RAINFALL CHARACTERISTICS OF TROPICAL RAIN FOREST AND TEMPERATE FOREST: COMPARISON BETWEEN BUKIT TAREK IN PENINSULAR MALAYSIA AND HITACHI OHTA IN JAPAN

Shoji Noguchi*,

Forestry and Forest Products Research Institute, P.O. Box 16, Tsukuba, Norin Kenkyu Danchinai, Ibaraki, 305 Japan

Abdul Rahim Nik,

Forest Research Institute Malaysia, Kepong 52109 Kuala Lumpur, Malaysia

Toshiaki Sammori, Makoto Tani & Yoshio Tsuboyama

Forestry and Forest Products Research Institute, P.O. Box 16, Tsukuba, Norin Kenkyu Danchinai, Ibaraki, 305 Japan

Received December 1995

NOGUCHI, S., ABDUL RAHIM, N., SAMMORI, T., TANI, M. & TSUBOYAMA, Y. 1996. Rainfall characteristics of tropical rain forest and temperate forest: comparison between Bukit Tarek in Peninsular Malaysia and Hitachi Ohta in Japan. We investigated the rainfalls of both Bukit Tarek (BT; tropical rain forest) in Peninsular Malaysia and Hitachi Ohta (HO; temperate forest) in Japan from 1992 to 1994. There were no pronounced peaks in total precipitation at each time of day at HO throughout the year. However, there was a distinct diurnal cycle in precipitation at BT, where about 60 % of the rainfall occurred between 13:00 h and 19:00 h. The sine wave, which was decomposed by Fourier transform consisting of 24-h, 12-h, and 8-h cycles and applied to the observed data at BT, was useful (r=0.97) in order to re-evaluate the diurnal cycle of precipitation. The mean amounts of rainfall in each rain event at BT and HO were almost the same (14 mm) but BT had a lower maximum value (less than 100 mm). The rainfall at BT was characterised by short duration and high intensity; about 55 % of rain events fell within 1-hour periods, testifying to the predominantly convectional storms. There was a high positive correlation at BT (r=0.95) between amount of rainfall in each rain event and maximum hourly rainfall intensity during rain event. Though only four rain events with more than 50 mm h^{-1} for 10 min occurred for three years at HO, such high intensity rain events occurred every month at BT. The obtained results are useful in order to analyse hydrological processes in tropical rain forest.

Key words: Rainfall characteristics - seasonal variation - diurnal cycle - totals - duration - rainfall intensity - tropical rain forest

*Corresponding author

NOGUCHI, S., ABDUL RAHIM, N., SAMMORI, T., TANI, M. & TSUBOYAMA, Y. 1996. **Ciri-ciri hujan di hutan hujan tropika dan hutan iklim sederhana: perbandingan diantara Bukit Tarek di Semenanjung Malaysia dan Hitachi Ohta di Jepun.** Kami mengkaji hujan di Bukit Tarek (BT; hutan hujan tropika) di Semenjung Malaysia dan Hitachi Ohta (HO; hutan iklim sederhana) di Jepun dari 1992 hingga 1994. Tidak terdapat puncak nyata dalam jumlah titisan pada setiap masa dalam sehari di HO pada sepanjang tahun. Bagaimanapun, terdapat kitaran diurnal yang nyata dalam BT; lebih kurang 60% daripada hujan yang turun berlaku di antara 13:00 jam dan 19:00 jam. Lengkungan sin yang dicaingkan oleh transformasi Fourier yang mengandungi kitaran 24 jam, 12 jam dan 8 jam, digunakan untuk data yang diperhatikan di BT, berguna (r=0.97) untuk menilai semula kitaran diurnal titisan. Jumlah purata hujan setiap kali hujan turun di BT dan HO hampir sama (14 mm) tetapi BT mempunyai nilai maksimun yang lebih rendah (kurang daripada 100 mm). Ciri-ciri hujan di BT ialah tempoh yang pendek dan keamatan yang tinggi; lebih kurang 55% hujan turun dalam masa 1 jam menunjukkan kelaziman terjadinya olakan ribut. Terdapat korelasi positif yang tinggi di BT (r=0.95) di antara jumlah hujan pada setiap kejadian hujan dengan keamatan hujan jaman maksimum semasa kejadian hujan. Walaupun hanya terdapat empat kejadian hutan dengan hujan lebih daripada 50 mm h^{-1} bagi 10 min berlaku untuk tiga tahun di HO, keamatan kejadian hujan yang begitu tinggi berlaku setiap bulan di BT. Keputusan yang diperolehi berguna untuk menganalisis proses hidrologi di hutan hujan tropika.

Introduction

The high rate of deforestation in tropical regions has become a cause of concern (FAO 1993) and its effects on runoff and erosion have been highlighted (Bonell 1993). Much attention has been given to forests which have functions of sediment disaster prevention and as regional effective water resources. Hydrological responses to storm events such as subsurface flow, rainfall interception loss and suspended sediment yield depend on rainfall characteristics (e.g. Anderson & Burt 1990, Lloyd 1990, Baharuddin & Abdul Rahim 1994). Therefore, it is important to understand rainfall characteristics in the region in order to clarify the hydrological processes. The Tropical Rainfall Measuring Mission (TRMM) satellite which is planned to be launched in 1997 has the rainfall measuring instruments to scan global area (Simpson *et al.* 1988). *In-situ* observations are important not only for calibration of the satellite data but also for understanding the process of the interaction between local scale and global scale in energy and water cycle.

Past studies on rainfall characteristics in Southeast Asia have been made. Shuin *et al.* (1995) analysed the characteristics of time series fluctuation and spatial distribution of precipitation at Mt. Merapi in Indonesia. Masukura *et al.* (1992) reported on the method of estimation of basin rainfall in Thailand by considering the spatial characteristics. In Singapore, Sia and Tan (1994) found the rainfall to have very temporal and spatial variability although the terrain was relatively flat and the area small. Tan and Sia (1995) also showed that the temporal characteristics of a tropical storm depended not only on the origin of the storm but also on the duration and quantity of rain-water of the storm. In Peninsular Malaysia, Dale (1959) distinguished five types of rainfall distribution by analysing monthly variation. In addition, Ramage (1964) found a diurnal variation, Nieuwolt (1968) obtained similar results, and Oki and Mushiake (1994) analysed the diurnal and seasonal changes of the mean intensity of precipitation. There were no discussions on rainfall-runoff processes in these reports because observations of discharge had not been conducted at the same sites except for some reports (e.g. Abdul Rahim 1983, Paul & Kuraji 1993).

Manley and Askwe (1993) examined the reason why it is difficult to obtain precise hydrological data in tropical region. The authors were of the opinion that the difficulty to operate instruments under high humidity and strong ultraviolet radiation is one of the causes. Rainfall, discharge and climatic variables have been observed at Bukit Tarek Experimental Watershed (BT) in Peninsular Malaysia (Abdul Rahim *et al.* 1995). In addition, the hydrological observations for elucidation of rainfall-runoff processes on a hillslope and mechanism of suspended solids production have been started at BT (Noguchi *et al.* 1994, 1995, Sammori *et al.* 1994). Detailed hydrological observations have also been conducted at the Hitachi Ohta Experimental Watershed (HO) in Japan. Some relevant hydrological studies have already been conducted at HO (e.g. Tsuboyama *et al.* 1994a, Sidle *et al.* 1995).

Recently, many hydrological studies have been conducted in tropical regions (e.g. Bruijnzeel 1990, Bonell 1993, Bonell & Balek 1993). However, rainfall characteristics and related hydrologic processes in temperate forest environments have been studied in greater detail (e.g. Dunne 1978, Anderson & Burt 1990). Storm runoff production depends on catchment properties such as soil hydraulic conductivity, soil thickness and vegetation cover (Anderson & Burt 1990). Though types of vegetation at BT and HO are different, soil hydraulic conductivities and soil thicknesses at both sites are almost similar (Tsuboyama *et al.* 1994b, Noguchi *et al.* 1994). It is believed useful to compare precise hydrological data between BT and HO in order to understand hydrological processes in tropical rain forest. Thus, in our investigation, the primary objective was to analyse the temporal distribution of rainfall at BT in a tropical forest. Secondarily, a comparison between rainfall characteristics of BT and HO was attempted.

Materials and methods

Site description

Bukit Tarek Experimental Watershed (BT) is located in Selangor Darul Ehsan of Peninsular Malaysia (3° 31' N, 101° 35' E, 48-213 m, Figure 1). The vegetation is dominated by *Koompassia malaccencis*, *Eugenia* spp. and *Canarium* spp. The average annual precipitation is 2414 mm based on 11 y (1976 - 1986) of record at Kuala Kubu Baru located about 20 km from Bukit Tarek (Saifuddin *et al.* 1991).

Hitachi Ohta Experimental Watershed (HO) is located in Ibaraki prefecture, Japan (36° 34'N, 140° 35'E, 280-340 m, Figure 2). The watershed was covered with coniferous forest (*Cryptomeria japonica* and *Chamaecyparis obtusa*) planted around 1920. In 1985 to 1987, the entire area except Basin B (Figure 2) was clearcut and replanted with the same species. The average annual precipitation is 1459 mm, based on 14 y (1981 - 1994) of record at Hitachi Ohta. The occurrence of winter snowfall is sporadic and a persistent snowpack is rarely developed.

Data collection

Rainfall data for the two watersheds were analysed from 1992 through 1994. Rainfall was measured at one site at BT and two sites at HO. Locations of the sites are shown in Figures 1 and 2, and the type of rain gauges at each location are given in Table 1. The data at BT using tipping-bucket and rainfall intensity sensor were taken within a period of one year in 1994, although data from November to December were missing.

A rain event is defined as having ≥ 1 mm of rain with an interval of more than six hours from the last recorded rainfall using hourly data.

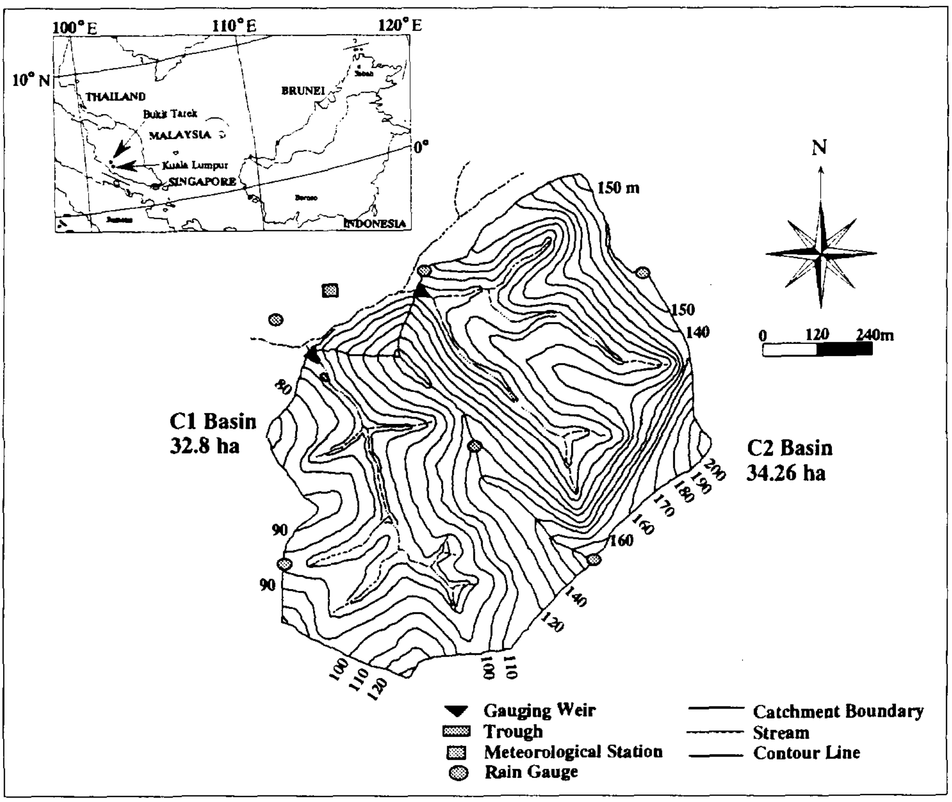

Figure 1. Map of the Bukit Tarek Experimental Watershed showing the locations of basins and their instrumentation

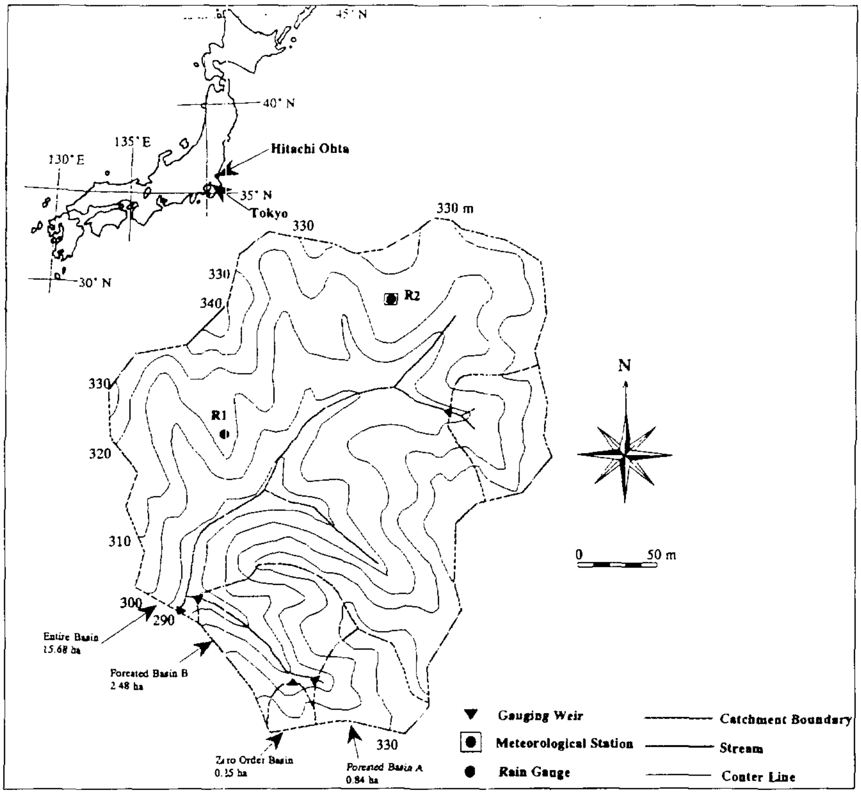

Figure 2. Map of the Hitachi Ohta Experimental Watershed showing the locations of basins and their instrumentation

Table 1. Rain sensors used in this study

Site	Detector	Sensitivity	Record	Interval time	Period
BT	Weight-type	0.5 mm	Paper roll	1 h	1992 - 1994
	Tipping-bucket	0.5 mm	Data logger	5 min	1994
	A drop of water	0.0083 mm	Data logger	5 min	1994
R1 of HO	Tipping-bucket	0.5 mm	Paper roll	1 h	1992 - 1994
R2 of HO	Tipping-bucket	0.1 mm	Data logger	10 min	1992 - 1994

HO: Hitachi Ohta, BT: Bukit Tarek.

Results and discussion

Diurnal and seasonal variations in precipitation

The minimum, maximum, and average monthly precipitations at BT were 106.3 mm (January), 354.3 mm (November), and 221.2 mm respectively (Figure 3a). Monthly precipitation at BT had a two-peak distribution (May and November). This suggests that the site was influenced by both the Southwest Monsoon and the Northeast Monsoon. Typically, 43.9 % of the annual rainfall occurred during the Northeast Monsoon (November to March), 37.1 % during the Southwest Monsoon (May to September) and the remaining 19.0 % during the transitional months (April and October). It may not be possible to divide a year into wet and dry seasons at BT. The heavy rain storms normally occur throughout the year with occasional short dry spells. These dry periods are not of sufficient length to be designated as dry seasons. The monthly variation of rainfall at BT is similar to that found for the west coast regime of Peninsular Malaysia as described by Dale (1959).

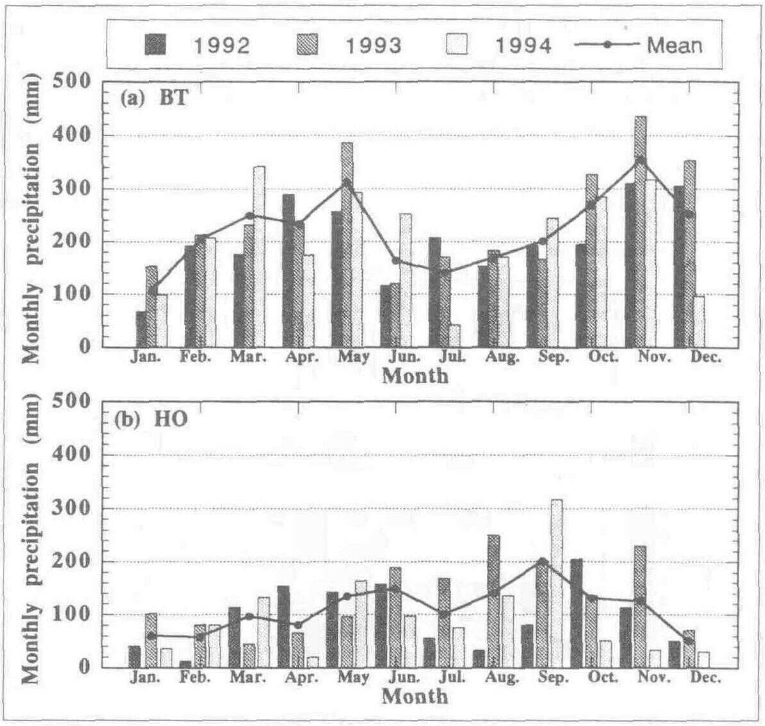

Figure 3. Monthly precipitation from 1992 through 1994 at Bukit Tarek (BT) and Hitachi Ohta (HO)

The minimum, maximum, and average monthly precipitations at HO were 50.5 mm (December), 200.2 mm (September) and 110.5 mm respectively (Figure 3b). The site experiences a Pacific Coast climate with two major periods of rainfall: the Bai-u season (early June to mid-July) and the typhoon season (late August to October). The winter monsoon picks up abundant moisture and precipitates a lot of snow on the Japan Sea side of the Japanese Islands through orographic effects. On the leeward side, the Pacific side of the Japanese Islands, a dry, fall wind prevails under blue skies (Fukui 1977). Therefore, there is little rainfall at HO in winter.

Knowledge of the diurnal cycle of precipitation is important for the evaluation of daily evapotranspiration which is affected by the precipitation time and duration of sunshine within a day (Oki & Musiake 1994). Figure 4a shows the total precipitation at each time of day in each month at BT. Nearly 74.3 % of hours with rain occurred in the daylight between 07:00 h and 19:00 h. There was a distinct diurnal cycle in precipitation at BT, in which 62.0 % of the rainfall occurred between 13:00 h and 19:00 h. This tendency for rainfall in the afternoon is most common during the wet months. Convectional storms are caused by differential solar heating of the ground and lower air layers, which typically occur during late summer afternoons when warm moist air covers an area (Hewlett 1969). In this regard, almost all rainstorms at BT can be classified as convectional storms. Ramage (1964) distinguished five types of diurnal rainfall patterns in Peninsular Malaysia. BT is located at about only 50 km from the west coast, but the diurnal variation at BT is similar to the inland-mountain regime and not the west coast regime among the five types. Interestingly, the same diurnal variation was also observed at the Reserva Florestal Ducke in Brazil (Lloyd 1990).

Figure 4b shows total precipitation at each time of day in each month at HO. Small peaks occurred in the afternoon during the Bai-u season and the typhoon season. However, there were no pronounced peaks throughout the year.

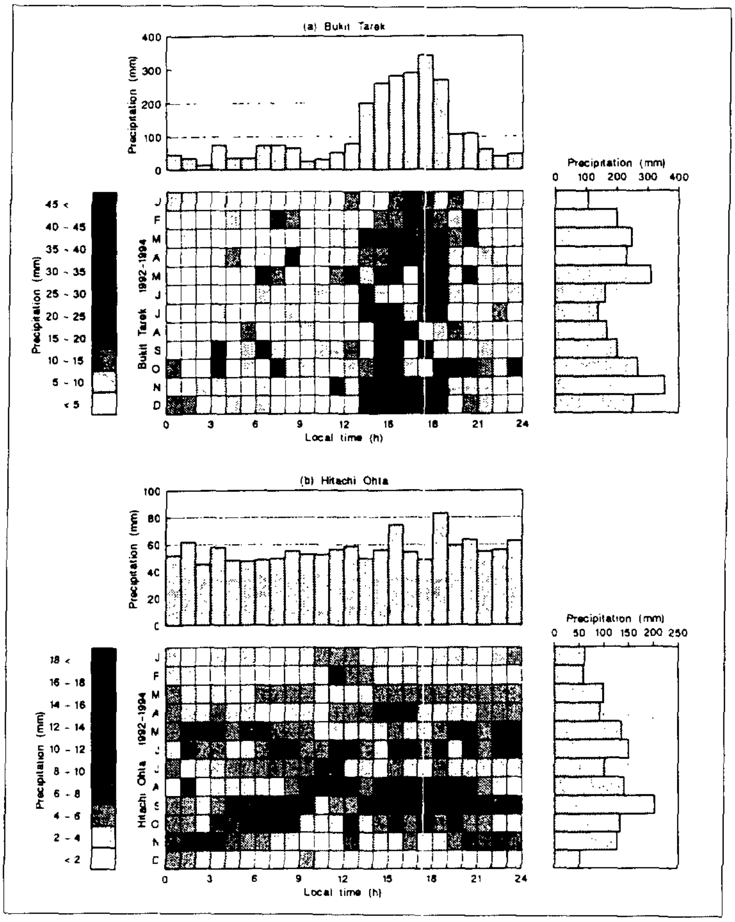

Figure 4. Total precipitation at each time of day in each month at Bukit Tarek (BT) and Hitachi Ohta (HO). Mean for three years (1992-1994).

Oki and Musiake (1994) used sine wave for analysis of the phase and amplitude of the diurnal cycle of rainfall in the inland regime of Peninsular Malaysia. The sine wave was decomposed by the Fourier transform consisting of 24-h, 12-h, and 8-h cycles. The equation is as follows:

$$Y = m1+m2\sin(2\pi/24\ X+m3)+m4\sin(2\pi/12\ X+m5)+m6\sin(2\pi/8\ X+m7)$$

where Y is rainfall (mm), X is local time (from 1 h to 24 h) and m1-7 are constants.

As the waves were applied to the observed data at BT and HO, the curve fitting was excellent at BT but poor at HO (Figure 5). The constants for the equation are shown in Table 2. There is small peak between 06:00 h and 09:00 h at BT (Figure 5). Although land breezes often cause early morning rainfall in coastal areas (Nieuwolt 1968), a further investigation is necessary to explain this phenomenon.

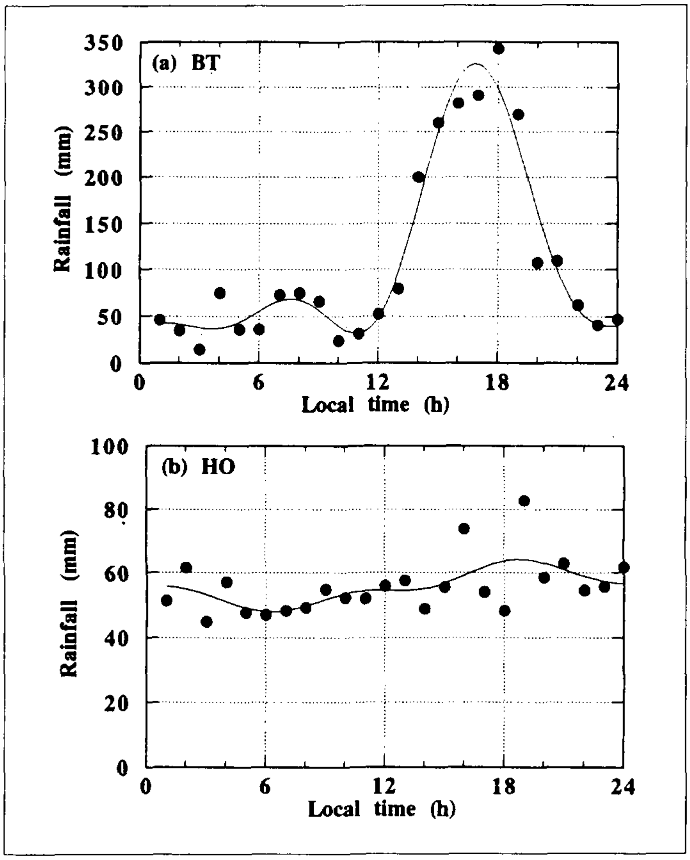

Figure 5. Total precipitation at each time of a day fitted to sine wave which is decomposed by Fourier transform consisting of 24-h, 12-h, and 8-h cycles. Original observations are plotted by circles for BT and HO.

Table 2. Constant values of the sine wave applied to the observed total precipitation at each time of day for BT and HO

Site	m1	m2	m3	m4	m5	m6	m7	r
BT	110.59	110.31	66.268	- 74.132	- 60.798	- 32.117	- 14.648	0.9734
HO	55.654	- 6.3367	6.0402	- 0.74763	0.26847	1.7687	- 0.30975	0.5567

r = correlation coefficient.

Characteristics of rainfall events

The total numbers of rain events at BT and HO were 555 and 276 respectively during the 3-y (1992-1994) period. Table 3 gives statistics for amount and duration of rain events. The frequency of the amount of rainfall in each event at both BT and HO was inverse J-shaped type distribution (Figure 6) and the mean values were almost the same. However, the maximum, skewness and kurtosis of BT were smaller than those of HO (Table 3).

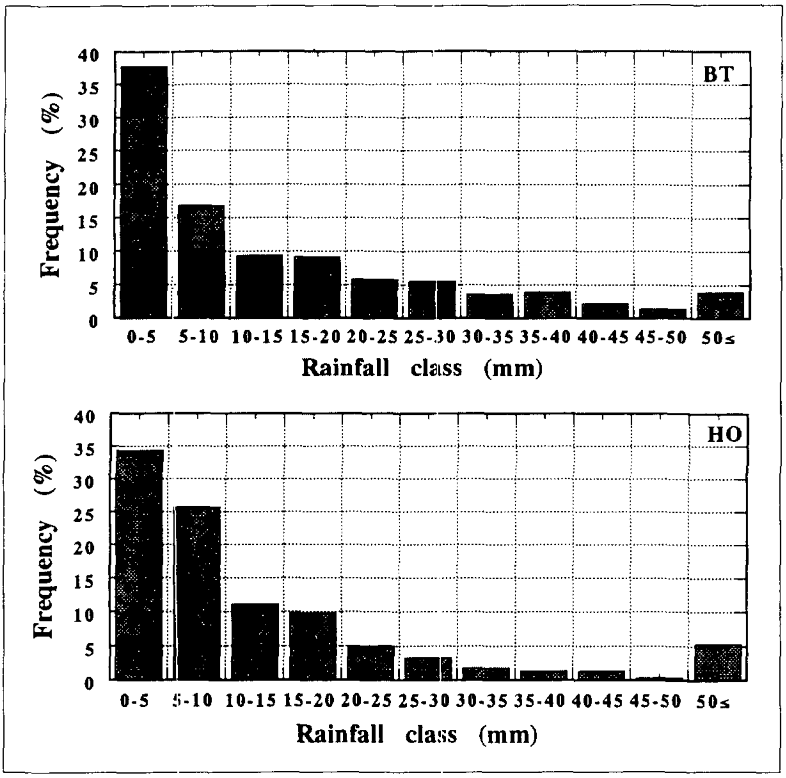

Figure 6. Frequency distribution of amount of rainfall in each rain event at Bukit Tarek (BT) and Hitachi Ohta (HO), from 1992 to 1994

Table 3. Statistical properties of amount and duration of rainfall

	Amount at HO (mm)	Amount at BT (mm)	Duration at HO (hour)	Duration at BT (hour)
Minimum	1.0	1.0	1.0	1.0
Maximum	200.0	96.0	73.0	18.0
Points	276	55	276	555
Mean	14.4	14.3	9.7	2.7
Median	7.5	8.0	7.5	1.0
RMS	26.29	21.30	13.09	3.865
Std. deviation	22.02	15.84	8.793	2.781
Variance	484.79	250.92	77.31	7.732
Std. error	1.325	0.672	0.529	0.118
Skewness	4.446	1.790	2.580	2.299
Kurtosis	26.41	3.768	11.40	6.370

HO = Hitachi Ohta, BT = Bukit Tarek.

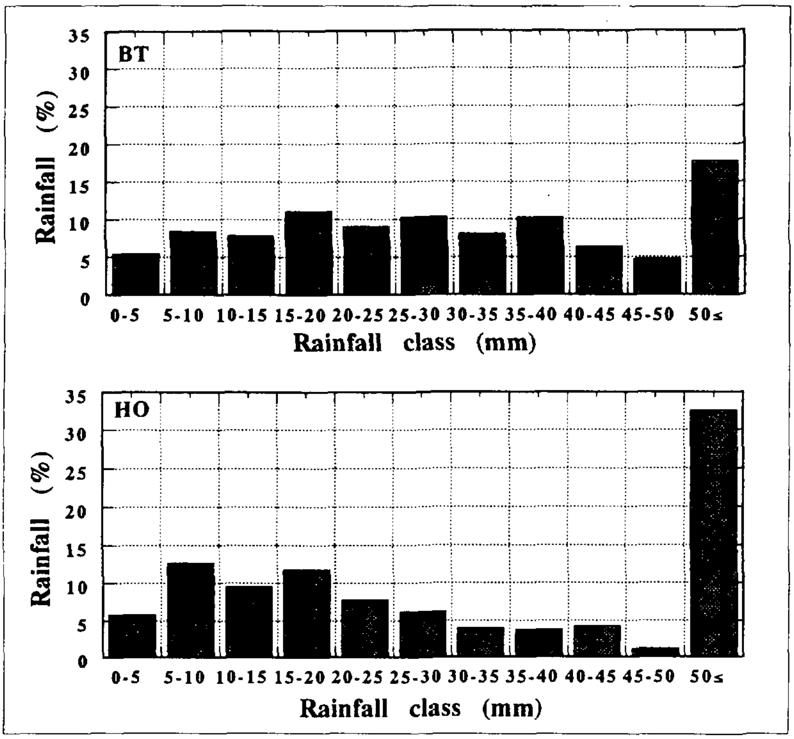

Figure 7. Percentage of rainfall in certain sized rain events at Bukit Tarek (BT) and Hitachi Ohta (HO), from 1992 through 1994

Figure 7 shows the percentage of rainfall in size classes at BT and HO. Events of more than 25 and 50 mm rain comprised 57.9 and 17.8 % of the total rainfall at BT and 52.1 and 32.6 % of the total rainfall at HO respectively. Rain events of more than 25 and 50 mm constituted 20.7 and 4.0 % of the total number of events at BT and 13.8 and 5.4 % of the total number of events at HO respectively (Figure 6). Although the smallest rain events (0-5 mm) constituted 37.8 and 34.4% of the total number of rain events at BT and HO (Figure 6), they produced only 5.5 and 5.9 % of the total rainfall respectively (Figure 7). This concentration of rain-fall in large storms ≥ 50 mm was more pronounced at HO than at BT. The reason for this higher concentration at HO is that frontal or cyclonic storms often produce heavy rain, in excess of 100 mm in Japan, from the more than ten years record at HO.

The frequency distributions of duration of rainfall in each rain event at BT and HO are given in Figure 8. About 55 % of rain events at BT fell within 1-h period. The mean value of storm duration at BT was about one-fourth that of HO (Table 3). Figure 9 shows the relationship between total amount of rainfall in each rain event and maximum hourly rainfall intensity during rain event. The amount of rainfall in each rain event is proportional to the maximum hourly rainfall intensity at both sites. In particular, there was a higher positive correlation at BT (r=0.95) than at HO (r=0.78). In addition, the slope of best fit line for BT was about 1.15, indicating that almost all rain events had only one major peak covering most of the total rainfall.

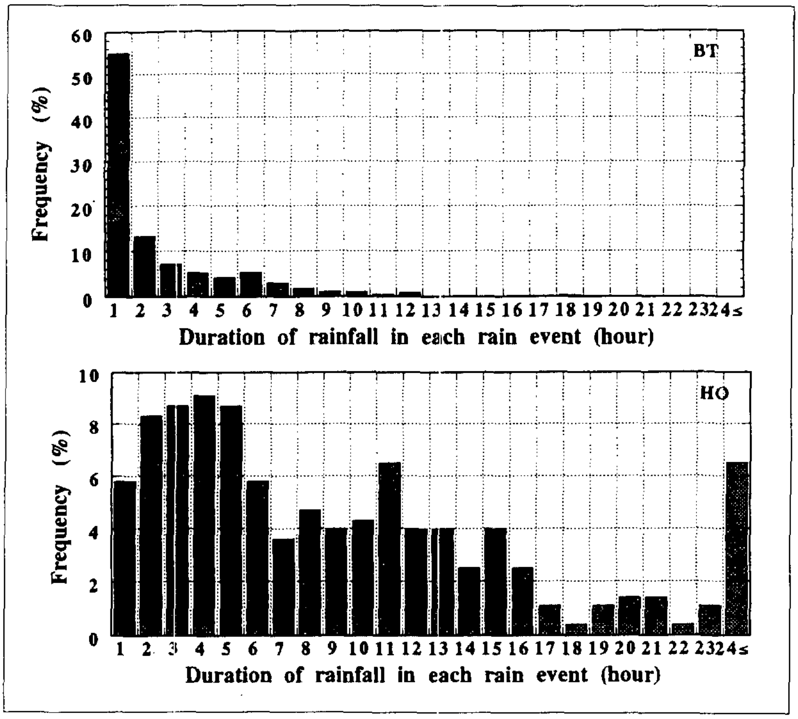

Figure 8. Frequency distribution of duration of rainfall in each rain event at Bukit Tarek (BT) and Hitachi Ohta (HO), from 1992 to 1994

While the maximum rainfall intensity at BT was calculated for durations of 5, 10, 20, 30, 40, 60, 80, and 120 min, the intensity at HO was calculated for durations of

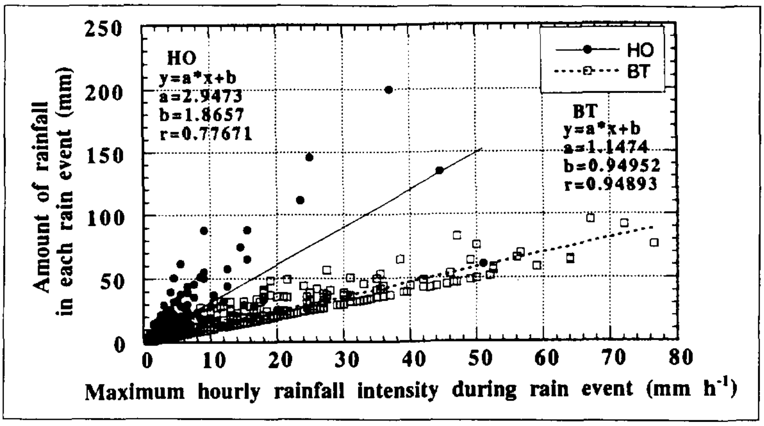

Figure 9. The relationship between amount of rain and the maximum rainfall per hour, at Bukit Tarek (BT) and Hitachi Ohta (HO)

10, 20, 30, 40, 60, 80, and 120 min. The following Ministry of Health formula is often applied to the relationship between time and rainfall intensity (Sumner 1978).

$$I = a / (t + b)$$

where I is the rainfall intensity (mm h^{-1}) over duration of rainfall, t is time (min), and a and b are constants. Rainfall intensity-duration data for selected rainfall events at BT and HO exhibited excellent fits with the formula (Table 4 and Figure 10). Only four rain events with more than 50 mm h^{-1} for 10 min occurred during the 3-y period at HO (Figure 10). On the other hand, such high intensity rain events occurred every month at BT. Though the total amount of rain events is small at BT, some rain events have high intensities; for example on 12 March 1994 a rate of 162 mm h^{-1} over 5 min was recorded at BT (Figure 10). It can be inferred that the occurrence of frequent high intensity rainfall may gave rise to soil erosion problems in tropical regions.

Table 4. Example of curve of the form $I = a/(t + b)$ for some rain events

Site	Date	Total (mm)	Duration (min)	*a*	*b*	r
HO	10/09/93	52.9	200	4967.2	51.469	0.96566***
	18/07/94	26.4	330	1406.6	17.066	0.95744***
	22/09/94	25.4	1250	693.98	3.2131	0.99916***
	28/09/94	132.2	2150	4937.6	62.073	0.98739***
BT	25/01/94	18.0	135	1149.8	6.2842	0.99216***
	12/03/94	51.0	280	2479.4	18.584	0.98322***
	13/04/94	8.6	30	486.34	6.5931	0.99277***
	05/05/94	99.7	185	6686.6	68.447	0.95066***

HO: Hitachi Ohta, BT : Bukit Tarek
a and *b* : constants for the Ministry of Health formula, r : correlation coefficient,
and* denote significance at p<0.01 and at p<0.001 respectively.

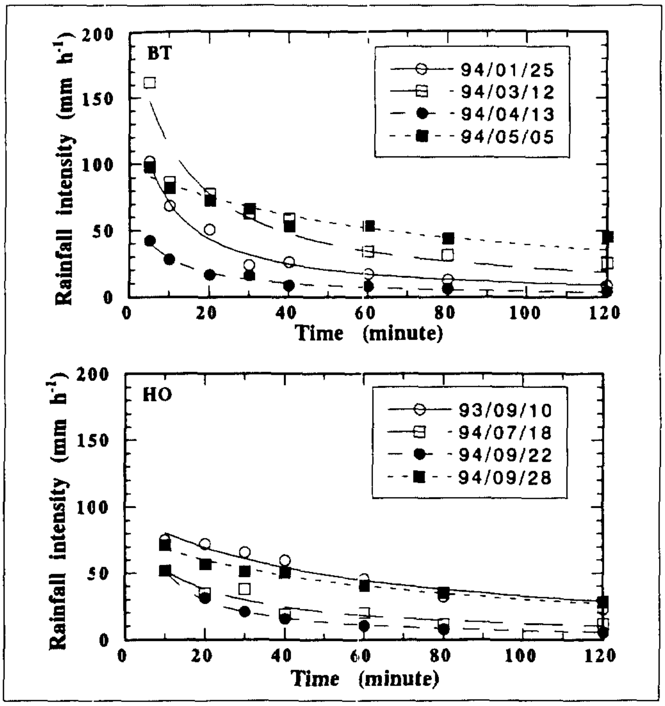

Figure 10. Examples of curve of the form $I = a/(t + b)$ for certain rainfall events at Bukit Tarek (BT) and Hitachi Ohta (HO)

Acknowledgements

The authors thank the Hydrology Section of the Forest Research Institute of Malaysia and the Water Resources Laboratory of the Forestry and Forest Product Research Institute in Ibaraki, Japan for providing the precipitation data. The authors also thank Roy C. Sidle and anonymous reviewers for their comments on the manuscript, and the State Forestry Department of Selangor for giving permission to use the research site. This study was carried out as part of a joint research project between the Forest Research Institute of Malaysia, Universiti Pertanian Malaysia and the National Institute for Environmental Studies of Japan (Global Environmental Research Programme granted by Japan Environment Agency, Grant No. E-3).

References

ABDUL RAHIM, N. 1983. Rainfall characteristics in forested catchments of Peninsular Malaysia. *Malaysian Forester* 46 (2) : 233 - 243.

ABDUL RAHIM, N., SAIFUDDIN, S. & ZULKIFLI, Y. 1995. Water balance and hydrological characteristics of forested watersheds in Peninsular Malaysia. Pp. 303-306 in Yasunari, T. *et al.* (Eds.) *Proceedings "The Second International Study Conference on GEWEX in Asia and GAME"*. Pattaya, Thailand, 6 -10 March 1995. Japan National Committee for GAME and National Research Council of Thailand.

ANDERSON, M. G. & BURT, T. P. 1990. Subsurface runoff. Pp. 365 - 400 in Anderson, M. G. & Burt, T. P. (Eds.) *Process Studies in Hillslope Hydrology.* John Wiley, New York.

BAHARUDDIN, K. & ABDUL RAHIM, N. 1994. Suspended sediment yield resulting from selective logging practices in a small watershed in Peninsular Malaysia. *Journal of Tropical Forest Science* 7 (2): 286 - 295.

BRUIJNZEEL, L. A. 1990. *Hydrology of Moist Tropical Forests and Effects of Conversion: A State of Knowledge Review.* UNESCO IHP Humid Tropics Programme, Paris. 244 pp.

BONELL, M. 1993. Progress in the understanding of runoff generation dynamics in forests. *Journal of Hydrology* 150 : 217 - 275.

BONELL, M. & BALEK, J. 1993. Recent scientific developments and research needs in hydrological processes of the humid tropics. Pp. 167 - 260 in Bonell, M., Hufschmidt, M.M. & Gladwell, J.S. (Eds.) *Hydrology and Water Management in the Humid Tropics.* UNESCO-Cambridge University Press.

DALE, W. L. 1959. The rainfall of Malaysia, Part I. *Journal of Tropical Geography* 13 : 23 - 37.

DUNNE, T. 1978. Field studies of hillslope flow processes. Pp. 227 - 293 in Kirkby, M. J. (Ed.) *Hillslope Hydrology.* John Wiley & Sons, New York.

FAO. 1993. *Forest Resources Assessment 1990.* Tropical Countries FAO Forest Paper 112, Rome.

FUKUI, E. 1977. *The Climate of Japan.* Elsevier Kodansha. 317 pp.

HEWLETT, J. D. 1969. *Principles of Forest Hydrology.* The University of Georgia Press. 183 pp.

LLOYD, C. R. 1990. The temporal distribution Amazonian rainfall and its implications for forest interception. *Quarterly Journal of the Royal Meteorological Society* 116 : 1487 - 1494.

MANLEY, R.E. & ASKEW, A.J. 1993. Operational hydrology problems in the humid tropics. Pp. 34 - 44 in Bonell, M., Hufschmidt, M.M. & Gladwell, J.S. (Eds.) *Hydrology and Water Management in the Humid Tropics.* UNESCO-Cambridge University Press.

MASUKURA, K., YOSHITANI, J, & YAMABE, M. 1992. Rainfall characteristic in Thailand. *Bulletin of the Technical Report of Public Work Research Institute, Ministry of Construction* 34(3) : 55 - 60. (In Japanese)

NIEUWOLT, S. 1968 Diurnal rainfall variation in Malaysia. *Annals of the Association of American Geographers* 58 : 313 - 326.

NOGUCHI, S., ABDUL RAHIM, N., SAIFUDDIN, S. SAMMORI, T. & TANI, M. 1994. Hydrological characteristics of tropical rain forest in Peninsular Malaysia (I). General hydrological observations on a hillslope. Pp. 275-282 in Ohta, T., Fukushima Y. & Suzuki, M. (Eds.) *Proceedings of the International Symposium on Forest Hydrology, 1994.* University of Tokyo, Tokyo.

NOGUCHI, S., ABDUL RAHIM, N., SAIFUDDIN, S. SAMMORI, T. & TANI, M. 1995. Hydrological responses on a hillslope covered with tropical rainforest in Peninsular Malaysia. Pp. 419 - 422 in Yasunari, T. *et al.* (Eds.) *Proceedings "The Second International Study Conference on GEWEX in Asia and GAME".* Pattaya, Thailand, 6 - 10 March 1995. Japan National Committee for GAME and National Research Council of Thailand.

OKI, T. & MUSIAKE, K. 1994. Seasonal change of the diurnal cycle of precipitation over Japan and Malaysia. *Journal of Applied Meteorology* 33 : 1445 - 1463.

PAUL, L. L. & KURAJI, K. 1993. *Transition Report of Hydrological Study on Forested Catchments in Sabah 1990-1992.* Forest Research Center, Sabah Forest Department, Malaysia. 59 pp.

RAMAGE, C. S. 1964. Diurnal variation of summer rainfall of Malaysia. *Journal of Tropical Geography* 19 : 62 - 68.

SAIFUDDIN, S., ABDUL RAHIM, N. & MUHAMMAD, R. 1991. *Establishment and Physical Characteristics of Bukit Tarek Watershed.* Research Pamphlet No.110. Forest Research Institute Malaysia. 51 pp.

SAMMORI, T., ZULKIFLI, Y., BAHARUDDIN, K., NOGUCHI, S. & TANI, M. 1994. Hydrological characteristics of tropical rain forest in Peninsular Malaysia (II). Characteristics of suspended solids transport. Pp. 283 - 290 in Ohta, T., Fukushima Y. & Suzuki, M. (Eds.) *Proceedings of the International Symposium on Forest Hydrology, 1994.* University of Tokyo, Tokyo.

SHUIN, Y., SHIBANO, H., SUZUKI, M. & OHTA, T. 1995. Temporal and spatial characteristics of rainfall at a south-west slope of volcanic Mt. Merapi in Indonesia. *Shin-Sabo* 47(5): 14 - 22. (In Japanese with English summary).

SIA, S. Y. & TAN, S.K. 1994. Spatial characteristics of tropical rainfall over a small catchment. Pp.201-208 in Cheong, H., Shankar, N., Chan, E. & Ng, W. (Eds.) *Ninth Congress of the Asian and Pacific Division of the International Association for Hydraulic Research, 1994, Singapore.* Proceedings Vol. 1, Department of Civil Engineering, National University of Singapore.

SIDLE, R. C., TSUBOYAMA, Y., NOGUCHI, S., HOSODA, I., FUJIEDA, M. & SHIMIZU, T. 1995. Seasonal hydrologic response at various spatial scales in a small forested catchment, Hitachi Ohta, Japan. *Jounal of Hydrology* 168 : 227 - 250.

SIMPSON, J., ADLER, R. F. & NORTH, G.R. 1988. A proposed Tropical Rainfall Measuring Mission (TRMM) satellite. *Bulletin of American Meteorological Society* 69 : 278 - 295.

SUMNER, G. N. 1978. The prediction of short duration storm rainfall intensity maxima. *Journal of Hydrology* 37 : 91 - 100.

TAN, S. K. & SIA, S. Y. 1995. Diurnal and temporal characteristics of tropical storms in Singapore. Pp. 368 - 371 in Yasunari, T. *et al.* (Eds.) *Proceedings "The Second International Study Conference on GEWEX in Asia and GAME".* Pattaya, Thailand, 6 -10 March, 1995. Japan National Committee for GAME and National Research Council of Thailand.

TSUBOYAMA, Y., SIDLE, R. C., NOGUCHI, S. & HOSODA, I. 1994a. Flow and solute transport through the soil matrix and macropores of a hillslope segment. *Water Resource Research* 30 : 879 - 890.

TSUBOYAMA, Y., HOSODA, I., NOGUCHI, S. & SIDLE, R. C. 1994b. Piezometric response in a zero-order basin, Hitachi Ohta, Japan. Pp. 217 - 224 in Ohta, T., Fukushima Y. & Suzuki, M. (Eds.) *Proceedings of the International Symposium on Forest Hydrology, 1994.* University of Tokyo, Tokyo.