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# LANDCOVER CHANGE ANALYSIS USING REMOTE SENSING AND GIS:

## INITIAL PHASE OF MEASURING CARBON SEQUESTRATION FOR REDD+ IN MERU BETIRI NATIONAL PARK, INDONESIA

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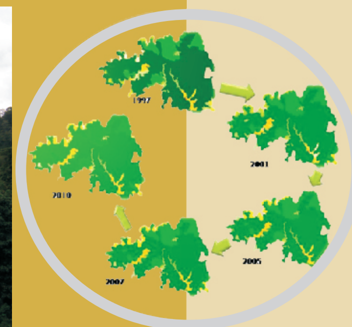

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# V. RECOMMENDATIONS

To enhance the accuracy and reliability of landcover mapping, more historical data on landcover and landuse and the application of high resolution radar imageries should be taken into account for further use, especially for biomass mapping.

Improved methods on biomass mapping should be considered since landcover mapping from optical sensor has quite high uncertainty.

Historical data on socio-economic and biophysical data should be well documented in order to be quantified as inputs for the drivers of change in Meru Betiri National Park.

The forecasting model shows that there is a tendency of forestland area per capita decrease when cropland and settlement per capita are increasing. Therefore, attention should be carefully put by the MBNP organization to the population growth in the villages surrounding the MBNP and the agricultural activities in the rehabilitation zone.



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# IV. CONCLUSION

The objective of this technical report is to obtain supporting data which will be used for measuring, monitoring and reporting (MRV) carbon emission in Meru Betiri National Park (MBNP) using IPCC Guidelines 2006.

Jember University and FORDA have been conducting research on landcover mapping of MBNP by using different satellite imageries and classification techniques. Supervised classification was used by Jember University and visual interpretation had been applied by FORDA for landcover mapping of MBNP. The results are quite different but one of the most prominent factor is due to different boundary map that were used by the two institutions.

Activity data has been calculated by FORDA by generating Landuse Change Matrix (LCM) for the year 1997, 2001, 2005, 2007 and 2010 based on 6 land categories of AFOLU IPCC GL 2006. The LCM indicates that Forest land tends to dominate the landcover in MBNP, followed by Crop land, Grassland, Other land and Settlement.

Annual deforestation rate has been calculated for MBNP. Deforestation rate among the study period was found to be maximum in the period of 2005-2007 (-0.08) and followed by the period of 2007-2010 (-0.03). During 2005-2007 period deforestation had occured mainly in the Northern part of the National Park, namely in the rehabilitation zone while during 2007-2010 period deforestation has taken place in the Eastern and Southern part of the National Park. Conversion of dryland forest into shrub mixed dryland agriculture was the major cause of deforestation.

Attempts has been made in this research to conduct landuse change forecasting. Lack of historical data of social and biophysical drivers on landuse pattern has made the analysis quite difficult. To overcome this problem, interpolation method and a simple trend analysis are used in this research. Trend analysis is conducted by using linear regression with forest area per capita as the independent variable and cropland area per capita and settlement area per capita as dependent variables as followings: Forest per capita = 0.540333 - 0.30458*cropland per capita – 200.08*settlement per capita. From this model, forest land area per capita in MBNP decreases in time when cropland area per capita and settlement area per capita increase. However, in general, the average forest area per capita in MBNP is 0.479 ha, which is similar as per capita forest cover in the South-East Asian sub-region of 0.48 hectares per person (FAO, 1993).

3. Agricultural activities in the rehabilitation zone

Involving local community to rehabilitate the rehabilitation zone is one of the goals to empower local community surrounding the MBNP. During this program, local community are allowed to plant crops between the woody trees. But at several locations, agricultural crops are more dominant than the woody trees. This should be controlled and monitored by the MBNP organization to overcome forest encroachment within the MBNP.



# LIST OF FIGURE

Table 20 gives the result of forecasted forest land area per capita using multiple regression model. From this model, forest land area per capita in MBNP decreases in time when cropland area per capita and settlement area per capita increase. However, in general, the average forest area per capita in MBNP is 0.479 ha, which is similar as per capita forest cover in the South-East Asian sub-region of 0.48 hectares per person (FAO, 1993).

Threats that are faced by MBNP and could have impacts on cropland per capita and settlement per capita increase in the future are:

1. Population increase in villages surrounding the MBNP

   Basically, population increase in the villages surrounding the MBNP is a potential threat for MBNP. Low education level among the villagers and the significant high percentage of the village population who are farmers (75.8% in 2002 and 73.6% in 2005) make the MBNP prone to be encroached by the local people.

   However, the impact of population pressure to the forest is controlled by the measures that had been taken by the MBNP organization to protect and guard the forest as followings:

   (1) Establish Community Voluntary Guarding Team (PAM Swakarsa) to safeguard the forest which are conducted by the local people surrounding the MBNP.

   (2) Establish Conservation Frontiers from local community and students who are trained by the MBNP organization

   (3) Establish Village Forestry Extension Center (Sentra Penyuluhan Kehutanan Pedesaan/SPKP) in 4 villages.

   These organizations are quite effective to increase people's awareness regarding forest conservation in order to preventing them from encroaching the forest or illegal logging.

2. Open access to nucleus and forest zone of MBNP

   There are two forest estate plantations inside the MBNP, namely PT Bandealit and PT Sukamade Baru. Although those plantations are located in the utilization zone, the existence of those plantations made open access to the nucleus and forest zone of MBNP. This access is a threat to the forest which could be used as transport facilities in forest encroachment activities.

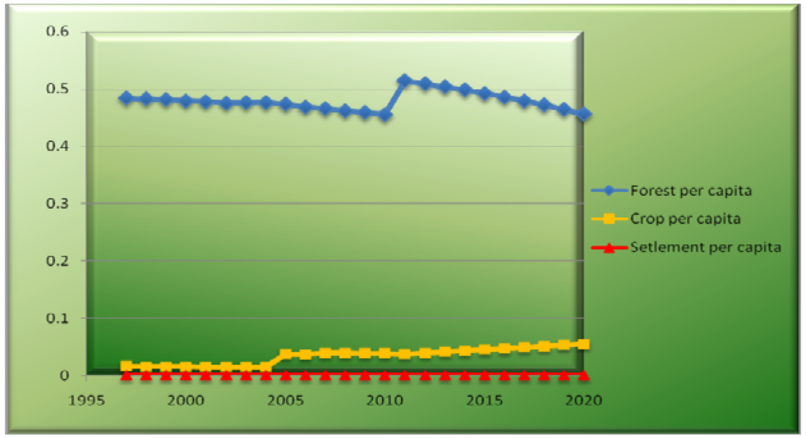



**Figure 31.** Forecasted forest area per capita, cropland per capita and settlement per capita in MBNP

Figure 31 shows the forecasted forest area per capita, cropland per capita and settlement per capita in MBNP until year 2020. Using the model, the forecasted forest land per capita tends to decrease in the future while cropland per capita and settlement per capita tend to increase.

**Table 20.** Forecasted forest land per capita using multiple regression

Forest per capita = 0.540333 - 0.30458*cropland per capita – 200.08*settlement per capita

| Year | Forest Land per capita | Year | Forest Land per capita |
|---|---|---|---|
| 1997 | 0.484122 | 2009 | 0.458777 |
| 1998 | 0.482641 | 2010 | 0.455641 |
| 1999 | 0.481146 | *2011* | 0.514058 |
| 2000 | 0.479637 | *2012* | 0.509247 |
| 2001 | 0.478088 | *2013* | 0.504036 |
| 2002 | 0.475431 | *2014* | 0.498425 |
| 2003 | 0.47601 | *2015* | 0.492413 |
| 2004 | 0.476579 | *2016* | 0.486002 |
| 2005 | 0.47315 | *2017* | 0.47919 |
| 2006 | 0.469101 | *2018* | 0.471978 |
| 2007 | 0.465697 | *2019* | 0.464366 |
| 2008 | 0.46254 | *2020* | 0.456354 |



# SUMMARY

Monitoring and estimating carbon dioxide emissions from deforestation and forest degradation at the national scale become a key element that has to be considered in Reducing Emission from Deforestation and Forest Degradation (REDD) activities. The measuring, reporting and verifying (MRV) system of REDD is based on the general requirements set by the United Nation Framework Convention on Climate Change (UNFCCC) and the specific methodologies for the land use and forest sectors provided by the Intergovernmental Panel on Climate Change (IPCC) (GOFC-GOLD, 2009).

The objective of this research is to analyze activity data in order to estimate carbon emission estimation by using the methods provided in the 2003 IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry (GPG-LULUCF) and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Uses (GL-AFOLU).

Landcover mapping has been conducted for Meru Betiri National Park using Landsat TM 5, Landsat ETM 7, SPOT 4, ALOS PALSAR and ALOS AVNIR from 1997 to 2010. Landuse Change Matrix (LCM) was then generated using 6 land categories based on 2006 IPCC GL. The LCM indicates that Forest land tends to dominate the landcover in MBNP, followed by Crop land, Grassland, Other land and Settlement.

Deforestation rate for successive years of forest cover mapping was calculated according to FAO method. Annual deforestation rate for each period was found to be maximum in the period of 2005-2007 (-0.08) and followed by the period of 2007-2010 (-0.03).

Forecasting of landuse change has been conducted for modeling the pattern and density of future landuse growth. Due to lack of historical data on drivers of changes in Meru Betiri National Park, interpolation and trend analysis using linear regression technique is used to understand historical or current patterns, and also used to examine future patterns of landuse in MBNP. Trend analysis is conducted by using linear regression with forest area per capita as the independent variable and cropland area per capita and settlement area per capita as dependent variables as followings: Forest per capita = 0.540333 - 0.30458*cropland per capita – 200.08*settlement per capita. From this model, forest land area per capita in MBNP decreases in time when cropland area per capita and settlement area per capita increase.

# *RINGKASAN*

*Pemantauan dan pendugaan emisi karbon dioksida dari deforestasi dan degradasi hutan pada skala nasional menjadi elemen kunci yang harus dipertimbangkan pada kegiatan Reducing Emission from Deforestation and Forest Degradation (REDD). Sistem pengukuran, pelaporan dan verifikasi (MRV) pada REDD haruslah mendasar pada sistem umum yang dibuat oleh United Nation Framework Convention on Climate Change (UNFCCC) dan metodologi yang spesifik untuk sektor penggunaan lahan dan hutan yang tersaji dalam Intergovernmental Panel on Climate Change (IPCC) (GOFC-GOLD, 2009).*

*Tujuan dari penelitian ini adalah untuk menganalisis data kegiatan untuk memperkirakan besarnya perkiraan emisi karbon dengan menggunakan metode yang ada pada 2003 IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry (GPG-LULUCF) and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Uses (GL-AFOLU).*

*Pemetaan tutupan lahan telah dilakukan untuk Taman Nasional Meru Betiri dengan menggunakan Landsat TM 5, Landsat 7 ETM, SPOT 4, ALOS PALSAR dan ALOS AVNIR 1997-2010. Matrix perubahan penggunaan lahan (LCM) kemudian dihasilkan dengan menggunakan 6 kategori tutupan lahan berdasarkan IPCC GL 2006. LCM menunjukkan bahwa lahan hutan cenderung mendominasi tutupan lahan di TNMB, diikuti dengan lahan pertanian, rumput, lahan lain dan pemukiman.*

*Tingkat Deforestasi sesuai tahun yang berurutan dari pemetaan tutupan hutan dihitung dengan menggunakan metode FAO. Laju deforestasi tahunan untuk setiap periode ditemukan maksimal pada periode 2005-2007 (-0.08) dan diikuti oleh periode 2007-2010 (-0.03).*

*Pendugaan perubahan penggunaan lahan telah dilakukan untuk memodelkan pola dan kerapatan pertumbuhan penggunaan lahan di masa mendatang. Karena kurangnya data historis tentang penyebab perubahan di Taman Nasional Meru Betiri, interpolasi dan analisis perubahan menggunakan teknik regresi linier kemudian digunakan untuk memahami pola historis atau saat ini, dan juga digunakan untuk menguji pola penggunaan lahan pada masa mendatang di TNMB. Analisis perubahan dilakukan dengan menggunakan regresi linier dengan wilayah hutan per kapita sebagai variabel bebas, dan wilayah pertanian dan pemukiman per kapita sebagai variabel tak bebas, dengan model sebagai berikut: Hutan per kapita = 0.540333 - 0.30458*pertanian per kapita – 200.08*penduduk per kapita. Dari model ini, wilayah hutan per kapita di TNMB berkurang ketika wilayah pertanian dan pemukiman per kapita meningkat.*



**Table 19.** Model summary and coefficients of multiple regression equation

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.94768 |
| R Square | 0.898097 |
| Adjusted R Square | 0.879569 |
| Standard Error | 0.003136 |
| Observations | 14 |

| | Coefficients | Standard Error | t Stat | P-value | Lower 95% | Upper 95% | Lower 95.0% | Upper 95.0% |
|---|---|---|---|---|---|---|---|---|
| Intercept | 0.540333 | 0.013423 | 40.25381 | 2.7E-13 | 0.510789 | 0.569877 | 0.510789 | 0.569877 |
| X Variable 1 | -0.30458 | 0.114969 | -2.64926 | 0.022616 | -0.55763 | -0.05154 | -0.55763 | -0.05154 |
| X Variable 2 | -200.08 | 52.24602 | -3.82958 | 0.002796 | -315.073 | -85.0874 | -315.073 | -85.0874 |

The equation explains the correlation of cropland per capita and settlement per capita on forest land per capita in MBNP as followings:

(1) $R^2$ = 0.898 indicates a strong relationship between the independent variables with dependent variable. Adjusted $R^2$ value is calculated which takes into account the number of variables in the model and number of observations the model is based on. From the equation above, the Adjusted $R^2$ value is 0.879 which indicates that the model has accounted for 87.9% of the variance in the dependent variable (forest land area). It can be concluded that the model is good.

(2) If the cropland area per capita in MBNP increases, while holding settlement constant, then the forest land area per capita tends to decrease. From t-test and P-value we can conclude that cropland per capita has a quite significant impact on forest land per capita.

(3) If the settlement area per capita in MBNP increases, holding cropland constant, then the forest land area per capita tends to decrease. From t-test and P-value we can conclude that settlement has a quite significant impact on forest land.

Cropland area per capita and settlement area per capita are chosen as independent variables with a hypothetical background that those variables could act as the major driving factors of deforestation or forest degradation in MBNP. Cropland per capita will reflect the estimated area of cropland in relation with the population in the villages surrounding the national park. Cropland is found to be a threat in MBNP due to its rapid increase and due to the fact that the major population in the villages surrounding the MBNP are farmers who highly depend on cropland.

The second variable is settlement per capita which indirectly reflects the population distribution within and surrounding the MBNP. Pahari *et. al,.*2000 indicated that population is the most important factor that influences deforestation. Boserup (1965) in Ruddiman *et. al* (2009) stated that integrated evidence from field studies proposed that land use intensifies with increasing population.

Cropland and settlement areas are calculated from GIS -time series-analysis desribed at the previous section. Population is calculated from residents in 12 villages surrounding the MBNP, namely (1) Curahnongko, (2) Andongrejo, (3) Wonoasri, (4) Sanenrejo, (5) Curahtakir, (6) Mulyorejo, (7) Pace, (8) Sidomulyo, (9) Sarongan, (10) Kandangan, (11) Kebonrejo and (12) Kalibaru Kulon village.

From the analysis, the multiple regression equation obtained is as followings:

**FOREST PER CAPITA = 0.540333 - 0.30458*CROPLAND PER CAPITA – 200.08*SETTLEMENT PER CAPITA**

With:

$R^2$ = 0.898;  Adjusted $R^2$ = 0.879



# I. INTRODUCTION

Land Use Change and Forestry or later known AFOLU (Agriculture, Forestry and Land Use) plays an important role in the global carbon cycle. According to estimates by the International Panel on Climate Change (IPCC) 1.6 billion tons of carbon are released annually by land-use change activities, of which a major part results from deforestation and forest degradation (Köhl et al., 2009). The Stern Report pointed out that nearly one fifth of today's total annual carbon emissions come from land-use change, most of which can be traced back to tropical deforestation. Deforestation is generally understood as the direct human-induced conversion of forest land to non-forest land, while forest degradation according to Intergovernmental Panel on Climate Change (IPCC) is the direct-human induced long-term loss of forest carbon stocks in areas which remain forest land. Among the causes of degradation are the collection of fuelwood, logging, forest fires, grazing or shifting cultivation (Köhl et al., 2009). Some scientists claim that deforestation in tropical forests is contributing between 17 to 20 percent of all global CO2 emissions per year (cf., Houghton, 2003, FAO, 2001).

*"Tropical Forest Conservation for Reducing Emissions from Deforestation and Enhancing Carbon Stocks in Meru Betiri National Park (MBNP), Indonesia"* is one of the demonstration activities for reducing emisiion from deforestation and degradation as well as enhancing carbon stock ( REDD+) in Indonesia which was launched by the Minister of Forestry on 6th of January 2010. The project is the first REDD program funded by ITTO and supported by the private company, 7&i Holdings Ltd in Japan. The specific objectives of the project are to  improve the livelihoods of local communities in  the MBNP  and develop a credible, measurable, reportable, and verifiable (MRV) system for monitoring emission reductions in the MBNP. For that purpose, a sub national green house gases inventories, estimating and reporting guidelines can be drawn from the 1996 IPCC (revised) Guidelines, the 2003 Good Practice Guidance for 265 LULUCF (GPG-LULUCF; Chapter 3 for UNFCCC reporting and Chapter 4 for methods specific to the Kyoto Protocol reporting).

The IPCC Guidelines refer to two basic inputs which have to be calculated for greenhouse gas inventories, namely activity data and emissions factors. Activity data refer to the extent of an emission/removal category, and in the case of deforestation and forest degradation refers to the areal extent of those categories, presented in hectares. In other words, activity data are referred to as area change data. Emission factors refer to emissions/ removals of greenhouse gases per unit area, e.g. tons carbon dioxide emitted per hectare of deforestation. Emissions/removals resulting from land-use conversion are manifested in changes in ecosystem carbon stocks, and for consistency with the IPCC Guidelines, we use units of carbon, specifically metric tons of carbon per hectare (t C ha-1), to express emission factors for deforestation and forest degradation (GOFC-GOLD, 2009).

According to IPCC, area changes can be assessed by remote sensing techniques which can be used for two purposes: (i) to monitor changes in forest areas (i.e. from forest to non forest land – deforestation – and from non forest land to forest land - reforestation) and (ii) to monitor area changes within forest land which leads to changes in carbon stocks (e.g. degradation) (GOFC-GOLD, 2009).

The aim of this study is therefore to monitor changes in forest areas to provide high accuracy activity data and reducing the uncertainty of emission factors through spatial mapping of main forest landcover types.



Figure 29 shows an increase forecast of Settlement area that remains as Settlement up to year 2020. The forecast was calculated using linear regression y=0.263x-499.808, with $R^2$ = 0.512. The $R^2$ value indicates that there is no strong relationship between independent and dependent variable, but this equation was choosen due to a quite stable trend analysis of Settlement area in the future. This could be explained that in MBNP the expansion of settlement is very restricted so the area of Settlement will not vary significantly in the future, except if there are other policies applied in the upcoming years.

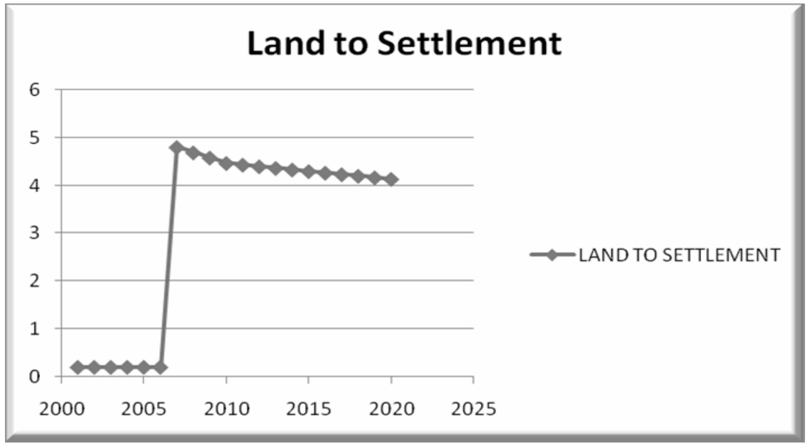



**Figure 30.** Land converted into Settlement area forecasting up to year 2020

Figure 30 shows that there was almost no conversion of Land into Settlement during 1997 to 2005. From 2005 onwards there was a marginal increase in Land that was converted into Settlement which tends to decrease in the future.

### 3.4.5. Forest land forecasting using multiple regression analysis

This section will describe the forecasting method of forest land per capita and analyze the factors that might have effects on forest land in MBNP. Multiple regression with least square method is applied in this analysis by using forest area per capita as the dependent variable and 2 independent variables, namely (1) cropland area per capita in MBNP and (2) settlement area per capita in MBNP.

Table 18 shows the forecasted area of Settlement in MBNP up to year 2020. Polynomial regression method was applied in the forecasting of Settlement area and Land converted into Settlement, while linear regression was applied in the forecasting of Settlement that remains Settlement up to year 2020.

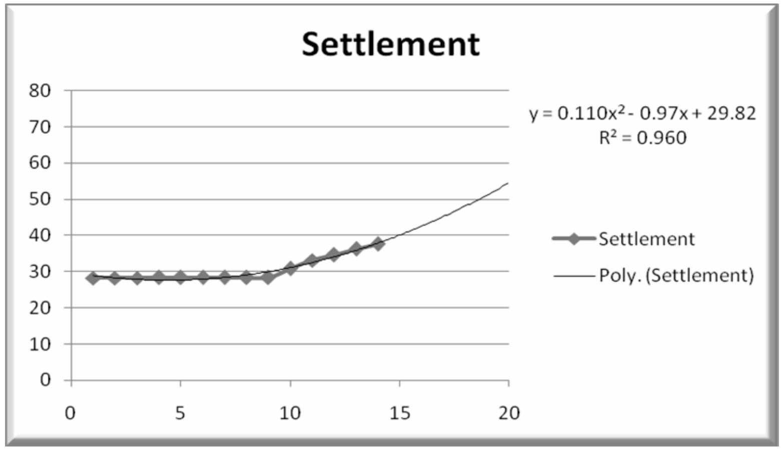



**Figure 28.** Settlement area forecasting up to year 2020

Figure 28 shows an increase trend in Settlement area for future projection. The forecast was calculated using polynomial regression method $y = 0.110x^2 - 0.97x + 29.82$ with $R^2 = 0.960$.

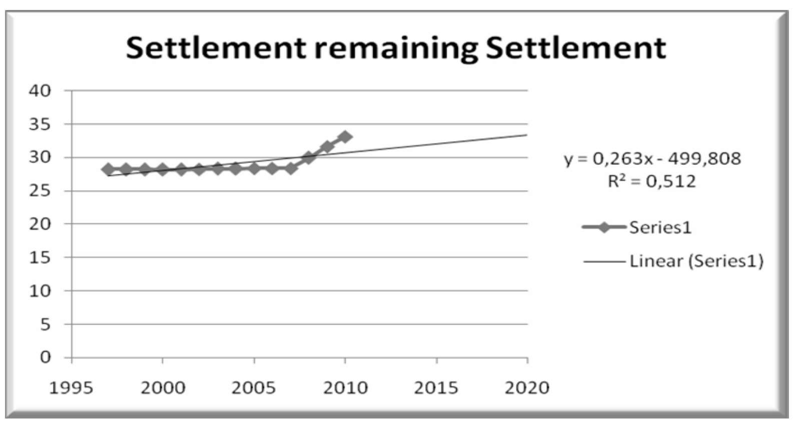



**Figure 29.** Settlement remaining Settlement area forecasting up to year 2020



# II. APPLIED METHODOLOGY

## 2.1. Study site

Meru Betiri National Park (MBNP) was established through the enactment of Ministerial Decree No. 277/Kpts-VI/1997. Based on this decree, the area of MBNP covered about 58,000 ha, and is located in Jember and Banyuwangi District, East Java Province. Within the area, nucleus zone is the largest proportion of the MBNP (48.13%), followed by forest zone (39%), rehabilitation zone (6.94%), intensive use and buffer zone (5.94%) (Figure 1). Each zone has its characteristics and function. Based on Ministerial Decree No. 56/2006, nucleus zone is a pristine and dense forest, characterised by indigenous flora and fauna. Forest zone is a buffer for nucleus zone, and situated between nucleus zone and utilization zone. Rehabilitation zone is a degraded area that need to be rehabilitated. Buffer zone is an area managed specially for accomodating protection and conservation of natureal park, including ecotourism. Utilization zone is utilized for ecotourism and other environmental services purposes.

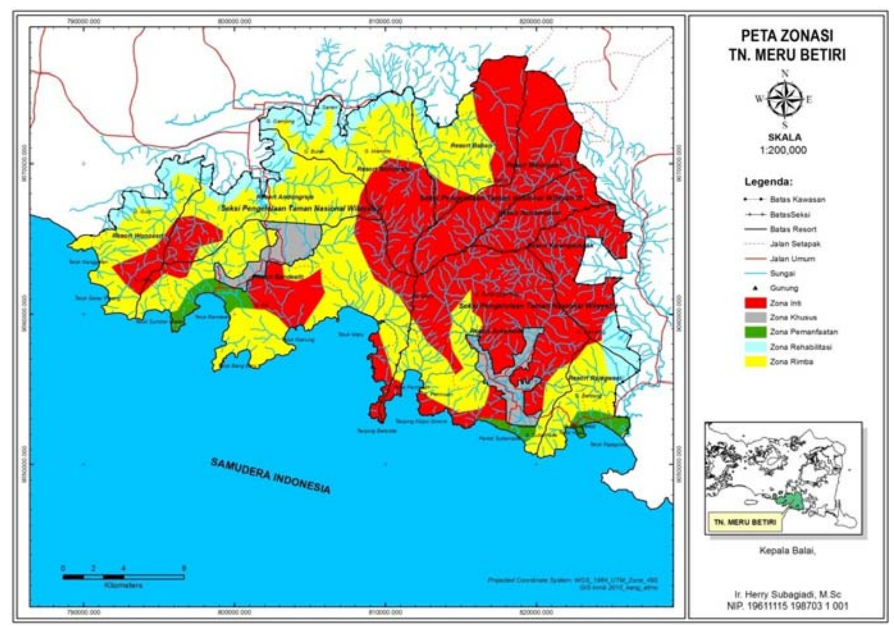



**Figure 1.** Zonation map of MBNP, 1999.

## 2.2. Instruments

Instruments used for conducting data analysis is a unit of computer equipment with software Erdas Imagine 9.1, Er Mapper 7.0, ArcView 3.2, Microsoft Excel 2007 and Microsoft Word 2007. A handheld GPS is used for ground truthing activities in the study site.

## 2.3. Data sources

There are two institutions involved in conducting change detection analyses for MBNP, namely Forest Research and Development Agency (FORDA) and Jember University. Satellite imageries used by FORDA for change detection analyses are as follows:

(i) Landsat TM 5 Path 117 Row 066 for acquisition for year 1997 and 2001,

(ii) Landsat ETM 7 for acquisition year 2005, 2007, 2010,

(iii) ALOS PALSAR for 2007, 2008 and 2009.

For the same time series analyses, Jember University has used multispectral images of SPOT 4 for acquisition year 1997 and 2005, Landsat ETM 7 for acquisition year 1999, 2001 and 2003 and ALOS PALSAR for acquisition year 2007 and 2009.

General information of each types of satellite imageries used in this study are described in Table 1 below.

**Tabel 1.** General information of each types of satellite imageries

| Nr | Sensor | Spatial Resolution | Temporal Resolution | # of bands |
|---|---|---|---|---|
| 1. | Landsat MS/ETM | 30 m | 16 days | 7 (multispectral) |
| 2. | SPOT | 20 m | 26 days | 3 (multispectral) |
| 3. | ALOS PALSAR | 50 m | 46 days | 1 (L band) |



**Table 18.** Forecasted area of Settlement

| Year | Settlement (ha) | S remaining S (ha) | Land converted to S (ha) |
|---|---|---|---|
| 1997 | 28 | 28 | 0.00 |
| 1998 | 28.27 | 28.22 | 0.00 |
| 1999 | 28.31 | 28.21 | 0.00 |
| 2000 | 28.36 | 28.21 | 0.00 |
| 2001 | 28 | 28 | 0 |
| 2002 | 28.42 | 28.25 | 0.20 |
| 2003 | 28.43 | 28.28 | 0.20 |
| 2004 | 28.44 | 28.32 | 0.20 |
| 2005 | 28 | 28 | 0 |
| 2006 | 30.82 | 28.38 | 0.20 |
| 2007 | 33 | 28 | 5 |
| 2008 | 34.66 | 29.98 | 4.69 |
| 2009 | 36.20 | 31.65 | 4.58 |
| 2010 | 38 | 33 | 4 |
| 2011 | 40.02 | 30.97 | 4.43 |
| 2012 | 42.46 | 31.23 | 4.39 |
| 2013 | 45.12 | 31.50 | 4.36 |
| 2014 | 48 | 31.76 | 4.33 |
| 2015 | 51.1 | 32.02 | 4.29 |
| 2016 | 54.42 | 32.29 | 4.26 |
| 2017 | 57.96 | 32.55 | 4.23 |
| 2018 | 61.72 | 32.81 | 4.19 |
| 2019 | 65.7 | 33.08 | 4.16 |
| 2020 | 69.9 | 33.34 | 4.13 |

Figure 26 indicates an increase in Grassland that remains Grassland up to year 2020. The forecast was used by applying linear regression y=69.97x-92243 with $R^2$ =0.739.

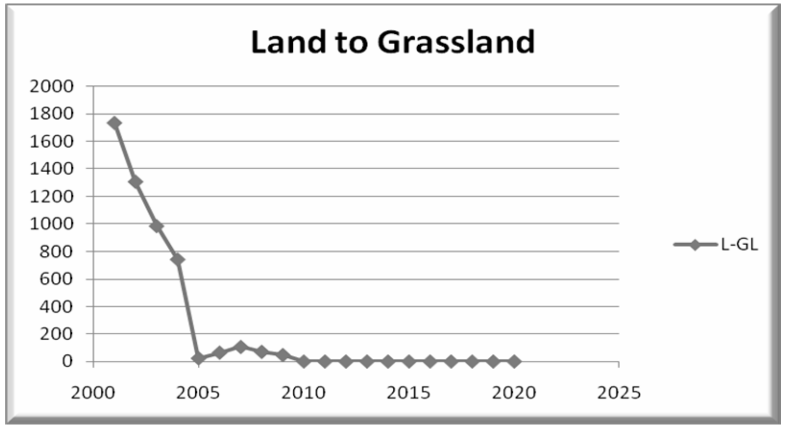



**Figure 27.** Land converted to grassland forecasting up to year 2020

Figure 27 shows a decrease trend of Land that is converted into Grassland, by which it tends to stabilize up to year 2020. The forecast was calculated using interpolation method.

#### 3.4.4. Settlement

**Table 17.** Area of settlement

| Year | Settlement (ha) | S remaining S (ha) | Land to S (ha) |
|---|---|---|---|
| 1997 | 28 | 28 | 0 |
| 2001 | 28 | 28 | 0 |
| 2005 | 28 | 28 | 0 |
| 2007 | 33 | 28 | 5 |
| 2010 | 38 | 33 | 4 |

Table 17 shows the actual area of Settlement which will be used to forecast up to year 2020 as shown in Table 18 below.



## 2.4. Methods

The methods used for monitoring of forest cover change using satellite remote sensing can be divided into several steps as follows: (i) Pre-processing including geometric correction, image classification, ground truthing and re-classification, and (ii) Analysis of data including determining land change matrix, and landuse change forecasting analysis.

### 2.4.1. Pre-processing

Satellite imageries undergone several steps of pre-processing process before being ready to be interpreted in order to generate land cover maps:

#### 2.4.1.1. Geometric Correction

Geometric correction of satellite images involves modelling the relationship between the image and ground coordinate systems (Armston, J.D., et. al, 2002). Generally, geometric correction is a processing procedure that corrects spatial distortion in an image and to ensure that the images in a time series overlaid properly. In this process images are compared to ground control points on accurate basemaps and resampled, so that exact locations and appropriate pixel values can be calculated.

Geometric correction has three main objectives, namely:

a. Perform rectification or restoration (recovery) of the image for the image coordinates in accordance with geographic coordinates.
b. Registration (match) the position of the image with a basemap scale of 1:25.000 (Rupa Bumi Indonesia BAKOSURTANAL, 2000) and GCP points measured with GPS (Global Positioning System).
c. Transform the image into a map coordinate system, which produces an image with a specific projection systems. Projection system used for MBNP is the Universal Transvers Mercator (UTM) Zone 49 South and ellipsoid datum WGS 84.

Geometric correction is done by using corrected Landsat image of 2007 as a reference (reference image). Erdas Imagine software ver 9.1 is used to do the correction by putting Ground Control Points (GCP) in permanent locations such as river crossings or object that is not expected to change in the long term (buildings).

(a). (b).

**Figure 2.** Landsat Imagery (a) before geometric correction, (b) after geometric correction.

#### 2.4.1.2. Image Classification

Image interpretation is a process of identifying objects or conditions in images and determining their meaning into land cover classification. Visual interpretation is addressed to classify land cover with element interpretations that are known in the field. Element interpretations that are used, include (The University of Edinburgh):

a. **Tone** refers to the relative brightness or colour of objects in an image. Generally, tone is the fundamental element for distinguishing between different targets or features. Variations in tone also allows the elements of shape, texture, and pattern of objects to be distinguished.

b. **Shape** refers to the general form, structure, or outline of individual objects. Shape can be a very distinctive clue for interpretation. Straight edge shapes typically represent urban or agricultural (field) targets, while natural features, such as forest edges, are generally more irregular in shape, except where man has created a road or clear cuts. Farm or crop land irrigated by rotating sprinkler systems would appear as circular shapes.

c. **Size** of objects in an image is a function of scale. It is important to assess the size of a target relative to other objects in a scene, as well as the absolute size, to aid in the interpretation of that target.



Table 16 presents the forecasted area for Grassland. Landuse forecasting of Grassland and Grassland remaining Grassland (GL-GL) is conducted by applying trend analysis using exponential and linear regression. Forecast of Land converted to Crop Land is used by interpolation of Grassland area using growth coefficient.

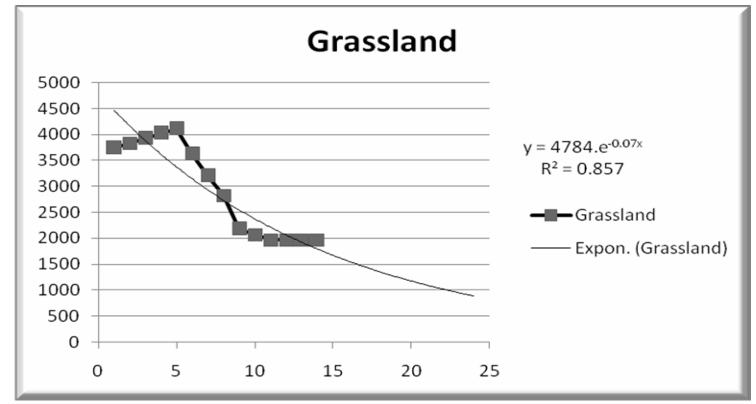



**Figure 25.** Grassland forecasting up to year 2020

Forecasted Grassland area is calculated by applying trendanalysis using exponential regression. The equation derived is $y=4784.e^{-0.07x}$ with $R^2$ = 0.857 that indicates a good relationship between the growth of Grassland area as a function of time. Figure 25 shows a decline in the area of Grassland up to year 2020.

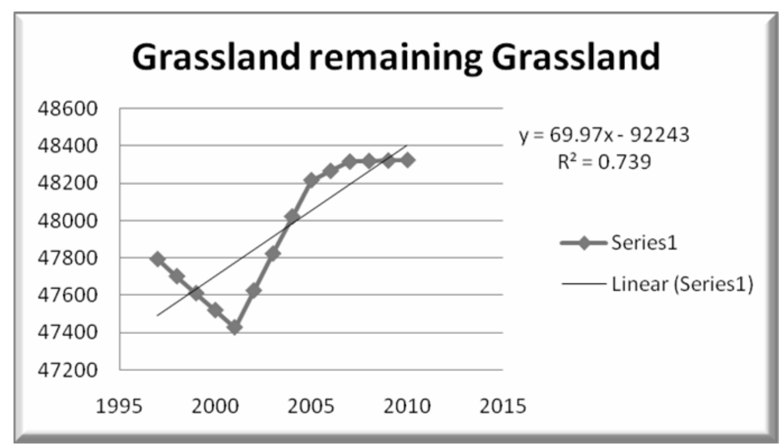



**Figure 26.** Grassland remaining grassland forecasting up to year 2020

Table 15 shows actual area of Grassland in MBNP which will be used to forecast the trend of Grassland in the future as shown in Table 16 below.

**Table 16.** Forecasted area of Grassland

| Year | Grassland (ha) | GL remaining GL (ha) | Land converted to GL (ha) |
|---|---|---|---|
| 1997 | 3738 | 47793 | 0 |
| 1998 | 3830.699 | 47701.76 | 0 |
| 1999 | 3925.918 | 47610.59 | 0 |
| 2000 | 4023.504 | 47519.59 | 0 |
| 2001 | 4109 | 47428 | 1733 |
| 2002 | 3625.498 | 47624.87 | 1305.253 |
| 2003 | 3198.556 | 47822.83 | 983.3175 |
| 2004 | 2821.892 | 48021.61 | 740.786 |
| 2005 | 2174 | 48216 | 23 |
| 2006 | 2070.374 | 48266.13 | 64.307 |
| 2007 | 1967 | 48316 | 105 |
| 2008 | 1967.038 | 48318.78 | 70.24733 |
| 2009 | 1967.038 | 48321.58 | 46.83156 |
| 2010 | 1967 | 48324 | 0 |
| 2011 | 1674.102 | 48473.71 | 0 |
| 2012 | 1560.923 | 48543.69 | 0 |
| 2013 | 1455.395 | 48613.66 | 0 |
| 2014 | 1357.001 | 48683.63 | 0 |
| 2015 | 1265.259 | 48753.61 | 0 |
| 2016 | 1179.72 | 48823.58 | 0 |
| 2017 | 1099.964 | 48893.55 | 0 |
| 2018 | 1025.599 | 48963.53 | 0 |
| 2019 | 956.2623 | 49033.5 | 0 |
| 2020 | 891.6131 | 49103.48 | 0 |



d. **Pattern** refers to the spatial arrangement of visibly discernible objects. Typically an orderly repetition of similar tones and textures will produce a distinctive and ultimately recognizable pattern.

e. **Texture** refers to the arrangement and frequency of tonal variation in particular areas of an image. Rough textures would consist of a mottled tone where the grey levels change abruptly in a small area, whereas smooth textures would have very little tonal variation. Smooth textures are most often the result of uniform, even surfaces, such as fields, asphalt, or grasslands. A target with a rough surface and irregular structure, such as a forest canopy, results in a rough textured appearance. Texture is one of the most important elements for distinguishing features in radar imagery.

f. **Shadow** is also helpful in interpretation as it may provide an idea of the profile and relative height of a target or targets which may make identification easier. However, shadows can also reduce or eliminate interpretation in their area of influence, since targets within shadows are much less (or not at all) discernible from their surroundings. Shadow is also useful for enhancing or identifying topography and landforms, particularly in radar imagery.

g. **Association** takes into account the relationship between other recognizable objects or features in proximity to the target of interest. The identification of features that one would expect to associate with other features may provide information to facilitate identification. In the example given above, commercial properties may be associated with proximity to major transportation routes, whereas residential areas would be associated with schools, playgrounds, and sports fields.

The objects are classified into 23 land cover classes based on the above mentioned elements interpretation of the images.

#### 2.4.1.3. Ground Truthing

Ground truthing is addressed to check similarity between land cover classification in the map and the actual ground condition. Point for observations were located randomly but accessible to check in the ground. Ground truthing is undertaken by first identifying coordinate point using GPS (Geographic Positioning System), and the result would be used for correction of initial image classification. Post-classification, can then be undertaken with better accuracy.

#### 2.4.1.4. Post-classification

Post-classification refers to activity to improve initial image classification based on result from ground truthing activity.

### 2.4.2. Analysis of Data

#### 2.4.2.1. Land Change Matrix (LCM)

To calculate landcover changes during the study period in MBNP, the landcover classification according to DG of Forest Planology Classification (2006) should be re-classified according to Existing frameworks for the Land Use, Land Use Change and Forestry (LULUCF) sector under the UNFCCC (2003 GPG and 2006 GL-AFOLU) as follows:

| Nr. | Landcover classification (DG of Planology, Ministry of Forestry, 2006) |
|---|---|
| 1 | Primary dryland forest |
| 2 | Secondary dryland forest |
| 3 | Mangrove forest |
| 4 | Dryland agriculture |
| 5 | Shrub mixed dryland agriculture |
| 6 | Plantation |
| 7 | Bush/Shrub |
| 8 | Grassland |
| 9 | Settlement |
| 10 | Bare land |
| 11 | Water |

| Nr. | IPCC Classification |
|---|---|
| 1 | Forest land (FL) |
| 2 | Crop Land (CL) |
| 3 | Grassland (GL) |
| 4 | Wetland (WL) |
| 5 | Settlement (S) |
| 6 | Other land (OL) |

**Figure 3.** Reclassification of landcover into IPCC GL 2006-AFOLU.



Figure 23 shows CL remaining CL forecasting up to year 2020 using trend analysis with linear regression y = 230.6x-459855, where y= forest land area and x=year; $R^2$ = 0.701. The forecast indicates an increase in Crop Land that remains Crop Land up to year 2020.

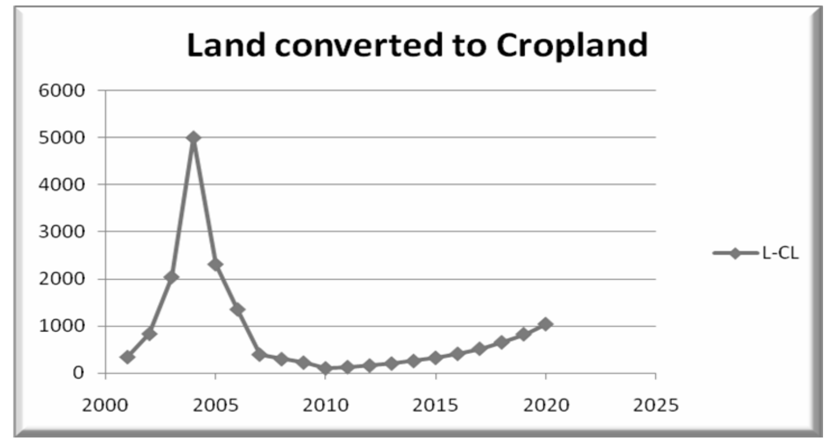



**Figure 24.** Land converted to Crop Land forecasting up to year 2020

Figure 24 presents the forecast of Land converted into Crop Land in MBNP which increases significantly in 2005 and declines sharply until 2010. Forecasted Crop Land area tends to increase up to year 2020. Interpolation method is used instead of trend analysis using linear regression due to low $R^2$ value (0.13).

#### 3.4.3. Grassland

**Table 15.** Area of grassland

| Year | Grassland (ha) | GL remaining GL (ha) | Grassland to CL (ha) |
|---|---|---|---|
| 1997 | 3738 | 3738 | 0 |
| 2001 | 4109 | 2377 | 1733 |
| 2005 | 2174 | 2150 | 23 |
| 2007 | 1967 | 1862 | 105 |
| 2010 | 1967 | 1967 | 0 |

Table 14 presents the forecasted area for Crop Land. Landuse forecasting of Crop Land and Crop Land remaining Crop Land (CL-CL) is conducted by applying linear regression. Forecast of Land converted to Crop Land is used by interpolation of Crop Land area using growth coefficient.

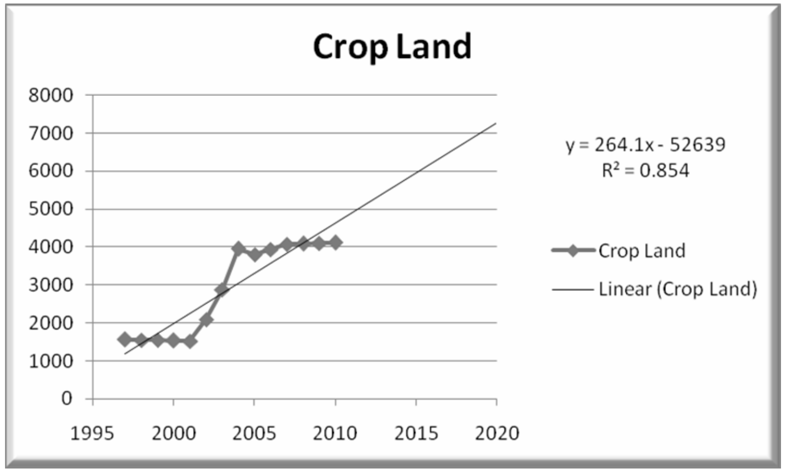



**Figure 22.** Crop Land forecasting up to year 2020

Figure 22 shows Crop Land forecasting up to year 2020 using trend analysis with linear regression y=264,19x-526398, where y= forest land area and x=year; $R^2$ = 0.854. The forecast indicates an increase in Crop Land up to year 2020. The value of $R^2$ shows a good relationship between Crop Land area as a function of time.

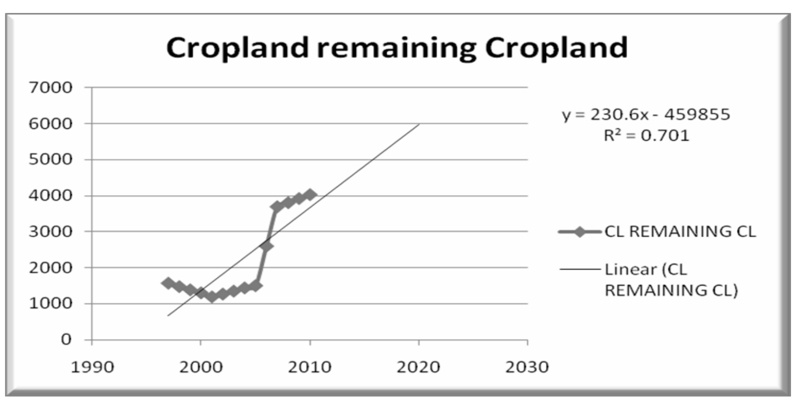



**Figure 23.** Crop Land remaining Crop Land forecasting up to year 2020



Figure 3 explains the reclassification of landcover classification based on DG of Forest Planology (2006) into 6 land categories according to IPCC GL 2006, where the Primary dryland forest, Secondary dryland forest and Mangrove forest are reclassified into Forest Land (FL) class; Dryland agriculture, Shrub mixed dryland agriculture and Plantation are reclassified into Cropland (CL) class; Bush/shrub and Grassland are reclassified into Grassland (GL) class; Bare land and Water are reclassified into Other land (OL) class; and Settlement is still classified as Settlement.

According to IPCC GL 2006, carbon stock change in biomass on Forest Land is likely to be an important sub-category because of substantial fluxes owing to management and harvest, natural disturbances, natural mortality and forest regrowth. In addition, land-use conversions from Forest Land to other land uses often result in substantial loss of carbon from the biomass pool. Trees and woody plants can occur in any of the six land-use categories although biomass stocks are generally largest on Forest Land. Therefore, for inventory purposes, changes in C stock in biomass are estimated for (i) land remaining in the same land-use category and (ii) land converted to a new land-use category (Figure 4).

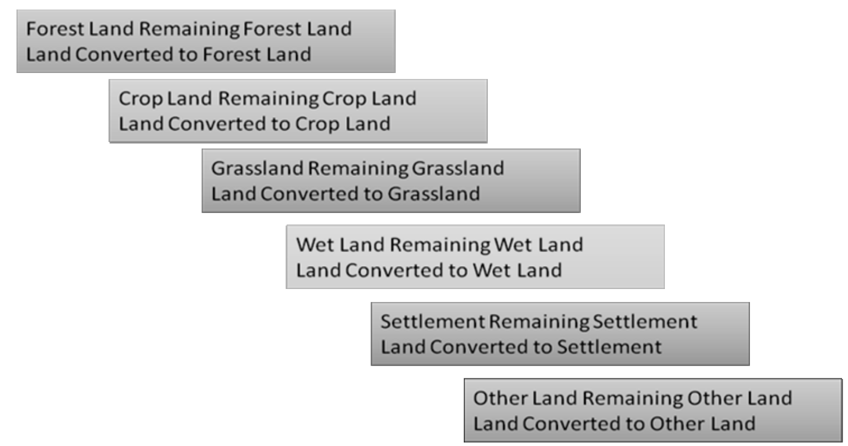



**Figure 4.** Landuse change analysis according to IPCC GL 2006.

Table 2 presents the reporting format of LCM which will be used for inventory GHGs using IPCC method. It is expected that by implementing these 6 categories of land, the inventory of landcover changes will be more accurate, reduce uncertainty and consistent in the distribution of land categories.

**Table 2.** Reporting format of landuse change matrix

| Category | Sub-category | Year monitoring | | | |
|---|---|---|---|---|---|
| | | .. (ha) | .. (ha) | .. (ha) | .. (ha) |
| Total | | | | | |
| Land Category | | | | | |
| A. Forest Land (FL) | | | | | |
| 1. FL remain FL | | | | | |
| | Dry land forest | | | | |
| | Mangrove forest | | | | |
| | Swamp forest | | | | |
| | Plant forest | | | | |
| 2. Land converted to FL | | | | | |
| 2.1 Crop land converted to FL | | | | | |
| 2.2 Grass land converted to FL | | | | | |
| 2.3 Wet land converted to FL | | | | | |
| 2.4 Settlement converted to FL | | | | | |
| 2.5 Other land converted to FL | | | | | |
| | | | | | |
| B. Crop Land | | | | | |

#### 2.4.2.2 Deforestation Rate Analysis

Deforestation is recognized as one of the most significant component in LULC and global changes scenario. It is imperative to assess its trend and the rates at which it is occurring. The changes will have long-lasting impact on regional climate and in turn on biodiversity.

Deforestation rate for successive years of forest cover mapping was evaluated using forest area for time 1 and time 2 as given by FAO (1995) in Puyravaud (2002). According to FAO (1995) in Puyravaud (2002), the annual rate of forest change is derived from the Compound Interest Law and calculated as:



Based on Table 13 trend analysis using linear regression and interpolation was conducted to analyze Crop Land forecasting up to year 2020. Table 13 shows the resulted projected Crop Land area.

**Table 14.** Forecasted area of crop land

| Year | Crop Land (ha) | CL remaining CL (ha) | Land converted to CL (ha) |
|---|---|---|---|
| 1997 | 1565 | 1565 | 0 |
| 1998 | 1555.11 | 1470.14 | 0.00 |
| 1999 | 1545.40 | 1381.15 | 0.00 |
| 2000 | 1535.76 | 1297.54 | 0.00 |
| 2001 | 1526 | 1186 | 340 |
| 2002 | 2095.97 | 1263.36 | 832.61 |
| 2003 | 2879.19 | 1345.82 | 2039.79 |
| 2004 | 3955.08 | 1433.67 | 4997.24 |
| 2005 | 3806 | 1496 | 2311 |
| 2006 | 3941.74 | 2589.79 | 1352.02 |
| 2007 | 4077 | 3684 | 393 |
| 2008 | 4090.57 | 3794.79 | 295.86 |
| 2009 | 4104.16 | 3908.93 | 222.64 |
| 2010 | 4118 | 4016 | 101 |
| 2011 | 4888.08 | 3881.60 | 127.84 |
| 2012 | 5152.27 | 4112.20 | 161.40 |
| 2013 | 5416.46 | 4342.80 | 203.76 |
| 2014 | 5680.65 | 4573.40 | 257.25 |
| 2015 | 5944.84 | 4804.00 | 324.77 |
| 2016 | 6209.03 | 5034.60 | 410.02 |
| 2017 | 6473.22 | 5265.20 | 517.64 |
| 2018 | 6737.41 | 5495.80 | 653.52 |
| 2019 | 7001.60 | 5726.40 | 825.06 |
| 2020 | 7265.79 | 5957.00 | 1041.62 |

Figure 20 shows FL remaining FL forecasting up to year 2020 using trend analysis with linear regression y = 69.97x-92243, where y= forest land area and x=year; $R^2$ = 0.739. The forecast indicates an increase in Forest Land that remains Forest Land up to year 2020. $R^2$ shows a quite good relationship between the dependent and independent variables.

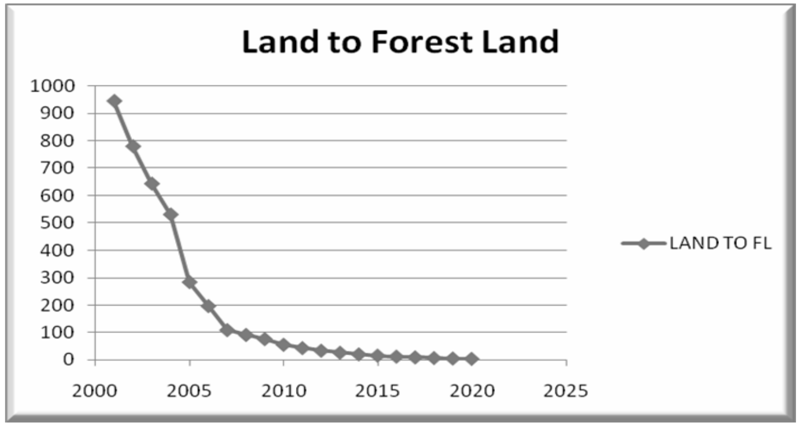



**Figure 21.** Conversion of Land to Forest Land Forecasting up to year 2020

Figure 21 shows the forecast of Land into Forest Land in MBNP which tends to decline up to year 2020. This resulted from negative value of the average of area growth coefficient from 1997 to 2010 (-0.215).

### 3.4.2. Crop Land

**Table 13.** Area of crop land

| Year | Crop Land (ha) | CL remaining CL (ha) | Land to CL (ha) |
|---|---|---|---|
| 1997 | 1565 | 1565 | 0 |
| 2001 | 1526 | 1186 | 340 |
| 2005 | 3806 | 1496 | 2311 |
| 2007 | 4077 | 3684 | 393 |
| 2010 | 4118 | 4016 | 101 |



$$Q = [A_2/A_1]^{1/(t_2-t_1)} - 1$$

Where $A_2$ and $A_1$ are the forest cover at time $t_1$ and $t_2$ respectively (the unit : per year or percentage per year).

### 2.4.2.3. Landuse Forecasting Analysis

For a long time the terms of land use and land cover have been considered with the same definition. But natural scientists distinguished land cover as biophysical features of the earth surface while defining land use as human activities that influences landcover condition (Nagendra, H. et al., 2003). Land-use and land-cover forecast models must endeavor to establish causality, linking human decision-making with environmental and socioeconomic drivers at all representative scales of analysis.

Forecasting is the establishment of future expectations by the analysis of past data, or the formation of opinions. Two approaches prevail for modeling the spatial pattern and density of future development: regression and transition based. Regression is common used to understand historical or current patterns, it is also used to examine future patterns (Theobald, et al., 1998).

Regression is the study of relationships among variables, a principal purpose of which is to predict, or estimate the value of one variable from known or assumed values of other variables related to it. To make predictions or estimates we must identify the effective predictors of the variable of interest: which variables are important indicators and can be measured at the least cost, which carry only a little information, and which are redundant. The equation developed can be used to predict an average value over the range of the sample data. The forecast is good for short to medium ranges.

Lack of historical data of social and biophysical drivers on landuse pattern has made the forecasting analysis quite difficult. To overcome this problem, interpolation method and a simple trend analysis are used in this research. Trend analysis is conducted by using linear regression with time as the independent variable and area as dependent variable.

The strength of the relationship between the variables can be assessed by statistical tests of that hypothesis such as the null hypothesis which are established using t-distribution, R-squared, and F-distribution tables.

# III. RESULTS

## 3.1. Land Cover Map

The first step of the study is to generate land cover maps from all the satellite images using landcover classification according to DG of Forest Planology, Ministry of Forestry of Indonesia, 2006. Jember University had classified 10 classes of landcover in MBNP from 1997, 1999, 2001, 2003, 2005, 2007 and 2009 using supervised classification with its coverage as follows:

**Table 3.** Landcover classification of MBNP using supervised classification (Irawan and Purnomosiddy, Jember University, 2010)

| No. | LANDCOVER | Spot 1997 (m2) | Landsat 1999 (m2) | Landsat 2001 (m2) | Landsat 2003 (m2) | Spot 2005 (m2) | Alos 2007 (m2) | Alos 2009 (m2) |
|---|---|---|---|---|---|---|---|---|
| 1 | Primary dryland forest | 256,948,139.98 | 206,435,673.50 | 235,033,358.62 | 229,224,034.69 | 199,543,900.72 | 222,466,601.85 | 217,449,660.65 |
| 2 | Secondary dryland forest | 160,424,141.75 | 114,056,894.34 | 179,528,840.82 | 178,406,743.82 | 169,158,939.11 | 193,163,433.27 | 210,310,382.97 |
| 3 | Primary mangrove forest | 332,794.65 | 386,388.86 | 379,933.40 | 383,251.32 | 329,624.16 | 321,196.15 | 316,178.10 |
| 4 | Bush/shrub | 74,670,403.97 | 69,740,440.72 | 70,886,936.95 | 76,539,693.00 | 63,115,175.32 | 64,156,582.13 | 63,629,685.28 |
| 5 | Shrub swamp | 5,669,369.59 | 3,120,364.12 | 6,541,412.30 | 5,698,945.35 | 6,442,687.71 | 5,155,500.15 | 5,464,969.17 |
| 6 | Plantation | 1,090,803.61 | 1,083,428.97 | 1,193,633.38 | 1,187,246.82 | 1,140,944.42 | 1,143,695.20 | 1,148,611.91 |
| 7 | Settlement | 80,470.68 | 99,644.46 | 89,433.86 | 89,709.79 | 96,070.19 | 92,187.94 | 90,217.56 |
| 8 | Barren land | 144,040.82 | 155,639.37 | 157,717.48 | 167,559.82 | 171,033.28 | 189,275.76 | 142,718.99 |
| 9 | Cloud | 25,435,415.00 | 112,925,796.52 | 28,511,673.14 | 28,570,567.31 | 54,872,108.85 | 42,009,813.27 | 29,725,522.51 |
| 10 | No data | 23,313,092.68 | 40,104,727.65 | 25,785,895.58 | 27,841,620.02 | 53,238,276.10 | 19,411,465.64 | 19,831,653.58 |
| | TOTAL(m2) | 548,108,672.74 | 548,108,998.49 | 548,108,835.53 | 548,109,371.95 | 548,108,759.86 | 548,109,751.35 | 548,109,600.73 |

In line with Jember University, FORDA had distinguished 11 classes of landcover in MBNP using visual interpretation from 1997, 2001, 2005, 2007 and 2010 with the results as follows:



Table 12 presents the interpolated area for Forest Land and Land Converted to Forest Land (L-FL) from year1997 up to 2020. Landuse forecasting of Forest Land remaining Forest Land (FL-FL) is conducted by applying linear regression equation y = 69,97x – 92243, where y = forest land area and x = year, $R^2$ = 0.739. Forest Land forecastings for each type of conversion are shown in the following graphs.

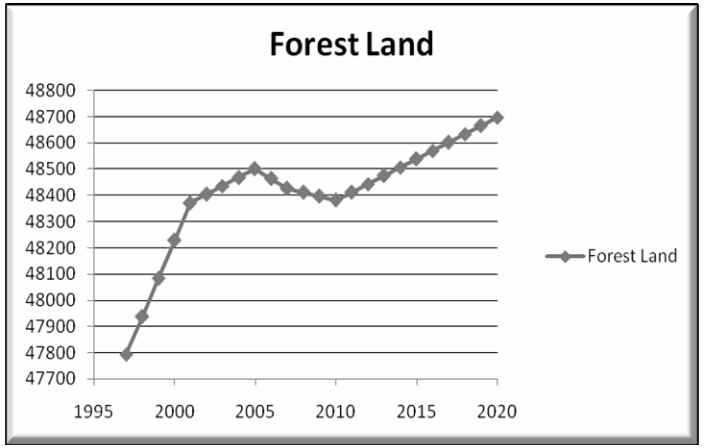



**Figure 19.** Forest Land Use forecasting up to year 2020

Figure 19 indicates an increase in Forest Land up to year 2010. Linear regression was not applied in forecasting Forest Land due to low $r^2$ value obtained from the regression equation ($R^2$ = 0.57).

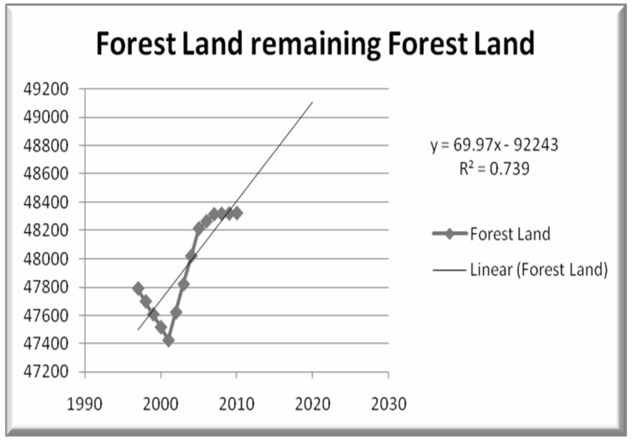



**Figure 20.** Forest Land remaining Forest Land forecasting up to year 2020

**Table 12.** Forecasted area of forest land

| Year | Forest Land (ha) | FL remaining FL (ha) | Land converted to FL (ha) |
|---|---|---|---|
| 1997 | 47793 | 47793 | 0 |
| 1998 | 47937.86 | 47701.762 | 0 |
| 1999 | 48082.87 | 47610.591 | 0 |
| 2000 | 48228.31 | 47519.595 | 0 |
| 2001 | 48372 | 47428 | 944 |
| 2002 | 48403.85 | 47624.87 | 778.97 |
| 2003 | 48436.14 | 47822.83 | 642.91 |
| 2004 | 48468.46 | 48021.61 | 530.61 |
| 2005 | 48501 | 48216 | 284 |
| 2006 | 48463.26 | 48266.13 | 197.13 |
| 2007 | 48426 | 48316 | 110 |
| 2008 | 48410.82 | 48318.78 | 92.04 |
| 2009 | 48395.81 | 48321.58 | 77.11 |
| 2010 | 48381 | 48324 | 56 |
| 2011 | 48412.36 | 48466.67 | 44.30 |
| 2012 | 48443.96 | 48536.64 | 34.79 |
| 2013 | 48475.57 | 48606.61 | 27.33 |
| 2014 | 48507.21 | 48676.58 | 21.46 |
| 2015 | 48538.87 | 48746.55 | 16.86 |
| 2016 | 48570.55 | 48816.52 | 13.24 |
| 2017 | 48602.24 | 48886.49 | 10.40 |
| 2018 | 48633.96 | 48956.46 | 8.17 |
| 2019 | 48665.70 | 49026.43 | 6.42 |
| 2020 | 48697.46 | 49096.40 | 5.04 |



**Table 4.** Landcover classification of MBNP using visual interpretation by: FORDA

| LANDCOVER | 1997 | 2001 | 2005 | 2007 | 2010 |
|---|---|---|---|---|---|
| | Hectare | | | | |
| Water | 52 | 52 | 52 | 52 | 52 |
| Bush/Shrub | 2654 | 1965 | 1932 | 1814 | 1814 |
| Primary dryland forest | 40309 | 39460 | 39218 | 38537 | 37965 |
| Secondary dryland forest | 7413 | 8810 | 9181 | 9788 | 10315 |
| Mangrove forest | 71 | 102 | 102 | 101 | 101 |
| Settlement | 28 | 28 | 28 | 33 | 38 |
| Plantation | 1058 | 1186 | 1425 | 1394 | 1373 |
| Dryland agriculture | 0 | 75 | 633 | 872 | 685 |
| Shrub mixed dryland agriculture | 507 | 265 | 1749 | 1812 | 2060 |
| Grassland | 1084 | 2144 | 242 | 153 | 153 |
| Barren land | 1385 | 474 | 0 | 6 | 6 |
| **Total Area (ha)** | **54562** | **54562** | **54562** | **54562** | **54562** |

From the above mentioned tables, the landcover resulted from classification of Jember University and FORDA showed differences in the total area of MBNP. This is due to different boundary of MBNP that is used by FORDA and Jember University during the research. At first both institutions used the same boundary (which is still used by Jember University until the end of the study), but when the research has entered the final phase, the MBNP GIS unit had reviewed MBNP boundary. There are slight changes in the north eastern part of MBNP; the reviewed boundary had altered adjusting to the stream network, so the river becomes the boundary between MBNP and adjacent forest area. Hence, the total area of MBNP according to the reviewed boundary is 54,562 ha, or about 250 ha smaller than the former boundary. The circle in Figure 5 showed the changes that has taken place between the former and reviewed boundary. The red lines depict the old boundary and the blue lines present the reviewed boundary.

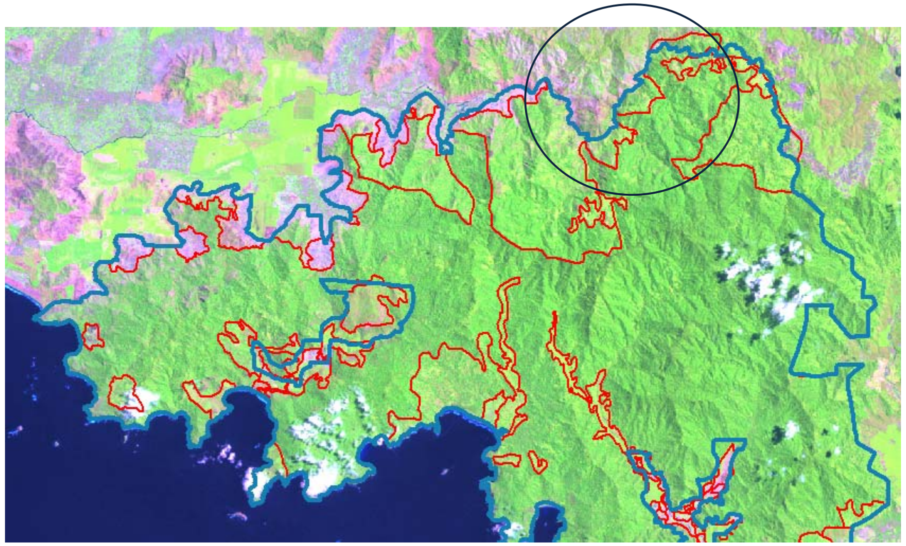


**Figure 5**. Changes in the north eastern part of MBNP boundary.

The landcover maps resulted using supervised classification by Jember University are shown below:


**Figure 6.** MBNP landcover classification from SPOT, 1997 (Irawan and Purnomosiddy, Jember University, 2010).



change (Sohl et al., 2009), and linkages between social and biophysical drivers of change and changes in land-use patterns.

Lack of historical data of social and biophysical drivers on landuse pattern has made the analysis quite difficult. To overcome this problem, interpolation method and a simple trend analysis are used in this research. Trend analysis is conducted by using linear regression with time as the independent variable and area as dependent variable.

### 3.4.1. Forest Land

Table 11 presents interpolation method to forecast forest land area.

**Table 11.** Area of forest land

| Year | Forest Land (ha) | FL remaining FL (ha) | Land to FL (ha) |
|---|---|---|---|
| 1997 | 47793 | 47793 | 0 |
| 2001 | 48372 | 47428 | 944 |
| 2005 | 48501 | 48216 | 284 |
| 2007 | 48426 | 48316 | 110 |
| 2010 | 48381 | 48324 | 56 |

Calculation of area growth coefficient by using the following formulae:

Coeff. = (y2-y1)/y1/(x2-x1)= ((y2/y1)-1)/x2-x1

Where:

Y = Area

X = Time

Interpolated area for a given period is calculated using the following formulae:

$Y_2 = Y_1 * (1 + \text{Coeff.})$

Annual deforestation rate for each period are shown in Table 10. The average deforestation rate for MBNP is 0.06. Deforestation rate among the study period was found to be maximum in the period of 2005-2007 (-0.08) and followed by the period of 2007-2010 (-0.03). GIS analysis showed that during 2005-2007 period deforestation had occured mainly in the Northern part of the National Park, namely in the rehabilitation zone. Conversion of dryland forest into shrub mixed dryland agriculture was the major cause of deforestation (92,236.83 ha), followed by conversion of dryland forest into shrubs (20.5 ha), conversion of secondary dryland forest into dryland agriculture (23.73 ha).

During period of 2007-2010 deforestation has taken place in the Eastern and Southern part of the National Park. The results are attributed to conversion of dryland forest into dryland agriculture which was the major cause of deforestation in that period (95.03 ha), followed by conversion of dryland forest into shrub mixed dryland agriculture (6.23 ha).

Table 10 indicates that in the period of 1997-2001 and 2001-2005 there are positive values of annual deforestation rates, which indicates of an increase in forest cover. GIS analysis showed that in the period of 1997-2001 forest growth took place in the Northern (rehabilitation zone) and Southern part of MBNP. The main cause of forest growth was due to the growth of shrubs to secondary dryland forest (770.07 ha) followed by the regrowth of grassland into secondary dryland forest (172.96 ha).

During the period of 2001-2005 forest cover increase took place in the area of Bandealit. Forest increase was resulted from shrub/bushes growth into secondary forest (210.89 ha) and the regrowth of plantation into secondary forest (8.41 ha). Generally, marginal increase in forest cover which is indicated by positive value of deforestation rate (0.07) was observed in the entire area of MBNP.

### 3.4. Landuse Forecasting Analysis

Assuming that the pattern of landuse change in the past can give influence to the future, forecasting analysis of landuse need to be supported by the availability of temporal historical data that could be quantified numerically. Many constraints are found for the landuse forecasting analysis of MBNP, especially for the acquisition of spatial data representative of key drivers of




**Figure 7.** MBNP landcover classification from Landsat, 1999 (Irawan and Purnomosiddy, Jember University, 2010).

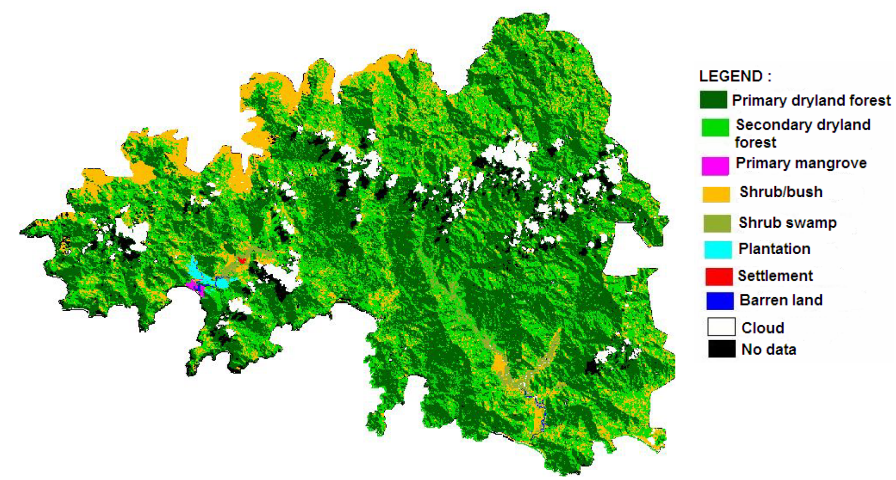



**Figure 8.** MBNP landcover classification from Landsat, 2001 (Irawan and Purnomosiddy, Jember University, 2010).

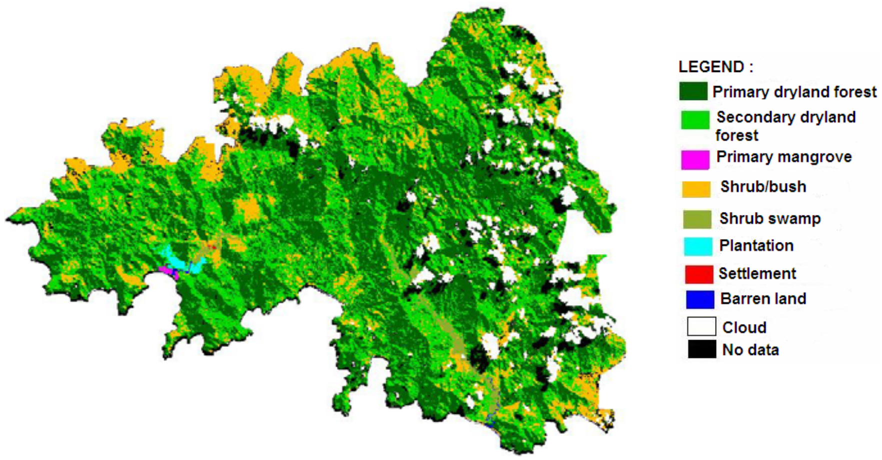



**Figure 9.** MBNP landcover classification from Landsat, 2003 (Irawan and Purnomosiddy, Jember University, 2010).

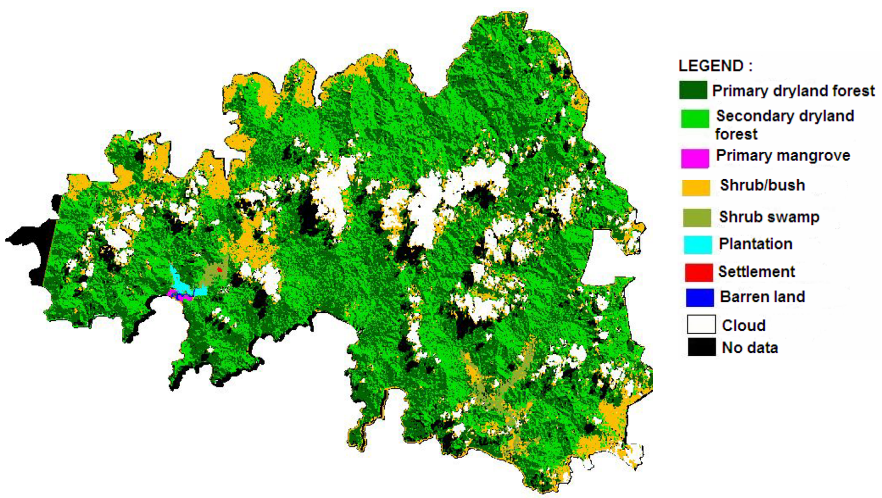



**Figure 10.** MBNP landcover classification from SPOT, 2005 (Irawan and Purnomosiddy, Jember University, 2010).



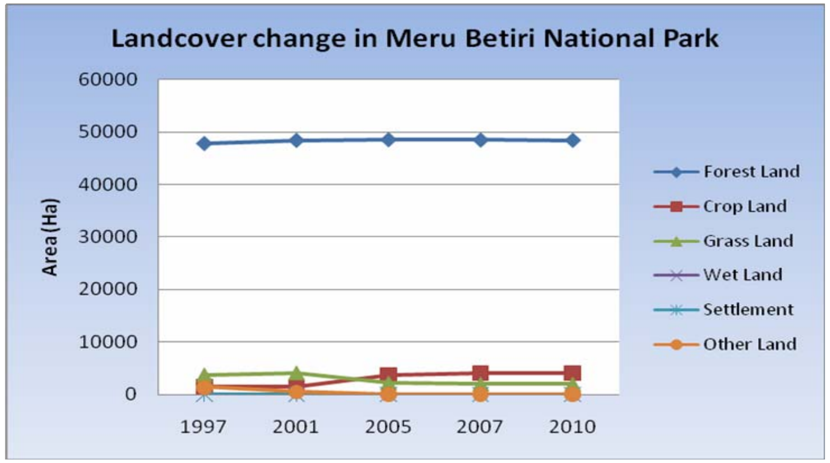



**Figure 18.** Landcover change in MBNP from 1997 to 2010

### 3.3. Deforestation Rate Analysis

Deforestation rate can be measured using satellite imageries and spatial analyses. The annual rate of forest cover change is calculated by comparing the area under forest cover in the same region at two different times. According to FAO (1995) in Puyravaud (2003), the annual rate of forest change is derived from the Compound Interest Law and calculated as:

$$Q = [A_2/A_1]^{1/(t_2-t_1)} - 1$$

Where $A_2$ and $A_1$ are the forest cover at time $t_1$ and $t_2$ respectively (the unit : per year or percentage per year).

**Table 10.** Deforestation rate from 1997 to 2007 for total forest cover changes in MBNP

| Period | Annual Deforestation rate (%) |
|---|---|
| 1997-2001 | 0.30 |
| 2001-2005 | 0.07 |
| 2005-2007 | -0.08 |
| 2007-2010 | -0.03 |
| **Average deforestation rate** | **0.065** |

Table 9 describes the area and percentage of each land category according to IPCC GL 2006. Forest land is dominating the whole landcover through the study period. Its coverage from 1997 until 2010 amounted 89% of the total area. Conversion of land into forest land fluctuates and the highest value is found in 2001 (944 ha). This phenomenon could be as a result of intensive reforestation and rehabilitation programme conducted in the rehabilitation zone where in 1997 the area was classified as shrubs/bushes and bare land. Within 4 years period, the shrubs/bushes were grown as a secondary forest which is the most likely to be the dominant factor of the increase of forest land in the North Eastern part of MBNP.

Cropland area shows a distinct increase from 2001 to 2005. The changes occured mostly in the rehabilitation zone in the Northern part of MBNP. Reforestation programme in the rehabilitation zone provides the involvement of local community where they can plant agricultural plants between the wooden trees or which is called as intercropping. As a result, in 2005 the shrubs/bushes class which covered a quite large amount in the rehabilitation zone had been converted into cropland (shrub mixed dryland agriculture).

Land converted to Grassland and to Other Land area tends to decrease. Basically this could be used as one of a parameter to measure the success of reforestation programme in MBNP. While settlement is quite stable through the study period because there is almost no settlement expansion in MBNP.

Figure 18 shows the trend of landcover change in MBNP throughout the study period (from 1997 to 2010). From this graph the area of Forest land tends to dominate followed by crop land, grassland, other land and settlement.



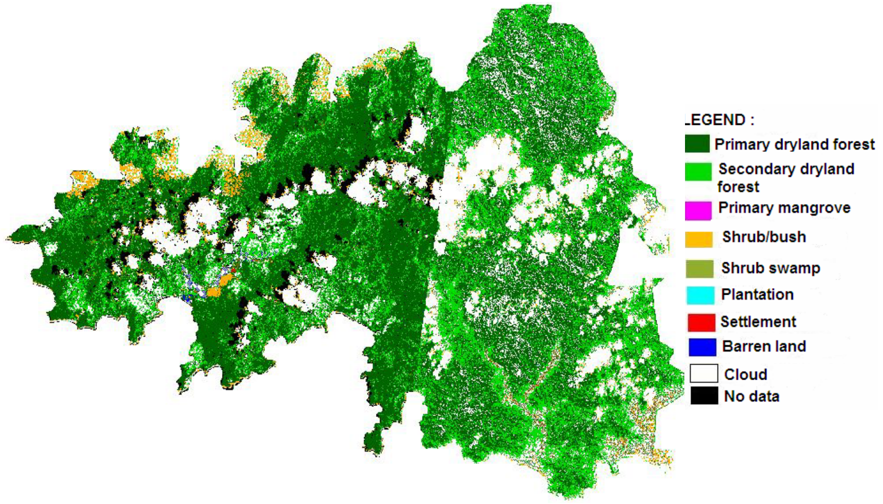



**Figure 11.** MBNP landcover classification from ALOS, 2007 (Irawan and Purnomosiddy, Jember University, 2010).

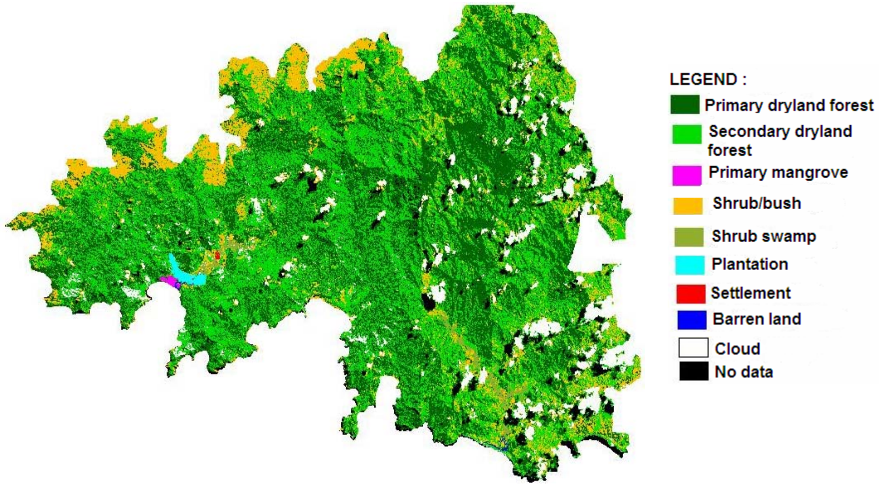



**Figure 12.** MBNP landcover classification from ALOS, 2009 (Irawan and Purnomosiddy, Jember University, 2010).

Table 5 summarizes the percentage of landcover classification generated by Jember University from 1997 until 2009. The table shows that Primary dryland forest is the dominant landcover in MBNP, followed consequently by secondary dryland forest, shrub/bush, bush swamp, plantation, primary mangrove forest, barren land and settlement. Cloud and no data class present throughly the study period, but their occurence in the image is still below 20% which is still acceptable for conducting research and analysis.

**Table 5.** Percentage of landcover in MBNP (Jember University, 2010)

| No. | KLASIFIKASI | Spot 1997 | Landsat 1999 | Landsat 2001 | Landsat 2003 | Spot 2005 | Alos 2007 | Alos 2009 |
|---|---|---|---|---|---|---|---|---|
| 1 | Primary dryland forest | 46.88 | 37.66 | 42.88 | 41.82 | 36.41 | 40.59 | 39.67 |
| 2 | Secondary dryland forest | 29.27 | 20.81 | 32.75 | 32.55 | 30.86 | 35.24 | 38.37 |
| 3 | Primary mangrove forest | 0.06 | 0.07 | 0.07 | 0.07 | 0.06 | 0.06 | 0.06 |
| 4 | Shrub/bush | 13.62 | 12.72 | 12.93 | 13.96 | 11.52 | 11.71 | 11.61 |
| 5 | Bush swamp | 1.03 | 0.57 | 1.19 | 1.04 | 1.18 | 0.94 | 1.00 |
| 6 | Plantation | 0.20 | 0.20 | 0.22 | 0.22 | 0.21 | 0.21 | 0.21 |
| 7 | Settlement | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| 8 | Barren land | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 9 | Cloud | 4.64 | 20.60 | 5.20 | 5.21 | 10.01 | 7.66 | 5.42 |
| 10 | No data | 4.25 | 7.32 | 4.70 | 5.08 | 9.71 | 3.54 | 3.62 |
| | TOTAL (%) | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Landcover classification conducted by FORDA by using visual interpretation has distinguished 11 classes in MBNP, namely (1) primary dryland forest, (2) secondary dryland forest, (3) Mangrove forest, (4) Bush/shrub, (5) Plantation, (6) Dryland agriculture, (7) Shrub mixed dryland agriculture, (8) Grassland, (9) Settlement, (10) Bare land and (11) Water (Table 7). The use of ALOS PALSAR with radar sensor which can penetrate into the clouds in this research had helped the interpretation in the locations where clouds are present. Accordingly, there are no “cloud” and “no data” classes had been used in the classification conducted by FORDA.



**Table 9.** (Continued)

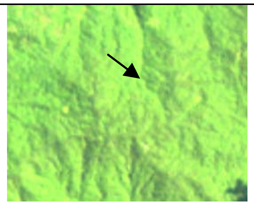
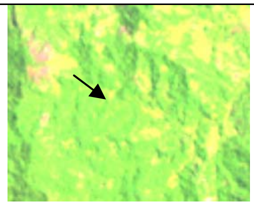
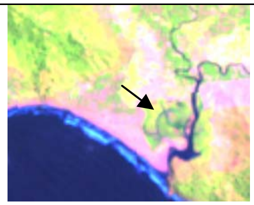
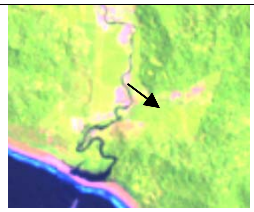
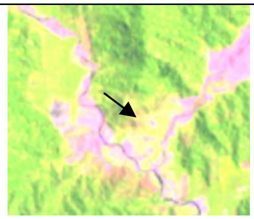
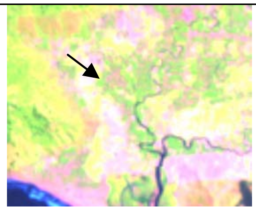
| Category | Data source (Landsat TM 1:50.000) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1997 | | 2001 | | 2005 | | 2007 | | 2010 | |
| | Ha | % | Ha | % | Ha | % | Ha | % | Ha | % |
| **F. Other Land (OL)** | **1438** | **3** | **527** | **1** | **52** | **0** | **59** | **0** | **59** | **0** |
| 1. OL remaining OL | 1438 | | 77 | | 52 | | 52 | | 59 | |
| 2. Land converted to OL | 0 | | 449 | | 0 | | 6 | | 0 | |
| **G. No Data (ND)** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| 1. ND remaining ND | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2. Land converted to ND | 0 | | 0 | | 0 | | 0 | | 0 | |

**Table 9.** Recapitulation of land change matrix of MBNP

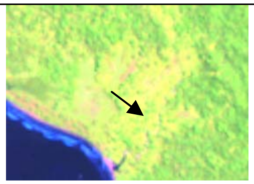
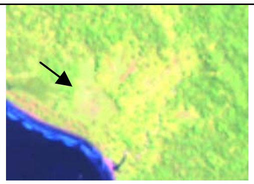
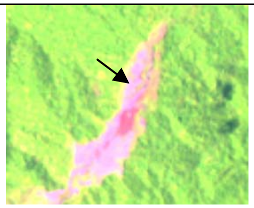
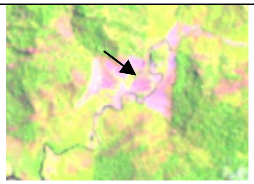
| Category | Data source (Landsat TM 1:50.000) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1997 | | 2001 | | 2005 | | 2007 | | 2010 | |
| | Ha | % | Ha | % | Ha | % | Ha | % | Ha | % |
| Total area | 54562 | 100 | 54562 | 100 | 54562 | 100 | 54562 | 100 | 54562 | 100 |
| Land category | | | | | | | | | | |
| **A. Forest Land (FL)** | **47793** | **88** | **48372** | **89** | **48501** | **89** | **48426** | **89** | **48381** | **89** |
| 1. FL remaining FL | 47793 | | 47428 | | 48216 | | 48316 | | 48324 | |
| 2. Land converted to FL | 0 | | 944 | | 284 | | 110 | | 56 | |
| **B. Crop Land (CL)** | **1565** | **3** | **1526** | **3** | **3806** | **7** | **4077** | **7** | **4118** | **8** |
| 1. CL remaining CL | 1565 | | 1186 | | 1496 | | 3684 | | 4016 | |
| 2. Land converted to CL | 0 | | 340 | | 2311 | | 393 | | 101 | |
| **C. Grass Land (GL)** | **3738** | **7** | **4109** | **8** | **2174** | **4** | **1967** | **4** | **1967** | **4** |
| 1. GL remaining GL | 3738 | | 2377 | | 2150 | | 1862 | | 1967 | |
| 2. Land converted to GL | 0 | | 1733 | | 23 | | 105 | | 0 | |
| **D. Wetland (WL)** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| 1. WL remaining WL | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2. Land converted to WL | 0 | | 0 | | 0 | | 0 | | 0 | |
| **E. Settlement (S)** | **28** | **0** | **28** | **0** | **28** | **0** | **33** | **0** | **38** | **0** |
| 1. S remaining S | 28 | | 28 | | 28 | | 28 | | 33 | |
| 2. Land converted to S | 0 | | 0 | | 0 | | 5 | | 4 | |



**Tabel 6.** Appearances of multiple objects in landsat

| No. | Object | Landsat (Band 5-4-3) | Description |
|---|---|---|---|
| 1. | Primary dry land forest |  | Comprises all appearance of forests in the flat plain, hilly and the mountainous area, have not undergone the characteristics of logging, including low trees grown on massive rocks. |
| 2. | Secondary dry land forest |  | All of forests on flat plain, hilly and the mountainous area have presented the characteristics of logging (open space and logging tracks) |
| 3. | Mangrove forest |  | Dominated by mangrove and nypa fructicans near the shore. |
| 4. | Estate/crop Plantation |  | |
| 5. | Dryland agriculture |  | All agricultural activities in dryland areas such as mixed farm when dominated by agricultural plants. |
| 6. | Shrub mixed dryland agriculture |  | All agricultural activities in dryland areas intercropped with shrubs/bushes and logged over area. |

**Tabel 6.** (Continued)

| No. | Object | Landsat (Band 5-4-3) | Description |
|---|---|---|---|
| 7. | Shrub |  | Ex forest area that has undergone succession, dominated with shrubs |
| 8. | Grassland |  | Non-forest,dominated by grass, small amount of bushes or trees. |
| 9. | Bare land |  | Area without vegetation, and open space in ex forest fires sites. Mining area is included in this class. |
| 10. | Settlement |  | Group of buildings in urban or rural area. |
| 11. | Water |  | Water body i.e. river, lake, pond, etc. |

Landcover maps generated using visual interpretation by FORDA are shown below:



The LCM above shows the changes occured from each land category. Zero values showed for Wetland is due to no presence of wetlands in MBNP. No data class is also not avalaible because the problem caused by cloud factor had been resolved by using ALOS PALSAR during the classification. In 1997, we also obtain zero values for land category that is converted to other land category. The reason of this is because 1997 is considered to be the reference image so we assume that landcover data before 1997 is not available. In response to this, any landcover changes taken place before 1997 is assumed to be as zero. Table 9 represents the recapitulation of the landuse change matrix described above.

**Table 8.** (Continued)

| Category | Sub Category | Data source (Landsat TM 1:50.000) 1997 Ha | 1997 % | 2001 Ha | 2001 % | 2005 Ha | 2005 % | 2007 Ha | 2007 % | 2010 Ha | 2010 % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **F. Other Land (OL)** | | **1438** | **3** | **527** | **1** | **52** | **0** | **59** | **0** | **59** | **0** |
| 1. OL remaining OL | | 1438 | | 77 | | 52 | | 52 | | 59 | |
| 2. Lahan converted to OL | | 0 | | 449 | | 0 | | 6 | | 0 | |
| 2.1 FL converted to OL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.2 CL converted to OL | | 0 | | 372 | | 0 | | 6 | | 0 | |
| 2.3 GL converted to OL | | 0 | | 77 | | 0 | | 0 | | 0 | |
| 2.4 WL converted to OL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.5 S converted to OL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.6 ND converted to OL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| **G. No Data (ND)** | | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| 1.ND remaining ND | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2. Lahan converted to ND | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.1 FL converted to ND | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.2 CL converted to ND | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.3 GL converted to ND | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.4 WL converted to ND | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.5 S converted to ND | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.6 OL converted to ND | | 0 | | 0 | | 0 | | 0 | | 0 | |



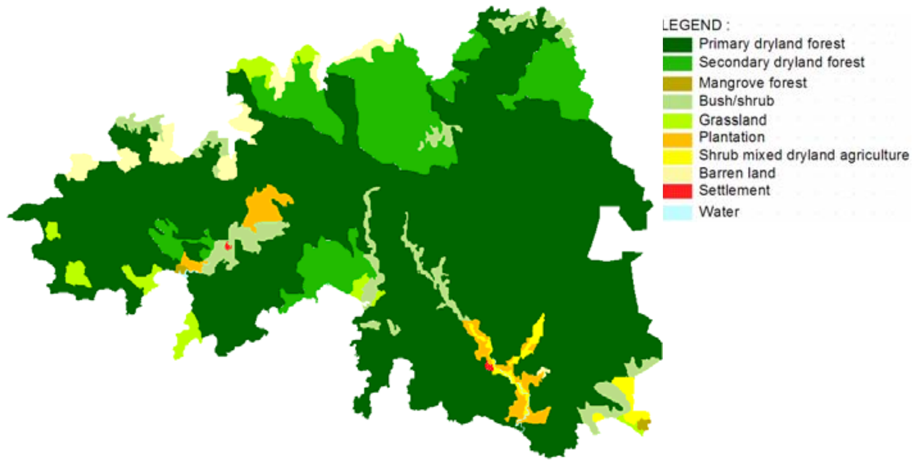



**Figure 13.** MBNP landcover classification from Landsat, 1997 by: FORDA.

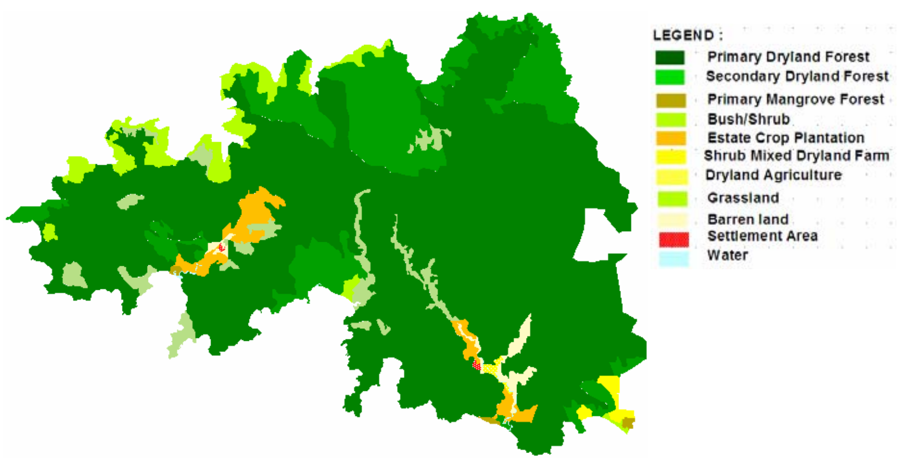



**Figure 14.** MBNP landcover classification from Landsat, 2001 by: FORDA.

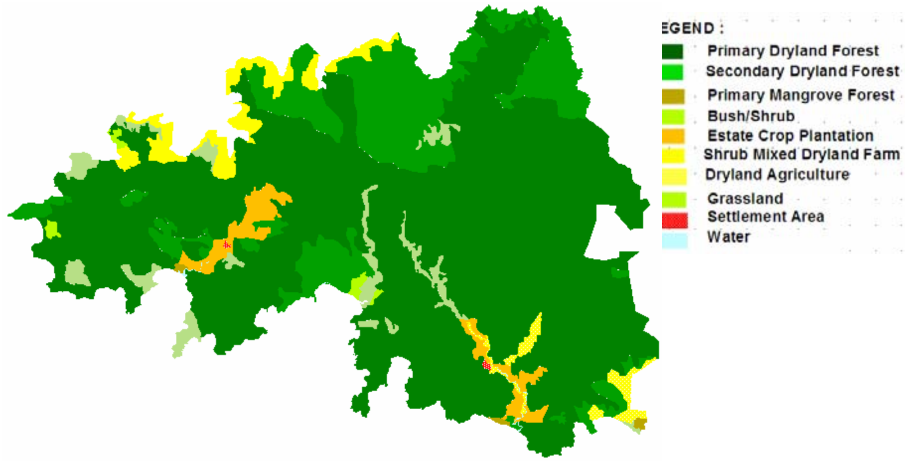



**Figure 15.** MBNP landcover classification from Landsat, 2005 by: FORDA.

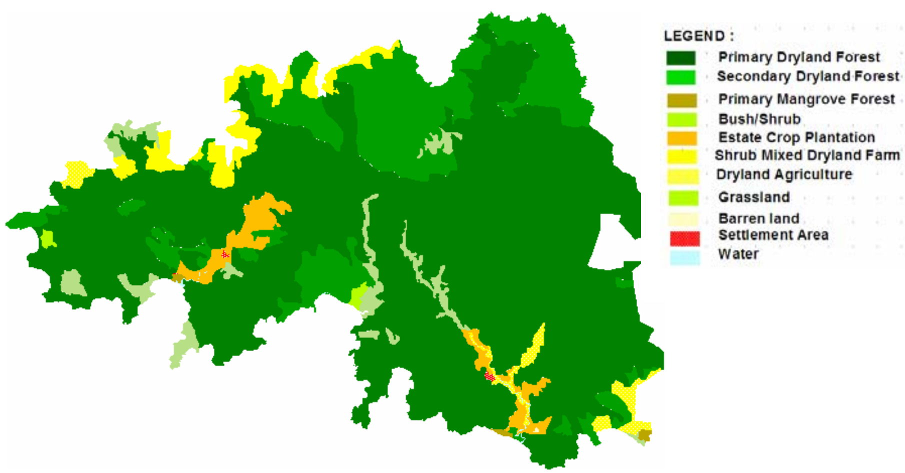



**Figure 16.** MBNP landcover classification from Landsat, 2007 by: FORDA.



**Table 8.** (Continued)

| Category | Sub Category | Data source (Landsat TM 1:50.000) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1997 | | 2001 | | 2005 | | 2007 | | 2010 | |
| | | Ha | % | Ha | % | Ha | % | Ha | % | Ha | % |
| **D. Wetland (WL)** | | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| 1. WL remaining WL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2. Lahan converted to WL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.1 FL converted to WL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.2 CL converted to WL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.3 GL converted to WL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.4 S converted to WL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.5 OL converted to WL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.6 ND converted to WL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| **E. Settlement (S)** | | 28 | **0** | **28** | **0** | **28** | **0** | **33** | **0** | **38** | **0** |
| 1. S remaining S | | 28 | | 28 | | 28 | | 28 | | 33 | |
| 2. Lahan converted to S | | 0 | | 0 | | 0 | | 5 | | 4 | |
| 2.1 FL converted to S | | 0 | | 0 | | 0 | | 1 | | 0 | |
| 2.2 CL converted to S | | 0 | | 0 | | 0 | | 3 | | 4 | |
| 2.3 GL converted to S | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.4 WL converted to S | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.5 OL converted to S | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.6 ND converted to S | | 0 | | 0 | | 0 | | 0 | | 0 | |

**Table 8.** (Continued)

| Category | Sub Category | Data source (Landsat TM 1:50.000) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1997 | | 2001 | | 2005 | | 2007 | | 2010 | |
| | | Ha | % | Ha | % | Ha | % | Ha | % | Ha | % |
| 2.5 OL converted to CL | | | | | | | | | | | |
| | Plantation | 0 | | 0 | | 232 | | 0 | | 0 | |
| | Agriculture | 0 | | 0 | | 242 | | 0 | | 0 | |
| | Paddy field | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.6 ND converted to CL | | | | | | | | | | | |
| | Plantation | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Agriculture | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Paddy field | 0 | | 0 | | 0 | | 0 | | 0 | |
| **C. Grassland (GL)** | | **3738** | **7** | **4109** | **8** | **2174** | **4** | **1967** | **4** | **1967** | **4** |
| 1. GL remaining GL | | 3738 | | 2377 | | 2150 | | 1862 | | 1967 | |
| 2. Land converted to GL | | 0 | | 1733 | | 23 | | 105 | | 0 | |
| 2.1 FL converted to GL | | 0 | | 366 | | 1 | | 21 | | 0 | |
| 2.2 CL converted to GL | | 0 | | 7 | | 22 | | 85 | | 0 | |
| 2.3 WL converted to GL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.4 S converted to GL | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.5 OL converted to GL | | 0 | | 1360 | | 0 | | 0 | | 0 | |
| 2.6 ND converted to GL | | 0 | | 0 | | 0 | | 0 | | 0 | |



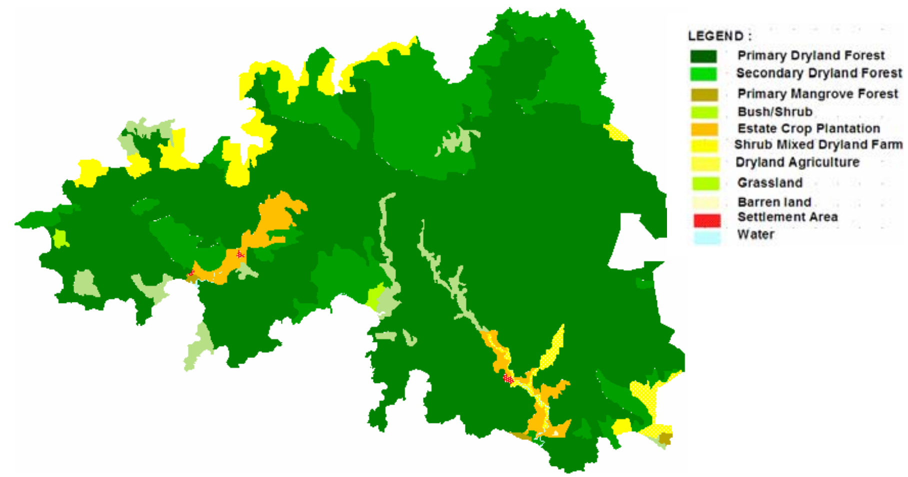



**Figure 17.** MBNP landcover classification from Landsat, 2010 by: FORDA.

Time series analyses for landcover change in MBNP (FORDA, 2010) showed there are quite distinct changes in the Northern part of MBNP, namely in the rehabilitation zone. In 1997/1998 during the reformation period, forest encroachment and illegal logging had been occured in the former forested area in MBNP. Since then the area were barren (approximately 4,023 ha) and slowly it was covered with shrub and bushes (Landsat 2001). Since 2003, the area was assigned as rehabilitation zone where intensive reforestation programmes had been conducted. This effort had an impact to landcoverage, where forest trees are planted intercropped with dryland agriculture vegetation. Landsat 2010 also shows that the area currently dominated with shrub mixed and dryland agriculture vegetation.

Table 7 shows the area and percentage of landcover in MBNP for 1997, 2001, 2005, 2007 and 2010. Generally, primary dryland forest dominated the area of MBNP, followed by secondary dryland forest, bush/shrub, shrub mixed dryland agriculture, plantation, grassland, dryland agriculture, barren land and settlements. The trend analyses of each landcover type will be described in the following sections. Further analysis in this report will use the landcover change data generated by FORDA.

**Table 7.** Landcover classification according to DG of Forest Planology Classification (2006) using visual interpretation by: FORDA.

| LANDCOVER | 1997 | | 2001 | | 2005 | | 2007 | | 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ha | % | Ha | % | Ha | % | Ha | % | Ha | % |
| Water | 52 | 0 | 52 | 0 | 52 | 0 | 52 | 0 | 52 | 0 |
| Bush/Shrub | 2654 | 5 | 1965 | 4 | 1932 | 4 | 1814 | 3 | 1814 | 3 |
| Primary dryland forest | 40309 | 74 | 39460 | 72 | 39218 | 72 | 38537 | 71 | 37965 | 70 |
| Secondary dryland forest | 7413 | 14 | 8810 | 16 | 9181 | 17 | 9788 | 18 | 10315 | 19 |
| Mangrove forest | 71 | 0 | 102 | 0 | 102 | 0 | 101 | 0 | 101 | 0 |
| Settlement | 28 | 0 | 28 | 0 | 28 | 0 | 33 | 0 | 38 | 0 |
| Plantation | 1058 | 2 | 1186 | 2 | 1425 | 3 | 1394 | 3 | 1373 | 3 |
| Dryland agriculture | 0 | 0 | 75 | 0 | 633 | 1 | 872 | 2 | 685 | 1 |
| Shrub mixed dryland agriculture | 507 | 1 | 265 | 0 | 1749 | 3 | 1812 | 3 | 2060 | 4 |
| Grassland | 1084 | 2 | 2144 | 4 | 242 | 0 | 153 | 0 | 153 | 0 |
| Barren land | 1385 | 3 | 474 | 1 | 0 | 0 | 6 | 0 | 6 | 0 |
| **Total Area (ha)** | **54562** | **100** | **54562** | **100** | **54562** | **100** | **54562** | **100** | **54562** | **100** |



**Table 8.** (Continued)

| Category | Sub Category | Data source (Landsat TM 1:50.000) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1997 | | 2001 | | 2005 | | 2007 | | 2010 | |
| | | Ha | % | Ha | % | Ha | % | Ha | % | Ha | % |
| 2. Land converted to CL | | **0** | | **340** | | **2311** | | **393** | | **101** | |
| 2.1 FL converted to CL | | | | | | | | | | | |
| | Plantation | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Agriculture | 0 | | 0 | | 154 | | 163 | | 101 | |
| | Paddy field | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.2 GL converted to CL | | | | | | | | | | | |
| | Plantation | 0 | | 309 | | 8 | | 0 | | 0 | |
| | Agriculture | 0 | | 31 | | 1675 | | 230 | | 0 | |
| | Paddy field | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.3 WL converted to CL | | | | | | | | | | | |
| | Plantation | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Agriculture | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Paddy field | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.4 S converted to CL | | | | | | | | | | | |
| | Plantation | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Agriculture | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Paddy field | 0 | | 0 | | 0 | | 0 | | 0 | |

**Table 8.** (Continued)

| Category | Sub Category | Data source (Landsat TM 1:50.000) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1997 | | 2001 | | 2005 | | 2007 | | 2010 | |
| | | Ha | % | Ha | % | Ha | % | Ha | % | Ha | % |
| 2.5 OL converted to FL | | | | | | | | | | | |
| | Dryland forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Mangrove | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Swamp forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Plantation forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.6 ND converted to FL | | | | | | | | | | | |
| | Dryland forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Mangrove | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Swamp forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Forest Plantation | 0 | | 0 | | 0 | | 0 | | 0 | |
| **B. Crop Land (CL)** | | **1565** | **3** | **1526** | **3** | **3806** | **7** | **4077** | **7** | **4118** | **8** |
| 1. CL remaining CL | | **1565** | | **1186** | | **1496** | | **3684** | | **4016** | |
| | Plantation | 1058 | | 877 | | 1184 | | 1394 | | 1373 | |
| | Agriculture | 507 | | 309 | | 311 | | 2290 | | 2644 | |
| | Paddy field | 0 | | 0 | | 0 | | 0 | | 0 | |



### 3.2. Landuse Change Matrix (LCM)

Landuse change matrix is generated after adjustment of landcover classification based on DG of Forest Planology (2006) into 6 land categories of IPCC GL 2006. The adjustment made in LCM is conducted by classifying each land category of IPCC GL 2006 into sub categories of classification of DG of Forest Planology (2006). This resulted as followings: the Primary dryland forest, Secondary dryland forest and Mangrove forest are reclassified into Forest Land (FL) class; Dryland agriculture, Shrub mixed dryland agriculture and Plantation are reclassified into Cropland (CL) class; Bush/shrub and Grassland are reclassified into Grassland (GL) class; Bare land and Water are reclassified into Other land (OL) class; and Settlement is still classified as Settlement. In LCM, changes in landcover area and its percentage are estimated for (i) land remaining in the same land-use category and (ii) land converted to a new land-use category. The LCM of MBNP for 1997, 2001, 2005, 2007 and 2010 is presented in Table 8 below.

**Table 8.** Landuse Change Matrix of Meru Betiri National Park (MBNP)

| Category | Sub Category | Data source (Landsat TM 1:50.000) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1997 | | 2001 | | 2005 | | 2007 | | 2010 | |
| | | Ha | % | Ha | % | Ha | % | Ha | % | Ha | % |
| **Total Area** | | **54562** | **100** | **54562** | **100** | **54562** | **100** | **54562** | **100** | **54562** | **100** |
| **Land category** | | | | | | | | | | | |
| **A. Forest Land (FL)** | | **47793** | **88** | **48372** | **89** | **48501** | **89** | **48426** | **89** | **48381** | **89** |
| 1. FL remaining FL | | **47793** | | **47428** | | **48216** | | **48316** | | **48324** | |
| | Dryland forest | 47722 | | 47325 | | 48114 | | 48215 | | 48224 | |
| | Mangrove | 71 | | 102 | | 102 | | 101 | | 101 | |
| | Swamp forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Plantation forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2. Land converted to FL | | **0** | | **944** | | **284** | | **110** | | **56** | |
| 2.1 CL converted to FL | | | | | | | | | | | |
| | Dryland forest | 0 | | 0 | | 8 | | 28 | | 56 | |
| | Mangrove | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Swamp forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Plantation forest | 0 | | 0 | | 0 | | 0 | | 0 | |

**Table 8.** (Continued)

| Category | Sub Category | Data source (Landsat TM 1:50.000) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1997 | | 2001 | | 2005 | | 2007 | | 2010 | |
| | | Ha | % | Ha | % | Ha | % | Ha | % | Ha | % |
| 2.2 GL converted to FL | | | | | | | | | | | |
| | Dryland forest | 0 | | 944 | | 276 | | 82 | | 0 | |
| | Mangrove | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Swamp forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Plantation forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.3 WL converted to FL | | | | | | | | | | | |
| | Dryland forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Mangrove | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Swamp forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Plantation forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| 2.4 S converted to FL | | | | | | | | | | | |
| | Dryland forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Mangrove | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Swamp forest | 0 | | 0 | | 0 | | 0 | | 0 | |
| | Plantation forest | 0 | | 0 | | 0 | | 0 | | 0 | |