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Profile, Level of Vulnerability and Spatial Pattern of Deforestation in Sulawesi Period of 1990 to 2018

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Abstract: Deforestation is an event of loss of forest cover to another cover. Sulawesi forests have the potential to be deforested as with Sumatra and Kalimantan. This study aims to provide information on deforestation events in Sulawesi from 1990 to 2018. The data used in this study are (1) land cover in 1990, 2000, 2010; (2) Landsat 8 imagery in 2018; (3) administrative map of BIG in 2018. The methods used are (1) image classification with on-screen digitation techniques following the PPIK land cover classification guidelines, Forestry Planning Agency (2008) using ArcGIS Desktop 10.6 from ESRI; (2) overlapping maps; (3) analysis of deforestation; (4) analysis of deforestation profiles, (5) vulnerability analysis; and (6) analysis of distribution patterns of deforestation. The results showed that the profile of deforestation occurring on Sulawesi Island in the 1990–2018 observation period was dominated by profile 3-1-1 (the proportion of large forest area, the highest incidence of deforestation early stage at the beginning, at a low rate) in 13 districts. The level of vulnerability to deforestation is a non-vulnerable category (37 districts) which is directed to become a priority in handling deforestation in Sulawesi. Spatial patterns of the deforestation that occurred randomly and were scattered are dominated by shrubs, dryland agricultural activities, and small-scale plantations.

Keywords: deforestation; deforestation profile; vulnerability; spatial distribution; Sulawesi

1. Introduction

Recently, the impact of climate change caused by the conversion of forest cover in tropical forest areas has been a major topic [1–5]. Climate change has a broad impact on human life and other life components. These impacts include the accumulation of greenhouse gases in the atmosphere [6,7].

Conversion or change of forest cover to non-forest cover that occur permanently is called deforestation [8–10]. In Indonesia, deforestation occurs in forest areas with a wide and diverse rate. Deforestation in Sumatra has eliminated more than 50% of forest cover from the 1990 to 2016 observation period [2,8–10] with an estimated deforestation rate of 6.5 million ha (28%) in the period 1985–1997. Sumatra has lost around 7.54 million ha of primary forest in the period 1990–2010 and only 30.4% remains [9]. Although it has happened for a long time, deforestation continues to this day. The extent of the deforested area continues to spread with varying spatial distribution patterns.

Deforestation is a global environmental problem followed by issues of land degradation, biodiversity, food security, and environmental sustainability [11,12]. Deforestation has an impact on climate change, increased weather, the occurrence of forest fires, the increasing incidence of natural disasters, and threats to biodiversity. Other impacts are decreasing habitat quality to species extinction [13].

Furthermore, deforestation causes forest degradation. Forest degradation is a change in the condition of stands or treads in a forest that has a negative impact [14]. Degradation that occurs will reduce species composition, biodiversity, and forest productivity [15]. Forest degradation also results in a decline in land productivity in the future [16]. Land degradation due to deforestation will have an indirect impact on the occurrence of community poverty in and around the forest [17]. Forest degradation is also an important process in landscape fragmentation [18].

Forest areas that are directly adjacent to human activities have the potential to be immediately deforested [19]. Increasing population numbers trigger deforestation, forest degradation, and fragmentation [20–23]. The remaining forest due to deforestation has been damaged and has decreased in quality. Declining forest quality is characterized by a reduction in canopy cover. Deforestation also results in increasingly fragmented forests [21,24–26]. This incident resulted in forest cover forming a specific pattern into groups of forests that were scattered and not as compact as before. Small forests have a high potential for deforestation [25].

Deforestation in Indonesia needs to be controlled immediately. Deforestation control raises the need for indicators of environmental change [26], namely the development of deforestation assessment indicators. These environmental indicators include the development of deforestation assessment indicators. Broader and deeper knowledge to describe deforestation events is very important. So far, research related to deforestation has only focused on broad aspects, the rate of deforestation, fragmentation and measured at one time-period of observation [7,8,10,14,24,27,28]. This method of measuring deforestation is inadequate in explaining deforestation events. The development of better measurement methods was initiated by Ferraz et al., 2009 who developed indicators of deforestation in conservation areas [27]. In addition, Hietel et al (2004) revealed an analysis of land cover change with an emphasis on environmental variables [29]. Both studies were developed through more comprehensive research. The information needed is information on spatial, behavioral, and time deforestation events. The deforestation event is called the deforestation profile [8,10,30].

The profile of deforestation is illustrated by three variables, namely the proportion of forest area to the area of district administration. Secondly, the highest deforestation event in an observation period. Thirdly, the highest measure of deforestation rates during an observation period. This formula is called the deforestation profile which has advantages in describing deforestation events [10,30]. The profile of deforestation is needed to control deforestation at each level of vulnerability and the distribution pattern of deforestation. This information is needed for priority handling and control in the right areas to prevent deforestation. Spatial patterns of deforestation indicate factors driving deforestation [8,10] such as those caused by logging, encroachment, fire, grazing, large and small-scale plantations, agriculture, agriculture and other events such as natural disasters [26].

In Indonesia, three islands experiencing high deforestation are Sumatra, Kalimantan, and Sulawesi. Generally, the forest lost is natural forest which is a primary forest that experiences fragmentation, degradation and finally deforestation. This incident can also be found in South Sulawesi Province in the period of 1990–2000 [9]. Primary forest loss reaches more than 50% as in Sumatra [10]. Deforestation that occurs in Sulawesi is very important to know so that biodiversity conservation (Wallace region) of endemic flora and fauna wealth can be saved.

For this reason, this study was conducted to determine the behavior of deforestation in all districts in Sulawesi. The results can be used to identify priority areas of prevention, control deforestation, and restore forest conditions through forest rehabilitation (reforestation).

2. Material and Methods

2.1. Time and Location

This research was carried out in all forest areas in Sulawesi (South Sulawesi, West Sulawesi, Southeast Sulawesi, Central Sulawesi, Gorontalo and North Sulawesi). Sulawesi is the eleventh largest island in the world at 3°30′ N–7°30′ S and 118°40′ E–123°55′ E with an area of 18,644,396 hectares. The topography varies from flat on the seashore to mountainous. The mountainous topography extends from north to south in the central part of the island. The high mountains in Sulawesi are predominantly non-volcanic. Deforestation was observed in several periods, namely the period of

1990 to 2000, the period of 2000 to 2010, the period of 2010 to 2018. The forest cover area of Sulawesi Island is 11,274,944.21 ha (1990) and the remaining 9,144,505.45 ha (2018).

Sulawesi is the eleventh largest island in the world. The central part of the island is mountainous with a rough surface, so the peninsula on Sulawesi is basically far from each other. The island is formed by the deep-sea edge that surrounds it until the inland region consists of high slopes, and mostly non-volcanic.

2.2. Tools and Material

The tool used in this study is a laptop that has ArcGIS Dekstop 10.6 software (Educational License of Hasanuddin University) from Environmental Systems Research Institute (ESRI) which used to interpret satellite imagery, deforestation analysis, and spatial analysis. Field survey equipment consists of the Global Positioning System (GPS), compass, digital camera, tape recorder, and tally sheet.

The research data used was ground survey data, interview data, land cover data of the Ministry of Environment and Forestry of the Republic of Indonesia, Landsat 8 in 2018, river network maps, administrative maps, road network maps, and population data of the Central Statistics Agency of the Republic of Indonesia.

2.3. Data Analysis Procedure

2.3.1. Data Processing

Data processing was carried out on the land cover data of the Ministry of Environment and Forestry of the Republic of Indonesia in 1990, 2000, and 2010. For land cover data in 2018, it was obtained through the processing of Landsat imagery 8. The image processing is through pre-processing with geometric and radiometric correction stages, layer stacking, mosaic, and cropping using ArcGIS 10.1. Image classification using the on-screen digitation technique follows the PPIK land cover classification guidelines, Forestry Planning Agency (2008) [10,26,30].

The classifications of established land cover (1990, 2000, 2010, and 2018) were overlaid with Administration Map in Sulawesi in 2018. The reliability of the classification results is evaluated and validated using accuracy tests using reference data. Reference data was obtained through ground checks conducted by purposive sampling on each land cover in 2018. Evaluation of the image classification results of the recordings of 1990, 2000, and 2010 was carried out using a "key interpretation" approach in the form of "monogram" satellite imagery Landsat which was built using image recordings in 2018. Accuracy testing uses Overall Accuracy (OA) [10,25,31,32]. The result of the interpretation can be accepted if the suitability of land cover with the existing field conditions was above 85%.

Analysis of deforestation was carried out on land cover change in the period of 1990–2000, 2000–2010, 2010–2018. Forest land cover is grouped into forest cover. Other types of covering such as plantations, settlements, dryland agriculture, rice fields, swamp bushes, bushes, open land, water bodies, and airports are grouped into non-forest [10,30]. Changes in forest cover in plantations are not categorized as deforested areas because changes in cover do not occur permanently. The deforestation table is modified from the land change table in Pando, Northern Bolivia [10,30].

2.3.2. Data Analysis

Data analysis was carried out by utilizing the overlay results between land cover change and district administration in all provinces in Sulawesi in several periods of years. The first analysis was the analysis of deforestation. The analysis of deforestation was carried out for the period of 1990–2000, 2000–2010, and 2010–2018 and produced spatial data and extensive deforestation per period. Furthermore, the rate of deforestation was analyzed in all observation periods. Annual deforestation is calculated by the annual rate of change in forest cover which is derived from multiple interest laws [33,34]. The annual deforestation rate (r) is recommended because it is more intuitive than the formula used by FAO (q) [35]. In some research results, the value of r is always higher than q. The difference in the value of both is lower than the value of sampling error [35].

The rate of change in annual forest cover (r, %/year) is calculated based on the initial forest cover area (A1, ha) in the initial period (t1, year) and final forest cover area (A2, ha) (t2, year). The formula is formulated as follows [8,30,35]:

$$r = \left(\frac{1}{t_2 - t_1}\right) \times \ln\left(\frac{A_2}{A_1}\right) \quad (1)$$

The extent and rate of deforestation during the observation period in each region can provide information on trends in deforestation events in Sulawesi.

The next analysis is the profile analysis of deforestation. This analysis shows the spatial and temporal behavior of deforestation. This approach is different from the approach of Ferraz et al and Hietel et al., which creates a profile of the land use category variable [23]. The profile analysis of deforestation is carried out by considering the importance of the existence of the initial forest area of each region, the highest period of deforestation events and the rate of deforestation [8,27,30].

Deforestation profiles are defined as a combination of three components. The first component is the proportion of initial forest area to the total area categorized as small, medium, and large (small, medium, large). The proportion is based on the minimum forest area rule (30%) of a region/district in Indonesia. The second component is the proportion that indicates the highest deforestation event that occurred in the three observation periods, namely the period 1990–2000, 2000–2010, and 2010–2018. Each of these proportions is categorized as beginning, middle, and end (early, middle, late deforestation). The third component of the profile is the rate of deforestation in three periods. This category is grouped into low, medium, and high (low, moderate, high deforestation). The deforestation rate category is based on the rate of deforestation in Southeast Asia. Deforestation in Indonesia is higher than deforestation in Southeast Asian countries. Deforestation of countries in Southeast Asia only reached 1% from 1990 to 2000 and only 0.4% from 2000 to 2010 [15].

Deforestation profiles (DP) are formulated through formulas as follows:

DP = PFA–PDE–RD;
PFA = $\frac{\text{FA}}{\text{RA}} \times 100\%$
PDE = If DA $1 - $ DA $2 > 20\%$; *th en* PDE = I

Else: If DA $1 - $ DA $2 < -20\%$; *th en* PDE = III
Else: PDE = II

RD = average (RD1; RD3)

Information:

PFA: Proportion of forest area per regency;

small (<30%), medium (30%–50%), large (>50%)

PDE: The highest proportion of deforestation events;

Early (1990–2000), middle (2000–2010), lately (2010–2018)

RD: Average rates of deforestation for periods 1, 2 and 3;

low (<1%), moderate (1%–2%), high (>2%);

FA: Forest area at the beginning of the year of observation (Ha)
RA: Area of administrative regency (Ha)
DA: Deforestation area

RD1: Deforestation rate for the first period of 1990–2000 (%)
RD2: Deforestation rate for the second period of 2000–2010 (%)
RD3: Deforestation rate for the last period of 2010–2018 (%)

The number of profiles of deforestation that can be formed is 27 profiles (Table 1).

Table 1. Profile of deforestation.

No	Profile of Deforestation	Code
1	Small-early-low	1–1–1
2	Small-early-moderate	1–1–2
3	Small-early-high	1–1–3
4	Small-middle-low	1–2–1
5	Small-middle-moderate	1–2–2
6	Small-middle-high	1–2–3
7	Small-lately-low	1–3–1
8	Small-lately-moderate	1–3–2
9	Small-lately-high	1–3–3
10	Medium-early-low	2–1–1
11	Medium-early-moderate	2–1–2
12	Medium-early-high	2–1–3
13	Medium-middle-low	2–2–1
14	Medium-middle-moderate	2–2–2
15	Medium-middle-high	2–2–3
16	Medium-lately-low	2–3–1
17	Medium-lately-moderate	2–3–2
18	Medium-lately-high	2–3–3
19	Large-early-low	3–1–1
20	Large-early-moderate	3–1–2
21	Large-early-high	3–1–3
22	Large-middle-low	3–2–1
23	Large-middle-moderate	3–2–2
24	Large-middle-high	3–2–3
25	Large-lately-low	3–3–1
26	Large-lately-moderate	3–3–2
27	Large-lately-high	3–3–3

Analysis of vulnerability levels based on profiles formed was categorized into three classes, namely classes not vulnerable, vulnerable, and very vulnerable. The very vulnerable class is a deforestation event that occurs in a district that has a small proportion of forest area to the regency area (PFA), highest deforestation event (PDE) at the end period (late), and high deforestation rate (RD) (high). Non-vulnerable class is a deforestation event that has a large proportion of area to area (PFA), highest deforestation event (PDE) in the early period and low (low) deforestation rate (RD).

The next stage is an analysis of the spatial distribution patterns of deforestation. This analysis was carried out to obtain information on the distribution of deforestation on Sulawesi Island in the period of 1990–2000, 2000–2010, and 2010–2018. Spatially, deforestation occurred in groups caused by large-scale plantations and agriculture [10,28]. Deforestation that occurs randomly or spread is caused by encroachment, small-scale plantations by communities, forest fires, landslides, and natural disasters [10,28]. In addition, the spatial distribution of deforestation is also influenced by topographic aspects [29] and accessibility [36].

3. Results and Discussion

The results of land cover interpretation using Landsat 8 images and the Ministry of Environment and Forestry of Indonesia data are grouped into 11 cover classes, namely forests, plantations, plantations, settlements, dry land agriculture, rice fields, swamp bushes, bushes, open land, water bodies, and airports. Multi-time spatial analysis can use Landsat image with sufficient quality [23].

Forest land cover is classified into forest groups, while other cover is classified as non-forest cover [5,37]. The results of grouping forests and non-forests are then used for analysis of deforestation per period [10,30] in each region on Sulawesi. The results of the validation using OA showed an acquisition value of 89.5%. These results are then analyzed by deforestation.

3.1. Area of Early Forests and Rate of Deforestation

Sulawesi Island consists of six provinces, namely South Sulawesi, West Sulawesi, Central Sulawesi, Southeast Sulawesi, Gorontalo, and North Sulawesi. In 1990, Sulawesi Island had a total forest area of 11,274,944.21 ha. The area of forest in 2018 left 9,144,505.45 ha or reduced by 18.90%. Based on the results of the land cover analysis, the highest forest area was obtained in 1990, in Banggai Regency (650,505.58 ha) and remaining 491,116.62 ha in 2018 (reduced by 24.50%).

The decline in forest cover area in the period of 1990–2018 shows that the largest forest cover loss occurred in North Sulawesi Province, which was 23.29%, and the smallest occurred in South Sulawesi Province (13.57%). The decrease in forest cover area from the period of 1990–2018 can be seen in Figure 1.

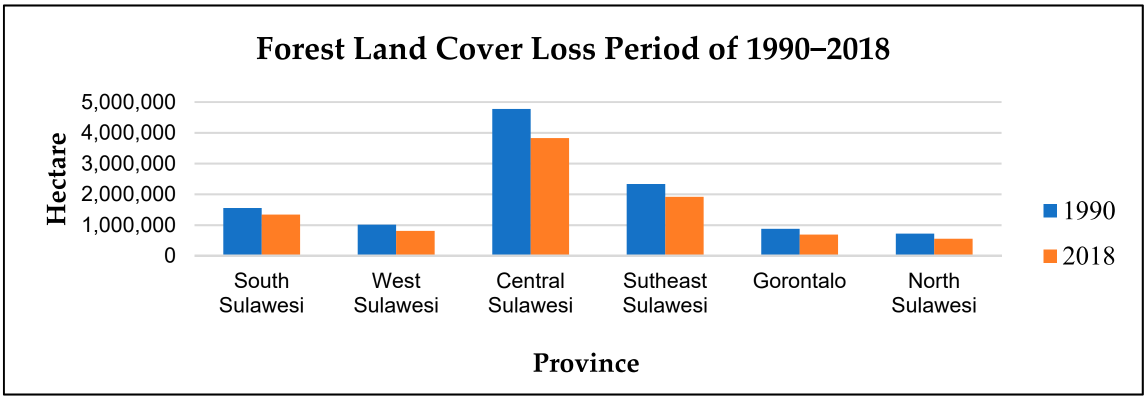


Figure 1. Forest Cover Loss in 1990–2018.

The graph above shows the variation in the decline in forest area from 1990 to 2018. Based on the forest area deforested, the graph above shows that Central Sulawesi Province experienced the greatest deforestation. This is driven by the size of the forest which is almost 500,000 ha. The existence of forests is very influential on deforestation [27]. Large forests are one of the factors driving deforestation [10,30]. Districts that have high forest areas tend to experience greater deforestation [30].

The results showed that the average deforestation rate in Sulawesi was generally less than 2%. This rate is equal to the average deforestation rate in Southeast Asia from 1990 to 2000 [15]. However, there are still areas that experienced high rates, namely Tomohon and Manado (North Sulawesi), Selayar (South Sulawesi) and Gorontalo (Gorontalo). A small forest area with high deforestation area produces high rates [10,30].

3.2. Profile of Deforestation in Sulawesi

Profile of deforestation describes the proportion of forest area, deforestation events, and deforestation rates. This profile is very important information in handling deforestation in Sulawesi [10,30]. The profile of deforestation formed in each regency/city can be seen in Table 2.

Table 2. The Profile of Deforestation in Sulawesi from 1990 to 2018.

Province	Regency	PFA	PDE	RD	Deforestation Profile
South Sulawesi	Bantaeng	1	2	1	1–2–1
	Barru	2	1	1	2–1–1
	Bone	1	2	1	1–2–1
	Bulukumba	1	3	1	1–3–1
	Enrekang	1	1	1	1–1–1
	Gowa	1	1	1	1–1–1
	Jeneponto	1	3	1	1–3–1
	Kota Pare-Pare	1	3	1	1–3–1
	Luwu	2	1	1	2–1–1
	Luwu Timur	3	3	1	3–3–1
	Luwu Utara	3	3	1	3–3–1
	Makassar	1	3	2	1–3–2
	Maros	1	1	1	1–1–1
	Palopo	1	2	1	1–2–1
	Pangkajene and Kepulauan	1	3	1	1–3–1
	Pangkajene Kepulauan	3	3	2	3–3–2
	Pinrang	1	2	1	1–2–1
	Selayar	2	3	3	2–3–3
	Sidenrengrappang	1	3	1	1–3–1
	Sinjai	1	1	1	1–1–1
	Soppeng	1	2	1	1–2–1
	Takalar	1	1	3	1–1–3
	Tanatoraja	1	2	1	1–2–1
	Toraja Utara	2	2	1	2–2–1
	Wajo	1	1	3	1–1–3
West Sulawesi	Majene	2	1	1	2–1–1
	Mamasa	3	3	1	3–3–1
	Mamuju	3	2	1	3–2–1
	Mamuju Utara	3	1	1	3–1–1
	Polewali Mandar	2	1	3	2–1–3
Central Sulawesi	Banggai	3	1	1	3–1–1
	Banggai Kepulauan	2	3	1	2–3–1
	Buol	3	1	1	3–1–1
	Donggala	3	1	1	3–1–1
	Kota Palu	2	3	2	2–3–2
	Morowali	3	1	1	3–1–1
	Morowali Utara	3	2	1	3–2–1
	Parigimoutong	3	1	2	3–1–2
	Poso	3	1	1	3–1–1
	Sigi	3	1	1	3–1–1
	Tojouna-Una	3	1	1	3–1–1
	Tolitoli	3	2	2	3–2–2
Sutheast Sulawesi	Bau-Bau	2	1	2	2–1–2
	Bombana	2	1	2	2–1–2
	Buton	3	1	1	3–1–1
	Buton Selatan	1	1	1	1–1–1
	Buton Utara	3	1	1	3–1–1
	Butontengah	1	2	3	1–2–3
	Kendari	2	1	2	2–1–2
	Kolaka	3	1	2	3–1–2
	Kolaka Timur	3	2	1	3–2–1
	Kolaka Utara	3	2	1	3–2–1
	Konawe	3	1	1	3–1–1
	Konawe Kepulauan	3	1	2	3–1–2
	Konawe Selatan	2	1	1	2–1–1
	Konawe Utara	3	2	1	3–2–1
	Muna	2	1	1	2–1–1
	Wakatobi	1	1	1	1–1–1

Table 2. *Cont.*

Province	Regency	PFA	PDE	RD	Deforestation Profile
Gorontalo	Boalemo	3	2	1	3–2–1
	Bonebolango	3	2	1	3–2–1
	Gorontalo	3	1	3	3–1–3
	Gorontalo Utara	3	1	1	3–1–1
	Kota Gorontalo	1	2	3	1–2–3
	Pohuwato	3	2	1	3–2–1
North Sulawesi	Bitung	3	2	3	3–2–3
	Bolaangmongondow	3	2	1	3–2–1
	Bolaangmongondow Selatan	3	2	1	3–2–1
	Bolaangmongondow Timur	3	2	2	3–2–2
	Bolaangmongondow Utara	3	1	1	3–1–1
	Kep. Sangihe	2	2	3	2–2–3
	Kep. Sangihe and Talaud	1	2	1	1–2–1
	Kep. Siau Tagulandang Biaro	1	2	2	1–2–2
	Kep. Talaud	2	1	1	2–1–1
	Kotamobagu	1	1	3	1–1–3
	Manado	1	2	3	1–2–3
	Minahasa	1	2	3	1–2–3
	Minahasa Selatan	2	1	3	2–1–3
	Minahasa Tenggara	1	2	2	1–2–2
	Minahasa Utara	1	2	2	1–2–2
	Tomohon	1	2	3	1–2–3

The deforestation profile above shows variations in deforestation events in Sulawesi during the period of 1990 to 2018. The profile of deforestation provides information on the incidence of deforestation in Sulawesi both spatially, temporally and also behavior in each district. Tabulation of deforestation profiles for each regency/city in Sulawesi is shown in Figure 2.

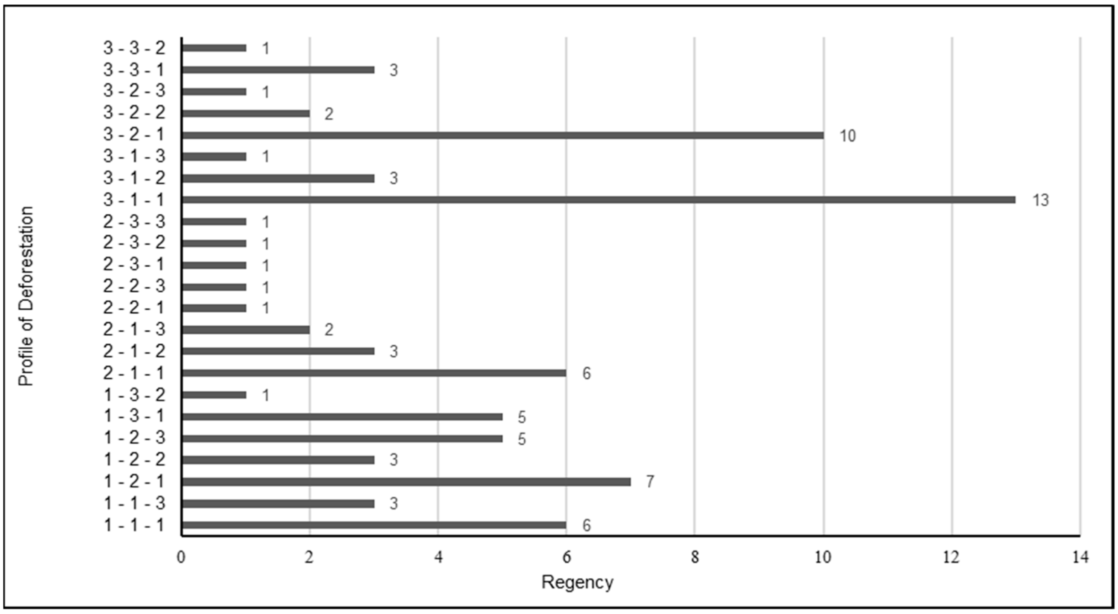


Figure 2. Tabulation Graph of Profile of Deforestation in Sulawesi Period 1990 to 2018.

Based on these tabulations, the most profiles in Sulawesi are profiles 3-1-1 (13 districts) and 3-2-1 (10 districts). This profile shows that deforestation events in Sulawesi in the 1990–2018 period were predominantly deforestation in districts that had a large proportion of forest area, were highly deforested in the early period (1990–2000) and middle (2000–2010), and at a low rate (<1%). This shows a declining trend of deforestation. Decreasing deforestation trend due to decreasing forest availability.

3.3. Deforestation Vulnerability Level

The level of vulnerability to deforestation is grouped based on the profile of deforestation and the rate of deforestation. Accumulated deforestation rates in the same profile are grouped and classified into several vulnerability classes. In addition, the level of vulnerability can also be done by looking at the characteristics of the deforestation profile (spatial, behavioral and temporal). The level of vulnerability to deforestation can be seen in Table 3 and Figure 3.

Table 3. Risk of Deforestation Profile in Sulawesi from 1990 to 2018.

No	Profile of Deforestation	Total	Level of Vulnerability
1	3-3-2	1	Very vulnerable
2	3-3-1	3	Very vulnerable
3	3-2-3	1	Prone/vulnerable
4	3-2-2	2	Prone/vulnerable
5	3-2-1	10	Prone/vulnerable
6	3-1-3	1	Not prone/not vulnerable
7	3-1-2	3	Not prone/not vulnerable
8	3-1-1	13	Not prone/not vulnerable
9	2-3-3	1	Very vulnerable
10	2-3-2	1	Very vulnerable
11	2-3-1	1	Very vulnerable
12	2-2-3	1	Prone/vulnerable
13	2-2-1	1	Prone/vulnerable
14	2-1-3	2	Not prone/not vulnerable
15	2-1-2	3	Not prone/not vulnerable
16	2-1-1	6	Not prone/not vulnerable
17	1-3-2	1	Very vulnerable
18	1-3-1	5	Very vulnerable
19	1-2-3	5	Prone/vulnerable
20	1-2-2	3	Prone/vulnerable
21	1-2-1	7	Prone/vulnerable
22	1-1-3	3	Not prone/not vulnerable
23	1-1-1	6	Not prone/not vulnerable

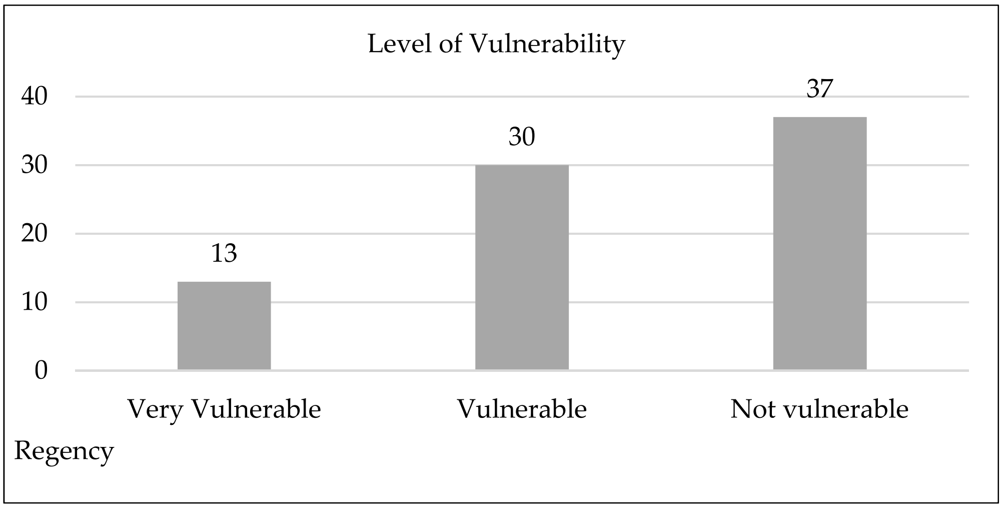


Figure 3. Level of vulnerability to deforestation in Sulawesi from 1990 to 2018.

The level of vulnerability to deforestation in Sulawesi is dominated by deforestation events that are not prone (37 districts). Very vulnerable categories are found in 13 districts. Areas that are categorized as very vulnerable are directed to become priority in deforestation handling in Sulawesi. This very vulnerable category is generally deforestation that occurred in the 2010–2018 period with a moderate to high rate. This period is a period of implementation of regulations related to regional autonomy in Indonesia [38].

So far, the assessment of deforestation is only based on the rate of deforestation and has the potential to cause misinformation. Generally, low (or zero) deforestation rates are defined as districts that do not experience deforestation [10,30]. Low deforestation rates are interpreted as better regions. This assessment occurs both at the district and provincial levels in Indonesia and even in the world. This condition also occurs in assessing the level of forest destruction in Sumatra.

3.4. Deforestation Spatial Distribution Level

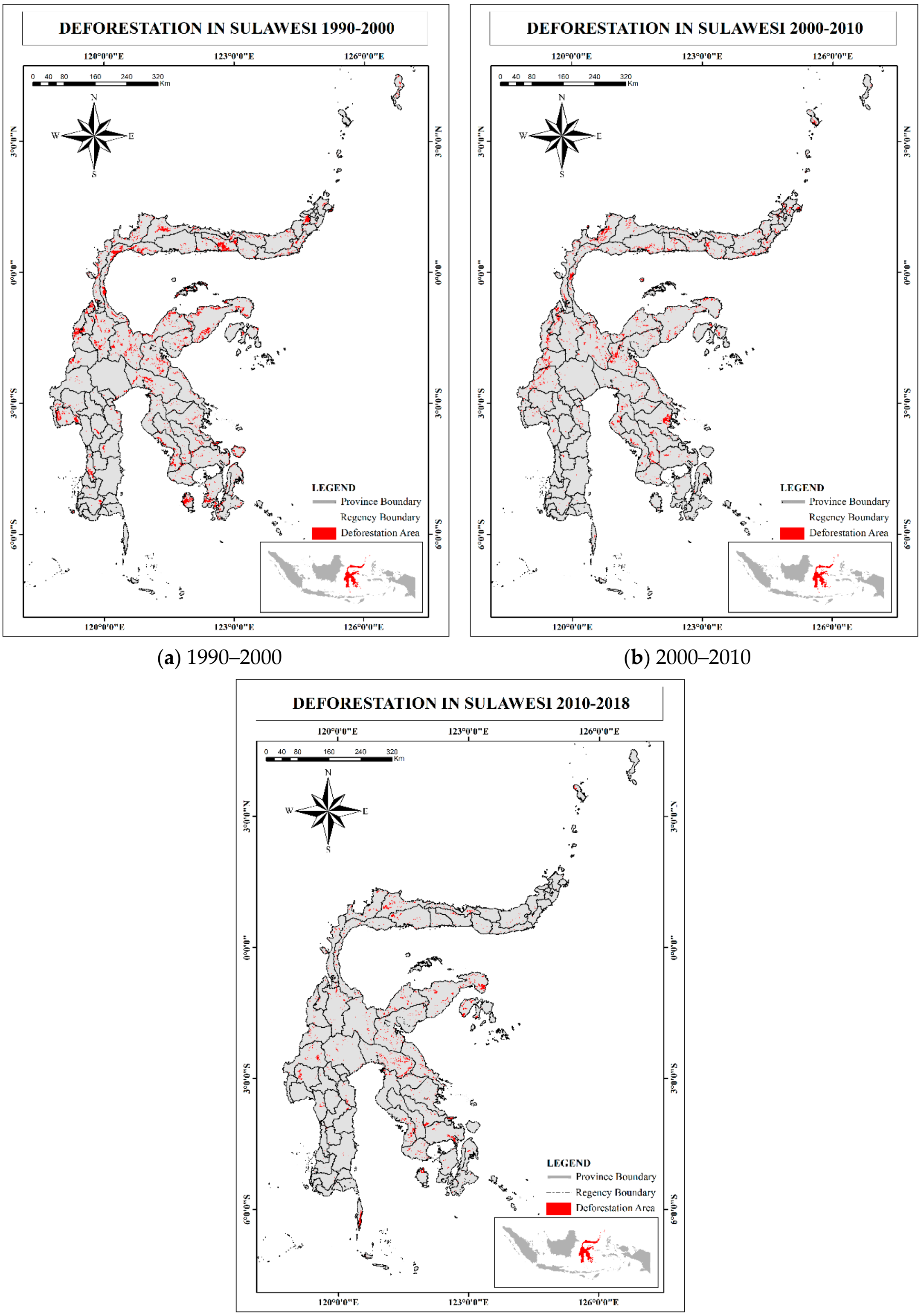
Conversion of forest area to non-forest area in all Sulawesi regions is generally caused by conversion to shrub land with an area of 874,409.95 ha. The extent of each conversion area from forest to non-forest closure can be seen in Table 4. Opening of forest land into other non-forest areas in Sulawesi is opening for agriculture, plantations, grazing, and illegal logging by the community and industry and forest fires.

Spatial distribution maps of deforestation for each period can be seen in Figure 4a–c. Deforestation occurred in all observation periods. Deforestation in the period 1990–2000 occurred with a high rate of deforestation. It was caused by the regional development and it was very high in the Suharto Presidential era. In the period of 2000–2010, the deforestation rate had declined compared to the previous period. In this period, several regions experienced area expansion including Gorontalo as a New Province. Gorontalo City (Gorontalo Province) has the highest deforestation rate in this period. In the 2010–2018 period, deforestation still occurred despite a decline. The highest deforestation rate occurred in Selayar Islands Regency. Throughout the observation period, deforestation shows a declining trend of deforestation. Declining deforestation trends are caused by the decreasing availability of forest cover [9] which has been deforested in the previous period [30].

Table 4. Conversion of Forest Land Cover to Non-Forest Period 1990–2018.

No	Land Cover 1990–2018	Area (ha)
1	Forest—Thicket Bush	874,409.95
2	Forest—Shrubs Mixed Dryland Agriculture	768,659.70
3	Forests—Dryland Agriculture	161,186.52
4	Forest—Plantation	139,897.08
5	Open Land	67,355.88
6	Forest—Rice fields	54,884.51
7	Forest—Pond	39,562.53
8	Forest—Swamp Bushland	31,763.27
9	Forests—Mining	12,145.64
10	Forests—Settlements	10,927.10
11	Forests—Meadows	4,773.92
12	Forest—Body of Water	4,299.29
13	Forest—Transmigration	1,278.65
14	Forests—Plantations	1,155.26
15	Forest—Swamp	408.18
	Total Area (ha)	2,172,707.48

Conversion of forest to non-forest is dominated by shrubs, mixed bushland dryland agriculture, dryland agriculture, and plantations. It shows that forest land conversion is carried out for agricultural activities, cultivation, and plantations. Research related to factors that influence deforestation is still lacking [5]. The leading causes of deforestation are agricultural expansion, timber harvesting, and infrastructure development. Besides, there are five other driving factors, namely population, economy, technology, policy and institutions, and cultural factors [5,39]. The primary drivers of deforestation are agriculture, either for food crops or livestock [40].



(**a**) 1990–2000

(**b**) 2000–2010

(**c**) 2010–2018

Figure 4. The spatial pattern of deforestation in Sulawesi in (**a**–**c**).

The spatial distribution pattern of deforestation in Sulawesi during the period of 1990 to 2018 spread throughout the region. Deforestation occurred in all regions randomly, scattered and clustered. Spatial distribution can show the causes and factors driving deforestation. If deforestation events are randomly distributed, deforestation generally occurs due to forest encroachment by the community or due to natural disasters including forest fires. Deforestation is clustered and large, with regular patterns caused by large-scale plantations [30]. In general, the spatial pattern of deforestation in Sulawesi is different from the spatial pattern of deforestation in Sumatra. The spatial pattern of deforestation in Sulawesi is dominated by shrubs, dryland agricultural activities, and small-scale plantations. In Sumatra, deforestation is dominated by large-scale plantations [10,30].

Deforestation is affected by topography, accessibility, distribution of urban land and agricultural land. Topographic factors and accessibility affect the forest area. Deforestation is faster in flat areas with affordable accessibility [10,41]. Low to medium slope shows higher degradation than steep slopes. This is due to ease in managing and clearing land. This area is used for agriculture, horticulture, and grazing by the community [42]. Land distribution is also related to GDP per capita [41].

Forests in areas with high slopes and low accessibility are maintained. Deforestation tended not to occur in areas with steep topography [10,43–45]. Forest areas on steep topography are maintained and intact. This clustered forest landscape is found in the hills or mountains [29]. Deforestation in Sulawesi was illustrated that changes in forest cover are scattered in areas close to the community. In addition, the development of the road network also triggered deforestation. This is due to the increasing population and increasing accessibility. Increasing population and increasing accessibility would encourage deforestation [38].

4. Conclusions

This study shows that the profile of deforestation is a formula that provides information better than the assessment so far which is only based on the value of the rate and extent of deforestation. The rate of deforestation assessment can provide false information regarding the condition of the forest in a region. The small value of the rate generally means that deforestation does not occur and is interpreted as a region that has better forest. This deforestation profile shows a more complete deforestation event, namely information on spatial, behavioral and temporal deforestation.

The profile of deforestation on Sulawesi Island from 1990 to 2018 occurred in areas with large forest areas (1990–2000 and 2000–2010) at a low rate (<1%). The vulnerable categories of deforestation found in 13 districts are recommended as priority areas for handling deforestation in Sulawesi. The spatial distribution of deforestation occurs randomly and spreads, which is dominated by bush cover, dryland agriculture, and small-scale plantations. This finding is very important information in efforts to mitigate deforestation in Sulawesi. These results need to be further developed through further research. The study is a research related to the driving factors of deforestation per period based on the profile of deforestation. With this information, prevention of deforestation events and rehabilitation/reforestation efforts can be done better, more efficiently, effectively, and more precisely.

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References

1. Gullison, R.E.; Frumhoff, P.C.; Canoadell, J.G.; Field, C.B.; Nepstad, D.C.; Hayhoe, K.; Avvisar, R.; Curran, L.M.; Friedlingstein, P.; Jones, C.D.P.; et al. Environment. Tropical forests and climate policy. *Science* **2007**, *316*, 985–986. [CrossRef] [PubMed]
2. Miles, L.; Kapos, V. Reducing greenhouse gas emissions from deforestation and forest degradation: Global land use implications. *Science* **2008**, *320*, 1454–1455. [CrossRef] [PubMed]
3. Phelps, J.; Webb, E.L.; Agrawal, A. Does REDD+ threaten to recentralize forest governance? *Science* **2010**, *328*, 312–313. [CrossRef] [PubMed]
4. Mon, M.S.; Mizoue, N.; Htun, N.Z.; Kajisa, T.; Yoshida, S. Factor affecting deforestation and forest degradation in selectively logged production forest: A case study in Myanmar. *Forest Ecol. Manag.* **2012**, *267*, 190–198. [CrossRef]
5. Kane, S.; Dhiaulhaq, A.; Sapkota, L.M.; Gritten, D. Transforming forest landscape conflicts: the promises and perils of global forest management initiatives such as REDD+. *J. For. Soc.* **2018**, *2*, 1–17. [CrossRef]
6. Heal, G.; Kriström, B. Uncertainty and climate change. *Environ. Resour. Econ.* **2002**, *22*, 3–39. [CrossRef]
7. Ozanne, C.M.P.; Anhuf, D.; Boulter, S.L.; Keller, M.; Kitching, R.L.; Körner, C.; Meinzer, F.C.; Mitchell, A.W.; Nakashizuka, T.; Dias, P.L.; et al. Biodiversity meets the atmosphere: A global view of forest canopies. *Science* **2003**, *301*, 183–186. [CrossRef] [PubMed]
8. *Country Report: Myanmar, FRA2005/107*; Global Forest Resources Assessment 2005; FAO: Rome, Italy, 2005. Available online: http://www.fao.org/docrep/008/a0400e/a0400e00.htm (accessed on 24 November 2018).
9. Margono, B.A.; Turubanova, S.; Zhuravleva, I.; Potapov, P.; Tyukaniva, A.; Boccini, A.; Goetz, S.; Hansec, M.C. Mapping and monitoring deforestation and forest degradation in Sumatera (Indonesia) using Landsat time series data sets from 1990 to 2010. *Environ. Res. Lett. J.* **2012**, *7*, 16.
10. Rijal, S.; Saleh, M.B.; Jaya, I.N.S.; Tiryana, T. Pola Spasial, Temporal dan Perilaku Deforestasi di Sumatera. *IPB Repository* **2016**. Available online: http://repository.ipb.ac.id/handle/123456789/83529 (accessed on 24 November 2018).
11. Olson, J.M.; Misana, S.; Campbell, D.J.; Mbonile, M.; Mugisha, S. *A Research Framework to Identify the Root Causes of Land Use Change Leading to Land Degradation and Changing Biodiversity*; LUCID Working Paper; International Livestock Research Institute: Nairobi, Kenya, 2004.
12. Foley, J.A.; DeFries, R.; Asner, G.P.; Barford, C.; Bonan, G.; Carpenter, S.R.; Chapin, F.S.; Coe, M.T.; Daily, G.C.; Gibbs, H.K.; et al. Global consequences of land use. *Science* **2005**, *309*, 570–574. [CrossRef] [PubMed]
13. Vance, C.; Geohegan, J. Temporal and spatial modelling of tropical deforestation: A survival analysis linking satellite and household survey data. *Agric. Econ.* **2002**, *27*, 317–332. [CrossRef]
14. Lund, H.G. *What Is a Degraded Forest?* Forest Information Services: Gainesville, VA, USA, 2009; p. 39.
15. *Global Forest Resources Assessment 2010, Country Report: Sri Lanka*; Forest Resource Assessment; Food and Agriculture Organization of the United Nations: Rome, Italy, 2010.
16. Oldeman, L.R. The global extent of soil degradation. In *Soil Resilience and Sustainable Landuse*; Greenland, D.J., Szabolcs, I., Eds.; CAB International: Wallingford, UK, 1994; Volume 352, pp. 99–119.
17. Lamb, D.; Erskine, P.D.; Parrota, J.A. Restoration of degraded tropical forest landscapes. *Science* **2005**, *310*, 1628–1632. [CrossRef] [PubMed]
18. Batistella, M.; Brondizio, E.S.; Emilio, M. Comparative analysis of landscape fragmentation in Rondônia, Brazilian Amazon. *Int. Arch. Photogramm. Remote Sens.* **2000**, *33*, 148–155.
19. Wade, T.G.; Riitters, K.H.; Wickham, J.D.; Jones, K.B. Distribution and Causes of Global Forest Fragmentation. *Conserv. Ecol.* **2003**, *7*, 7. [CrossRef]
20. Nagendra, H.; Southworth, J.; Tucker, C. Accessibility as a determinant of landscape transformation in Western Honduras. *Landsc. Ecol.* **2003**, *18*, 141–158. [CrossRef]
21. Newman, M.E.; McLaren, K.P.; Wilson, B.S. Assessing deforestation and fragmentation in a tropical moist forest over 68 years; the impact of roads and legal protection in the Cockpit Country, Jamaica. *For. Ecol. Manag.* **2014**, *315*, 138–152. [CrossRef]
22. Secretariat of the Convention on Biological Diversity (CBD). *Handbook of the Convention on Biological Diversity Including its Cartagena Protocol on Biosafety*, 3rd ed.; Convention on Biological Diversity: Montreal, CA, USA, 2005.

23. Townsend, P.A.; Lookingbill, T.R.; Kingdon, C.C.; Gardner, R.H. Spatial pattern analysis for monitoring protected areas. *Remote Sens. Environ.* **2009**, *113*, 1410–1420. [CrossRef]
24. Reddy, C.S.; Sreeleksmi, S.; Jha, C.S.; Dahdwal, V.K. National assessment of forest fragmentation in India: landscape indices as measure of the effect of fragmentation and forest cover change. *Ecol. Eng.* **2013**, *60*, 453–464. [CrossRef]
25. Samsuri. Model Spasial Indeks Restorasi Lanskap Hutan Tropis Terdegradasi Daerah Aliran Sungai Batang Toru Sumatera Utara. Ph.D. Thesis, IPB University, Bogor, Indonesia, August 2014. (In Indonesian)
26. Rijal, S.; Saleh, M.B.; Jaya, I.N.S.; Tiryana, T. Spatial Metrics of Deforestation in Kampar and Indragiri Hulu, Riau Province. *J. Trop. For. Manag.* **2016**, *22*, 24–34. [CrossRef]
27. Ferraz, S.F.d.B.; Vettorazzi, C.A.; Theobald, D.M. Using indocators deforestation and land-use dynamics to support conservation strategies: A case study of central Rondonia, Brazil. *For. Ecol. Manag.* **2009**, *257*, 1586–1595. [CrossRef]
28. Panta, M.; Kim, K.; Joshi, C. Temporal mapping of deforestation and forest degradation in Nepal: Applications to forest conservation. *For. Ecol. Manag.* **2008**, *256*, 1587–1595. [CrossRef]
29. Hietel, E.; Waldhardt, R.; Otte, A. Analyzing land-cover changes in relation to environmental variables in Hesse, Germany. *Landsc. Ecol.* **2004**, *19*, 473–489. [CrossRef]
30. Rijal, S.; Saleh, M.B.; Jaya, I.N.S.; Tiryana, T. Deforestation profile of regency level in Sumatera. *Int. J. Sci. Basic Appl. Sci.* **2016**, *25*, 385–402.
31. Jaya, I. *Analisis Citra Dijital: Perspektif Penginderaan Jauh untuk Pengelolaan Sumber Daya Alam*; Institut Pertanian Bogor (IPB) Press: Bogor, Indonesia, 2009. (In Indonesian)
32. Jaya, I.; Kobayashi, S. Classification of detailed forest cover types based upon the separability algorithm: A case study in the Yahiko Mountain and Shibata Forest Area. *J. Remote Sens. Soc. Jpn.* **1995**, *15*, 40–53.
33. Marsik, M.; Stevens, F.R.; Southworth, J. Amazon deforestation: Rates and patterns of land cover change and fragmentation in Pando, northern Bolivia, 1986 to 2005. *Prog. Phys. Geogr.* **2011**, *35*, 353–374. [CrossRef]
34. Puyravaud, J.P. Standardizing the calculation of the annual rate of deforestation. *For. Ecol. Manag.* **2003**, *177*, 593–596. [CrossRef]
35. Ramesh, B.R.; Menon, S.; Bawa, K.S. A vegetation-based approach to biodiversity gap analysis in the Agastyamalai region, Western Ghats, India. *Ambio* **1997**, *26*, 536–539.
36. Zhang, L.; Nurvianto, S.; Harrison, S. Factors affecting the distribution and abundance of *Asplenium nidus L.* in a tropical lowland rain forest in Peninsular Malaysia. *Biotropica* **2010**, *42*, 464–469. [CrossRef]
37. Jaya, I. *Teknik-Teknik Pemodelan Spasial Dalam Pengelolaan Sumberdaya Alam dan Lingkungan*; IPB Press: Bogor, Indonesia, 2006. (In Indonesian)
38. Liu, S.; Dong, Y.; Deng, L.; Liu, Q.; Zhao, H.; Dong, S. Forest fragmentation and landscape connectivity change associatedwith road network extension and city expansion: A case study in the Lancang River Valley. *Ecol. Indic.* **2014**, *36*, 160–168. [CrossRef]
39. Sulistiyono, N.; Jaya, I.N.S.; Prasetyo, L.B.; Tiryana, T. Detection of deforestation using low resolution satellite images in the island of Sumatra 2000–2012. *Int. J. Sci. Basic Appl. Res.* **2015**, *24*, 350–366.
40. Geist, H.J.; Lambin, E.F. Proximate causes and underlying Driving forces of tropical deforestation. *Bioscience* **2002**, *52*, 143–150. [CrossRef]
41. Nandy, S.; Kushwaha, S.P.S.; Dadhwal, V.K. Forest degradation assessment in the upper catchment of the river tons using remote sensing and GIS. *Ecol. Indic.* **2011**, *11*, 509–513. [CrossRef]
42. Houghton, R.A. Carbon emissions and the drivers f deforestation and forest degradation in the tropics. *Curr. Opin. Environ. Sustain.* **2012**, *4*, 1–7. [CrossRef]
43. Sheng, S.; Liu, M.S.; Xu, C.; Yu, W.; Chen, H. Application of CLUE-S model in simulating land use changes in Najing metropolitas region. *Chin. J. Ecol.* **2008**, *27*, 235–239.
44. Cabral, D.d.C.; Freitas, S.R.; Fiszon, J.T. Combining sensors in landscape ecology: imagery based and farm level analysis in study human driven forest fragmentation. *Soc. Nat.* **2007**, *19*, 69–87. [CrossRef]
45. Soma, A.S.; Kubota, T. Landslide susceptibility map using certainty factor for hazard mitigation in mountainous areas of Ujung-loe watershed in South Sulawesi. *J. For. Soc.* **2018**, *2*, 79–91. [CrossRef]