Spatial Dynamics Model of Earthquake Prone Area in Ambon City

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Abstract. Ambon City has limitations in the development of residential areas because it is in an area prone to earthquake disasters. This is because Ambon City is in a very active tectonic area and 65% of settlement land / land built in Ambon City is in an active and weak fault zone and if there is a plate movement there will be an earthquake along the weak zone. One of the first steps to the effort to stigmatize disasters is to estimate how large the area of settlements that have been analyzed using cellular automata markov-chain located in earthquake-prone areas. This study aims to analyze changes in Ambon city land cover in 2012, 2017, 2021 and predict land cover in 2031 and synthesize spatial dynamics of settlement land availability with earthquake-prone areas in Ambon City in 2021 and 2031. This study uses Cellular Automata modeling to predict ambon city land cover in 2031 which will be covered with a map of earthquake-prone areas obtained from BPBD Ambon City to see residential areas that are in earthquake prone areas in Ambon City in 2021 and 2031. The results showed that the area of built land affected in earthquake-prone areas has a straight proportional relationship with the year of land development built. So that the more years then the area of land is built in areas prone to earthquakes and increasing. This research is expected to be used as a reference in the management of sustainable settlement area development and for efforts to organize space based on disaster mitigation in order to minimize losses and casualties due to earthquake disasters that will occur in Ambon City in this future.

1. Introduction

Ambon City has limitations in the development of residential areas because it is in areas prone to earthquake and tsunami disasters [1],[2] this is because Ambon City is in a very active and complex tectonic area [3]. The National Disaster Management Agency (BNPB, 2020) explained that Ambon City is an area that has the highest disaster risk index in Maluku Province in this case, namely earthquake disasters [4].

The last earthquake felt in Ambon City was on September 26, 2019 with a magnitude of Mw 6.5 in Ambon-Kairatu centered at 3.38 S-128.43 BT [5],[6]. This earthquake is caused by the deformation of rocks with active fault movement mechanisms, this is due to a complicated tectonic order [7],[8]. This tectonic order is directly related to the activity of banda volcanoes, and the topographic form of Maluku Province [9]. The National Disaster Management Agency (2019) reported that the quake caused damage to buildings and public facilities, more than 6000 buildings were damaged, 41 people died, and 1,578 others were injured. About 150,000 people were evacuated to safer ground, due to frequent aftershocks and fears of a tsunami from the quake [6],[9]

Based on the geographical and geological conditions of Ambon City is an area prone to earthquake disasters because it is close to the kolisi zone in the banda arc [10],[7] Galih & Handayani in 2007 has previously conducted research on mapping the pattern of earthquakes in Indonesia with fractal methods, he argues that Maluku is the highest potential area for earthquake disasters [11]. With growing
population growth, the land will grow [12], increasing the risk of natural disasters as a threat that is difficult to predict [13],[14]. According to Sahara et al., (2021) 65% of settlement land / land built in Ambon City is in an active and weak fault zone and if there is a plate movement there will be an earthquake along the weak zone. The National Disaster Management Agency explained that Ambon City is an area that has the highest disaster risk index in Maluku Province. The geographical location of Ambon City which is an earthquake-prone area needs serious attention from the government [16], considering the development of settlement land that continues to increase every year, the higher the risk of earthquake disasters that will be faced [17].

The study used Cellular Automata modeling to predict earthquake-prone areas in Ambon City in 2021 and 2031. Previously this model has been used by Supriatna to predict tsunami-prone areas in Pariaman City [14]. Cellular Automata is believed to be an excellent method for predicting future spatial change patterns[ 18]. This study aims to analyze changes in Ambon city land cover in 2012, 2017, 2021 and predict land cover in 2031 and synthesize spatial dynamics of settlement land availability with earthquake-prone areas in Ambon City in 2021 and 2031. This research is expected to be used as a reference in the management of residential area development in a sustainable manner and for efforts to organize space based on disaster mitigation in order to minimize losses and victims due to the earthquake disaster that will occur in Ambon City in the future.

2. Methods

2.1. Research Location
This study was conducted in Ambon City, Maluku Province, Indonesia which is geographically located at 3°34'4.80'' - 3°47'38.4'' South Latitude and 128°1'33.6'' - 128°18'7.20'' East Longitude and administratively Ambon City consists of serimau sub-district, Nusaniwe, South Leitimur, Ambon Bay, Ambon Bay Baguala, with a total area of Ambon City of 32,573.68 Ha [19]

2.2. Data Collection
To predict changes in land cover and land distribution built in earthquake-prone areas in Ambon City in 2021 and 2031, it is necessary to do with data collection carried out through three events, namely literature studies, agencyal studies and field surveys for primary data and secondary data and validation. The type of data used in this study consists of primary data and secondary data. The primary data needed in this study includes, observation of land cover in 2021 Ambon City and Observation of vulnerabl...
Table 1. Data Collection Techniques

| NO | Data Type       | Data Components         | Data Source                           | Data Retrieval Techniques |
|----|----------------|-------------------------|---------------------------------------|---------------------------|
| 1  | Primary Data   | Cover Validation Land   | Citra IKONOS                          | BAPPEKOT Ambon            | Literature Studies               |
|    |                |                         | Citra SPOT 6                          | BAPPEKOT Ambon            | Literature Studies               |
|    |                |                         | Administration                        | Geospatial/ RTRW Ambon City | Literature Studies               |
|    |                |                         | Regional Spatial Plan                 | RTRW Ambon City 2011-2031 | Literature Studies               |
|    |                |                         | Protected Areas                       | RTRW Ambon City 2011-2031 | Literature Studies               |
|    |                |                         | Jaringan Jalan                        | Geospatial/ BAPPEKOT Ambon Information Agency | Literature Studies |
| 2  | Secondary Data | River Network           | Geospatial/ BAPPEKOT Ambon            | Literature Studies         |
|    |                |                         | Coastline                             | Geospatial/ BAPPEKOT Ambon Information Agency | Literature Studies |
|    |                |                         | Activity Center                       | SPOT 6 Image Interpretation and Field Survey | Literature Studies and Field Surveys |
|    |                |                         | Height of territory                   | DEMNAS BIG                | Literature Studies               |
|    |                |                         | Slope slope                           | DEMNAS BIG                | Literature Studies               |
|    |                |                         | Earthquake                           | BPBD Kota Ambon           | Literature Studies               |
|    |                |                         | Vulnerability Map                    |                           |                           |

2.3. Data Processing

2.3.1. Multi Temporal Satellite Image Data Processing

Please note that IKONOS 2012 satellite imagery data and SPOT 6 satellite imagery in 2017 and 2021 obtained from BAPPEKOT Ambon have been carried out radiometric correction and geometric correction process and rgb band composite has been done. Digitization is done to create a map of land cover in the research area, with interpretation of the image [20]. Digitization is done using ArcMap software [21]. Digitization is done to obtain data on the area built in 2012, 2017 and 2021 actual and temporal land use fractions. Verification of the type of land cover with aerial surveys is conducted based on the cluster random sampling method [22]. Samples were taken based on the type of land cover classification of each village administrative boundary. The number of sample points in the study was adjusted to the classification of land cover based on SNI 7465:2010, namely settlements, agricultural areas, non-agricultural areas, open land and waters [23].

2.3.2. Processing Data Driving Factors

Processing of data driving factors is carried out using ArcMap 10.8 software [24], using fuzzy overlay techniques and producing output in the form of driving factors [25]. Fuzzy is a logical system [26],[27] which aims to formalize approximate reasoning represented in the form of interest levels that have a
value range of 0-1 (Boolean) [28],[29]. According to Peter et al., (2021) logic in fuzzy is an excellent thing to interpret data that occurs continuously effectively and efficiently, this is a good way to do cellular automata-based modeling because it uses parallel computations consisting of cells that are interconnected and have continuous values. So, in this study the author processed driving factors data using the concept of fuzzy logic.

The driving factors data in the study included distance from the coastline [32], distance from road [33], altitude [34], slope slope [34], distance from river [35], distance from center of economic activity [36] and distance from protected areas [37] (Table 2). This data processing is a processing carried out using spatial data processing software (ArcGis 10.8) spatial data processing techniques in this processing will issue one output containing all the driving factors combined.

| No | Variable                                      | Classification                        |
|----|-----------------------------------------------|---------------------------------------|
| 1  | Slope of slope [34]                           | 0 – 3 %                               |
|    |                                               | 3 – 15 %                              |
|    |                                               | 15–40 %                               |
|    |                                               | >40 %                                 |
|    |                                               | 0-2 mdpl                              |
|    |                                               | 2-7 mdpl                              |
|    |                                               | 7-25 mdpl                             |
|    |                                               | 25-100 mdpl                           |
|    |                                               | 100-500 mdpl                          |
|    |                                               | >500 mdpl                             |
|    |                                               | 0-100 meters                          |
|    |                                               | 101-200 meters                        |
| 2  | Region Height [34]                            | 0 – 2000 m                            |
|    |                                               | 201-300 meters                        |
|    |                                               | 301-500 meters                        |
|    |                                               | >500 meters                           |
| 3  | Distance from the River [35]                  | 0 – 2000 m                            |
| 4  | Center for Economic Activity [36]             | 2001-2500 m                           |
|    | Location from Center for Economic Activity [36] | >2500 m                              |
|    |                                               | 0-25 m                                |
|    |                                               | 25-50                                 |
| 5  | Distance from the Road [33]                   | 50-100                                |
|    |                                               | 100-1000                              |
|    |                                               | >1000                                 |
|    |                                               | < 100                                 |
|    |                                               | 101-500                               |
| 6  | Distance from Coastline [32]                  | 501-1000                              |
|    |                                               | 1001-1500                             |
|    |                                               | >1500                                 |
|    |                                               | >500 m                                |
| 7  | Distance from Protected Area [37]             | 0-100 m                               |
|    |                                               | 0-100 m                               |

2.3.3. **Cellular Automata Spatial Data Processing**

The process of modeling land cover in 2021 and 2031 is done using Idrisi Selva 17 modeling software, in the process of making this model used LCM (Land Change Modeller) tools. Here are the steps:

1. All data must be raster raster idrisi (rst). To see changes in land cover temporally used LCM tools. After the data is obtained, to see TPM (Transitional Probability Matrix) is done by running Markov Chains, then there will be a magnitude of TPM value in each class of land cover.
2. To perform the modeling process, data driving factors are incorporated into Idrisi Selva's software. The data is used to model land cover in 2021.

3. After the model is produced, the model accuracy test will be tested using the calculation of OA (Overall Accuracy)/ Kappa Coefficient [38]. From the results of the simulation obtained it is expected that accuracy reaches >70% [14].

4. At this stage, if the accuracy value >70 then modeling is carried out until 2031 (RTRW scenario). After the modeling results are obtained, the RTRW digitization results are compared to the results of the 2031 land cover model to see the accuracy value. If the accuracy value >70 then it can be used for further analysis [14]

2.3.4. Spatial Data Processing of Earthquake Prone Areas

To determine earthquake-prone areas, earthquake hazard data is needed. This data was obtained from the National Disaster Management Agency (BPBD) of Ambon City. This data is processed using ArcGIS 10.8 software. Here are the work steps carried out in this stage process: 1). Prepare earthquake hazard data obtained from BPBD Ambon City. 2). Then the georeferencing prores was conducted using RBI data of Ambon City on a scale of 1:50,000. 3). After that earthquake-prone data is classified into three classes, namely low, medium and high.

3. Results and Discussions

3.1. Land Cover Development in Ambon City

In general, land use between 2012, 2017 and 2021 which led to changes in land cover in Ambon City tends to increase the area of settlements and built-up areas and the reduction of agricultural land area, especially mixed gardens, forests and plantations. Increasingly limited land in Ambon City has an impact on the development and growth of the city occurs wildly (hazard growth) as a result of social conflict
so that security factors are the most important thing in choosing a place to live, where, there is an increase in land use in settlements and built areas of 4,427.58 ha in 2021.

Changes in ambon city land cover in the period 2012-2021 showed an increase in the type of residential land cover and open land, while the type of agricultural land cover and non-agricultural land cover decreased. This is made clear by Table 3 and Figure 2 below.

| Types of Land Cover       | Spacious (Ha) |
|---------------------------|---------------|
|                           | 2012          | 2017          | 2021          |
| Settlements               | 3.846.42      | 4.173.81      | 4.421.33      |
| Open Land                 | 471.12        | 627.36        | 837.94        |
| Agricultural Area         | 16.659.05     | 16.272.03     | 15.865.53     |
| Non-Agricultural Areas    | 11.417.92     | 11.323.95     | 11.272.36     |
| Waters                    | 176.53        | 176.53        | 176.53        |
| **Total**                 | **32,573.68** |               |               |
3.2. Land Cover Prediction Model for 2021
The modeling of Ambon city land cover in 2021 was done using Markov Chains and driving factors data that have been prepared. The magnitude of the possibility of land cover changes is called the Transition Probability Matrix (TPM) while the numbers contained in the TPM Table show the retirement of the possibility of land cover that has changed to other land cover.

| Table 4. Transition Probability Matrix (TPM) from 2012 - 2021 |
|-----------------|----------------|----------------|----------------|----------------|
|        | I   | II   | III  | IV   | V   |
| I     | 0.9930 | 0.0003 | 0.0036 | 0.0031 | 0   |
| II    | 0.0446 | 0.9490 | 0.0064 | 0     | 0   |
| III   | 0.0180 | 0.0079 | 0.9739 | 0.0002 | 0   |

Figure 2. Ambon City Land Cover Map Year a) 2012, b) 2017 and c) 2021
Table 4 is a Transition Probability Matrix (TPM) from 2012 to 2021 where roman numeral I is a settlement, Roman numeral II is open land, roman numeral III is agricultural, Roman numeral IV is non-agricultural and Roman numeral V is water. The value of 0 in the Transition Probability Matrix (TPM) indicates that there is no change in land cover in one area to another. While the value of 1 indicates that the land cover will remain and not change to other land cover.

In Table 4 above shows that the land cover of the type of open land area has a higher possibility of changing to settlement land with a Transition Probability value of 0.0446, the agricultural area land cover class has a Transition Probability value of 0.0446 for the possibility of turning into a settlement, while non-agricultural areas are likely to turn into settlements with a Transition Probability value of 0.0019 and waters have a Transition Probability value of 0 means it will not turn into other types of land cover. Spatially the 2021 land cover model can be seen in Figure 3 below.

The Accuracy Test is conducted to find out if the first resulting model can be used to create a second predictive model. The accuracy test was conducted with existing land cover data in 2021 as basic data (reference image) and land cover prediction model data in 2021 as a comparison image. The results of the accuracy test can be seen in Figure 4 showing that the kappa value (K standard) is 0.9860 or 98.60% which shows that this accuracy value is said to be very good and can be continued to model ambon city land cover in 2031.
Figure 4. Kappa Model 2021 Value Accuracy Test Validation Results

Figure 4 shows the results of the 2021 existing land cover accuracy test and the 2021 model. The accuracy test results resulted in a kappa value of 0.9256 or 92.56%, meaning that the accuracy test results obtained are very good and can be used to model land cover in 2031.

3.3. Land Cover Prediction Model for 2031

Ambon City’s land cover prediction model in 2031, is the second modeling in this stage using the same driving factor as in the first modeling in 2021, but this second modeling also uses the Markov Chains method and also produces a Transition Probability Matrix (TPM) value that is different from the first modeling where the transition probability seen has a span of 10 years from 2021 to 2031 using the RTRW 2031 scenario. For more details it can be seen in Table 5 and spatially can be seen in Figure 5

Table 5. Transition Probability Matrix (TPM) from 2021 - 2031

|      | I     | II    | III   | IV    | V     |
|------|-------|-------|-------|-------|-------|
| I    | 0.9933| 0     | 0.0041| 0.0026| 0     |
| II   | 0.0637| 0.9363| 0     | 0     | 0     |
| III  | 0.0172| 0.0078| 0.9750| 0     | 0     |
| IV   | 0.0017| 0.0044| 0.0044| 0.9895| 0     |
| V    | 0     | 0     | 0     | 0     | 1     |

| Information       | I Settlements | II Open Land | III Agricultural Area | IV Non-Agricultural Areas | V Waters |

Table 4 is a Transition Probability Matrix (TPM) from 2021 to 2031 where roman numeral I is a settlement, roman numeral II is open land, roman numeral III is agricultural, roman numeral IV is non-agricultural and roman numeral V is water. Based on Table 4 above it is known that each class of land cover undergoes changes in other land cover by 2031. Open land has the highest transition probability value for the possibility of turning into residential land with a TMP value of 0.0637, open land has a transition probability value of 0.0172 to turn into residential land while non-agricultural areas have a
transition probability value of 0.0017 and the waters have a transition probability value of 0 which most likely remains a water by 2031. Spatially the 2031 land cover model can be seen in Figure 5 below.

Figure 5. Ambon City Land Cover Model in 2031

The prediction of changes in ambon city land cover in 2031 will compare with the land cover of AMBON City RTRW in 2011-2031. In the Ambon City RTRW Regulation, the government focuses ambon city on the development of one of them realizing ambon city as a pilot water front city [37], based on cellular automata predictions, in 2031 the area of settlements in Ambon City is 4,958.33 ha.

Figure 6. Kappa Model 2031 Value Accuracy Test Validation Results

Just like the land cover model in 2021, the model of prediction of land cover changes in 2031 is also carried out accuracy tests (Figure 6). In contrast to the accuracy test in the 2021 model, the 2031 prediction model was conducted by an accuracy test using the RTRW room pattern map of Ambon City in 2011-2031 which has been generalized into a land cover map. The results of the accuracy test showed that the 2031 model year had an accuracy value of 0.8736 or 87.36%. This means that the 2031 land cover prediction model is said to be very good for use in subsequent analysis.
3.4. Earthquake Prone Area in Ambon City

Spatially earthquake-prone areas can be seen in Figure 7 which is the result of digitization of the earthquake vulnerability map in Ambon City obtained from the Ambon City Regional Disaster Management Agency and in more detail can be seen in Table 6 explaining the area of earthquake prone areas in each district in Ambon City.

Table 6. Area prone to earthquakes in Ambon City

| District Name | Area Prone to Earthquakes (Ha) | District Area (Ha) |
|---------------|-------------------------------|-------------------|
|               | Low | Medium | High |                  |
| Nusaniwe      | 2,297.04 | 214.51 | 2,172.45 | 7,834.30 |
| Sirimau       | 1,437.56 | 81.97 | 2,182.94 | 6,280.38 |
| T.A.Baguala   | 2,463.10 | 1,501.44 | 2,110.56 | 4,011.00 |
| South Leitimur | 2,448.14 | 1,325.28 | 977.55 | 506.00 |
| Ambon Bay     | 7,219.61 | 4,257.64 | 1,883.89 | 9,388.00 |

Based on Figure 7 and Table 6 can be known for the area that has the highest class of earthquake insecurity, namely Sirimau Subdistrict with an area of 2,182.94 ha, the district that has the second earthquake-prone area is Nusaniwe subdistrict with an area of 2,172.45 ha, while the district that has the lowest area is the South Leitimur subdistrict which is 977.55 ha. The district that has the highest area prone to earthquakes at the level of moderate insecurity is Ambon Bay subdistrict with an area of 4,257.64 ha, followed by Ambon Bay District Baguala with an area of 1,501.44 ha and the subdistrict that has the lowest area, namely Serimau subdistrict with an area of 81.97 ha. For the lowest level of earthquake vulnerability, Ambon Bay subdistrict covers an area of 7,219.61 ha and the area that has the lowest area is Sirimau subdistrict with an area of 1,437.56 ha.

Figure 7. Earthquake Prone Areas in Ambon City

3.5. Spatial Dynamics of Settlement Land Availability with Earthquake Prone Areas in 2021 and predictions for 2031 in Ambon City
Based on data obtained from the Meteorology Climatology and Geophysics Agency (BMKG) Of Ambon Class I Meteorological Station and The Regional Disaster Management Agency (BPBD) of Ambon City that Ambon City is at a very high intensity of earthquake and tsunami danger so that earthquake natural disasters become a top priority threat to be anticipated so that the adverse impact of both fatalities and damage to buildings can be minimized. One form of anticipation is to estimate how large the area of settlements that have been analyzed using cellular automata Markov-chain located in earthquake-prone areas. Both of these variables are analyzed by overlay techniques outlined in the Table 7 and Figure 8 analysis.

**Table 7 Distribution of Earthquake-Prone Areas and Prediction of Affected Settlement Land**

| Settlement Area (Ha) | Area Prone to Earthquakes (Ha) |
|----------------------|---------------------------------|
|                      | Low  | Medium | High |
| Year 2021            | 82.75| 173.97 | 4.164.37 |
| Year 2031            | 96.36| 196.55 | 4.665.41 |

![Diagram a) and b) of Earthquake-Prone Areas and Affected Settlement Land](image)
Table 7 and Figure 8 show the distribution of earthquake-prone areas in 2021 and in 2031 models analyzed using cellular automata markov-chain. Every year, the area of settlements spread in each class prone to earthquakes always increases, where in 2021 the area of settlements in low-grade earthquake prone areas of 82.75 ha increases to 96.36 ha in 2031, as well as the moderate class where in 2021 the area of only 196.55 ha has increased by 196.55 ha in 2031 and areas that have earthquake prone levels continue to increase in area of 4,164.37 ha in 2021 to 4,665.41 ha in 2031. Based on the predictions of the development of settlement land in Ambon City in 2031, it can be concluded that the more years the increasing area of settlement land spread in earthquake-prone areas in Ambon City.

In an effort to mitigate earthquake disasters in Ambon City from the aspect of spatial arrangement, the spatial distribution of earthquake-prone areas is the most important analysis [14]. From the results of the map of earthquake-prone areas obtained from BPBD Ambon City will be covered with land cover map of Ambon City in 2021 and the results of the prediction of land cover in 2031, it can be seen the land built / settlements that are prone to earthquakes. So, it is in these areas that mitigation efforts both structural and non-structural must be optimally empowered [39]. Historically earthquake events will have a very large impact on the social, economic, and spatial conditions of an area prone to earthquakes.

4. Conclusion
During the last 15 years from 2011, 2017 and 2021 changes in Ambon city land cover that continues to increase, namely land cover of residential and open land, while land cover is not agricultural and agricultural areas decreased and for land cover water bodies did not increase or decrease. Residential land has increased the area by 4,421.33 ha in 2021. The development of land cover is built mostly to the east and south. Subdistricts that experience a fairly rapid increase in the area of built land are Sirimau District 1,140.83 ha and Nusaniwe Subdistrict by 1,055.65 ha. Based on the prediction of cellular automata markov chain model in 2031, land cover was built to increase the area to 4,958.33 ha or 49,583,268 m², with the population of Ambon City in 2031 predicted to amount to 2,445,961 people.

Earthquake prone areas in the research area are divided into low classes located in coastal areas and are on an active fault line with an area of 15,865.45 ha, a moderate class that has an area of 7,380.83 ha and a high class located in the central part of Ambon City with an area of 9,327.39 ha. The area of land built that is affected in earthquake-prone areas has a relationship that is directly proportional to the year of land development built. So that the more years then the area of land is built in areas prone to earthquakes and increasing. This research is expected to be used as a reference in the management of residential area development in a sustainable manner and for efforts to organize space based on disaster mitigation in order to minimize losses and victims due to the earthquake disaster that will occur in Ambon City in the future.

5. Acknowledgment
The author thanked the Ambon City Planning and Development Agency and the Ambon City Regional Disaster Management Agency for facilitating the authors in this study.
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