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Effects of selective logging methods on runoff characteristics in paired small headwater catchment

Hatma Suryatmojo[a,*], Fujimoto Masamitsu[b], Ken'ichiro Kosugi[a], Takahisa Mizuyama[a]

[a]*Laboratory of Erosion Control, Division of Forest and Biomaterials Science, Graduate School of Agriculture, Kyoto University, Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan*
[b]*Educational Unit for Adaptation and Resilience for a Sustainable Society, Center for the Promotion of Interdisciplinary Education and Research, Kyoto University, Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan*

Abstract

Reduction of vegetative cover by forest harvesting generally increases the average surface runoff volume and peak discharge for a given area of land. Forest harvesting in tropical Indonesian rainforest is managed using a selective logging system. The purpose of this study is to find the effect of controlled selective logging technique to reduce the hydrological effect on runoff. This study was conducted in three paired small headwater catchments in natural tropical rainforest area of Central Kalimantan, Indonesia. Catchment A was an undisturbed catchment for control. Catchment B and C were treated with reduce impact logging technique in selective logging activities. Controlled selective logging activities in the catchment B and C reduced canopy cover to 30% of natural cover. Discharging hydrograph response in the logged catchment produced higher peak discharge as consequences of high surface runoff. The runoff hydrograph parameter in the three catchments showed similar response to rainfall event, and the highest response of peak discharge was in the catchment B which had largest opened area. The average of direct runoff ratio in the catchment A, B and C were 31.35%; 46.12% and 44.83%, respectively. Implementation of reduce impact logging technique was effective to control the impact of logging on the runoff responses.

Keywords: Tropical rain forest, intensive forest management system, direct runoff, reduce impact logging

* Corresponding author. Tel.: +81-80-3840-2726; fax: +81-75-753-6088.
E-mail address: mayong@kais.kyoto-u.ac.jp.

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1. Introduction

Vegetation cover change has a profound influence on the hydrological cycle. Reduction of vegetative cover by forest harvesting generally increases the average surface runoff volume and total water yield for a given area of land. Tropical Indonesia rainforest is managed using an intensive forest management system. The main activity is selective logging for timber harvesting and intensive line planting to enrichment the standing stock. Rainfall intensity in a tropical rainforest on Kalimantan Island, Indonesia, is high; therefore, hydrologic responses, such as peak discharge and direct runoff, are potentially to become problems when land use or forest cover changes [1].

Selective logging in the forested area is suspected to dramatically impact soil properties. In a previous study, the infiltration capacity of a tropical rainforest 1 year after selective logging and intensive line planting treatment decreased to 81.8% that of a virgin forest [2]. The effect of human activities on runoff regimes has been demonstrated by several experimental studies in various parts of the world. Much research has focussed on monitoring the influence of changes in land cover – mainly deforestation and afforestation processes [3, 4, 5, 6] – and the impact of logging [7, 8, 9]. Several studies have investigated the rainfall–runoff in Kalimantan, Indonesia [8, 10, 11, 12, 13]. However, research concerning the intensive forest management system with selective logging and intensive line planting is still limited [13]. Thus, there is a need existing to investigate the hydrologic response of tropical rainforests to runoff characteristics in forest managed under an intensive management system.

Paired catchment studies have been widely used as a means for determining the magnitude of hydrologic response changes resulting from changes in vegetation [14]. Paired catchment studies involve the use of two catchments with similar characteristics in terms of slope, aspect, soils, area, climate and vegetation located adjacent or in close proximity to each other. All catchments are monitored; one or more of the catchments is subjected to treatment and the other remains as a control. The changes in hydrologic response can, then, be attributed to changes in vegetation. This paper focuses on the impact of selective logging activities on runoff characteristics.

2. Methods

2.1. Study site and catchment characteristics

This study was conducted in tropical rainforest at the Sei Seruyan block of the Sari Bumi Kusuma concession area, a private forest company in Central Kalimantan, Indonesia (00º36'–01º10' south latitude and 111º 39'–112º 25' east longitudes). This location is part of a high-biodiversity area known as the "Heart of Borneo". The study site was located in the headwater region of the Katingan watershed, one of the largest watersheds in Central Kalimantan (Fig. 1.a.). The mean annual precipitation for the period 2001–2010 was 3,708 mm, with the highest average monthly precipitation (367 mm) occurring in November and the lowest average monthly precipitation (183 mm) occurring in August. According to the forest climate classification system of Schmidt and Ferguson, the area is a type A (very wet) tropical rainforest (monthly average rainfall > 100 mm). The number of rainy days varies from 95 to 112 days, and the mean temperature is 30ºC–33ºC at noon and 22ºC–28ºC at night [13].

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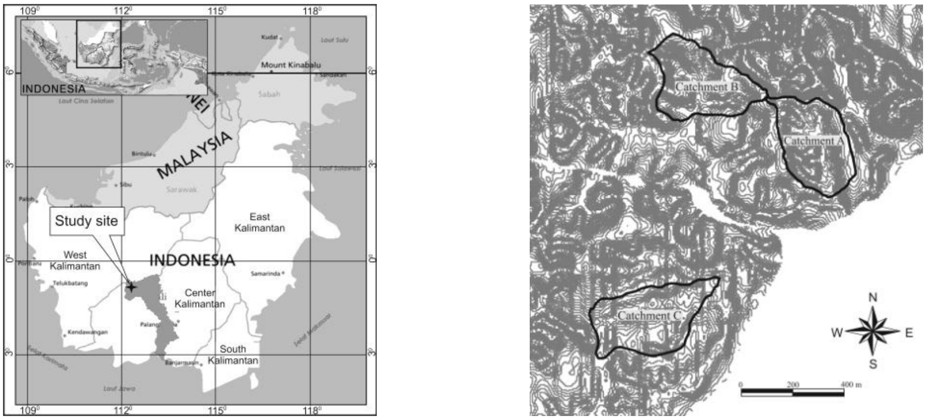

Fig. 1. (a) study site in the headwater of the Katingan watershed; (b) three paired small catchments

The three-paired small catchments with similar physical catchment characteristics (Table 1.) were established to analyze the hydrologic responses (Fig.1.b).

Tabel 1. Physical characteristics of the three catchments.

Catchment	Drainage area (km^2)	Catchment shape[a]	Catchment slope (%)	Drainage density (km/km^2)	Main river length (km)
Catchment A	0.087	0.57	30.9	17.84	0.47
Catchment B	0.087	0.80	32.5	15.66	0.38
Catchment C	0.094	0.34	22.4	15.28	0.52

Catchment A was monitored as a control, catchment B and C were subjected to treatment with selective logging. Catchment B and C treated and supervised with typical of present commercial logging practices with cutting regimes of 50 DBH for dipterocarp and non-dipterocarp, respectively. A stricter cutting regime coupled with several additional logging system control was imposed to minimize the reduced impact logging. This included alignment of logging roads along the contour, proper drainage for road surface runoff, skid trails rehabilitation by construction of cross-drains at 45-60° along the skid trails, skid trails deactivation at the end of skid trails line. No logging was allowed within buffer area of no less than 20 m on both sides of perennial streams. Logging operations generally involved tree felling and bucking using chainsaws, upslope skidding of logs using crawler tractors and transporting of logs using logging trucks.

2.2. Observations and analysis

To clarify the characteristics of rainfall among three catchments, an automatic tipping-bucket rain gauges (logging time, 15 min) were installed near the catchment. A 90° V-notch weir and a water-level logger with a time interval of 15 min were installed at each catchment outlet. Rainfall and hydrograph data were selected at each catchment. The hydrograph analysis was undertaken by dividing the runoff into direct runoff and base flow using a straight-line method and then calculating the direct runoff volume for each hydrograph of each catchment. Direct runoff was the sum of surface runoff, subsurface flow and channel interception.

3. Results

3.1. Canopy cover changes

Selective logging technique using heavy machine destroys surface soil and vegetation structure while cutting and skidding. A 1 hectare permanent sample plot was established on the three catchments to Table measure the vegetation structure and canopy cover in the catchment. Selective logging significantly decreased the canopy cover by reducing the number of trees (Table 2).

Table 2. Individual number / hectare of vegetation structure and percentage of canopy cover in the three catchments.

Vegetation structure	Catchment A (N/ha)	Catchment B (N/ha)		Catchment C (N/ha)	
		before logging	after logging	before logging	after logging
tree	229	167	135	178	101
pole	64	44	17	23	13
sapling	170	147	130	188	115
seedling	36	37	77	70	63
canopy cover	98%	88%	60%	79%	56%

Selective logging in the catchment B and C has decreased the individual number/hectare of vegetation structure and canopy cover 31.8% and 29.1%, respectively. In the conventional selective logging activities, the canopy cover has decreased to 38.5% [11]. Application of reduce impact logging technique could control the damage of vegetation structure.

3.2. Discharge hydrograph response

Physical catchment parameters, such as slope, shape, main-stream slope and drainage density affect stream flow and influence the shape of the hydrograph through catchment storage, runoff speed, infiltration and soil water content. The hydrologic behaviour of small catchments tends to be different from that of large catchments. A small catchment is very sensitive to high-intensity rainfall of short duration and land cover characteristics [15].

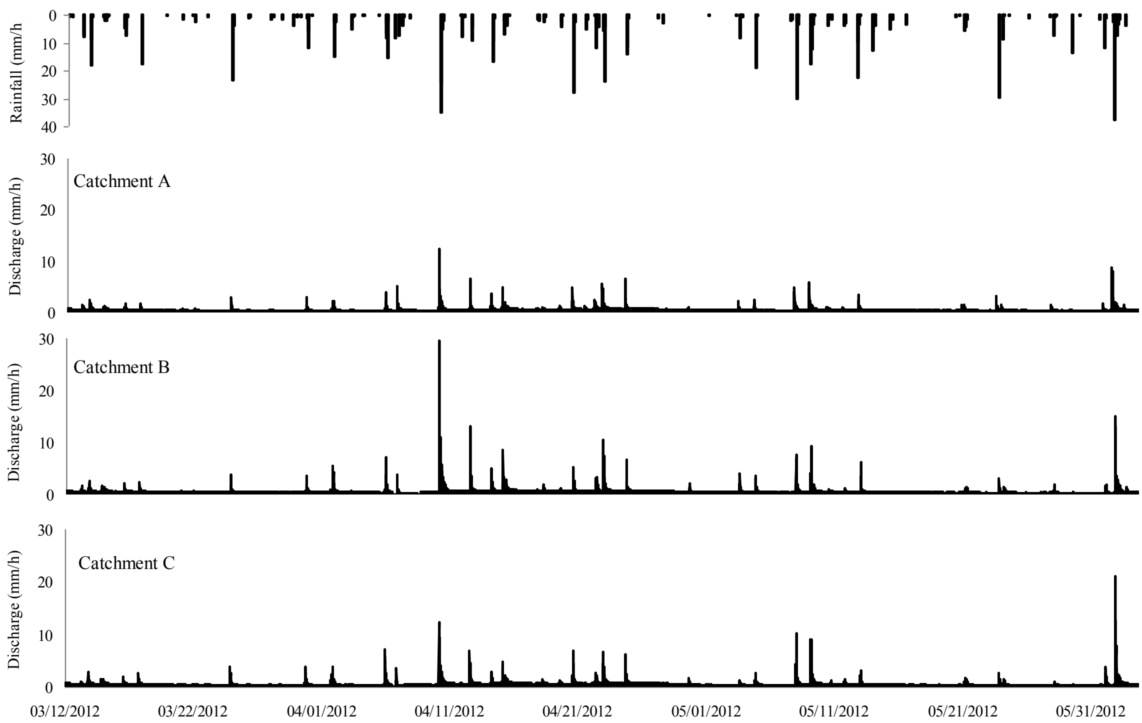

Fig. 2. Discharge hydrograph response in the catchment A, B and C

Figure 2 shows the discharge hydrograph responses from small rainfall event (<20 mm) in the catchment A, B and C which showed similar response to rainfall. Peak discharge response in the catchment B and C was slightly higher than that in the catchment A. In the medium rainfall event (20-40 mm), the discharge hydrograph response in the catchment B and C showed to be higher than that in the catchment A. Selective logging activities has reduced the forest interception from canopy cover. Large open area in the catchment B and C accelerated the surface runoff flow to the channel and increased the peak discharge. Significant differences indicated in the catchment B and C for high rainfall event (>40 mm). The peak discharge response in the catchment B and C has been significantly higher than that in the catchment A. Catchment A responded slowly relative to others catchment. Natural vegetation structure in the catchment A had significant role to control the discharge hydrograph response.

3.3. Runoff hydrograph characteristics

Runoff is the flow resulting from precipitation events. Some of these flows may occur during and immediately following the precipitation event and such is known as storm water runoff or direct runoff. During March – June 2012, 30 selected data of paired rainfall event and runoff hydrograph were analyzed from each catchment. Hydrograph characteristics were calculated from the parameter of time to peak (t_p); peak discharge (q_p); lag time (t_L); and base time (t_b). Hydrograph parameters response to rainfall is shown in Figure 3.

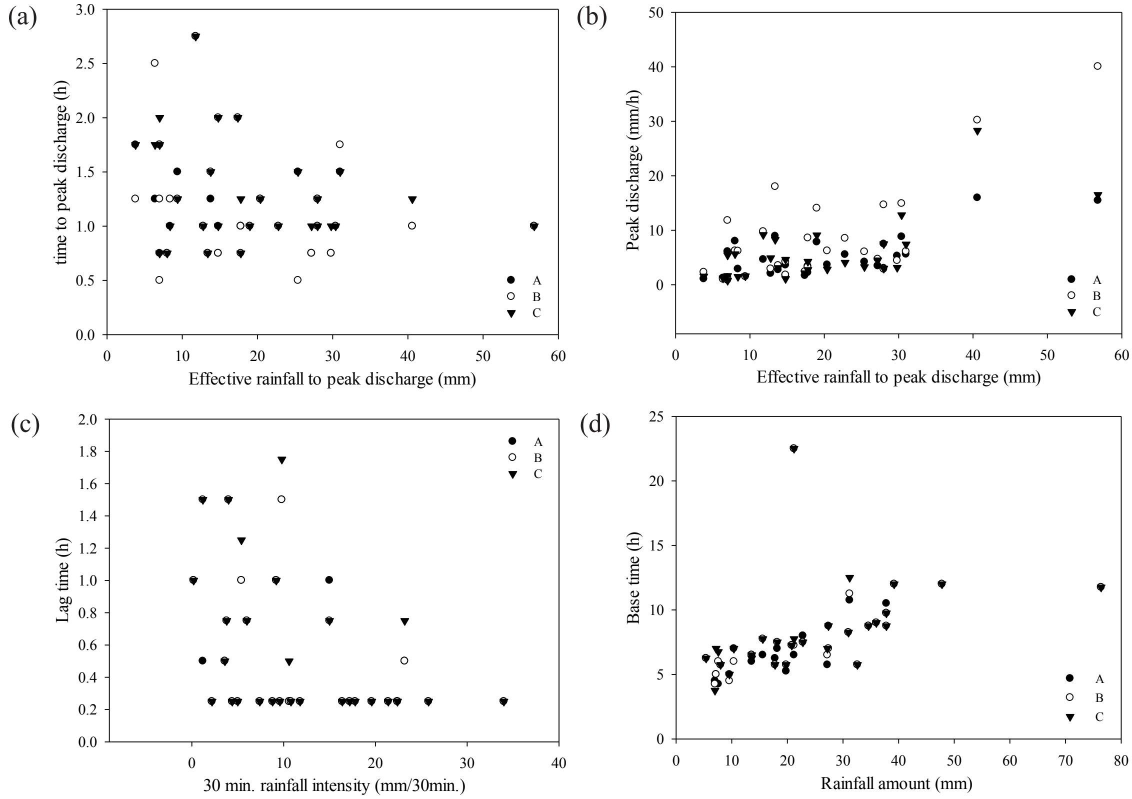

Fig. 3. Hydrograph parameters response to rainfall event in the three catchments: (a) time to peak (t_P); (b) peak discharge (q_D); (c) lag time (t_L) and (d) base time (t_B)

Fig. 3 shows the hydrograph parameters response to rainfall in the catchment A, B and C which had similar pattern. Higher of 30 min. rainfall intensity in Fig. 3.a. produced shorten time to peak. Time to peak in the catchment A and C was slightly longer than catchment B. Peak discharge response in the catchment B was higher than that in the catchment A and C (Fig. 3.b.). Fig. 3.c. shows the lag time in the catchment C was relatively longer to lag time in the catchment A and B; those were influenced by a longer time to peak and duration of rainfall. Hydrograph response of base time in the catchment A responded shorten time relative to the catchment B and C (Fig. 3.d.).

3.4. Direct runoff response

To understand the impact of canopy cover changes and selective logging activities in the stream runoff, the changes of peak discharge and direst runoff are needed for analysis. In the selected data of paired rainfall event and runoff hydrograph, the response of peak discharge and direct runoff were analyzed and shown in Figure 4.

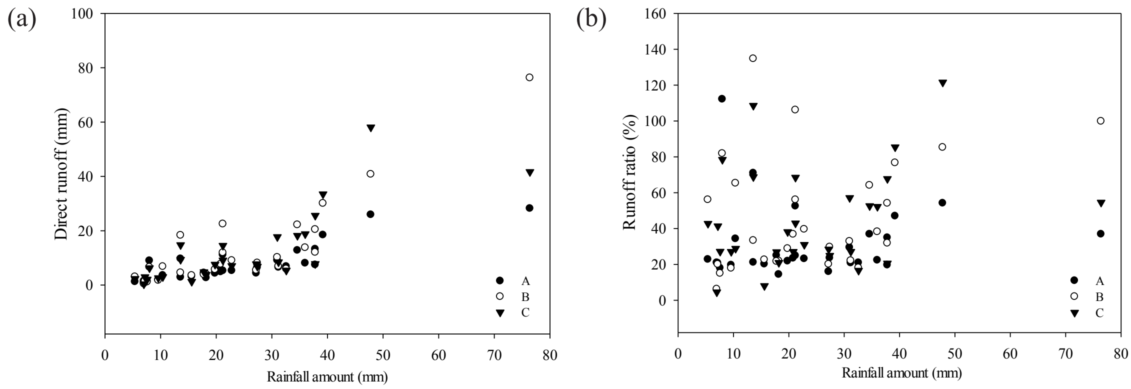

Fig. 4. (a) Direct runoff response to rainfall event in the three catchments: (a) direct runoff and (b) runoff ratio

Fig. 4.a. shows, in the rainfall event < 40 mm, the direct runoff response in the catchment A, B and C which showed similar response and those were significantly different in the large rainfall event (> 40 mm). In the large rainfall event, catchment B produced larger direct runoff than that in the catchment A and C. Runoff ratio is a catchment response of rainfall that became direct runoff. Average of runoff ratio in the catchment A, B and C were 31.35%; 46.12% and 44.83%, respectively (Fig. 4.b.).

4. Discussions

The selective logging has decreased the forest canopy cover and significantly influences the change of runoff hydrograph response in the three catchments. During the beginning of rainfall, water storage in the canopy increases with time and gradually levelled off at maximum canopy storage capacity. When the canopy interception reaches the maximum, any excess water will make its way to the stream channel as surface runoff quickly. Reducing the forest canopy cover decreases the canopy interception and increases the net rainfall in the forest floor. The changes of net precipitation influence the surface runoff and finally change the runoff hydrograph. In our study site, the canopy cover density in the undisturbed catchment of catchment A was higher than that in the disturbed catchment of catchment B and C which were 98%, 60% and 56%, respectively (Table 2.). The canopy interception in the natural forest catchment and 1 year logged catchment were 24.61% and 15.15% of rainfall, respectively [16].

In the catchment A, vegetation structure was dominated by trees (Table 2). Minimum sunlight under canopy trees allowed limited growth of understory vegetation, such as saplings (shrubs) and seedlings. Rainfall in this catchment was captured and stored in the canopy as canopy interception. When the rainfall interception in the maximum capacity, rainfall was accumulated in the forest floor, stored in the litter interception and followed the process of infiltration and surface runoff.

In the catchment B and C, reduction of canopy cover by selective logging has decreased the canopy interception and increased the net rainfall to the forest floor. In the catchment B, the logging road construction has increased the open area of catchment. The movement of heavy machine on forest harvesting has increased the soil compaction on skid trails that might have reduced the infiltration capacity. The damaged of understory vegetation minimized the forest floor resistance. Those conditions caused the rainfall mostly became surface runoff. On the other side, logging activities left a pile of branches and stems on the forest floor and those would increase the forest floor resistance.

In the discharge hydrograph response, the selective logging in the catchment B and C has increased the peak discharge higher than that in the undisturbed forest in catchment A (Fig.2.). In the same rainfall amount, hydrograph response in the catchment B and C produced higher peak discharge. A low canopy interception increased the amount of net rainfall on the forest floor and increased the amount of surface runoff; those caused the hydrograph response in the catchment B and C much higher than that in the catchment A.

Runoff hydrograph analysis of catchment A, B and C in Figure 3 showed similar response to rainfall event. Time to peak (Fig. 3.a.) and lag time (Fig. 3.c.) responses in the three catchments had similar response. Similar physical catchment characteristics influenced the similar catchment response in time to peak and lag time. Peak discharge responses in Figure 3.b. of catchment C showed higher amount than that in the catchment A and C. More open areas from logging road in the catchment B produced large amount of surface runoff and increased the amount of peak discharge rather than catchment A and C. Catchment B and C produced longer base time than that in the catchment A. Catchment B and C produced larger surface runoff and those would extend the time to base on the runoff hydrograph and caused longer base time.

Detail analysis of direct runoff in Figure 4.a. indicated that catchment A, B and C produced similar direct runoff amount. In the rainfall amount < 40 mm, surface runoff could be retained by the forest floor and controlled the direct runoff in the channel. When the large rainfall occurred, the surface runoff became larger and exceeded the forest floor retention, which caused the direct runoff in the catchment B and C were larger than in the catchment A. In the rainfall amount > 40 mm, catchment B tended to produce larger direct runoff amount than that in catchment A and C. Larger open area produced larger surface runoff that caused higher direct runoff in the stream channel. Those also caused the runoff ratio in the catchment B higher than that in the catchment A and C (Fig. 3.b.).

5. Conclusions

We investigated the hydrologic response of runoff characteristics using three paired small headwater catchments. The effect of forest canopy cover changes on the hydrologic response is an important factor in catchment hydrology and forest management. Our monitoring data provided strong linkages between selective logging activities, forest canopy cover, vegetation structure and the runoff characteristics in discharging hydrograph, runoff hydrograph parameters and direct runoff. Our main results were: (1) Controlled selective logging activities in the catchment B and C reduced canopy cover to 30% of natural cover; (2) discharging hydrograph response in the logged catchment produced higher peak discharge as the consequences of high surface runoff; (3) the runoff hydrograph parameter in the three catchments showed similar response to rainfall event, and the highest response of peak discharge was in the catchment B which had the largest opened area; (4) the average of direct runoff ratio in the catchment A, B and C were 31.35%, 46.12% and 44.83%, respectively.

These differences in hydrograph parameter, peak discharge and direct runoff among the three catchments were attributed to different land cover conditions by selective logging activities. In addition, physical catchment characteristics, including topography, catchment shape and soil characteristics, were contributing in affecting hydrograph shape responses.

Forest managers' thinking about implementing the selective logging system in tropical rainforests must implement the reduce impact logging technique and consider the impact of runoff characteristics, especially in the first year after logging. A proper system of monitoring would allow more direct associations to be made between management practices and their impacts, thereby, enabling the identification of problems so that managers can take appropriate preventive measures to improve the forest management technique.

References

[1] Suryatmojo H, Masamitsu F, Kosugi K, Mizuyama T. Runoff characteristics at different forest cover catchments in a Tropical Indonesia Rainforest. *Proceeding of The IHP Symposium on Extreme events "Meteorological, Hydrological and Tsunami disaster: Social adaptation and Futures"*. Kyoto University, Japan; 2011, p. 19-28.

[2] Suryatmojo H. The Effect of Line Planting Toward Infiltration. *Proceeding of International Seminar "Research on Plantation Forest Management : Challenges and Opportunities"*, Bogor; 2009.

[3] Cosandey C, Andreassian V, Martin C, Didon-Lescot JF, Lavabre J, Folton N, Mathys N, Richard D. The Hydrological Impact of The Mediterranean Forest: a review of French research. *Journal of Hydrology* 2005;**301**(1):235–249.

[4] Chaves J, Neill C, Gemer S, Neto SG, Krusche A, Elsenbeer H. Land Management Impacts on Runoff Sources in Small Amazon Watersheds. *Hydrological Processes* 2008; **22**(12):1766–1775.

[5] Huang M, Zhang L, Gallichand J. Runoff Responses to Afforestation in a Watershed of the Loess Plateau, China. *Hydrological Processes* 2003;**17**(13):2599–2609.

[6] Moody JA, Martin DA. Post-fire, Rainfall Intensity-Peak Discharge Relations for Three Mountainous Watersheds in the Western USA. *Hydrological Processes 2001*;**15**:2981-2993.

[7] Douglas I. Predicting Road Erosion Rates in Selectively Logged Tropical Rain Forests. Proceedings of Symposium HS01 held during IUGG2003 at Sapporo, July 2003. *IAHS Publ* 2003; **279**:199-205.

[8] Stadtmueller T. Soil Erosion in East Kalimantan, Indonesia. Proceedings of the Fiji Symposium. *IAHS-AISH Publ* 1990;**192**:221-230.

[9] Van Der Plas MC, Bruijnzeel LA. Impact of Mechanized Selective Logging of Rainforest on Topsoil Infiltrability in the Upper Segama Area, Sabah, Malaysia. Hydrology of Warm Humid Regions. *IAHS Publ* 1993;**216**: 203-211.

[10] Hartanto H, Prabhu R, Widayat ASE, Asdak C. Factors Affecting Runoff and Soil Erosion: Plot-level Soil Loss Monitoring for Assessing Sustainability of Forest Management. *Journal of Forest Ecology and Management* 2003;**180**(1-3):361-374.

[11] Ruslan M, Manan S. The effect of Skidding Roads on Soil Erosion and Runoff in the Forest Concession of Pulau Laut, South Kalimantan, Indonesia. (in Indonesia language). *Proceeding of Seminar on Hydrology and Watershed Management, Surakarta, Indonesia*; 1980, p. 169-194,.

[12] Suryatmojo H, Kosugi K, Mizuyama T, Nugroho P, Hakim AR. Water Balance in Tropical Rain Forest with Selective Cutting and Line Planting Treatment. *Proceeding of* the 1st *International Conference "Sustainable Future for Human Security",* Kyoto University. Japan; 2010.

[13] Suryatmojo H, Masamitsu F, Kosugi K, Mizuyama T. Impact of selective logging and intensive line planting system on runoff and soil erosion in a Tropical Indonesia rainforest. *Proceedings of River Basin Management VI.* Wessex Institute of Technology, UK; 2011, p. 288-300.

[14] Brown AE, Zhang L, McMohan TA, Western AW, Vertessy RA. A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *Journal of Hydrology* 2005;**310**:28-61.

[15] Chang M. *Forest Hydrology*, *An Introduction to Water and Forests*. 2nd ed. CRC Press, U.S.A; 2006, p. 201-2010.

[16] Suryatmojo H, Masamitsu F, Kosugi K, Mizuyama T. Impact of canopy cover changes to rainfall interception in the intensive forest management system in a Tropical Indonesia Rainforest. *Proceeding of the 2nd International Conference "Sustainable Future for Human Security",* Kyoto University. Japan; 2011, p. 557-564.