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Possibility of evapotranspiration estimates by the hourly hydrologic data based short-time period water-budget method in a rainforest watershed at Lambir Hills National Park

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Abstract The hydrological cycle in tropical rainforests is very active. Hydrological data such as rainfall, runoff, and evapotranspiration (ET) are important for not only forecasting of global-scale environmental changes and predicting disaster but also managing local agriculture, industry, human health and environment; however, it is difficult to obtain long-term hydrological data in such areas. We intermittently observed runoff at the Lambir Hills National Park, Sarawak, Malaysia. The climate is humid tropical with a weak seasonal change in rainfall and little seasonal variation in temperature. To estimate ET values in this study site, we applied the short-time period water-budget method. This method is usually used for temperate zone watersheds, with daily rainfall and runoff data collected over the course of a year. Because of the rainfall characteristics such as short duration and high intensity with no substantial seasonal climate change in the study region, we applied hourly data to this method instead of daily data. By using daily data, we were able to estimate ET for approximately 50 % of the observation period. ET could be estimated before and after large rainfall events; however, it was difficult to estimate during the frequent intensive rainfall periods and the dry period. By using hourly rainfall and runoff data, we were able to estimate ET during most of the total observation period. Annual ET was approximately 1700 mm in this watershed. We believe that the hourly short-time period water-budget method was appropriate because of the characteristics of the rainfall.

Keywords Short-time Period Water-Budget method, Discharge, Evapotranspiration, Field observation, Tropics

Introduction

Tropical rain forests are the most active water cycle regions. They are located near the equator and have a major influence on climate at both a regional and global scale. Therefore, obtaining hydrological data such as rainfall, runoff, and evapotranspiration (ET) for tropical rainforests is extremely important for not only forecasting of global-scale environmental changes and predicting disaster but also managing local agriculture, industry, human health and environment. Currently, the area of rainforests has been decreasing (FAO 2010), particularly in Southeast Asia where the tropical rainforest is more endangered than in other regions such as South America and Africa (Conservation International 2011). We must clarify the water balance at Asian tropics as soon as possible.

Obtaining long-term observations of hydrological data in rainforests is difficult compared with the temperate zone, despite the importance of such data. Additionally, compared with the Amazonian rainforest, water cycling in the Southeast Asian rainforest is not perceptive enough. The study site, Lambir Hills National Park (LHNP), is in the Malaysian state of Sarawak on the island of Borneo. Much ecological research has been conducted there, and the studies have revealed that this area exhibits the highest vegetation diversity in Southeast Asia (Lee et al. 2002). In this area, short rainfall events occur more frequently than in other climatic regions (Kuraji 1996). Rainfall in LHNP has previously been under continuous observation (Kumagai et al. 2001); however, in this region, runoff is hard to obtain and observation tends to be intermittent, making it difficult to achieve long-term water budgets for the area.

ET is a major component of the hydrological budget of forest which rainfall and vegetation affect to at catchment scale (Zhang et al. 2001). We cannot observe ET directly but there are several ways to estimate it. The short-time period water-budget (SPWB) method is a simple meteorological method used to estimate catchment ET (Linsley et al. 1958; Hamon 1961). This method is usually used in temperate zone watersheds and addresses the daily rainfall and runoff data over the course of a year. By using this method, monthly ET has been estimated for several watersheds in Japan (Tasake and Maruyama 1976; Suzuki 1980, 1985). Although this method has been applied to tropical rainforests (Kuraji and Paul 1994; Noguchi et al. 2004), fewer cases have been reported.

In this study, we investigated the possibility of using intermittent runoff data for estimating ET. It was hard to get continuous estimated ET value by using original SPWB method, we applied the SPWB method to hourly rainfall and runoff data.

Materials and methods

Study area

The study area was the CL (crane large) watershed, which covers 21.97 ha, and is located in LHNP (4°20'N, 113°50'E, approximate area of 6500 ha), centered at Mount Lambir (elevation 495 m) in north-central Borneo (Fig. 1). Its geology includes tertiary sandstone and shale. The majority of the soil is classified as yellowish-red podzolic soil, and immature sandy soil is distributed from the hills to the lowlands (Ishizuka et al. 1998).

From 2000 to 2006, the average annual rainfall in the park was approximately 2600 mm and the average annual temperature was 27 °C. Rainfall was low from February to September, with under 220 mm/month, and the minimum rainfall was 135 mm/month in August. Rainfall was high from October to January, with over 250 mm/month, and the maximum rainfall was 370 mm/month in December (Kumagai et al. 2005, 2009).

The study site was established within undisturbed mixed dipterocarp (Dipterocarpaceae) forest, the typical lowland evergreen vegetation of the region. The tree canopy is stratified, and

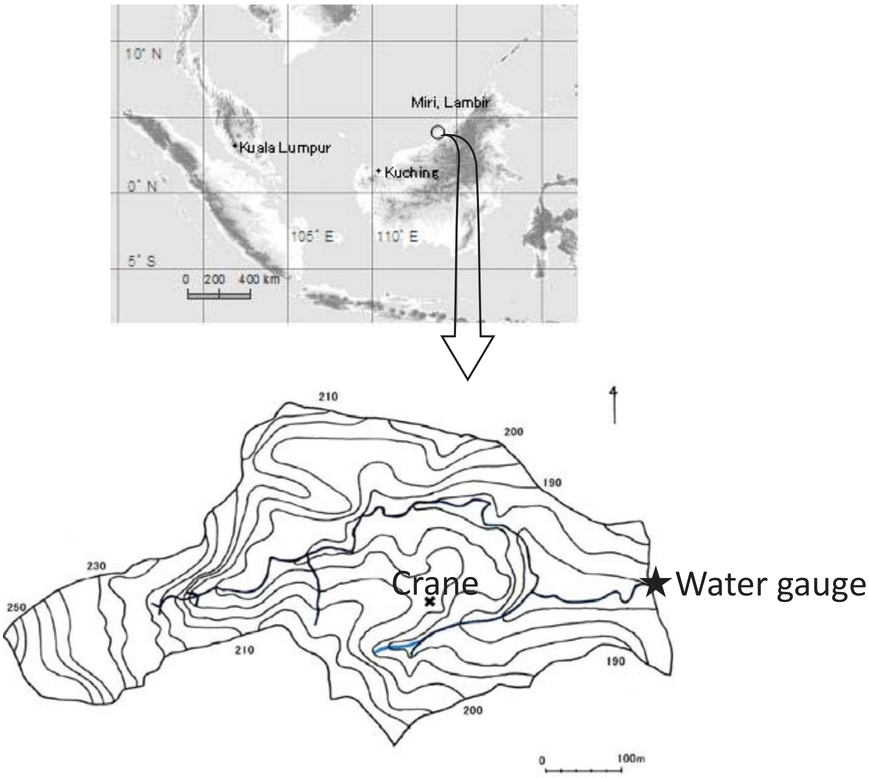

Fig. 1 Map of the CL (Crane Large) watershed in Lambir Hills National Park, Malaysia.

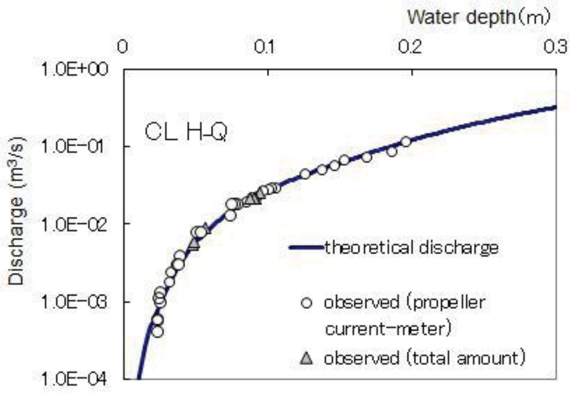

Fig. 2 H-Q curve (discharge rating curve).

although dominated by Dipterocarpaceae, reaching heights of approximately 40 m, emergent trees exceed heights over 70 m.

Rainfall was measured using 0.5-mm tipping-bucket rain gauges at two locations in the park: on a crane jib (approximately 80 m in height) as shown in Figure 1 and on Tower 2 (approximately 50 m in height, and approximately 550 m Southeast of the crane). To measure runoff, pressure type automatic water gauges (KADEC21-MIZU, NorthOne Co. Ltd., Japan) were set at the outlet of the CL watershed (Fig. 1) and recorded the water level at 5-min intervals. A stainless steel ruler was also set on one side of the riverbed as a water level gauge. The water level was measured at a step-pool-shaped area with a riverbed of exposed bedrock composed of alternating sandstone and shale layers. To determine the runoff, we created a discharge rating curve (H–Q curve; H means height, Q means quantity of runoff) using observed and calculated values (solid line in Fig. 2). Flow velocity was measured for all water levels using a propeller-type current meter (VR-201, KENEK Co. Ltd., Japan). To validate the H–Q curve, we measured the total volume (the triangles in Fig. 2) of stream runoff.

Topographic measurements such as the altitude, direction, angle, and convexity of slopes have been conducted previously as part of a large study plot with an area of 52 ha by Yamakura et al. (1995). Intensive ecological measurements have also been performed within this area (Yamakura et al. 1995). However, the topography of most other parts of the basins had not yet been surveyed. We therefore performed a topographic survey of the basins. We established several reference points using a Global Positioning System (GPS; ProMark2, Ashteck, USA) and conducted a traverse survey with a compass to pass the reference points. We also used a handheld GPS (VISTA HCX, Garmin Ltd., USA) to record the locations of the channel heads and penetration points.

Data analysis for the SPWB method

The SPWB method is a simple method to estimate ET using daily rainfall and runoff. Assume that water storage in the basin $S(t)$ and the runoff rate $q(t)$ is satisfied by:

$$S(t) = f\,[q(t), dq/\mathrm{d}t] \quad (1)$$

If $S(t_1)$ and $S(t_2)$ are equal when time t_1 and t_2 have equivalent values of both $q(t)$ and dq/dt, then the change of water storage in the basin ΔS (= $\mathrm{S}(t_2) - \mathrm{S}(t_1)$) is zero. ET can therefore be calculated using the following expression:

$$ET = \int_{t2}^{t1} p(t)\,dt - \int_{t2}^{t1} q(t)\,dt \quad (2)$$

where $p(t)$ is rainfall intensity.

Times t_1 and t_2 are determined when the following three conditions are satisfied:

1) There is neither precipitation on the start day t_1 and the end day t_2 nor antecedent precipitation a days before those days.

2) Only days for which the difference in daily runoff rate of t_1 and t_2 are not less than or equal to x % of the daily runoff can be selected.

3) The period must be between b days and c days.

The first condition is to remove rapid flow where dq/dt is high, and the second is to find the equivalent q at times t_1 and t_2. For the first condition, Suzuki (1985) set a days as 2 days, and for the second condition, Suzuki (1985) adopted a value of 2 %, while Murakami et al. (2000) and Noguchi et al. (2004) used 5 %. The period (b–c days) was 8–60 days in the study of Suzuki (1985), 8–60 days in the study of Murakami et al. (2000), and 17–116 days or 24–116 days in the study of Kuraji and Paul (1994). These conditions (a, b, and c) were set by trial and error to obtain a large range of ET samples. Small parameter c cannot obtain many ET samples; however, it is recommended that parameter c be small because long time water budget period is not suitable for estimating seasonal change of ET.

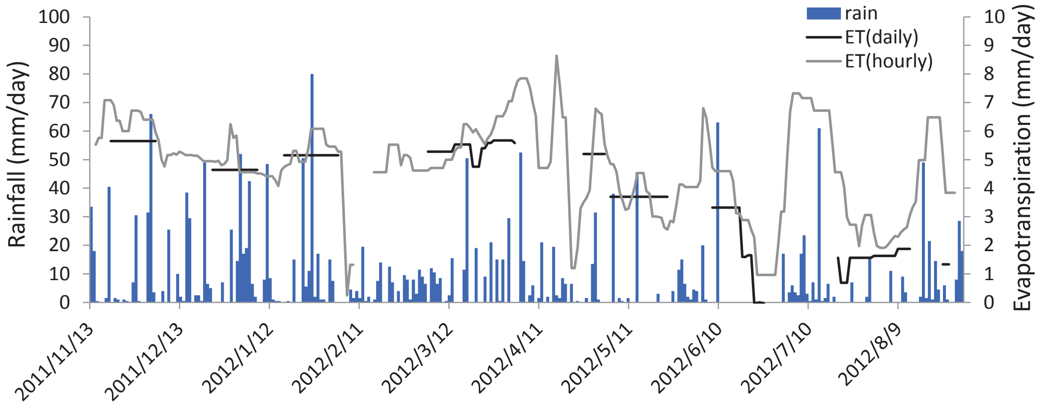

Fig. 3 ET estimated by the daily and hourly SPWB method

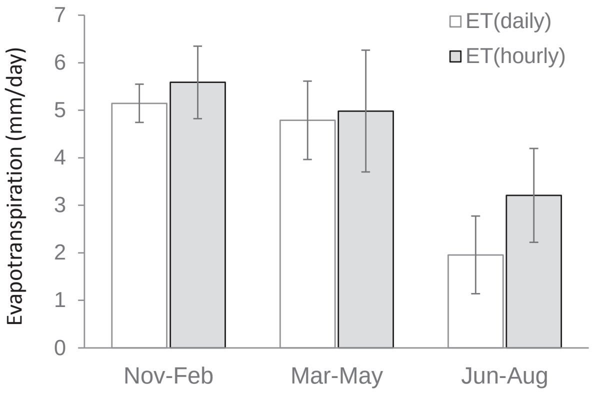

Fig. 4 Average of daily estimated ET by daily and hourly SPWB method at every three or four months

Initially, daily data were applied to the SPWB method to determine the best parameters. The following ranges of parameters were tested: parameter *a*, 1–3; *b*, 1–5; and *c*, 10–30. These parameters were compared to increase the number of ET samples. For getting short time water budget period, we set parameter *c* as a small value. After deciding on the best parameters using the daily SPWB method, the same parameters were used with an hourly SPWB method. For both the daily and hourly SPWB method, the parameter *x* was set to 10 %. A mean value was used when more than one ET sample was attained for the same period. The observation period for rainfall and runoff was from November 13, 2011 to August 21, 2012 (293 days).

Results and Discussion

By using the SPWB method with daily rainfall and runoff data, the estimated ET covered approximately 50 % of the observation period (Fig. 3, ET daily). The total number of ET samples was 20, and the best fitting parameters were $a = 1$, $b = 1$, and $c = 20$. ET could be estimated before and after large rainfall events; however, estimation of ET during the frequent intensive rainfall period and the dry period is difficult.

When the SPWB method was used with hourly rainfall and runoff data, the estimated ET was almost the same as that obtained with the daily SPWB method. Figure 4 shows the average of daily estimated ET by daily and hourly SPWB method at every three or four months within a same period covered by using daily SPWB method. From November to February (51 days), estimated daily ET by daily SPWB was 5.1 ± 0.4 mm and by hourly SPWB was 5.6 ± 0.8 mm. From March to May (58 days), estimated daily ET by daily SPWB was 4.8 ± 0.8 mm and by hourly SPWB was 5.0 ± 1.3 mm. However, from June to August (42 days), estimated daily ET by daily SPWB was 2.0 ± 0.8 mm and by hourly SPWB was 3.2 ± 1.0 mm. Compare to the hourly SPWB, ET estimated by the daily SPWB was too small. Suzuki (1985) shows that daily SPWB method tends to underestimate ET during drought season. From June to August, there was also a small rainy period and ET estimated by daily SPWB was reduced by this drought.

With the hourly method, ET almost covered the total observation period (Fig. 3, ET hourly). The total number of ET samples was 128 using the same parameters as those used in the daily SPWB. We believe that the hourly SPWB method can be used in the same level as the daily SPWB method and it can be possible to evaluate ET more continuous in rainforest watersheds with frequent rainfall, rapid decreases in runoff, and no clear seasonal change. The estimated monthly ET was 142.3 ± 25.0 mm, resulting in an estimate for annual ET of 1708 mm.
Previous studies at the same site estimated ET as 1545 mm/year (Kumagai et al. 2005) and 1323 ± 75 mm/year (Kume et al. 2011). Although these are values of different year or long-term average year, our estimated ET was comparatively high. The SPWB method could not separate ET from other water losses, such as deep infiltration. Therefore, when using this method, we must pay attention to the characteristics of the watershed such as size, soil thickness, and base rock type.

Conclusions

ET in a tropical rainforest was estimated by the SPWB method using daily and hourly rainfall and runoff data. When hourly data were utilized, the SPWB method covered a higher percentage of the study period than that covered using daily data. The estimated monthly ET was 142.3 ± 25.0 mm, resulting in an annual ET of approximately 1708 mm. Because estimated ET almost covered the total observation period, we believe that the hourly SPWB method was appropriate for up to one year of the rainfall and runoff data in the studied tropical rainforest, which was subject to intensive and frequent rain events, and had no substantial seasonal climate change. However, ET estimated in our study by the SPWB method was much higher than that estimated in previous studies. We believe this estimated ET value included values for deep percolation.

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