Spatial Analysis of Deforestation in Water Recharge Area at the Toyoaning Sub-Watershed as a Drought Mitigation Effort

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Abstract. The groundwater crisis in Kediri District has increasingly felt its effects lately, especially in Sepawon Village, Plosoklaten Subdistrict, which is located in the upstream of the Toyoaning sub-watershed. There were a land cover change and forest conversion in groundwater recharge areas which causes reduced infiltration of rainwater and thus a reduction in groundwater reserves. The objectives of this study are: (1) to determine water recharge areas and water discharge areas in the Toyoaning sub-watershed, (2) to analyze the land cover change, and (3) to predict the land cover. This study uses weighting - overlaying methods for analyzing the variables used for determining groundwater recharge and discharge area. The results showed that forest cover was decreased in the groundwater recharge area, which was indicated as a cause of drought in the study area since September 2017. The area of primary forest lost from 2013 to 2018 is 0.71 km² and the prediction area of primary forest in 2028 is 4.84 km². The forest in the groundwater recharge area is being converted into plantation and shrub/grassland. The government and the community together should be able to maintain the forest area to mitigate drought.

1. Introduction
Regional development in Indonesia is often related to population growth, so much land is changed to meet the needs of the population, which affects the availability of groundwater resources. Especially if there is a change of forest area or deforestation on the upstream of the river and the upper slope of the mountain so that it can result in reduced water absorption into the aquifer. As a result, the phenomenon of water problems almost occurs everywhere in Indonesia, including the drought. Land cover change in the form of deforestation has the potential to increase the impact of droughts, reduced rainfall and disruption of the hydrological cycle also occur in deforestation areas [1]. This situation will get worse when a region constantly experiences below-average rainfall.

Kediri District which is part of East Java Province is located between two mountains namely Wilis and Kelud. The existence of the mountain as a high land that has a forest area serves as a water recharge area, but drought still occurs in Kediri District. Sepawon Village in Plosoklaten Subdistrict is one of the areas experiencing drought. The drought that occurred in Sepawon Village is located at the Toyoaning sub-watershed area. The water resources of residents in the highlands began to dry up. This situation is allegedly due to land cover change in the form of deforestation in the upstream of sub-watershed on the upper slopes of Mount Kelud. A combination of land surface responses and atmospheric feedbacks from historical deforestation has affected the watersheds [2]. The drought in this region was first happened in September 2017 until the beginning of 2019 during the dry season. Head of Kediri regional disaster management agency (BPBD), explained that there is logging of trees in the forest area of Kelud Mountain used for agricultural land and other needs, thus influencing the absorption of water that disrupts the water resources [3]. Deforestation has disrupted the groundwater balance, moreover, this situation occurs in the upstream of sub-watershed areas that should be conserved. Deforestation reduces rainfall interception so that the water cannot be absorbed maximally into the aquifer [4].

Deforestation is environmental problems that occur everywhere including in the Toyoaning sub-watershed area. Forests should always be preserved, but there are changes in forest cover that caused drought in Sepawon Village. There has been a decrease in water discharge from the Clangap and Ringin...
Putih springs in the dry season which has affected the drought of groundwater, because of the forest trees that function to help absorb rainwater into the aquifer layer have turned into agricultural land and other land cover [5]. Reducing forest cover can interfere with rainwater interception into the ground, increase surface runoff, increase the potential for drought in the dry season and reduce relative humidity [6]. Deforestation and change in forest cover to other land covers have disrupted the groundwater balance, especially this situation occurs in the upper slope of Mount Kelud that should be preserved. If groundwater recharge conservation is the main goal, then the presence of trees should be on the middle slope and the upper slope [7].

Analysis of the change in forest cover is needed as a means of drought mitigation or prevention so that the existence of the forest with all its functions is maintained. Deforestation has resulted in changes in land cover that can be observed by analyzing the pattern of changes. The pattern can be used to build a prediction model for future changes in land cover. The method that can be used to predict land cover is Cellular Automata - Markov Chain (CA-MC). Cellular Automata is spatial-based modeling that can predict future conditions from inter-cellular local interactions on a regular grid, where each cell represents land cover. Markov chain in the concept that the probability of an event is determined by the event that directly precedes it and can be used to predict the next event, the probability is often called the transition probability [8]. The choice of using Cellular automata markov chain because it can study a simple pattern to a complex pattern with simple principles. The land cover model using CA-MC can be used to predict the extent of forest cover in the Toyoaning sub-watersheds so that it can be used for policy analysis related to the groundwater drought mitigation.

2. Methods
The research stage starts from determining the topic and searching the literature to develop research methods. The drought in Sepawon Village is located in the upstream of Toyoaning sub-watershed, according to local government agencies, the drought is due to deforestation and changes in forest cover to other land covers. This research is conducted by distinguishing water recharge and discharge areas, then analyze changes in land cover at upstream of Toyoaning sub-watershed that occurred in 2013 (before the drought) and 2018 (during drought), then predict the area of land cover for 2028 to projecting the land cover change in the future.

2.1. Distinguish the Groundwater Recharge Area
Identification of water recharge areas using the weighting method. The stages of determining groundwater absorption and discharge zones in this study used parameters including 1) Rock porosity; 2) Rainfall intensity; 3) Land cover; 4) Slopes; and 5) Depth of groundwater level [9]. Each parameter has an influence on water infiltration into the soil which is distinguished by the weight value. Parameters that have the highest weight value are the parameters that most determine the ability of infiltration to naturally add groundwater into the aquifer layer.

| Parameters                  | Weighting value |
|-----------------------------|-----------------|
| Porosity of rock            | 5 Very high     |
| Rainfall intensity          | 4 High          |
| Land cover                  | 3 Sufficient    |
| Slopes                      | 2 Immediate     |
| Depth of groundwater level  | 1 Low           |

Source: Danaryanto, et al. (2007)

The classification of groundwater recharge areas is carried out in classifying groundwater recharge and discharge areas based on their values, which are summing the results of multiplication between the value of the weights and the rank values on each parameter with the following formula.

\[ WRD = (Kb \times Kp) + (Pb \times Pp) + (Sb \times Sp) + (Lb \times Lp) + (Mb \times Mp) \] (1)
2. Analysis and Prediction of Land Cover Change

Supervised classification is a classification method that provides flexibility for computers and humans to classify images independently. This classification uses algorithms to examine several unknown pixels and share them in classes based on grouping histogram [10]. Supervised classification is carried out with the ENVI 5.2 software. Classification of land cover is carried out through interpretation of data on Landsat Satellite Imagery in 2013 and 2018 by dividing into 10 classes of land according to SNI 7645:2010, namely primary forest, secondary forest, seasonal cropland, plantations, irrigated rice field, shrubs/grassland, lava, settlement areas, open pasture and commercial units. The results of the land cover classes were carried out by vectorization and then calculated the land cover area with ArcGIS ArcMap 10.5 software. Predicting the forest area in the water recharge area each of the classification results in 2028 at the Toyoaning sub-watershed using Cellular Automata-Markov Chain with IDRISI Selva 17 software.

3. Results and Discussion

The upstream of Toyoaning sub-watershed is located on the top of Kelud Mountain, while the downstream is in Papar subdistrict, Kediri. Weighting analysis is carried out first to obtain the difference between the recharge and discharge area and then overlaying each parameter. A land cover analysis is carried out only in water recharge areas because this drought is caused by land cover changes in the upstream of Toyoaning sub-watershed which at the upper slope of Mount Kelud. Predicting land cover is also needed to determine the spreading of land cover change.

3.1. Groundwater Recharge and Discharge Area

The determination of the water recharge area is obtained from the assessment of five parameters (rock porosity, rainfall, land cover, slope, groundwater depth) in Toyoaning sub-watershed. The parameter that has the highest weight is the parameter that most determines the ability of water absorption to add groundwater to the aquifer [11]. The rock porosity parameter has the highest weight value because it has a high effect on water absorption. Water recharge areas are characterized by high permeability of rock so that they can slip off the water. The area that has a high annual rainfall can receive a lot of rainwater to absorb. The area has a land cover that supports water infiltration such as dominated by vegetated open land. The steep slope of an area will make it easier to absorb water. Groundwater depth parameters have a low effect, so the weight is also low [12]. Water recharge areas are characterized by deep groundwater levels so that they can add more water infiltration due to soil conditions that are not saturated with groundwater.

The Toyoaning sub-watershed has an area of 171.02 km². The weighting values can be divided into two types shown in Figure 1, the area of the water recharge area is 66.04 km² while the area of the water discharge area is 104.98 km². The water discharge area has the final value of the weighting result between 37-54. Based on the geology map, the lithology found in this area is dominated by sand and alluvial clays which have hydraulic conductivity values 0.0002 m/day [13]. Rainfall intensity is 2.000-2.500 mm/year. Land cover from Landsat 8 imagery is dominated by settlements and irrigated rice fields, the amount of land developed and water-saturated land can inhibit water infiltration into the soil. Based on data DEM, this area is found in slope condition with undulating to flat, whereas the relatively flat area is at the bottom of the slope which has a slope of 0-10°. The depth of the groundwater level from the surveying is about 0-10 meters.

The recharge area based on the weighting results is located on the upper slope Mount Kelud. This area has a weighting value of 55-64. The lithology found in the study area is volcanic breccias and tuffs
which have gravel-sand sized fragments. Breccia and tuffan have rock hydraulic conductivity values of 0.2 m / day which has a higher porosity than clay [13]. The rainfall intensity is 2.500-3.000 mm/year which is higher than in the water discharge area. Land cover dominated by vegetation so that more leverage in absorbing water. The area with a slope of 20-40° is found in the morphological peak of the Mount Kelud. The depth of the groundwater level is more than 30 meters. Based on this analysis, it is known that the Sepawon village that is experiencing drought is located in the water recharge area of the Toyoaning sub-watershed.

![Figure 1. Water recharge and discharge area in Toyoaning sub-watershed](image)

Groundwater management can be carried out intact which includes groundwater discharge areas and recharge areas. Groundwater discharge areas and groundwater recharge areas have different hydrogeological characteristics so that management functions are also different. Groundwater recharge associated with rainfall percolation across the landscape is strongly influenced by local vegetation and climate characteristics [14]. Management in the groundwater discharge area can be done through careful management involving physical and social components so that groundwater extraction can be controlled.

The drought that had occurred in Sepawon Village, Plosoklaten subdistrict was due to groundwater reserves being unable to the needs of the population, besides that based on data from the PDAM of Kediri District that there were no residents in Plosoklaten subdistrict who used distilled water, so the residents only relied on the availability of groundwater that originated from springs in Plosoklaten subdistrict [15].

3.2. Land Cover Change in the Groundwater Recharge Area

Previous weighting and overlay analysis have divided the Toyoaning sub-watershed area into two areas, water recharge and discharge areas. Then an analysis is carried out on the water recharge area to identify changes in land cover. The results of processing Landsat 8 imagery data from two different years in 2013 and 2018 used to determine land cover changes have indicated a reduction in forest area. Changes in forest area are shown in the map in Figure 2 and differences in the forest area in 2013 and 2018 are shown in Figure 3, based on the diagram it is known that the area of primary forest lost from 2013 to 2018 is 0.72 km².
Figure 2. Land cover change in water recharge area in 2013 and 2018

The forest area, both primary and secondary forests are decreasing. Trees on the slopes of Mount Kelud have been cut down by a sand mining company and a group of irresponsible people. Mount Kelud is an active volcano that last erupted in February 2014, the eruption has released various materials including pyroclastic materials such as volcanic sand. The existence of abundant volcanic sand at the top of Mount Kelud has economic value for mining companies, so they are not reluctant to open forests to mine sand and open a path for sand transportation. This situation resulting in the loss of part of the primary forest on the top of the mountain as shown in Figure 3.

Figure 3. Land cover change in 2013 and 2018

The primary forest area has been converted into shrub/grassland. The secondary forest area has also been converted into agricultural land in the form of plantations and seasonal cropland. Figure 2 shows the area of secondary forest land that has been converted to cropland and plantation, then in Figure 3 that the area of secondary forest has decreased by 7.41 km². Plantation commodities cultivated in the secondary forest area of the Toyoaning sub-watershed include cloves, pineapple, corn, and coffee. Cloves are the leading commodity in the Sepawon village, while pineapple is the leading commodity in the Wonorejo Trisulo village [15].
Figure 4. Condition of plantations in the study area (a) pineapple plantations on sloping hillsides, (b) pineapple plantations on slopes, (c) clove plantations associated with other vegetation, (d) groundwater distribution systems in clove plantation areas

The processing stage with Markov Chain obtained a probability transition matrix from the land cover change in 2013 and 2018. Transitional probability simply means the magnitude of the likelihood of change from one land cover category to another land cover category [16]. The probability of change from one land cover class to another land cover class is shown in Figure 5. Markov analysis produces the value of the transition area that has a probability of change in land cover. Figure 5a shows the probability of a change in primary forest land cover (class 1) having the possibility to change to shrub/grassland (class 6), while secondary forest (class 2) is likely to become open pasture (class 8). Figure 5b shows that primary forests (class 1), secondary forests (class 2) and seasonal cropland (class 3) experience a transition to plantation area (class 4).

Figure 5. (a) Change probability of land cover, (b) Transition area of land cover change

The forest area which was reduced from 2013 to 2018 has resulted in drought. Forests that continue to decrease in the future will have the potential to cause even more severe drought. The prediction in the next stage is through cellular automata-Markov chain using 15 iterations so that the modeling calculation is done every year and resulted in a validation K standard of 0.8002, Kno of 0.8172, Klocation and KlocationStrata of 0.8972. Prediction results in 2028 through cellular automata-Markov chain modeling as shown in Figure 6 there are large changes in primary and secondary forest areas that continue to decrease, while the shrub/grassland, seasonal cropland, and plantation area are increasing. The prediction area of primary forest in 2028 is 5.13 km², while the area of secondary forest is 4.93 km². The
forest area which continues to decrease from the prediction results will occur if no reforestation and forest preservation efforts.

![Figure 6](image6.png)

**Figure 6.** Prediction of land cover in 2028 at the water recharge area of the Toyoaning sub-watershed

Validation is done to test the results of modeling in predicting a case. The purpose of validation in this study is to measure the accuracy of the results of land classification with the actual conditions in the field. Validation is done by field observation or ground check [17]. Field observations were not made in the entire Toyoaning sub-watershed, due to slope conditions and accessibility that is difficult to reach in the Kelud mountain peak area and plantation areas that are limited to the public. The determination of sample location points is done by a simple random sampling method. Field observations using a checklist, GPS (Global Positioning System), and the CarryMap Observer application installed on a smartphone. The ground check map for model validation is shown in Figure 7. There are 59 checkpoints, including 48 suitable points and 11 points that are not suitable for the land classification on the map, then the validity is 81.36%. Thus, the land cover classification has been able to describe the land cover classification in the Toyoaning sub-watershed area.

![Figure 7](image7.png)

**Figure 7.** Ground check map

The primary forest area which continues to decrease turns into grasslands and shrubs because it is included in the degraded forest area. Forest is an initial type of land cover that will always change in the future [18]. Plantation land dominates land that was previously secondary forest. Forest land conversion
has the potential to increase the impact of droughts, reduced rainfall and disruption of the hydrological cycle also occur in deforestation areas [1]. Reduced forest land can be prevented or mitigated by including regulating the development of land cover changes such as tightening the law on Environmental Impact Analysis, prohibiting large-scale deforestation in upstream watersheds, establishing buffer zone areas for deforestation and limited zones for rivers main, monitor and implement the development of river erosion control and build sediment management applications for all types of development [19]. Increase the scale and focus of research and development and innovation investments to reduce costs, improve quality and improve the efficiency of vegetation recovery, taking into account environmental, social and economic factors [20].

4. Conclusions
Forest cover in the water recharge area of the Toyoaning sub-watershed from 2013 has been reduced in 2018. Based on the results of the discussion it can be concluded that the forest land cover change has caused a reduction in water that seeps into the aquifer layer so that this condition results in a drought which happened since the end of 2017 until now during the dry season in Sepawon Village, Plosoklaten, Kediri. Prediction results in 2028 also indicate that the area of primary and secondary forests will be increasingly reduced. The government, the company, and the community, together can protect the forest in water recharge area to mitigate the drought.

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