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# Seasonal Spatio-temporal Land Cover Dynamics in the Upper Brantas Watershed

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**Abstract.** Quantitative assessment for sustainable watershed management is essential. Hydrological parameters such as stream discharge, surface runoff, infiltration, groundwater recharge, and water quality are susceptible to the changes of the components in the river basin ecosystem. Numerous studies have shown that the Land Use Land Cover (LULC) changes such as deforestation, extensive agriculture, urbanization, and mining are recognized as the main factors to changes in LULC, which are related to the changes of the hydrological components of the river basin of all scale. This paper particularly shows the spatiotemporal variability of LULC in the Upper Brantas Basin and the effects on the river discharge variation. We showed that the changes in LULC, particularly cultivated and managed vegetation and urban/built-up area, contributed significantly to the river discharge. Particularly in the Upper Brantas Basin, it was indicated that almost half of the increased river discharge was explained by the increase of urban/built-up and the decrease in cultivated and managed vegetation area.

Keywords: land cover change, seasonal watershed dynamics, river discharge

## 1. Introduction

Water resources condition determines human wellbeing, which leads to the production activities and economic development [1]. Therefore, ensuring good and sustainable water resources management is of critical importance for society [2]. Sustainable water resources management can be reflected in Land Use and Land Cover (LULC) changes. LULC changes are the major determining factor that impacted the ecosystem. These changes have significant effects on climate, hydrology, and biodiversity [3]. Anthropogenic activities had affected the modification of 39 and 50% of the terrestrial ecosystem [4]. Anthropogenic-led LULC changes mainly result from agricultural land conversion, population expansion, and socio-economic development [5]. Therefore, monitoring and examining the LULC changes and feedback are essential for engineers, hydrologists, ecologists, and water resources managers.

Much research has investigated the correlation of LULC changes on water resources conditions (watershed hydrology). However, various studies showed contradictory results [3]. For instance, the general conclusion on forest and water linear relations does not hold for fragmented watersheds and dynamic land-use patterns, especially in tropical developing countries [3], [6]. To understand the intricate relationship, studies have been conducted at spatially diverse scales (plot, watershed, and regional), empirical and physical (lumped and spatially distributed) modeling, and time series analysis in an attempt to isolate LULC changes [3]. To our knowledge, approaches to assessing the LULC changes are usually based on a short period of time, and few consider the seasonal effect of the LULC, especially in tropical countries.

Remotely sensed data, in this case, is satellite imagery, commonly used as a source for observing and analyzing landscape changes. Earth observation by satellite can cover various spatial and temporal scales, making it an efficient approach for LULC mapping. Satellite-based long-term observation provides a consistent and robust mapping over large areas [1]. The use of multiple resources remote sensing datasets can improve landscape classification [7]. Analyzing multi spatiotemporal and resources datasets requires high computational power. The cloud-based computational platform may address the challenges posed.

Several satellite-based land cover products have been produced, e.g., MODIS Yearly Global 500m [8, p. 12], GlobCover: Global Land Cover Map 300m (2009-2010) [9], Copernicus CORINE Land Cover (1986-2018) [10], LUCAS Harmonized [11], Copernicus Global Land Cover Layers: CGLS-LC100 Collection 3 100m (2015-2019) [12]. The Indonesian government released the annual land cover maps provided by the Ministry of Environment and Forestry. In this study, we used the CGLS-LC100 Collection 3 as it has a medium resolution, consistent map, released on a periodical basis, and was already used in many researches by several research groups, e.g., the nature map, Food and Agriculture Organization of the United Nations (FAO).

This study's overarching goal is to quantify 5-year LULC changes and the hydrologic response of the Upper Brantas Watershed. It will contribute to understanding the effect of LULC within the urbanized upper watershed. This study tried to contribute to the following questions: how has LULC changed from 2015-2019, and how does LULC affect the river discharge within the Upper Brantas Watershed. We hypothesize that LULC, especially the amount of urban/ developed area, forest, and agricultural land, play significant roles in altering the river discharge.

## 2. Material and Method

This study is located in Brantas Basin, East Java Province, Indonesia. The Brantas is one of the important rivers in Java Island, with a length of 320 km and a total catchment area of 11,050 km$^2$, thus, making it the second-largest river of Java [13]. Its catchment covers about 35% of the total area of East Java Province. The study focuses on the Upper Brantas Basin (Figure 1), with a total catchment area of about 2190 km$^2$. The annual average rainfall is 2,263 mm/year (2003-2012), with the lowest annual rainfall reaching 1,736 mm/year while the highest is 3,895 mm/year. About 89% of the rainfall falls during the wet season. The Upper Brantas is categorized as type C climate based on Schmidt-Fergusson classification, meaning equal wet and dry months in a year. The Upper Brantas Basin is populated by approximately 3.7 million residents (2019 census). The rapid population has altered the landscape and added pressure on ecology, especially water management. Water resource conservation aims to maintain the continuity of water resources' carrying capacity, capacity, and function. Water resources protection and preservation, water preservation, water quality management, and water pollution control with reference to the pattern of water resources management assigned to each river basin.

LULC data for 2015-2019 were obtained from the Copernicus Global Land Cover Layers: CGLS-LC100 Collection 3. It is a consistent land cover map for the entire globe derived from the PROBA-V 100m time series, a high-quality land cover training database, and several ancillary datasets. The accuracy reaches 80.2+/-0.7% at a global and continental scale. It has continuous vegetation fields that provide proportional estimates for vegetation cover for all base classes [12]. The CGLS-LC100 Collection 3 dataset was retrieved from Google Earth Engine [14]. The workflow is as follows: import the image collection, define the study area, define the period, select the classification and filter the data, reduce the image collection to image, clip the image, and export to Google Drive. The elevation data was retrieved from the DEMNAS product of the Indonesian Geospatial Agency. The DEMNAS was generated based on several datasets, i.e., IFSAR (5m resolution), TERRASAR-X (5m resolution), ALOS PALSAR (11.25m resolution), and mass point dataset from the stereo-plotting. DEMAS has 0.27 arcsecond resolution with vertical datum EGM2008 [15]. The river data was downloaded from Indonesia geoportal (https://tanahair.indonesia.go.id/portal-web).

The catchment was delineated by using WhiteboxTools [16] in QGIS [17]. WhiteboxTools is a geospatial data analysis package that contains more than 480 tools for processing different types of geospatial data. The workflow of generating the catchment with WhiteboxTools is as follow: reproject the DEM into projected, burn river in DEM with FillBurn tools, generate D8 Pointer raster, fill sinks, define the outlet, calculate the flow accumulation, snap pour point to the raster, delineate the catchment with Watershed tool, convert raster to polygon, and fix the geometries and clip the rivers. The 5-year river discharge dataset derived as inflow to the Sengguruh reservoir was obtained from Perum Jasa Tirta 1, a state-owned water company. The distributions of seasonal variation of river discharge were explored with a histogram.

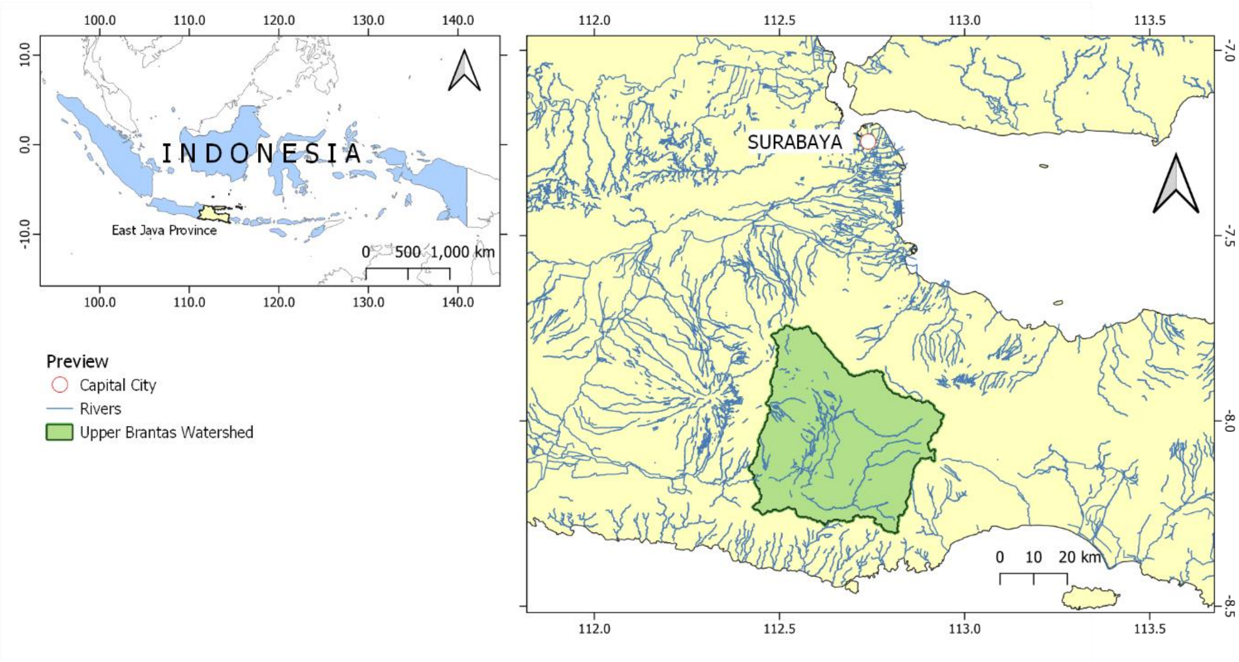


**Figure 1.** Study area

## 3. Results and Discussion

On the baseline of the study period (2015), based on the CGLS-LC100 Collection 3 dataset, the Upper Brantas Basin is predominantly covered by closed forest with evergreen broadleaf, which encompassed around 44.598% of the total area, followed by cultivated and managed vegetation (22.257%), and urban/ built-up (16.980%) (Table 1). The cultivated and managed vegetation had experienced the highest area decrease in 2019 with a loss of 2.279 km$^2$ (22.154%). The urban/built-up area had the highest total percentage increase between 2015-2019, increasing 1.081 km$^2$. All of the forest categories (closed forest evergreen and open forest evergreen-other) followed a decreasing trend in small changes, with total loss of 0.147 km$^2$, 0.138 km$^2$, and 0.462 km$^2$ loss of area, respectively. The LULC developments of the Upper Brantas Basin are presented in Figure 2. The dynamics are presented on an annual basis, which started from 2015 to 2019. Detail on the changes can be inspected in Figure 3.

**Table 1.** LULC area per category (km$^2$ and %). Urban area increases during the study period, the cultivated & managed vegetation, closed forest and open forest (all categories), and permanent water bodies decrease.

| Value | Categories | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|
| 20 | Shrubs | 0.147<br>(0.007%) | 0.147<br>(0.007%) | 0.147<br>(0.007%) | 0.147<br>(0.007%) | 0.147<br>(0.007%) |
| 30 | Herbaceous Vegetation | 2.613<br>(0.118%) | 2.652<br>(0.120%) | 2.652<br>(0.120%) | 2.652<br>(0.120%) | 2.652<br>(0.120%) |
| 40 | Cultivated and managed vegetation | 491.018<br>(22.257%) | 489.830<br>(22.203%) | 489.427<br>(22.185%) | 489.083<br>(22.170%) | 488.739<br>(22.154%) |
| 50 | Urban / built up | 374.597<br>(16.980%) | 374.685<br>(16.984%) | 374.951<br>(16.996%) | 375.147<br>(17.005%) | 375.678<br>(17.029%) |
| 60 | Bare / sparse vegetation | 0.511<br>(0.023%) | 0.511<br>(0.023%) | 0.511<br>(0.023%) | 0.511<br>(0.023%) | 0.511<br>(0.023%) |
| 80 | Permanent water bodies | 5.629<br>(0.255%) | 6.699<br>(0.304%) | 6.748<br>(0.306%) | 6.365<br>(0.289%) | 6.247<br>(0.283%) |
| 90 | Herbaceous wetland | 8.222<br>(0.373%) | 7.750<br>(0.351%) | 8.065<br>(0.366%) | 8.811<br>(0.399%) | 8.959<br>(0.406%) |
| 112 | Closed forest, evergreen broad leaf | 983.883<br>(44.598%) | 983.834<br>(44.596%) | 983.707<br>(44.590%) | 983.756<br>(44.593%) | 983.736<br>(44.592%) |
| 116 | Closed forest, not matching any of the other definitions | 64.880<br>(2.941%) | 65.627<br>(2.975%) | 65.548<br>(2.971%) | 65.450<br>(2.967%) | 65.430<br>(2.966%) |
| 122 | Open forest, evergreen broad leaf | 97.434<br>(4.417%) | 97.424<br>(4.416%) | 97.375<br>(4.414%) | 97.355<br>(4.413%) | 97.296<br>(4.410%) |
| 126 | Open forest, not matching any of the other definitions | 177.166<br>(8.031%) | 176.940<br>(8.020%) | 176.970<br>(8.022%) | 176.822<br>(8.015%) | 176.705<br>(8.010%) |

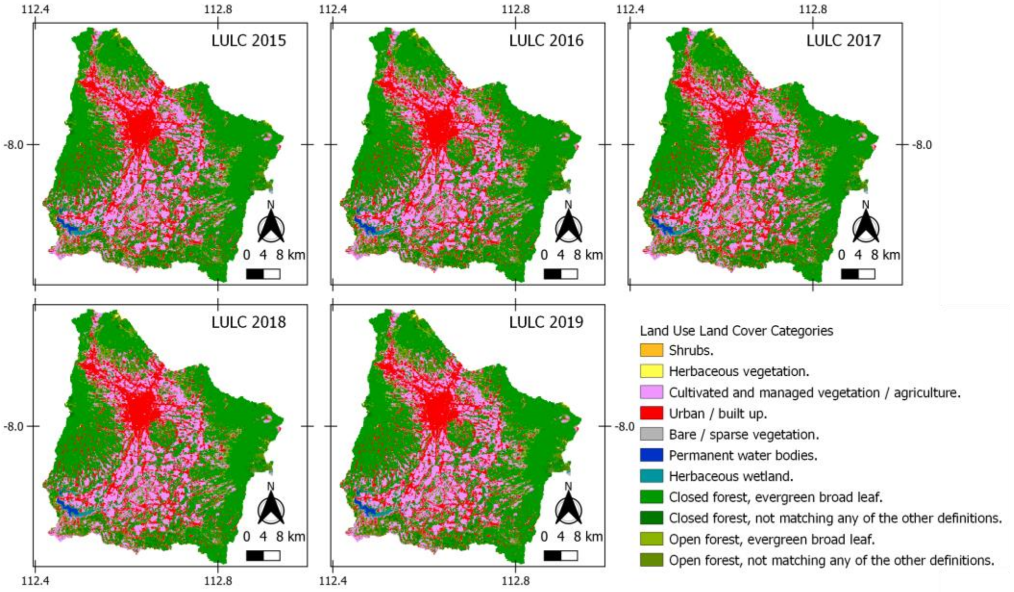


**Figure 2.** LULC based on Copernicus Global Land Cover Collection 3 with 100m resolution. The five years land use land cover dynamics are presented. The LULC face colour scheme is based on the Copernicus Land Use standard.

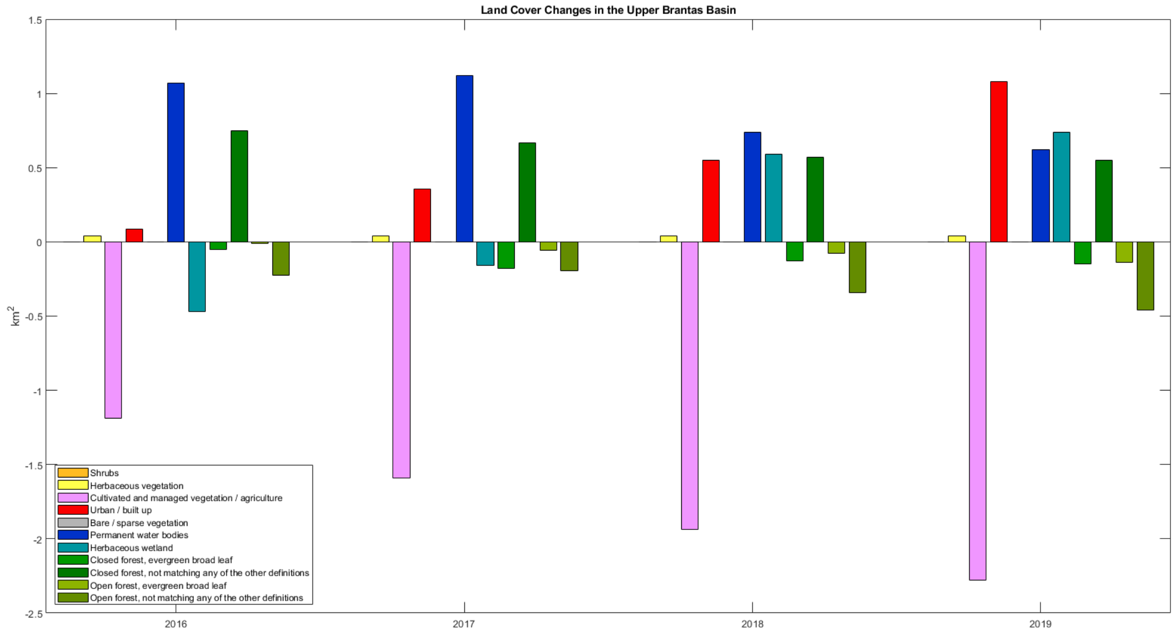
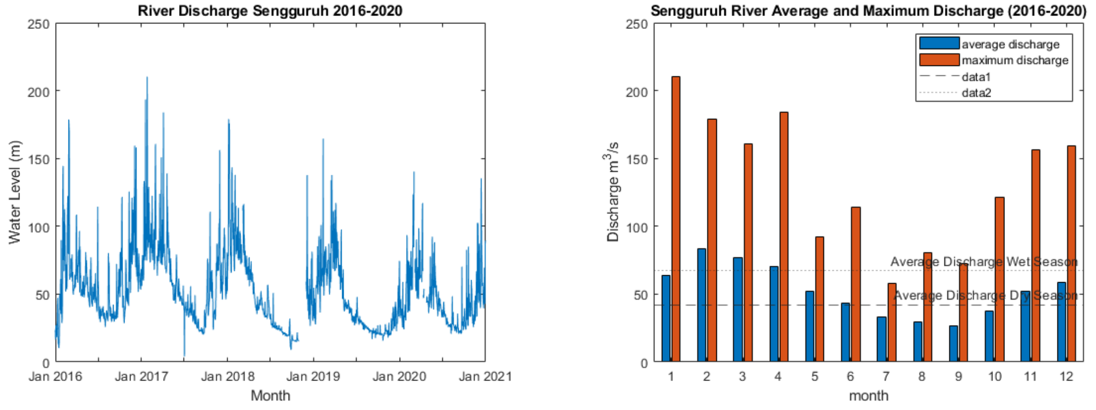


**Figure 3.** Land use land cover evolution over the 5-year observation. The LULC changes are based on the year 2015.

The seasonal trend of the river discharge can be observed in Figure 4 and Figure 5. Figure 4a clearly shows the seasonal variation and the climate variation difference every year. The wettest year was observed in 2017, while the driest was in 2020. The peak river discharge in comparison with the average value is notable. The peak discharge is around two times larger than the average one (Figure 4b). The variation of the discharge and the distribution is easier to be observed in the histogram as in Figure 5. The mode of peak river discharge is around 40-50 $m^3/s$ for all periods. The mode value is equal to the average discharge during the dry season. When compared with the averaged discharge of all of the observation periods, the value is lower. The mode value of the averaged discharge was around 20-40 $m^3/s$. This shows the effect of the seasonal variability on the discharge and the peak discharge of the study location.



a.

b.

**Figure 4.** River discharge dataset from 2016-2020 in the downstream (Sengguruh station). The pattern of the wet and dry seasons can be seen in Figure 4a. The average and maximum discharge of each station are illustrated in Figure 4b. The high discharge is notable during the wet season.

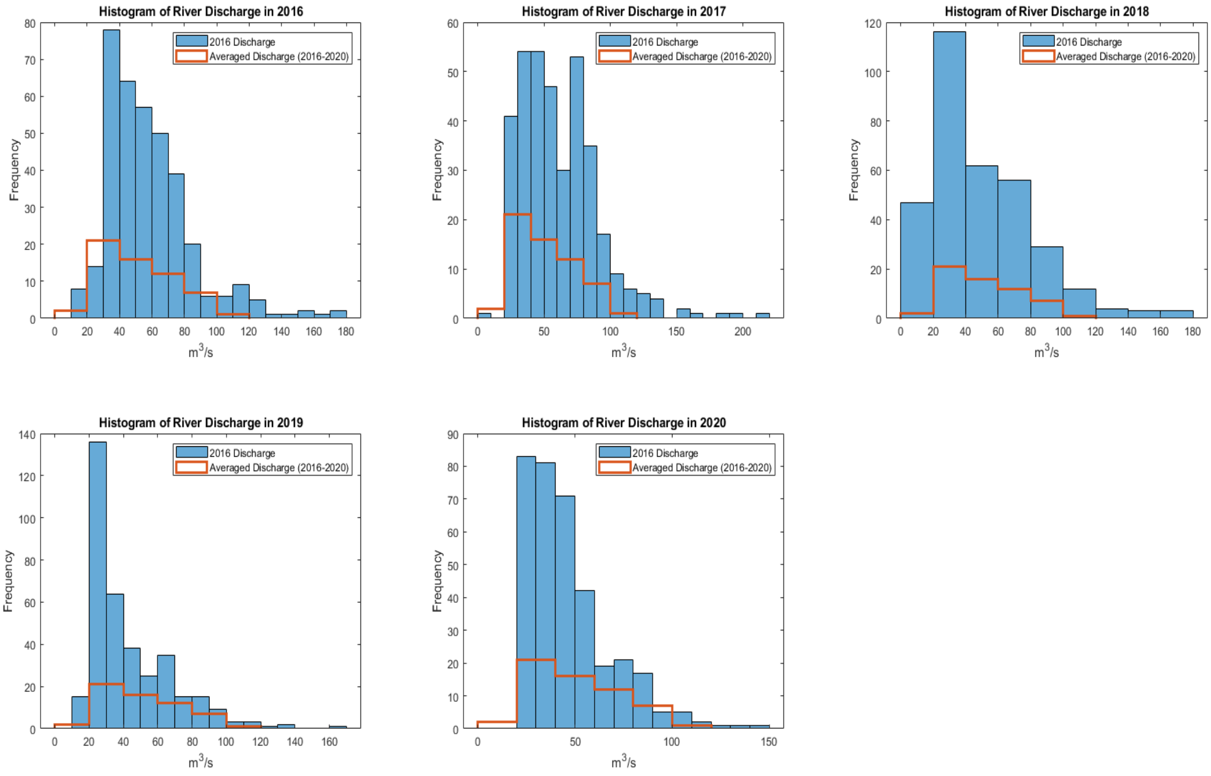


**Figure 5.** Histogram of river discharge during the observation period of 2016-2020. The river discharge of the observation period is shown in filled blue colour, while the average river discharge during 2016-2020 is shown in the red line. The figure shows the discharge variation in every observation period in comparison with the averaged value.

In general, urban/ built-up area increased in every observation period along with the decrease of forested area and substantial decrease of cultivated and managed vegetation. The most notable urban/ built-up area increase was in 2018-2019, where the growth was 196%, growing from 0.55 km$^2$ to 1.081 km$^2$ concerning the 2015 baseline. In the perspective of forested area decrease, the most observable change was for the open forest-other, which lost around 0.462 km$^2$. However, the impact is negligible since the total area percentage is quite low (8%). Compared to the observed river discharge, the decreased area of forested area (closed evergreen forest) is not likely correlated to the increase of the river discharge.

It is because the total area percentage of the closed evergreen forest tended to remain consistent (44.594% ± 0.03%). Statistically, the correlation of changes in the closed forest is also relatively low ($R^2$=0.0002). On the other hand, the increase of urban/ built-up exhibited a positive correlation with the increase of river discharge, similar to the decrease of cultivated and managed vegetation. With the $R^2$ value of 0.496, it is indicated that a 49.6% increase in river discharge in the Upper Brantas Basin was explained by the increase of urban/ built-up area.

The increase in cultivated/ managed vegetation area, to some extent, played a role in a decreasing river discharge trend by 69.4%. The trend is based on the observed river discharge from 2016-2021 and LULC changes in 2015-2020. As shown in this research, the correlation of LULC category per km2 with river discharge is also observed in the study by Lei, et al., 2018 [18]. Due to the difference in the available dataset, the correlation was made from 2016 through 2020. The correlation of the three LULC categories is explained in Figure 6.

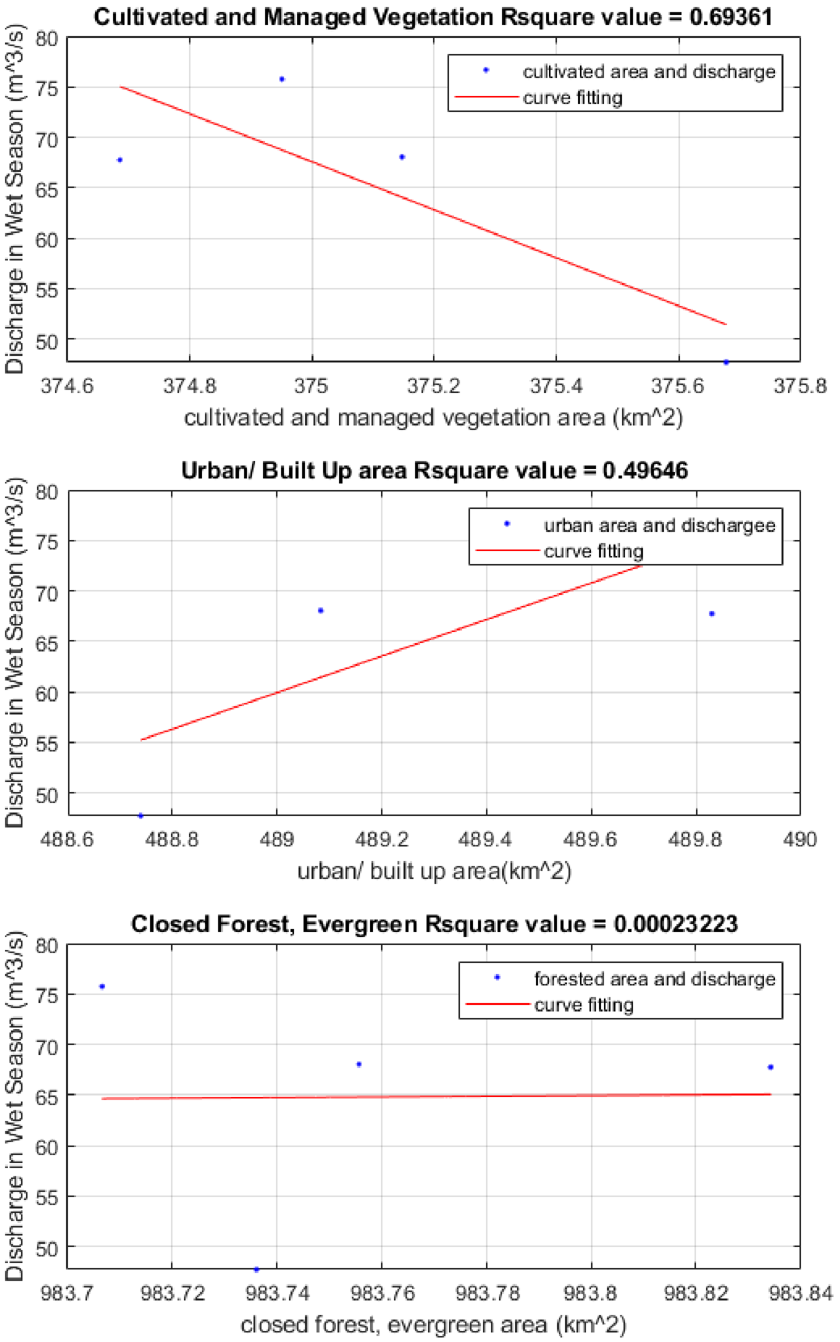


**Figure 6.** LULC variable per km$^2$ in comparison to river discharge.

As observed, there has been consistent land cover conversion in the Upper Brantas Basin. The decreasing area of cultivated and managed vegetation and increasing urban/ built-up area along 2015-2019. Forested area sawed a rather stable slow steady growth, however, with a decreasing trend. The changes are likely to be correlated with the population growth and business activities in the Upper Brantas Watershed. The Upper Brantas Watershed covers the three growing regions, namely Malang City, Malang Regency, and Batu City, known as Greater Malang. Malang City, in particular, is marked as the second populous city in the East Java Province region. At the same time, Batu City is the center of tourism activities in this region.

The river discharge is consistently showing a similar variation during the observation period (2016-2020). Analysis showed the correlation of the LULC changes with the river discharge variation. Most notably, with the urban/ built-up area and the cultivated and managed vegetation. The river discharge increase is likely correlated with the increase of urban area and the decrease in cultivated and managed vegetation area. River discharge was affected by the intensity of urban and cultivated areas during the study period. The declined cultivated and managed area had affected the river's capacity by probably due to the conversion to the urban area, thus adding the runoff to the river. However, interestingly, the cultivated area, with the high correlation with the river discharge, can probably be of interesting further discussion. It is suggested that better cultivated, and managed vegetation should be developed for the river discharge or runoff. It is because, particularly in the Upper Brantas Basin, it was indicated that the changes of the cultivated area contributed to more than half of the river discharge.

## 4. Conclusions

The detection and assessment of LULC changes are crucial to planning sustainable watershed management. We used the publicly available dataset of LULC, provided by the Copernicus Global Land Cover Layer in 100m resolution. The seasonal variability of discharge and the correlation with the LULC for five years were analyzed. The seasonal meteorological variation and LULC changes in higher spatiotemporal resolution will provide additional knowledge. On the upper Brantas Watershed dynamics, traditional analysis was assessed annually. This research shows that the changes in LULC, mainly cultivated and managed vegetation and urban/ built-up area, contributed significantly to the runoff followed by river discharge. The $R^2$ value showed the 49.6% increase in urban/ built-up area, while the 69.4% decrease in the cultivated area affected the river discharge increase. The development of the Greater Malang area is suggested to also look at the water resources perspective, which is the river discharge variability. Interestingly, in the future development of sustainable cultivated and managed vegetation, it covered 22% of the Upper Brantas Basin. The findings in this study are likely to provide more knowledge on understanding the LULC dynamics and the corresponding effects on the seasonal variation of the river discharge.

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