Impact of Land Use Land Cover (LULC) Change on Surface Runoff in an Increasingly Urbanized Tropical Watershed

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Abstract

Upper-Brantas watershed in East Java, Indonesia, is a tropical watershed experiencing rapid landscape change, a phenomenon typical to developing countries. This study demonstrates the impact of Land Use Land Cover (LULC) changes on surface runoff in a tropical, urbanized, and data scarce watershed. The LULC changes were quantified between 1995 and 2015 and their impact on the hydrological processes was analyzed using the Soil and Water Assessment Tool (SWAT) model. During the study period, the watershed experienced an increase in settlement and dryland agriculture, and a decrease in the forest, rice field, and sugarcane plantation. The SWAT model results for the calibration (2003–2008) and validation (2009–2013) periods matched observed values [$R^2 > 0.91$ and NSE (Nash-Sutcliffe Efficiency) >0.91]. In the long-term, the model predicted changes in runoff (+8%), water yield (+0.28%), groundwater (−1.8%), and evapotranspiration (−1.15%) due to changes in LULC. LULC changes showed a linear relationship with runoff generation, and the most significant factors affecting surface runoff were changes in the forest, agriculture, and settlements. Increasing urbanization, industrialization, and agricultural intensification will increase runoff which in turn will enhance the flow of nutrients and sediments into the water bodies.

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1 Introduction

Changes in land use and land cover (LULC) due to anthropogenic drivers are often associated with alteration in various natural support systems such as the quantity and quality of water resources (Giri and Qiu 2016), biodiversity (Solar et al. 2016), food security (Rutten et al. 2014), and energy supply (Preston and Kim 2016). From a hydrological perspective, LULC change within a watershed has been recognized as one of the critical factors influencing runoff generation (Chang 2007), which has become more critical with climate change (Li et al. 2012; Luo et al. 2018). In Southeast Asia's tropical regions, the impact of LULC changes and climate on streamflow can be severe due to greater energy inputs and faster anthropogenic changes.

Southeast Asian countries have been experiencing the fastest LULC change over the last few decades. For example, the forest loss in Indonesia has been extremely high, the second fastest after Brazil (Margono et al. 2014). Indonesia's major source of water resources relies on approximately 5,590 rivers, 521 lakes, and 100 reservoirs (Lehmusluoto et al. 1997). The increased water use and degrading watershed conditions have intensified the overall stress on already diminishing water resources (Pawitan and Haryani 2011) and require an intensive management intervention (Fulazzaky 2014).

Numerous studies have been conducted examining the impact of LULC changes on hydrological parameters such as runoff in different environments (Eshtawi et al. 2016; Ghaffari et al. 2010; Wagner et al. 2013). Quantifying the consequences of LULC change to hydrological response is challenging due to the variability of hydrological systems, limited numbers of controlled experiments, relatively short hydrological records, and difficulties in controlling land use (DeFries and Eshleman 2004). Some studies have shown contradictory findings and lack of consistency (Beck et al. 2013). For example, Ghaffari et al. (2010) showed a small unnoticeable change in hydrological responses (i.e., surface runoff, ground water flow and stream flow) for a 40-year period, whereas, Silveira and Alonso (2009) observed large changes, up to −38% in discharge due to land use change in Uruguay. A canceling-out effect can appear, where influences from sub-basins can potentially mask out the impacts of LULC change in the whole watershed (Wagner et al. 2013). The lack of understanding of this issue has primarily been attributed to the heterogeneity of watershed characteristics, land use pattern and configuration, threshold behavior in hydrological processes, and inference of climate, which are all difficult to quantify (Wang et al. 2014). Therefore, a similar study from a particular watershed bears some merits in enhancing our understanding of LULC change impact on the watershed.

Assessing the impact of LULC changes on hydrological processes has been regularly performed in previous studies using pair catchment experiments and hydrological modeling. Previous paired catchment studies are often impractical to implement due to the need for a large temporal window, but they are simpler and produce rapid results to aid the local decision-making process (Ochoa-Tocachi et al. 2016). In hydrological modeling, the Soil Water Assessment Tool (SWAT) tool is a robust model to assess the impacts of LULC change on hydrological processes and hydrologically influenced ecosystem services (Francesconi et al. 2016; Gassman et al. 2007; Sahoo et al. 2019). Despite numerous studies worldwide, there have been limited SWAT-based hydrological studies carried out in Indonesia (Barkey et al. 2017; Rahayuningtyas et al. 2014; Setyorini et al. 2017). Setyorini et al. (2017) investigated the land use change in the Upper Brantas watershed, Indonesia between 1989 to 2006 and provided its impact on stream flow and water

balance without quantifying the relationship between LULC change and watershed characteristics. This study is novel because it comprehensively examined the relationship between LULC change and runoff in this rapidly urbanizing and relatively data scarce watershed over a larger time domain going beyond 2006 when the rate of urbanization was higher.

Java Island is home to around 60% of the country's population. It has been experiencing increased pressure on land resources, and exhibit a transition from a mainly rural to a largely urbanized environment (Handayani 2013). Several studies have highlighted the impacts of increasing urbanization on Java, such as increasing farm loss (Partoyo 2013), water pollution (Djuangsih 1993), and accelerated sedimentation and flood events (Valentin et al. 2008). Since hydrology serves as the main driver governing sediment and nutrients inflow, knowing the hydrological response, especially the runoff generation in Javanese watersheds is of importance. The objectives of this study were to: (i) simulate the impacts of LULC change over the past two decades (1995–2015) on the hydrological response of catchment with a focus on surface runoff, and (ii) investigate the relationship between runoff generation and the pathways of the LULC changes especially settlement or dryland agriculture.

2 Materials and Methods

2.1 Study Area

The study site is the Upper Brantas watershed located in East Java, Indonesia (Fig. 1). Upper Brantas watershed is a part of the *Wilayah Sungai* (WS) or "River Region" Brantas. Brantas is a delineated river basin management area in Indonesia that holds strategic economic and ecological importance.

The WS River basin covers multiple watersheds called *Daerah Aliran Sungai* (DAS). It is managed under a concept known as "one river basin one management" (Bappenas 2012; Kementrian 2011). The WS Brantas contains the longest river network of East Java and meets 73% of the total water demand of the province. It also produces approximately 63% of the electricity that is consumed by the province, and plays a critical role in water conservation, water resource utilization, and acts as a water hazards controller (Adi et al. 2013). Over the years, the Upper Brantas has attracted scrutiny due to increasing reports of environmental problems such as sedimentation (Adi et al. 2013), reservoir eutrophication (Sulastri and Suryono 2004) and heavy discharge of pollutants (Fulazzaky 2009). Upper Brantas watershed is surrounded by mountains creating a circularly-shaped drainage area of almost 2,000 km². The elevation ranges from 223 m to 3673 m above sea level, with a slope ranging from 0° to 78°. Upper Brantas experiences abundant rainfall (annual average rainfall of 2063 mm between 1991 and 2015) and intense precipitation during the wet season (October–March), peaking in December–January, and low precipitation during April – September (Dry Season). The watershed experiences a temperature variation from 19 °C to 30 °C.

2.2 SWAT Model

SWAT is a continuous, semi-distributed, watershed-based hydrological model developed to predict the impact of land management practices on water, sediment and chemicals from agricultural land within a watershed (Neitsch et al. 2011). It has been widely applied to study hydrological responses and pollutant loads at varying spatial and temporal scales with adequate accuracy and reliability (Gassman et al. 2007; Milewski et al. 2009).
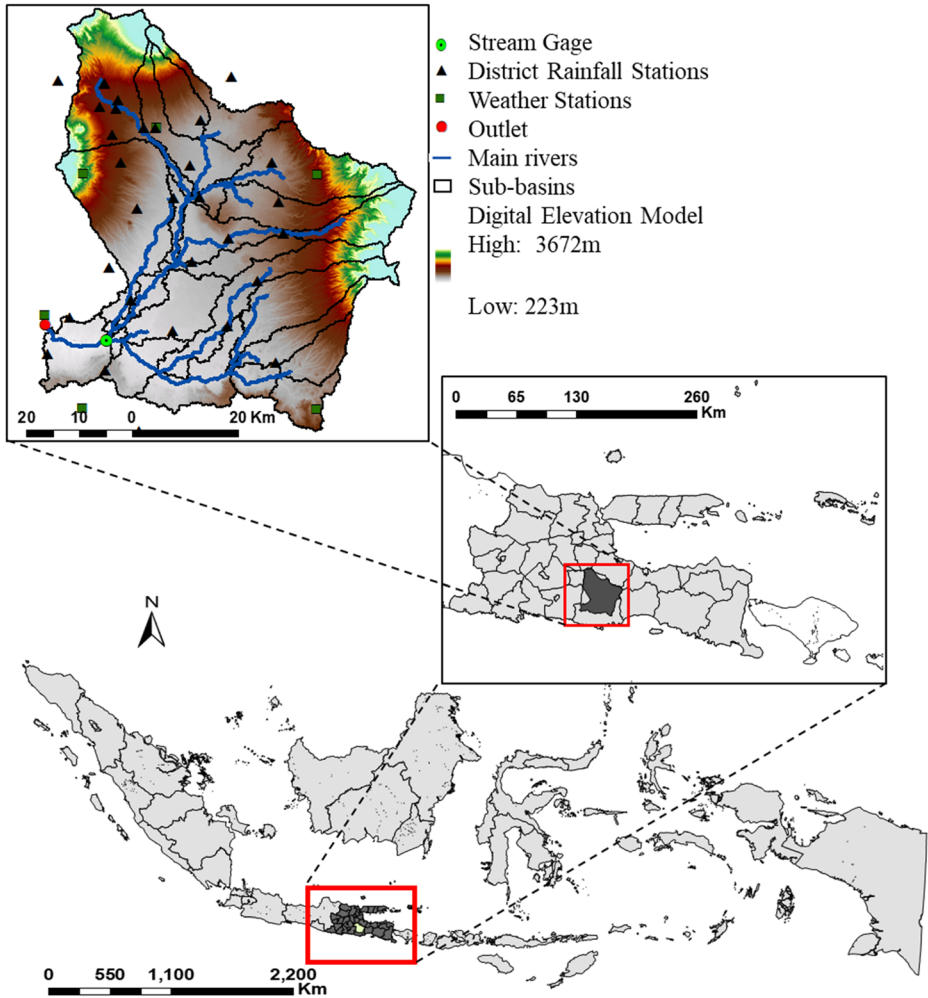
Fig. 1 Map of Indonesia, East Java and Upper Brantas watershed with corresponding elevation and location of gaging stations

SWAT divides a watershed into multiple sub-watersheds and hydrologic response units (HRUs). Each HRU is a designated area with a unique combination of land use, soil characteristics, and slope. It uses a water balance principle to simulate the hydrological process within a watershed and all flow parameters are routed to a sub-basin level, and eventually to a basin level as described in (Neitsch et al. 2011).

2.3 Input Data

SWAT input data includes topography, climate, land use and land cover, and soil. Topography data was obtained from a 30 m ASTER Digital Elevation Model (ASTER GDEM V2, from USGS (USGS 2017). The land use maps (Fig. S1a and S1b) were obtained from a previous study analyzing land use patterns in 1995 and 2015. Those maps were derived from an Object-Based Image Analysis (OBIA) classification technique using Landsat images (Astuti et al.

2018). The land use types which was adopted from the Indonesian Ministry of Forestry's land use classification scheme, were reclassified to meet the nomenclature used in the SWAT land cover database. URMD (Urban Residential Medium Density) was selected instead of Urban Residential High Density (URHD) or Urban Residential Low Density (URLD) with an assumption that settlement areas in Java are not heavily covered with impervious surface. URMD class is assumed to have around 38% of the impervious surface in the settlement areas (Neitsch et al. 2011), which is applicable to most urban areas in Java. Slope classes used in this study were in accordance with the Guidelines of Land Rehabilitation from Indonesia's Ministry of Forestry (MOF 1987). The land use maps for the site were produced with an overall accuracy of 85% (Kappa Coefficient: 81%). SWAT data inputs are summarized in Table S1. Soil data were obtained from the Harmonized Soil World Database (Fig. S1c).

2.4 Model Evaluation

The model evaluation covers calibration, sensitivity analysis, and validation. Sensitivity analysis represents the model response to changes made in the model parameters and identifies important input parameters. The initial parameters were selected based on watershed characteristics and previously published literature (Ghaffari et al. 2010; Seyoum et al. 2015). The SWAT model was calibrated (2000–2008) and validated (2009–2013) at a monthly time step with three years of warm-up.

The SWAT-Calibration Uncertainty Program (SWAT-CUP) was used to perform calibration, validation and sensitivity analysis using the Sequential Uncertainty Fitting version 2 (SUFI-2) routine (Abbaspour 2015). Overall, the model performance was assessed using R^2, Nash-Sutcliffe Efficiency (NSE), and Percent BIAS (PBIAS). The coefficient of determination (R^2) measures the proportional variation in the simulated variable explained by the measured variable and indicates the linear relationship between the estimated and measured variables. NSE determines the relative magnitude of the residual variance compared to the observed data (Moriasi et al. 2007). It ranges from $-\infty$ to 1 with 1 representing a perfect agreement between the simulated and measured values. PBIAS measures the percentage of the overestimation or underestimation of the simulated variables.

2.5 Model Implementation

The calibrated SWAT model was used to simulate the impact of LULC change over the past two decades on the hydrological responses. The "impact" was determined as the quantified change, which was calculated by following the method used in past studies (Ghaffari et al. 2010; Wagner et al. 2013; Wang et al. 2014). This was implemented by running the model using different land use data, while keeping the other data inputs the same. In this approach, all the changes to hydrological variables were assumed to be the result of the changes in land use inputs. The validated parameters from the LULC 1995 were then applied to the 2015 LULC while keeping other parameters such as climate, soil, and topography same. The climate during 2000–2013 was assumed to have no significant changes and was confirmed using a Mann-Kendall (MK) trend test. The MK test was used to detect the presence of a rainfall trend, testing whether the rainfall trends show significant variability. The null hypothesis for the MK test revealed no trend in the data, which was tested at a significance level of 0.05. This test is often used in hydrological applications (Pingale et al. 2014). The test results showed that the Thiessen

weighted rainfall within the study area did not show any statistically significant trends over the past 20 years as shown in Fig. S2.

2.6 Influence of LULC Change on Hydrological Processes

A comparison was performed to provide an overview of changes in surface runoff due to LULC change in 1995 and 2015. The correlation was used to identify the relative importance of each major land cover type. To better understand the hydrologic response to particular land use classes, a gradual land use change was applied by running SWAT on one land use map using a specified scenario (Eshtawi et al. 2016; Ghaffari et al. 2010). For this purpose, a gradual change (0% to 100%) scenario on LULC 1995 was simulated to examine the relative impact of urbanization and agricultural expansion on surface runoff. For these, the scenario was applied to the selected sub-basin (sub-basin 6). This sub-basin was selected because it represents one of the major sub-basins with all existing LULC types. This sub-basin has been subject to significant forest and farm loss for settlement development to support trade and tourism activities (Widianto and Lestariningsih 2001).

3 Results

3.1 Main Parameters and Model Performance

The calibration and validation of the watershed/SWAT model were initiated with 27 parameters using SWAT-CUP. The model was simulated, run, and iterated four times before reaching the final six sensitive parameters. The most sensitive parameters, six of which are statistically significant, (absolute t-stat values ≥2 and p value ≤0.05) are shown in the supporting document (Table S2). Most of these parameters are related to soil and groundwater characteristics, which are similar to the findings from a similar study in Lesti catchment, East Java (Rahayuningtyas et al. 2014).

The statistical fits produced for streamflow on a monthly time step according to Moriasi et al. (2007) were "very good", indicating that the SWAT model set up was reliable for the further application (Fig. 2). The high R^2 and NSE values in the calibration and validation simulations (in Table S3) suggest that the calibrated model can reasonably describe the variability of streamflow within the basin and thus be further applied to assess the impacts of LULC change on hydrological responses.

3.2 LULC Change over 20 Years

Comparison between LULC 1995 and 2015 revealed that the Upper Brantas watershed has experienced noticeable LULC changes. In the past 20 years, there has been a reduction in forested areas, plantation and rice fields, ranging from 2% to - 4% of the total watershed size. On the other hand, mixed-dryland agricultural areas within Upper Brantas increased by 62 km², adding around 3% of the total area. Over the past two decades, the changes in each LULC class were relatively small, ranging from 0.06% to 6.83% of the total basin area.

The settlement became the LULC class that experienced the biggest shift with an increase of around 135 km² by 2015 (Table 1). This represents almost 80% change from its urban size in 1995, accounting for 6.9% of the total catchment area. Results show that forest land area
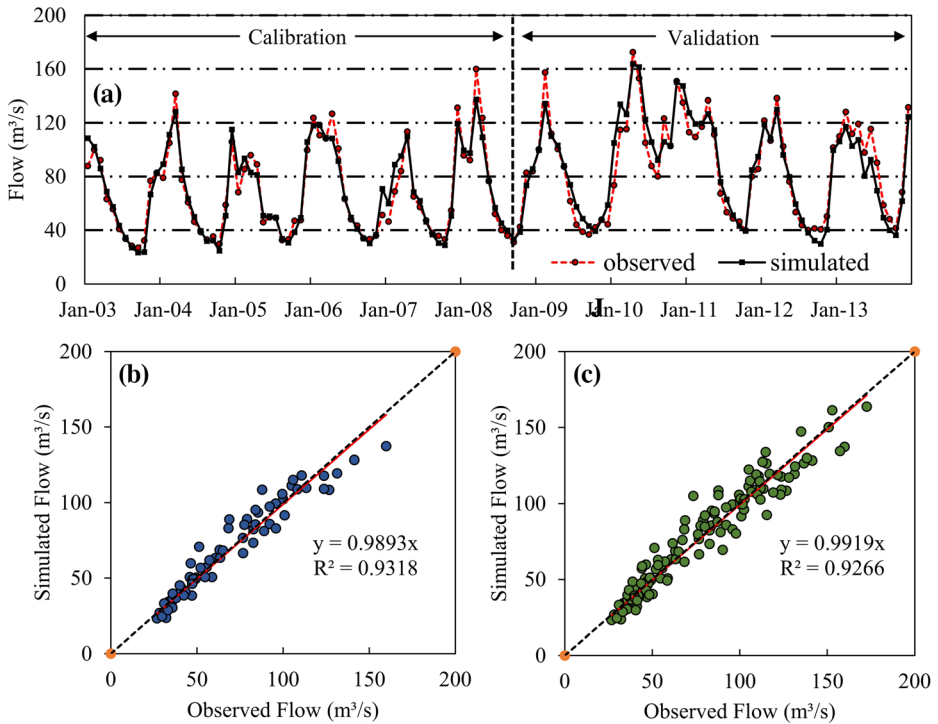
Fig. 2 (a) Hydrograph of the observed and simulated flow used for calibration and validation. Fitted values of observed versus simulated flow for (b) calibration, and (c) validation

reduction was mainly caused by the conversion to mixed-dryland agriculture (Table 2). Meanwhile, rice and mixed-dryland were converted to developed area to accommodate the increase in the urban population. Larger changes involved changes in dryland agriculture and urban development. Approximately 9% and 14% of mixed dryland agriculture in 1995 was converted to rice fields and urban areas respectively by 2015. In this period, a small reduction of forest land (3% of the total watershed) occurred. From this converted forest, approximately 20% was replaced by mixed dryland agriculture. A relatively larger shift in the landscape was

Table 1 LULC change over the past 20 years (1995–2015) in Upper Brantas watershed

LULC	1995	2015	Change (km²)	% Change of 1995	% Change of total area
Agriculture (AGRL)	684.69	746.61	61.9	9.0	3.1
Forest evergreen (FRSE)	364.12	302.68	−61.4	−16.9	−3.1
Sugarcane Plantation (SUGC)	263.73	175.17	−88.6	−33.6	−4.5
Rice field (RICE)	415.46	371.16	−44.3	−10.7	−2.3
Rangeland Bushland (RNGB)	49.57	49.15	−0.4	−0.8	0.0
Rangeland Grassland (RNGE)	3.29	0.19	−3.1	−94.4	−0.2
Urban Residential Medium Density (URMD)	170.23	304.92	134.7	79.1	6.9
Water (WATR)	15.04	16.24	1.2	8.0	0.1
Total (km²)	1966.12	1966.12			

Table 2 Transition matrix of LULC from 1995 to 2015

		Land use 2015								
		AGRL	FRSE	SUGC	RICE	RNGB	RNGE	URMD	WATR	Total (Km²)
Land use 1995	AGRL	482.7	14.5	34.8	92.6	1.2	0.0	57.6	1.3	684.7
	FRSE	70.8	268.5	0.0	1.7	20.7	0.1	2.4	0.0	364.1
	SUGC	96.3	0.0	79.3	60.5	0.0	0.0	27.1	0.5	263.7
	RICE	77.0	0.1	54.9	177.5	0.0	0.0	103.4	2.6	415.5
	RNGB	4.6	17.7	0.0	0.1	26.9	0.1	0.2	0.0	49.6
	RNGE	1.3	1.4	0.0	0.0	0.3	0.0	0.1	0.0	3.3
	URMD	13.1	0.5	5.9	36.9	0.1	0.0	113.2	0.7	170.2
	WATR	0.8	0.0	0.3	1.8	0.0	0.0	0.9	11.2	15.0
	Total (km²)	746.6	302.7	175.2	371.2	49.2	0.2	304.9	16.2	1966.1

the reduction of rice fields. Around 26% of the rice fields in 1995 were converted to settlement in 2015.

The loss of rice fields has become an increasing concern due to its significant role as the staple food source for Indonesians. From 1995 to 2015, the population in Malang city and Malang municipality increased from 2,869,596 to 4,556,648 (BPS 2016). This rapid increase in the urban areas was experienced due to the rapid economic development within the watershed in the last few decades.

3.3 Changes in Overall Water Balance

The resulting simulation using two land use maps from 1995 and 2015 revealed changes in all water balance components. The average annual basin surface runoff in 2015 increased from 460 mm to 496 mm, an 8% increase from 1995. In contrast, the annual evaporation average decreased from 481 mm to 476 mm. Conversely, an increase in water yield from 1628 mm to 1633 mm and a decrease in annual groundwater recharge from 893 to 877 mm were simulated during the two decades. One limitation of SWAT is that it does not rigorously estimate the groundwater process (Rostamian et al. 2008). Thus, groundwater-related estimates should be considered relative, not absolute. The increase in water yield can be attributed to the increase in surface runoff. This was due to the decrease in groundwater percolating into the soil. Figure 3 summarizes the changes in the annual average of water budget components for the whole watershed. The annual average changes in surface runoff, evapotranspiration, groundwater, and water yield were relatively small (less than 40 mm). Compared to others, changes in surface runoff was the most evident which was also reflected in the long-term simulation results. Changes in surface runoff from LULC 1995 to LULC 2015 was more pronounced than changes in other hydrologic facets.

At the sub-basin level, 25 of 27 sub-basins experienced an increase in annual average runoff, with changes varying from 1% to 50% (Fig. 4). Some sub-basins underwent an increase, while some others exhibited a decrease, creating a canceling-out effect for the entire watershed. Variation of LULC change was observed among sub-basins, e.g., mixed dryland agriculture varied from −17% to 29%. Variations in the changes in urban areas among sub-basins ranged from 0.6% to 20%.
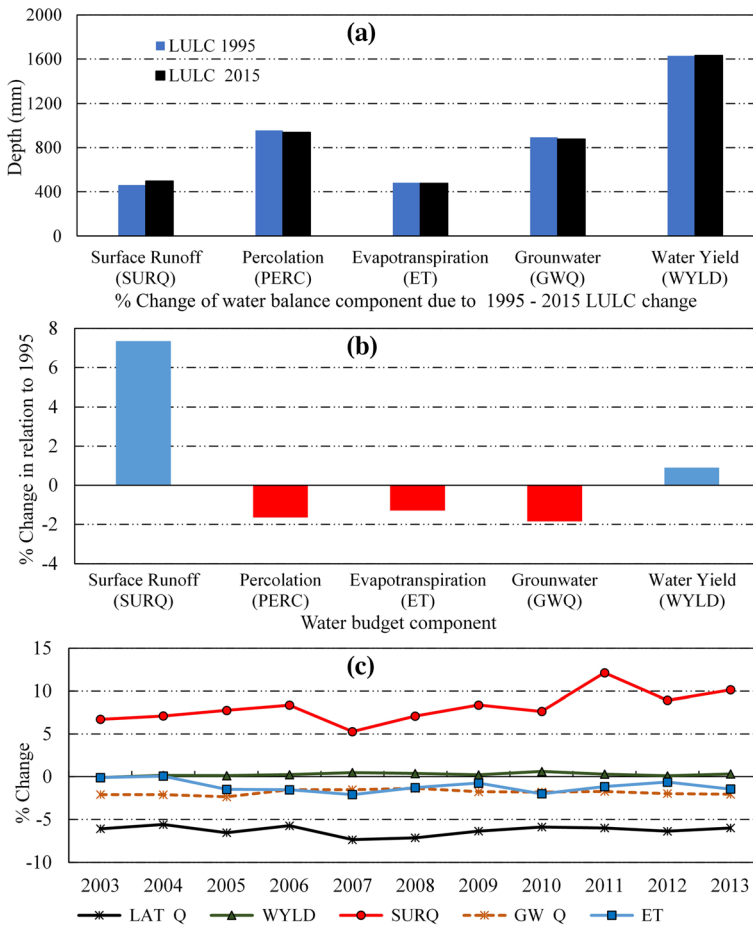
Fig. 3 LULC change impacts on watershed's water balance between 1995 and 2015: (A) % change; (B) absolute change; and (C) annual trends of changes

3.4 Relative Impact of LULC Change on Surface Runoff

The 21-year LULC change in Upper Brantas appeared to cause an increase in surface runoff at varying degrees at the sub-basin level. This suggests that each land use type might have a different relative sensitivity to runoff generation and other hydrologic components. 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 (Marhaento et al. 2017; Sajikumar and Remya 2015), soil conditions (Milewski et al. 2014), and different climatic factors (Pingale et al. 2014).

In order to relate the LULC change to water budget, the relationship between changes in each water budget component to changes in each land use in each sub-basin was computed using the non-parametric Spearman rho-correlation (Hughes et al. 2012; Zemke 2016). As indicated in post-classification change detection matrix, some of the major changes in LULC in 21 years involved forest (FRSE) conversion to dryland agriculture, loss of rice field (RICE) and mixed dryland agriculture (AGRL) to settlement development (URMD). These major
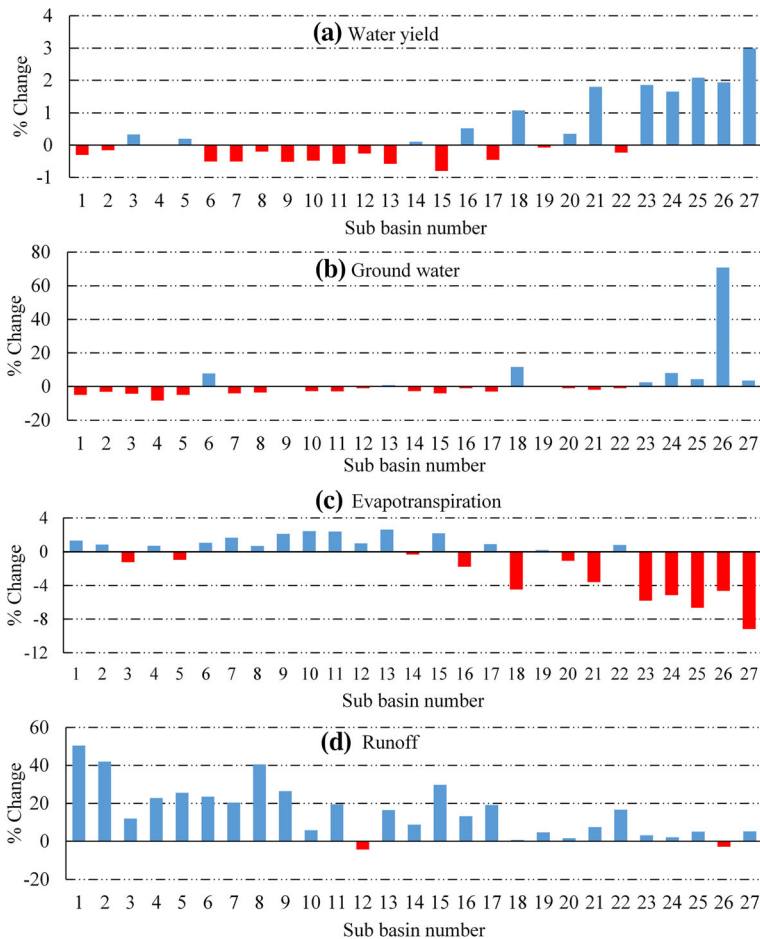
Fig. 4 Changes (in %) at sub-basin level for (A) water yield, (B) groundwater, (C) evapotranspiration and (D) surface runoff

LULC trajectories were confirmed with relatively high negative correlation (Table 3). Correlation between changes in runoff and changes in LULC types suggest that runoff generation was associated mainly with the increase in dryland agriculture and settlement, and reduction in the forest area.

Relationship between changes in runoff and the three LULC types (AGRL, FRSE, and URMD) can be observed in Fig. 5a, b, and c. The changes to FRSE accounted for 52% (R^2 = 0.52) of runoff variations, as opposed to AGRL and URMD which showed an R^2 of 0.35 and 0.11 respectively. All three LULC types' impact on runoff were significant ($p < 0.1$ at level 90% for URMD and $p < 0.005$ for FRSE and AGRL). The lower R^2 values are attributed to the presence of several LULC types in each sub-basin with varying degrees of change. The changes in runoff might be stemming from the changes in these LULC types. Thus, it is difficult to discern the relative impact of a particular LULC type. The magnitude of increase in runoff can result from an increase in AGRL, URML or FRSE together in a particular sub-basin. Figure 5d shows the trajectories of changes in the surface runoff for four major LULC types. A linear relationship between runoff and forest/farm loss and urban development was

Table 3 Correlation between changes in hydrologic components and four major LULC types from 1995 to 2015*

	ET	SURQ	GW	WYLD	LATQ	FLOW	ARGL	FRSE	RICE	SUGC	URML
ET											
SURQ	**0.56**										
GW	−0.48	−0.45									
WYLD	**−0.97**	0.30	0.34								
LATQ	0.48	−0.25	**−0.60**	−0.23							
FLOW	**−0.78**	0.01	0.22	**0.61**	0.02						
ARGL	0.22	**0.63**	**−0.57**	−0.11	0.23	0.13					
FRSE	0.19	**−0.70**	0.19	−0.17	0.03	0.39	**−0.59**				
RICE	−0.28	−0.37	0.44	0.25	−0.36	0.12	0.12	−0.17			
SUGC	−0.06	−0.45	0.46	0.04	−0.07	−0.08	−0.56	0.05	−0.07		
URML	0.34	**0.53**	**−0.60**	**−0.55**	0.43	−0.48	0.26	−0.06	**−0.58**	−0.23	

*ET: Evapotranspiration, SURQ: Surface Runoff; WYLD: Water Yield; LATQ: Lateral Flow; GW: Groundwater flow, FLOW: Streamflow, AGRL: Mixed-Dryland Agriculture, FRSE: Dryland Forest, RICE: Rice field, SUGC: Sugar cane/Napier grass association plantation. URML: Settlement. Bold numbers are for $p < 0.05$
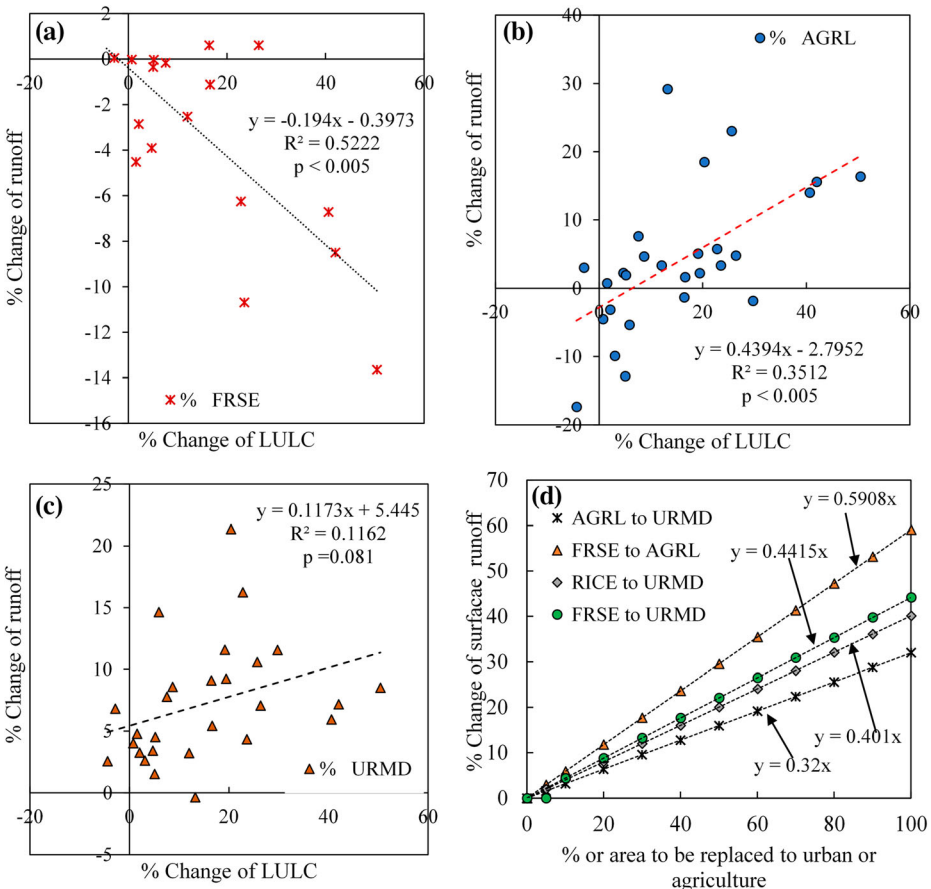

Fig. 5 The relative impact of LULC changes on runoff due to changes in (a) FRSE, (b) AGRL, (c) URMD, and (d) impact on surface runoff for four different LULC change trajectories

observed in all simulations. This linear relationship was similar to the simulation result of urban sprawl in Gaza (Eshtawi et al. 2016). However, somewhat contrasting findings were reported by Ghaffari et al. (2010), who found a non-linear relationship between runoff change after a 70% removal of rangeland. Different gradients for different LULC change paths demonstrate the sensitivity of each LULC type removal to runoff generation. The result confirmed that the conversion of forests to other LULC types has a pronounced effect on surface runoff (Fig. 5d).

4 Discussion

Simulating a 21-year LULC change in Upper Brantas watershed revealed the changes in watershed's hydrological processes. The two decades of LULC change resulted in a slight increase in long-term annual average runoff and water yield, and a decrease in evapotranspiration and groundwater flow. The overall magnitudes of changes at the basin or catchment level were relatively small. However, at the sub-basin level, the percentages of change in these elements were higher. Variation among sub-basins was noticeable, especially for water yield and evapotranspiration. Wagner et al. (2013) found that the influence of LULC change on hydrological responses can be masked by the complexities found in a large catchment. It can be argued that in 21 years, the changes in LULC with the biggest change of only 7% of the total area might not be significant enough to create a distinct change in the long-term annual average of water yield. Yet, the canceling-out effect was also found in other studies with more pronounced LULC changes such as higher than 10% of the total watershed (Gyamfi et al. 2016; Marhaento et al. 2017; Wagner et al. 2013). It is also important to note that the sub-basin areas in Upper Brantas delineated by SWAT vary greatly from 130 to 24,000 ha. In addition, it is a catchment with large variation in topography and LULC types. AGRL class represents a generic dryland agriculture in East Java, which can vary in terms of plant types. Farmland classified as mixed-dryland can have a composition of crops, fruits, vegetables and shrubs or bushes, or even hard trees such as coconuts and mangoes, whose density and species diversity can vary from one piece of land to another. The variations in the magnitude of changes in four hydrological components support the study by Bruijnzeel (2004) which demonstrated that the variability in topography, soil types, and geological settings can all play a role in affecting the water balance.

The runoff changes in the watershed can mainly be attributed to the loss of forest and an increase in mixed-dryland agriculture and settlement. Sub-basin level analysis revealed that the distinct runoff increases were observed mostly in sub-basins located either in north-east upper parts, where forest encroachment and agricultural expansion occurred, or in the central part where urbanization is more concentrated. Another factor that can possibly contribute to this is the lithology of the watershed. Groundwater contribution to the stream flow has been dominant in Brantas watershed (ratio of GWQ/P and LATQ/P around 40% and 20%). The geological formations in these sub-basins are mixed between impervious and pervious rocks that restrict infiltration. While most sub-basins exhibited runoff increase, sub-basins 12 and 26 were the only ones experiencing slightly reduced runoff. LULC change in these sub-basins showed a noticeable reduction in mixed dryland agriculture and the smallest forest loss that might have contributed to the reduction in runoff magnitudes. However, considering sub-basin 12 is only 139 ha in area, being the smallest sub-basin, the pronounced change in groundwater might not be a representative hydrological process.

Results from gradual LULC change simulations using different trajectories confirmed that forest conversion to mixed-dryland agriculture is the most detrimental. The changes in runoff were greater than the changes resulted from conversion of forest to settlement, rice to settlement, and mixed-dryland agriculture to settlement. The gradient of runoff changes from forest to dryland agriculture is steeper than from forest to urban, suggesting that the increase in agriculture might have caused higher runoff than the increase in settlement. The plausible explanation for this is that it may be a result of the combined effect of topography and LULC characteristics. For instance, around 43% of total AGRL areas were located on steep terrains with slopes between 25 and 45%, while settlement areas were mainly distributed on gentler slopes (below 15%). With intense rainfall and mild temperature at a higher elevation, mixed-dryland agricultural types in the upper part of the basin are dominated by vegetable farming. The land management practices for growing vegetables in this region involve traditional terracing against the contour lines that allow water running down the slope directly for better aeration, a favorable condition for vegetable plots. This condition can amplify the runoff generation within the landscape. On the other hand, settlement areas on gentler slopes, except in the cities, are relatively sparse and the presences of trees with denser canopy might allow a higher amount of water to be retained from the soil, thus producing a smaller runoff.

Despite relatively small changes in runoff generation due to the 21-year LULC change, the findings suggest that increasing urbanization and forest conversion to dryland agriculture in Upper Brantas can impose serious threats in the long run. This will be more complicated with the ongoing rapid economic development within the watershed and continued threats from increasing point-source pollutions. Increased runoff leads to increased sediments. Polyakov et al. (2010) found a non-linear increase in sediment yield with an increase in runoff in the semi-arid watersheds of Arizona while, Michaelides et al. (2012) found a linear increase in nutrient yield associated with the runoff. Elevated nutrients runoff will increase the risks of eutrophication in receiving water bodies (Smith et al. 1999). Sutami Reservoir within Upper Brantas watershed has been reported to undergo increasing frequency of intense eutrophication.

This study showed the potential of using a hydrologic modeling framework for a data scare watershed in Indonesia. Setyorini et al. (2017) also studied both LULC change (1987–2006) and climate impacts in the Brantas Basin. The results from their study showed that the significant changes in LULC and climate, especially temperature impacted the surface runoff and other hydrologic characteristics of the watershed. However, this study provided the most recent changes in LULC (1995–2015) and its impacts on watershed characteristics. The increase in surface runoff was predicted by both studies at the watershed level but this study showed that the effect of LULC change on surface runoff has been lower in the recent past. The use of Object-Based Image Analysis (OBIA) using Landsat images produced accurate LULC type in this study and demonstrated that the LULC change in the basin is multidirectional (Table 3) compared to unidirectional, i.e., from forest to another LULC type, as shown in Setyorini et al. (2017). Moreover, this study provided more in-depth results at the sub-watershed scale and quantified the impact of each LULC change type to the surface runoff (Fig. 5). Results can be used to identify and prioritize the implementation of best management practices in the most vulnerable areas to prevent the deterioration of the current situation.

5 Conclusions

Upper Brantas represents a typical tropical watershed in a developing country undergoing rapid LULC change. Lack of regulations and poor watershed management practices have remained as troubling issues in Upper Brantas. With this condition, any rapid LULC change can impose more serious threats for the watershed, especially in regions where data is very limited for frequent monitoring.

The land use change in Upper Brantas for the past 21 years was relatively similar to those typically observed in developing countries in Southeast Asia, where LULC changes mainly involve forest loss to compensate for the agricultural expansion and increasing urbanization. Over the past two decades, urban/settlement in Upper Brantas experienced the largest growth followed by an increase in dryland agriculture and loss in forest cover. Simulation using two different land use maps revealed the changes in the long-term average of water balance components, leading to increased runoff and water yield, and decreased groundwater flow and evapotranspiration. Among all, surface runoff experienced the most pronounced increase, denoting to 8% change in long-term average runoff depth, while other variables were less noticeable. The effect of land use change at the sub-basin level was more pronounced, showing high variability in changes in hydrological responses. Significant runoff increases were mostly restricted to sub-basins experiencing higher loss in the forest and an increase in urban expansion. The simulation results highlight the importance of watershed management for a sustainable future. The impact of increased runoff and water yield is expected to be more evident with continuing urbanization, especially in the upper part of the watershed. Future studies should investigate the impact of LULC change on water quality, which will ultimately help to develop a plan for sustainable use of the watershed.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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