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Changes in Hydrological Response of Forest Conversion to Agroforestry and Rainfed Agriculture in Renggung Watershed, Lombok, Eastern Indonesia

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Abstract

Forest is an ideal ecosystem for a hydrological cycle, however converting forests to agroforestry or rainfed agriculture is inevitable. This study elaborates a hydrological response of infiltration, runoff, and soil moisture in three land uses at Renggung watershed. Field measurements were conducted in 2014−2015 in those system with soil types of entisols at upstream, inceptisols at the middle, and vertisols at downstream. Results showed that constant infiltration rate at upstream in forest was 55.6 cm hr^{-1}, in 15−30 years agroforestry was 32.4 cm hr^{-1} on average and in rainfed was 26.4 cm hr^{-1}. Infiltration in agroforestry at the middle and downstream was 16.8 cm hr^{-1} and 11.2 cm hr^{-1}, respectively, while in rainfed was 2.4 cm hr^{-1} and 4.8 cm hr^{-1}. Runoff at upstream with 29.3 mm hr^{-1} rainfall in forest was zero, in agroforestry was 0.026 mm hr^{-1} and in rainfed was 0.071 mm hr^{-1}. Runoff in agroforestry at the middle and downstream with 37.1 mm hr^{-1} and 23.8 mm hr^{-1} rainfall were 0.045 mm hr^{-1}, and 0.026 mm hr^{-1}. There was a half and one third of that in rainfed. Soil water content in successive order from high to low was in forest, agroforestry, and rainfed. So, capacity of agroforestry in sustaining the hydrology cycle was in between forests and rainfed agriculture.

Keywords: land use, deforestation, infiltration, runoff, soil water

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Introduction

It has been no doubt that tropical forests play an important role in a hydrological cycle (Bruijnzeel 2004) as well as climate change (Chramer *et al*. 2004; Bush *et al*. 2015; Lawrence *et al*. 2015). However, deforestation and forest degradation due to over logging and forest conversion in tropical areas are inevitable. In most developing country such as Indonesia, deforestation and forest degradation is affected by many factors including economic interest, population growth and unclear land tenure (Indarto *et al*. 2012). Deforestation and forest degradation in tropical areas still continue at a certain rate, although there have been strong commitment from governments to minimize it. During the period of 2000−2010 deforestation in the tropical area was estimated at a rate of 6 million ha year^{-1} (Achard *et al*. 2014).

In Indonesia, communities living surrounding forest may have right to manage forest nearby, under Community Forest Management Unit policy. This policy is considered as an alternative solution to directly deliver socio-economic function of forests for improving the prosperity of local communities and at the same time, they take responsibility to maintain the ecological function of forests (Bowler *et al*. 2010). Porter-Bolland *et al*. (2012) showed that community-based forest management presented lower annual deforestation compared to that of protected area. However, the activity of communities inside the forest, for example in the tropical forest, in Indonesia, often change natural forest cover to agroforestry system or even agricultural land to some extent. In Indonesia, community forest also participate in protecting forests (Kaskoyo *et al*. 2014), although, the community tend to change natural trees to fruit trees or multipurpose tree species which are considered to be more economically beneficial.

Long term human activities (anthropogenic factor) inside forests possibly alter characteristics of soils and land cover. The soil characteristics that may change includes soil structure, bulk density, soil organic matter (Hajabbasi *et al*. 1997; Price *et al*. 2010; Agnese *et al*. 2011; Pirastru *et al*. 2013). Land cover change from lowland tropical forests to tree cash crop plantation such as palm oil, rubber, and cacao practising agroforestry also could also decrease soil organic carbon up to 50%, particularly in the top soil (Straaten *et al*. 2015). These changes may affect hydrological response indicating by changing in infiltration rate, runoff, erosion, and sediment (Moehansyah *et al*. 2002; George *et al*. 2013; Shit *et al*. 2014; Suryatmojo 2014; Mahmoud & Alazba

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2015). Though, it is not easy to draw the same conclusion on the effect of land use change on soil properties as well as hydrological response to that change. Afforestation and replanting trees in the tropic region increase infiltration. There was still severely lack of knowledge on infiltration rate under different edaphic condition and species effect (Ilstedt *et al*. 2007). Therefore, more reports from the diverse area with specific local characteristics will enhance current data and information related to the impact of land use change on the hydrological response.

This study had elaborated hydrological response of land use conversion from forest to community forest (agroforestry) and rainfed agriculture at Renggung watershed in Lombok, Eastern Indonesia.

Methods

Site description Field measurements were carried in three different land use systems, namely, natural forest, agroforestry, and rainfed agriculture at upper stream (E116° 22' 51", S8° 32' 7"), and in two land use systems, namely agroforestry and rainfed agriculture at the middle stream (E116° 20' 55', S8° 41' 48") and downstream (E116° 21' 11", S8° 45' 16") of Renggung watershed (Figure 1). Field works were carried out from June 2014 to March 2015. Soil types of the sites (Soil Survey Staff 2014); in the upper, middle, and downstream were entisols, inceptisols, and vertisols respectively. The soil profile taken from the infiltration measurement site is presented in Figure 2. Soil surface of measurement sites in the forest, agroforestry, and rainfed rice field was covered by grass with variation in density along catchment. Grass population was dense in upper stream and getting lower in the middle and downstream. Dominant wood trees in the forest site were Mahagony with a density of 10 trees 100 m^{-2}, while on agroforestry at upper, middle and down sites consisted of combination between trees and multi-purpose tree species with the density of 10−15trees 100 m^{-2}. Meanwhile, vegetation on rainfed agriculture was seasonal cash crops.

Roots of seasonal crops were found abundance in the first layer and the root density decreased to the second layer. Roots of trees were found up to 100 cm soil depth. In the upstream site, it seems that pumice stone was dominant and it was found from upper layer to more than 100 cm depth. The pumice stone with a large size was deposited in the third layer, below 40 cm.

Annual average rainfall at Renggung watershed was 2,550 mm at upper stream, 1,440 mm at middle stream, and 1,290 mm at downstream. Climate type according to Schmid Fergusson was type C at the upper, type D at the middle, and type E at downstream (As-syakur 2009).

Measurement of infiltration, runoff and soil moisture Hydrological data were regularly measured at each different land uses included infiltration rate, runoff and soil water content. Undisturbed soil samples were collected for bulk density, specific soil density, soil texture and soil organic matter.

Infiltration rate was measured by double-ring method (Lili *et al*. 2008) using a double ring infiltrometer. Measurement was directly carried out in the fields. A portable double ring infiltrometer consists of two drum cylinders with 60 cm in diameter of outer ring and 30 cm in diameter of the inner ring. Both rings were 50 cm height. The double ring infiltrometer were installed as follows: inner ring was firstly inserted into soil to 25 cm depth and about 25 cm was left on the soil surface. The outer ring was then adjusted and firmly inserted to enclose the inner ring with similar depth. Water was filled into the inner and outer rings. Water level drop in the inner ring was thoroughly measured during a period measurement.

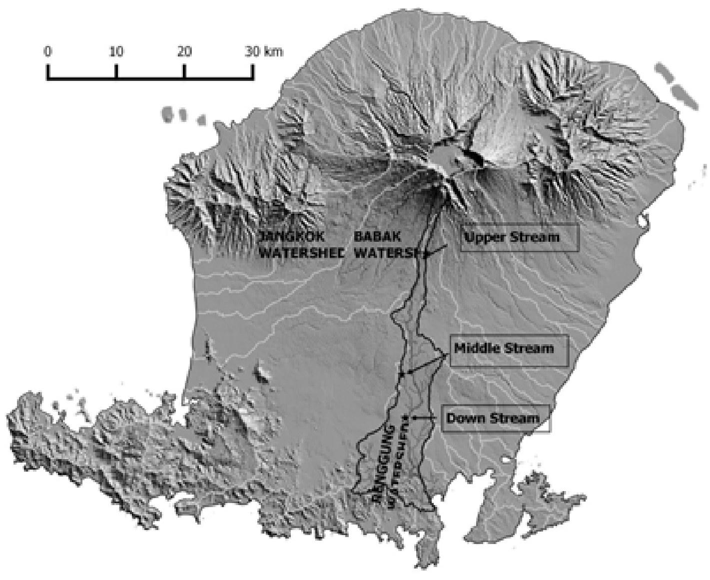

Figure 1 Study area in Renggung Watershed of Lombok Island, eastern Indonesia.

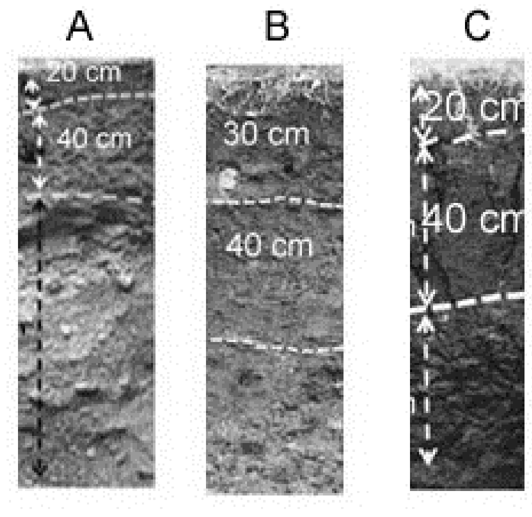

Figure 2 Soil profile in gray color of study site in the upstream (A), middle stream (B) and downstream (C).

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A constant infiltration rate (*f*c) was determined by using Horton infiltration model (Horton 1941).

$$f(t) = fc + (fo - fc)e^{-kt} \qquad [1]$$

Note: f(t) = infiltration capacity (mm h^{-1}) at time t (hour), *fo* = initial infiltration capacity (mm h^{-1}), *fc* = the infiltration capacity at final equilibrium (mm h^{-1}), *k* = a recession constant

In the forest area, infiltration measurement was carried out in a 50 years of the mahagony forest with the density of 10 trees $100m^{-2}$. In agroforestry at upstream, it was measured at three sites, namely agoroforestry-1, agroforestry-2, and agroforestry-3 where these were managed by farmers for 10−15 years, 15−30 years, and >30 years, respectively.

Runoff was measured at all plots during rainy days in rainy season from December 2014 to March 2015. Runoff was measured by collecting excess water flowing out from an isolated plot of 3m x 5m. Along circumference of the squre plot was isolated by a bund made of bamboo sealed with clay soil of 15 cm high and 15 cm wide to prevent water entering the plot. A plastic container equipped with a plastic hose of 0.5 m long, and 2.5 cm in diameter was connected to the outlet of the run off plot. The container was only collect water out from the outlet during measurement which was carried out during rainfall event. Rainfall was daily measured as well as within a period of run off measurement in 24 hours, by using an ombrometer.

Soil moisture contents were measured on each 10 days interval by taking soil samples using a soil borer from two different depths; 0−20 cm and 20−40cm. Sampling points for next 10 days measurement was about 100 cm apart from previous sampling points. Soil moisture contents were determined by using a gravimetric method in Soil Laboratory, Agriculture Faculty of Mataram University.

Measurement of soil properties Measurement of soil properties included soil bulk density, specific density, soil structure, soil texture, and soil organic matter. Soil bulk density was volumetrically measured using undisturbed soil samples. Soil texture was measured using a sedimentation method, and soil organic matter was measured using Walkey & Black method. Composite soil samples for bulk density, specific density, soil structure, soil texture, and soil organic matter were taken from 0−20 cm and 20−40 cm soil depth.

Results and Discussion

Infiltration rate and capacity Figure 3 showed infiltration rate of three different land use systems, namely forest, agroforestry and rainfed agriculture at the upper stream. As shown in Figure 3, infiltration rate and its capacity based on Horton model in forest system was higher than that of agroforestry and rainfed agriculture. Constant infiltration rate (*f*c) at natural forest area was 55.6 cm hr^{-1}. It was the highest rate which could be as a reference for the non disturbed system. Infiltration rate for agroforestry-1, agroforestry-2, and agroforestry-3 was 28.8 cm hr^{-1} (52% of natural forest), 30 cm hr^{-1} (55% of forest) and 37.8 cm hr^{-1} (68% of forest), respectively (Figure 6). It is clear from these figures that constant infiltration rate (*f*c) in agroforestry system could reach infiltration rate of natural forest after a long-term practice of agroforestry. However, infiltration rate at rainfed agriculture was 26.4 cm hr^{-1} which was 47% of infiltration rate in a natural forest. It is clear from the data that conversion from natural forest to agroforestry or rainfed agriculture could result in decreasing of infiltration rate. Wang *et al.* (2015) showed that infiltration in alley cropping system was significantly higher after 9 years compared to that of in monoculture system. It was also found that speed of wetting from downward movement, as well as the depth of maximum infiltration of alley cropping system, was higher than that of in the monoculture system. Concerning water management for the upper part, agroforestry could be an alternative system to sustain infiltration rate of soils. As it is seen from agroforestry-3 with >30 years old that infiltration rate was higher than younger agroforestry system.

Infiltration rate was also carried in a hillock system at middle stream of the watershed. Hillock system is common formation of land physiography at the middle stream. It was formerly covered by densed trees with nearly similar to forest characteristic. Nowadays, it is due to increasing of land demand for food and housing, vegetations on hillock formation have changed to agroforestry system and, in some case, it was converted to upland agriculture. Soil type was complex inceptisols (Figure 2b), soil texture was sandy clay. Roots were commonly found in the first layer (0−30 cm from surface), while gravels with the diameter of 2−3 cm were found in the second layer (30−70 cm from surface), and gravels with diameter >3−5cm was deposited in the third layer (>70 cm from surface).

Infiltration rate on the hillock with agroforestry system and upland agriculture system are presented in Figure 4. It can be seen from the figure that infiltration rate on agroforestry of hillock was 16.8 cm hr^{-1}. It was higher than that of upland agriculture which was 2.4 cm hr^{-1}. A significant change of infiltration rate occurred after converting land use on hillock system to upland agriculture without annual trees. Upland agriculture could result in decreasing of soil infiltration capacity. It was because of tillage practice, removing an organic residue of agriculture crops out of land and exposure of soil surface which intensify soil erosion.

Measurement of infiltration at downstream was also carried out in agroforestry system and rainfed agriculture on vertisols. Figure 2c shows soil profile of vertisols at the measurement site. Vertisols was characterized by cracking when dry, and sticky as well as swelling when wet. Soil texture is clay which is dominated by *montmorillonite*. This causes infiltration rate very slow. Figure 5 shows infiltration rate in agroforestry and rainfed agriculture in Vertisols. It is clear from the figure that constant infiltration rate in agroforestry was higher than that of rainfed agriculture or rice field, i.e. 11.2 cm hr^{-1} and 4.8 cm hr^{-1}, respectively. Agroforestry in vertisols maintains the soils under the unsaturated condition, deep root penetrating which allows water to easily infiltrate during the rain event. However, rainfed agriculture or rice field is commonly under flooding condition or saturated soils. Rice field experiences paddling process during land cultivation. It is to prevent water infiltrating into lower layers of the soil profile and to keep water standing (flooding) on the soil surface. This practice is

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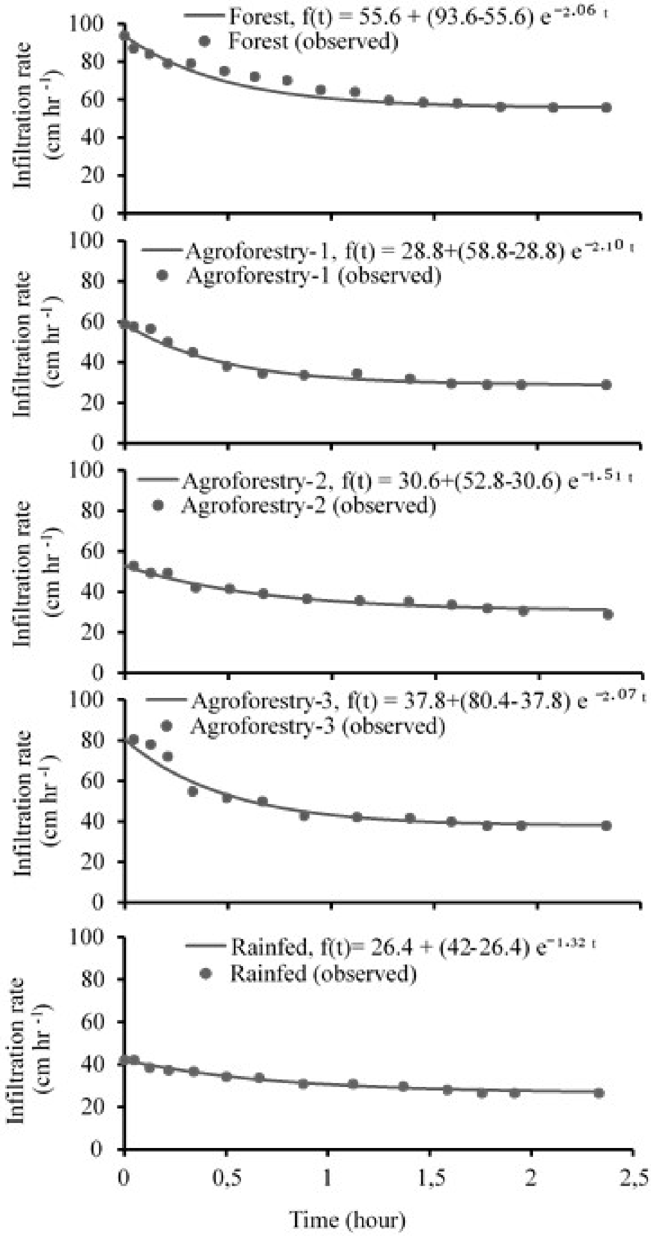

Figure 3 Observed and Hortonian Infiltration model for forest, agroforestry, and rainfed agriculture in upstream

common for rice cropping system which results in reducing infiltration capacity of soils; destroying soil structure and allowing soil compaction.

The results of this study indicate that infiltration rate for tree planting area was higher than that of rainfed agriculture for each three different soil types. Higher infiltration capacity on forest and tree covered land may attribute to soil macroporosity. Shougrakpam *et al.* (2010) presented that undisturbed forest soils had a high degree of soil macroporosity throughout the soil profile, in contrast, paddy fields practices could seal of macropores at the topsoil due to paddling and a *hard pan* formation. Change of soil organic matter due to land cover change (Hajabbasi *et al*. 1997; Haque *et al*. 2014) could also resulted in the different rate of infiltration.

Runoff Tabel 1 shows runoff for each land use at the upper stream (forest, agroforestry, and rainfed agriculture), at the middle (agroforestry and upland agriculture), and at downstream (agroforestry and rainfed agriculture). Characteristics of rainfall during runoff observation showed that intensity of rainfall during measurement was 29.2±11.2 mm hr^{-1}, 37.3±10.1 mm hr^{-1}, and 23.8±10.1 mm hr^{-1}, at upper, middle, and downstream, respectively.

It is clear from the Table 1 that there was no runoff in a relative flat natural forest ecosystem at upper stream. In agroforestry system, runoff was 0.30 mm hr^{-1} and in rainfed agriculture was 0.71 mm hr^{-1}. It was twice of that on

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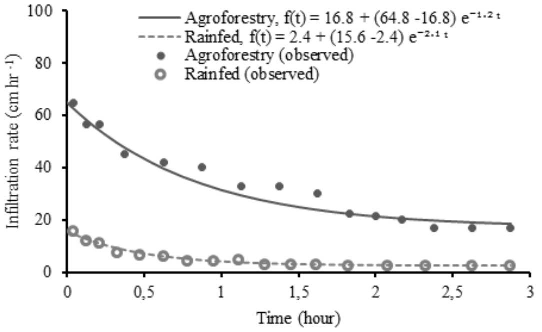

Figure 4 Observed and Hortonian Infiltration model for forest, agroforestry and rainfed in middle stream.

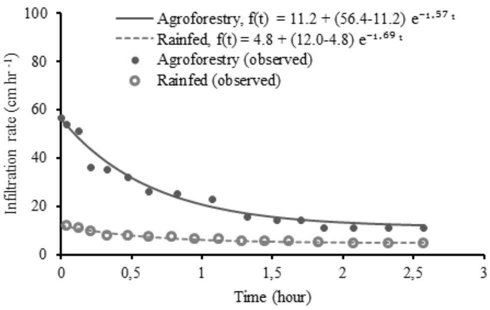

Figure 5 Observed Hortonian Infiltration model for agroforestry and rainfed agriculture in downstream.

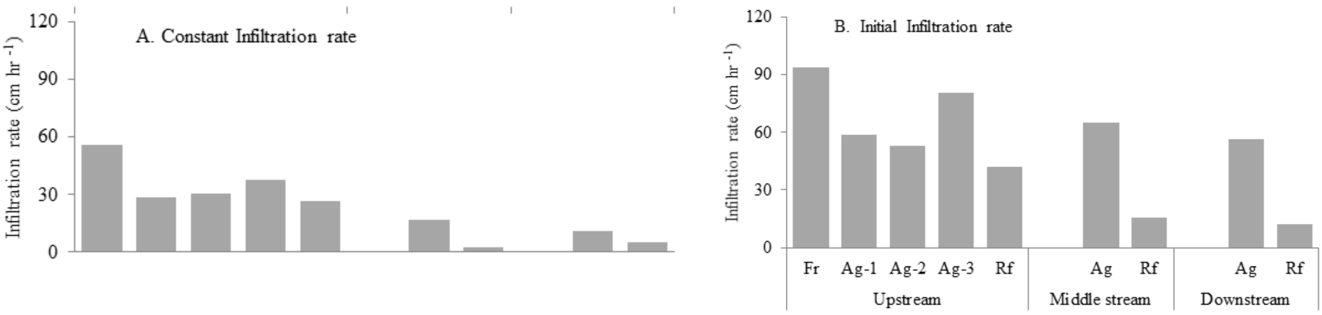

Figure 6 Initial and constant infiltration rate for three study site.

agroforestry. In the middle stream at hillock system, runoff in agroforest was 0.045 mm hr^{-1}. This figure was a half of runoff in upland agriculture where runoff was 0.098 mm hr^{-1}. Terraced upland agriculture on hillock formation could prevent runoff, while conventional agroforestry or "*kebun*" could not effectively prevent runoff on sloppy hillock formation. It is strongly recommended to combine agroforestry and terracing practice on the hillock. The canopy of the vegetation of agroforestry could intercept rain droplets, while terrace could reduce the slope of the land. At downstream, runoff was 0.026 mm hr^{-1} in agroforestry and 0.077 mm hr^{-1} in rainfed agriculture. It is clear that land with physical borders or bunds has a significant effect on preventing runoff. While, agroforestry system has significant role in sustaining infiltration capacity of soils by preventing soil surface exposure, soil compaction and soil erosion.

The result of this study clearly showed that there had been the impact of land use conversion on runoff and sediment. As it was expected that rainfed agricultural practice presented higher runoff and sediment compared to that of forest and agroforestry system. Sànchez *et al*. (2002) conducted an experiment in the Venezuelan Andes showed that erosion in the natural forest was 0.43 mg ha^{-1}, which was lower than horticultural crops in rotation (22 mg ha^{-1}), apple tree (1.96 mg ha^{-1}), and pasture without grazing (1.11 mg ha^{-1}). Ngo *et al*. (2015) reported that land use change in Da River Basin in Vietnam from forest to field crop and urban area increased annual runoff and sediment, while forest expansion conservation decreased runoff and sediment.

Soil mositure dynamic Table 2 and Tabel 3 show soil moisture dynamic in the forest, agroforestry, and rainfed agriculture at upper, middle, and downstream for dry season (August to October 2014) and rainy season (November 2014−March 2015), and for two soil depths, namely 0−20 cm and 20−40 cm. Soil samples for measuring soil water content was taken every 10 days by using soil driller. The position for successive soil sampling was about 100 cm apart from the last position of sampling. It moved horizontal and from down to upper.

It can be seen from the Table 2 that in the upstream, soil water content of 0−20 cm depth in the forest was higher than that of agroforestry and rainfed agriculture. At the middle and downstream, soil water content of similar depth in agroforestry was higher than that of rainfed. The pattern of soil moisture dynamic at 0−20 cm depth was similar to 20−40 cm depth. Soil water content in forest ecosystem was higher than that of agroforestry and rainfed agriculture at upstream. Soil water content in agroforestry was always higher than that of upland agriculture at the middle stream and rainfed agriculture at downstream.

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Tabel 1 Runoff for each land use in the upper stream (forest, agroforestry, and rainfed agriculture), in the middle (agroforestry and upland agriculture) and at down stream (agroforestry and rainfed agriculture).

Site/land use	Average	Maximum	Minimum	Deviation
UPPER STREAM Site : Aikbual				
Rainfall (mm hr^{-1})	29.294	67.500	13.263	11.240
Forest (mm hr^{-1})	0.000a	0.000	0.000	0.000
Agroforestry-1 (mm hr^{-1})	0.014ab	0.086	0.000	0.021
Agroforestry-2 (mm hr^{1})	0.030bc	0.178	0.000	0.037
Agroforestry-3 (mm hr^{-1})	0.035c	0.258	0.000	0.054
Runoff Rainfed (mm hr^{-1})	0.071d	0.441	0.015	0.091
HSD 5%	0.019			
MIDDLE STREAM Site: Selebung				
Rainfall (mm hr^{-1})	37.311	56.000	14.000	10.187
Agroforestry (mm hr^{-1})	0.045a	0.116	0.000	0.028
Rainfed (mm hr^{-1})	0.098b	0.405	0.029	0.077
HSD 5%	0.017			
DOWNSTREAM Site: Sukaraja				
Rainfall (mm hr^{-1})	23.840	44.000	10.200	10.473
Agroforestry (mm hr^{-1})	0.026a	0.060	0.000	0.024
Rainfed (mm hr^{-1})	0.077b	0.305	0.015	0.084
HSD 5%	0.016			

Tabel 2 Water content in dry season August–October 2014

	Water content 0−20 cm (%)				Water content 20−40 cm (%)			
	Average	Max	Min	Dev	Average	Max	Min	Dev
UPPER STREAM Site: Aikbual								
Forest (%)	32.22 b	43.89	28.53	5.32	26.40 b	39.30	19.92	7.06
Agroforestry-1 (%)	30.76 b	41.36	24.27	5.82	20.25 a	33.75	13.85	7.48
Agroforestry-2 (%)	29.12 b	39.51	24.04	5.27	20.40 a	33.61	14.97	5.97
Agroforestry-3 (%)	27.72 ab	40.79	22.23	6.38	20.37 a	33.07	14.77	5.83
Rainfed (%)	23.32 a	34.01	16.94	5.88	16.92 a	33.22	11.01	7.46
HSD 5%	4.16				4.92			
MIDDLE STREAM Site: Selebung								
Agroforestry (%)	14.68 b	19.53	9.88	3.20	15.48 b	18.33	11.50	2.32
Rainfed (%)	10.76	13.54	8.07	1.87	14.12	18.60	10.15	2.66
HSD 5%	1.40				1.34			
DOWNSTREAM Site: Sukaraja								
Agroforestry (%)	16.67 b	21.47	11.54	3.20	20.03 b	23.80	16.03	2.50
Rainfed (%)	13.19	19.00	9.96	2.99	18.33	22.07	13.29	2.76
HSD 5%	1.66				1.41			

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Tabel 3 Water content in rainy season November 2014−March 2015

	Water content 0−20 cm (%)				Water content 0−20 cm (%)			
	Average	Max	Min	Dev	Average	Max	Min	Dev
UPPER STREAM Site: Aikbual								
Forest (%)	56.70 b	65.10	52.37	4.36	56.93 c	63.80	50.50	4.87
Agroforestry-1 (%)	54.28 a	60.97	50.64	3.78	51.90 b	56.47	48.20	2.76
Agroforestry-2 (%)	54.51 ab	62.80	50.33	4.18	50.49 ab	54.23	48.73	1.75
Agroforestry-3 (%)	54.68 ab	61.37	49.97	3.74	51.33 a	56.67	48.40	2.41
Rainfed (%)	52.73 a	59.70	46.67	4.15	50.09 a	53.53	47.33	1.68
HSD 5%	2.24				1.62			
MIDDLE STREAM Site: Selebung								
Agroforestry (%)	49.29 b	52.27	40.03	4.07	51.57b	54.80	41.93	3.56
Rainfed (%)	47.43 a	50.87	39.23	3.86	50.11 a	54.60	41.37	3.31
HSD 5%	1.61				1.39			
DOWNSTREAM Site: Sukaraja								
Agroforestry (%)	50.12 b	54.53	44.70	2.66	53.18 b	55.80	50.53	1.50
Rainfed (%)	47.41 a	52.47	40.33	3.73	51.40 a	55.00	48.87	1.73
HSD 5%	1.31				0.65			

It is obvious that soil water content during the dry season was lower than that of the rainy season (Table 2 and Table 3). This finding stated that natural forest was the best ecosystem in term of soil moisture conservation. It was possible for agroforestry to conserve soil moisture during wet and dry seasons. Shifting from forest system to either upland agriculture or rainfed agriculture would result in decreasing the capacity of soils to conserve moisture. Haque *et al.* (2014) presented that soil moisture content, water holding capacity of deforested sites was lower than that of forest sites.

Variation of soil water content under forest, agroforestry and rainfed associated to different in soil properties and land use. Soil texture in the forest, agroforestry and rainfed at upper was loam to sandy loam with coarse material of pumice stones. Soil texture in agroforestry, and rained in the middle is clay loam, and agroforestry and rainfed at downstreamwas clay. Soil bulk density (BD) of the soils was similar for each site. Soil organic matter in the forest, agroforestry and rainfed at the upper was 6.8%, 5.0%, and 3.5%, respectively, while for agroforestry and rained at the middle was 3.5% and 2.7%, in agroforestry and rainfed at downstream was 2.5% and 1.7%, respectively.

The result of this study showed that land cover affected soil moisture status. Wang *et al*. (2012) which conducted soil moisture monitoring during the growing season in Loess Plateau in northern China showed that soil moisture under the corn was higher than that of grass, shrubs, and plantation forest. D'Odorico *et al.* (2007) stated that soil moisture under canopy was higher than that in inter canopy space, though soon after rainfall soil moisture in the inter canopy are wetter to that of under canopy. Investigation of spatial and temporal variation of soil moisture in silvopastoral of Loess Plateau in the Province of west Shanxi showed that soil moisture content both in grass land and forest land decreased by increasing soil depth (Lei *et al*. 2011).

Conclusion

Land use and land cover change from natural forest to either agroforestry or rainfed agriculture with cash crops at upper stream of Renggung Catchment had significantly reduced infiltration capacity of soils; from 56.6 cm hr^{-1} (in the forest) to 28.8 cm hr^{-1} in agroforestry of 10−15 years old, to 30.0 cm hr^{-1} in 15−30 years agroforestry, and to 37.8 cm hr^{-1} in > 30 years agroforestry. There was more than half capacity of soil infiltration rate had lost due to converting the natural forest into rainfed agriculture that was 26.4 cm hr^{-1}. High capacity of soil infiltration in the natural forest at upper stream resulted in zero runoff. Agroforestry system could serve for better soil infiltration of inceptisols on hillocks formation at the middle stream and of heavy clay vertisols at downstream. The capacity of agroforestry system in preventing runoff was in between forest and rainfed agriculture. The natural forest and long-term established of agroforestry had potential capacity to conserve soil moisture at the level of 0 to 40 cm soil depth during the dry season. There was unfortunately that soil moisture in rainfed agriculture continually depleted to the level of a wilting point during a peak of the dry season. At middle and downstream, soil water content for both depths was significantly higher in agroforestry compared to that of rainfed. Overall, results of the study could be considered as an empirical and scientific proof that agroforestry would be an acceptable practice in sustaining hydrology cycle and soil water conservation in the watershed.

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