Australian Journal of Basic and Applied Sciences, 9(1) January 2015, Pages: 65-70

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

New and Old Waters Separation using Isotopic Approaches for Oil Palm and Regenerated Forest Catchments in Sarawak, Malaysia

[1]Geoffery James Gerusu, [2]Chow Ming Fai, [3]Belden Giman, [4]Awan Janting, [4]Raymond Dunggat and [5]Zamri Rosli

[1]*Department of Forestry Science, Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia, Bintulu Sarawak Campus, Bintulu, Sarawak, Malaysia*
[2]*Center for Sustainable Technology and Environment (CSTEN), Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.*
[3]*Conservation Department, Grand Perfect Sdn Bhd, Bintulu, Sarawak, Malaysia*
[4]*Boustead Pelita, BPK Ladang Maong Plantation,Sibu, Sarawak, Malaysia*
[5]*Department of Forestry Science, Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia, Bintulu Sarawak Campus, Bintulu, Sarawak, Malaysia.*

ARTICLE INFO

Article history:
Received 19 September 2014
Received in revised form
19 November 2014
Accepted 22 December 2014
Available online 2 January 2015

Keywords:
New water, Old water, Hydrograph separation, Regenerated forest catchment, Oil palm catchment.

ABSTRACT

Forest conversion has potentially affecting the hydrological processes within the catchment area especially in tropical countries due to the frequent and intense rainfall. Thus, the aims of this study are:- i) to evaluate the water flow pattern for oil palm plantation and regenerated forest catchments; and ii) to compute the new and old water contributions to stream discharge from these two types of catchments during storm events. Isotopic (Oxygen-18 ($\delta^{18}O$)) approach was applied to perform two-component hydrograph separation for the monitored five storm events. Our results showed that new water was ranging between 51 to 59% under regenerated forest catchment and 63 to 69% under oil palm plantation catchment, respectively. This implies that more new water was generated in the overland flow from oil palm canopies due to limited infiltration (soil compaction) within oil palm catchment. Our results also discovered that new water has dominated the runoff volume during peak flow. It is evidenced that rainfall has become the main source of supplying new water in both catchments due to overland flow or rapid subsurface delivery of storm water. Detailed study on the long term flow regime is necessary to formulate an effective management strategy for protecting water resources in the tropic.

To Cite This Article: Geoffery, J.G., M.F. Chow, G. Belden, J. Awan, and D. Raymond and Zamri Rosli., New and old waters separation using isotopic approaches for oil palm and regenerated forest catchments in Sarawak, Malaysia. ***Aust. J. Basic & Appl. Sci.,*** *9(1): 65-70, 2015*

INTRODUCTION

In Malaysia, increasing lands conversion to profitable land uses such as oil palm estate and forest plantation have raised concerns among authorities, scientists, environmentalists and relevant communities. It has been associated by the removal of the primary forest and expanded significantly (Koh and Wilcove, 2008). It was estimated that about 1.2 million hectares of rainforests have been developed into oil palm plantation in year 2012 and was projected to be increased to 1.5 million hectares by the year 2020. The wide-spread and extensive clearance of rainforest into large scale oil palm plantations was mainly driven by the high global market prices, which provide good profit margin compared to other types of land use. The state government of Sarawak has allocated 1 million hectares of land that will be developed for tree plantations due to the increasing demand for industrial wood (Chan, 1998). Other activities such as urbanisation and rural development also drastically increased which directly reduce the rate of forested areas. The decline of forested area is inevitable as new land needed for the expansion of settlements to meet the demand of the growing population which is expected to reach 32 million by year 2020 (Thang, 2009). The environmental consequences of land use change have been depicted through deterioration of water quantity and quality, loss of biodiversity, soil fertility degradation and effects on freshwater macro invertebrates (Ahern et al., 2011; Mercer *et al*., 2013).

In general, land use changes always link to the disturbance of forest functional systems and instability of environmental conditions in catchment areas, for example, the overland flow generation of hydrological systems (Ziegler *et al.*, 2004). Forest conversion has potentially affecting the hydrological processes within the catchment area (Lambin & Geist, 2003). It is essential to first understand the hydrological behaviour of the catchment system in order to assess any form of disturbances associated with land uses (Dykes and Thornes,

Corresponding Author: Geoffery James Gerusu, Department of Forestry Science, Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia, Bintulu Sarawak Campus, Bintulu, Sarawak, Malaysia
Tel.: +60173472890. E-mail: mingfaichow12345@gmail.com

2000). Black box approach in hydrological study, by relying only on rainfall and discharge data often has limitation in describing numerous different processes or combination of process that influence a catchment hydrologic regime (Beven, 1991; Latron and Gallart, 2008). For example the hydrograph behaviour is the interplay of several processes such as rainfall characteristics, canopy interception storage and loss, evapotranspiration, surface runoff, hydrograph separation to quantify event and pre-event water, and soil water content. All these components are needed to quantify runoff generation processes for ensuring sustainable land use.

In addition, the conversion of complex structure of forest canopies in the tropics into mono-structure canopies might alter the runoff generation processes within catchment area and are suggested to be sensitive to such land use changes (Shuttleworth, 1988). The impact of land development in Malaysia especially on runoff generation processes in agricultural plantation ecosystem has not been studied so far in a significant way. Information on runoff generation processes is still not well understood especially under oil palm catchments as many hydrological researches in Malaysia are confined to forested ecosystems. Consequently, it is vital that the runoff generation processes are properly study in the oil palm ecosystems. Thus, the objectives of this study are: i) to investigate the runoff flow pattern from oil palm plantation and regenerated forest catchments; and ii) to determine the contribution of new and old waters into the stream discharge from both type of catchments during storm events.

MATERIALS AND METHODS

Site Description:

The study sites are located at Sg. Maong oil palm plantation catchment, Sibu district (N 01° 54' 23.1"; E 112° 14' 13.4") and Sg. Mina regenerated forest catchment, Bintulu district (N 02° 49' 44.6"; E 113° 13' 41.4") of Sarawak, Malaysia (Fig. 1). Generally, Sg. Mina is a tributary of Sg. Kakus headwater while Sg. Maong is a tributary of Sg. Kanowit headwater catchment. The summary of physiographic description of these two catchments are showed in Table 1.

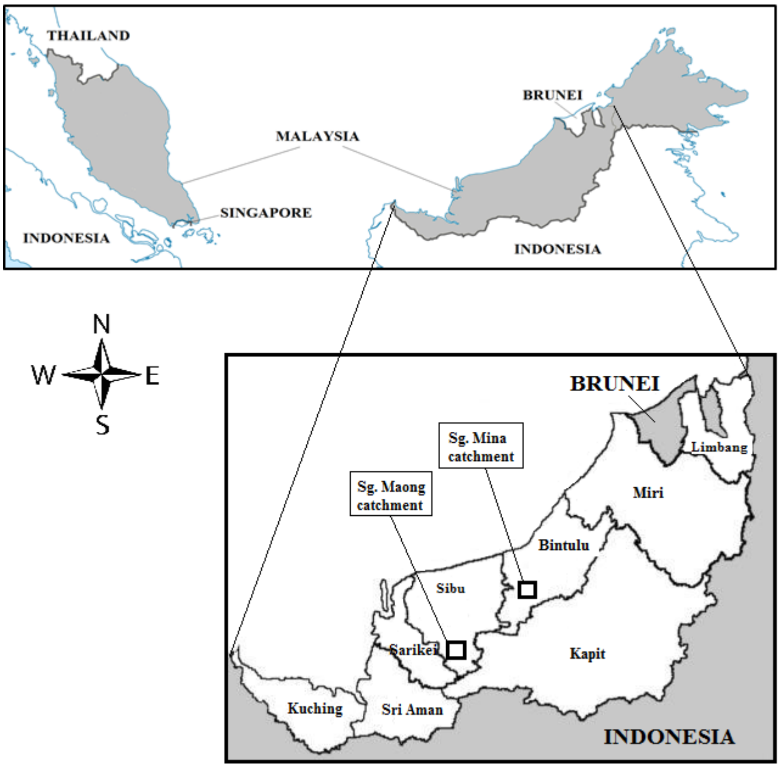

Fig. 1: Location of Sarawak and study catchments.

Rainfall-Runoff Measurements:

Rainfall was measured by using 0.2 mm tipping bucket rain gauge (HOBO ONSET RGM-2) during the study period. An automatic water level recorder (MDS-Dipper pressure sensor) associated with data logger was installed at both studied catchments for monitoring the continuous stream water level. Stream discharge was measured by using volumetric gauging method. Rainfall and stream water samples were collected from five storm events at these two catchments. The rainfall and stream water samples were analyzed for oxygen-18

($\delta^{18}O$) isotope at Malaysian Nuclear Agency (MINT) laboratory by using SIRA 10 mass spectrometer (SIRA 10 MS).

Table 1: Summary of physical characteristics of the study catchments.

Catchment	Sg. Mina	Sg. Maong
Location	Bintulu Division	Sibu Division
Topography	Rolling hill area	Undulating hill area
Soil texture	-sandy clay	- course sandy clay
Total area (ha)	approx. 25.0	23.0
Stream length (m)	651	453
Stream max. elevation (masl)	78	63
Stream slope	0.032	0.063
Catchment length (m)	772	521
Catchment max. elevation (masl)	87	83
Mean catchment slope (m/m)	0.055	0.076

Two-component Hydrograph Separation Analysis:

The well-established two component model was used to estimate the contributions of new and old waters to the total storm flow runoff during the storm event (Pinder & Jones, 1969). In the case of *n* runoff components and *n*-1 observed tracers $t_1, t_2, \ldots t_{n-1}$, the following *n* linear mixing equations can be written as follows:

$$Q_T = Q_1 + Q_2 + \ldots + Q_n \quad (1)$$

$$c_T^{t_i} Q_T = c_1^{t_i} Q_1 + c_2^{t_i} Q_2 + \ldots + c_n^{t_i} Q_n \quad (2)$$

Where, Q_T is the total runoff; $Q_1, Q_2, \ldots, Q_n$ are the runoff components; and $c_1^{t_i}, c_2^{t_i}, \ldots, c_n^{t_i}$ are the respective concentrations of one observed tracer t_i. (Hoeg *et al.,* 2000).

The application of these equations is based on some certain assumptions: 1) there is a significant difference between tracers of different components; 2) rainfall can be characterized by a single isotopic value; 3) the tracer concentrations are constant in space and time; 4) contributions of an additional component must be negligible; 5) the tracers mixed conservatively (Sklash & Farvolden, 1979; Buttle, 1994).

Then, the contribution of new water (Q_E) and old water (Q_P) to total (Q_T) can be estimated by using Equation (3) and Equation (4), respectively.

$$\frac{Q_E}{Q_T} = \frac{c_{T_{18O}} - c_{P_{18O}}}{c_{E_{18O}} - c_{P_{18O}}} \ldots\ldots(3) \quad \text{and} \quad \frac{Q_P}{Q_T} = \frac{c_{T_{18O}} - c_{E_{18O}}}{c_{P_{18O}} - c_{E_{18O}}} \ldots\ldots(4)$$

Oxygen-18 ($\delta^{18}O$) is suggested to be applied for hydrograph separation because this component is stable in the sense that it does not change its physio-chemical characteristics during the flow phenomenon or during contact with soil (Bowen, 1991; Matsubayashi *et al.,* 1993).

RESULTS AND DISCUSSION

A total of 29 individual water samples were collected from five storm events at both catchments. The runoff water samples were collected from discharges ranged from 0.003 to 0.05 m^3s^{-1} during these five storm events (Figs. 2 and 3). Isotopic $\delta^{18}O$ values for forested and oil palm catchment were ranged from -7.70 ± 0.044‰ to -12.63 ± 0.039‰ and -10.46 ± 0.034‰ to -13.22 ± 0.013‰, respectively. The total rainfall depth at forested and oil palm catchments were observed at a range of 12.3 to 42.7 mm and 11.7 to 37.3 mm, respectively. The runoffs were ranged from 1.7 to 6.3 mm (regenerated forest) and 1.2 to 5.2 mm (oil palm plantation), respectively. Time to peak and time of concentration (T_c) during the study period were ranged from 0.30 to 0.55 hrs (regenerated forest); 0.28 to 0.49 hrs (oil palm plantation); and 1.5 to 2.5 hrs (regenerated forest); 1.4 to 2.3 hrs (oil palm plantation), respectively (Table 2). Two-component hydrograph separations analysis revealed that higher percentage of new water occurred in both catchments. These findings showed similar pattern with other studies elsewhere such as Goller *et al.* (2005) in Ecuador and Liu *et al.* (2008) in China, which both reported that new water was dominate in stormflow runoff. Sklash & Farvolden (1979) observed that both overland and stream flow were dominated by new water in response to a very intense storm on a much drier basin.

In addition, higher percentage of new water was observed for oil palm catchment compared to forested catchment. Our results showed that new water was ranging between 51 to 59% under regenerated forest catchment while 63 to 69% under oil palm plantation catchment, respectively. This implies that more new water was generated from oil palm canopies due to limited infiltration (soil compaction) within oil palm catchment. Our results also discovered that new water has dominated the runoff volume during peak flow. It is evidenced that rainfall has become the main source of supplying new water in both catchments which was due to overland

Australian Journal of Basic and Applied Sciences, 9(1) January 2015, Pages: 65-70

flow or rapid subsurface delivery of storm water. The results also indicating the rapid response of the stream water levels to the onset of rainfall (Figs. 2 and 3). Goller *et al.* (2005) found that new water will use the near-surface flow paths to reach the stream channel quickly. They had observed a rapid change of $\delta^{18}O$ values of stream water right after the storm was ceased.

Table 2: Storm characteristics for 5 storm events at forested and oil palm catchments.

New dates	Total new rainfall (mm)	Total Runoff (mm)	Oxygen-18 (mm)	Time to Peak (hour)	Time of Concentration (Tc-Center of Rainfall) (hour)	Catchment Location
9/3/2012	42.7	6.3	3.7 (58.7%)	0.55	2.5	Forested
22/8/2012	12.3	1.7	0.9 (52.9%)	0.3	1.5	Forested
23/7/2012	37.3	5.2	3.6 (69.2%)	0.49	2.3	Oil Palm
25/9/2012	11.7	1.2	0.7 (58.3%)	0.28	1.4	Oil Palm
18/12/2012	33.7	4.8	3.0 (62.5%)	0.44	2.1	Oil Palm

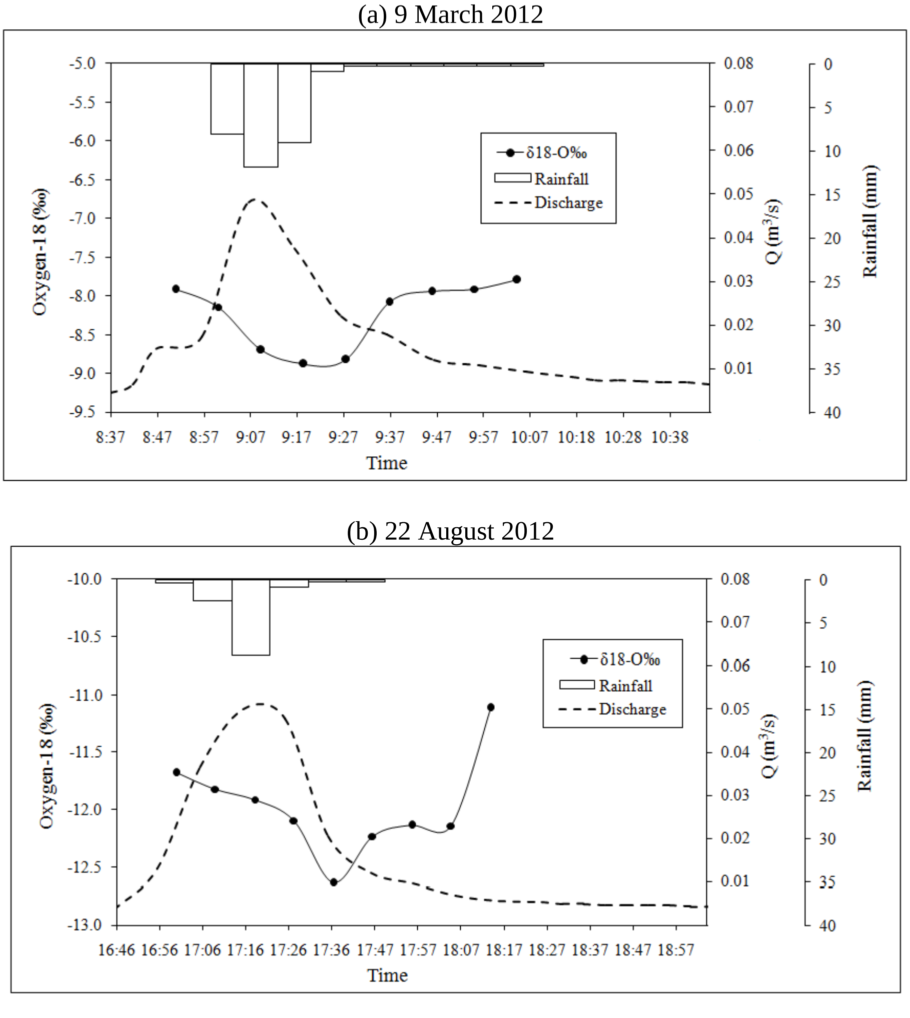

Fig. 2: Variations of $\delta^{18}O$‰ in forested catchment compared with discharge and hyetograph-hydrograph characteristics for (a) 9 March 2012 and (b) 22 August 2012 storm events.

Australian Journal of Basic and Applied Sciences, 9(1) January 2015, Pages: 65-70

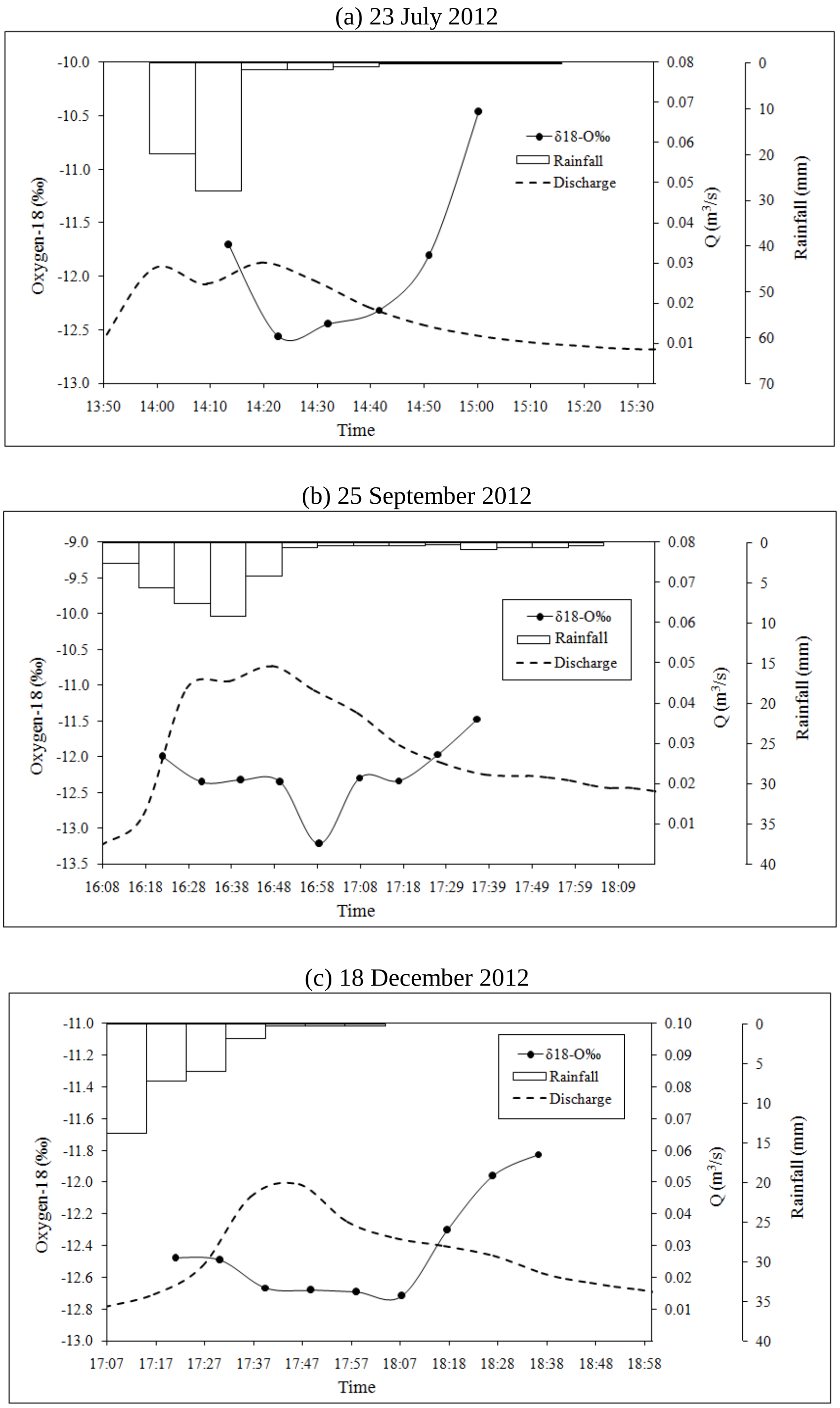

Fig. 3: Variations of $\delta^{18}O$‰ in oil palm catchment compared with discharge and hyetograph-hydrograph characteristics for (a) 23 July 2012, (b) 25 September 2012 and (c) 18 December 2012 storm events.

Conclusions:

This study has monitored five storm events for the hydrological processes at regenerated forest and oil palm catchments in Sarawak, Malaysia. Two-component hydrograph separation analysis was carried out to determine the contribution of old and new waters into the stream discharge during the storm event. The following conclusions have been made:

i) New water has dominated the runoff volume during peak flow at regenerated forest and oil plam plantation catchments.

ii) Higher percentage of new water was generated under oil palm canopy compared to regenerated forest during storm event.
iii) Soil condition and rainfall characteristics are the two main parameters in determining the proportions of old and new waters that contributing to the storm water runoff.

ACKNOWLEDGEMENT

This study was supported by Universiti Putra Malaysia under RUGS grant (Vot No 9303200). The authors wish to acknowledge Grand Perfect Sdn Bhd and Boustead Sdn Bhd staffs for access to the study areas of forested and oil palm catchments.

REFERENCES

Ahern, M., M. Hendryx, J. Conley, E. Fedorko, A. Ducatman and K. Zullig, 2011. The Association between Mountaintop Mining and Birth Defects among Live Births in Central Appalachia, 1996–2003. Environmental Research, 111(6): 838-846.

Beven, K., 1991. Hydrograph separation? In the Proceedings of the Third National Hydrology Symposium, pp: 3.1-3.7.

Bowen, R., 1991. Isotopes and climates. Elsevier Applied Science, London and New York.

Buttle, J.M., 1994. Isotope Hydrograph Separations and Rapid Delivery of Old Water from Drainage Basins. Progress in Physical Geography, 18: 16-41.

Chan, B., 1998. Concerns of the industry on tree plantations in Sarawak. In: Proceedings of Planted Forests in Sarawak-An International Conference, Eds., Chan, B., Kho, P.C. and Lee, H.S. Forest Department Sarawak, Sarawak Timber Association and Sarawak Development Institute.

Dykes, A.P. and J.B. Thornes, 2000. Hillslope Hydrology in Tropical Rainforest Steeplands in Brunei. Hydrological Processes, 14: 215-235.

Goller, R., W. Wilcke, M.J. Leng, H.J. Tobschall, K. Wagner, C. Valarezo and W. Zech, 2005. Tracing Water Paths through Small Catchments under a Tropical Montane Rain Forest in South Ecuador by an Oxygen Isotope Approach. Journal of Hydrology, 308: 67-80.

Hoeg, S., S. Uhlenbrook and C. Leibundgut, 2000. Hydrograph Separation in a Mountainous Catchment-Combining Hydrochemical and Isotopic Tracers. Hydrological Processes, 14: 1199-1216.

Koh, L.P. and D.S. Wilcove, 2008. Is Oil Palm Agriculture Really Destroying Tropical Biodiversity? Conservation Letters, 1: 60-64.

Lambin, E.F. and H.J. Geist, 2003. Regional Differences in Tropical Deforestation. Environment, 45: 22-36.

Liu, Y., N. Fan, S. An, X. Bai, F. Liu, X. Zhen, Z. Wang and S. Liu, 2008. Characteristics of Water Isotopes and Hydrograph Separation during the Wet Season in the Heishui River, China. Journal of Hydrology, 353: 314-321.

Matsubayashi, U., G.T. Velasquez and F. Takagi, 1993. Hydrograph Separation and Flow Analysis by Specific Electrical Conductance of Water. Journal of Hydrology, 152: 179-199.

Mercer, E.V., T.G. Mercer and K.S. Alexander, 2013. Effects of Forest Conversions to Oil Palm Plantations on Freshwater Macro invertebrates: A Case Study from Sarawak, Malaysia. Journal of Land Use Science, 1-18.

Pinder, G.H. and J.F. Jones, 1969. Determination of the Ground-water Components of Peak Discharge from the Chemistry of Total Runoff. Water Resources Research, 5(2): 439-445.

Sklash, M.G. and R.N. Farvolden, 1979. The Role of Groundwater in Storm Runoff. Journal of Hydrology, 43: 45-65.

Shuttleworth, W.J., 1988. Evaporation from Amazonian rainforest. In the Proceedings of the Royal Society of London, Series, B233: 321-346.

Thang, H.C., 2009. Malaysia Forestry Outlook Study. Working Paper No.APFSOS II/WP/2009/02. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, pp: 61.

Ziegler, A.D., L.T. Tran, T.W. Giambelluca, R.C. Sidle, R.A. Sutherland, M.A. Nullet and D.V. Tran, 2004. Effective Slope Lengths for Buffering Hillslope Surface Runoff in Fragmented Landscapes in Northern Vietnam. Forest Ecology and Management, 224: 104-118.