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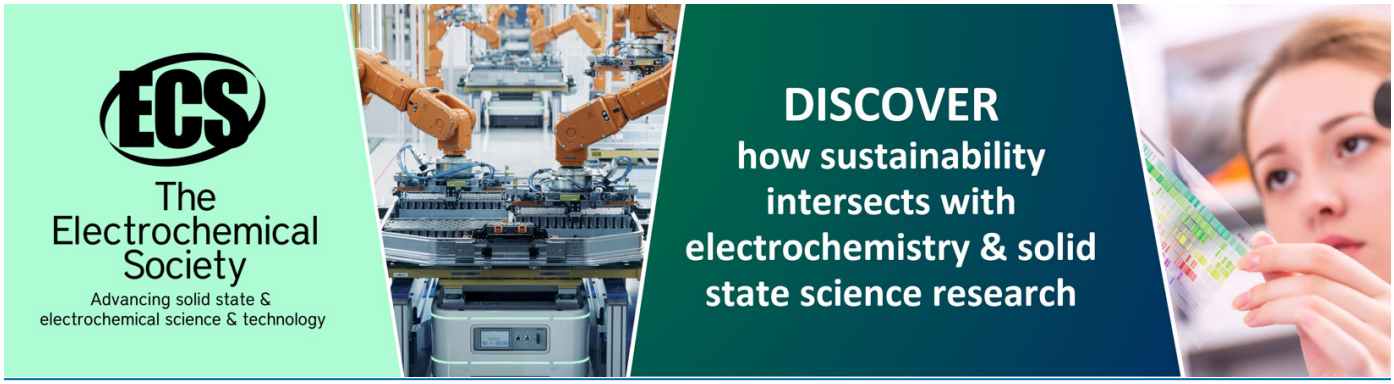

Landscape patterns changes and relation to water infiltration of *Krueng Peusangan* Watershed in Aceh

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Abstract. Watershed has played an important source of ecosystem services (ES). The *Krueng Peusangan* watershed (KPW) is considered to be the "lungs" and ecological border in the central region of Aceh, Indonesia. This study aims to monitor landscape patterns in the watershed area of 2009-2019 and to predict changes in 2039 and their relationship with infiltration. The selection of this research area is due to the notion that KPW is one of the numerously deforested watersheds in the country. Temporal spatial monitoring of landscape (land use/cover, LUC) patterns are required to inform policy and support future spatial management planning towards sustainability. Landscape patterns changes in KPW, including the extent of loss and addition of forest over the last few years, have not been quantified. In constructing the regional development policies, information regarding the effects of landscape changes and climatic patterns on ecosystem services is essential. Therefore, the knowledge development of this relationship is encouraged. The comparison value between potential and actual infiltration could identify the watershed category. The upstream area of KPW is classified as a significantly critical watershed due to LUC changes. Therefore, it is deemed necessary to improve the absorption zone for the continuation of groundwater protection.

1. Introduction

Changes in landscape (land use/cover, LUC) patterns are among the main factors for global change thereby endangering the natural environment [1]. These changes directly impact people's welfare through changes in environmental conditions, such as land degradation [2] and the value of ecosystem services (ES) (the benefits people derive from ecosystems) [3]. Changes in landscape and climate patterns present a significant impact on ES [4]. Watersheds becomes an essential source of various ES, including provisioning, regulatory, supporting, and cultural services [5]. Watershed includes biological, social, physical, and economic processes; thus, they are often applied as landscape planning and natural resource management [6]. Watershed is however vulnerable to drastic landscape changes due to deforestation [7]. Deforestation affects landscape patterns because it can change the composition of the landscape (such as loss or reduced forest cover) and the configuration of landscape (such as spatial connectivity and landscape elements fragmentation) [8].

In Indonesia, the rate of deforestation remains high due to poor governance, incompatible spatial planning between the centre and the regions, and weak capacity in forest management, which are fundamental problems in forest management in Indonesia [9]. In 2015, the forest area in Indonesia reached 128 million ha, while in 2017, it decreased to 126 million ha [9]. In 2018, the loss of forest cover in Aceh Province reached 15,071 ha. This rate of deforestation has dramatically impacted the

disasters that occurred in Aceh, such as floods and droughts. In addition, deforestation in KPW, one of the watersheds whose management is prioritized, has severely damaged this watershed [10].

As a water system unit, the watershed is influenced by upstream conditions, especially the biophysical conditions of the watershed. The identification for watershed condition is conducted by comparing the potential infiltration value (slope, rainfall, and soil type) with the actual infiltration value [11].

LUC refers to a complex system determined by the interaction of space and time from human factors and biophysical [12]. Impregnation or infiltration depends on rainfall, surface runoff, soil type, slope, vegetation type, and land use. LUC changes that are not following their designation are also causes of the land surface becoming watertight, therefore the rainwater that falls cannot enter the ground [10].

Remote Sensing (RS) has become an important data source in monitoring activities and many environmental studies, including mapping forest cover and monitoring LUC changes and impacts that occur [13]. LUC maps derived from RS data could provide important information and monitor landscape patterns, including their composition and spatial configuration [14,15]. Furthermore, monitoring landscape patterns is essential to improve understanding and assessment of the level, dimensions, consequences, and causes of LUC changes to predict the future tendency changes [16,17].

2. Materials and Methods

2.1 Study Area

Situated in KPW 5^{0}16'34"NL-96^{o}27'12"EL and 4°30'38"LU-97°02'40"EL, KPW has an area of 2,557.8 km^{2}, covering six districts (Aceh Tengah, Bener Meriah, Bireuen, Aceh Utara, Pidie, and Nagan Raya) [10] (Figure 1).

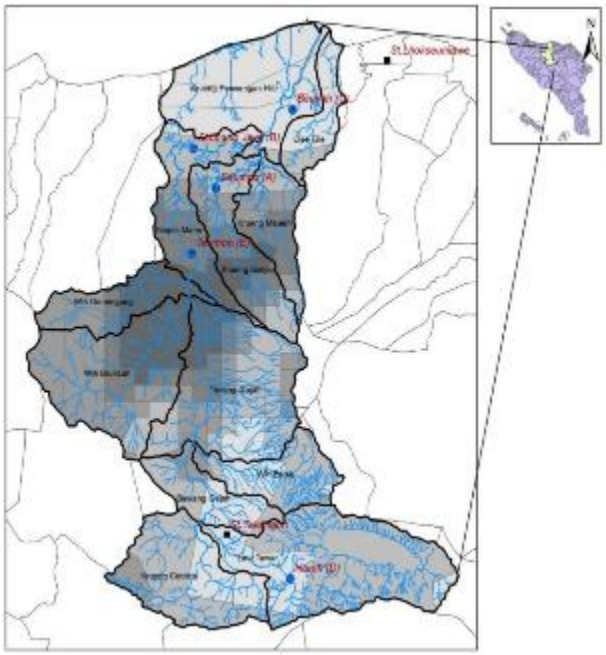

Figure 1. Study location [18]

2.2 Data

Total population and Gross Regional Domestic Product (GRDP) were obtained from the Central Statistics Agency of Aceh. The climate data was gathered from Meteorological, Climatological, and Geophysical Agency (Pegasing and Malikussaleh stations), while the Landsat Satellite Imagery was obtained from https://glovis.usgs.gov/ for 2009 and 2019.

2.3 Analysis Method

LUC category was identified by implementing Landsat imagery (Table 1), performed with a supervised classification approach available in ArcGIS® 10.1, becoming LUC 2009 and LUC 2019. LUC is divided into six categories: water body, built-up area, vegetation, agriculture, wetland, and bareland. In this study, the water bodies include lakes and rivers, the built-up area include concrete structures, such as building pavements, houses, roads, bridges, and others. Vegetationis dominated by forests, consists of trees. Agriculture includes cropland and plantation, a wetland in fish ponds, dams, and other land saturated by water, while bareland refers to empty or undeveloped area.

Table 1 Description of landsat satellite imagery (https://glovis.usgs.gov/)

Sensor	Scene ID	Acquisition Date	Time (GMT)	Season
Landsat 5 TM	LT51300572009330BKT00	2009-11-26	03:36:56	Dry
Landsat 8 OLI / TIRS	LC81300572019006LGN00	2018-08-15	93:45:46	Dry

Testing accuracy was initiated by extracting the reference points on the LUC 2009 and LUC 2019 maps. The determination of these reference points utilizes the ERRMAT module [19] on TerrSet®, by employing stratified random sampling. There are 1,200 reference points to test this accuracy. Then the Kappa coefficient is calculated using Equations (1), (2), (3), dan (4) [20].

Persentase benar = $\frac{\sum_{k=1}^{q} n_{kk}}{n}$ x 100 ……..…..… (1)

User's accuracy = $\frac{n_{ii}}{n_{i+}}$ ……..….(2)

Producer's accuracy = $\frac{n_{ii}}{n_{+i}}$ ……..….. (3)

Koefisien kappa = $\frac{n\sum_{i=0}^{q} n_{kk} - \sum_{i=0}^{q} n_{k+}n_{+k}}{n^2 - \sum_{i=0}^{q} n_{k+}n_{+k}}$ ……..… (4)

Landscape change detection was performed with the Markov chain model [16,21,22] to generate a transition from one time to time (using TerrSet®). The transition probability is denoted as the transition matrix *P of the* form:

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1k} \\ p_{21} & p_{22} & \cdots & p_{2k} \\ \cdots & \cdots & \cdots & \cdots \\ p_{k1} & p_{k2} & \ldots & p_{kk} \end{bmatrix} \quad \text{……..……(5)}$$

At time 0 the initial distribution of the state is $P\ (X_0 = i) = p_i\ (0) \quad \forall i \epsilon\ (1,\ldots .., k)$.

Meanwhile, water infiltration areas are classified by *overlay* soil types, rainfall, and slopes in order to obtain natural potential infiltration capabilities. LUC, particularly the type of vegetation, affects infiltration through roots and pores. Vegetation can reduce runoff (Regulation of the Minister of Forestry of the Republic of Indonesia Number: P.32/MENHUT- II/ 2009). Determination of the condition of the infiltration area was withdrawn by providing a score on the parameters including: rainfall, soil type, slope, and land use.

The scoring results were further classified into the level of absorption criticality, consisting of the categories of good condition, natural normal, critical begin, mildly critical, critical, very critical. Classification of the watershed with the following criteria: a). good condition, such as if the actual infiltration value is greater than the potential infiltration value, b). natural normal condition, such as if the actual infiltration value is the same or remains the same as the potential infiltration value, c). critical starting condition, such as if the actual infiltration value has decreased by one level from the

potential infiltration value, d). slightly critical condition, such as if the actual infiltration value has decreased by two levels from the potential infiltration value, e). critical condition, such as if the actual infiltration value has decreased by three levels from the value infiltration potential, f). very critical condition, such as if the actual infiltration value changes from very large to very small. The comparison of the potential infiltration value and the actual infiltration value obtained a combination of identification of water infiltration.

3. Results and Discussion

3.1 Results

The results of the accuracy-test indicate that the LUC 2009 and 2019 are generated, as can be seen in Fig. 2 and Fig. 3, has an accuracy of the kappa coefficient of 87.90 and 84.20, respectively; these results qualify for further analyzes, for predicting the models for future change patterns. The most significant increase in the area of the LUC category occurred in the agriculture category, followed by vegetation and built-up areas. Meanwhile, the most significant decrease in the area of the LUC category occurred in the vegetation, agriculture, and built-up areas, as indicated in Fig. 3 and Fig. 4. The percentage details regarding the changes that occur can be seen in Table 2.

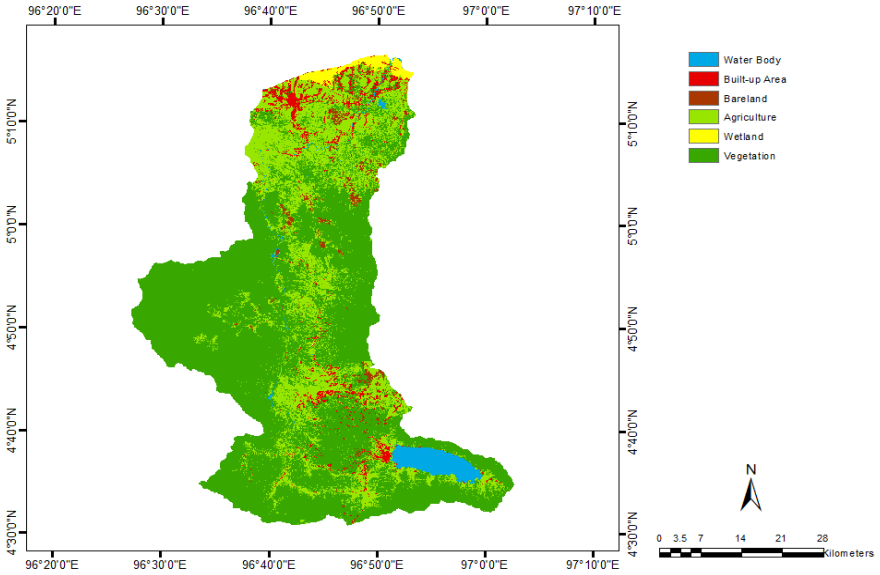

Figure 2. LUC 2009

Table 2. LUC 2009 dan LUC 2019 changes

Category	LUC			
	2009 (ha)	2019 (ha)	Change (ha)	Percentage (%)
Water body	7,056.36	7,093.80	37.44	0.53
Built-up area	9,474.21	15,336.81	5,862.60	61.88
Bareland	3,035.16	1,286.37	- 1,748.79	- 57.62
Agriculture	64,561.77	98,537.85	33,976.08	52.63
Wetland	3,158.10	2,911.41	- 246.69	- 7.81
Vegetation	168,010.74	130,130.10	- 37,880.64	- 22.55
Total	255,296.34	255,296.34		

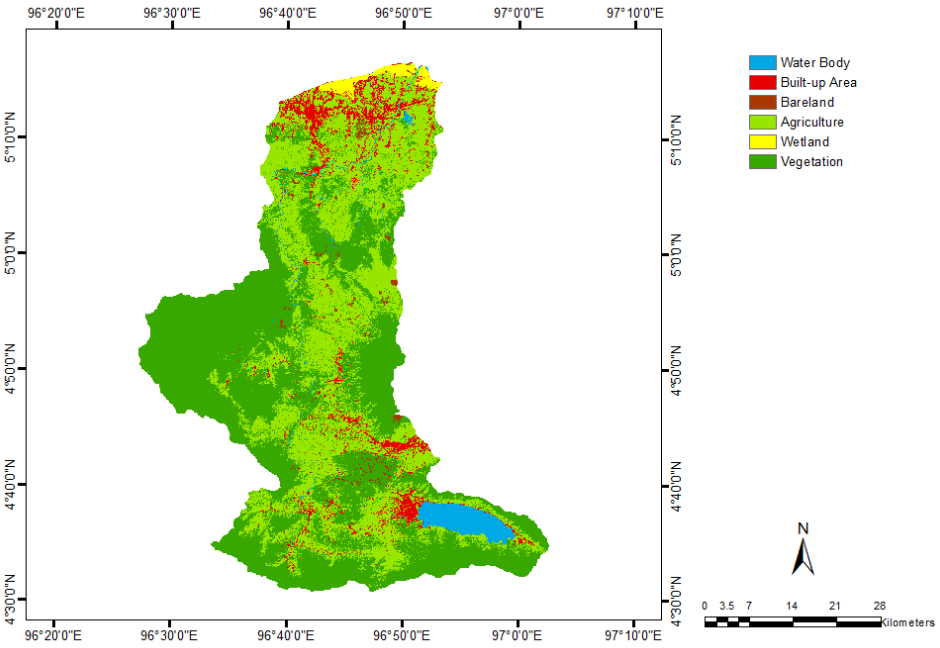

Figure 3. LUC 2009

The highest percentage of LUC changes was in the category built-up area, reaching 61.88%, increasing. The change in area in the bareland category was also relatively significant, reaching 57.62%, despite a significant decline. Other categories that experienced a vast decline were wetlands and vegetation, 7.81% and 57.62% respectively.

The prediction results using the CA-Markov model for 2039 are indicated in Fig. 4, where there is an increase in the built-up area to 29,923.20 ha or an increase from 2019 to 95.11% over 20 years. LUC changes that reduce land porosity, such as from agricultural land (vegetative) to non-agricultural (non-vegetative), and from open land to cemented land, would reduce the water infiltration into the soil. The sub-watersheds of the Krueng Peusangan watershed which are categorized as very critical are in the sub-watershed of Tawar, Krueng Ceulala (0.644%), critical (5.79%), mildly critical (10.21%), begin critical (25.0%) and good and natural normal (57.98%). The upstream area, which has a critical category, is located in the Lut Tawar and Krueng Ceulala sub-watershed. The transition area from the watershed is located in the Teupin Mane and Kreng Simpo sub-watershed.

3.2 Discussion

LUC changes between 2009 and 2019 with the highest percentage were indicated in the built-up area category. In general, changes in the land to built-up areas are caused by increased population and activity [23,24]. Drastic changes have also occurred in agriculture indicating rapid increase trend. In general, this land represents a transformation from the vegetation category. The decline in vegetation will decrease the value of ecosystem services, in which the category of vegetation or forest has the most significant role [25,26]. Decreasing vegetation around urban areas will also cause the urban heat island (UHI) phenomenon. It requires the right strategy to control ecosystem services value adequately [27].

If this pattern of change is applied for future predictions; in 2039, the pattern of change is projected to indicate similar pattern, where the agriculture and built-up areas will proliferate, thereby decreasing ecosystem services' value and the emergence of an urban heat island in several urban areas, such as in Lake Laut Tawar and the northern part of the watershed [10,27].

Water infiltration in a watershed is strongly influenced by rainfall, slope, soil type, and land use. Water absorption will decrease if there is a LUC change from forest to residential or another category.

If that happens, it will cause the protection of water resources to decrease [11]. With increasing population and LUC changes without regard to conservation rules, groundwater absorption will be disrupted. It is related to the curve number value, which has increased runoff to decrease the volume of savings [18].

The area of Krueng Ceulala and Lut Tawar are categorized as significantly critical watershed. The area comprises a residential category (built-up area), wet/dry agricultural land, plantations, and livestock. Land that was once a forested area or watershed has turned into a non-forested area. As a result, the area used to absorb large amounts of water has decreased due to LUC changes [10]. In order to maintain the availability of groundwater, it is deemed pivotal to improve the absorption zone. If the watershed is in good condition, it can store water, especially forest land (vegetation) and green open space. Nevertheless, the LUC category of vegetation (secondary agriculture and livestock), water bodies (rivers, ponds) and bareland (accessible to erosions) are classified as vulnerable areas [28].

LUC that does not follow sustainability will affect the environment and humans [29]. Landscape patterns present the long-term results of interactions between human and natural activities that reveal ecological conditions, spatial variability characteristics and environmental problems in watersheds [30]. Differences in LUC from one place to another additionally affect water infiltration because the response of each LUC to rainwater falling on the ground is different [31,32].

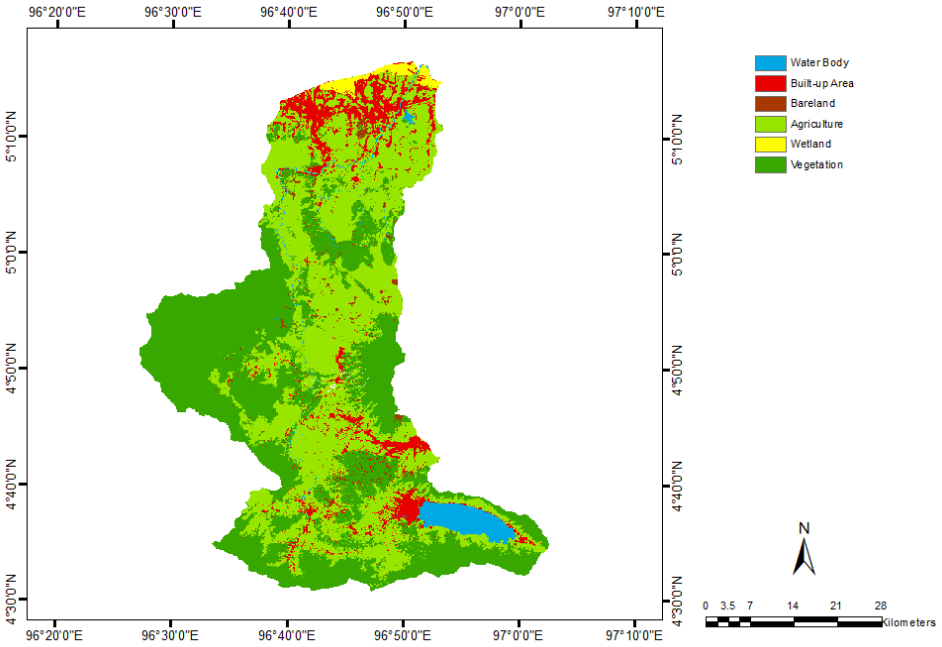

Figure 4. LUC prediction for 2039

4. Conclusion

Between 2009 and 2019, there have been LUC changes patterns in the Krueng Peusangan watershed in Aceh. The most significant change in the area is in the agriculture category, followed by vegetation and built-up area. However, in terms of percentage, the most significant increase occurred in the built-up area with 61.88%.

In addition, the LUC changes also result in decreasing watersheds. LUC predictions for 2039 indicate that the area has been more built up could decrease the vegetation thereby compromising the water infiltration. Upon addressing this issue, an appropriate policy is required since the initiation of conservation program thereby saving the vegetation and encouraging the watershed optimal function.

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