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Research Article

Water balance, flow duration and frequency in a small experimental watershed in Kinabalu Park, Sabah

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ABSTRACT. We examined the water balance and hydrological characteristics of tropical montane forests in Kinabalu Park. A small experimental watershed, named Mempening (KM), was established and continuous monitoring of rainfall and discharge was conducted from January 2006 to December 2007. Annual rainfall in 2006 and 2007 was 3,203 and 3,109 mm, respectively. Annual discharge at KM in 2006 and 2007 was 2,350.5 and 2,022.3 mm, respectively. Rainfall and flow duration curves in KM were compared with those observed in two other experimental watersheds in Sabah (Sapulut; SP and Ulu Kalumpang; UK). The probability of daily rainfall greater than 1 mm in KM, SP and UK was 83%, 73% and 68%, respectively. The probability of a daily discharge less than 1 mm in KM, SP and UK was zero, 34% and 2.5%, respectively. In KM and UK, discharge did not cease during the year, whereas in SP the flow frequently ceased. The difference between daily discharge when the probability of occurrence exceeded 80% (D80) and 20% (D20) in KM, SP and UK was 13.7, 5.6 and 2.2 mm, respectively; showing that the fluctuation of daily discharge was the smallest in UK and the greatest in KM. This difference can be explained by the watershed bedrock geology, which is Tertiary Sedimentary Rock in KM and SP but volcanic ash in UK.

Keywords: Kinabalu Park, tropical montane forests, hydrology, water balance, flow duration curve.

INTRODUCTION

The Island of Borneo is experiencing rapid and extensive changes driven by population growth and economic expansion. Tropical forests have been converted to other land uses for subsistence cultivation and large-scale monoculture plantations with irreversible losses of forest biodiversity. Such land use changes coupled with recent global climate changes may affect the remaining tropical forest ecosystem through an increase in the frequency of drought. The increase in the frequency of drought can affect the ecology of forests via forest fires (Mohd. Husni *et al.*, 2005), plant mortality (Nakagawa *et al.*, 2000; Newbery & Lingenfelder, 2004), plant phenology and general flowering (Harrison, 2005; Sakai *et al.*, 2006). To predict the impact of such land use and climate changes on the tropical forests that remain, including those in conservation areas, it is vital to understand water budgets and hydrological cycles on the small catchment scale of remaining forests.

Several forest hydrological cycle and water balance studies have been conducted in

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Borneo at sites in Sapulut and Ulu Kalumpang, Sabah (Kuraji, 2004), Danum Valley, Sabah (Douglas *et al.*, 1992; Bidin *et al.*, 2004; Chappel & Sherlock, 2005), Mendolong, Sabah (Malmer, 2004), Temburong, Brunei (Dykes, 1997; Dykes & Thornes, 2000), Lambir Hills, Sarawak (Kume *et al.*, 2008, Manfroi *et al.*, 2006) and Central Kalimantan (Asdak *et al.*, 1998, Vernimmem *et al.*, 2007), among others. These studies cover a wide range of hydrological observations of rainfall, throughfall, stemflow, soil water, groundwater, stream flow and evapotranspiration. However, only a limited number of hydrological studies have focused on montane forests in Borneo; notwithstanding that there are a number of comprehensive hydrological studies for Central and South American tropical montane forests. In this paper, we examine the water balance and hydrological characteristics of undisturbed tropical montane forests in Kinabalu Park in Sabah. A small experimental watershed was established, and continuous monitoring of rainfall and discharge was conducted to estimate the water balance from January 2006 to December 2007. Our results are compared with data obtained at a number of other locations in Malaysia.

MATERIALS AND METHODS

Site description

Kinabalu Park, 75,400 ha, is situated about 50 km east of Kota Kinabalu (KK), the capital of the state of Sabah. It is home to Mt. Kinabalu (4,095.2 m above sea level), the highest peak in Southeast Asia. The mountain comprises pristine and diverse forest types from lowland Dipterocarp forests at 500 m to alpine vegetation above 3,400 m (Kitayama, 1992). Tertiary sedimentary rock predominantly covers areas below 3,000 m while granitic rock covers areas above 3,000 m. Quaternary sedimentary substrates occur in patches within mountain areas. Rainfall observation and rainwater sampling is conducted at the park headquarters area, 1,563 m in elevation, where one of four automatic weather stations operates (Kitayama *et al.* 1999). The annual rainfall observed at the weather station is 2,781 mm (1996-2000 and 2006-09, 9 years) but extraordinary lows associated with El Nino events were seen in 1997 (1685.0 mm) and 1998 (1739.3 mm) (Kitayama *et al.*, 1999). The mean annual air temperature at the weather station is 18.3°C (1996-2000, 5 years). long-term mean annual rainfall and temperature at KK are 2,625 mm (1951-2001) and 27.1°C (1968-2001), respectively (Kuraji & Ichie, 2006).

An experimental watershed, Mempening (KM), was established on old sedimentary rocks folded in the Tertiary period (Hutchison, 2005) on the southern slope of Mt. Kinabalu (Figure 1). The weir of KM watershed is located at 1,697.7 m above sea level, and the area of watershed is 1.8 (Figure 1 ; Table 1).

Rainfall measurement

Rainfall was measured using a tipping-bucket rain gauge (20 cm in diameter and 0.5 mm in tip resolution; Ohta Keiki Co., Tokyo, Japan) and a data logger (event recording, 1 second time resolution; KADEC-PLS, KONA System Co., Sapporo, Japan) installed at the weather station at 1,563 meter above sea level (Figure 1). No rainfall data was missing for the entire two year period.

Discharge measurement

Discharge was measured through water level measurements of the stilling pool of V-notch weir at KM using an automatic water level recorder (SE-TR/WT500, TruTrack Co., New Zealand). The data recording interval was 10 minutes. To convert from water level to discharge, an empirical power function between water level and discharge was used. To determine the parameters of that function, discharge measurements were carried out 4 times from August 2005 to July 2006 in KM weir using cylinder, polyethylene bucket and stopwatch. Figure 2 shows the observed discharge at each water level and the functions between water level and discharge. The respective equation is:

$$Q = 1.548\ H^{2.5}$$

where Q is discharge *[m3/sec]* and H is water level *[m]*.

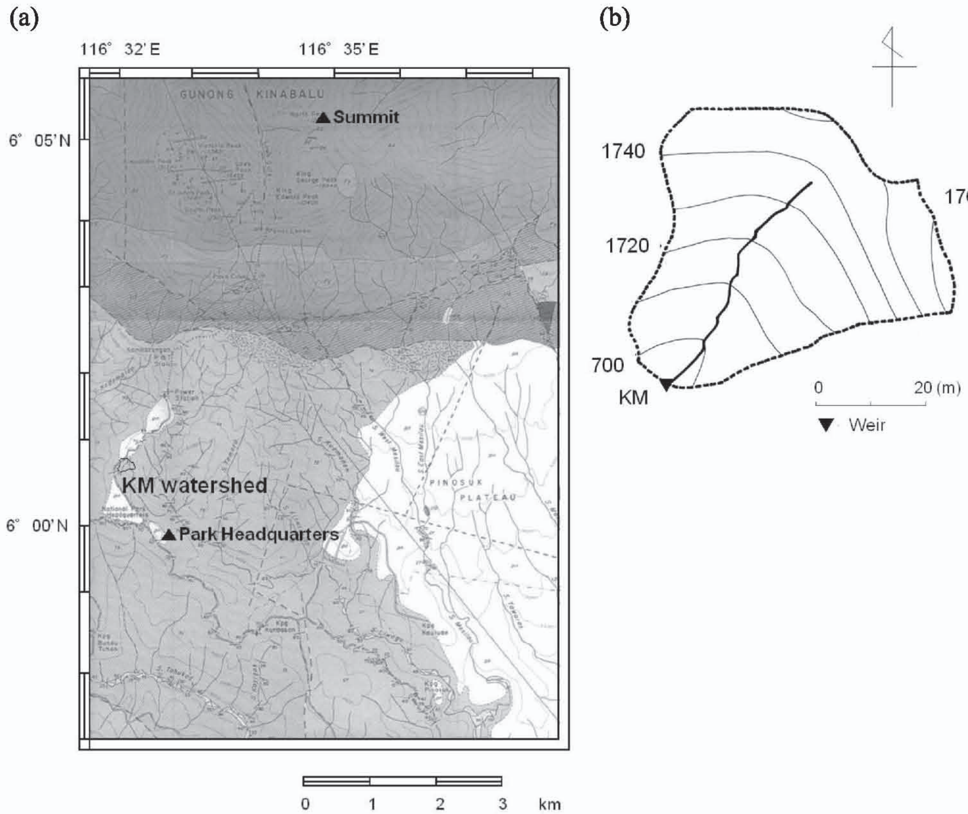

Figure 1. (a) Location of KM watershed based on the map in Jacobson (1970). (b) Location and topography of KM watershed. Climate station is located near the park headquarters.

Table 1. Site description of Kinabalu Mempening (KM), Sapulut (SP) and Ulu Kalumpang (UK).

Watershed name	Longtitude (N)	Latitude (E)	Elevation (m.a.s.l.)	Area (ha)	Vegetation	Soil (USDA)	Geology
KM	6 ° 00'	116 ° 32'	1.695-1.750	1.8	*Tristaniosis, Dacrycarpus, Podocarpus*	Spodosol	Tertiary sedimentary rocks
SP	4 ° 42'	116 ° 44'	515-760	59.4	Lowland hill dipterocarp forest	Ultisols	Middle Tertiary sedimentary rocks, predominantly sandstone and shale
UK	4 ° 31'	118 ° 03'	200-275	22.3	Secondary forest dominated by *Macaranga*	Andisol	Pleistocene; volcanic deposits

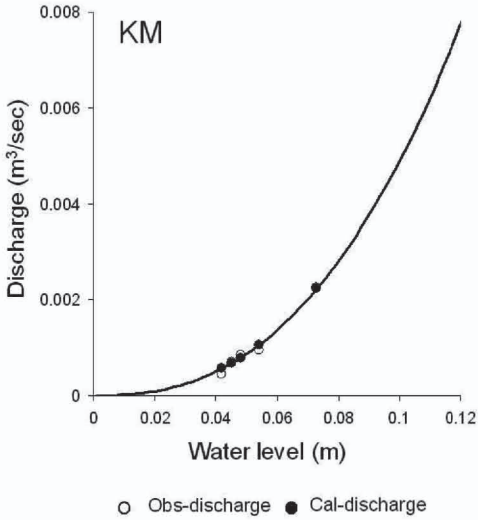

Figure 2. Relationship between water level and discharge at KM watershed.

Rainfall - runoff modeling to fill the missing discharge data

Some discharge measurement data for the two year period are missing. These include 39 days (from 13 October to 20 November) in 2006 and 42 days (from 3 February to 16 March) in 2007. To fill in for the missing data, a rainfall - runoff simulation model developed by one of the authors of this paper (Kuraji, 1996) was applied. Observation data from 1 September 2005 to 29 February 2006 was used for model calibration. The model is a simple lumped model with minimum parameters (Figure 3). The time resolution of the input rainfall and output discharge data are one hour and the calculation time step is also one hour. First, rainfall is stored in the canopy storage tank and overflows if the water exceeds the maximum water storage *(Sc [mm])*. Canopy interception *(Ei [mm/hour])* occurs when the canopy storage tank is not empty. The water that overflows is equal to the net rainfall *(Rn [mm/hour])*, and is separated into effective rainfall *(Re [mm/hour])* which enters the discharge tank, and infiltration flow which enters the soil storage tank. The effective rainfall ratio (α) was calculated by a function of the water storage of the soil storage tank *(Sb [mm])* as follows:

$$\alpha = \frac{Sb - S0}{S100 - S0}$$

where *S100 [mm]* and *S0 [mm]* stand for the water storage of the baseflow tank when the effective rainfall ratios are 100% and 0%, respectively. In daytime when the canopy storage tank is empty, transpiration *(Et [mm/hour])* occurs from the soil storage tank. The discharge-storage function of the discharge tank is as follows:

$$Sd = Kd \cdot Dd^{0.3}$$

where *Dd [mm/hour], Sd [mm]* and *Kd* $[mm^{0.7}\ hour^{0.3}]$ stand for discharge, water storage in the discharge tank and the coefficient of the discharge tank, respectively.

The results of the model calibration and simulation of the periods with data missing and the parameters determined by the calibration period are shown in Figure 4 and Table 2, respectively.

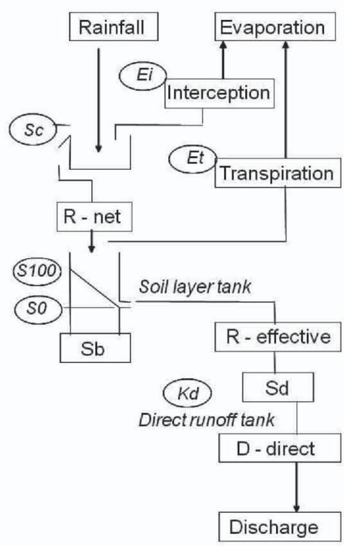

Figure 3. Schematic diagram of the hydrological cycle model developed by one of the authors of this paper (Kuraji, 1996).

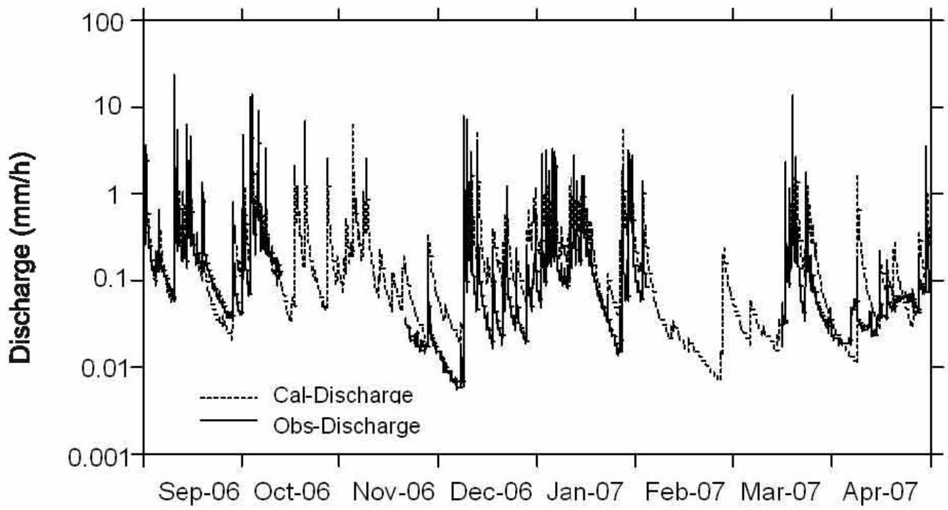

Figure 4. Model output and observed hourly discharge of the KM watershed from September 2006 to April 2007.

Table 2. List of the parameters of the hydrological cycle model.

		KM
Maximum storage of the canopy	*Sc [mm]*	0.6
Interception rate from the wet canopy	*Ei [mm/h]*	0.06
Transpiration rate	*Et [mm/h]*	0.19
Soil storage for the runoff coefficient of 100%	*S100 [mm]*	107.4
Soil storage for the runoff coefficient of 0%	*S0 [mm]*	53.7
Storage function coefficient of the direct runoff	*Kd* $[mm^{0.7}\ hour^{0.3}]$	0.4

RESULTS AND DISCUSSION

Annual water balance

Annual rainfall in 2006 and 2007 was 3,203 and 3,109 mm, respectively. Annual discharge at KM in 2006 and 2007 was 2,350.5 and 2,022.3 mm, respectively. In 2006, rainfall and discharge were 94 mm and 328 mm greater, respectively, than for 2007. However, the loss in 2006 was 234 mm less than in 2007. Figure 5 shows a time series of daily rainfall and discharge in KM from January 2006 to December 2007. A series of rainfall events observed at the end of December 2007 are shown in Figure 5. One possibility for the greater loss in 2007 compared with that in 2006 is that the discharge of the rainfall at the end of 2007 may have been delayed to early January 2008. To compare the annual losses observed in other experimental watersheds throughout Malaysia, Table 3 lists the other watersheds, their elevation, area, observation period, mean annual rainfall, discharge and loss. The relationship between mean annual rainfall and loss (a) and the relationship between elevation and mean annual loss (b) as in Table 3 is shown in Figure 6. No clear correlation between mean annual rainfall and loss (a) was found, but there was significant (99 %) negative correlation between elevation and mean annual loss (b). The probable reason why we obtained lower loss in KM than any other experiments in Peninsular Malaysia was the annual evapotranspiration in KM may be less than that of other sites due to the higher altitude and lower temperature.

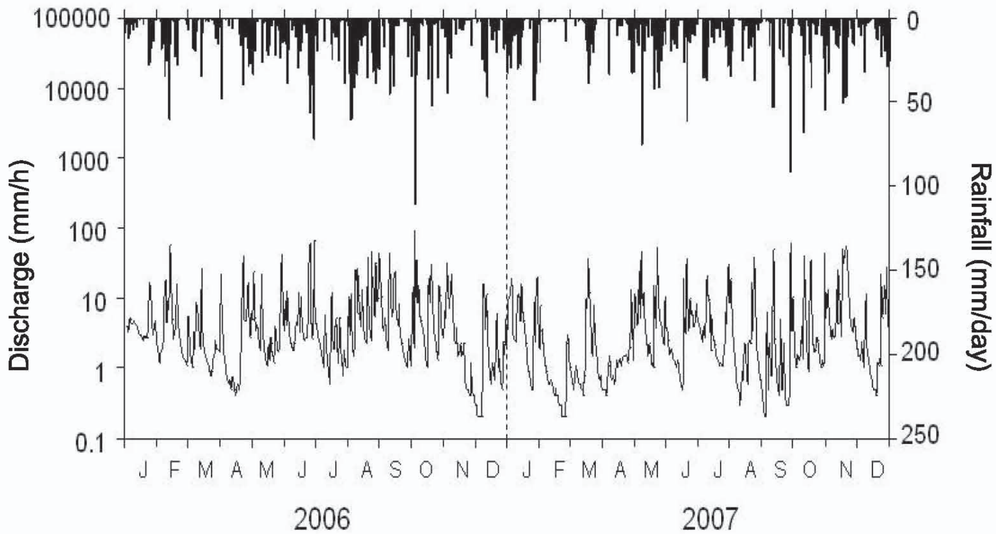

Figure 5. Daily rainfall and daily discharge at KM watershed from January 2006 to December 2007.

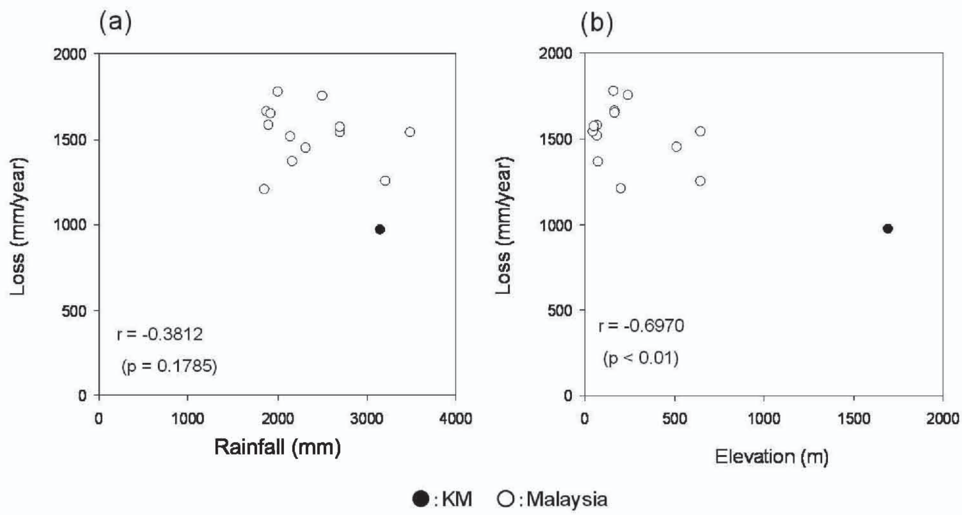

Figure 6. Comparison of relationship between (a) loss and rainfall, (b) loss and elevation in the tropical forested catchments in Malaysia.

Table 3. Water balance in the tropical forested catchments in Malaysia (<100 ha).

No.	Site name	Catchment name	Elevation (m.a.s.l.)	Catchmen t area (ha)	Observation period (Num. of hydro.year)	Rainfall (mm)	Runoff (mm)	Loss (mm)	References
Malaysia									
1	Ulu Combak		244-548	31.5	1968-1969 (1)	2,500	750	1,750	Kenworthy (1969)
2	Sungai Tekam	C	70	56.2	1977-1986 (9)	1,902	322	1,580	DID (1989)
		sub B	68.5	59.2	1983-1986 (3)	2,148	634	1,514	DID (1989)
		A	72.5	37.7	1983-1986 (3)	2,171	804	1,368	DID (1989)
3	Berembun	C1	168-252	12.9	1980-1983 (3)	1,884	223	1,661	Abdul Rahim *et al.* (1985)
		C2	168-223	4.2	1980-1983 (3)	1,922	275	1,648	Abdul Rahim *et al.* (1985)
		C3	160-293	29.6	1980-1983 (3)	2,003	225	1,778	Abdul Rahim *et al.* (1985)
4	Bukit Tarek	C1	48-175	32.8	1989-1994 (5)	2,700	1,160	1,540	Abdul Rahim *et al.* (1985)
		C2	53-213	34.3	1989-1994 (5)	2,700	1,132	1,568	Abdul Rahim *et al.* (1985)
5	Mendolong	W3	650-750	18.2	1985-1990 (5)	3,215	1,962	1,253	Malmer (1993)
		W6	650-750	4.5	1985-1990 (5)	3,490	1,950	1,540	Malmer (1993)
6	Sapulut		515-760	59.4	1991-1992 (2)	2,318	880	1,450	Kuraji & Paul (1995)
7	Ulu Kalumpang		200-275	22.3	1991-1992 (2)	1,851	581	1,206	Kuraji & Paul (1995)
8	Kinabalu Park	Mempening	1,695-1,750	1.8	2006-2007 (2)	3,156	2,186	970	Gomyo *et al.* (this study)

Flow duration curves

Rainfall duration curves in KM for two years (2006 and 2007) are shown in Figure 7. Rainfall and flow duration curves observed in two other experimental watersheds in Sabah (Kuraji, 1996) for two years (1991 and 1992) are also shown. The probability of daily rainfall greater than 1 mm in KM, SP and UK was 83 %, 73 % and 68 %, respectively. The probability of daily discharge less than 1 mm in KM, SP and UK was zero, 34 % and 2.5 %, respectively. In KM and UK, there is water flow in the stream throughout the year, whereas in SP the flow frequently ceased. The shape of the flow duration curve in UK looks gentler than that of KM and SP. To compare the gentleness of the curve, the differences of daily discharge when the probability of occurrence exceeds 80 % (D80) and 20 % (D20) were compared. The differences between D20 and D80 in KM, SP and UK were 13.7, 5.6 and 2.2 mm, respectively, showing that the fluctuation of daily discharge was the smallest in UK and the greatest in KM. The difference of the flow duration curve was caused by the difference in rainfall and watershed bedrock geology (Katsuyama *et al.*, 2008). The bedrock geology in KM and SP is Tertiary Sedimentary Rocks, whereas the geology in UK is volcanic ash, which may have greater water storage capacity than that of Tertiary Sedimentary Rocks.

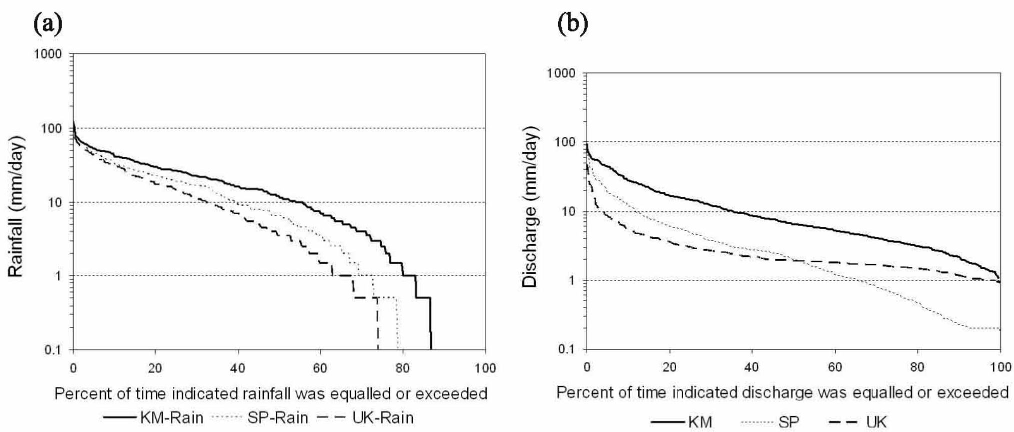

Figure 7. Daily rainfall (a) and flow (b) duration curves for two years daily rainfall and discharge data (KM = 2006 and 2007, SP and UK = 1991 and 1992).

CONCLUSION

From this study, we obtained the following conclusion. The annual rainfall and discharge in KM was 3,203 and 2,350.5 mm respectively in 2006, and 3,109 mm and 2,022.3 mm respectively in 2007. There was significant (99 %) negative correlation between elevation and mean annual loss. The probable reason why we obtained lower loss in KM than any other experiments in Peninsular Malaysia was the annual evapotranspiration in KM may be less than that of other sites due to the higher altitude and the lower temperature. The shape of rainfall frequency and flow duration curves in KM were different from those observed in two other experimental watersheds in Sabah which may be due to difference of the watershed bedrock geology.

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