Variation of suspended sediment transport in the Timah Tasoh Reservoir catchment, Perlis, Malaysia: human impacts and the role of tropical storms

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Abstract In recent years, soil erosion, sediment transport and deterioration of water quality in many river systems in Malaysia have become major concerns. Headwater streams emanating from forested and agricultural lands supply much of the potable water in this country. The quality, quantity and timing of water from these headwater catchments are strongly influenced by human activities such as deforestation associated with land conversion for agricultural purposes. This study investigates the impact of human activities and the role of tropical storms on the variation of sediment transported into the Timah Tasoh Reservoir, Perlis, Malaysia. The study period was two years, with water samples and gauging carried out bi-weekly and additional intensive sampling conducted during storm events. These samples were integrated with data from two continuous hourly transmitted water-level recording stations located at the major river input of the reservoir. Flow and suspended sediment rating curves were developed and used to estimate the discharge and suspended sediment load. Regression equations were used to estimate the discharge and suspended sediment loading at stations with limited and discontinuous data. The variation of suspended sediment load is significantly affected by the human activities and the rainfall and runoff in the catchment area.

Key words human impact; Malaysia; sediment load; Timah Tasoh Reservoir

INTRODUCTION

In recent years, soil erosion, sediment transport and deterioration of water quality in many river systems in Malaysia have become major concerns. Headwater streams emanating from forested and agricultural lands supply much of the potable water in this country. The quality, quantity and timing of water from these headwater catchments are strongly influenced by human activities such as deforestation associated with land conversion for agricultural purposes (e.g. Douglas *et al.*, 1992; Baharuddin & Abdul Rahim, 1994; Ziegler *et al*., 2000). The effect of land-use changes and human activities on hydrology and sediment transport are well documented by several researchers (Wan Ruslan & Zullyadini, 1994; Baharuddin, 1998; Steegen *et al*., 2000; Nelson & Booth, 2002). Under natural conditions, a forest delays runoff and encourages infiltration (Bruijnzeel, 1990), but due to human activity such as urbanization and settlement, construction, agriculture and other human activities, infiltration will be greatly reduced thus increasing total runoff and peak flows.

In tropical regions, storm events play an important role in determining the amount of sediment transported out of a catchment system (Wan Ruslan, 2000). Tropical rainfall is characterized by heavy and intense storms with large rain drops influencing soil erosion and the removal and transport of sediment. Rainfalls with intensities exceeding 200 mm h^{-1} have been reported, while those greater than 100 mm h^{-1} are common (Lal, 1976). In Peninsular Malaysia, about 125 mm h^{-1} is expected in 30-min duration storms occurring approximately once in five years, and 100 mm h^{-1} intensities occur once in two years (Douglas, 1984). Such storms would definitely create a higher erosion rate, and will produce a high amount of suspended sediment transported by river systems. This study investigates the role of tropical storms and the impact of human activities on variations in the amount of sediment transported into a reservoir.

THE STUDY AREA

Timah Tasoh Reservoir (6°36′N, 100°14′E) is located approximately 13 km north of Kangar town near the Thailand border (Fig. 1). The reservoir has a mean surface area of 13.33 km^2 and a storage capacity of about 40 million m^3. The reservoir receives inputs from two main rivers, the Tasoh River and Pelarit River, which have a combined basin area of 191 km^2 and supply approximately 97 million m^3 of water into the reservoir annually. The reservoir is shallow with a maximum depth of 10 m and submerged aquatic plants can be seen along the shoreline and in shallow areas. At present, the main purpose of the reservoir is to supply water for domestic and industrial use as well as for irrigation and flood control.

Three river catchments flowing into the reservoir have been selected as the study area, namely the Jarum River (R1), Upper Pelarit (R2) and Chuchuh River (R3). The location of each study catchment is illustrated in Fig. 1. R1 has a catchment area of 64.4 km^2, R2 42.7 km^2 and R3 14.8 km^2. Table 1 shows the areal proportion of the land use of each of the study catchments. The catchments can be grouped into three categories based on the percentage of forest cover. R3 is nearly 99% covered with forest and very little affected by anthropogenic disturbance. R2 can be categorized as partially disturbed, with almost 91% forest cover. However, this catchment has quarrying which will influence the production of suspended sediment. The third catchment, R1 is considered highly disturbed with anthropogenic activities occurring on 55.1% of the land area. The disturbances are in the form of agriculture activities such as sugar plantation, rubber and paddy.

Table 1 Land use in the study catchments.

Catchments	Jarum River (R1)		Upper Pelarit (R2)		Chuchuh River (R3)	
Land-use type	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Sugarcane	11.58	18.0	–	–	–	–
Urban & settlement	0.74	1.1	0.35	0.8	0.19	1.3
Mixed crop	2.22	3.4	0.21	0.5	–	–
Scrub	2.79	4.3	0.33	0.8	–	–
Rubber	12.94	20.1	2.09	4.9	–	–
Paddy	5.23	8.1	0.4	0.9	–	–
Forest	28.9	44.9	38.72	90.6	14.61	98.7
Grass	–	–	0.13	0.3	–	–
Quarry	–	–	0.5	1.2	–	–
Total	64.4	100	42.72	100	14.8	100

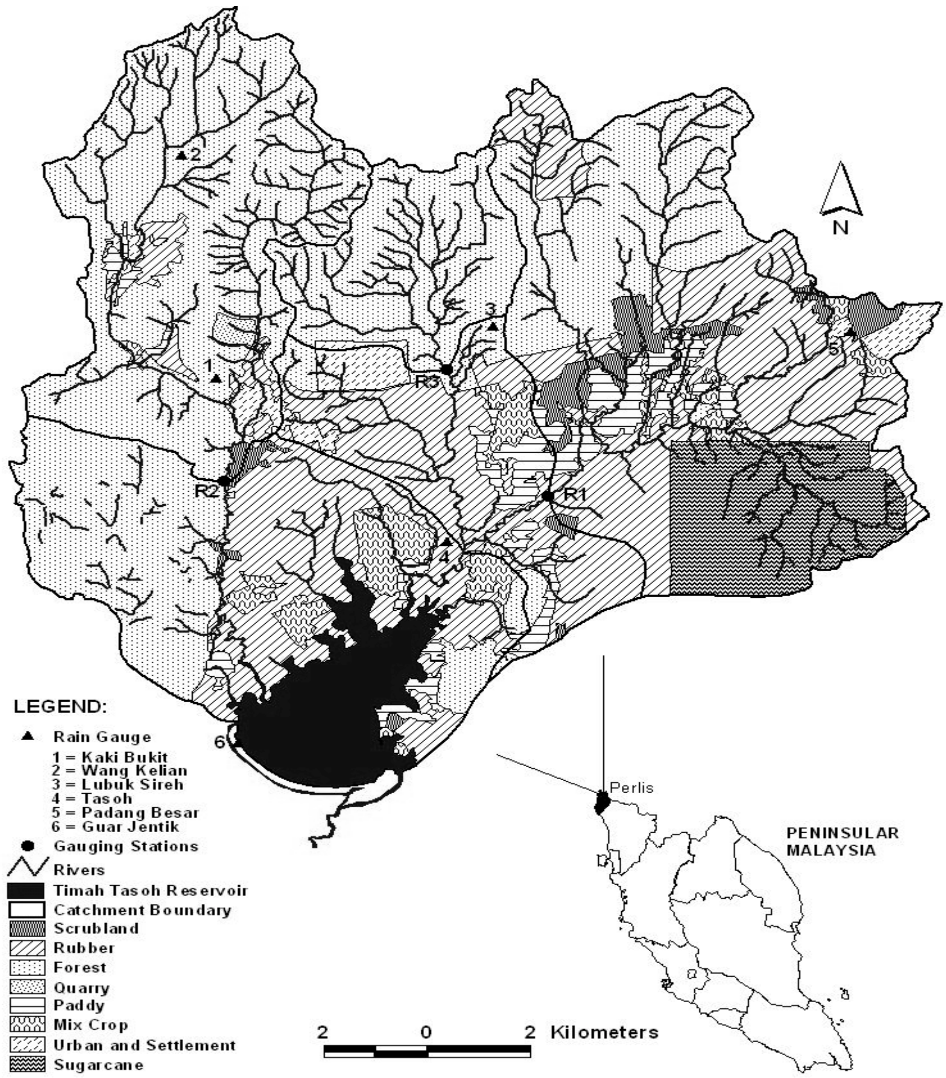

Fig. 1 The study catchments.

METHODOLOGY

Rainfall data were obtained from the six raingauges maintained by the Drainage and Irrigation Department (DID) of Perlis (Fig. 1). Streamflow gauging and water sampling were carried out every two weeks, integrated with frequent intensive sampling during storm events. Sampling was carried out from January 2001 to December 2002.

Continuous telemetrically-transmitted hourly water level records for R1 and R2 were obtained from the DID. Channel cross-sections, velocities and depths were measured to obtain discharge data and three replicates were taken for water sample analyses. The water samples were then filtered using Whatman GFC 47-mm filter paper and oven dried for 24 hours to obtain the suspended sediment concentration. The suspended sediment concentration was computed by applying the suspended sediment concentration rating curve equations summarized in Table 2. The suspended sediment load for each station was determined by multiplying water discharge and sediment concentration.

Table 2 Suspended sediment rating curve equations used to compute the suspended sediment concentration (SSC) for each study catchment.

	Regression equation (Year 2001)	r^2	*n*	Sig. level	Regression equation (Year 2002)	r^2	*n*	Sig. level
Jarum River (R1)								
All Data	$SSC = 0.126Q^{0.327}$	0.50	207	0.01	$SSC = 0.063Q^{0.494}$	0.67	110	0.01
Baseflow	$SSC = 0.139Q^{0.468}$	0.79	65	0.01	$SSC = 0.061Q^{0.562}$	0.34	22	0.01
Highflow	$SSC = 0.201Q^{0.167}$	0.51	43	0.01	$SSC = 0.03Q^{0.079}$	0.12	32	0.01
Rising limb	$SSC = 0.417Q^{-0.388}$	0.47	51	0.01	$SSC = 1.352Q^{-0.554}$	0.27	23	0.01
Falling limb	$SSC = 0.074Q^{0.361}$	0.28	48	0.01	$SSC = 0.057Q^{0.293}$	0.34	27	0.01
Upper Pelarit (R2)								
All Data	$SSC = 0.065Q^{0.607}$	0.28	107	0.01	$SSC = 0.032Q^{0.777}$	0.66	183	0.01
Baseflow	$SSC = 0.004Q^{-0.848}$	0.45	46	0.01	$SSC = 0.017Q^{0.516}$	0.44	49	0.01
Highflow	$SSC = 0.189Q^{0.780}$	0.20	36	0.01	$SSC = 0.024Q^{1.815}$	0.63	54	0.01
Rising limb	$SSC = 0.197Q^{0.472}$	0.46	44	0.01	$SSC = 0.081Q^{0.508}$	0.38	43	0.01
Falling limb	$SSC = 0.012Q^{0.889}$	0.45	46	0.01	$SSC = 0.034Q^{0.55}$	0.38	36	0.01
Chuchuh River (R3)								
All Data	$SSC = 0.122Q^{0.334}$	0.28	133	0.01	$SSC = 0.125Q^{0.4023}$	0.41	195	0.01
Baseflow	$SSC = 0.644Q^{0.348}$	0.42	48	0.01	$SSC = 0.049Q^{0.2863}$	0.36	97	0.01
Highflow	$SSC = 0.196Q^{0.201}$	0.23	37	0.01	$SSC = 0245Q^{0.2518}$	0.35	46	0.01
Rising limb	$SSC = 0.438Q^{1.567}$	0.63	17	0.01	$SSC = 0.438Q^{1.567}$	0.63	17	0.01
Falling limb	$SSC = 0.089Q^{1.536}$	0.82	31	0.01	$SSC = 0.095Q^{1.3553}$	0.72	35	0.01

RESULTS AND DISCUSSION

Total runoff

Upper Pelarit (R2) had the highest runoff during the study period at 2122.8 mm, while Chuchuh River (R3) and Jarum River (R1) recorded 1215.9 and 1159.4 mm, respect-tively (Table 3). When compared to the rainfall runoff coefficients, the same trend remains. The runoff for R2 is 61% of total rainfall. For R3 this drops to 34.7% of total rainfall and for R1 the runoff is 33.1% of total rainfall (not very much lower than R3).

The mean monthly runoff coefficients for each study area are 35.9%, 59.8% and 38.34% for R1, R2 and R3, respectively (Table 3), closely resembling the total runoff coefficients. For R1 the monthly runoff coefficients ranged between a minimum of 11.7% and a maximum of 86.72%. The maximum and minimum runoff coefficients were 8.2–165.4% for R2 and 12.5–92.6% for R3. The runoff exceeded rainfall twice at R2, during December 2001 and October 2002. This was due to delayed runoff because of the high rainfall in the previous month (239.4 and 259.3 mm in October and November 2001, respectively).

Baseflow and stormflow

The monthly average stormflow contribution in the Jarum River (R1) is 31.9%, varying from zero to 69.7% (Fig. 2). Maximum stormflow occurred in September 2002 reflecting high rainfall. As illustrated in Fig. 2, much of the runoff at R1 is dominated by baseflow, except during the wet season. In Upper Pelarit (R2), the monthly average of stormflow was 26.5%, with a maximum of 67.8%. As illustrated in Fig. 2, much of

Table 3 Summary of runoff coefficients for the study catchments during the study period.

	R1			R2			R3		
Year	Runoff (mm)	Rainfall (mm)	% Runoff	Runoff (mm)	Rainfall (mm)	% Runoff	Runoff (mm)	Rainfall (mm)	% Runoff
Total 2001	573.8	1697.4	33.8	1093.3	1812	60.3	604.3	1697.4	35.6
Total 2002	585.7	1808.6	32.4	1029.4	1669.5	61.7	611.6	1808.6	33.8
Total	1159.4	3506.0	33.1	2122.8	3481.5	61.0	1215.9	3506.0	34.7
Annual mean	292.8	904.3		514.7	834.8		305.8	904.3	
Month									
Mean	48.3	146.1	35.9	88.5	145.1	59.8	50.7	146.1	38.3
Max	139.9	295.3	86.7	226.5	308.3	165.4	145.5	295.3	92.6
Min	8.0	0.0	11.7	5.3	0.0	8.2	8.7	0.0	12.5
Std Dev	38.9	94.9	20.4	72.0	91.1	34.9	39.7	94.9	21.6

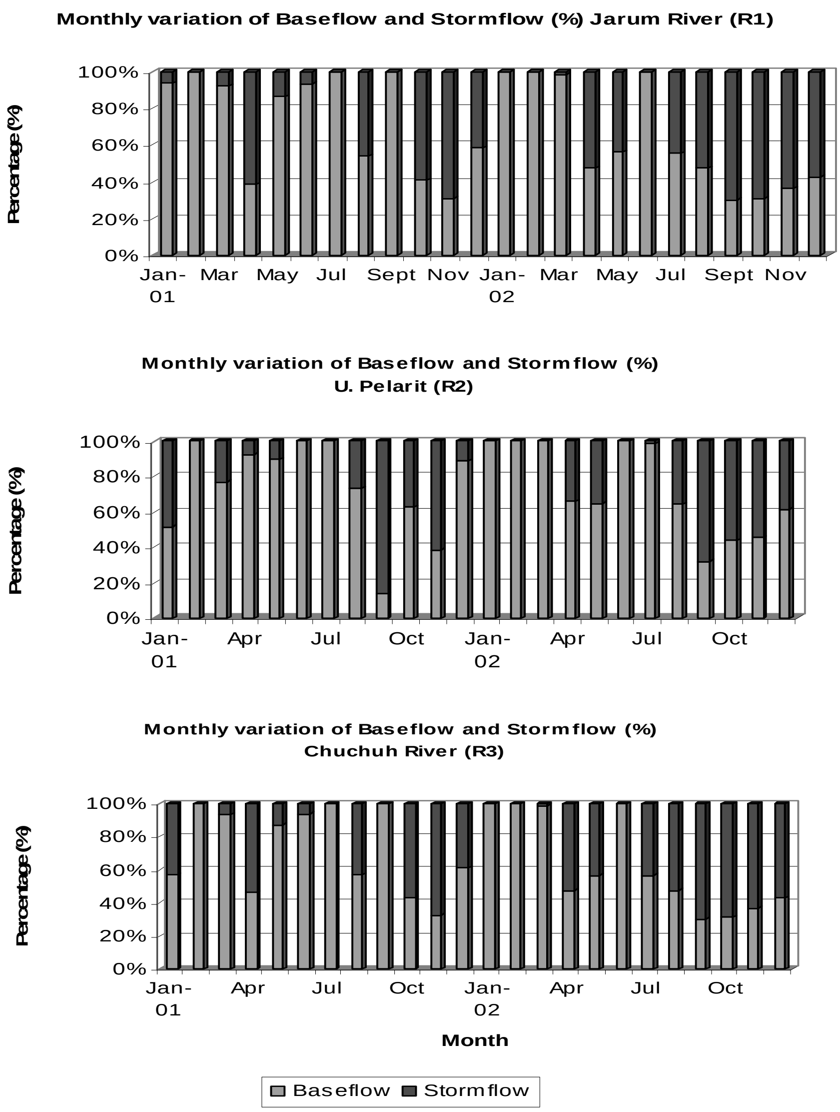

Fig. 2 Monthly variation of baseflow and stormflow (%)each of the study catchments during the study period.

the runoff in R2 is dominated by baseflow. Stormflow produces a monthly average of 35.3% of runoff in Chuchuh River (R3), with a maximum of 69.6%. Baseflow also dominates the monthly runoff at R3, except during the wet months of April, May and September–November. It is clear that stormflow plays a significant role in shaping the runoff patterns of each catchment during the study period.

Suspended sediment concentration

Generally, the suspended sediment concentrations closely follow anthropogenic activities in the catchments (Table 4). The Upper Pelarit (R2) has the highest mean concentration of suspended sediment compared to the other two catchments. Based on all the data for 2001, the maximum concentration at R2 was 1544 mg L^{-1} with a minimum of 1.2 mg L^{-1} and a mean of 202.2 mg L^{-1}. These are generally higher values than those recorded at the Jarum River (R1) and the Chuchuh River (R3). The maximum concentration at R1 was 1118.1 mg L^{-1}, with a minimum of 6.8 mg L^{-1} and a mean of 143.7 mg L^{-1}. Lower values were obtained at R3, with a maximum concentration of 702.4 mg L^{-1}, a minimum of 1.2 mg L^{-1} and a mean of 121.1 mg L^{-1}.

Based on the whole data set, suspended sediment concentrations for 2002 showed only slight differences from those of 2001. R1 reported a maximum of 864.8 mg L^{-1}, a mean of 117.9 mg L^{-1} and a minimum of 2.3 mg L^{-1}. Comparable values for R2 were 784.8, 147.2 and 1.6 mg L^{-1}, respectively. There was no difference in the maximum and minimum suspended sediment concentrations observed at R3 in 2001 and 2002 (Table 4).

When the suspended sediment concentration data were divided into baseflow and stormflow, a distinct contrast was apparent between the study catchments. During baseflow, mean concentrations at R2 and R3 were much lower than at R1. By contrast, at R2 the low sediment concentrations during baseflow give way to very much higher values during stormflow, which clearly contributes most of the suspended sediment. This is due to human activities around the catchment area. Quarrying and former tin mining in the catchment are the major sources of suspended sediment production during storm events. Quarrying activities clearly influence the suspended sediment concentration transported into a river system. Wan Ruslan & Zullyadini (1994) show that, during a single storm, the maximum suspended sediment concentration was 63 200 mg L^{-1} and the lowest concentration 1100 mg L^{-1}.

Table 4 Descriptive statistic of SSC (mg L^{-1}) at the gauging stations (all data).

	Upper Pelarit (R2)		Jarum River (R1)		Chuchuh River (R3)	
Year	2001	2002	2001	2002	2001	2002
Mean	202.2	147.2	143.7	117.9	121.1	97.3
Maximum	1544	784.8	1118.1	864.8	702.4	702.4
Minimum	1.2	1.6	6.8	2.3	1.2	1.2
SD	324.2	157.6	125.4	182.3	158.6	140.6
n	172	181	207	109	133	195

Suspended sediment load

As expected, the Upper Pelarit (R2) had a suspended sediment load that is higher than the other study catchments. The total suspended sediment load produced at R2 over both years was 19688.9 t, compared to 15978.7 and 1923.4 t for Jarum River (R1) and Chuchuh River (R3), respectively (Table 5). Storm runoff carried a small proportion of the sediment output of R3 (1360 t) compared to R1 (11 148.1 t) and R2 (13 322.3 t), but the proportion of storm output over total load was the highest at R3. Storms accounted for 70.7% of the sediment output at R3, slightly higher than that at R1 (69.8%) and R2 (67.7%).

Table 5 Summary of suspended sediment load values of each study catchments.

	R1	R2	R3
Period (year)	2	2	2
Total load (t)	15 978.72	19 688.88	1923.37
Total yield (t km^{-2})	248.12	490.88	129.96
Annual yield for 2001 (t km^{-2} $year^{-1}$)	92.34	310.15	58.24
Annual yield for 2002 (t km^{-2} $year^{-1}$)	155.78	150.73	71.72
Total storm load (t)	11 148.10	13 322.33	1360.00
Total storm yield (t km^{-2})	173.11	311.85	91.89
Annual storm yield for 2001 (t km^{-2} $year^{-1}$)	34.94	226.32	34.45
Annual storm yield for 2002 (t km^{-2} $year^{-1}$)	138.17	85.53	57.44
Proportion of storm output over total load (%)	69.77	67.66	70.71

The monthly suspended sediment loads varied, reflecting the seasonal rainfall of the study catchments (Table 6). At R1, the highest suspended sediment amount was observed in October 2002 (2732.6 t). During this month, storms contributed as much as 2615.1 t of suspended sediment load, accounting for 95.7% of total load of that month. The lowest suspended sediment load was observed in February 2002 (15.07 t), during which no storm event was recorded.

At R2, the highest monthly suspended sediment transported was in November 2001 (3766.9 t), during which 2625.6 t was contributed from storm events. The highest percentage of storm contribution was observed in January 2001 which accounted for 97.7% of the total load in that month, although January can usually be considered as a dry month. Nevertheless, the few storms that did occur during this month contributed much of the suspended sediment load. This was due to the availability of new sediment sources which had accumulated in the river channel and from the slopes during the previous wet month. The lowest monthly suspended sediment load was in March 2002 (1.39 t) reflecting the driest period during the study with no storms recorded since the end of January 2002.

At R3, the highest monthly suspended sediment load was recorded in November 2001 (283.1 t), of which 242 t was contributed from storms in this month. The highest monthly proportion of storm outputs was recorded in September 2002, reflecting the beginning of the wet season within the study period. Most of sediment accumulated

Table 6 Monthly variation of suspended sediment for each study catchment.

	Jarum River (R1)			Upper Pelarit (R2)			Chuchuh River (R3)		
	Load (t)	Storm (t)	% storm	Load (t)	Storm (t)	% storm	Load (t)	Storm (t)	% storm
Jan-01	737.76	62.02	8.4	1284.68	1255.61	97.7	85.23	9.65	11.3
Feb-01	93.57	0	0.0	9.04	0	0.0	11.55	0	0.0
Mar-01	188.21	29.95	15.9	288.84	273.14	94.6	20.86	2.84	13.6
Apr-01	278.63	215.02	77.2	338.92	228.6	67.5	32.5	24.63	75.8
May-01	674.93	117.05	17.3	33.14	11.31	34.1	69.54	15.35	22.1
Jun-01	431.82	46.27	10.7	10.12	0	0.0	44.11	5.19	11.8
Jul-01	35.77	0	0.0	10.14	0	0.0	5.72	0	0.0
Aug-01	498.27	240.46	48.3	2520.86	2248.67	89.2	74.72	49.74	66.6
Sep-01	232.2	0	0.0	736.73	427.26	58.0	15.65	0	0.0
Oct-01	1003.93	558.75	55.7	3684.53	2471.81	67.1	145.66	113.46	77.9
Nov-01	1293.53	751.4	58.1	3766.85	2625.61	69.7	283.1	241.95	85.5
Dec-01	477.77	229.04	47.9	565.84	126.41	22.3	73.33	47.12	64.3
Jan-02	19.01	0	0.0	9.33	0	0.0	5.47	0	0.0
Feb-02	15.07	0	0.0	2.01	0	0.0	4.41	0	0.0
Mar-02	28.34	15.84	55.9	1.39	0	0.0	3.88	0.1	2.6
Apr-02	697.43	630.83	90.5	87.98	72.95	82.9	59.48	44.71	75.2
May-02	616.93	467.19	75.7	103.57	87.46	84.4	58.32	39.33	67.4
Jun-02	15.57	0	0.0	3.13	0	0.0	4.53	0	0.0
Jul-02	176.44	162.17	91.9	27.42	0	0.0	18.04	13.89	77.0
Aug-02	960.16	905.73	94.3	591.85	397.42	67.2	97.52	72.7	74.6
Sep-02	2009.89	1857.17	92.4	1950.76	0	0.0	244.57	212.2	86.8
Oct-02	2732.63	2615.05	95.7	1724.59	1461.88	84.8	277.83	234.78	84.5
Nov-02	1638.22	1519.64	92.8	1218.21	1034.54	84.9	175.81	144.08	82.0
Dec-02	1122.65	724.5	64.5	718.95	599.67	83.4	111.52	88.29	79.2
Total	15978.73	11148.08	69.8	19688.9	13322.3	67.7	1923.35	1360.01	70.7
Mean	665.78	464.50		820.37	555.10		80.14	56.67	
Max	2732.63	2615.05	95.7	3766.85	2625.61	97.7	283.1	241.95	86.8
Min	15.07	0	0	1.39	0	0	3.88	0	0

and deposited in the channel was flushed out by the storms in this month. The lowest monthly suspended sediment load was recorded in March 2002 (3.9 t).

CONCLUSIONS

The variations in runoff and suspended sediment transported in the study catchments show the influence of anthropogenic activities in the catchment area as well as the effect of storms. This paper shows that there is a significant difference in suspended sediment concentration during the baseflow period compared to that during storm events. Human disturbance, such as quarrying activity, makes sediment available for transport during a series of storm events. Almost 70% of the suspended sediment load was transported during storms in the study catchments.

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