Suroso_2020_Impact of Land Use Land Cover Changes on River

by Suroso Suroso

Impact of Land Use Land Cover Changes on River Discharge at Brantas Catchment Area using SHETRAN Model

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Abstract. Changes in land use need to be assessed for future needs. One of them is in efforts to mitigate natural disasters. This research goal is analyzed the correlation between changes in land use land cover on the discharge in the river, in the range between 2001–2017. This research located at Brantas watershed, which is the largest watershed in East Java. It has an area of approximately 11,988 km^2. There are 24 million people who occupy this area and this is one of the national strategic watersheds. SHETRAN is modeling that is based on physical distribution. Reviewing spatial aspects, hydrological and climate data makes SHETRAN is comprehensive model. The method used is to combine input data of the digital elevation model, evaporation rate, rainfall data, land use land cover data, and soil properties classified using the British system. The results obtained for land use, the biggest change is for the grass area which increased by 80.49%, the forest area increased by 22.37%. As for river discharge, modeling results indicate that river flow rates upstream range 6–30 compare to downstream is between 1200–2200 meters^3/second.

1. Introduction

In the tropics, the impact of land use and climate change on watersheds can change the flow volume to be greater [18] due to large energy input and faster anthropogenic changes [12]. The most significant factors affecting surface runoff are changes in forests, dry agriculture, and urban areas. With increasing urbanization, intensification of industry and agriculture, increased runoff will increase the flow of nutrients and sediments to water bodies [33]. Uncontrolled logging makes forest vegetation from a hydrological point of view unstable. In a previous study, logging action could influence the impact of the 100-year return period rain. Land use evaluation is needed within a certain period in order to determine trends in natural change that can be used for mitigation needs in the future [32].

In addition to land use analysis, it is also necessary to develop a more up-to-date hydrological model to be implemented in Indonesia. There is a long history of research that has been carried out on automatic generation of river networks from digital elevation models (DEM) [10]. The basic method for extracting river channel networks then uses flow direction to calculate upstream contribution areas for each square grid [22]. Models are needed that can define channels to simulate hydrological mitigation needs.

SHETRAN is a physical-based distribution model (PBDM) for water flow, sediment and solute transport in river catchments [2]. Includes hydrological components for simulation: interception of rainfall by vegetation; evaporation and transpiration; snow formations and melted snow; land flow and

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channel; subsurface flow varies saturated; and river/aquifer. SHETRAN solves physics-based partial differential equations, for flow and transportation on rectangular finite elements.

The purpose of this study is to develop a modeling that was first carried out in Indonesia. The analysis carried out is an investigation of changes in land use that occurred on the results of SHETRAN for river discharge modeling. The research object chosen in the Brantas catchment area, East Java because in the recapitulation of existing data, the cities and regencies which include in Brantas catchment area account for approximately 50% of the total impact of buildings and humans due to flooding in East Java, and Brantas watershed is a watershed that is included in the national strategic area.

2. Data and Study Location

Brantas watershed chosen because it is one of major watersheds in Indonesia, which watershed area around of 11,988 km^2 or about 25% of East Java Province. Located at coordinates 110°30' East to 112°55' East and 7°01' East to 8°15' East. Covering 8 cities and 16 districts, upstream location is in Kediri Regency and the downstream is in Surabaya City.

Brantas watershed has great potential for various sectors, such as Surabaya city which is center of government in East Java, Kediri city which is the city with third highest Gross Regional Domestic Revenue, industrial and plantation cities in Batu and Malang, tourism and cultural cities in Ponorogo, and also other cities and districts. Brantas watershed also has a significant role in supporting East Java Province as a national food barn. In 2018, East Java Province will still be the backbone for rice, corn and cassava stockpiles by contributing ± 19.3% of the national food stock needs. In Brantas watershed there are also a total of 10 Irrigation Areas included in the Brantas watershed with an area around 113,368 Ha.

In terms of geography, Brantas watershed is crossed by volcanoes and mountains, which results in very varied topographic conditions ranging from flat, hilly, valley and mountainous. This causes the available land can not be fully cultivated to improve the welfare of the community, because there must be a protected area that must be protected and preserved to maintain environmental balance and prevent the recurrence of environmental damage, especially landslides and floods due to reduced land cover.

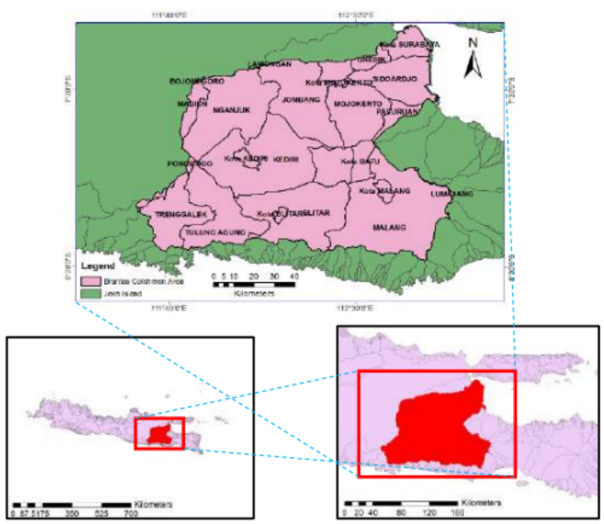

Figure 1. Research Location

3. Method

Hydrological model SHETRAN was utilized to perform runoff simulations for the Brantas Catchment Area. SHETRAN is a physically-based, distributed, deterministic, integrated surface and subsurface modelling system, designed to simulate water flow, sediment transport, and contaminant transport at the catchment scale ([2];[3]). SHETRAN has a modular design, in which each module or component is used to represent the different physical processes of the hydrological cycle in each part of the catchment. The methods used in SHETRAN to simulate the processes of its water flow component include Potential Evapotranspiration (PET), Actual Evapotranspiration (AET), Interception, Overland runoff, Infiltration/subsurface flow, River flow routing.

The catchment is conceptualized as an ensemble of columns and networks of stretches of channels, called river links. Each column is a stack of computational cells containing information of land cover/vegetation type at the top and sequential depth of soil/s horizons underneath it. Each river link runs along the edge of column tops. SHETRAN works out the water balance in each column. Spatially distributed data, including a digital elevation model, the soil and land use map were used in a raster format with a grid resolution maximum 200 × 200. The net outcome of hydrological processes at all the columns is the hydrological behaviour of the catchment.

In this model, the partial differential equations for flow and transport are solved by finite difference methods. The basin is discretized into a horizontal orthogonal river network and at each square grid in the vertical direction by a column of layers. A network of river links runs along the edges of grid squares representing the river network. The model explicitly incorporates spatial heterogeneity in topography, soil, land use and catchment properties with its grid-column structure. The model represents coupled surface/subsurface flow, allowing overland flow to be produced by rainfall excess over infiltration and by upward saturation of the soil column [4].

The interception of rainfall is represented by the modified Rutter model. The actual evapotranspiration is calculated from Potential Evapotranspiration (PET) as a function of soil water potential. The diffusive wave approximation of the St. Venant equation governs the overland and channel flow processes, while the Richards and Boussinesq equations give the one-dimensional flow in the unsaturated zone and two-dimensional flow in the saturated zone, respectively. The river aquifer interaction is calculated using the Darcy equation.

The procedure for the automatic generation of the river channel network in SHETRAN is different than typical approach. Therefore, the following procedure for the automatic generation of the river channel network in SHETRAN has been developed. Initially this follows a typical approach [8]: the pits in the DEM are removed, the flow directions are calculated and this gives an upstream contributing area for each grid square, and a procedure for channel extraction is defined.

In this study, the main steps undertaken from beginning to end are:

a) GIS processing to get ASCII files that will form coordinates as a basis for making maps on SHETRAN
b) Processing matrix as a record for input data that becomes a value for the output data formed
c) Configure XML to run SHETRAN model
d) Running SHETRAN to the standard version to get computational correction
e) Extract SHETRAN data results to be further processed for presentation of research data

4. Results and Discussion

4.1. Land Use Land Cover Change

Land use and cover data used is derived from MODIS which is a level 3 combination product from Terra and Aqua satellites (MCD12Q1). Provides information on annual land cover types with sinusoidal projections and spatial resolution of 500 meters, in HDF-EOS format, with an observation series from 2001 to 2017. The MCD12Q1 product is able to identify the geographical distribution of 17 land cover classes using a scheme defined by the International Geosphere Biosphere Program (IGBP). One MCD12Q1 product has several data layers, including the type of land cover, assessment layer and quality flag for each type of land cover. In this study, a similar approach was carried out by classifying 17 types of land cover from MODIS MCD12Q1 data into 7 categories that have been classified for the SHETRAN program, shown in Table 1.

Table 1. Conversion MODIS Classification to SHETRAN LULC Classification

MODIS Classification	SHETRAN Classification
Croplands, Natural Vegetation Mosaics	Arable
Permanent Wetlands, Barren, Water Bodies	Bare Ground
Grasslands	Grass
Deciduous Needleleaf Forest, Deciduous Broadleaf Forest, Mixed Forest	Deciduous Forest
Evergreen Needleleaf Forest, Evergreen Broadleaf Forest	Evergreen Forest
Closed Shrublands, Open Shrublands, Woody Savannas, Savannas	Shrub
Urban and Built-Up Lands	Urban

Table 2 shows the results of an analysis for 17 years in the Brantas catchment area. Two types were degraded, it is an arable 9.17% and deciduous forest 11.26%. While those who experienced an increase there were five types, namely bareground 2.54%; grass 80.49%; evergreen forest 22.37%; shrub 10.77%; urban 8.74%. If calculated from the entire area of the Brantas catchment area, the changes in each type of LULC range from 0.06% to 5.38%. The arable area has become a changing area, be it an urban, shrub, or evergreen forest area. The addition of green forest areas that bring a lot of benefits, including groundwater storage that can affect river discharge.

Table 2. LULC change over the past 17 years (2001–2017) in Brantas Catchment Area

LULC	2001 (km^2)	2017 (km^2)	Change (km^2)	%Change of 2017	%Change of Total Area	% LULC of Total Area
Arable	8118	7373	-745	-9,17	-5,38	55,8
Bareground	316	324	8	2,54	0,06	2,3
Grass	51	93	41	80,49	0,30	0,4
Deciduous Forest	73	65	-8	-11,26	-0,06	0,7
Evergreen Forest	1334	1632	298	22,37	2,15	9,2
Shrub	2921	3235	315	10,77	2,27	23,8
Urban	1039	1129	91	8,74	0,66	7,8
Total	13850	13850				100

In Figure 2 below, shows the percentage of each type of LULC SHETRAN to the total area of the Brantas watershed. Visible changes in each type of LULC every year in 2001 to 2017.

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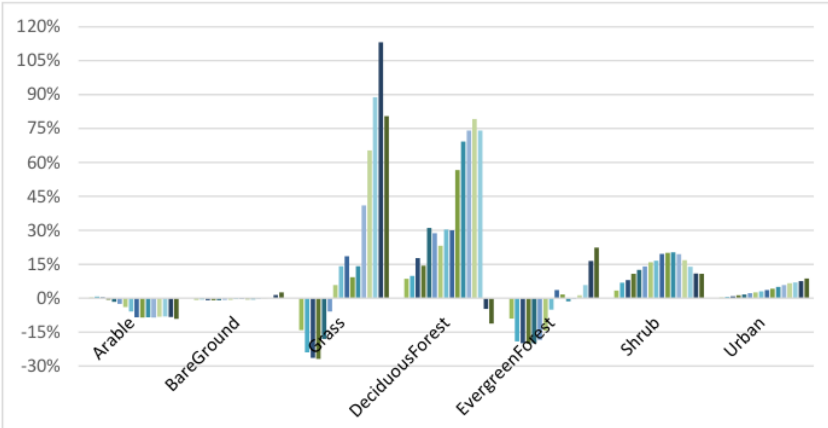
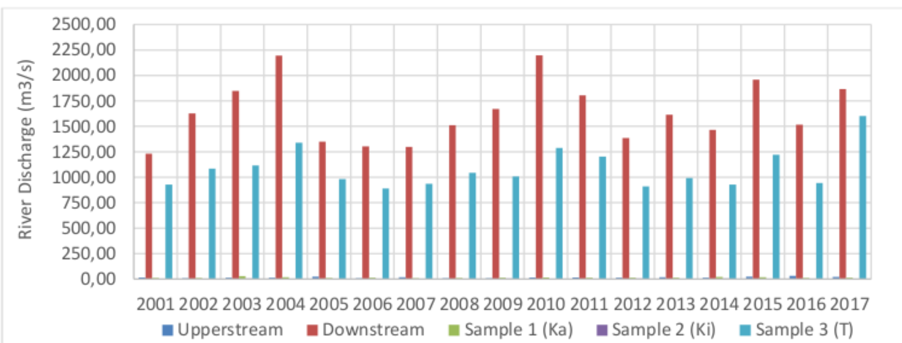


Figure 2. LULC change from 2001–2017 at Brantas Catchmen Area

4.2. River Discharge Analysis Based on SHETRAN Model

A



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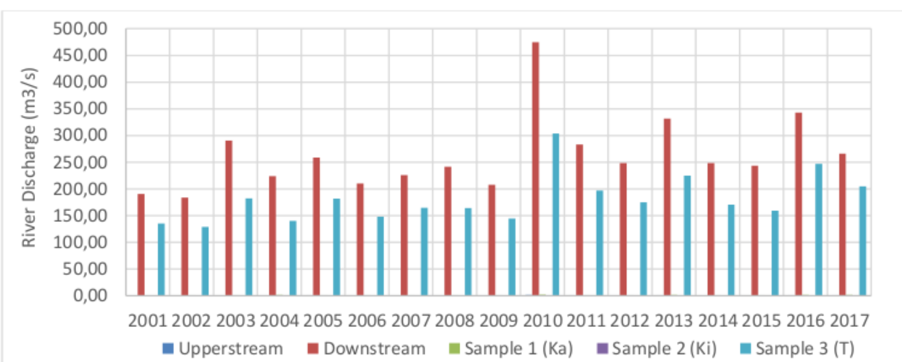

Figure 3. (A) Maximum river discharge, and (B) Average river discharge based on SHETRAN model (source : author)

In figure 3 (A), a very clear difference can be seen from the selected sample points. Discharge in the downstream area is different to more than 1000 meters^3/second when compared to upstream area. Sample points that are on the right and left side of the watershed also produce a discharge that is not too large. In line, figure 3 (B) show average river discharge produced by the SHETRAN model also shows a vast difference of more than 150 meters^3/second. In maximum flow analysis, discharges produced showed high results in 2004, 2010, 2015, and 2017. It is not much different from the data on rainfall and flood events.

The highest river discharge resulted by SHETRAN model in upper stream is 30,66 meters^3/second in 2016, which the lowest is 6,90 meters^3/second in 2008. In the outlet of Brantas catchment area, the highest river discharge resulted 2197,73 meters^3/second in 2010, and the lowest is 1230,87 meters^3/second in 2001. Still in the downstream area, the debit in the middle sample point obtained a large discharge, namely the lowest maximum discharge of 888.97 meters^3/second in 2006 and the highest maximum of 1600.15 meters^3/second in 2017. For the right sample point the maximum discharge results the highest is obtained 27.63 meters^3/second and the lowest maximum discharge is 8.77 meters^3/second. While the left sample, the results obtained 129.07 meters^3/second for the lowest and 303.96 meters^3/second for the highest maximum discharge, namely in 2002 and 2010.

For average discharge, from 2001-2017 shows a value that tends to stagnate, except in 2010 which found a significant increase in average discharge. Reviewing average daily discharge generated every year, the results obtained for outlets ranged from 200–350 meters^3/second, midpoint 150–250 meters^3/second, and for the right, left, and upstream samples ranging from 0.1–1.8 meters^3/second. The highest was in 2010, the average increase in debit at outlets and middle samples reached around 150 meters^3/second.

However, it should be noted that in actual cases, the sensitivity of a particular watershed to runoff generation is also impacted by other factors such as magnitudes of land use change, soil conditions, and different climatic factors [1].

5. Conclusion

Results of land use processing, obtained five types that have increased. The LULC types that have increased in sequence are: shrub, evergreen forest, urban, grass, and bareground. While those experiencing reductions along with the size of the area deficit: arable, and deciduous forest.

The most dominant area in the Brantas watershed is the arable type with an average of ± 55.8% of the total Brantas watershed area, then shrubs of ± 23.8%; evergreen forest ± 9.2%; urban ± 7.8%; bare-ground ± 2.3%; deciduous forest ± 0.7%; and grass ± 0.4%. Results of SHETRAN model on river discharge at each point show fluctuations because LULC every year are always changes. In 2010 or 2016, there was no significant forest growth in downstream location, while urban areas continued to increase. This result causes a lack of control over river discharge due to insufficient availability on absorption land. Meanwhile, the amount of discharge occurs when the condition of the largest deciduous forest like in 2014, or evergreen forest has not been degraded in a large amount like in 2001. It shows that good vegetation affects groundwater storage which will have an impact on surface water.

6. Acknowledgments

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