Models and spatial patterns of deforestation in the Jeneberang watershed

Syamsu Rijal¹, Tirza Tirsyayu¹, Chairil A¹, Munajat Nursaputra¹ and Andi Nurul Mukhlisa²

¹Laboratory of Forestry Planning and Information System, Faculty of Forestry, Hasanuddin University, Makassar
²Faculty of Agriculture, Animal husbandry, and Forestry, University of Muslim Maros

Email: jaysy.rijal@gmail.com

Abstract. Deforestation is an event of permanent land cover change from forest cover to non-forest cover. Deforestation events are very influential on the condition of a watershed area. One of the watersheds on the island of Sulawesi that has become a concern is the Jeneberang watershed because of its influence on the city of Makassar and is a priority watershed in Indonesia. This study aims to analyze the model and spatial pattern of deforestation in the Jeneberang watershed. The deforestation analysis model uses the binary logistic regression method by including factors such as a river, population density, road, count, and slope. Analysis of the spatial pattern of deforestation using Fragstat software based on three indices to describe the spatial pattern, namely the Clumpiness Index, Contiguity Mean Index, and Patch Density. The model of deforestation in the Jeneberang watershed shows the road network factor that has the most influence on the occurrence of deforestation. The road network is quite high in all areas in the Jeneberang watershed including the upstream part as a protection zone. The road network serves as community access between villages and sub-districts in Gowa Regency and connects other regencies such as Sinjai, Takalar, and Jeneponto. The spatial pattern of deforestation in the Jeneberang watershed is grouping, the level of connectivity is high, and it is not fragmented. This pattern shows that deforestation occurs in groups, is interconnected with previously deforested areas, and has a fairly large area. This pattern occurs at a relatively low rate and remains the same when the deforestation rate increases or decreases.

1. Introduction
Deforestation is a surface cover condition that undergoes a permanent change from forest to non-forest cover [1]. The condition of deforestation in Indonesia is of great concern because it has the second-highest deforestation rate among tropical countries [2]. Most of the deforestation in Indonesia occurs in large islands such as Sulawesi Island. The island is also a special concern because the masks in the Wallacea Region have high diversity.

Deforestation analysis in Sulawesi Island based on provincial to district administrative boundaries [3]. Deforestation draws profiles, vulnerabilities, and spatial patterns. The information is still macro spatial
and does not describe other ecosystem conditions such as hydrology. In addition, the factors that cause deforestation are also needed to determine the policies of a region.

Hydrology is the system of water on earth starting from the nature, formation, circulation, and distribution on earth in an ecosystem limited by plains basins called watersheds. Deforestation events greatly affect hydrological conditions in the form of an increase in surface runoff, an increase in water discharge during the rainy season, and an increase in sediment [4,5]. What's worse, the increase in surface runoff causes the frequency of flood disasters to occur frequently [6].

One of the watersheds that are of great concern on the island of Sulawesi is the Jeneberang watershed. In the last few years, from the downstream to the upstream area of the Jeneberang watershed, floods have occurred [7]. It is noted that the Jeneberang watershed has been designated as one of the priority watersheds in 2009 and the 2015-2019 National Medium-Term Development Plan, the Jeneberang watershed is one of the watersheds that must be restored in Indonesia. In addition, the Jeneberang watershed is very important because it supplies flood events in Makassar City.

Jeneberang watershed as a watershed that must be restored through several activities ranging from planning to technical activities such as counseling, and rehabilitation. Important initial information is the incidence of deforestation ranging from distribution, area, causal factors, and patterns [8]. The driving factors affect the number of deforestation events in each different area [9]. The deforestation pattern describes the distribution and forest relationships between forests. The condition of the forest with a small area has a high tendency of deforestation [10].

Based on this description, it is necessary to conduct a study related to the existing forest condition. Analysis of models, and spatial patterns of deforestation in the Jeneberang watershed as an analysis to see the condition of forests, and deforestation. This analysis of deforestation conditions will be the basis for determining comprehensive and integrated recovery activities in the Jeneberang watershed.

2. Methods
2.1. Research location
The research location is in the Jeneberang watershed, administratively the downstream is in Makassar City, and Gowa Regency and the entire upstream is in Gowa Regency. The Jeneberang watershed is geographically located between 5\(^\circ\)10'59" - 5\(^\circ\)25'42" North Latitude, and 119\(^\circ\)22'42" - 119\(^\circ\)56'31" East Longitude. The location of the research data is shown in Figure 1.
2.2. Research data collection
This research data collection is based on the Jeneberang watershed boundary from the Director-General of Watershed Control and Protected Forests, Ministry of Environment and Forestry in 2018. The first data collected is land cover data for four time periods, namely 1990, 2000, 2010, and 2020. The closure data was obtained from the Director-General of Planning and Environmental Management, Ministry of Environment and Forestry. Furthermore, the data is corrected based on the interpretation of Landsat imagery with the same time period. The land cover data was analyzed using a Geographic Information System approach to identify deforestation.

The deforestation data is used in the analysis of the spatial model of deforestation by using the binary logistic regression method by entering factors such as population density, settlements, roads, rivers, and slopes. Furthermore, the deforestation data is also used in analyzing the spatial pattern of deforestation using the Fragstat 4.0 software, with three indices to describe spatial patterns, namely Clumpiness Index, Contiguity Mean Index, and Patch Density. All data in model analysis and spatial patterns of deforestation are in raster data format.

2.3. Data analysis
2.3.1. Spatial models of deforestation. Spatial model to determine the factors causing deforestation using binary logistic regression. The logistic regression used was able to assess the degree of influence of the driving factors on predicting the likelihood of deforestation [8]. Binary logistic regression was used to test the possibility that the deforestation variable could be predicted with the explanatory variable. This study uses the independent variable in the form of a binary value in the form of 0 is no deforestation and 1 is deforestation occurs. which is the result of deforestation analysis in the form of raster data on the distribution of deforestation events for the period 1999 to 2020. The factors that cause deforestation are distance from rivers, slopes, population density, distance from roads, and distance from settlements. The analysis uses raster data from a grid map approach to vector data with a pixel size of 30 meters (Table 1).
The relationship between the incidence of land deforestation and the causal factors is represented by the following equation [11]:

\[ p = E(Y) = \frac{\exp(\beta + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \ldots + \beta_7 X_7)}{1 + \exp(\beta + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \ldots + \beta_7 X_7)} \]  

(1)

Equation 1 is then transformed as follows:

\[ \text{logit} (p) = \log \left( \frac{p}{1-p} \right) \]  

(2)

The result of the transformation of Equation 2 becomes as follows:

\[ \text{logit} (p_i) = \beta + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k \]  

(3)

Where:

- Logit \((p_i)\) : Probability of change/expansion
- \(\beta\) : Linear regression equation constant
- \(\beta_1\) : Coefficient of deforestation variable
- \(X\) : Causative factor

| Table 1. Analysis of the causes of deforestation |
|-----------------------------------------------|
| Variable | Analysis | Unit | Data Unit |
|----------|----------|------|-----------|
| \(\beta_1\) = Deforestation Event | Grid map | Area (ha) | Grid cell pixel size 30 m |
| \(X_1\) = Population density in 2020 | Grid map | Soul/km² | m |
| \(X_2\) = slope | Euclidean distance | Percent (%) | |
| \(X_3\) = Distance from settlement | | | |
| \(X_4\) = Distance from roads | | meters (m) | Continuous pixel size 30 m |
| \(X_5\) = Distance from rivers | | | |

2.3.2. Spatial pattern of deforestation. The spatial pattern of deforestation is carried out to obtain information on the distribution and pattern of deforestation. The analysis of the spatial pattern of deforestation in the period 1990–2000, 2000–2010, and 2010–2020 used Fragstat 4.1 software with three indices as follows.

2.3.2.1. Clumpiness index. Clumpiness Index (CI) is a description of the temporal spatial pattern of deforestation distribution which shows a range of values between -1 to 1. A value close to -1 indicates a patch is uniformly distributed, a value close to 0 means the patch is randomly distributed, and a value close to 1 indicates that the patch is clustered (clumped distributed) [12]. Clumpiness Index is calculated using the equation:

\[ \text{Given } Gi = \frac{\sum_{i=1}^{m} g_{ii}}{\sum_{k=1}^{n} g_{kk}} \]  

(4)
\[
Clumpy = \begin{cases} 
\frac{G_i - P_i}{1 - P_i} & \text{for } G_i \geq P_i \\
\frac{G_i - P_i}{1 - P_i} & \text{for } G_i < P_i; P_i \geq 5 \\
\frac{P_i - G_i}{1 - P_i} & \text{for } G_i < P_i; P_i < 5
\end{cases}
\]

Where:
- \(G_{ii}\) : number of bordering and corresponding class i patch pixels based on double calculation.
- \(G_{ik}\) : number of patch pixels class i bordering class ik based on double calculation.
- \(\text{min-ei}\) : the minimum perimeter (across a number of cell surfaces) of the patch type (class) i for the maximum grouping class.
- \(P_i\) : the proportion of landscape occupied by the class i patch.

2.3.2.2. Contiguity mean index. Contiguity Mean Index (Contig MN) is a method to describe the form of closeness and connectedness between patches. Contig MN is a shape metric that is used to assess the shape of a patch in describing the spatial connectivity or cell contact in an individual patch with other patches (connectedness and contiguity). Contig MN has a value range of 0-1. The higher the Contig MN value, the greater (closer) the connectivity between patches [12]. Likewise, the lower the Contig MN value, the lower the connectivity between patches. Contig MN value is calculated using the following equation.

\[
\text{CONTIG MN} = \frac{\sum_{j=1}^{n} x_ij}{n_i}
\]

Where:
- Contig MN : the average value of the same patch connectivity.
- \(X_{ij}\) : the value of the appropriate ijth patch mark me.
- \(N_i\) : the number of patches of the same type.

2.3.2.3. Patch density. Patch Density (PD) is a landscape metric that is used to indicate the level of fragmentation [13]. Patch Density (PD) has a value > 0. A high PD value indicates that land cover classes are increasingly scattered or fragmented. Patch density is the number of patches per 100 ha of landscape units. Patch Density (PD) is calculated using the following equation.

\[
PD = \frac{N}{A} \times (10000) \times (100)
\]

Where:
- PD : number of forest patches per 100 ha;
- \(N\) : number of forest patches, and
- \(A\) : forest landscape area.

The spatial temporal pattern of deforestation is constructed by combining the three spatial metric values. The combination of the three spatial metrics will form several combinations of spatial patterns of deforestation with the following information [14]:

Spatial Pattern of Deforestation : 3-2-1;
\(3 = C_1\ 2 = C_t\ 1 = PD\)
Clumpiness Index (Cl):
1 = Spread
2 = Random
3 = Grouping
Contiguity Mean Index (Ct):
1 = Low connectivity
2 = Moderately connected
3 = High Connectivity
Patch Density (PD):
1 = Not fragmented
3 = Fragmented

3. Results and discussion

3.1. Deforestation in Jeneberang watershed
Deforestation analysis is the result of interpretation of land cover data from Landsat images in 1990, 2000, 2010, and 2020 which consists of 16 land covers, namely settlements, open land, bodies of water, dry land agriculture, dry land mixed bush farming, rice fields, ponds, airports, mining, primary dryland agriculture, secondary dryland agriculture, plantation forest, shrubs, grasslands, secondary mangrove forest, and secondary dryland forest. Each land cover is classified into forest and non-forest. The forest classification consists of plantation forest, secondary mangrove forest, and secondary dryland forest, while other than the land cover classification, it is classified as non-forest [15]. The extent and distribution of deforestation in the Jeneberang watershed can be seen in Table 2 and Figure 2.

Table 2. Area of forest conditions, and deforestation in each period in the Jeneberang watershed

| Forest Conditions | Forest Conditions Per Period (ha) |
|-------------------|----------------------------------|
|                   | 1990–2000 | 2000–2010 | 2010–2020 |
| Forest            | 13,289.53 | 12,756.83 | 12,737.84 |
| Deforestation     | 814.81    | 603.12    | 44.77     |
| Aforestation      | -         | 70.41     | 25.78     |
The Jeneberang watershed always experiences deforestation every decade from 1990 to 2020. Although it is seen in each of these time periods, the incidence of deforestation continues to decline. This is in accordance with the FAO report in the 2015 Forest Resource Assessment, that forest reduction continues to decline in each time period [16]. This condition shows that the profile of deforestation is not vulnerable in the Jeneberang watershed, namely it has a small initial forest area, and the highest deforestation incidence in the early period [3].

It should be noted that the forest cover in the Jeneberang watershed is only 15 percent of the total area. Law Number 41 of 1999 concerning forestry stipulates that an area including watersheds is covered by at least 30 percent forest. Forest cover in an area is very influential on hydrological conditions [5]. The conversion of forest cover to non-forest cover patterns in each time period can be seen in Table 3.

| Land Cover          | Forest Conditions Per Period (ha) |
|---------------------|----------------------------------|
|                     | 1990-2000 | 2000 - 2010 | 2010 - 2020 |
| Dry Land Agriculture| 23.61      | 91.78       | 21.63       |
| Rice Field          | 91.91      | 50.74       | -           |
| Scrubs              | 649.63     | 460.60      | 23.14       |
| water land          | 49.66      | -           | -           |
| Total               | 814.81     | 603.12      | 44.77       |

Most of the forest cover was converted to a bush cover pattern. Conversion to shrubs is caused by logging or shifting cultivation by the surrounding community [17]. In addition, other forest cover conversions are dry land agriculture, and rice fields that dominate land cover in the Jeneberang watershed.
as a form of community activity in the area [18]. Conversion of forest to agricultural land will stimulate an increase in surface runoff and water discharge during the rainy season [4].

3.2. Spatial model of deforestation

Deforestation model analysis to determine the driving factors that cause deforestation events with logistic regression. The analysis uses five driving factors that describe natural physical conditions such as slopes and rivers. As for the artificial physical condition factors such as roads, settlements, and population density (Figure 3). The output of binary logistic regression analysis shows that the pseudo R square value of 0.76 is greater than 0.2 which indicates the model is feasible to use. The coefficient value shows the relationship between the driving factors and the probability of deforestation, which can be seen based on the following equation:

\[
\text{logit}(p_i) = 1.513787 - 0.413478(X_1) - 0.340389(X_2) - 0.372193(X_3) - 0.144961(X_4) - 0.076382(X_5) \tag{7}
\]
The equation shows that the five driving factors affect the incidence of deforestation. The equation also describes a value that is closer to 0, then this factor causes deforestation to be stronger. River and road factors have a major influence on the incidence of deforestation. Biophysical factors are the biggest driving factor that causes deforestation in tropical rain forest areas [19].

Rivers are identified as close to deforestation events. The community converts the forest into agricultural land close to the river as a source of water for the farming community. Rivers have different uses in each region. Most of the deforestation events in Sumatra, rivers become transportation for illegal logging [20]. In addition, the road factor is also very influential on the incidence of deforestation. The road network is quite high in all areas in the Jeneberang watershed including the upstream part as a protection zone. Roads are public access to natural resources in the form of land and forests. The closer the forest is to the road network, the greater the chance of deforestation [21].

### 3.3. Spatial pattern of deforestation

Analysis of the spatial pattern of deforestation uses three indices, namely the Clumpiness Index (CI), Contiguity Mean Index (Contig MN), and Patch Density (PD). The spatial pattern of deforestation is based on data on deforestation that occurred in the Jeneberang watershed in the period 1990–2000, 2000–2010, and 2010–2020, in order to obtain the spatial pattern of the three observation periods.

| Period       | Indeks     | Spatial Pattern of Deforestation | Index Value | Information    | Code |
|--------------|------------|----------------------------------|-------------|----------------|------|
| 1990-2000    | CI         | clustered                        | 0.9570      |                | 3    |
|              | Contig_MN  | high connectivity                | 0.8932      |                | 3    |
|              | PD         | not fragmented                   | 0.0254      |                | 1    |
| 2000-2010    | Contig_MN  | high connectivity                | 0.8293      |                | 3    |
|              | PD         | not fragmented                   | 0.0187      |                | 1    |
The Clumpiness Index (CI) is an index describing the spatial distribution and pattern of deforestation in the Jeneberang watershed for each period. The CI value of the Jeneberang watershed tends to be close to 1, which indicates that the patch is clustered (clumped distributed). During these three time periods, the Jeneberang watershed continued to experience a decline in the CI value due to the decreasing area of deforestation.

Contiguity Mean Index (Contig_MN) is a metric value of the form of connectivity which shows that the connectivity between patches. The Jeneberang watershed has a Contig_MN value that is not quite different in each period, and shows the same trend. The incident seen in the Jeneberang watershed is that the Contig_MN value is decreasing in each period. This shows that the location of the remaining forests is getting further apart so that the level of connectivity also decreases. However, the deforestation that occurred in the Jeneberang watershed is still relatively high because the value is close to 1. The high connectivity index indicates that deforestation events follow the distribution of the remaining forest (still available). Deforestation events that occur directly from the area where previous deforestation occurred to the surrounding forest area [14].

Patch Density is an index that describes the level of fragmentation of a deforestation event [13]. The fragmentation of deforestation events better illustrates the condition of forest loss that is scattered and not as compact as before. The Patch Density value, which is getting closer to 0 in each period, indicates that the incidence of deforestation in the Jeneberang watershed is not fragmented. The more dispersed condition of the Jeneberang watershed causes the patch size to be smaller and it continues to decrease each period.

The spatial pattern of deforestation that occurred in the Jeneberang watershed in the period 1990-2020 is a spatial pattern of accumulated deforestation with a high degree of connectivity and is not fragmented. The spatial pattern of deforestation almost always occurs in an aggregated manner and is connected to a fairly large area of previous deforestation (not fragmented). It also shows the incidence of deforestation that continues to spread and continues in adjacent or adjacent areas.

4. Conclusion

Rivers and roads have the most influence on the incidence of deforestation in the Jeneberang watershed. Rivers are the most influential because they are a source of water for the community's agricultural land in the form of horticulture. Roads as community access to resources or access to forests. The road network is quite high in all areas in the Jeneberang watershed including the upstream part as a protection zone. The spatial pattern of deforestation in the Jeneberang watershed is clustered, the level of relationship is high, and there is no fragmentation. This pattern shows that deforestation occurs in clusters and is interconnected with areas where previous deforestation has occurred and has a fairly large area. This pattern occurs at a relatively low rate and remains the same when the deforestation rate increases or decreases.

References

[1] Minister Of Forestry R O I 2009 Regulation Of The Minister Of Forestry Number : P.30/Menhut-II/2009 on The Implementation Procedures Of Reducing Emissions From Deforestation And Forest Degradation (Redd) (Jakarta)
[2] Food And Agricultural Organization (FAO) 2010 Global Forest Resources Assessment 2010
Country Report Indonesia Forest Resource Assessment (FRA) ed Main Report (Rome)

[3] Rijal S, Barkey R A, Nasri and Nursaputra M 2019 Profile, level of vulnerability and spatial pattern of deforestation in Sulawesi Period of 1990 to 2018 *Fores* 10 1–14

[4] Paudel, S and Basnet R 2018 Upstream-downstream Connectivity: An Overview of Hydrological and Ecological Functions in relation to the ChuriaTerai Conservation in Nepal *J. Inst. For.* 15 87–96

[5] Munoth P and Goyal R 2020 Impacts of land use land cover change on runoff and sediment yield of Upper Tapi River Sub-Basin, India *Int. J. River Basin Manag.* 18 177–89

[6] Bradshaw C J A, Sodhi N S, Peh K S and Brook B W 2007 Global evidence that deforestation amplifies flood risk and severity in the developing world *Glob. Chang. Biol.* 13 2379–95

[7] Badan Nasional Penanggulangan Bencana (BNPB) 2019 *Informasi Bencana Bulanan Teraktual* (Jakarta)

[8] Kumar R, Nandy S, Agarwal R and Kushwaha S P S 2014 Forest cover dynamics analysis and prediction modeling using logistic regression model *Ecol. Indic.* 45 444–55

[9] Ferraz S F de B, Vettorazzi C A and Theobald D M 2009 Using indicators of deforestation and land-use dynamics to support conservation strategies: a case study of central Rondônia, Brazil *For. Ecol. Manage.* 257 1586–95

[10] Samsuri S, Jaya I N S, Kusmana C and Murtilaksono K 2014 Tropical Forest Landscape Fragmentation in Batang Toru Watershed, North Sumatra *J. Manaj. Hutan Trop.* 20 77–85

[11] Menard S 2002 *Applied Logistic Regression Analysis (Quantitative Applications In The Social Sciences)* (California (US): Sage Publications.)

[12] McGarigal K T 2001 *Fragstats: landscape metric for categorical map patterns*

[13] Fahrig L 2003 Effects of habitat fragmentation on biodiversity *Annu. Rev. Ecol. Evol. Syst.* 34 487–515

[14] Rijal S, Saleh M B, Jaya I N S and Tiryana T 2016 Spatial Metrics of Deforestation in Kampar and Indragiri Hulu, Riau Province *J. Manaj. Hutan Trop.* 22 24

[15] Mon M S, Mizoue N, Htun N Z, Kajisa T and Yoshida S 2012 Factors affecting deforestation and forest degradation in selectively logged production forest: A case study in Myanmar *For. Ecol. Manage.* 267 190–8

[16] Keenan R J, Reams G A, Achard F, de Freitas J V, Grainger A and Lindquist E 2015 Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015 *For. Ecol. Manage.* 352 9–20

[17] Margono B A, Turubanova S, Zhuravleva I, Potapov P, Tyukavina A, Baccini A, Goetz S and Hansen M C 2012 Mapping and monitoring deforestation and forest degradation in Sumatra (Indonesia) using Landsat time series data sets from 1990 to 2010 *Environ. Res. Lett.* 7 34010

[18] Houghton R A 2012 Carbon emissions and the drivers of deforestation and forest degradation in the tropics Current Opinion in *Environ. Sustain.* 4 1–7

[19] Bax V, Francesconi W and Quintero M 2016 Spatial modeling of deforestation processes in the Central Peruvian Amazon *J. Nat. Conserv.* 29 79–88

[20] Rijal S, Saleh M B, Jaya I N S and Tiryana T 2016 *Pola Spasial, Temporal dan Perilaku Deforestasi di Sumatera* IPB Repository

[21] Arekhi M 2011 Modeling spatial pattern of deforestation using GIS and logistic regression: A case study of northern Ilam forests, Ilam province, Iran *African J. Biotechnol.* 10 16236–49