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Land Use Prediction Using Markov – Cellular Automata in the Peusangan Watershed, Aceh

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Abstract – The population growth rate is a factor that causes changes in land use that impact land ecology due to increased population activities related to social, economic, and cultural aspects. Land use change aims to develop facilities and infrastructure to meet the population's needs. This research seeks to interpret land-use changes in 1999, 2008, and 2019 and predict land use in the Peusangan watershed in 2030. The map overlay method analyzes land use change in 1999-2008, 2008-2019, and 2019-2030. In predicting land use, this study uses the Cellular Automata approach. The results of the analysis specifically show that the trend of land use change until 2030 is a decrease in the area of forest land use covering an area of 11,014 ha (4.27%), open land covering an area of 31 ha (0.01%), shrubs 6,083 ha (2.36%), and water bodies covering an area of 459 ha (0.18%). On the other hand, it is predicted that in 2030 the Peusangan watershed will see the most significant increase in land use for plantations of 14,225 ha (5.52%), followed by land use of 1,664 ha (0.65%), 817 ha (0.32%), settlements covering 710 ha (0.28%), 132 ha of rice fields (0.05%), and 28 ha of pond land use (0.01%). The results of this study are expected to be input for policymakers regarding land use planning in the Peusangan watershed in the future.

Keywords: Cellular Automata, Land Use, Peusangan Watershed.

Introduction

Changes in land use in the watershed tend to cause land degradation, resulting in decreased land productivity. Land use is closely related to human activities and land resources. The development progress in an area is in line with the increase in population. An increase in the standard of quality and quantity of the necessities of life always accompanies it. Furthermore, the increasing need for the availability of various facilities causes changes in land use (Permana *et al.*, 2019; Sitorus *et al.*, 2012). Increasing the area of a particular land use causes the surrounding land to change more dynamically (Munawir *et al.*, 2019). Land-use change is both a cause and a consequence of environmental change because it can affect climate change and further affect the physical properties of the land surface and the provision of global ecosystem services. (Turner *et al.*, 2007; Foley *et al.*, 2005; Alkama & Cescatti, 2016; Song *et al.*, 2018). Land conversion is one of the causes of damage to watersheds, causing complex physical, economic and social problems both upstream and downstream. The trigger is an economic orientation emphasizing short-term profits (Fitri *et al.*, 2018; Sitorus., 2017).

A Watershed is a land area that is an integral part of a river and its tributaries, which functions to accommodate, store, and drain water from rainfall to lakes or the sea naturally. The watershed area is limited by land topography, and the dividing boundary at sea to waters is still affected by land activities (Government Regulation Number 37 of 2012). Watershed management is a form of regional development where the watershed as a unitary management unit is interconnected between upstream and downstream in the biophysical aspect through the hydrological cycle. (Fitri *et al.*, 2020). The upstream Peusangan watershed is located in Central Aceh Regency, Bener Meriah Regency, Nagan Raya Regency, is one of the priority watersheds to be restored

(Kementerian Lingkungan Hidup dan Kehutanan, 2015). The uncontrolled exploitation of land use in the watershed has resulted in a decrease in the biophysical condition of the watershed, changes in the function of the watershed, the reduction of forest area, the area of dry fields, and an increase in residential areas. Land changes without an excellent spatial plan along the Peusangan watershed also cause damage to the ecosystem that has an impact on the survival of various ethnic communities. (Gayo dan Aceh) which inhabits the upstream, middle, and downstream areas of the Peusangan watershed (Ilhamsyah *et al*., 2012). Research on land use prediction using Markov – Cellular Automata in the Peusangan watershed is considered essential to understanding the future biophysical conditions of the Peusangan watershed. Changes in land use and land cover must be controlled and monitored to ensure the functioning of the watershed ecosystem. Detection of land cover change is critical for better understanding the landscape for sustainable land management (Fatimatuzahra *et al*., 2021; Thi *et al*., 2018). Markov - Cellular Automata is an effective model used to predict land-use changes spatially and analyze future land cover changes (Munthali *et al*., 2020; Permatasari *et al*., 2021). The CA-Markov model can simulate evolution and show land use over decades (Hazani *et al*., 2021). The results of this study can later be used as a reference for the sustainable planning and management of the Peusangan watershed. This research aims to interpret land use in 1999, 2008, and 2019 and predict land use in the Peusangan watershed in 2030.

Materials and Methods

Time and site

This research was carried out in the Peusangan watershed of Aceh Province from August 2021 to December 2021. Geographically, the Peusangan watershed is located at the coordinates of 05º 09' 48" North Latitude and 096º 26' 26" East Longitude. The Peusangan watershed has an area of 257,800 hectares. It is located in 6 (six) administrative regions, namely Central Aceh Regency, Bener Meriah Regency, Nagan Raya Regency, North Aceh Regency, Lhoekseumawe City, and Bireuen Regency.

Data collection

The data used in this study are primary data and secondary data. Primary data is in-field observations to verify location data that has changed land use. Meanwhile, secondary data was obtained from several related institutions, including the Earth Map of Indonesia at 1:25,000 scale in 2020 from the Geospatial Information Agency. The land use map was obtained from the interpretation of the Landsat TM 5 acquisition in May 1999, the Landsat ETM7 acquisition in February 2008, and the Landsat 8 OLI acquisition in July 2019 from the United States Geological Survey (USGS), Spatial pattern map (RTRW) of the Peusangan Watershed from BAPPEDA Aceh Province.

Land Use Interpretation

Land use classification in the Peusangan watershed is performed by interpreting satellite images of Landsat TM 5 in 1999, Landsat ETM7 in 2008, and Landsat 8 OLI in 2019 using a visual interpretation method (on-screen digitization). The analysis's elements are the basis of hue (tone), size, color, texture, pattern, shape, shadow, association, and site (Lillesand & Keifer, 1997). The results of this interpretation are the Peusangan watershed land use maps for 1999, 2008, and 2019. The interpreted land-use map is verified through field observations at 60 sampling points and interviews with the community on land-use objects still in doubt. Verification was carried out to determine the accuracy of the resulting land use interpretation. The accuracy test is based on the Kappa Accuracy value with an accuracy level of >85% obtained through the interpretation error matrix analysis (Table 1). Use maps that have been verified and met the accuracy level are then analyzed for land-use changes. Changes in land use at the research site were obtained from spatial analysis (overlay) of land use maps in 1999, 2009, and 2019. The analysis results are then presented in the form of a transition matrix of land use changes to determine changes in the area and attributes of types of use for various periods of the observation year. The data and information on land-use changes are input data in the prediction analysis of land-use changes.

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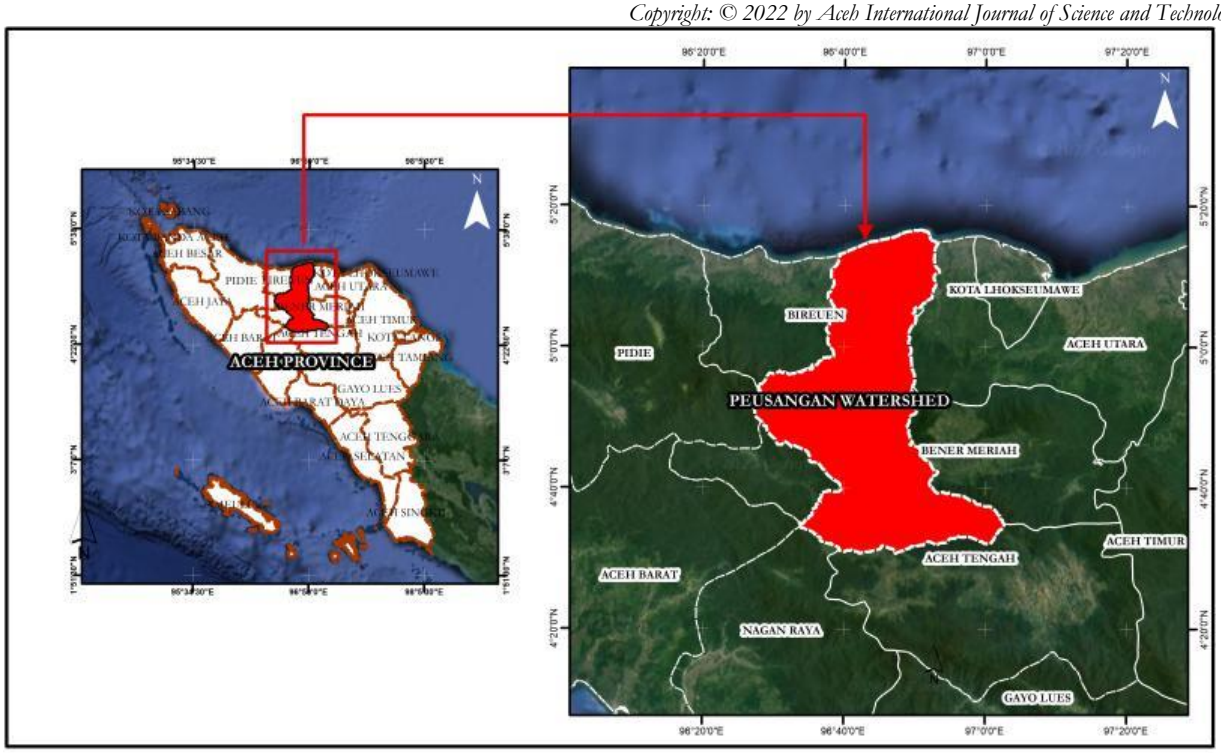

Figure 1. Location of the Peusangan Watershed in Aceh Province

Tabel 1. Error matrix

Interpreted land use	Validation Landuse					
	Pi+	Pi+	……	……	Pi+	Total
P+i	Xii					X+i
P+i		Xii				X+i
……			Xii			X+i
……				Xii		X+i
P+i					Xmm	X+i
Total	Xi+	Xi+	Xi+	Xi+	Xi+	N

Legend :
P+i : Types of land use result of interpretation
$N \sum_{i=1}^{r} \text{xii} - \sum_{i=1}^{r}.(x_{1+} + x_{1+})$Pi+ : Types of land use as a result of the validation
$N^2 - \sum_{i=1}^{r}.(x_{1+} * x_{1+})$
X+i : Total of points land use type resulting from the interpretation i-th
Xi+ : Total of points land use type resulting from the validation i-th
Xii : Total of land use type resulting from the interpretation i-th
i : Row or column
r : Total of land use type
N : Total of points land use type resulting from the validation
K : Kappa value

Land Use Prediction Analysis Method

Modeling and predicting land use in the Peusangan watershed using the Cellular Automata Markov Chain (CA Markov) method.). CA (Cellular Automata) is a computational method based on the neighborhood principle of cells to predict dynamic systems that depend on simple rules and develop only according to these rules over time (Wardani *et al.*, 2016). The Markov process as the system's state for the second time can be predicted with the system's condition first by providing a transition probability matrix from each land-use class to each land-use class (El-Hallaq & Habboub, 2015). With CA-Markov, the probability of changes in land-use pixels

following previous land-use changes, neighboring land uses around the pixels changing, and changes will be controlled following the transition probability matrix function. The transition probability is the probability of a land-use change from one type of use to another with a value range of 0-1. The closer the value is to 1, the higher the chance for a change to occur.

Before running the model, the data format is first transformed from vector to raster data format, using raster data with imagine (img) data type and 30 x 30 m pixel size. Furthermore, the transformation from the imagine (img) data type to the arc-raster (rst) is carried out again as a condition of the data type that can be used to run the model. The model simulation is carried out in the first 2 (two) stages, namely model validation, namely efforts made to determine the accuracy of the projected land-use change. This model will be accepted if the validation value is more than 85%, indicating that the model performance is good to continue the prediction process. The second stage is the prediction of land use in 2030 obtained based on trends in land-use change for 2008-2019. Predictions are made by assuming that changes that will occur in the future have patterns and opportunities similar to the designs of changes that happened during the previous period in the Peusangan watershed.

Results

Peusangan Watershed Land Use

The results of image interpretation in 1999, 2008, and 2019 land use in the Peusangan watershed resulted in 10 (ten) land use classifications, namely forest, mixed gardens, fields/moorlands, open fields, plantations, settlements, paddy fields, shrubs, ponds, and water bodies. This classification is adjusted to the map's scale and land use types commonly used in Indonesia. The land use of the Peusangan watershed is dominated by forests covering the forest area in 1999 (38%), 2008 (36%), and 2019 (33%). The location of each land use in the Krueng watershed is presented in Table 2.

Table 2. Land Use of the Krueng Peusangan Watershed in 1999, 2008, and 2019

No	Land use	1999		2008		2019	
		Area (ha)	%	Area (ha)	%	Area (ha)	%
1	Forest	97,471	38	91,882	36	84,556	33
2	Mixed Garden	1,340	1	1,441	1	1,348	1
3	Field / Moor	74,496	29	76,997	30	82,364	32
4	Open field	2,196	1	2,309	1	843	0
5	Plantation	22,307	9	22,307	9	27,624	11
6	Settlement	3,004	1	3,071	1	4,037	2
7	Paddy field	12,520	5	13,530	5	15,041	6
8	Shrubs	32,843	13,	34,631	13	30,345	12
9	Pond	2,854	1	2,854	1	2,854	1
10	Water Bodies	6,770	3	6,770	3	6,770	3
Total		257.800	100	257.800	100	257.800	100

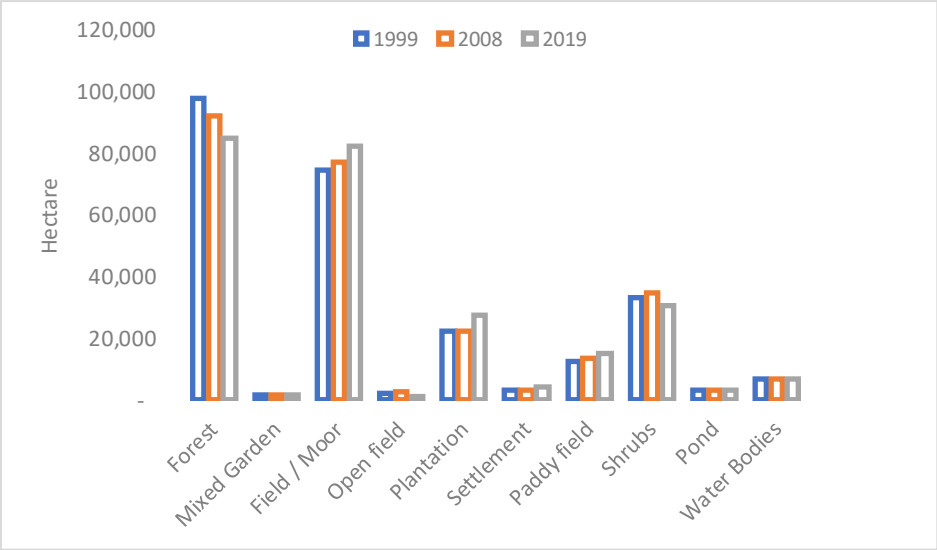

Figure 2. Land use in the Peusangan watershed in 1999, 2008, and 2019

The graph of land use trends over the last 20 years is shown in Figure 2, that the Peusangan watershed area, which has increased, is predicted to become fields/moorlands, plantations, and settlements. Sitorus (2017) revealed that the change/conversion of agricultural land functions occurs because of the encouragement of an economic orientation that emphasizes short-term profits without considering the benefits lost due to the transfer of process.

Figure 3 shows that land use for fields/moorlands, plantations, settlements, and rice fields in the Peusangan watershed has increased, while forest land, mixed gardens, plantations, and shrubs have decreased. Then, land uses that do not increase or decrease our ponds and water bodies. Figure 3 shows the composition of land use/moorland for the period 1999-2019 always shows an increase of 74,496 ha (29%) in 1999, 76,997 ha(30%) in 2008, and 82,364 ha (32%) in 2019. Plantations also showed an increase in each period of 22,307 ha (9%) in 1999, 22,307 ha (9%) in 2008, and 27,624 ha (11%) in 2019. Residential land use increased by 3,004 ha (1%) in 1999, 3,004 ha (1%) in 2008, and 4,037 ha (2%) in 2019. The use of paddy fields increased by 12,520 ha (5%) in 1999, 13,530 ha (5%) in 2008, and 15,041 ha (6%) in 2019. Forest land use decreased in each period by 97,471 ha (38%) in 1999, 91,882 ha (36%) in 2008, and 84,556 ha (33%) in 2019. Mixed garden land used 1,340 ha (1%) in 1999, 1,441 ha (1 %) in 2008, and 1,348 ha (1%) in 2019. Bushland use was 32,843 ha (13%) in 1999, 34,631 ha (13%) in 2008, and 30,345 ha (12%) in 2019. The pond land-use class had the same area from 1999-2019, around 27 2,854 ha (1 %) and 6,770 ha (3%) water bodies of the total area of the Peusangan watershed.

Land Use Changes in the Peusangan Watershed

Land use in the Peusangan watershed based on the results of overlaying land use maps in 1999, 2008, and 2019 shows that the trend of forest area has decreased while the area of dry land/fields continues to increase. This trend is in line with the population growth rate in the watershed area from year to year, both naturally and by migration, to increase population density in the Peusangan watershed area. The results of research by Sitorus *et al.* (2011) show that population growth is an essential factor influencing changes in the area of space in an area. This population increases significantly affects space requirements, resulting in reduced land in the Peusangan watershed. Peusangan watershed in 1999 had a population of 969,690 people. In 2008 131,186.6 people, and 2019, a population of 161,900.5 people (Badan Pusat Statistik, 2021). Table 3 presents the total area of land-use change during 1999-2019, and the trend of land-use change is shown in Figure 3.

The total area of land-use changes that occurred in the Peusangan watershed during the period 1999-2019 was 25,810 ha or 10.01% of the location of the Peusangan watershed (Table 2), namely forest land use, mixed gardens, fields/moorlands, plantations, settlements, and rice field. Forest area increased in that period by 12,915 ha (38%), fields/moorlands by 7,868 ha (23%), plantations by 5,316 ha (16%), rice fields by 2,520 ha (8%), and settlements 966 ha (3%) the total land-use change that occurred. A decrease also followed the increase in land-

use changes in other land uses, such as shrubland, which decreased drastically during that period, 2,498 (8%), followed by 1,353 (4%) open fields.

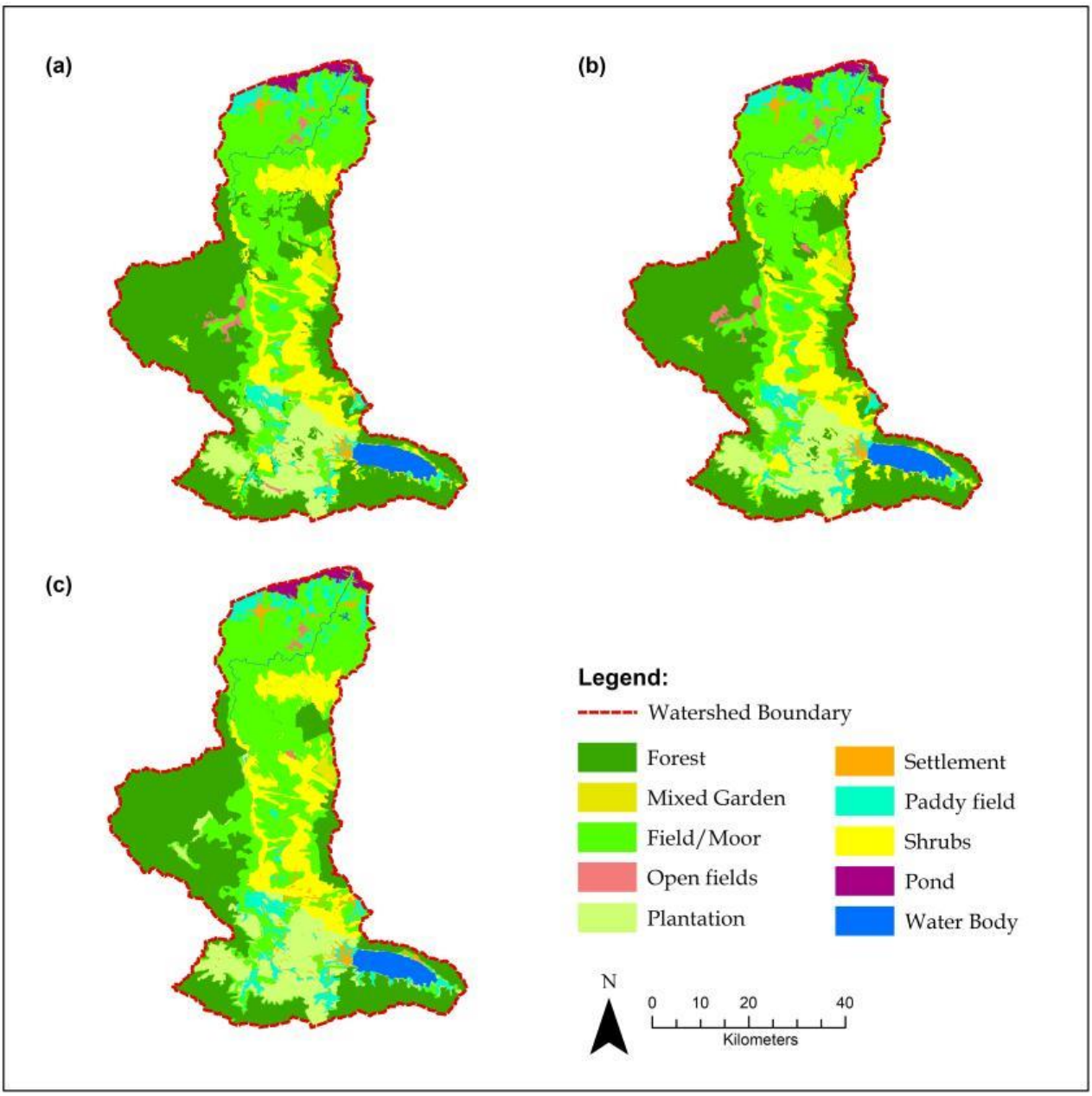

Figure 3. Land Use Map of Peusangan Watershed
(a) 1999, (b) 2008, (c) 2019

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Table 3. Trends in Land Use Change in the Peusangan Watershed in 1999, 2008, and 2019

No	Land Use	Period of the Year					
		1999-2008		2008-2019			
		Ha	%	Ha	%	Ha	%
1	Forest	-5,589	2.18	-7.326	2.86	12,915	38
2	Mixed Garden	101	0.04	-92	0.04	9	0
3	Field/Moor	2.501	0.98	5.367	2.10	7,868	23
4	Open fields	113	0.04	-1.466	0.57	-1,353	4
5	Plantation	0	0	5.316	2.08	5,316	16
6	Settlement	68	0.03	965	0.38	1,033	3
7	Paddy field	1.010	0.39	1.510	0.59	2,520	8
8	Shrubs	1.788	0.70	-4.286	1.68	-2,498	8
9	Pond	0	0	0	0	0	0
10	Water Body	0	0	0	0	0	0
Total						25,810	100

Increase area (+), Decrease area (-)

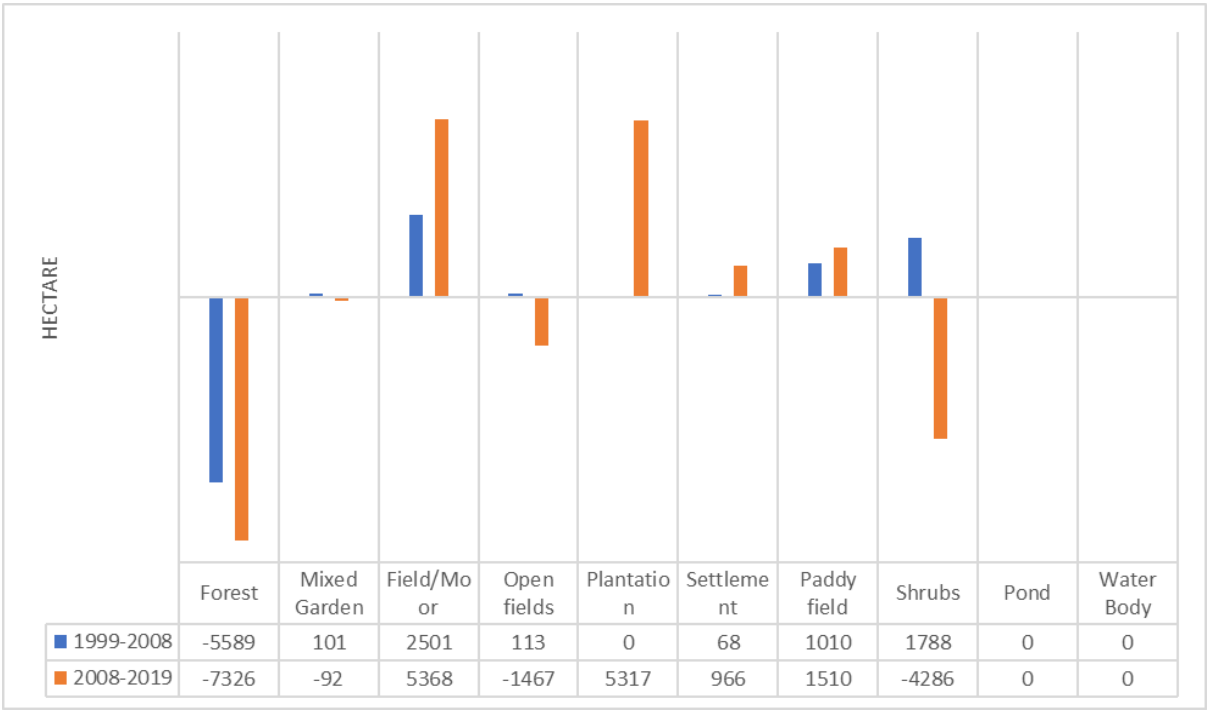

Figure 4. Graph of trends in a land-use change in the Peusangan watershed for the period 1999-2008 and 2008-2019

Figure 5 shows that land-use change/conversion in the Peusangan watershed in 1999 and 2008 mainly occurred in the middle of the watershed. In the middle watershed, almost all land uses have increased, except for forests, which have decreased. Peusangan watershed in 2008-2019, there was a change in land use and spread to the downstream watershed, except for forests, open fields, and shrubs, which experienced a decrease in area.

Prediction of Land Use Change

The results of the prediction of land-use changes in the Peusangan watershed through the Cellular Automata-Markov (CA Markov) simulation model have been obtained. The results of the kappa validation have an accuracy rate of 89.76% which means >85%, indicating that the data meets the requirements for the projection (Figure 6). The transition probability between land use 2019 result of Landsat interpretation and prediction use CA

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Markov showed in Figure 7. The prediction result is that the land-use area in 2030 is predicted to be only 29% of the total area of the Peusangan watershed. This prediction indicates that if the trend of forest area loss or deforestation (including primary and secondary forests on dry land and plantation forests) continues, the use of forest land, specially protected forest areas in the upstream Peusangan watershed, will be converted. Table 3 compares the percentage of forest land-use area where forest land use in 2019 was 33%, while in 2030, it was 29%. The prediction of land use changes is also followed by an increase in population due to the projected population in 2034, calculated using the arithmetic method. The number of people in the Peusangan watershed estimated from 1999 to 2030 will be 271,988.2.

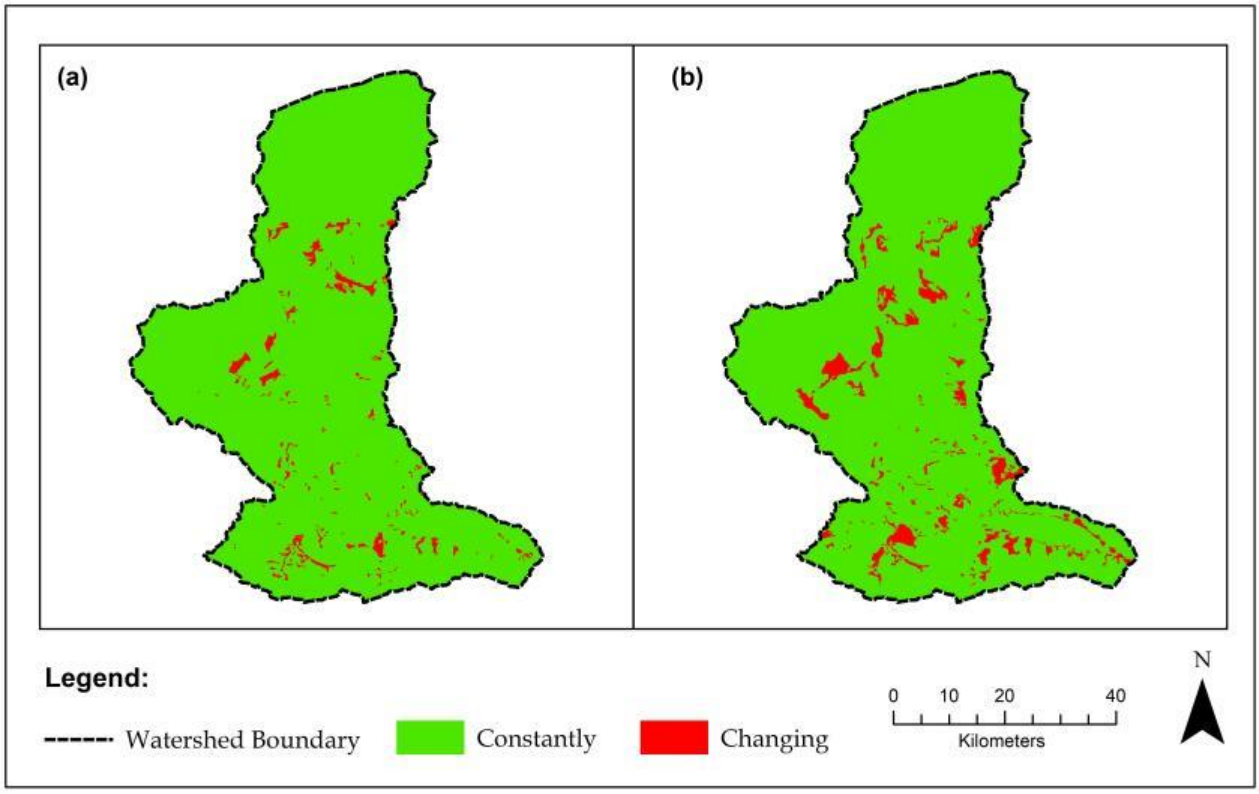

Figure 5. Trends in land-use change in various periods of the year of observation
(a) Period 1999-2008, (b) Period 2008-2019

Based on Table 4 shows the predicted results of land use in 2030 in the Peusangan watershed will decrease in the area of forest land use covering an area of 11,014 ha (4.27%), open land surrounding an area of 31 ha (0.01%), shrubs 6,083 ha (2.36%), and a body water area of 459 ha (0.18%). On the other hand, it is predicted that in 2030 the Peusangan watershed will see the most significant increase in plantation land use, covering an area of 14,225 ha (5.52%), followed by land use of 1,664 ha (0.65%), 817 ha (0.32%), settlements covering an area of 710 ha (0.28%), 132 ha of paddy fields (0.05%) and 28 ha of ponds (0.01%). Almost all predictions of land-use change trends in Indonesia show a reduction in forest land use and an increase in plantation and settlement land (Yudichandra et al., 2020). The tendency of land change in the Peusangan watershed area generally occurs in forests and shrubs, decreases, and increases in the use of plantation land and mixed gardens.

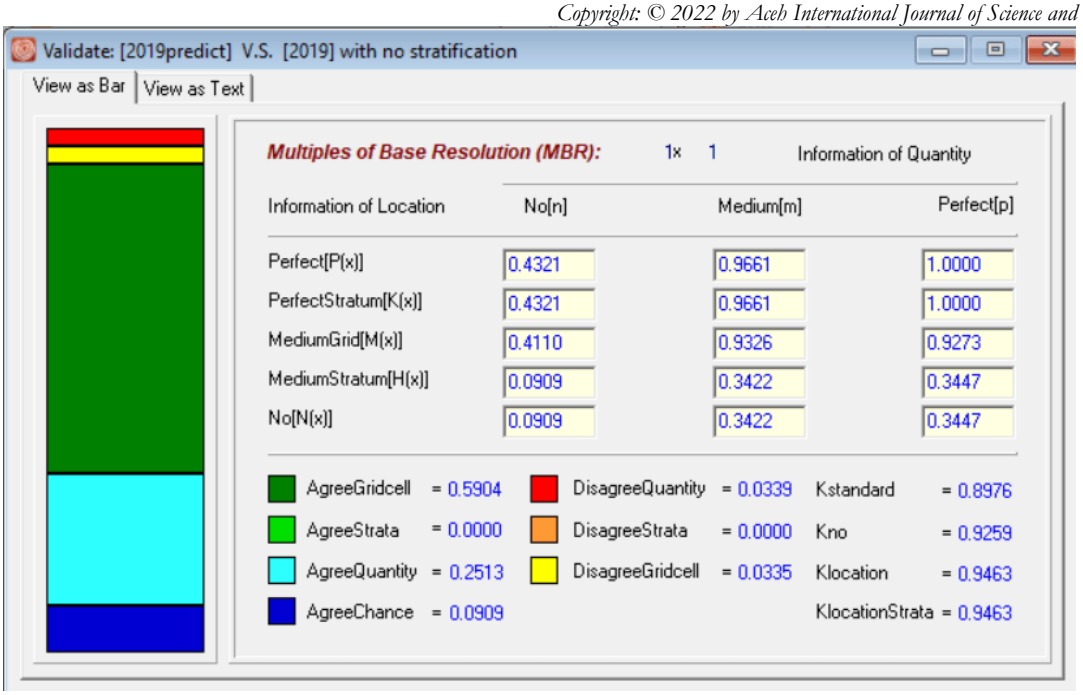

Figure 6. Kappa validation result

```
Given :    Probability of changing to :

           Cl. 1  Cl. 2  Cl. 3  Cl. 4  Cl. 5  Cl. 6  Cl. 7  Cl. 8  Cl. 9 Cl. 10

Class 1  : 0.8881 0.0375 0.0000 0.0116 0.0223 0.0000 0.0000 0.0405 0.0000 0.0000
Class 2  : 0.0000 0.9402 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0598 0.0000
Class 3  : 0.0000 0.0000 0.9422 0.0000 0.0000 0.0092 0.0487 0.0000 0.0000 0.0000
Class 4  : 0.0000 0.0000 0.0000 0.8437 0.0000 0.0000 0.1563 0.0000 0.0000 0.0000
Class 5  : 0.0056 0.0056 0.0056 0.0056 0.9500 0.0056 0.0056 0.0056 0.0056 0.0056
Class 6  : 0.0056 0.0056 0.0056 0.0056 0.0056 0.9500 0.0056 0.0056 0.0056 0.0056
Class 7  : 0.0056 0.0056 0.0056 0.0056 0.0056 0.0056 0.9500 0.0056 0.0056 0.0056
Class 8  : 0.0000 0.0915 0.0145 0.0000 0.0690 0.0000 0.0133 0.8117 0.0000 0.0000
Class 9  : 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0506 0.9494 0.0000
Class 10 : 0.0056 0.0056 0.0056 0.0056 0.0056 0.0056 0.0056 0.0056 0.0056 0.9500

Legend
Class 1  : Forest
Class 2  : Mixed Garden
Class 3  : Field/Moor
Class 4  : Open fields
Class 5  : Plantation
Class 6  : Settlement
Class 7  : Paddy field
Class 8  : Shrubs
Class 9  : Pond
Class 10 : Water Body
```

Figure 7. Transition probability between land use 2019 result of Landsat interpretation and prediction use CA Markov

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Table 4. Predicted Area and Land Use Change for the period 2019-2030

No	Land Use	Area					
		2019		2030		Changing	
		ha	%	ha	%	ha	%
1	Forest	84,556	33	73,543	29	-11,014	4,27
2	Mixed Garden	1,348	1	3,012	1	1,664	0,65
3	Fields/Moor	82,364	32	83,181	32	817	0,32
4	Open fields	843	0	812	0	-31	0,01
5	Plantation	27,624	11	41,848	16	14,225	5,52
6	Settlements	4,037	2	4,747	2	710	0,28
7	Paddy fields	15,041	6	15,172	6	132	0,05
8	Shrubs	30,345	12	24,262	9	-6,083	2,36
9	Ponds	2,854	1	2,882	1	28	0,01
10	Water Bodies	6,770	3	6,311	2	-459	0,18
	Total	257,800	100	257,800	100	35,161	13,64

Increase area (+), Decrease area(-)

It is predicted that the increase in land use in the Peusangan watershed into new plantation land by (5.52%) will generally threaten the forests in the Peusangan watershed. Indonesia tops the rankings by the quantity of plantation expansion. Expanding plantations have led to changes in the ecological landscape, where forests are degraded. Supported by the high growth of plantations into forest areas, the threat to the area's sustainability as a conservation area is increasing (Hidayah et al., 2016). Land cover by trees can affect water flow in several stages, such as interception, protection of soil aggregates, infiltration, water absorption, and landscape drainage. So the impact of the conversion can be seen from the combination and interaction of these various processes (Van Noordwijk et al., 2004). Suppose this change continues and is left unchecked. In that case, it is feared that it will endanger environmental conditions in the Peusangan watershed, such as increased surface water runoff and the risk of natural disasters, erosion, and landslides.

The spatial distribution of land-use changes in the Peusangan watershed for 2019-2030 can be seen in Figure 8, showing that land-use modifications tend to occur in the middle and downstream areas of the Peusangan watershed. Based on field observations, the changes in the central area of the Peusangan watershed were generally converted to land use for coffee plantations. In contrast, the changes were converted to oil palm plantations in the downstream watershed areas. The area of Arabica coffee plantations in the Peusangan watershed area, located in the Central Aceh district, reaches 2,441 hectares of immature plantations. Bener Meriah Regency has an area of 6,847 hectares of green plantations. North Aceh Regency has an area of 505 hectares of immature plantations. In contrast, the location of oil palm plantations in the Peusangan watershed is generally located in the downstream region of the watershed, namely in Bireuen Regency, covering an area of 2,076 hectares, Bener Meriah Regency covering an area of 575 hectares. (Badan Pusat Statistik, Provinsi Aceh, 2020).

Discussion

The analysis above shows that the trend of land use change until 2030 in the Peusangan Watershed has decreased the area of land in forests, open land, shrubs, and water bodies. The impact of changes in land use in watersheds can increase the danger of erosion (Andriyani *et al*., 2019). The threat of changes in land use for the Peusangan Watershed is increasing land use for monoculture plantations. The effect of monoculture land use results in decreased soil productivity, erosion, and landslides. However, this risk is important to receive attention, so it requires land conservation and land use for agroforestry as an optimal alternative for managing the Peusangan watershed, categorized as having to be restored. The strategy chosen to deal with changes in land use does not reduce the area of forest land (deforestation). Improving forest management patterns and making protected areas function as water catchment areas, so erosion does not occur (Pratiwi & Yusdiana, 2022). Therefore, the next stage of research focuses on the effects of change in use for sustainable management of the Peusangan watershed

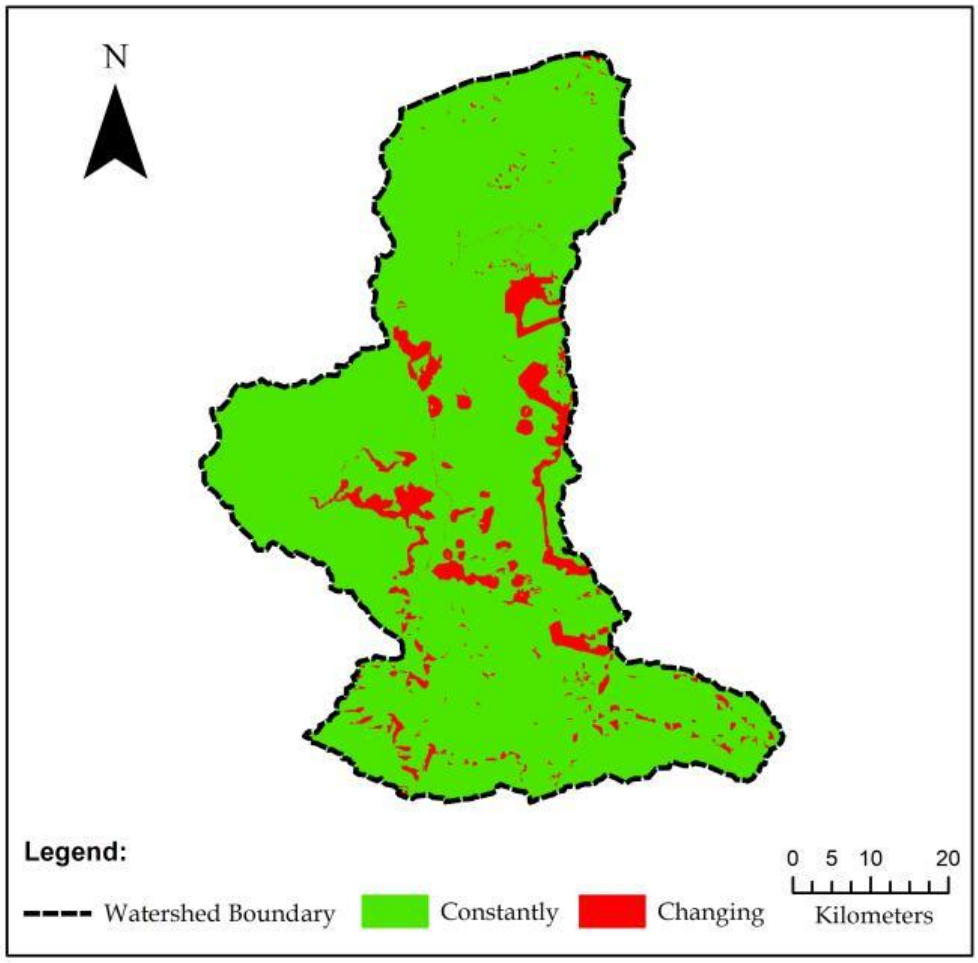

Figure 8. Spatial distribution of land-use changes for the period 2019-2030

Conclusion

The results of overlaying land use maps in the Peusangan watershed in 1999, 2008, and 2019 show that the area of forest land has a decreasing trend while the area of dry land and settlements has an increasing trend. Prediction results using the Cellular Automata-Markov (CA Markov) simulation model in 2030, a settlement area of 710 ha (0.28%) with a total population of 161,900,5 people from the Peusangan watershed area. The population is an essential factor that affects land-use change in the Peusangan watershed. From the population projections in the Peusangan watershed, it is estimated that the number of people in 2030 will be 271,988.2. Changes in land use in the Peusangan watershed in 1999-2019 spread from upstream to downstream of the watershed, except for forests, open land, and shrubs which experienced a decrease in area.

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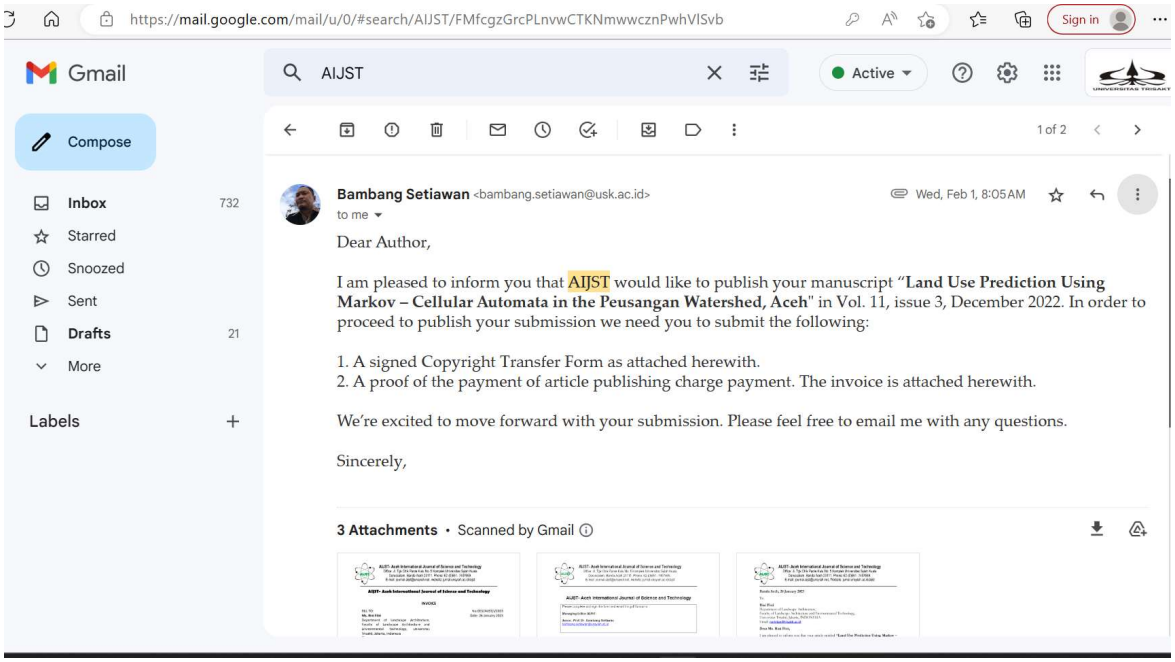

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