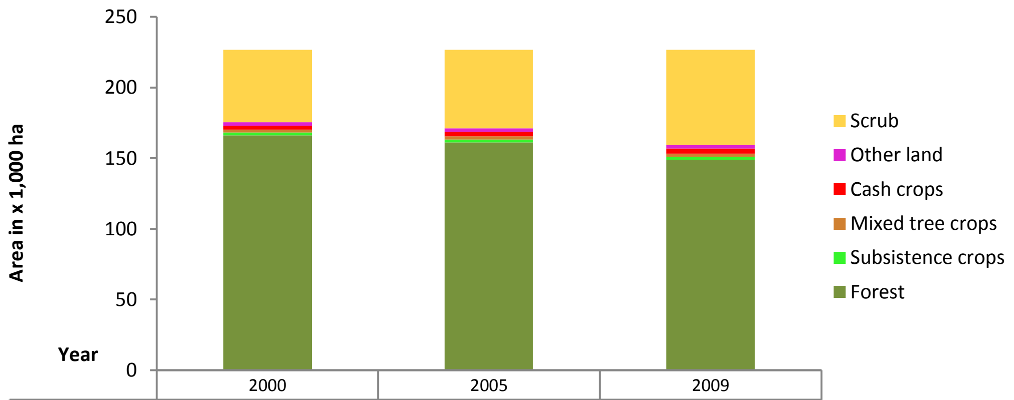
Table 3.9 Growth factors for Scenario sustainable

Period	Year	Growth of population	Growth of GDP	Growth of Productivity	
				Subsistence crops	Cash crops
1	2000-2005	1.0210	1.0450	1.0080	1.0062
2	2005-2010	1.0240	1.0450	1.0040	1.0150
3	2010-2015	1.0224	1.0400	1.0100	1.0250
4	2015-2020	1.0224	1.0300	1.0100	1.0250
5	2020-2025	1.0224	1.0300	1.0100	1.0250
6	2025-2030	1.0150	1.0200	1.0100	1.0180
7	2030-2035	1.0150	1.0200	1.0100	1.0180
8	2035-2040	1.0150	1.0200	1.0100	1.0180
9	2040-2045	1.0150	1.0180	1.0080	1.0100
10	2045-2050	1.0150	1.0180	1.0080	1.0100

4. RESULTS

4.1. Monitoring state of the forest

Analysis of forest state is conducted using land use maps 2000, 2005 and 2009. In 2000 the land use in this area covered 73% by forest and 23% by scrub. While 4% was divided among other land (settlement and mining), agriculture (subsistence crops and cash crops) and mixed tree crops. The highest land use change occurred on forest and scrub. For the period of 2000 – 2009, forest decrease from 166,227 ha to 148,811 ha with the rate of 1.23% per year. While scrub increased 7% from 51,238 ha to 67,287 ha (Figure 4.1). Furthermore, there is an increase of 1% in cash crops or estate crops area. These changes occurred from scrub to rubber plantation and the establishment of new oil palm plantation area. There were also changes took place in forest area to scrub and subsistence crops or rice paddy area.



	2000	2005	2009
Scrub	51,239	55,526	67,288
Other land	2,543	2,543	2,543
Cash crops	2,515	3,074	3,501
Mixed tree crops	2,230	2,334	2,271
Subsistence crops	1,865	1,954	2,206
Forest	166,228	161,189	148,811

Figure 4.1 Land use state for periods of 2000, 2005 and 2009

Figure 4.2 shows the location of changes occurring in the periods of 2000 - 2005 and 2005 - 2009. High concentration of forest conversion area were spreading from previously deforested area, which are in line with studies by Siles (2009) and Harris et al., (2008). Furthermore, there are with small amount of forest conversion in 2009 starting in the middle of the forest.

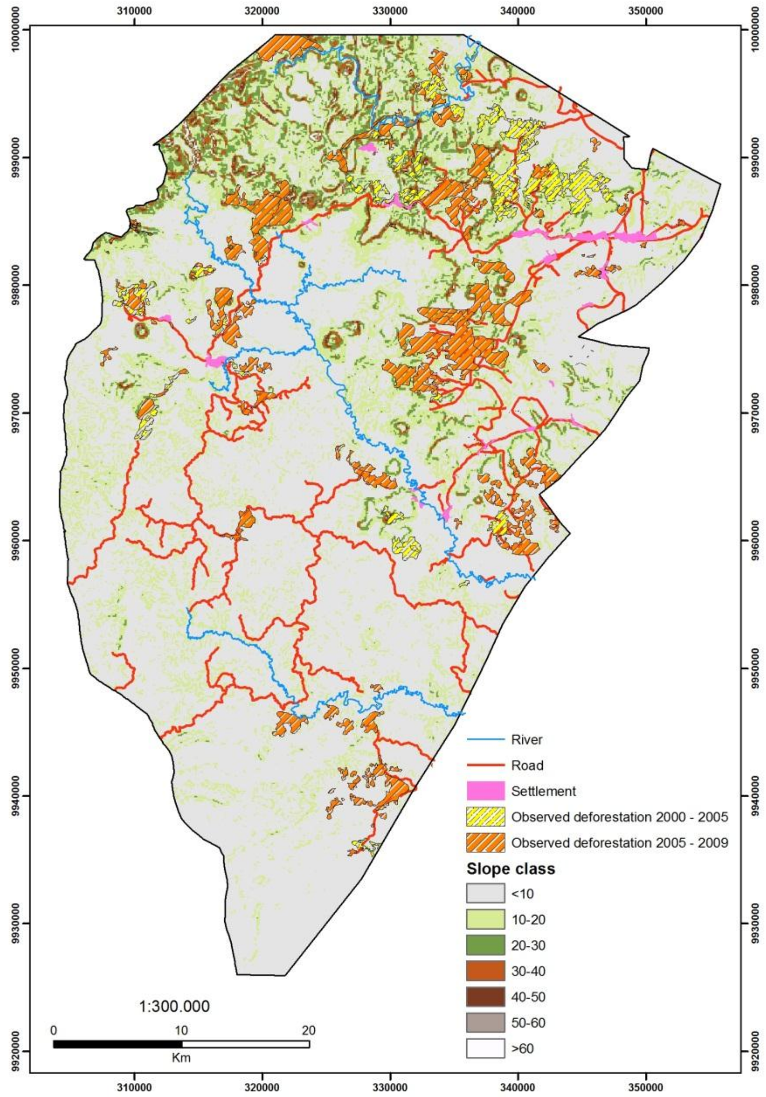


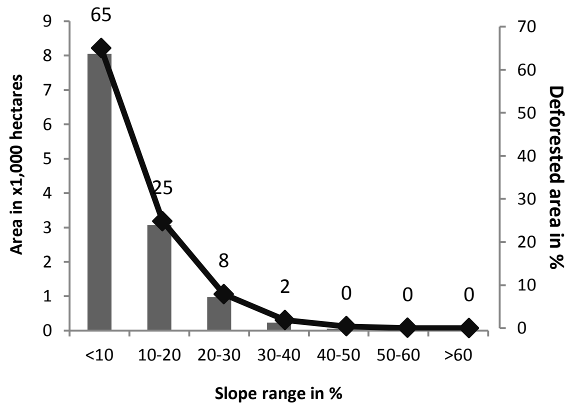
Figure 4.2 Distribution of deforested area for periods of 2000 - 2009 with relation to access related factors

The slopes in the study area are dominated by slopes of less than 20% (Figure 4.2). According to Decree of Ministry of Agriculture Number 837/Kpts/Um/11/1980, slopes higher than 25% are considered steep. In the period of 2000 – 2009, forest conversion was occurring on slopes of less than 40%. Forest conversion was concentrated on slopes range from 0% to 20% reaching 90% of the total deforested area, while 10% of the deforestation took place in areas with slopes ranging from 20% – 40% (see Figure 4.3a).

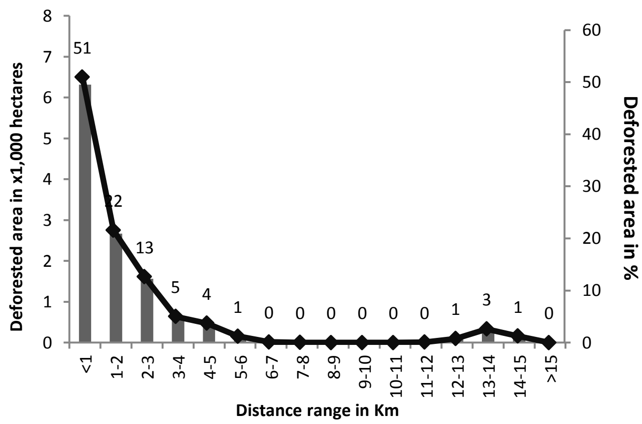
The highest concentration of forest conversion occurred in distance below 1 Km from the road, which reaching to 51%. Furthermore 44% of deforested area occurring in distance range 1 – 6 Km. However, there was 4 % deforested area in distance ranges 12 – 15 Km, which located on the edge of the study area boundary (Figure 4.3b).

Distance to rivers shows varied results (Figure 4.3c). This study found that 98% of the deforested areas were distributed in distance range 1 km to 9 km. Furthermore, in Nyuatan watershed there is a low concentration of deforested areas at distances range 9 – 10 km.

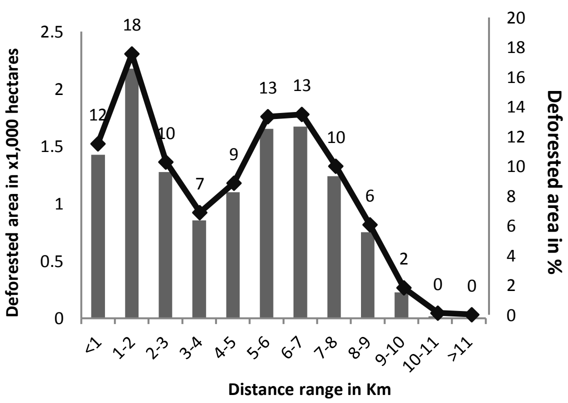
Deforested area in relation to distance to settlements was distributed in distance range 2 – 9 Km, reaching 77% (Figure 4.3d). While for distance below 1 Km, deforested area was found only 2%. Forest conversion then occurred 21% in distance range 9 – 24 Km.



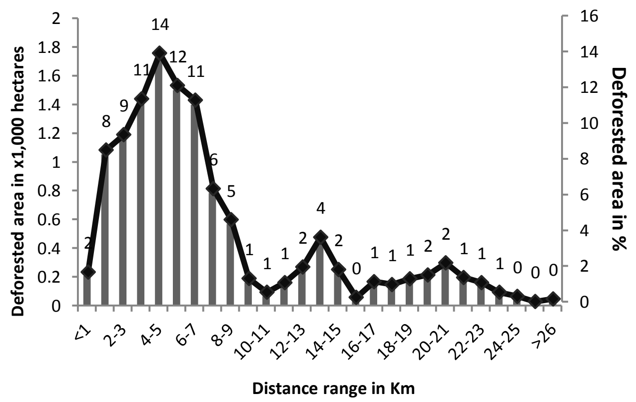
a. Deforested area in relation to slope



b. Deforested area in relation to distance to roads



c. Deforested area in relation to distance to river



d. Deforested area in relation to distance to settlement

Figure 4.3 Distribution of deforested area in relation to factor maps (data labels showed in each of the bar refer to percentage of deforested area)

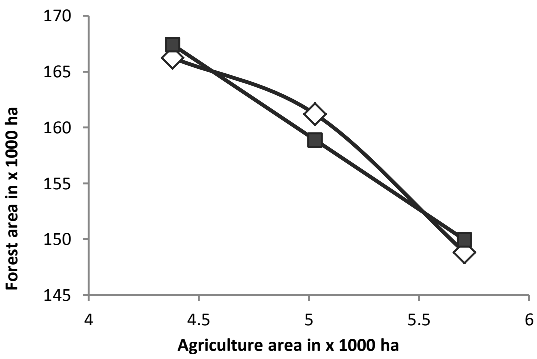
4.2. Modeling forest conversion using Area Production Model

4.2.1. Model calibration

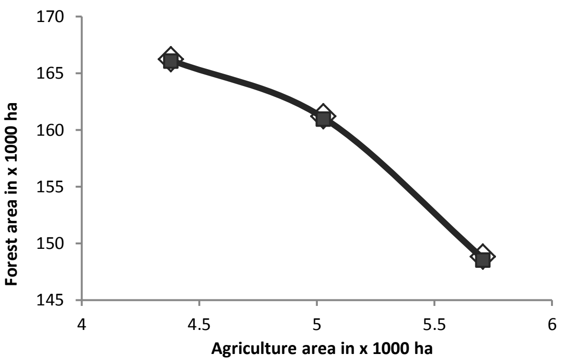
Statistical analysis of the three regression models is presented in Table 4.1. The observation was done using three series of land use, which are periods of 2000, 2005 and 2009. From comparison of statistical analysis in Table 4.1, model 2 resulted into the highest R^2 which was 1, while R^2 for Model 1 was 0.95. Furthermore, the graphs in Figure 4.4 show that model 2 has the closest trend line of the forest estimate with the observed forest area. Therefore, model 2 was used to link numerical APM and spatial APM.

Table 4.1 Statistic of 3 models from regression

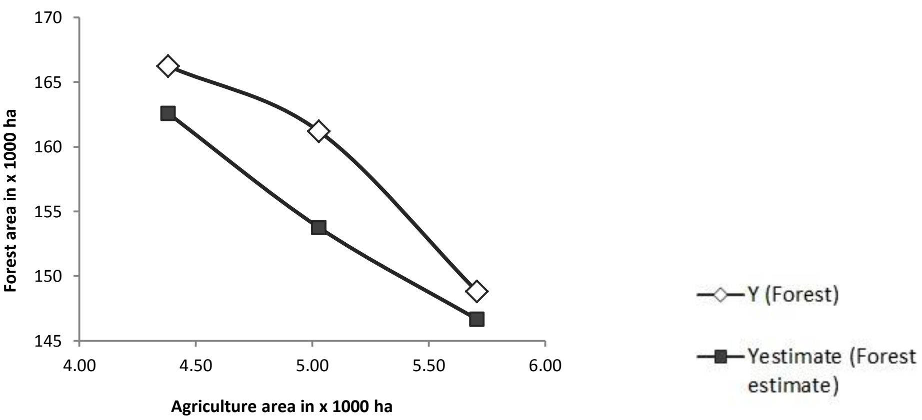
Model	Constant	R^2	No of observations	Degrees of freedom	X coefficient	
					1	2
1. $Y = a + bX$	225,104	0.95	3	2	-13.17	
2. $Y = a + bX + cX^2$	26,480	1	3	2	66.467	-0.0079
3. $Y = a + (b/X)$	94,095	0.9119	3	2	3.00E+08	



a. Model 1 : $Y = a + bX$



b. Model 2 : $Y = a + bX + cX^2$



c. Model 3 : $Y = a + (b/X)$

Figure 4.4 Plot charts of 3 different regression models

Model 2 then developed to estimate future forest, and resulted to this equation:

$$F_{forest} = 26{,}480 + 66.467\, D_{proj} - 0.0079\, D_{proj}^{2}$$

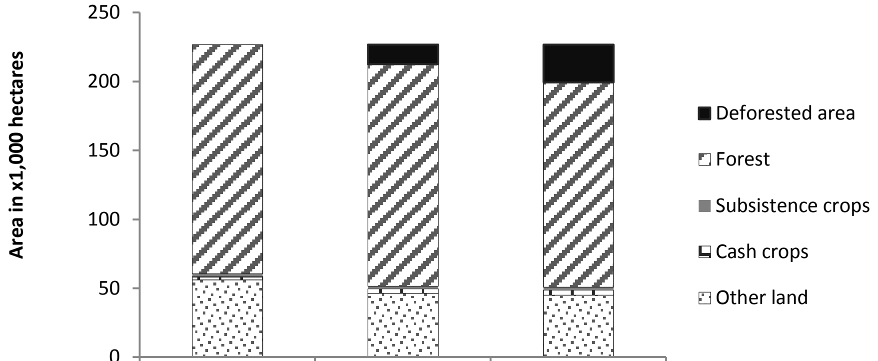
Where F_{forest} : estimation of future forest area (ha)

D_{proj} : projected agriculture land (ha)

4.2.2. Prediction of forest conversion

In order to predict the agriculture expansion for the long periods, first the APM was used to simulate the forest conversion for periods of 2005 and 2009. These periods are chosen based on the available land used data which are land use maps of 2000, 2005 and 2009. The projected agriculture land using APM was based on growth factors in Table 3.2 and land use priority in Table 3.4. The initial year for the prediction is the period of 2000, which is the reason that the deforested area is started to showing in the period of 2005.

The result of the simulation is presented on Figure 4.5. The APM simulates that in the periods of 2000 – 2009 forest decreased to 17,667 ha. While the agriculture increase 1,324 ha from 4,381 ha to 5,705. This numerical graph can be compared with the observed land use change occurring in the period of 2000 to 2009 (see Figure 4.1). The amount of projected agriculture land using APM (Figure 4.5) does not have much difference than the observed agriculture land (Figure 4.1). The assessment of the result of numerical and spatial APM will be discussed in the section 4.3.



Year	2000	2005	2009
Deforested area	0	14,218	27,373
Forest	166,228	160,960	148,561
Subsistence crops	1,865	1,989	2,152
Cash crops	2,515	3,039	3,553
Other land	56,012	46,415	44,982

Figure 4.5 Prediction of forest land use condition by APM for periods of 2000 to 2009

4.3. Model validation

The APM model was validated using a pixel by pixel comparison. The model was run for period 2005 – 2009 and output would be called predicted deforestation map. The result of the model was validated using land use change map 2005 – 2009.

Numerical accuracy was determined by comparing the deforestation using spatial APM with the forest conversion from land use change map 2005 – 2009. While spatial accuracy was determined by measuring the correct location of deforestation from spatial APM based on the forest conversion from land use change map 2005 – 2009. The numerical accuracy reached 86% (Table 4.2). The difference of amount of deforestation predicted by APM and observed deforestation was due to priority given (see Table 3.4). The deforestation was occurring in forest and scrub, since the same priority was given to both land use type. The result shows 65% of the deforestation pixels were correctly located to the observed deforestation (Table 4.2).

Table 4.2 Validation assessment of spatial APM

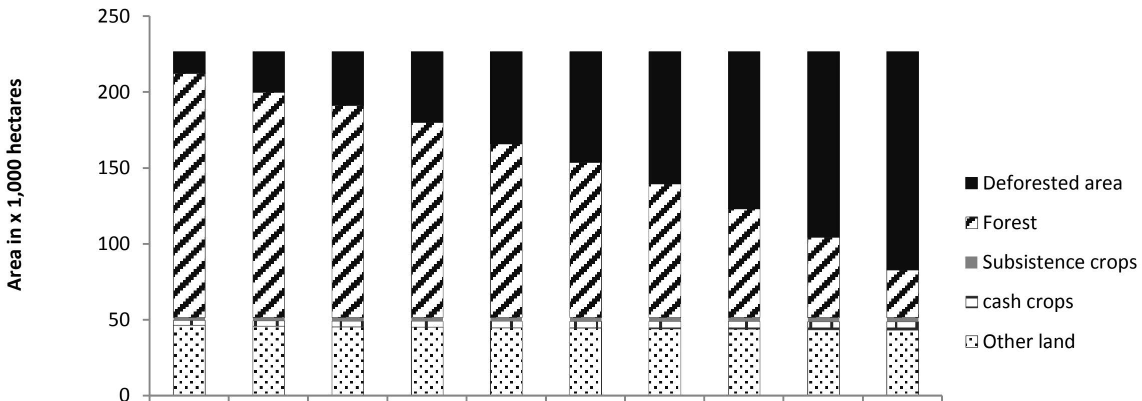
Calculated deforestation 2005 - 2009 using land use map (ha)	12388.75
Calculated deforestation 2005 - 2009 using APM (ha)	10613
Correctly classified deforestation (ha)	8001
Numerical accuracy (%)	86
Spatial accuracy (%)	65

4.4. Prediction of agriculture expansion

The prediction of agriculture expansion discussed below was divided into 3 scenarios, which are scenario business as usual, scenario moderate and scenario sustainable.

The land use change based on scenario business as usual (BAU) is presented in Figure 4.6. The projected subsistence crops using scenario BAU predicts that in 50 years the areas used for subsistence crops will increase from 1,989 ha to 2,775 ha. Cash crops will increase from 3,039 ha to 5,563 ha. In total the projected agriculture land will increase 1.5% from 5,028 ha to 8,338 ha.

When looking at the forests the BAU scenario predicts that in 50 years the forest area will decline 57% from 160,960 ha to 31,436 ha and that the deforested area will increase from 14,218 ha to 143,742 ha. In 50 years, it is estimated that the remaining forest only covers 14% of the total amount of land and that degraded forest dominating the area.

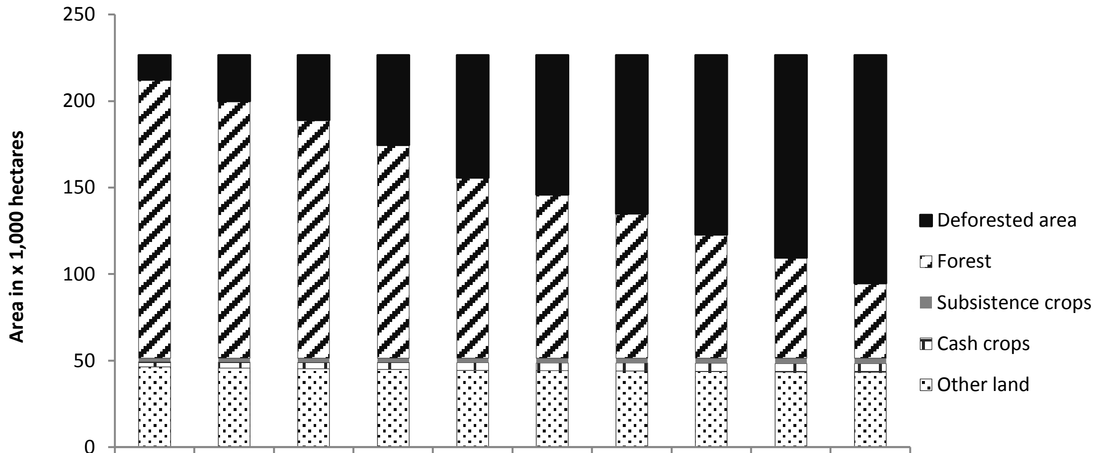


Year	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Deforested area	14,218	26,755	35,442	46,595	60,636	72,918	87,144	103,528	122,307	143,742
Forest	160,960	148,422	139,736	128,583	114,542	102,259	88,034	71,650	52,871	31,436
Subsistence crops	1,989	2,195	2,260	2,327	2,397	2,468	2,542	2,617	2,695	2,775
cash crops	3,039	3,516	3,780	4,064	4,369	4,585	4,812	5,051	5,301	5,563
Other land	46,415	45,732	45,403	45,051	44,677	44,389	44,089	43,775	43,447	43,104

Figure 4.6 Prediction of land use change by APM based on scenario BAU

Projected agriculture land for scenario moderate is presented in Figure 4.7. The APM was predicted that the changes were allowed in land class forest and scrub (see Table 3.4). Projected agriculture land in 50 years was expected to increase from 4,380 ha in 2000 and to 8,152 ha in 2050. The increase of area for cash crops in 50 years almost doubled the initial cash crops area, which increase from 3,039 ha to 4,943 ha. For subsistence crops area the increase occurred from 1,989 ha to 3,209 in 50 years.

Forest area in 2050 was estimated to decrease dramatically by 52% from 160,960 ha to 43,309 ha, while the deforested will area increase from 14,218 ha to 131,869 ha.

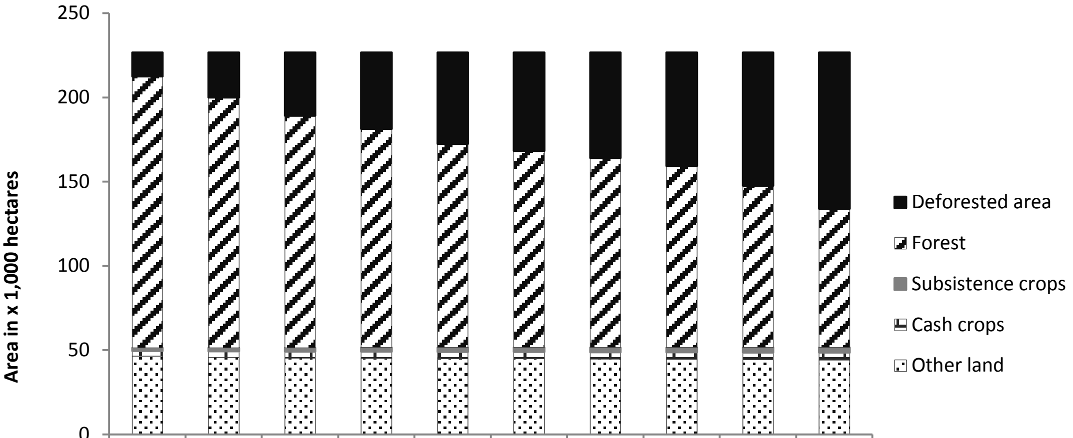


Year	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Deforested area	14,218	26,755	37,612	52,087	70,855	80,714	91,655	103,765	117,137	131,869
Forest	160,960	148,422	137,566	123,091	104,323	94,464	83,523	71,412	58,041	43,309
Subsistence crops	1,989	2,195	2,333	2,479	2,635	2,741	2,851	2,966	3,085	3,209
Cash crops	3,039	3,516	3,781	4,066	4,372	4,481	4,592	4,706	4,823	4,943
Other land	46,415	45,732	45,329	44,898	44,435	44,221	43,999	43,770	43,534	43,290

Figure 4.7 Prediction of land use change by APM based on scenario moderate

For the sustainable scenario the projected agriculture expansion was prioritized to degraded land or scrub area (see Table 3.8). The land use change for this scenario is presented in Figure 4.8. In 50 years the projected subsistence crops using scenario sustainable was expected to increase from 1,989 ha to 3,041 ha, while cash crops will increase 3,039 ha to 4,423 ha. In total the projected agriculture land will increase 1.08% from 5,028 ha to 7,465 ha.

Furthermore, in 50 years the forest area was predicted to decrease 34.6% from 160,960 ha to 82,424 ha. On the other hand, deforested area will increase 34.6% from 14,218 ha to 92,680 ha. With scenario sustainable, it is estimated in 50 years, the forest area remained in this area was 36.4% of its total land.



Year	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Deforested area	14,218	26,755	37,612	45,219	54,245	58,311	62,636	67,230	79,142	92,680
Forest	160,960	148,422	137,566	129,885	120,859	116,793	112,468	107,873	95,961	82,424
Subsistence crops	1,989	2,195	2,333	2,479	2,635	2,701	2,769	2,838	2,938	3,041
Cash crops	3,039	3,516	3,781	3,874	3,969	4,008	4,048	4,088	4,252	4,423
Other land	46,415	45,732	45,329	45,163	44,912	44,807	44,700	44,591	44,326	44,052

Figure 4.8 Prediction of land use change by APM based on scenario sustainable

The oil palm concession has a total area of 18,386 ha and located in other use according to forest status (Figure 4.9). The plantation is situated in an area that consists of scrub (41%) and forest (58%), while 1% of the area falls within production forest. Since the oil palm plantation was not established yet, the analysis to determine the ability of APM in predicting forest conversion due to oil palm was undertaken by comparing the oil palm concession area with the predicted forest conversion (Figure 4.9). Assuming that the company permit was valid for 30 years, the prediction of forest conversion on the year 2040 was taken. The result shows that the prediction of forest conversion in 2040 for scenario moderate match 78% of the concession area, while for business as usual scenario match 74% and sustainable scenario match 62%. However this calculation was not done to determine which scenario is better to predict oil palm expansion, but rather to observe the result of each scenario in relation to oil palm expansion.

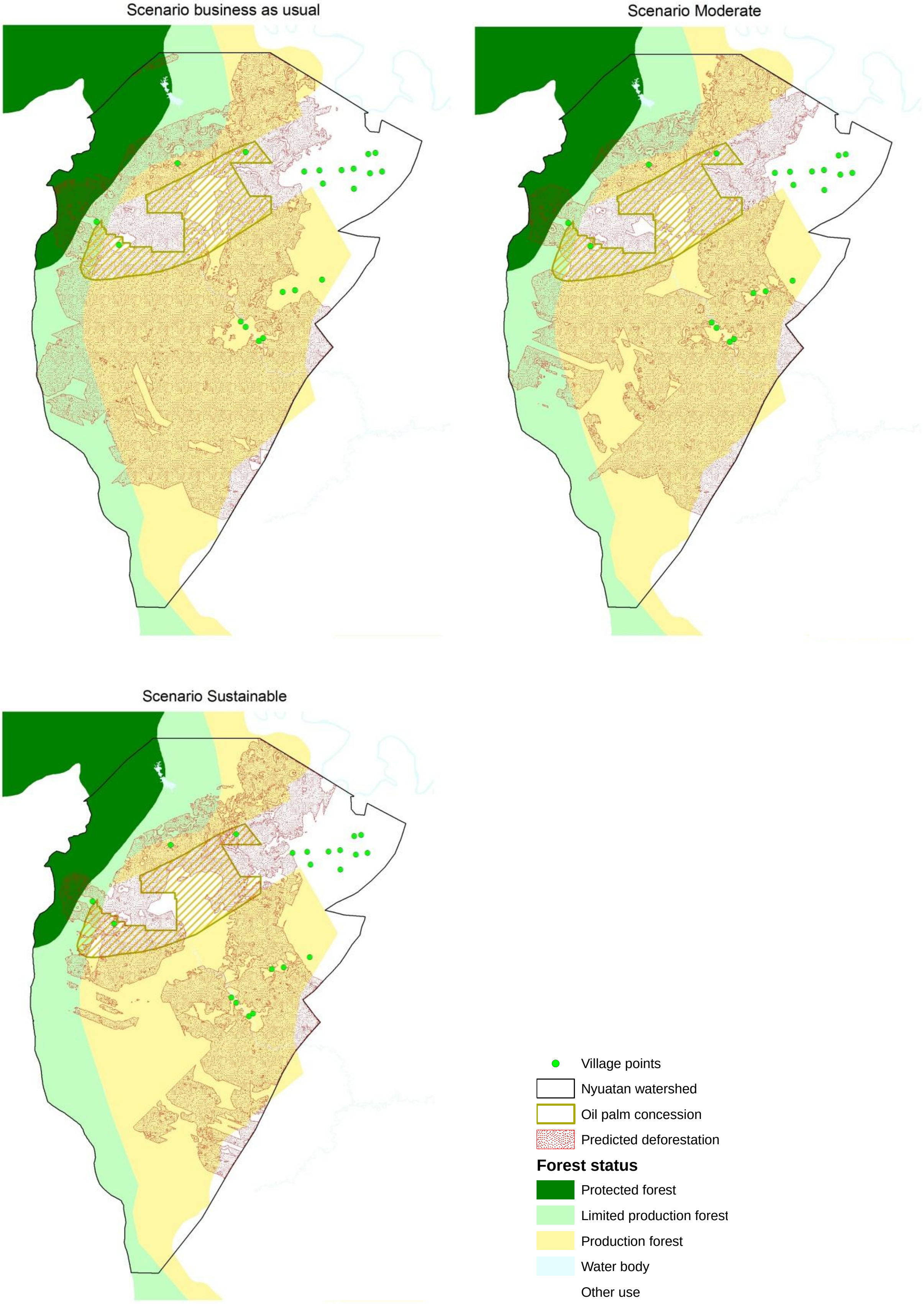


Figure 4.9 Prediction of forest conversion based on 3 different scenarios in relation to oil palm expansion

5. DISCUSSION

The rate of deforestation in the period of 2000 – 2009 in Nyuatan watershed reached to 1.23% per year, with the current trend in agriculture development deforestation was expected to continue. Harris, et al., (2008) showed that the rate of deforestation during period 1997 – 2003 in East Kalimantan reached to 2.9 per year. This study showed that forest in East Kalimantan is facing a high threat of forest conversion, including Nyuatan watershed.

Generally, the study area is suitable for deforestation, considered from the suitability map and that the area used to have a timber logging company. The area not suitable for forest conversion in the map is the area which has higher slope and further from access facilities such as roads (see Figure 3.3). The occurrence of deforested area in Nyuatan watershed was more concentrated in distance close to the roads and in low slope condition. In this area the logging roads are already existed from the previous logging company, which then provide access to the forest areas. Furthermore, the occurrence of deforested areas showed varies results in relation to distance to rivers. This study found occurrence of deforested areas within the distance of 10 km, which is different than the result by Ato (1996) in Thailand, which showed that more than 70% of the deforested areas occurred within the distance range of 1 km from the river.

The result of the distribution of forest conversion areas related to access related factors corresponds with the outcome of Fuller et al., (2010) which showed that these factors are most closely related to proximate causes of deforestation. There are studies that also have considered these factors as contributing factors of forest conversion (Echeverria et al., 2008; Fuller, et al., 2010; Siles, 2009). Major investments on natural resources exploitation and agricultural expansion has opened access to forest resources and increasing threats to higher forest conversion.

In numerical APM, the projected agriculture land was calculated to predict how much the forest being converted due to the influence of agriculture land. The projected agriculture land was influenced by factors of growth of GDP, population and agriculture productivity. These factors were assumed to have effect on the demand of agriculture land which leads to the increase of forest conversion. However, these factors may have a positive correlation on the projected agriculture land. According to numerical APM, when the GDP increase, it can increase the projected agriculture land. Furthermore, in reality the increase of agriculture land will increase the GDP condition. If there is a high correlation between the factors it can affect the performance of the model in predicting forest conversion in relation to the projected agriculture land.

The calibration using regression models can be applied in APM simulation. In this study the regression model which was used has an R^2 of 1. The perfect fit of R^2 in the model chosen may have an effect to the prediction. There can be overfitting in the model prediction and this can resulted into misinterpretation of the model or misleading.

Nyuatan sub district is one of the areas which have high production of rice paddy. Furthermore this area also experiencing the increase of cash crops production. According to the Estate Agency of Kutai Barat by 2011 the rubber plantation has increased to 17 million stands. While total oil palm planted to 2011 reach to 95,300 tree stands. This condition has changed the agriculture pattern in Kutai Barat district including Nyuatan watershed to cash crops which is considered more profitable.

APM was able to predict the quantity and the location of forest conversion due to agriculture expansion. Agriculture expansion, one of the main drivers of deforestation in developing countries was in this study set to predict expansion to forest and scrub. The numerical accuracy acquired from this study reach to 86% which is better than the simulation in East Java by de Gier, et al., (1999) with accuracy of 77%. However, the numerical accuracy in the case of Thailand by Ato (1996) obtain better accuracy which is 99.5%. Spatial accuracy acquired in this study reached to 65% which is slightly better compared to Ato (1996) and de Gier, et al., (1999), which reached 60.1% and 53.8% respectively.

Like studies which used predictive models (Echeverria, et al., 2008; Harris, et al., 2008), APM also used assumptions in the model simulation. In Hargyono (1993) and Ato (1996) the assumptions for growth factors were based on the current trend of each study area. In this study, the assumptions of the growth factors were based on current trend as well as on the influence of the establishment of oil palm plantation in the area.

Figure 5.1 shows the location of correct and incorrect predicted and also observed deforestation. However, the spreading of deforestation was over estimated by the model. The incorrect prediction of deforestation in these areas[4] (Figure 5.1) occurred due to the influence of the factor maps. The difficulty of predicting location of deforestation also was found in, for example Schneider et al., (2001) which were caused by underlying causes of deforestation that may exist. The suitability of deforestation map resulted from the combination of factor maps (see Figure 3.3) influenced the direction of the spreading of deforestation would occur.

However, there are a number of locations which the APM did not predict[1,2,3] (Figure 5.1). The upper right part of the study area is located near a mining area, and possibly affected by mining activities (see Figure 5.1 point 1). Unfortunately, there was no map of mining concession to show whether the forest conversion occurring inside or outside of the mining concession.

The lower right area where deforestation was observed but not predicted was located in the boundary of the study area (Figure 5.1 point 3). The inset map provided in Figure 5.1 described that the road network in this area was extended to outside of the boundary. There are villages located 9 km from the deforestation area which are not belong to Nyuatan or Linggang Bigung sub district, but belongs to Damai sub district. So there are pressure factors outside of the study area which may contribute to the forest conversion.

Due to the limited data in this research, the validation was done using land use map 2009 which was also used in model calibration. In Pontius et al., (2004) there should be clear distinction in both the method and data used for calibration and validation. The validation in the case of Nyuatan watershed which was used the same data for calibration may have an effect in the validity of the output model and the future prediction by the model itself.

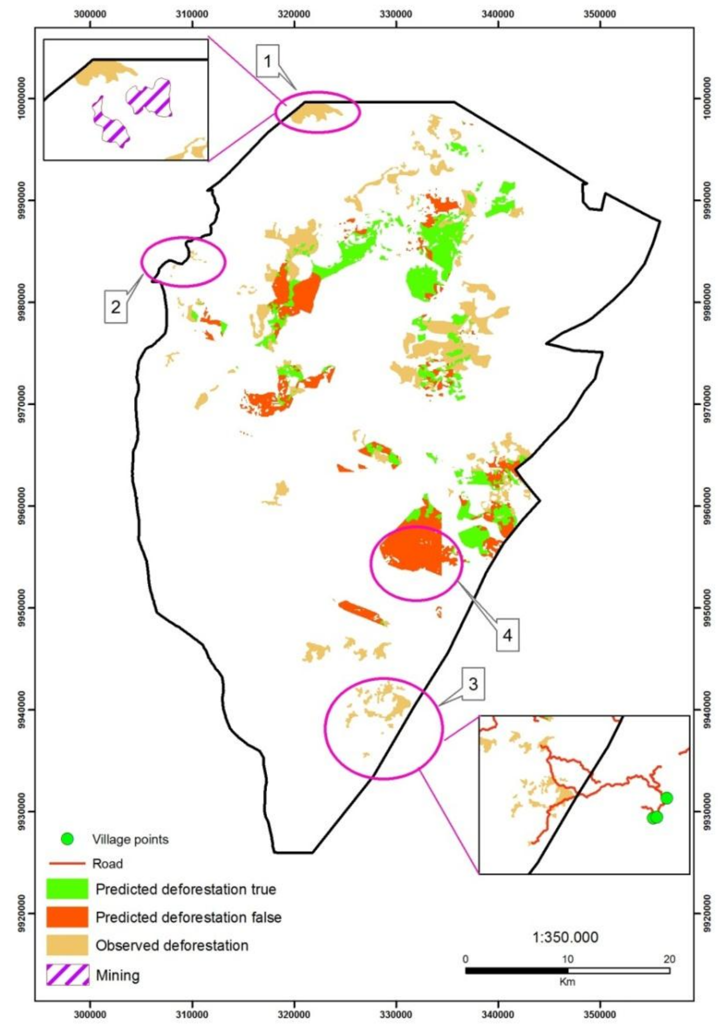


Figure 5.1 Observed and predicted of forest conversion area for the period of 2005 – 2009

One study by (Sandker, et al., 2007) used STELLA for modeling forest conversion due to oil palm expansion in Malinau District, East Kalimantan. The model was based on the establishment of oil palm and the impact of population growth. The study modeled that 500,000 ha of oil palm plantation will be expanding and predicted that when oil palm development attracted immigration it would take 11.7% of the forest area.

The study in Nyuatan watershed, on the other hand, did not predict forest conversion solely due to oil palm, but incorporated oil palm to agriculture expansion. However, this prediction is also based on the fact that there will be expansion of oil palm in the study area. The oil palm company has plans to plant in more than 18,000 hectares. The concession area itself is located in non-forest according to forest status classification but 58% of the area was actually covered by forest. Therefore, the oil palm plantation contributed to forest conversion. The APM was able to predict forest conversion due to oil palm. The oil palm was categorized as cash crops along with rubber plantation in the simulation, and from the prediction was also expanding outside the concession area. However, validation of oil palm expansion was only possible within the concession area.

The oil palm plantation in the Nyuatan watershed was already taking a large part of the non-forest area or Other Use according to Forest status classification scheme (Figure 4.9). Consequently the agricultural area for local community was very limited and this may lead to even more agriculture expansion into the forest area. During fieldwork, 9 villages located on the edge and inside the production forest (Figure 4.9). According to Government Decree No.06/2007 it is allowed for the community to extract non-timber forest products but it is not allowed to use the area for agriculture. This can lead to competition for agricultural land and illegal timber logging by the local community (Marti, 2008).

Spatial models, such as APM, can assist policy makers and other stakeholders to understand where, when and how much deforestation will occur with different scenarios. Scenario business as usual predicted that in 50 years the forest will decrease 57%, while scenario moderate predicted 52% decrease in forest area and sustainable scenario predicted forest decrease 34%. Scenario business as usual and moderate showed that more than 50% of forest area will decrease. This occurred due to the preference of these two scenarios in opening new agriculture area to forest area.

The business as usual scenario will provide the decision makers and other stakeholders of the forest condition if practises of agriculture expansion to the forest area keep continuing. In this study scenario business as usual predicted that in 50 years forest cover will decrease by 57%. Moreover, when the sustainable scenario was used, the forest conversion can be reduced to 34% if agriculture expansion was prioritized to scrub.

Based on the APM predictions and scenarios alternatives should be created: the agriculture land should be prioritized to scrub areas rather than to forest. Furthermore, the oil palm companies should employ people living in the surrounding of the plantation. This condition can also reduce population growth since immigration can be avoided. It was assumed that with the employment of the local people there is an alternative for livelihood and in this case new agricultural areas can be reduced.

Oil palm plantations in Indonesia have expanded rapidly and with the current government plan to expand the oil palm plantation to 20 million hectares (Cholhester, et al., 2006) this condition will likely to continue. Pros and cons are still facing the status of oil palm plantation. One can't argue that oil palm is increasing economic growth (Sheil, et al., 2009), but the conversion of forest area to oil palm had impact to biodiversity (Fitzherbert et al., 2008; Koh, et al., 2008). Furthermore, conflicts and weak law enforcement in Indonesia have created social problems (Joewono B. N., 2011; Rosarians, 2011).

A study by Harris et al., (2008) showed that Kutai Barat is one of the area in East Kalimantan which has a medium to high carbon stock but is facing a high threat when looking at forest conversion. With the agreement between the Government of Indonesia and the Norwegian Government that Indonesia must reduce deforestation and forest degradation significantly and the government must take immediate actions to achieve this. The development of spatial models, such as APM, as a planning tool will be able to support decision makers and other stakeholders to develop proper planning approaches. Furthermore the development of scenarios will describe the condition of the study area with each scenario and decision makers can create alternatives to overcome the issues.

6. CONCLUSIONS AND RECOMMENDATIONS

Forest area in Nyuatan watershed in the period of 2000 – 2009 had decrease by 17,416 hectares with the rate of deforestation 1.23% per year. The access to the forest area is already existed from the previous logging and mining company. In this study access related factors were analysed in relation to the forest conversion. Slope and distance to roads influences the occurrence of forest conversion while distance to settlement and distance to rivers have smaller impact to the occurrence of deforestation.

The forest conversion is largely caused by the increase of clearing land for agriculture. The increase of opening land for cash crops had contributed to the forest conversion. Cash crops are considered more profitable than subsistence crops and increase higher than subsistence crops. Forest conversion will likely to increase considering the trend of agriculture and the establishment of oil palm plantation in this area.

The regression model chosen during the model calibration has an R^2 of 1. The perfect fit may resulted into overfitting the model and influence the performance of the model prediction.

The APM simulates that in the periods of 2000 – 2009 forest decreased to 17,667 ha from 166,228 to 148,561. On the other hand agriculture increased 1,324 ha from 4,381 ha to 5,705. The APM numerical predicted 86% accurately when compared to the observed deforestation. The spatial APM simulation resulted to 65% accuracy. However, due to the limited data the map used for validation was also used for calibration. When the same data for calibration was used for validation, it may have an effect in the validity of the output model and the future prediction by the model itself.

The scenarios were developed to business as usual, moderate and sustainable scenarios. Scenario business as usual predicted that in 50 years the forest will decrease 57%, while scenario moderate predicted 52% decrease in forest area and sustainable scenario predicted forest decrease 34%. The development of scenarios in APM simulation will show the decision makers and stakeholders the agriculture expansion in relation to forest conversion with each scenario. Therefore, they will be able to develop proper planning approaches to overcome the issues.

Recommendations

The recommendations for further studies are as follows:

- Calibration in this study was done by calibrating the amount of forest converted in relation to agriculture expansion. Spatial calibration needs to be done to give a better spatial accuracy. The spatial calibration can improve the factor maps and increase the ability of spatial APM in more accurately predicting the exact locations of deforestation.
- In the calibration using regression models, each of the models should be simulated to the spatial APM. Each of the regression models can have different result on APM simulation. The comparison of each regression models can support researcher to decide which model performed the best.
- The factors which are used to project agriculture land in numerical APM should be tested for correlation between the factors. Each of the factors should be tested to determine the effect of the factors in the demand of agriculture land.
- There should be clear distinction in calibrating and validating the model. The data which is used for validation should not be used for calibration since it can mislead the interpretation of the model. A separate dataset should be reserved for validation.

LIST OF REFERENCES

Angelsen, A., Brown, S., Loisel, C., Pesket, L., Streck, C., & Zarin, D. (2009). *Reducing Emissions from Deforestation and Forest Degradation (REDD): An Options Assessment Report*: Meridian Institute.

Ato, V. A. (1996). *Prediction of deforestation using area production model and GIS : a case study of Phrao, Chiang Mai,Thailand.* Unpublished MSc Theses, ITC, Enschede.

Badan Perencanaan Pembangunan Daerah Provinsi Kalimantan Timur. (2008). *Peraturan Daerah Provinsi Kalimantan Timur Nomor 5 Tahun 2008 tentang Rencana Pembangunan Jangka Panjang Daerah Provinsi Kalimantan Timur Tahun 2005 – 2025. East Kalimantan Provincial Regulation No. 5 of 2008 on the Long Term Development Plan of East Kalimantan Province from 2005 to 2025.*

Badan Pusat Statistik Kutai Barat. (2008). *Kutai Barat dalam angka 2008. Kutai Barat in figures 2008.* Sendawar, Kutai Barat: Badan Pusat Statistik Kabupaten Kutai Barat

Badan Pusat Statistik Kutai Barat. (2010). *Kutai Barat dalam angka 2010. Kutai Barat in figures 2010.* Sendawar, Kutai Barat: Badan Pusat Statistik Kabupaten Kutai Barat

Bode, J. (1995). The crystal globe: research after the impact of spatial factors on the process of forest degradation in Kali Konto (Java) with the help of ILWIS computer model. Unpublished GIS-ILWIS H4 final research. The Netherlands.

Cholhester, M., Jiwan, N., Andiko, Sirait, M., Firdaus, A. Y., Surambo, A., & Pane, H. (2006). *Promised Land: Palm Oil and Land Acquisition in Indonesia - Implications for Local Communities and Indigenous Peoples*: Forest Peoples Programme, Perkumpulan Sawit Watch, HuMA and the World Agroforestry Centre.

Cooke, F. M. (2006). *Recent Development and Conservation Interventions in Borneo. State, Communities and Forests in Contemporary Borneo.* The Australian National University, Canberra, ANU E Press.

Corley, R. H. V. (2009). How much palm oil do we need? *Environmental Science & Policy, 12*(2), 134-139.

de Gier, A., & Hussin, Y. A. (1993). Spatially resolved area production model in Kali Konto, Indonesia. *In: GIS-LIS '93 : proceedings annual conference & exposition : 31 October - 4 November 1993, Minneapolis, Minnesota, USA : Vol. 1, pp. 157-169.*

de Gier, A., Hussin, Y. A., Hargyono, & Bode, J. (1999). application of spatial area production model APM in Kali Konto, East Java, Indonesia. *In: Data management and modelling using remote sensing and GIS for tropical forest land inventory : proceedings of the FIMP - INTAG international conference, October 26-29, 1998, Jakarta, Indonesia / Y. Laumonier ...[et al.] (eds.) Jakarta : Rodeo International, 1999. ISBN 979-95696-0-5 pp. 507-514.*

Department of Natural Resources. (2004). *The area production model (APM). Part II : Spatial Context. Case studies and exercises*. Enschede, The Netherlands: International Institute for Aerospace Survey and Earth Sciences.

Dewi, S., Belcher, B., & Puntodewo, A. (2005). Village economic opportunity, forest dependence, and rural livelihoods in East Kalimantan, Indonesia. *World Development, 33*(9), 1419-1434.

Echeverria, C., Coomes, D. A., Hall, M., & Newton, A. C. (2008). Spatially explicit models to analyze forest loss and fragmentation between 1976 and 2020 in southern Chile. *Ecological Modelling, 212*(3–4), 439-449.

FAO. (2010). *Global Forest Resource Assessment*. Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. (2011). *State of the world's forest*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Fitzherbert, E. B., Struebig, M. J., Morel, A., Danielsen, F., Brühl, C. A., Donald, P. F., & Phalan, B. (2008). How will oil palm expansion affect biodiversity? *Trends in Ecology & Evolution, 23*(10), 538-545.

Fuller, D., Hardiono, M., & Meijaard, E. (2011). Deforestation Projections for Carbon-Rich Peat Swamp Forests of Central Kalimantan, Indonesia. *Environmental Management*, 1-12.

Fuller, D., Meijaard, E. M., Christy, L., & Jessup, T. C. (2010). Spatial assessment of threats to biodiversity within East Kalimantan, Indonesia. *Applied Geography, 30*(3), 416-425.

Hargyono. (1993). *Occurence and prediction of forest degradation : a case study of Upper Konto watershed, East Java, Indonesia.* Unpublished MSc Theses, ITC, Enschede.

Harris, N. L., Petrova, S., Stolle, F., & Brown, S. (2008). Identifying optimal areas for REDD intervention: East Kalimantan, Indonesia as a case study. *Environmental Research Letters, 3*. doi:10.1088/1748-9326/3/3/035006

Indonesian Palm Oil Board. (2007). *Indonesian Palm Oil in Numbers*. Jakarta, Indonesia: Indonesian Palm Oil Board.

Joewono B. N. (2011, 24 November 2011). Lagi, ditemukan kerangka orangutan korban pembantaian (Found orangutan skeleton victims of slaughter). *Kompas*. Retrieved from http://regional.kompas.com/read/2011/11/24/19203225/Lagi.Ditemukan.Kerangka.Orangutan.Korban.Pembantaian

Joshi, L., Wijaya, K., Sirait, M., & Mulyoutami, E. (2004). *Indigenous systems and ecological knowledge among Dayak people in Kutai Barat, East Kalimantan – a preliminary report*. Bogor, Indonesia: ICRAF.

Koh, L. P., & Wilcove, D. S. (2008). Is oil palm agriculture really destroying tropical biodiversity? *Conservation Letters, 1*(2), 60-64.

Lambin, E. F. (1994). *Modelling deforestation processes : a review* (Vol. 1). Brussels: European Commission Joint Research Centre, Institute for Remote Sensing Applications ; ESA.

Linkie, M., Smith, R. J., & Leader-Williams, N. (2004). Mapping and predicting deforestation patterns in the lowlands of Sumatra. *Biodiversity and Conservation, 13*(10), 1809-1818.

Lomulder, R. (2004). *Appropriate modelling: Application of Sobek 1D2D for dike break and overtopping at the Elbe.* Unpublished MSc Thesis, University of Twente, Enschede, The Netherlands.

Malaysian Palm Oil Board. (2008). Overview of the Malaysian palm oil industry 2007. Retrieved 16 January 2012 23:41. http://econ.mpob.gov.my/economy/overview07.htm

Marti, S. (2008). *Losing Ground. The Human Rights Impact of Oil Palm Plantation Expansion in Indonesia*: Friends of the Earth, LifeMosaic and Sawit Watch.

Pontius Jr, R. G., Huffaker, D., & Denman, K. (2004). Useful techniques of validation for spatially explicit land-change models. *Ecological Modelling, 179*(4), 445-461.

Pontius, R., Boersma, W., Castella, J.-C., Clarke, K., de Nijs, T., Dietzel, C., Duan, Z., Fotsing, E., Goldstein, N., Kok, K., Koomen, E., Lippitt, C., McConnell, W., Mohd Sood, A., Pijanowski, B., Pithadia, S., Sweeney, S., Trung, T., Veldkamp, A., & Verburg, P. (2008). Comparing the input, output, and validation maps for several models of land change. *The Annals of Regional Science, 42*(1), 11-37.

Potter, L. (2005). Commodifying, Consuming and Converting Kalimantan's Forests, 1950–2002. In P. Boomgaard, D. Henley & M. Osseweijer (Eds.), *Muddied Waters: Historical and Contemporary Perspectives on Management of Forests and Fisheries in Island Southeast Asia*. Leiden: KITLV.

Puyravaud, J.-P. (2003). Standardizing the calculation of the annual rate of deforestation. *Forest Ecology and Management, 177*(1–3), 593-596.

Rignot, E., Salas, W. A., & Skole, D. L. (1997). Mapping deforestation and secondary growth in Rondonia, Brazil, using imaging radar and thematic mapper data. *Remote Sensing of Environment, 59*(2), 167-179.

Rosarians, F. (2011, 16 December 2011). Soal Mesuji, pemerintah diminta periksa investor Malaysia. (About Mesuji, Government was asked to check investors from Malaysia). *Tempo*. Retrieved from http://www.tempo.co/read/news/2011/12/16/063371990/Soal-Mesuji-Pemerintah-Diminta-Periksa-Investor-Malaysia.

Rykiel, E. J. J. (1996). Testing ecological models: the meaning of validation. *Ecological Modelling, 90*(3), 229-244.

Sandewall, M., & Nilsson, N. E. (2001). The Area Production Model: A tool and concept for sustainable land-use and forest-resource management. *Journal of Environmental Management, 62*(4), 415-427.

Sandker, M., Suwarno, A., & Campbell, B. M. (2007). Will forests remain in the face of oil palm expansion? Simulating change in Malinau, Indonesia. *Ecology and Society* Retrieved 24 January 2012. From: http://www.ecologyandsociety.org/vol12/iss2/art37/

Schneider, L. C., & Gil Pontius Jr, R. (2001). Modeling land-use change in the Ipswich watershed, Massachusetts, USA. *Agriculture, Ecosystems & Environment, 85*(1–3), 83-94.

Sheil, D., Casson, A., Meijaard, E., Noordwijk, M. v., Gaskell, J., Sunderland-Groves, J., Wertz, K., & Kanninen, M. (2009). *The Impacts and Opportunities of Oil Palm in Southeast Asia. What Do We Know and What Do We Need to Know*. Bogor: CIFOR.

Siles, N. J. S. (2009). *Spatial modelling and prediction of tropical forest conversion in the Isiboro sécure national park and indigenous territory TIPNIS, Bolivia.* Unpublished MSc Theses, ITC, Enschede.

UNFCC. (2011). Kyoto Protocol. Retrieved 03 August 2011 14:36. From http://unfccc.int/kyoto_protocol/items/2830.php

USDA. (2007). *Economic research service. Oil crops yearbook*.

Wakker, E. (2006). *The Kalimantan Border Oil Palm Mega-project.* Amsterdam, The Netherland: AIDEnvironment.

Wicke, B., Sikkema, R., Dornburg, V., & Faaij, A. (2011). Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. *Land Use Policy, 28*(1), 193-206.

Yanuardi, T. (1999). *Sustainable land allocation. GIS-based decision support for industrial plantation development in Indonesia* Unpublished PhD dissertation, ITC, Enschede.

Zikri, M. (2009). *An Econometric Model for Deforestation in Indonesia*: Center for Economics and Development Studies, Department of Economics, Padjadjaran University.

APPENDICES

Appendix 1. Script of Spatial APM

```
breakdep deforest.mpr
breakdep deforest_code.mpr
breakdep mapcross.tbt
breakdep predictnew.tbt
breakdep mapcross2.tbt
breakdep mapcross2.mpr
breakdep mapcross2.dom
breakdep mapcross.mpr
breakdep mapcross.dom
breakdep vilfact.mpr
breakdep mapout1.mpr
breakdep mapout.mpr
breakdep friction.mpr
breakdep tot_weight.mpr
breakdep tot_weight1.mpr
breakdep forprior.mpr
breakdep priornew.tbt
breakdep popnew.tbt

del deforest.mpr -force
del deforest_code.mpr -force
del mapcross.tbt -force
del predictnew.tbt -force
del mapcross2.tbt -force
del mapcross2.mpr -force
del mapcross2.dom -force
del mapcross.mpr -force
del mapcross.dom -force
del vilfact.mpr -force
del mapout1.mpr -force
del mapout.mpr -force
del friction.mpr -force
del tot_weight.mpr -force
del tot_weight1.mpr -force
del forprior.mpr -force
del priornew.tbt -force
del popnew.tbt -force

// Copy table PREDICT, open this copy PREDICTNEW, the user can edit column agricultural area and new agricultural area
copy predict.tbt predictnew
open predictnew.tbt
```

```
message You can edit the columns agr_land (initial agricultural land area in hectares), future_agr (future agricultural land area in hectares) and future_years (time period of the calculation) in the table PREDICTNEW - ATTENTION: FIRST EDIT THE TABLE AND THEN PRESS THE OK BUTTON TO CONTINUE APM!
closeall

// Copy table Populat, calculate the columns Pressure, Vilfact and Weight in the POPNEW table
copy populat.tbt popnew
open popnew.tbt
message You can edit the column popgrowth (population growth by village)  in the table POPNEW - ATTENTION: FIRST EDIT THE TABLE AND THEN PRESS THE OK BUTTON TO CONTINUE APM!
closeall

tabcalc popnew Pressure:=number/surface
tabcalc popnew Vilfact:=pressure*popgrowth
tabcalc popnew
weight:=iff(isundef(vilfact),0,(iff(vilfact<10,5,iff(vilfact<20,4,iff(vilfact<30,3,iff(vilfact<40,2,1))))))

// Copy table PRIORITY, open this copy PRIORNEW, the user can edit column Priority
copy priority.tbt priornew
open priornew.tbt
message You can edit the Priority column in the table PRIORNEW - ATTENTION: FIRST EDIT TABLE PRIORNEW AND THEN PRESS THE OK BUTTON TO CONTINUE APM!
closeall

// Take the maximum value of column Priority in the PRIORNEW table
opentbl priornew.tbt
tabcalc priornew.tbt max:=max(priority)
closetbl priornew.tbt
setatttable Landuse_code.mpr priornew.tbt
setatttable village_thies.mpr popnew.tbt
setatttable roaddis.mpr roaddis.tbt
setatttable settldis.mpr settldis.tbt
setatttable slope.mpr slope.tbt
setatttable riverdis.mpr riverdis.tbt

// Calculate the map FORPRIOR
Forprior:=Landuse_code.mpr.priority/Landuse_code.max*5

// Calculate the map VILFACT
Vilfact.mpr{dom=value;vr=-1:7:1}=village_thies.weight

// Calculate the map FRICTION and the SOURCE map for the distance operation
tot_weight1:=roaddis.weight+settldis.weight+slope.weight+riverdis.weight
tot_weight:=mapfilter(tot_weight1,avg3x3)
```

```
Friction:=iff((Landuse_code="11") OR (Landuse_code="13"),0,(iff(Village="River",-1,tot_weight)))

// Calculate the map MAPOUT
Mapout1:=(forprior*vilfact*friction/100)
mapout:=iff(mapout1<0,0,mapout1)


// Calculate the histogram of MAPOUT
Mapout.his=TableHistogram(Mapout)
calc mapout.hisf

// Create crosstable Mapcross and calculate column cumarea (Cumulative Area)
mapcross:=TableCross(mapout.mpr,mapout.mpr,mapcross,IgnoreUndefs)
opentbl mapcross.tbt
tabcalc mapcross.tbt cumarea = cum(Area)
closetbl mapcross.tbt

//  calculate columns deforesttemp and deforest
opentbl predictnew.tbt
tabcalc predictnew.tbt present_forest=26480+(66.467*predictnew.tbt.agr_land)-
0.0079*POW(predictnew.tbt.agr_land,2)
tabcalc predictnew.tbt future_forest=26480+(66.467*predictnew.tbt.demand_agr)-
0.0079*POW(predictnew.tbt.demand_agr,2)
tabcalc predictnew.tbt deforestation:=(present_forest*10000)-(future_forest*10000)+mapcross.cumarea[1]
closetbl predictnew.tbt

opentbl mapcross.tbt
tabcalc mapcross.tbt
deforesttemp{dom=Landuse_groups}=iff(cumarea<predictnew.tbt.deforestation[1],"Deforestation",?)
tabcalc mapcross.tbt deforest=iff(mapout<>0,deforesttemp,?)
tabcalc mapcross.tbt
deforesttemp_c{dom=Landuse_code}=iff(cumarea<predictnew.tbt.deforestation[1],0,?)
tabcalc mapcross.tbt deforest_c=iff(mapout<>0,deforesttemp_c,?)
closetbl mapcross.tbt

setatttable mapcross.mpr mapcross.tbt

// Calculate forest degradation map
deforest_code{dom=Landuse_code}:=ifundef(mapcross.deforest_c,Landuse_code)
deforest{dom=Landuse_groups}:=ifundef(mapcross.deforest,Landuse_groups)

open deforest.mpr -noask
```

Appendix 2. Data source

Data Type		Data	Year	Source	Remarks
Spatial	Image	Landsat image	2000, 2005, 2009,	Tropenbos International and http://glovis.usgs.gov/	
		ALOS PRISM	2009	Tropenbos International	
	Map	Land use	2000, 2005, 2009,	Tropenbos International	Landsat image interpretation. Information about existing agricultural land, forest land (function-based forest land), settlement and other land use.
		Administration		Development Planning Agency of East Kalimantan Province	information about administration boundary
		Slope		http://srtm.csi.cgiar.org	Derived from SRTM 90 m
		Roads		Digitizing Landsat image	
		Settlement		Digitizing ALOS PRISM image	Derived from ALOS PRISM
		River		Digitizing Landsat image	
Non spatial (Input variables)		Population growth	2005, 2006, 2007, 2008, 2009	Statistical Agency of Kutai Barat	
		GDP growth			
		Growth of production of subsistence crops			
		Growth of production of local market crops			
		Growth of production of industrial / export crops			

Appendix 3. Land use coordinates from field observation

X	Y	Land use type
309673.00	9977583.00	land clearing
309801.37	9977609.42	mixed tree crops
310373.19	9977234.63	mixed tree crops
310736.97	9977624.56	mixed tree crops
310818.25	9978008.25	mixed tree crops
317284.89	9970894.23	mixed tree crops
309331.12	9978133.57	mixed tree crops
309314.31	9978515.97	mixed tree crops
310452.13	9979190.66	mixed tree crops
312879.97	9977420.24	mixed tree crops
311806.95	9977274.71	mixed tree crops
311225.34	9977529.41	mixed tree crops
313586.39	9976456.70	mixed tree crops
314257.14	9975422.05	mixed tree crops
314882.71	9974204.46	mixed tree crops
343122.40	9980921.99	mixed tree crops
334092.84	9985355.73	mixed tree crops
328676.44	9986057.97	mixed tree crops
342685.21	9981432.49	palm oil plantation
403029.15	9922232.30	palm oil plantation
402148.87	9924704.13	palm oil plantation
402761.84	9928040.36	palm oil plantation
342380.50	9944714.02	palm oil plantation
340009.98	9941232.63	palm oil plantation
342657.38	9981429.68	palm oil plantation
362701.61	9927634.53	palm oil plantation
360549.63	9884953.50	palm oil plantation
360429.47	9930176.77	palm oil plantation
317444.96	9973994.89	palm oil plantation
342279.04	9980994.45	palm oil plantation
342606.79	9981436.19	rubber plantation
341464.77	9980597.12	rubber plantation
318136.07	9970870.86	secondary forest
317672.76	9971397.88	secondary forest
316098.98	9971186.46	secondary forest
318554.77	9974719.81	secondary forest
318340.82	9970847.95	secondary forest
318301.86	9970883.33	secondary forest
318218.36	9970903.22	secondary forest
309550.08	9977400.83	secondary forest
309595.72	9977365.45	secondary forest
309744.90	9977345.56	secondary forest
309773.85	9977289.16	secondary forest
326475.32	9986444.11	shrub
323139.61	9984995.39	shrub

Appendix 4. Land use photos from field observation

Land clearing for agriculture

Land clearing for agriculture

Oil Palm seedling

Forest

Forest

Mixed tree crops with *durian* trees

Rubber plantation

Appendix 5. Socio economic data

Population growth

Year	Population		
	Sub District Nyuatan	Sub District Linggang Bigung	Study area
2000	3,790	12,290	16,080
2001	3,832	12,425	16,257
2002	4,665	13,701	18,366
2003	4,398	12,317	16,715
2004	5,326	12,868	18,194
2005	6,346	13,649	19,995
2006	6,363	14,109	20,472
2007	6,077	14,551	20,628
2008	6,023	14,606	20,629
2009	5,391	13,657	19,048

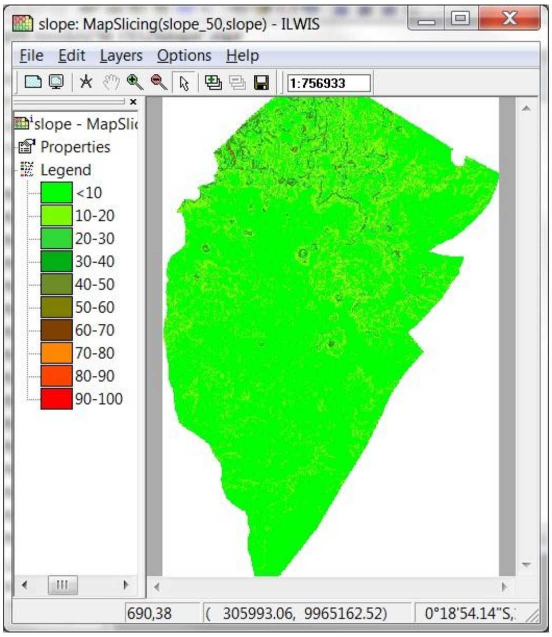
Gross Domestic Product growth

Year	GDP (US$)	GDP per capita (US$)	Income per capita (US$)	GDP per capita without mining sector (US$)	Income per capita without mining sector (US$)
2000	166,507,769	1,225,971,472	943,361,971	697,533,180	414,923,679
2005	261,828,512	1,701,424,764	1,282,752,321	887,542,154	500,607,464
2009	337,808,742	2,088,100,618	1,579,210,939	1,006,164,806	497,275,125

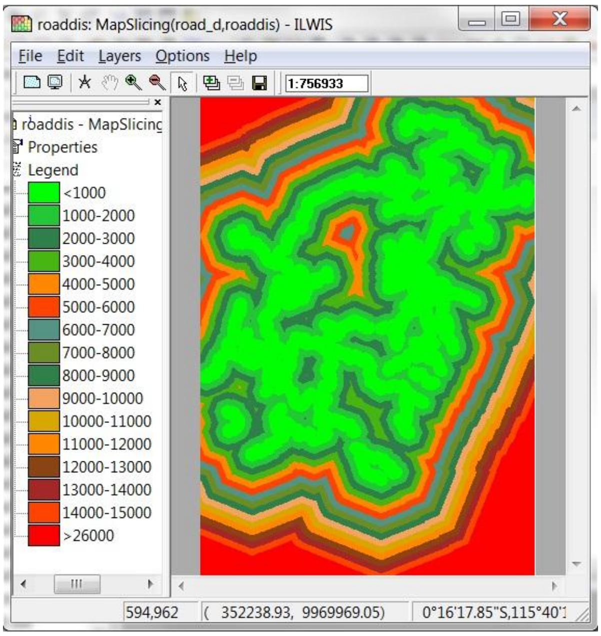
Agriculture growth

Agriculture products	2000			2005			2009		
	area (ha)	production (ton)	productivity (ton/ha)	area (ha)	production (ton)	productivity (ton/ha)	area (ha)	production (ton)	productivity (ton/ha)
Horticulture	3,029.48	23,641.64	7.80	2,364.00	17,141.36	7.25	1,462.96	2,253.00	1.54
Rice paddy	1,175.07	2,641.19	2.25	1,188.00	2,670.24	2.25	1,224.00	3,199.00	2.61
Oil palm and rubber plantation	4,210.68	5,411.99	1.22	4,257.00	5,471.52	1.29	2,697.00	5,395.13	2.00

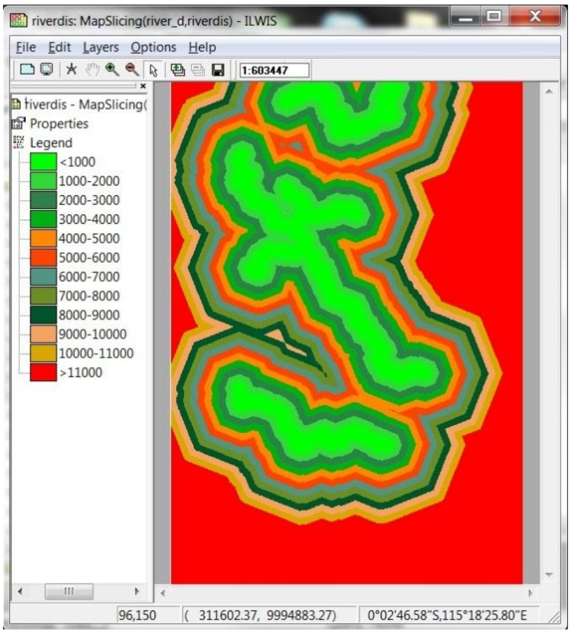
Appendix 6. Factor maps



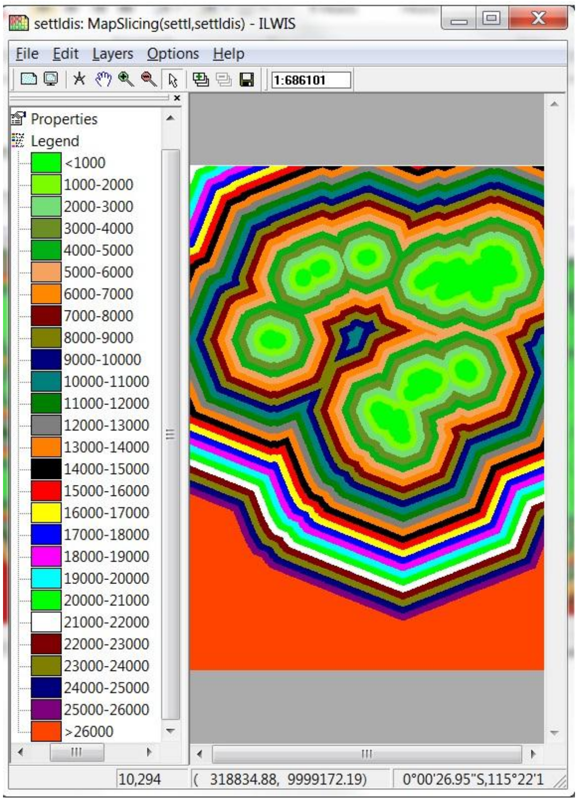
a. Slope map



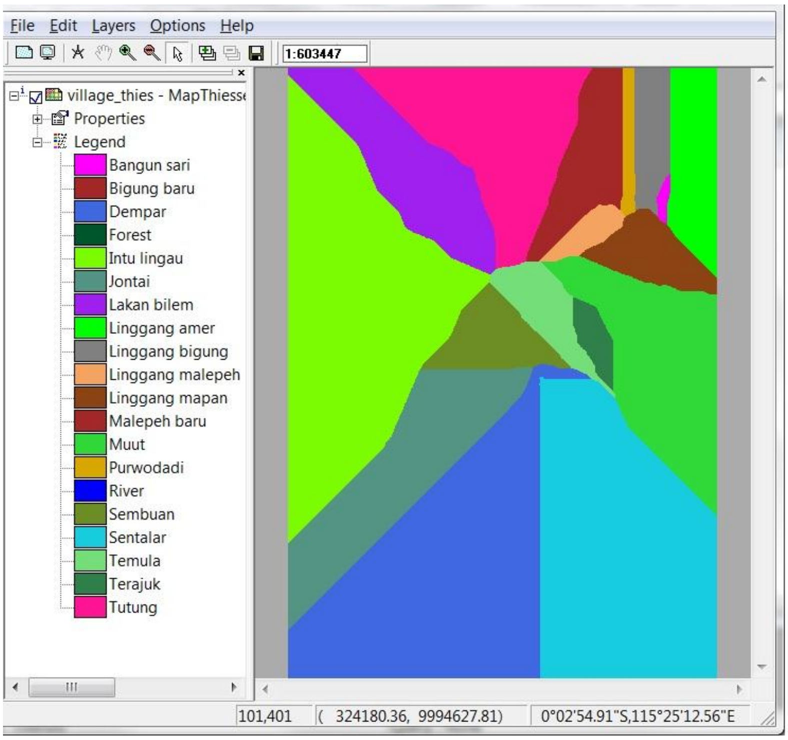
b. Distance to road map



c. Distance to river map



d. Distance to settlement map



e. Village boundary map

Appendix 7. Weight of factor maps

a. Slope map

Slope Class (%)	Class weight
<10	1.000
10-20	2.554
20-30	7.429
30-40	23.229
40-50	46.458
50-60	62.829
60-70	65.970
70-80	65.970
80-90	65.970
90-100	65.970

b. Road map

Distance class (Km)	Density	Relative weight	Class weight
<1000	50.980	45.514	1.000
1000-2000	21.550	16.084	2.305
2000-3000	12.640	7.174	3.811
3000-4000	4.990	-0.476	8.678
4000-5000	3.720	-1.746	11.013
5000-6000	1.220	-4.246	23.414
6000-7000	0.120	-5.346	46.411
7000-8000	0.040	-5.426	49.981
8000-9000	0.000	-5.466	51.980
9000-10000	0.000	-5.466	51.980
10000-11000	0.000	-5.466	51.980
11000-12000	0.080	-5.386	48.130
12000-13000	0.780	-4.686	29.202
13000-14000	2.620	-2.846	14.359
14000-15000	1.250	-4.216	22.553
>26000	0.000	-5.466	51.980

c. River map

Distance class (Km)	Density	Relative weight	Class weight
<1000	11.5100	6.0437	1.0000
1000-2000	17.5600	12.0937	0.6740
2000-3000	10.2900	4.8237	1.1080
3000-4000	6.8900	1.4237	1.5860
4000-5000	8.8700	3.4037	1.2670
5000-6000	13.3300	7.8637	0.8730
6000-7000	13.4900	8.0237	0.8630
7000-8000	10.0000	4.5337	1.1370
8000-9000	6.0600	0.5937	1.7720
9000-10000	1.8200	-3.6463	4.4360
10000-11000	0.1300	-5.3363	11.0710
>11000	0.0000	-5.4663	12.5100

d. Settlement map

Distance class (Km)	Density	Relative weight	Class weight
<1000	1.67	-3.80	5.3070
1000-2000	8.49	3.02	1.5610
2000-3000	9.34	3.87	1.4340
3000-4000	11.35	5.88	1.2030
4000-5000	13.90	8.43	1.0000
5000-6000	12.10	6.63	1.1350
6000-7000	11.27	5.80	1.2110
7000-8000	6.32	0.85	2.0130
8000-9000	4.58	-0.89	2.6190
9000-10000	1.29	-4.18	4.1550
10000-11000	0.53	-4.94	2.9280
11000-12000	1.08	-4.39	3.8300
12000-13000	1.94	-3.53	4.8030
13000-14000	3.62	-1.85	3.1490
14000-15000	1.80	-3.67	5.0790
15000-16000	0.24	-5.23	10.7350
16000-17000	1.13	-4.34	6.5600
17000-18000	0.96	-4.51	7.0500
18000-19000	1.29	-4.18	6.1340
19000-20000	1.50	-3.97	5.6450
20000-21000	2.17	-3.30	4.5130
21000-22000	1.36	-4.11	5.9540
22000-23000	1.07	-4.40	6.7160
23000-24000	0.53	-4.94	8.7470
24000-25000	0.30	-5.17	10.2680
25000-26000	0.01	-5.46	12.7660
>26000	0.00	-5.47	14.9000

e. Population pressure

Village	Surface	Number	Population growth	Pressure	Village factor	Weight
Bangun sari	99.45	1524	1.021	15.32	15.64172	4
Bigung baru	52.35	426	1.021	8.14	8.31094	5
Dempar	17.00	529	1.021	31.12	31.77352	2
Forest	225357.57	0	0.000	0.00	0.00000	5
Intu lingau	100.00	2088	1.021	20.88	21.31848	3
Jontai	47.00	890	1.021	18.94	19.33774	4
Lakan bilem	13.00	433	1.021	33.31	34.00951	2
Linggang amer	43.88	1098	1.021	25.02	25.54542	3
Linggang bigung	140.38	3489	1.021	24.85	25.37185	3
Linggang malepeh	50.00	1231	1.021	24.62	25.13702	3
Linggang mapan	84.91	927	1.021	10.92	11.14932	4
Malepeh baru	70.00	1567	1.021	22.39	22.86019	3
Muut	30.00	613	1.021	20.43	20.85903	3
Purwodadi	82.68	1389	1.021	16.80	17.15280	4
River	39.00	0	0.000	0.00	0.00000	5
Sembuan	20.41	495	1.021	24.25	24.75925	3
Sentalar	16.64	347	1.021	20.85	21.28785	3
Temula	18.00	372	1.021	20.67	21.10407	3
Terajuk	29.33	579	1.021	19.74	20.15454	3
Tutung	75.00	2458	1.021	32.77	33.45817	2

Appendix 8. Observations of 3 different regression models for APM calibration

Model $Y=a+bX$

X (Agriculture land)	Y (Forest)	$Y_{estimate}$ (Forest estimate)
4,405.73	166,302.35	168,103.27
4,080.20	161,354.51	156,688.32
3,876.21	146,662.99	149,535.17

Model $Y=a+bX+cX^2$

X (Agriculture land)	Y (Forest)	$Y_{estimate}$ (Forest estimate)
4,405.73	166,302.35	166,047.08
4,080.20	161,354.51	160,950.65
3,876.21	146,662.99	148,504.19

Model $Y=a+(b/X)$

X (Agriculture land)	Y (Forest)	$Y_{estimate}$ (Forest estimate)
4,405.73	166,302.35	170,373.66
4,080.20	161,354.51	159,508.41
3,876.21	146,662.99	151,769.62

Appendix 9. Projected agriculture area using numerical APM

	Projected agriculture land (ha)		
Year	Subsistence crops	Cash crops	total
2000	1,866.79	2,538.94	4,405.73
2005	1,839.34	2,586.77	4,426.11
2010	1,932.78	2,635.50	4,568.28
2015	2,013.18	2,685.14	4,698.32
2020	2,096.93	3,014.66	5,111.58
2025	2,184.15	3,384.61	5,568.76
2030	2,248.43	3,618.39	5,866.82
2035	2,314.61	3,685.88	6,000.49
2040	2,382.73	3,754.63	6,137.36
2045	2,452.85	3,824.67	6,277.52
2050	2,525.04	3,896.01	6,421.04