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SPATIAL AND TEMPORAL PATTERN OF SOIL CONSERVATION IN MOUNTAIN ECOSYSTEM: CASE STUDY OF PATUHA MOUNTAIN, WEST JAVA - INDONESIA

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ABSTRACT: The Patuha Mountain area located 50 km south of Bandung City and the upstream of the longest river in West Java, The Citarum River. 12% of the Patuha Mountain area categorized as the steep slope area (>25º). Agriculture and plantations on steep slope locations require appropriate soil conservation methods to reduce erosion rates and avoid the threat of landslides. Land use in The Patuha Mountain area dominated by tea plantations, paddy fields, and various agricultural commodities such as coffee, corn, scallion, and beans. The objective of this study is to identify the spatial and temporal patterns of soil conservation applied by farmers from 1990 to 2018 and project it to 2036 to understand the possible impact in the future. The scenario used in the analysis is the Business as Usual (BAU) scenario. The method used to model the changes in agricultural land use is Cellular Automata - Markov Chain by various driving factors, such as distance from the road, river, settlements, forests, and percent slope. The slope and other driving factors are then correlated with agriculture land to identify soil conservation methods and later validated by field survey. The results indicate that the spatial pattern of soil conservation methods carried out by the community is closely related to slope conditions and the changes in agricultural land caused by development pressure and type of commodities planted by farmers. Agricultural land on <15% slope adopt chemical and vegetative conservation methods, while agricultural land on >40% slopes adopts mechanical, vegetative, and chemical conservation method.

Keywords: Soil conservation, Agriculture, Spatial and temporal pattern, Markov chain

1. INTRODUCTION

Erosion is the loss of land or parts of the land from a place by wind or water [1]. On a large scale, erosion is a potential landslide disaster that can threaten human life and also capable of damaging facilities and community buildings in various locations. The impact of erosion indicated by the loss of nutrients located in the topsoil caused by the force of water-worn away and removed various soil materials, thus resulting in reduced soil productivity [2].

Resisting high soil loss rates and Reducing the impact of damage due to erosion requires soil conservation activities [1]. Based on this, in order to avoid the negative impacts of soil erosion and prevent significant loss, soil conservation activities are needed not only to prevent disasters but also to increase productivity by optimizing the use of soil in agricultural sector. The importance of soil conservation activities is inseparable from land-use conversion activities and physical aspects that drive the process itself. The relationship built between soil conservation and land use conversion illustrates the importance of information on future land use projections or future trends from known baseline or current activities for a reevaluation of current conservation planning and analysis that have been carried out by stakeholders in the research area.

Increasing developments in society tend to stimulate land conversion as a complex process of supporting human activities in certain regions. The process mentioned will lead to the escalation of the erosion process that will cause harm and disadvantage so that land use planning and erosion management are needed to avoid significant losses. Therefore, the application of soil conservation needs to be carried out and examined as a solution to problems caused by degraded soil.

The selection of the Patuha Mountain area as a research area is because of the existence of physical characteristics such as steep slopes and high rainfall intensity and social processes that could potentially cause disasters. Social factors such as population growth and economic factors often lead to changes in land use. Studies show the increasing population number and changes in population structure inevitably led to land-use conversion [3], while numbers of socio-economic factors influence its change like shifting cultivation, increasing demand for forest and farm products and migration [4], to which can also deliver pressure to soil resulting in landslides disaster and followed by major loss or costly damage. The Patuha Mountain Area captured the ecological processes of erosion and its relation to human aspects such as agriculture and hazard. Based on the previous description and the occurrence of landslides and land use, it is necessary to review conservation actions in the research area, especially conservation of soil in the agriculture of the Patuha Mountain area.

2. MATERIALS AND METHODS

2.1 Research Area

The Patuha Mountain area is part of the administrative area of Bandung Regency, West Java. Three Districts included in the Patuha Mountain Area, namely Ciwidey, Rancabali, and Pasirjambu Districts. Astronomically, the Patuha Mountain Area located between 107°12" E - 107°30" E and 7°6" S - 7°12" S.

The Patuha Mountain covers an area of 43,642 hectares. The Patuha Mountain region which consists of 3 Districts then divided into 22 villages. The Majority of Residents in The Patuha Mountain Area derive their livelihood from agricultural activities or best known as farmer's livelihoods. Our research area is also known for its agricultural products such as tea and coffee, reaching 550 ton production for coffee in 2017 [5]. The regional policy also states that in 2007 Ciwidey sub-district was set to be an agropolitan area through Ciwidey Agropolitan Masterplan, thus confirming the functionality of the research area [6].

The Patuha Mountain area is still parts of the upstream zone of the Citarum watershed and followed by the physical condition of a relatively steep slope. The slope of the Patuha Mountain area classified into three classes, namely <15%, 15-40%, and> 40%. When viewed from Fig. 1, the dominant steep area is on the Southeast side of the Patuha Mountain Region. The slope class that dominates the research area is class 15-40% with an area of 21,714 Ha or about 54% of the total area of research, while the slope class with the smallest area is a slope class of 40% which has an area of 8,179 Ha or 20% of the area scattered research.

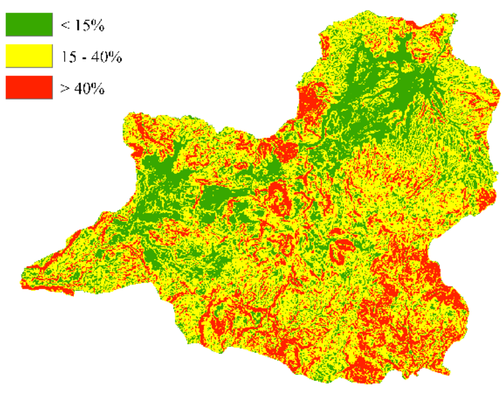

Fig. 1. Slope map of the Patuha Mountain area

2.2 Data and variables

The variables used to analyze and predict land-use changes are land use of 1990, 2000, and 2018, slope, distance from the road, distance from the river, distance from the forest, and distance from the settlement. Landsat satellite imagery was used in our research because of its reliable archive and rich collections spanning from 1972 to recent years globally, with 30 m resolution freely available [7]. The need for an extended period of data in our research leads us to use Landsat 5 and 8 for land-use variables. The gap in data availability solved by implementing different Landsat imagery because Landsat 5 imagery is only available up to 2012, while Landsat 8 starts from 2013. Landsat 5 was used for deriving land use data in 1990 and 2000. Landsat 8 imagery is used for land use data processing in 2018. Other thematic data such as slope, distance from the road, distance from the river, distance from the forest, and distance from the settlement were used as the driving factors for changes in land use.

Land-use data and slope data were overlaid based on recent data to determine survey points. Stratified Random Sampling is used to identify the sampled points; thus, population classification is applied based on previous overlaid results. The number of samples is determined by a random selection system [8], and a total of 30 points samples is randomly selected in three sub-districts in the Patuha Mountain Area: Rancabali, Pasirjambu, and Ciwidey District.

2.3 Data Processing

In processing land use data, the initial step taken was to visually interpret the imagery to produce land use maps in 1990, 2000, and 2018, to first acquire the information of land-use changes in 1990 to 2018. Visual interpretation with Landsat 5 and Landsat 8 was done in natural color composite bands of each Landsat image; 321 and 432 respectively, to identify vegetation and other land use. The national classification system was used to classify various land use in our research area, and 11 class was identified, as seen in Table 1.

Land-use maps of 1990 and 2000 were used for land-use modeling in 2018. The land-use model in 2018 was tested with the kappa method to determine the accuracy of the predicted results. Kappa validation is done by comparing the 2018 land use prediction from IDRISI software with visually interpret 2018 land use maps. The kappa value threshold, according to Landis [9], is K> 0.75 shows an excellent agreement, 0.4≤ K <0.75 shows a pretty good agreement and K <0.4 indicates a weak agreement. The expected kappa value is ≥75% if it is less than this number; the data repair process must be carried out until it reaches ≥75%. After we obtained the appropriate validation value, then we can proceed with predicting land use in 2036 with 2018 as the base year input. The year 2036 was selected for the upper threshold based on the Regional Spatial Plan (RTRW) Bandung Regency which applies from 2016 to 2036.

We used the Markov Chain-Celular Automata model with five driving factors to predict and project the land use in 2036, which is: the distance from the road, the distance from the river, the distance from the settlement, the distance from the forest, and slope. Variables data was Processed using ArcGIS 10.5, and Idrisi Selva Software was used to analyze land-use changes and to perform the accuracy test. The driving factor variable is calculated using the Euclidean distance method to produce distance from plantation and agriculture. Euclidean distance is the physical distance in two or three-dimensional space to multidimensional space [10]. The results of the field survey are used as a basis for determining land conservation parameters and then used to model soil conservation on the land use map.

3. RESULTS AND DISCUSSION

3.1 Land Use Changes

Land use in 1990, 2000, and 2018 was used as the basis for analyzing land-use changes for the past 28 years. Land use in the Patuha Mountain region in 1990, 2000, and 2018 dominated by the use of plantation and agricultural land as a whole. Land use in the Patuha Mountain area in 3 Period Year shows that almost all land uses continue to change each year. Significant changes in land-use changes that can be observed from 1990 to 2018 are the plantation and primary forest, resulting in increasing 14,767 Ha of plantation and the declining 4,086 Ha of primary forest in 2018 (Table 1).

Significant changes occurred on the south and southeast side of the Patuha mountain area. The central part of the Gunung Patuha area in 1990 was only a small portion of open land, which was 6 ha. However, in 2000 open land increased significantly to 303 ha. The changes show that in 1990-2000 there had been a lot of land clearing, which would be converted into another land, and it could be proved in 2018 that the land had changed into plantation land.

Table 1. Land use area in the Patuha Mountain

Land Use	Area (ha)		
	1990	2000	2018
Primary Forest	5.068	4.828	4.087
Secondary Forest	5.138	5.004	5.030
Forest Plantation	5.099	5.180	5.662
Shurbs	892	873	183
Plantation	13.864	13.894	14.768
Settlement	1.693	1.752	1.817
Water	66	66	66
Dryland Agriculture	1.679	1.647	2.094
Dryland Mixed Agriculture	2.124	2.137	1.910
Paddy	4.450	4.395	4.450
Bare Land	6	303	12

Source: Analysis Result (2019)

The decreasing rate of Plantation and agricultural land is observed from 1990 to 2000, and this is likely to occur because of the impact of the monetary crisis that occurred in that period in Indonesia. In 1997 the industrialization process shifted the agricultural sector resulting in reduced production of primary commodities produced by the agricultural sector so that Indonesia had to import 9 million tons of rice [11]. In 2000-2018 there was an increase of plantation, dryland agriculture, and paddy area. Significant changes occurred in plantations and dryland agriculture. The changes happen because according to the community, plantations and dryland agriculture has a higher economic value compared to rice fields. So that many people use the land as dryland farming compared to rice fields.

In this study, the prediction of land use in 2018 was carried out with an accuracy test with actual land use in 2018 using kappa validation. K standard values show results of 0.9082 or 90%, which indicates a high level of accuracy (>75%). High Accuracy test results confirm the model to continue projecting for land use in 2036.

Modeling of land use in 2036 in the process requires the influence of driving factors. The driving factor is the variables used to estimate the probability value of each pixel in the research area. The driving factor estimates the probability value of each pixel to remain or change to another element. Each variable is classified and scored to determine the value of compatibility for plantation and agricultural land use. The variables used are the distance from the road, distance from the river, distance from the settlement, distance from the forest, and slope. Closer the area is to roads, settlements, and forests show that the land is highly prospective to change, while the more it located closer to the river indicates that the land has little chance to change and the more level or flat the land is, it is more likely to change.

Modeling of land use in 2036 is carried out with Business as Usual scenario. BAU scenario refers to the condition given in a specific period without any policy applied or regulation intervention [12], which can cause the model to behave differently with various base years or starting points. Modeling of land use in 2036 was used as a reference in determining the spatial distribution of soil conservation methods applied in the 2036 prediction model. It can be seen in Fig. 2, in 2036, results predicted that there would be a significant change in the area and distribution of land use; however, plantation and agricultural land are still the dominant class in the region. Changes often occur within the area nearer to roads and directly adjacent to the forest area. Land use that experienced the most significant increase was dryland agriculture reaching 2,871 Ha or 7% of the total area of research. Meanwhile, land use which experienced the most significant decline in 2036, was a primary forest, which was 2,944 Ha.

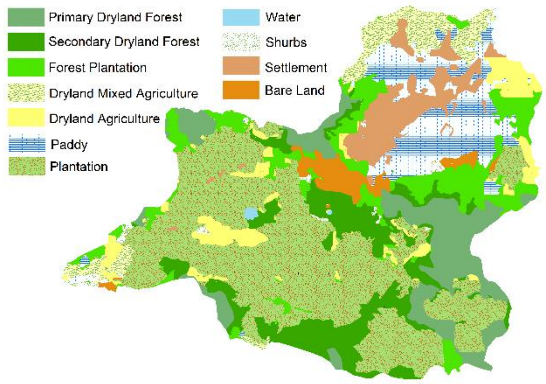

Fig. 2. Land use map in 2036

Figure 3 shows a graph of plantation and agricultural area in 2018 and 2036 in the Patuha Mountain Area. In 2036 results predicted that the area of plantations, mixed dryland agriculture, and paddy fields decreased. However, dryland agriculture experienced a significant increase. This change in the area can cause changes in the area of land conserved in 2036, assuming the physical condition of the slope is fixed.

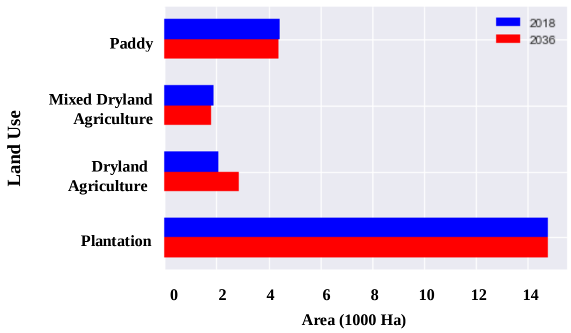

Fig. 3. Plantation and agriculture land area in 2018 and 2036

3.2 Soil Conservation

Vegetative, mechanical, and chemical soil conservation methods are applied by the community on plantation and agricultural land in 2018. However, the community does not only apply one conservation method in each field but is divided into two, namely a combination of two soil conservation methods (vegetative and chemical) and combinations of three soil conservation methods (vegetative, mechanical, and chemical). The combination of the two methods is used for plantation and agricultural land on slopes <15%, while the combination of the three methods is used for plantation and agricultural land on slopes between 15% and 179% degree. Plantations and agriculture that are on relatively steep slopes (15% - 179%) have a higher risk of landslides, so conservation activities carried out must be supplemented with mechanical conservation methods to achieve stronger soil structure and reduces the risk of landslides.

In the Patuha Mountain Area, soil conservation with the use of a combination of three methods is the most dominant one, which is an area of 16,005 Ha or 69% of the total area conserved (Table 2). Soil conservation using a combination of three methods requires a higher cost than soil conservation using two combinations. However, using a combination of three methods on steep slopes can better protect the land to avoid landslides.

Table 2. Land Area Conserved in the Patuha Mountain Area in 2018

Soil Conservation Method	Area (Ha)	Percentage (%)
Vegetative and Chemical	7.205	31
Vegetative, Mechanical, and Chemical	16.005	69

Source: Analysis Result (2019)

The local community has conducted several means to implement vegetative conservation methods, i.e., by using crop residues, using cover crops, and crop rotation. The method of vegetative soil conservation using plant residues is carried out in the form of mulch which is spread over the surface of the soil. Mulch can be in the form of organic and inorganic (Fig. 4). Organic mulch is like the remains of plants or straw, while inorganic mulch is made of synthetic materials such as plastic. Vegetative soil conservation method using plants to cover the topsoil is done in three ways, by using low soil cover plants (grasses or vines), medium ground cover plants (shrubs), high cover crops (trees). Crop rotation as a vegetative conservation method in the Patuha Mountain Area is identified with three patterns, including all-season paddy fields, paddy to vegetable crops, and all-season vegetables crops.

Fig. 4. Organic mulch and inorganic mulch

Mechanical conservation methods are conducted by the local community in several means, including by making *guludan*, which is a pile of dirt or soil, trenches, terrace, *rorak*, which is a dead-hole to trap and absorb water into the soil and accommodate sediments, and irrigation. Mechanical conservation method implemented by making *guludan* is done by making soil piles, the size of it is determined by the type of plant and the structure of the soil. Trenches are carried out in order to accommodate or channel surface flow. Trenches are usually made on areas with long slopes. The terrace is made by cutting contour lines which usually carried out on land that has a relatively steep slope (Fig. 5). There are two types of terraces, which is wide-based terrace and terrace stairs or bench terraces.

Fig. 5. Mechanical soil conservation method by making the terrace

The mechanical soil conservation method by making *rorak* is done by making a hole between plants. Large *rorak* varies, but usually, *rorak* has a depth of 50 cm. *Rorak* is used to store plant debris, which can later be used as organic fertilizer; *rorak* can also be used to hold and absorb water. Irrigation Method is executed to provide and regulate water (Fig. 6). Irrigation channels are made to irrigate plants so that the plants get enough water supply. Irrigation channels are usually used on agricultural wetlands so that the plants remain submerged in water achieving no shortage of water supply.

Fig. 6. Mechanical soil conservation method by making irrigation

Several chemical conservation method carried out by the local people of Mount Patuha is by providing chemical fertilizers such as Phonska, Triple Super Phosphate (TSP), Zwavelzure Ammoniac (ZA), urea, Potassium Chloride (KCl), ZN, and kieserite. The content in each fertilizer is very diverse, such as nitrogen, carbon, hydrograph, oxygen, phosphate, potassium, sulfur, calcium, magnesium, and sulfur.

Soil conservation in the Patuha Mountain Area in 2036 is predicted to continue using two types of combine methods, namely a combination of two (vegetative and chemical) and a combination of three (vegetative, mechanical, and chemical) soil conservation methods (Fig. 7). The land-use model in 2036 predicted that plantation and agricultural land in 2036 is still dominating and expanding. Therefore in 2036, the whole region is predicted as having an increased total of conserved soil area by 23,722 hectares or 59% of the total area of the study.

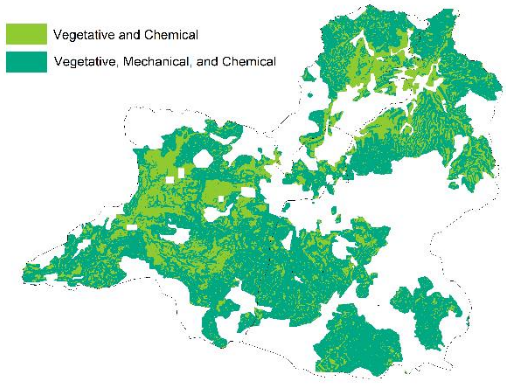

Fig. 7. Soil conservation method in 2036

It can be seen in Fig. 8, is predicted that the combination of three methods of soil conservation used in 2036 will still dominates, which will expands to 16,584 Ha or 69% from all land that is conserved. While the combination of the two methods in 2036 decreased to 7,200 hectares or 31% of all the land that was conserved in the study area. The result shows that plantation and agricultural land on relatively steep slopes (15% - 179%) in 2036 is predicted to increase while plantations and agriculture on relatively flat slopes (15%) decreased., so in 2036 the prediction of combination three methods of soil conservation are mostly carried out compared to the combination of two soil conservation methods.

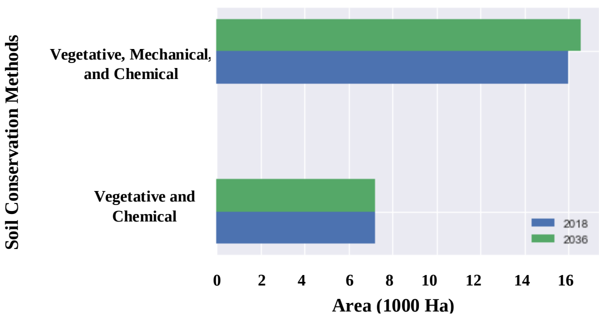

Fig. 8. Soil conservation methods area in 2018 and 2036

4. CONCLUSIONS

Land use in the Patuha Mountain area in 1990, 2000 to 2018, experienced significant changes and plantation, and agricultural land always dominated every year. Changes in the plantation area and agriculture will affect changes in the land that must be conserved. Vegetative, mechanical and chemical soil conservation methods are applied by the community on plantation and agricultural land in 2018, but the community does not only apply one conservation method in each field but rather a combination of two methods (vegetative and chemical) and a combination of three methods (vegetative, mechanical, and chemical). The combination of the two methods is carried out by the community on the plantation, and agricultural land which is on a relatively flat slope (<15%) and a combination of three methods are done on plantation and agricultural land which is on relatively steep slopes (15% - 179%). In 2036 plantation and agricultural land are predicted to increase, resulting in increasing conserved land in 2036. Plantations and agriculture on relatively steep slopes (15% - 179%) increased while plantations and agriculture on relatively flat slopes (<15) decrease, resulting in higher application of three combination methods in our research area rather than two by 2036, this occurs most likely because of the combination of three methods applied on steep slopes that can better protect the soil to avoid landslides and degrade the quality of soil in specific area.

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