Land Use Change Modeling to Support the Management Plan of Protected FMU Unit II FMU Region XV Kabanjahe

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ABSTRACT

Deforestation results in environmental degradation, so it is necessary to conduct a study to determine land use changes that occur and predict land changes with appropriate directions to support the Protected FMU Unit II FMU Region XV Kabanjahe management plan. This study aims to analyze changes and predictions of land use in 2013-2033, factors that influence land use change, and formulate directions for land use plans in Protected FMU Unit II FMU Region XV Kabanjahe. This research uses a Geographic Information System approach with the Artificial Neural Network (ANN) method prediction model. Factors driving land use change as model inputs consist of distance to road, distance to permit, distance to settlement, distance to river, elevation, geology, soil type, and slope. The results showed that there has been a decrease in dryland forest by 6,957 ha in the 2013-2018 period, and the driving factor that has the highest degree of relationship based on the results of the correlation test is the distance to the road, which is 0.2444. The land use change prediction model has an accuracy of 89.42% based on Kappa Index Agreement (KIA). The direction of the land use plan in Protected FMU Unit II FMU Region XV Kabanjahe in 2033 consists of Protected Forest Area which has the largest area, namely 64,678 ha, Production Forest covering 7,077 ha, and Limited Production Forest covering 9,278 ha.

Keyword: Artificial Neural Network (ANN), Forest Management Unit, Geographic Information System (GIS), Land Use, Spatial Analysis

1. Introduction

Karo Regency is one of the regencies in North Sumatra, where agriculture is one of the important factors in building the regional economy. 38.09% or 81,033.40 ha of the 212,700 ha total area of Karo Regency is included in the working area of Forest Management Unit (FMU) Region XV Kabanjahe. The FMU Region XV Kabanjahe consists of Protected FMU Unit II Karo and Production FMU Unit IV Dairi. The Forest Management Unit (FMU) is one of the products of national forestry policy in the form of an organisation of forest management units at the site level, which is expected to achieve sustainable forest management [1], [2].

Land is a very limited resource, so the very high demand for land will lead to land conversion (land use change) [3]. Karo Regency is famous as a fruit and flower producing area, and the main livelihoods are food agriculture, horticultural products and smallholder plantations [4]. The community around the Protected FMU Unit II FMU Region XV Kabanjahe area encroaches on the area to open seasonal crop gardens and business locations that are used as both main and side livelihoods. The gardens cultivated by the community in the FMU area have generally been going on for a long time. Various land use utilization activities by the community in the

management area that are not in accordance with the forest planning, will cause disruption to the forest ecosystem [5], [6].

In addition, forest and land fires are one of the causes of deforestation and forest and land degradation. Forest and land fires can be a hindrance or obstacle in the development of an area. According to the Disaster Risk Assessment Analysis in the Regional Medium-Term Development Plan of Karo Regency for 2021 - 2026, the danger of forest and land fires is 66,117 ha with a high hazard level class.

Land cover is the physical surface of a land related to all types and current appearances of the earth's surface regardless of human activities on these objects, while land use is an expression of the interaction between the environment and human activities that try to make the environment suitable for life and its needs [6]. The dynamics of land change can be reviewed quantitatively spatially through remote sensing data. The results of this analysis can be used as a reference to conduct further analysis in the form of spatial land cover prediction modeling [7]. According to land use change as a combination of temporal interactions that occur directly or indirectly can have various impacts on the environment [8], [9]. The occurrence of deforestation is one of the real things that results in environmental degradation, so it is necessary to conduct a study to determine land use changes that occur and predict land changes with appropriate directions to support the management plan of the Forest Management Unit, especially Protected FMU Unit II FMU Region XV Kabanjahe. A prediction of land use change can provide opportunities to deal with environmental problems and regional changes in the future.

2. Method
2.1 Study Area

The research location was Protected FMU Unit II FMU Region XV Kabanjahe North Sumatra, located in Karo Regency, North Sumatra Province, Indonesia (Figure 1). Processing and analysis of research data were carried out at the Forest Management Laboratory, Faculty of Forestry, Universitas Sumatera Utara.
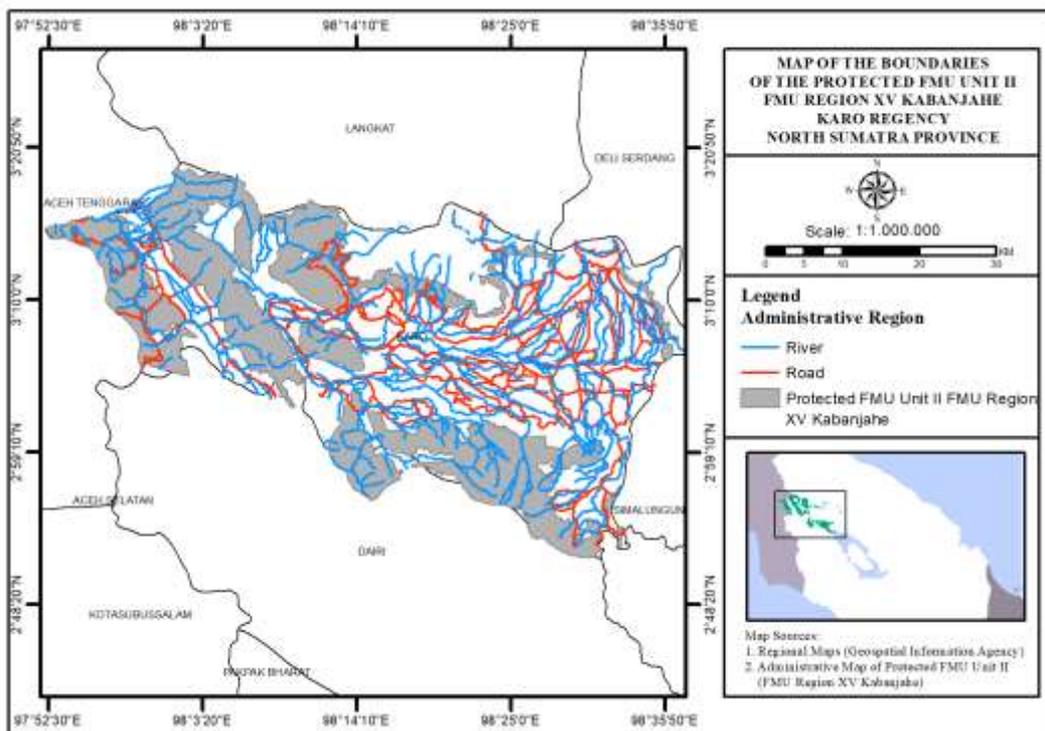

Figure 1. Map of Research Location

2.2 Material and Tools

The materials used in this research are data taken from other sources in the form of Landsat 8 OLI/TIRS images in 2013, 2018, and Landsat 9 OLI/TIRS images in 2023. The path and row used are 129 and 058, using Level-1 Top Of Atmosphere (TOA) Reflectance data processing level, and Cloud/quality mask using QA_PIXEL. Date range for 2013 is 01-01-2013 to 31-12-2013. Year 2018 is, 01-01-2018 to 31-12-2018. The year 2023 is 01-01-2023 to 31-12-2023. The bands used consist of B1, B2, B3, B4, B5, B6, and B7. In addition, the 1:50,000 scale Indonesian Earth Map, National Digital Elevation Model, Soil Type Map, Geological Map,

Forest Utilisation Permit Distribution Map, Area Boundary Administration Map, and Ground check data were also used in this research. The tools used in this research consist of data collection tools and data analysis tools. The tools used in this research consist of data collection tools and data analysis tools. Field data collection tools were Global Positioning System (GPS), digital camera, and stationery. The data analysis tools used were computer, ArcGIS 10.3, Erdas Imagine 9.1, Google Earth Engine (GEE), and IDRISI Selva.

2.3 Method of Research
2.3.1 Land cover classification

This classification uses Guided Classification with Classification and Regression Tree (CART) algorithm [9]. The creation of training areas is the initial stage in classification to retrieve statistical information on land cover types. Training samples were created for each land cover class based on the digitisation of representative areas in the composite image as well as reference field data and supporting maps [10].

Sampling was conducted using purposive sampling method from the results of land cover stratification. The sample points were determined, spread evenly according to the research objectives by considering the ease of accessibility to the sample points. The accuracy test sample was taken separately from the training sample to avoid bias. The land cover training sample and testing data for accuracy testing used a ratio of 70% training sample and 30% testing data from the total sample to get optimal results [9]. Testing data was selected in locations that were not used for training and still fulfilled the criteria of the core class area. Validation is done through confusion matrix or error matrix analysis. The accuracy test aims to evaluate the level of accuracy of the land cover classification based on the training area that has been analysed and the results of field checks, then the accuracy value is calculated using overall accuracy and kappa accuracy [11]-[13].

2.3.2 Analysis of drivers of land use change

Land use change analysis was conducted through an overlay process between 2013, 2018 and 2023 land use maps. Land use in 2013 and 2018, as well as 2018 and 2023 were compared using cross tabulation which will result in a land use change transition matrix. The selection of factors that influence land cover change in this study is based on the support of previous literature. Distance to roads, riversand settlements considered because accessibility factors influence land conversion [5], [14], [15]. Slope, soil type, geology and elevation were selected because their biophysical conditions determine the potential and suitability of land use [5], [8], [15].

Each driving factor is processed into a map for the next process of analyzing the relationship between driving factors and land use change. The analysis of the relationship between driving factors and land use change was conducted using Cramer's V test. Driving factors need to be tested for Cramer's V value to see the relationship between driving factors and land use change. The Cramer's V value ranges from 0-1, where a value of 0 indicates unrelatedness and a value of 1 indicates a very close relationship [15].

Maps of distance to roads, distance to rivers, and distance to settlements obtained from Indonesian Earth Data per Karo Region are calculated based on Euclidean Distance. The distance map to the boundary of the forest utilization permit area was analyzed from data on the existence of forest area use permits in the form of shapefile (shp). The slope map was obtained from processing Digital Elevation Model (DEM) data from the Geospatial Information Agency website. Processing using the slope menu in ArcGIS 10.3 software. The soil type map was obtained from processing the soil type shapefile which was then adjusted to the boundaries of the research area. Geological maps were obtained from processing shp data of the Indonesian Geological Map of North Sumatra Province which was then adjusted to the boundaries of the research area. The elevation map was calculated using DEM data from the Geospatial Information Agency website in the form of National DEM Data.

2.3.3 Modeling and prediction of land use change

The data used to predict land use in 2033 was built from land use data in 2013, 2018 and 2023. Modeling and prediction were conducted using the Land Change Modeler (LCM) menu in the Idrisi Selva software. The stages used were change analysis, transition potential, and change prediction.

The model is based on the 2013 and 2018 interpreted land use maps which are then validated with the 2023 land use map. The transition potential stage is a stage to test the potential of land changes that occur using dependent and independent variables. After determining the dependent and independent variables, the model will be run.

To make land use predictions for the coming year, the change prediction stage is used. At this stage, the Markov Chain method is used to create a transition matrix that will be used as the basis for predicting land use

in 2023 and 2033. The map of 2023 land use prediction results with the actual 2023 land use map is used to validate the land use change model and to prove that the model is good for prediction in the coming year. Furthermore, after the results obtained are accurate enough, the 2033 land use prediction is made.

2.3.4 Land use direction for forest management plan

The preparation of land use direction uses data from land use or land cover prediction results, and forestry policy direction in the form of area function determination, license existence, and indicative social forestry direction. Area function serves as a determinant of block naming (Table 1). Block division design is part of Forest Management design, which is made in accordance with the function and condition of the site. Block naming is carried out in accordance with the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 8 of 2021 concerning Forest Planning and Preparation of Forest Management Plans, as well as Forest Utilization in Protected Forests and Production Forests.

Table 1. Determination of forest planning blok plan direction

Area Function	Block	Description
Protection Forest	Core Blocks	Restricted to NTFP collection activities by not destroying forest stands

	Utilization Block	a. Utilization blocks for business licensing, in the form of:
		  1. Area Utilization
		  2. Utilization of environmental services
		  3. Collection of NTFPs
		b. Utilization block for social forestry management

	Special Blocks	Accommodating special interests in the FMU area
Production Forest	Protection Block	a. NTFP collection b. Utilization of Environmental Services
	Utilization Block	a. Utilization block for business licensing b. Utilization block for social forestry management
	Special Blocks	Accommodate special interests in the FMU area.

3. Result and Discussion

3.1 Area Characteristics

3.1.1 Topography

The Protected FMU Unit II FMU Region XV Kabanjahe area is a plain to hilly topographic area with varying slope levels. Based on the analysis, the slope is dominated by very steep class (>45%) covering 31,289 ha or 38.61%. Soils on very steep slopes are more prone to erosion, as rainwater flows faster and carries soil particles. Therefore, the soil is easily eroded and eroded. The distribution and percentage of slope inclination can be seen in Table 2 and Figure 2.a.

Table 2. Slope of the Protected FMU Unit II FMU Region XV Kabanjahe area

No	Slope Class	Classification	Area (ha)	Area (%)
1	0 - 8%	Flat	3,996	4.93
2	8 - 15%	Ramps	6,082	7.51
3	15 - 25%	Somewhat Steep	12,106	14.94
4	25 - 45%	Steep	27,559	34.01
5	> 45%	Very steep	31,289	38.61
	Total		81,033	100.00

3.1.2 Geological formations and soil types

The Protected FMU Unit II FMU Region XV Kabanjahe area has diverse geological formations, including volcanic geological formations such as Sinabung Volcano Rocks, Sibayak, and Toba Tuffa which are influenced by volcanic activity in the region, as well as sedimentary formations such as alluvium and bedding formations. In addition, the relationship between mines and geological formations directly influences land use change. Mines are generally built in locations with geological formations that contain mineral or energy resources. This leads to land use change from natural areas, such as forests, farmland or open land, to mining areas. The distribution and percentage of geological formations can be seen in Table 3 and Figure 2.b.

Table 3. Geological formations of Protected FMU Unit II FMU Region XV Kabanjahe area

No	Geology Class	Area (ha)	Area (%)
1	Alluvium	1,488	1.84
2	Barus Volcano Rocks	1	0.00
3	Peuet Sague Volcanic Rocks, Samalanga	461	0.57
4	Rocks of Sinabung Volcano	930	1.15
5	Breakthrough Rocks	2	0.00
6	Pedestal Formation	20,496	25.29
7	Batumilmil Limestone Formation	1,351	1.67
8	Bohorok Formation	6,291	7.76
9	Butar Formation	18,373	22.67
10	Haranggaol Volcano Formation	143	0.18
11	Kluet Formation	17,404	21.48
12	Kutacane Formation	973	1.20
13	Keteran Granite	839	1.04
14	Sibayak Center	654	0.81
15	Takur-Takur Center	1,381	1.70
16	Toba Center Sibutan Unit	1,230	1.52
17	Tuffa Toba	9,018	11.13
	Total	81,033	100.00

Soil types in the Protected FMU Unit II FMU Region XV Kabanjahe area are dominated by alluvial, andosol, grumosol, brown podzolic, yellow red podzolic, and renzina types. The most dominant soil type in this region is brown podzolic covering 46,509 ha or 57.39%, while the lowest soil type presentation is grumosol covering 2,445 ha or 3.02%. Brown podzolic soils are formed through the process of weathering parent rocks in wet climatic conditions with high rainfall and are found in highland areas. The distribution and percentage of soil types can be seen in Table 4 and Figure 2.c.

Table 4. Soil types in the Protected FMU Unit II FMU Region XV Kabanjahe area

No	Soil Type	Area (ha)	Area (%)
1	Alluvial	2,575	3.18
2	Andosol	4,044	4.99
3	Grumosol	2,445	3.02
4	Brown Podzolic	46,509	57.39
5	Yellow Red Podzolic	15,962	19.70
6	Renzina	9,499	11.72
	Total	81,033	100.00

3.1.3 Elevation

Based on the results of the analysis, most of the Protected FMU Unit II FMU Region XV Kabanjahe area is at an altitude ranging from 500 - 1000 masl, namely 28,834 ha which indicates that this area is dominated by highlands and medium slopes which are part of the Bukit Barisan mountain range that stretches along the island of Sumatra. The area with an altitude of 2000 meters above sea level is very limited, namely 561 ha, indicating the lack of peak areas or very high mountains. The distribution and percentage of elevation can be seen in Table 5 and Figure 2.d.

Table 5. Height of place (elevation) in the Protected FMU Unit II FMU Region XV Kabanjahe area

No	Elevation Class	Area (ha)	Area (%)
1	0 - 500 meters above sea level	14,757	18.21
2	500 - 1000 meters above sea level	28,834	35.58
3	1000 - 1500 meters above sea level	26,290	32.44
4	1500 - 2000 meters above sea level	10,591	13.07
5	> 2000 meters above sea level	561	0.69
	Total	81,033	100.00

a. Slope Map of Protected FMU Unit II
FMU Region XV Kabanjahe

b. Geological Map of Protected FMU
Unit II FMU Region XV Kabanjahe

c. Soil Type Map of Protected FMU Unit
II FMU Region XV Kabanjahe

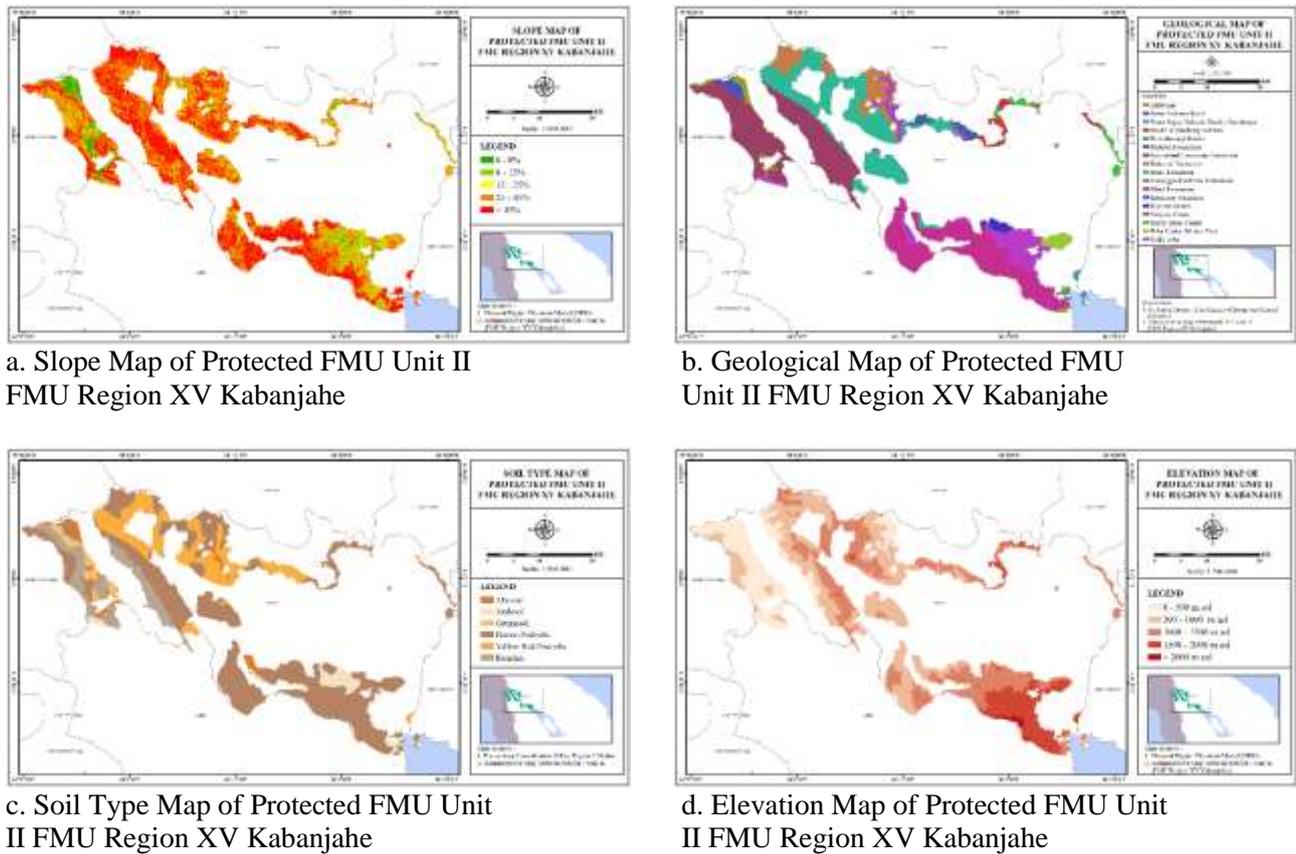d. Elevation Map of Protected FMU Unit
II FMU Region XV Kabanjahe

Figure 2. Characteristics of The Protected FMU Unit II FMU Region XV Kabanjahe Area
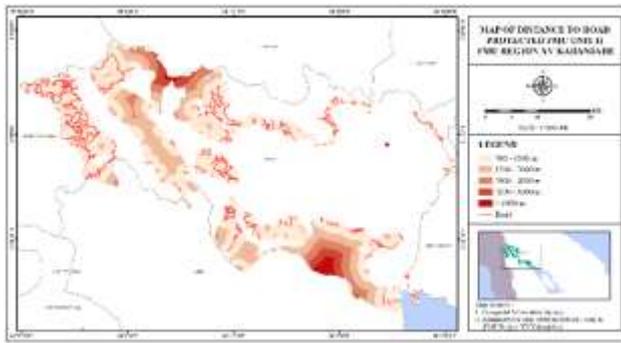
3.1.4 Accessibility

Accessibility is one of the important variables used as an estimator variable in analyzing factors affecting land use in the Protected FMU Unit II FMU Region XV Kabanjahe area. This variable includes various indicators related to the level of affordability of a location and ease of access to various surrounding infrastructure and resources. These indicators include distance to roads, distance to rivers, distance to settlements, and distance to forest utilization permit area boundaries.

Distance to roads, distance to rivers, distance to settlements, and distance to forest utilization permit area boundaries were processed using the *Euclidean Distance* technique. Distance to roads is divided into 5 (five) classes, namely 500-1,500 m, 1,500-3,000 m, 3,000-4,500 m, 4,500-6,000, and >6,000 m (Figure 3.a). Distance to river is divided into 5 (five) classes, namely 0-500 m, 500-1,000 m, 1,500-2,000 m, and >2,000 m (Figure 3.b). Distance to settlements is divided into 5 (five) classes, namely 0-2,000 m, 2,000-4,000 m, 4,000-6,000 m, 6,000-8,000 m, and >8,000 m (Figure 3.c). Distance to forest utilization permit area boundaries is divided into 5 (five) classes, namely 0- 2,000 m, 2,000-4,000 m, 4,000-6,000 m, 6,000-8,000 m, and >8,000 m (Figure 3.d).

3.2 Land Use Analysis
### 3.2.1 Land cover classification

Interpretation of Landsat satellite imagery was conducted to obtain an overview of land use in the Protected FMU Unit II FMU Region XV Kabanjahe area. The satellite images used were recorded in 2013, 2018, and 2023. Based on the results of Supervised Classification with the CART algorithm, Protected FMU Unit II FMU Wilayah XV Kabanjahe has 7 land cover/use classes, namely dryland forest, shrubs, plantations, dryland agriculture, open land, settlements, and water bodies. Based on the confusion matrix analysis, overall accuracy and kappa accuracy values of the 2023 land use interpretation results are 93.42% and 0.883.
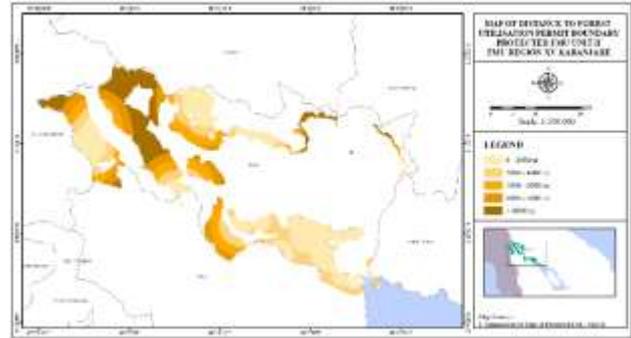
a. Map of Distance to Road
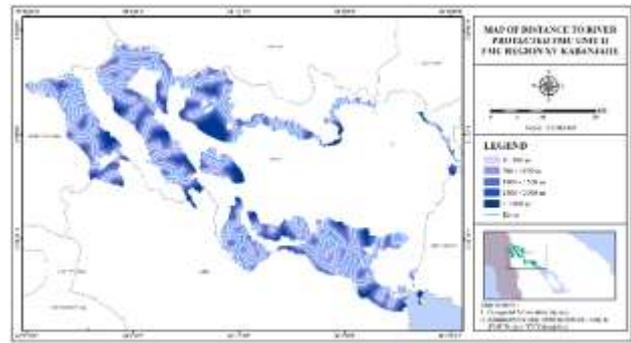
b. Map of Distance to River
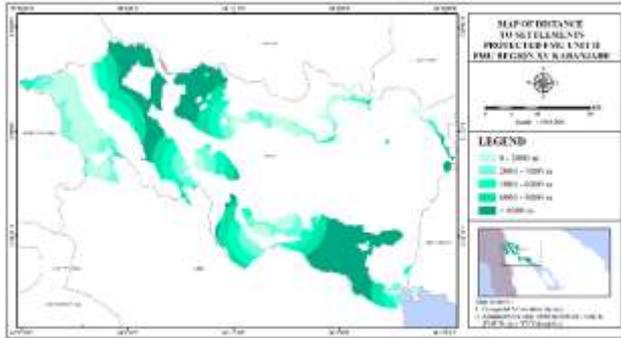
c. Map of Distance to Settlements

d. Map of Distance to Forest Utilisation Permit Boundary

Figure 3. Accessibility of The Protected FMU Unit II FMU Region XV Kabanjahe

3.2.2 Land use change

Land use change in Protected FMU Unit II FMU Region XV Kabanjahe was observed based on 3 (three) interpreted year points, namely 2013, 2018, and 2023 (Table 6). Conversion of natural forests leads to soil degradation and decreased ecological functions of forests [16]. The trend of land use change during the period 2013-2023 reflects the pressure on forest areas that require attention in rehabilitation efforts and sustainable management. If not controlled, this conversion has the potential to accelerate environmental degradation, worsen hydrological conditions, and reduce biodiversity in the Protected FMU Unit II FMU Region XV Kabanjahe area. The land cover maps for 2013, 2018, and 2023 for Protected FMU Unit II FMU Region XV Kabanjahe can be seen in Figure 4.

**Table 6.** Land use area in 2013, 2018, and 2023 Protected FMU Unit II FMU Region XV Kabanjahe

Land Use	Year 2013		Year 2018		Year 2023	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Dryland Forest	48,122	59.39	41,165	50.80	32,894	40.59
Shrubs	19,952	24.62	22,486	27.75	27,016	33.34
Plantation	5,769	7.12	6,482	8.00	5,088	6.28
Dryland Agriculture	2,396	2.96	5,214	6.43	8,125	10.03
Water Land	4,385	5.41	5,208	6.43	7,278	8.98
Settlements	347	0.43	416	0.51	576	0.71
Water Body	61	0.08	61	0.08	56	0.07
Total	81,033	100.00	81,033	100.00	81,033	100.00

a. Land cover map 2013 Protected
FMU Unit II FMU Region XV Kabanjahe

b. Land cover map 2018 Protected
FMU Unit II FMU Region XV Kabanjahe
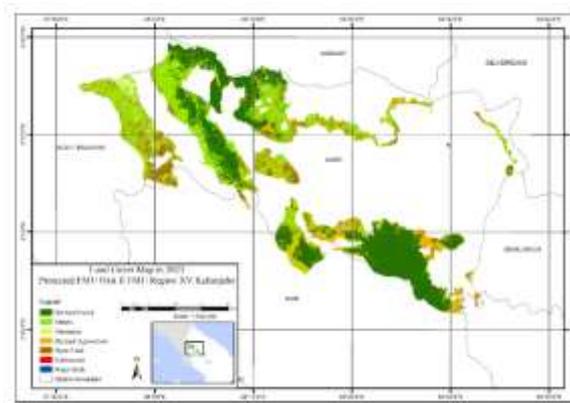
c. Land cover map 2023 Protected
FMU Unit II FMU Region XV Kabanjahe

Figure 4. Land cover map 2013-2023 Protected FMU Unit II FMU Region XV Kabanjahe

3.2.3 Factors driving land use change

Based on the results of the correlation test, distance to the road has the highest degree of relationship, at 0.2444, while the factor that has the lowest degree of relationship is elevation, at 0.0319 (Table 7). The P Value obtained is usually very low because the P Value indicates that *Cramer's V* is not significantly different from 0. The smaller the P Value does not indicate that the factor is getting better, but a high P Value can indicate that the factor can be rejected. According to Ashari et al [17], it states that if the Cramer's V value is close to 1, then the factor has an influence on the transition factor, otherwise if it is close to 0, it is not a consideration in the model.

Table 7. Test the correlation of supporting factors

No	Variables	Cramer's V test	P Value
1	Distance to Road	0.2444	0.0000
2	Distance to Settlement	0.2158	0.0000
3	Distance to Permit	0.0786	0.0000
4	Distance to River	0.0534	0.0000
5	Elevation	0.0319	0.0000
6	Geology	0.0942	0.0000
7	Slope	0.0559	0.0000
8	Soil Type	0.0601	0.0000

3.3 Analysis of Land Use Change Prediction Model

The land use prediction method used is *Markov Chain.* This stage produces a probability matrix for 2013-2018. The probability of change in the matrix is based on land use change from 2013 to 2018. The probability of changes occurring from 2013 to 2018 is an illustration of the likelihood of changes occurring in the future.

In the diagonal component (Table 8), the values that have probability values close to 1 to 1 are the land use types of dryland forest, shrubs, plantations, open land, settlements, and water bodies. This indicates that these land uses have a high chance of not changing to other land uses. This is in accordance with the statement of Darmawan et al. [18], which states that in the on-diagonal component, a value close to 1 means that the land cover has a high chance of not changing to another land cover. Meanwhile, dryland agricultural land use has an opportunity value close to 0, which is 0.4386. This indicates that the chance of dryland agricultural land use changing to other land uses is quite large.

Table 8. *Markov Chain* matrix based on empirical year 2013 and 2018

Given :	Probability of changing to :						
	Dryland Forest	Shrubs	Plantation	Dryland Agriculture	Open Land	Settlements	Water Body
Dryland Forest	0.8547	0.0764	0.0201	0.0299	0.0190	0.0000	0.0000
Shrubs	0.0000	0.8708	0.0274	0.1018	0.0000	0.0000	0.0000
Plantation	0.0000	0.0345	0.7930	0.0832	0.0893	0.0000	0.0000
Dryland Agriculture	0.0000	0.2162	0.1388	0.4386	0.1935	0.0128	0.0000
Open Land	0.0000	0.1696	0.0145	0.0488	0.7583	0.0088	0.0000
Settlements	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Water Body	0.0000	0.0000	0.00000	0.0000	0.0000	0.0000	1.0000

3.4 Validation of Land Use Prediction Map

Validation was conducted to see the suitability of the 2023 prediction map modelled using the Multi-Layer Perceptron (MLP) method with the actual land use map in 2023 from the interpretation as a reference in the accuracy of future land cover predictions. The model validation method used in this stage is the crosstab method. The modeling validation process in this study resulted in an Overall Kappa value of 89%. Through this validation value, it is considered that the modeling can be used in predicting the 2033 land use map. The Kappa value of 89% reflects a high level of accuracy, which can increase confidence in the prediction results produced by the model. Therefore, this method is worth using to support decision-making in future land use planning. The predicted 2033 land cover map for Protected FMU Unit II FMU Region XV Kabanjahe can be seen in Figure 5.
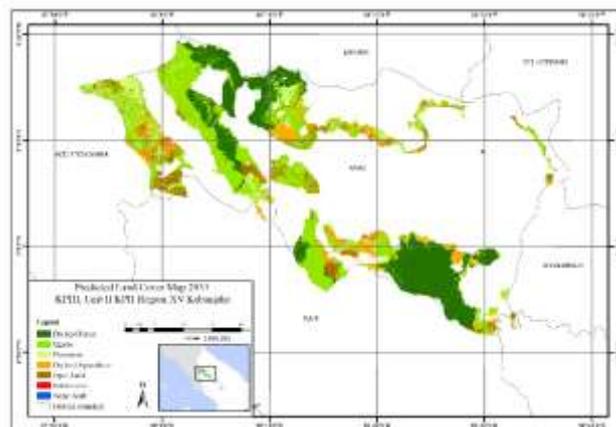

Figure 5. Land cover map of Protected FMU Unit II FMU Region XV Kabanjahe predicted for 2033

3.5 Land Use Direction

The direction of the land use plan in Protected FMU Unit II FMU Region XV Kabanjahe refers to the predicted land use map in 2033. The function of the area in 2033 in Protected FMU Unit II FMU Region XV Kabanjahe consists of Protected Forest covering 64,678 ha, Production Forest covering 7,077 ha, and Limited Production Forest covering 9,278 ha. This is based on the results of the analysis of changes in each type of land use in 2023 actual and 2033 prediction. The 2023 land use map and the 2033 prediction map were overlaid with the boundaries of the area functions, which then obtained the land use area in each area function in accordance with the direction of the use of area functions. This is based on the results of the analysis of changes in each type of land use in 2023 actual and 2033 prediction. Protected Forest areas are directed for biodiversity conservation, disaster mitigation, and environmental services management, including education-based nature tourism. This area also supports forest rehabilitation, ecosystem restoration, and management of non-timber forest products. Production Forest focuses on the utilization of non-timber forest products as well as ecosystem-based activities that are environmentally friendly. Limited Production Forests are directed towards selective and sustainable timber utilization and management of non-timber forest products. Protected Forest, Production Forest, and Limited Production Forest involve local communities through Community Forest and Village Forest schemes to improve welfare while preserving the ecosystem [19].

4. Conclusion

In the 2013-2023 period, only dryland forests and plantations decreased, by 15,228 ha and 681 ha, respectively. Based on the correlation test results, the main driving factors of land use change are distance to roads (0.2444) and settlements (0.2158), while elevation (0.0319) has the lowest influence. The 2033 land use plan focuses on managing 64,678 ha of Protected Forest, 7,077 ha of Production Forest, and 9,278 ha of Limited Production Forest in a sustainable manner by involving the community through Community Forest and Village Forest schemes.

References

[1] Fitria W, Suharjito D, Ekawati S, "Peran Kesatuan Pengelolaan Hutan (FMU) dalam Implementasi Perhutanan Sosial: Studi di FMU Produksi Kerinci, Provinsi Jambi dan FMU Lindung Sijunjung, Provinsi Sumatera Barat," *Jurnal Analisis Kebijakan Kehutanan*, vol. 18, no.2, pp.145-160, 2021.

[2] Oktavia A, Slamet B, Syahputra OKH, "Performance Analysis of Forest Management Unit Region III Kisaran, North Sumatra Province", *Journal of Sylva Indonesiana*, vol.07, no.1, pp.65-75, 2024.

[3] Adhiatma R, Widiatmaka, Lubis I, "Perubahan dan Prediksi Penggunaan/Penutupan Lahan di Kabupaten Lampung Selatan", *Journal of Natural Resources and Environmental Management*, vol.10, no.2, pp.234-246, 2020.

[4] Koedadiri MA, Purwoko A, Sulistyono N, "Pemodelan Spasial Daerah Rawan Kebakaran Hutan dan Lahan Pada Kabupaten Karo Menggunakan Metode Analytical Hierarchy Process", *Jurnal Serambi Engineering,* vol. 9, no.2, pp.8638-8650, 2024.

[5] Ilyas M, Munibah K, Rusdiana O, "Analisis Spasial Perubahan Penggunaan Lahan dalam Kaitannya dengan Penataan Zonasi Kawasan Taman Nasional Gunung Halimun-Salak", *Jurnal Majalah Ilmiah Globe,* vol.16, no.1, pp.33-42. 2014.

[6] Juniyanti L, Prasetyo LB, Aprianto DP, Purnomo H, Kartodihardjo H, "Perubahan Penggunaan dan Tutupan Lahan, serta Faktor Penyebabnya di Pulau Bengkalis, Provinsi Riau (periode 1990-2019)", *Journal of Natural Resources and Environmental Management,* vol.10, no.3, pp.419-435, 2020.

[7] Alshari EA, Gawali BW, "Development of Classification System for LULC Using Remote Sensing and GIS", *Global Transitions Proceedings,* no.2, pp.8-17, 2021.

[8] Septiono DS, Mussadun, "Analisa Perubahan Penggunaan Lahan Di Daerah Aliran Sungai Serayu Hulu Dengan Pengginderaan Jauh dan Sistem Informasi Geografis", *Jurnal Pembangunan Wilayah dan Kota*, vol.12, no.3, pp.277-292, 2016.

[9] Rizaldi A, Darmawan A, Kaskoyo H, Setiawan A, "Pemanfaatan Google Earth Engine untuk pemantauan lahan agroforestri dalam skema perhutanan sosial", *Majalah Geografi Indonesia,* vol.37, no.1, pp.12-21, 2022.

[10] Temesgen F, Warkineh B, Hailemicael A, "Seasonal Land Use/Land Cover Change and The Drivers in Kafta Sheraro National Park, Tigray, Ethiopia", *Heliyon,* vol.8, no.12, pp.1-21, 2022.

[11] Alkaf M, Munibah K, Rusdiana O, "Model Spasial Perubahan Penggunaan Lahan di Taman Nasional Gunung Merbabu dan Daerah Penyangganya", *Majalah Ilmiah Globë,* vol.16, no.1, pp.43-50, 2014.

[12] Sampurno RM, Thoriq A, "Klasifikasi Tutupan Lahan Menggunakan Citra Landsat 8 Operational Land Imager (OLI) di Kabupaten Sumedang (Land Cover Classification using Landsat 8 Operational Land Imager (OLI) Data in Sumedang Regency)", *Jurnal Teknotan,* vol.10, no.2, pp.61-70, 2016.

[13] Marwati A, Prasetyo Y, Suprayogi A, "Analisis Perbandingan Klasifikasi Tutupan Lahan Kombinasi Data Point Cloud Lidar dan Foto Udara Berbasis Metode Segmentasi dan Supervised (Studi Kasus : Tanggamus Lampung)", *Jurnal Geodesi Undip,* vol.7, no.1, pp.36-45, 2018.

[14] Kusniawati I, Subiyanto S, Amarrohman FJ, "Analisis Model Perubahan Penggunaan Lahan Menggunakan Artificial Neural Network di Kota Salatiga", *Jurnal Geodesi Undip*, vol.9, no.1, pp.1-11,2020.

[15] Ridwan F, Ardiansyah M, Gandasasmita K, "Pemodelan Perubahan Penutupan/Penggunaan Lahan dengan Pendekatan Artificial Neural Network dan Logistic Regression (Studi Kasus: Das Citarum, Jawa Barat)", *Jurnal Buletin Tanah dan Lahan*, vol.1, no.1, pp.30-36, 2017.

[16] Widyati E, Nuroniah HS, Tata HL, Mindawati N, Lisnawati Y, Darwo, Abdulah L, Lelana NE, Mawazin, Octavia D, Prameswari D, Rachmat HH, Sutiyono, Darwiati W, Wardani M, Kalima T, Yulianti, Noordwijk MV, "Soil Degradation Due to Conversion from Natural to Plantation Forests in Indonesia", *Forests*, vol.13, pp.1-21, 2022.

[17] Ashari AF, Ashar Z, Munawir, Zaman N, Risal D, Rachmat A, Arfadly, "Model Spasial Pengendalian Area Terbangun di Kota Makassar", *Jurnal Ecosulum,* vol.11, no.2, pp.136-156, 2022.

[18] Darmawan AR, Puspaningsih N, Saleh MB, "Kajian Perubahan Tutupan Lahan dengan Menggunakan Metode Multi Layer Perceptron dan Logistic Regression di Taman Nasional Gunung Ciremai", *Jurnal Media Konservasi*, vol.22, no.3, pp.252-261, 2017.

[19] Dewi IN, Awang SA, Andayani W, Suryanto P, "Pengembangan Ekowisata Kawasan Hutan Dengan Skema Hutan Kemasyarakatan Di Daerah Istimewa Yogyakarta", *Jurnal Manusia & Lingkungan,* vol.24, no.2, pp.95-102, 2017.