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Land cover change impact analysis: an integration of remote sensing, GIS and DPSIR framework to deal with degraded land in Lepan Watershed, North Sumatra, Indonesia

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Abstract. *Rahmawaty, Rauf A, Harahap MM, Kurniwan H. 2022. Land cover change impact analysis: an integration of remote sensing, GIS and DPSIR framework to deal with degraded land in Lepan Watershed, North Sumatra, Indonesia. Biodiversitas 23: 3000-3011.* The Lepan Watershed is located in North Sumatra Province, Indonesia. The types of land cover in the Lepan Watershed were examined to analyze the impact of changes in land cover over periods of five years and ten years (2009-2014-2019). This study used three analyses: analysis of land cover type, land cover change, causes and impacts of those changes, and government responses to those changes. Analysis of land cover types and changes was conducted using geographic information system (GIS). The land cover change impacts were analyzed using the driving forces, pressure, state, impact, and response (DPSIR) approach. Twelve land cover types were identified, i.e., water body, dryland forest, industry, mixed garden, open land, mangrove, rubber plantation, oil palm plantation, settlement, paddy field, shrub, and pond. For five years, changes in land cover occurred in the Lepan Watershed. During ten years (2009-2019), the mixed garden, oil palm plantation, and settlement increased, while dryland forest, mangrove, rubber plantation, paddy field, shrub, and pond decreased. The water body and industry land cover types did not undergo extensive changes over the past five and ten years. Changes in land cover resulted in the following impacts: decreasing biodiversity, increasing the risk of floods, increasing damage to mangroves, and decreasing rice production. The prevention of land use change to maintain environmental sustainability is a shared responsibility of all stakeholders.

Keywords: Biodiversity, critical land, forest, mangrove, plantation

INTRODUCTION

Changes in land cover can occur due to a continuous increase in the population (Supatra et al. 2012; Wijaya 2015), resulting in increased needs for resources (Purba et al. 2019; Satriawan et al. 2015). According to data from the Environmental Agency of Langkat District 2020, the population of Langkat District in North Sumatra Province increases every year. The increase in population is accompanied by changes in accessibility patterns, especially transportation, that affect the demand for land. Land use is the condition of the land caused by exploitation activities carried out by humans for various purposes and to fulfill their daily needs. Land cover, in contrast, is defined as the type of appearance on the Earth's surface (Rahmawaty et al. 2019a). This study focuses on changes in land cover. Each land cover type has a unique characteristic element of interpretation. Several studies related to land cover changes have been carried out in several areas, including a study on land-use change and land degradation in China (Batunacun et al. 2018), a historical review of land-use changes in Portugal (Jones et al. 2011), a transition matrix analysis of land cover change in Argentina (Biondini and Kandus 2006), land studies on the influence of land use changes in Mexico (Benítez-Badillo et al. 2018), land use/land cover change dynamics and drivers (Ellis et al. 2010), and the impact of land use and land cover dynamics on soil erosion and sediment yield in Ethiopia (Kidane et al. 2019). Although many studies have been carried out in different places and at different times (Abdulla-Al Kafy et al. 2021; Azeb et al. 2018; Butt et al. 2015; El-Alfy et al. 2020; Gibson et al. 2018; Othow et al. 2017; Zhang et al. 2010; Zhu et al. 2016;), because the dynamics of land cover changes occurring at each particular location and time vary, land cover change research remains a top priority.

Current information about changes in the land cover of areas is important for decision-making related to local planning. In this respect, the latest data regarding land cover changes in the Lepan Watershed will be useful to local governments and other stakeholders for sustainable development. Based on previous studies, the analytical ability to monitor the level of land cover change is important for society in general, and especially for planners and policymakers. Monitoring programs should be managed periodically to observe ecosystem alterations (Wardhana et al. 2020). However, the difficulties in obtaining data, information, and analysis methods have become obstacles for analysts in detecting land cover changes. Previous studies on land use and land cover changes for formulating policies have been conducted regarding the analysis of nature conservation policies (Assaf et al. 2021), land cover change and agricultural protection site evaluation (Schaefer et al. 2019), land cover change scenarios in South African grasslands and their implications of altered biophysical drivers on land management (Gibson et al. 2018), and the simulation and prediction of land use and land cover change (Han et al. 2015).

Recently, increased access to availability and quality of data, and advanced analytical methods, have made it possible to carry out land cover detection faster and cheaper. Land cover type analysis and monitoring of land changes are needed to determine the direction of development of an area and thus benefit the community and the sustainability of land resources. In order to support these efforts, it is necessary to have access to technology that can provide information on periodic changes in land cover that can be used to analyze changes in land cover in areas such as the Lepan Watershed. One of the most important forms of technology-based data management today is the management using remote sensing data, spatial data, and geographical information system (GIS) technology, which improves the accuracy and effectiveness of land management systems. Land-use change is characterized by either a shift in land use towards different land uses (conversion) or diversification of existing land uses. With the rapid development of information technology, obtaining location information has become much easier, using methods such as remote sensing (through satellite image data) and GIS. Different definitions of GIS have been discussed in several studies (Hama et al. 2019; Rahmawaty et al. 2015; Rahmawaty et al. 2019a; Rahmawaty et al. 2019b; Rahmawaty et al. 2020a); in general, GIS can be defined briefly as a system that deals with geographic information. GIS is used widely, especially in fields related to geography and computing technology.

However, the use of GIS is not limited to geographic and computational fields but has spread to other fields, such as agriculture, economy, mathematics, and spatial and city planning, and is applied to investigating map land suitability (Rahmawaty et al. 2020b; Rahmawaty et al. 2020c), and natural resource mapping (Rahmawaty et al. 2017a; Rahmawaty et al. 2017b; Rahmawaty et al. 2019c; Al-Bakri et al. 2016). With GIS, maps can be viewed based on information systems and thus show more detail, facilitating our understanding of remote sensing map data such as satellite imagery, radar, and aerial photographs. Thus, land use change in remote sensing data in the form of satellite imagery is one of the most frequently used data in GIS applications. Combined remote sensing and GIS investigations have been carried out in several countries (Alphan et al. 2009; Ardakani et al. 2018; Degife et al. 2018; Ganasri et al. 2016; Hansen et al. 2012; Haque and Basak 2017; Kanth et al. 2010; Megahed et al. 2015; Muke and Haile 2018; Nurda et al. 2020; Özdoğan et al. 2018; Rahmawaty et al. 2022; Roy and Inamdar 2019; Schaefer and Thinh 2019; Wijaya 2015).

To analyze the impact of land cover changes in an area, the driving forces, pressure, state, impact, response (DPSIR) framework can be used. In 1994, the Organization for Economic Co-operation and Development (OECD) published the initial model of environmental condition indicators in the pressure-state-response (PSR) arrangement, defined as human activities that exert pressure on the environment, causing changes in the quality and quantity of natural resources. Subsequently, the European Environment Agency (EEA) 1999 developed the existing baseline model into the DPSIR model. Environmental problems arise because of limitations of natural resources in the environment (1999). Several studies related to DPSIR have been carried out, including those conducted by Mosaffaie et al. (2021) and Schjønning et al. (2015). The current information on land cover changes is essential for decision makers in land resource management; however, for the Lepan Watershed, the latest information on land cover changes and their impacts is not yet available. Therefore, this study is urgently needed and expected to provide input for local governments preparing regional planning, especially in Langkat District, North Sumatra Province, Indonesia. The objectives of this study were to determine the land cover types and analyze the transition matrix of land cover changes and impacts of land cover changes that occurred in the Lepan Watershed over periods of five and ten years (2009-2014-2019).

MATERIALS AND METHODS

Research location and materials used

This research was conducted from April to September 2020 in the Lepan Watershed (Figure 1). Administratively, the Lepan Watershed is included in the administrative area of Langkat District, North Sumatra Province, Indonesia. Because the Lepan Watershed is located within only one district, it is categorized as a local watershed. Image processing and data analysis were carried out at the Forest Inventory Laboratory, Faculty of Forestry, Universitas Sumatera Utara, Medan, North Sumatra Province, Indonesia. This study was carried out using the following materials: the Lepan Watershed administrative map, land cover maps of 2009, 2014, and 2019, Landsat-5 imagery of 2009, Landsat-8 imagery of 2014, and sentinel satellite imagery of 2019. The analyses were performed using ArcGis and image data processing (Erdas imagine) software, and other tools utilized included a global positioning system (GPS), compass, and digital camera.

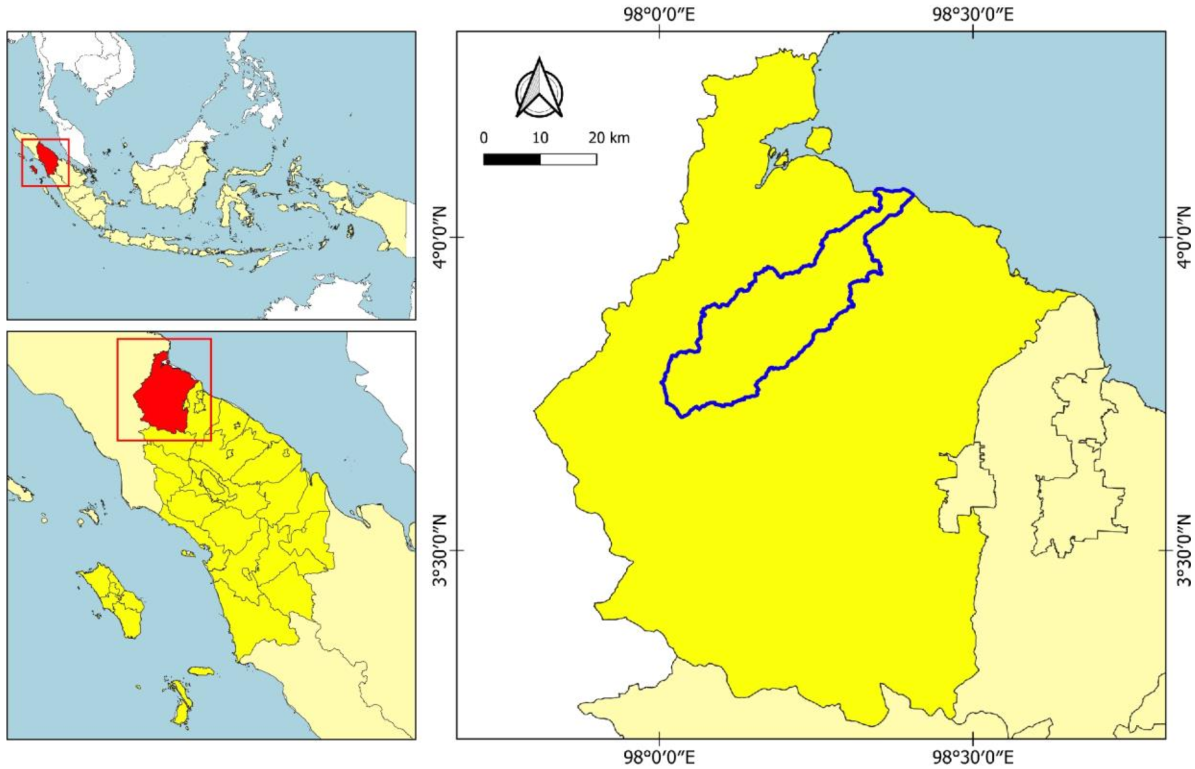

Figure 1. Map of research location in Lepan Watershed, Langkat District, North Sumatra Province, Indonesia

Data analysis

Analysis of land cover types

An important initial step was to perform geometric corrections of the image data obtained, for which the first image correction had already been performed. The geometric correction was carried out to adjust the image data for the shift in coordinates, resulting in the position of the points (pixel) in the image matching the position of the geographic points on Earth's surface. This position is the geographic position of the area recorded in the image. The first step of the geometric corrections consisted of determining the type of projection and coordinates used. The projection used in this study was the Universal Transverse Mercator (UTM) projection system and geographic coordinate system. The next step was a distortion correction, which was done by determining the field tie point placed into the map coordinates according to the image coordinates. Then, image resampling was performed using the maximum likelihood method or the maximum proximity method.

Following geometric correction, the image data was cut (subset image) to determine the boundaries of the area to be studied (Pattilouw et al. 2019). Here, the corrected image data was cut to constrain the research location area, i.e., the Lepan Watershed area. Then, image data classification was carried out, which determines the classes contained in the image data. The classes representing land categories were based on the colors seen in the image data. The classification was performed by grouping the same colors in a given image into certain classes. This classification was based on field data obtained in the form of coordinate points marked with GPS. The classes defined indicate the land cover types present in the field. The result of this image classification was a land cover map. An overview of the land covers was obtained by processing the geographic maps, area boundary maps, and Landsat imagery. Finally, attribute data were processed, which was needed for analyzing the factors of land cover change that had occurred.

Analysis of land cover change

GIS was used to analyze land cover changes that occurred over five-year and 10-year periods in the Lepan Watershed, namely between 2009-2014, 2014-2019, and 2009-2019. GIS is software that has five capabilities in handling data, including data input, data output, data management (data storage and retrieval), data analysis, and data manipulation. Thus, it can be used to analyze land cover changes that occurred in the Lepan Watershed. In addition, GIS is designed to use data that has spatial information (geographically referenced). It is capable of recording, checking, integrating, manipulating, analyzing, and displaying data that spatially reference Earth's conditions (Rawat and Kumar 2015). Various studies using GIS have been carried out by various researchers in various regions (Alphan et al. 2009; Degife et al. 2018; Ganasri et al. 2016; Haque and Basak 2017; Hama et al. 2019; Hansen et al. 2012; Kanth et al. 2010; Megahed et al. 2015; Muke and Haile 2018; Nurda et al. 2020; Özdoğan et al. 2018; Rahmawaty et al. 2015; Roy and Inamdar 2019; Schaefer and Thinh 2019). The GIS technology has also been used to map land cover changes that occurred in the Lepan Watershed, using extension change detection available in the ArcGIS software (Tiwari and Saxena 2011).

Analysis of causes and impacts of land cover changes, and responses to those changes

The DPSIR approach framework was used to analyze the causes and impacts of land cover changes and responses to those changes in the Lepan Watershed. Five main indicators in the DPSIR framework were analyzed, namely drivers, pressure, state, impact, and response. Driving Force/Drivers (trigger factors) (Rahmawaty et al. 2021a) are anthropogenic activities that may affect the environment. Pressure is an indicator that describes the pressure from human activities on the environment and natural resources. State or environmental conditions are indicators that describe the quality and quantity of natural resources and the environment. Impact is an indicator that describes the environmental impacts that arise due to pressure. Finally, response is an indicator that shows the level of stakeholder concern about environmental changes, whether from government, industry, NGOs, research institutions, or the community.

RESULTS AND DISCUSSION

Land cover types in the Lepan Watershed

The Lepan Watershed is located within one district, namely Langkat District, North Sumatra Province, Indonesia; thus, it is categorized as a local watershed. The boundaries of the Lepan Watershed are the Babalan Watershed, Besitang Watershed, and Malacca Strait in the North, the Batang Serangan Watershed in the South, the Batang Serangan and Besitang Watersheds in the West, and the Batang Serangan Watershed in the East. The shape of the Lepan Watershed, its boundaries, and the areas of each of its sub-watersheds are shown in Figure 1.

The total area of the Lepan Watershed is 57,347.47 ha. Administratively, the Lepan Watershed covers seven sub-districts in Langkat District, namely the Babalan, Batang Serangan, Besitang, Gebang, Padang Tualang, Sawit Seberang, and Sei Lepan sub-districts. The Lepan River Basin extends from 3°42'42.96" to 4°04'34.96" north latitude and the meridian 98°00'09.43" to 98°24'16.30" east longitude. The land cover in the Lepan Watershed was classified into twelve types of land cover, namely water body, dryland forest, industry, mixed garden, open land, mangrove, rubber plantation, oil palm plantation, settlement, paddy field, shrub, and pond. The land cover classified as a water body in the Lepan Watershed is a river. Dryland forest is a land covered by vegetation dominated by trees. Mixed garden is a land planted with various types of plants. Open land is a land without vegetation, whose surface will be eroded and become degraded land (Satriawan et al. 2015). Mangroves are tropical coastal vegetation communities dominated by several species of mangrove trees that grow and develop in muddy tidal coastal areas. Rubber plantation is a land planted with rubber. Oil palm plantation is a land planted with oil palms. Settlement is a land covered by permanent or semi-permanent buildings where rainwater does not fall directly on the ground, such as residential houses, offices, schools, public facilities, and roads. Paddy field is a land planted with rice. Shrub is a land overgrown with grass, small plants less than 2 m in height, and ferns and vines. Ponds are bodies of water measuring 1 m^2 to 2 ha that are permanent or seasonal. Various types of land cover and areas in the Lepan Watershed are presented in Figure 2 and Table 1.

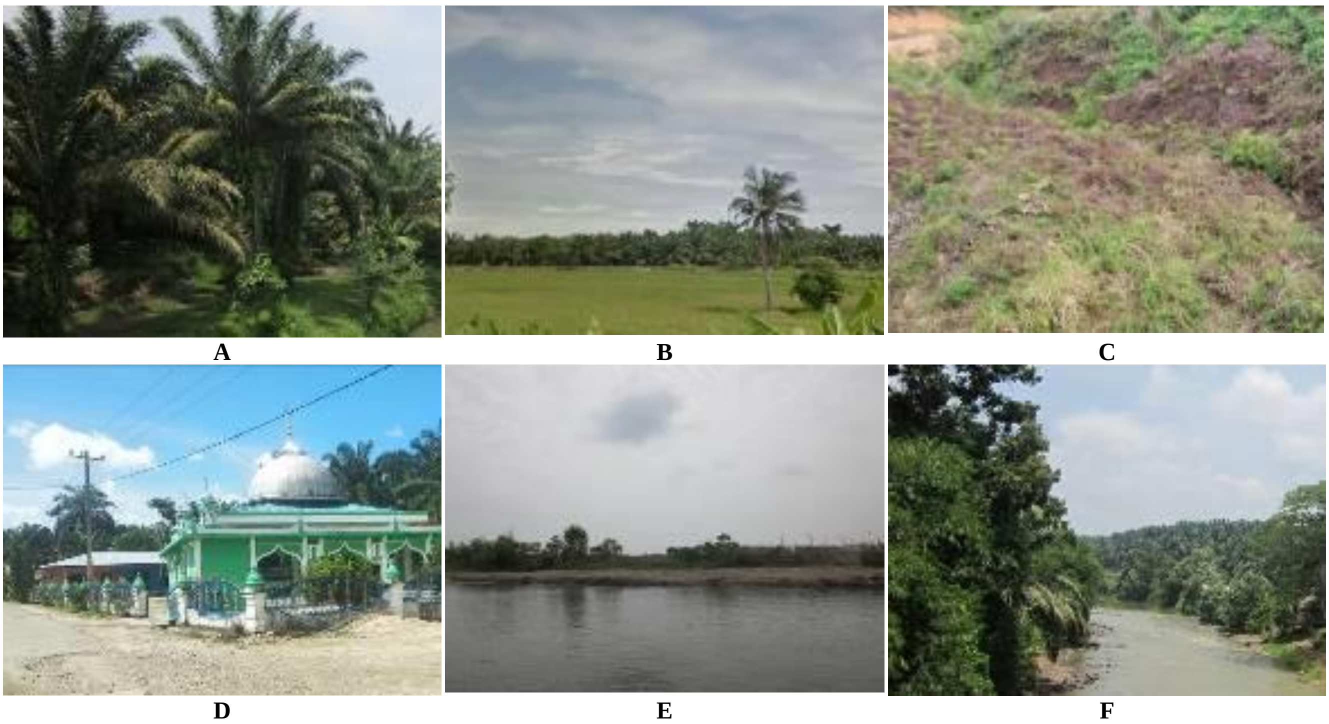

Figure 2. Different types of land cover in the Lepan Watershed, North Sumatra, Indonesia. A. Oil palm plantation, B. Paddy field, C. Open land, D. Settlement, E. Pond, F. Water body

Table 1. Land cover types in the Lepan Watershed in 2009, 2014, and 2019

Land cover	2009		2014		2019	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Water body	283.86	0.49	283.86	0.49	283.86	0.49
Dryland forest	15,256.30	26.60	14,355.69	25.03	14,289.38	24.92
Industry	15.09	0.03	15.09	0.03	15.09	0.03
Mixed garden	3,615.17	6.30	4,527.07	7.89	4,846.36	8.45
Open land	894.37	1.56	1,430.52	2.49	365.88	0.64
Mangrove	140.62	0.25	109.11	0.19	109.11	0.19
Rubber plantation	5,506.15	9.60	5,543.56	9.67	5,367.31	9.36
Oil palm Plantation	27,281.87	47.57	27,562.19	48.06	28,633.69	49.93
Settlement	1,136.82	1.98	1,140.02	1.99	1,141.60	1.99
Paddy field	2,511.50	4.38	1,871.70	3.26	1,788.78	3.12
Shrub	245.21	0.43	114.70	0.20	114.48	0.20
Pond	460.50	0.80	393.96	0.69	391.92	0.68
Total	57,347.47	100.00	57,347.47	100.00	57,347.47	100.00

Changes in land cover in the Lepan Watershed

As shown in Table 1, in 2009, 2014, and 2019 oil palm plantation was the dominant type of land cover in the Lepan Watershed, covering 47.57%, 48.06%, and 49.93% of the total area, respectively. Each period saw an increase in oil palm plantation area, with the area increasing by 0.49% between 2009 and 2014 and by 1.87% between 2014 and 2019. During the 10-year period (2009-2019), the area of oil palm plantation increased by 2.36%. Dryland forest was the second most abundant land cover type in the Lepan Watershed in 2009 (26.60%), 2014 (25.03%), and 2019 (24.92%). In contrast to oil palm plantation, dryland forest decreased in area in each period. Between 2009 and 2014, dryland forest decreased by 1.57%, between 2014 and 2019 by 0.12%, and during the 10-year period by 1.69%. Rubber plantation covered the third largest area in the Lepan Watershed in 2009, 2014, and 2019, covering 9.60%, 9.67%, and 9.36% of the total area of the Lepan Watershed, respectively. Between 2009 and 2014, the rubber plantation area increased by 0.07%; between 2014 and 2019, it decreased by 0.31%, and during the 10-year period, it decreased in area by 0.24%. Mixed garden was the fourth most abundant land cover type in the Lepan Watershed in 2009 (6.30%), 2014 (7.89%), and 2019 (8.45%). Between 2009 and 2014, the mixed garden area increased by 1.59%, between 2014 and 2019 by 0.56%, and during the 10-year period by 2.15%.

Paddy field was the fifth most abundant land cover type in the Lepan Watershed in 2009 (4.38%), 2014 (3.26%), and 2019 (3.12%), and experienced a reduction in area in each period. Between 2009 and 2014, the paddy field areas decreased by 1.12%, between 2014 and 2019 by 0.14%, and during the 10-year period by 1.26%. The other land cover types, namely open land, mangrove, settlement, industry, shrub, water body, and pond, each covered an area of less than 2% of the total area of the Lepan Watershed. Ponds also experienced a decrease in area in each period. Meanwhile, the water body and industry land cover types did not change significantly during the five-year and 10-year periods. Changes in land cover based on the time period are presented in Tables 2, 3, and 4. A comparison of land cover types in 2009, 2014, and 2019 is presented in Figure 3. The changes in land cover over periods of five years and 10 years in the Lepan Watershed are presented in Figure 4. The land cover maps of the Lepan Watershed of 2009, 2014, and 2019 are shown in Figure 5.

Table 2. Changes in land cover in 2009 and 2014 in the Lepan Watershed

Land cover	2009	2014	Changes (ha)
Water body	283.86	283.86	-
Dryland forest	15,256.30	14,355.69	- 900.61
Industry	15.09	15.09	-
Mixed garden	3,615.17	4,527.07	+ 911.90
Open land	894.37	1,430.52	+ 536.15
Mangrove	140.62	109.11	- 31.51
Rubber plantation	5,506.15	5,543.56	+ 37.40
Oil palm plantation	27,281.87	27,562.19	+ 280.33
Settlement	1,136.82	1,140.02	+ 3.20
Paddy field	2,511.50	1,871.70	- 639.81
Shrub	245.21	114.70	- 130.50
Pond	460.50	393.96	- 66.55
Total	57,347.47	57,347.47	-

Note: (+) = increase, (-) = decrease

Table 3. Changes in land cover in 2014 and 2019 in the Lepan Watershed

Land cover	2014	2019	Changes (ha)
Water body	283.86	283.86	-
Dryland forest	14,355.69	14,289.38	-66.31
Industry	15.09	15.09	-
Mixed garden	4,527.07	4,846.36	+319.29
Open land	1,430.52	365.88	-1,064.64
Mangrove	109.11	109.11	-
Rubber plantation	5,543.56	5,367.31	-176.24
Oil palm plantation	27,562.19	28,633.69	+1,071.49
Settlement	1,140.02	1,141.60	+1.59
Paddy field	1,871.70	1,788.78	-82.92
Shrub	114.70	114.48	-0.23
Pond	393.96	391.92	-2.03
Total	57,347.47	57,347.47	

Note: (+) = increase, (-) = decrease

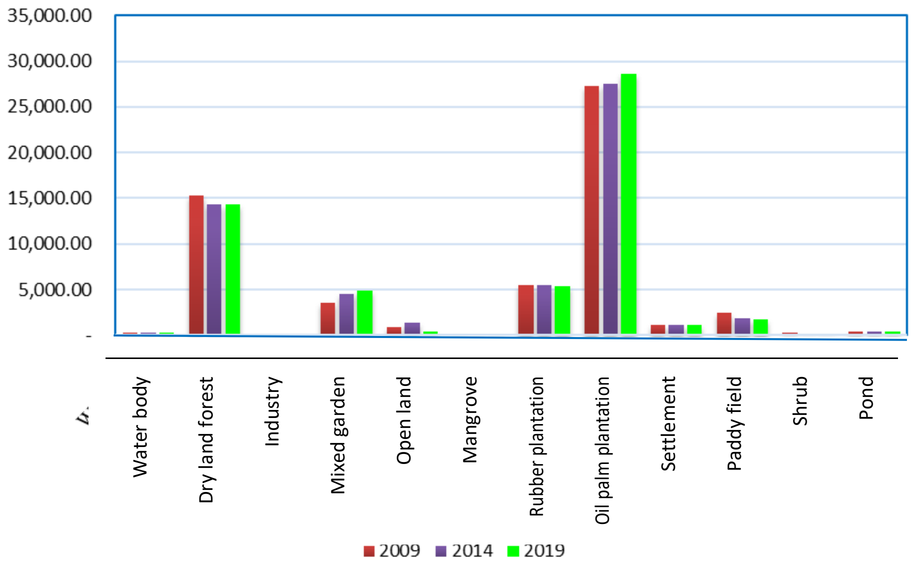

Figure 3. Comparison of land cover types in 2009, 2014, and 2019 in the Lepan Watershed

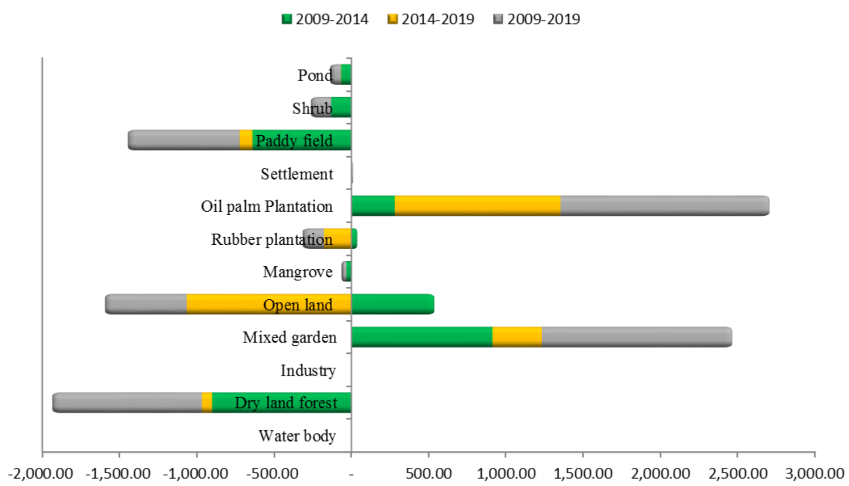

Figure 4. Changes in land cover over periods of five and ten years in the Lepan Watershed

Table 4. Changes in land cover in 2009 and 2019 in the Lepan Watershed

Land cover	2009	2019	Changes
Water body	283.86	283.86	-
Dryland forest	15,256.30	14,289.38	-966.92
Industry	15.09	15.09	-
Mixed garden	3,615.17	4,846.36	+1,231.19
Open land	894.37	365.88	-528.49
Mangrove	140.62	109.11	-31.51
Rubber plantation	5,506.15	5,367.31	-138.84
Oil palm plantation	27,281.87	28,633.69	+1,351.82
Settlement	1,136.82	1,141.60	+4.78
Paddy field	2,511.50	1,788.78	-722.72
Shrub	245.21	114.48	-130.73
Pond	460.50	391.92	-68.58
Total	57,347.47	57,347.47	

Note: (+) : increase; (-) : decrease

Transition matrix of land cover change in the Lepan Watershed

The matrix of changes in the land cover area in the 2009-2014 period in the Lepan Watershed is presented in Table 5. As shown in Table 5, during the five-year period of 2009-2014, the dryland forest land cover type partly turned into mixed gardens, covering an area of 738.75 ha, and open land, covering an area of 161.86 ha. Areas of mixed garden turned into open land, covering an area of 217.28 ha, and rubber plantation, covering an area of 0.35 ha; however, some areas of dryland forest, open land, and paddy field changed to mixed garden areas. Open land turned into mixed gardens, covering an area of 282.77 ha, rubber plantation, covering an area of 61.90 ha, and oil palm plantation, covering an area of 436.55 ha. Other land cover type areas, however, partly turned into open land, including areas of dryland forest, mixed garden, mangrove, rubber, oil palm plantation, shrub, pond, and paddy field.

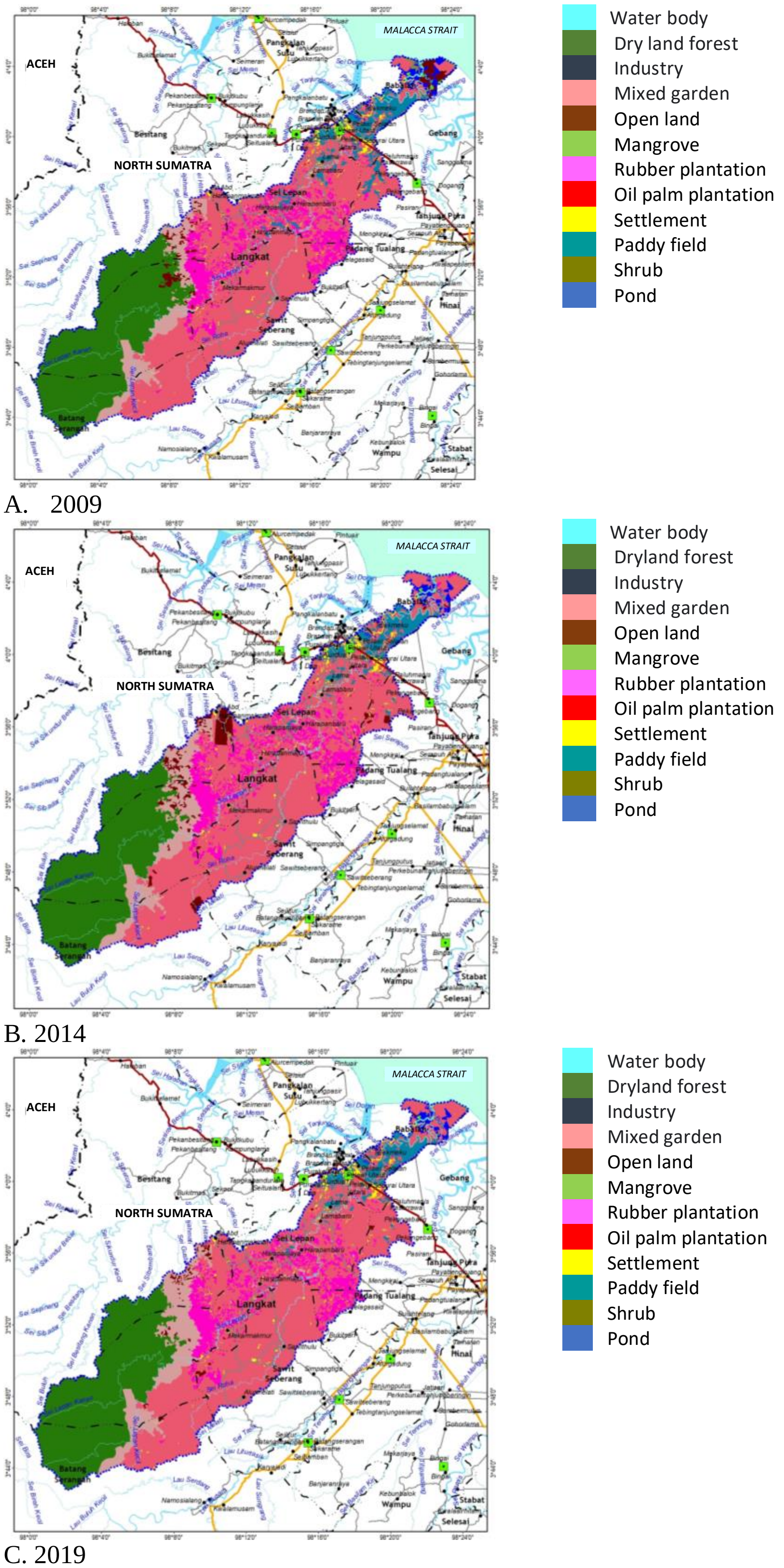

Figure 5. Land cover maps of the Lepan Watershed of (A) 2009, (B) 2014, and (C) 2019

During this period, it was also seen that mangrove changed to open land, covering an area of 4.52 ha, rubber plantations, covering an area of 9.46 ha, and oil palm plantations, covering an area of 17.53 ha. Similar changes also occurred for paddy field, mixed garden, open land, rubber plantation, oil palm plantation, settlement, and pond. The matrix of changes in land cover area of the 2014-2019 period in the Lepan Watershed is presented in Table 6.

Table 6 shows that during the five-year period of 2014-2019, dryland forest areas turned into a mixed garden, covering an area of 60.76 ha, and open land areas, covering an area of 5.55 ha. Some mixed garden areas changed into open land, covering an area of 209.94 ha, while some open land areas turned into a mixed garden, covering an area of 468.47 ha. Open land were further turned into rubber plantations, covering an area of 13.35 ha, and oil palm plantations, covering an area of 904.51 ha. However, some land cover types, including dryland forest, mixed garden, rubber plantation, oil palm plantation, shrub, pond, and paddy field, changed to open land. Furthermore, during this period, paddy fields changed to open land, covering an area of 41.19 ha, oil palm plantations, covering an area of 78.84 ha, settlements, covering an area of 0.57 ha, and ponds, covering an area of 2.33 ha. The matrix of changes in the land cover area of the 10-year period (2009-2019) in the Lepan Watershed is shown in Table 7.

As shown in Table 7, over a period of ten years (2009-2019), dryland forest areas turned into mixed gardens, covering an area of 936.70 ha, and open land, covering an area of 30.22 ha. Mixed gardens turned into open land (176.74 ha), while open land turned into mixed garden areas (360.97 ha). Open land areas further turned into rubber plantations (66.81 ha), and oil palm plantations (436.55 ha), whereas some land cover types, including dry land forest, mixed garden, rubber plantation, oil palm plantation, pond, and paddy field, changed to open land. During this period, some paddy fields changed to oil palm plantations (599.12 ha), mixed gardens (110.62 ha), and rubber plantations (6.47 ha). The change of the dryland forest to other types of land cover is an issue that needs to be considered and resolved urgently, given that dryland forest is predominant in the upstream of Lepan Watershed. Based on the Decree of the Minister of Forestry of the Republic of Indonesia Number 8088 (2018), the forest area in Gunung Leuser National Park in the upstream watershed is a conservation area and the authenticity of the ecosystem needs to be maintained, which is in agreement with Rahmawaty et al. (2021b); Rahmawaty et al. (2021c); Thoha et al. (2022).

DPSIR approach for the analysis of causes, impacts, and responses to land cover changes

Based on the results presented in Tables 1-7 and Figures 3-5, DPSIR analysis was carried out. The results are presented in Figure 6.

Driving force

The factor that triggers changes in land cover in Langkat District is economic growth (Figure 6). Changes in urban land use can be linked to economic growth. Economic growth and urban expansion have resulted in a number of agricultural lands being converted into roads, residential buildings, and other urban facilities. A land-use land cover (LULC) simulation using data on land use, population growth, and economic growth was conducted in Daqing City (Yu et al. 2011). Their results indicate that rapid economic growth has resulted in a significant increase in land built-up while grassland and rice field areas decreased, which is consistent with our results.

Table 5. Matrix of land cover changes in the Lepan Watershed over the five-year period of 2009-2014

Land cover 2009	Land cover 2014												Total
	Water body	Dry land forest	Industry	Mixed garden	Open land	Mangrove	Rubber plantation	Oil palm plantation	Settlement	Paddy field	Shrub	Pond	
Water body	283.86												283.86
Dry land forest		14,355.69		738.75	161.86								15,256.30
Industry			15.09										15.09
Mixed garden				3,397.54	217.28		0.35						3,615.17
Open land				282.77	113.15		61.90	436.55					894.37
Mangrove					4.52	109.11	9.46	17.53					140.62
Rubber plantation					29.82		5,434.50	41.83					5,506.15
Oil palm plantation					890.46			26,388.59	2.22	0.37	0.23		27,281.87
Settlement									1,136.82				1,136.82
Paddy field				108.02	2.60		6.47	520.33	0.97	1,871.32		1.79	2,511.50
Shrub					6.43			124.30			114.48		245.21
Pond					4.39		30.89	33.06				392.17	460.50
Total	283.86	14,355.69	15.09	4,527.07	1,430.52	109.11	5,543.56	27,562.19	1,140.02	1,871.70	114.70	393.96	57,347.47

Table 6. Matrix of land cover changes in the Lepan Watershed over the five-year period of 2014-2019

Land cover 2014	Land cover 2019												Total
	Water body	Dry land forest	Industry	Mixed garden	Open land	Mangrove	Rubber plantation	Oil palm plantation	Settlement	Paddy field	Shrub	Pond	
Water body	283.86												283.86
Dry land forest		14,289.38		60.76	5.55								14,355.69
Industry			15.09										15.09
Mixed garden				4,317.13	209.94								4,527.07
Open land				468.47	44.19		13.35	904.51					1,430.52
Mangrove						109.11							109.11
Rubber plantation					21.45		5,353.97	168.14					5,543.56
Oil palm plantation					77.35			27,482.20	1.01			1.63	27,562.19
Settlement									1,140.02				1,140.02
Paddy field					1.19			78.84	0.57	1,788.78		2.33	1,871.70
Shrub					0.23						114.48		114.70
Pond					5.99							387.97	393.96
Total	283.86	14,289.38	15.09	4,846.36	365.88	109.11	5,367.31	28,633.69	1,141.60	1,788.78	114.48	391.92	57,347.47

Table 7. Matrix of land cover changes in the Lepan Watershed over a 10-year period (2009-2019)

Land cover 2009	Land cover 2019												Total
	Water body	Dry land forest	Industry	Mixed garden	Open land	Mangrove	Rubber plantation	Oil palm plantation	Settlement	Paddy field	Shrub	Pond	
Water body	283.86												283.86
Dry land forest		14,289.38		936.70	30.22								15,256.30
Industry			15.09										15.09
Mixed garden				3,438.08	176.74		0.35						3,615.17
Open land				360.97	30.05		66.81	436.55					894.37
Mangrove						109.11		31.51					140.62
Rubber plantation					21.45		5,293.69	191.02					5,506.15
Oil palm plantation					100.25			27,176.43	3.24	0.37		1.58	27,281.87
Settlement									1,136.82				1,136.82
Paddy field				110.62	1.19		6.47	599.12	1.55	1,788.41		4.16	2,511.50
Shrub								130.73			114.48		245.21
Pond					5.99			68.33				386.18	460.50
Total	283.86	14,289.38	15.09	4,846.36	365.88	109.11	5,367.31	28,633.69	1,141.60	1,788.78	114.48	391.92	57,347.47

Economic growth is an increase in the total production of an area and can further be defined as increases in per capita income and the welfare of the community. One measure commonly used to describe economic growth is the Gross Regional Domestic Product (GRDP) of an area. In Langkat District, the GRDP growth increased from 2015 to 2019; however, it increased from its nominal amount but decreased in percentage. Based on data obtained from the Langkat District Environmental Service (2020), GRDP growth in Langkat District has increased every year. In 2015-2016, it increased by 9.86%, in 2016-2017 by 7.91%, in 2017-2018 by 7.11%, and in 2018-2019 by 6.22%. The increase in the GRDP amount in Langkat District must have implications for or correlate with the increase in the area of non-built land use types into built-up land and vice versa; in Langkat District, it was found to be related to an increase in the area of land use (The Langkat District Environmental Office 2020).

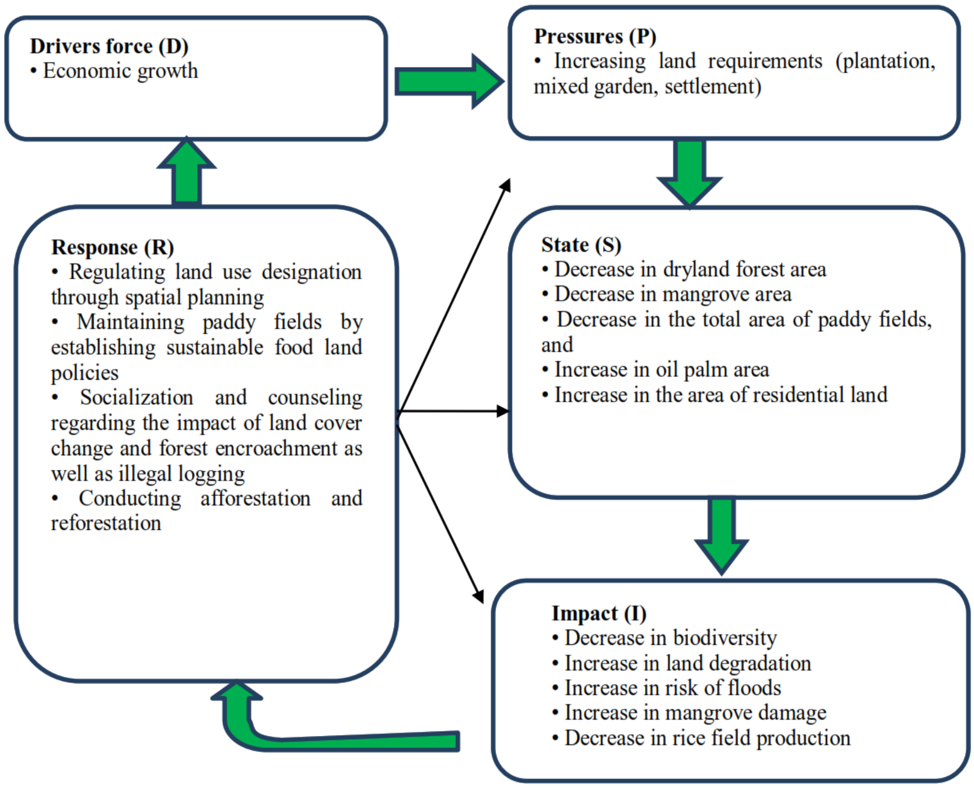

Figure 6. Relations among the DPSIR indices related to land cover changes in the Lepan Watershed

Pressure

An indicator that illustrates the pressure from changes in land cover is the increased need for land, especially for plantations, mixed gardens, and settlements. Based on Tables 2-4, there has been an increase in oil palm plantations, settlement, and mixed garden areas in the Lepan Watershed. This has resulted in reduced dryland forest, paddy fields, and mangrove land cover (Table 5-7).

State

The results of the land cover change analysis showed that there were 12 types of land cover in the Lepan Watershed (Table 1). The land cover in Deli Serdang District was dominated by oil palm plantations, followed by dry land forests and rubber plantations. As can be seen in Figure 4, the land cover changes over periods of five and 10 years resulted in a reduction in dryland forest, mangrove, and paddy fields. On the other hand, areas of oil palm plantations, mixed gardens, and settlements increased.

Impact

In all analyzed periods, the five-year and 10-year periods, the land cover in the Lepan Watershed changed. These changes can increase deforestation and land degradation, disrupting the function of forests in absorbing CO_2 from and releasing O_2 into the air and resulting in a loss of flora and fauna. In addition, changes in land cover in the Lepan Watershed increase the risk of flooding and mangrove damage and decreases rice production, mainly as a result of changes in the forest (Table 5-7). The decrease in biodiversity can occur due to reduced forest areas, which are a source of biodiversity (Perez-Vega et al. 2012). The same holds true for deforestation and land degradation (Jones et al. 2011). These results agree with those of the research regarding the impact of land use/land cover changes on land degradation (Bajocco et al. 2012). Changing the function of forests is one of the impacts of land cover changes. Forests can absorb CO_2 from the air and release O_2 (Rahmawaty et al. 2017a; Rahmawaty et al. 2017b). Furthermore, floods can occur due to water in watershed areas that cannot absorb water into the ground, and water will inundate the lowlands and open land areas. This is in accordance with the results of research previously (Magpantay et al. 2019) about land use and land cover (LULC) change impact assessment on surface runoff responses, and the effectiveness of soil conservation for erosion control on several land-use types (Satriawan et al. 2015).

The reduced area of mangrove vegetation is an important problem in land resource management because mangroves have many benefits, including economic, ecological, and social benefits. Mangrove forest areas in the Lepan Watershed have been converted into land for ponds and plantations. Another impact that arises due to changes in land cover in the Lepan Watershed is the decline of rice production due to reduced paddy fields. Based on the research results of Putri and Ahamed (2018), paddy fields are often converted into settlement areas.

Response

Various efforts have been made by the central government, local governments, communities, academics, and other stakeholders to prevent the impact of changes in land cover, including regulating land use designations through spatial planning, maintaining paddy fields by establishing sustainable food land policies, and socialization and counseling regarding the impact of land cover change and forest encroachment, as well as illegal logging. These programs have been carried out in collaboration with the government and academics, watershed forums, and extension workers/assistants. In addition, reforestation and applications of soil and water conservation techniques have been performed, and research has been conducted (Haregeweyn et al. 2015) in this area in collaboration with the Wampu Sei Ular Watershed Management Center, academics, Watershed Forum, and community-based organizations.

In conclusion, there are 12 types of land cover in the Lepan Watershed, and within five and ten-year periods, there were land cover changes driven by economic pressures, which resulted in increasing deforestation and land degradation and reducing biodiversity and rice production. We found that using remote sensing, GIS, and DPSIR framework is crucial for analyzing land cover changes. We recommend that all stakeholders prevent further land cover changes to maintain the sustainability of Lepan Watershed.

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