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Suspended Sediment and Turbidity Relationships for Individual and Multiple Catchments

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ABSTRAK

Perhubungan di antara kepekatan sedimen ampaian dan kekeruhan telah dianalisis pada tahap membubung dan menurun, pada peringkat kawasan tadahan yang berasingan dan digabungkan. Keputusan menunjukkan terdapat korelasi yang tinggi di antara kepekatan sedimen ampaian dan kekeruhan bagi keseluruhan data kawasan kajian. Melalui kaedah gandadua terkecil didapati bahawa data-data tersebut mempunyai pertalian persamaan fungsi kuasa berbentuk:$Y=a(T)^b$. Hubungan yang konsisten di antara kekeruhan dan kepekatan sedimen ampaian melalui kajian ini menunjukkan pengukuran kekeruhan boleh digunakan sebagai alternatif bagi menganggarkan beban sedimen ampaian sungai di kawasan tadahan dalam kajian dan mana-mana kawasan tadahan yang lain yang mempunyai ciri-ciri yang serupa.

ABSTRACT

The relationships between suspended sediment concentrations and turbidity were analysed at rising and falling stages, using individual and combined catchments. Results suggested a high correlation exists between suspended sediment concentration and turbidity for most of the field data. The least square fit of all the data suggested that the relationships obtained followed a power function in the form of $Y = a(T)^b$. Consistent turbidity and suspended sediment concentration relationships found in this study imply that turbidity measurement could reasonably be used as a surrogate in estimating stream suspended sediment concentration of the study catchments and of those under similar conditions.

Keywords: sediment, turbidity, catchment, stage height

INTRODUCTION

Sampling of suspended sediment concentration can provide a useful indication of the quantity of sediment in transport within a river system. Traditionally, suspended sediment rating curves or sediment load versus discharge relationship was commonly used to estimate sediment discharge as it required knowledge of water discharge only. However, erosion and sediment movement within unstable catchments are variable and difficult to predict. Under such conditions, the use of suspended sediment discharge-water discharge rating curves can often exhibit scatter when plotted on log-log paper and have proved to be unreliable (Gregory and Walling 1973).

Generally, a better correlation between turbidity and suspended sediment concentration is expected for unstable catchments, because turbidity and suspended sediment response are not directly related to water discharge (Truhlar 1978). However, this is not always true as turbidity varies with the optical properties of sediment (Richards 1982). Few studies have addressed the relationship between suspended sediment concentrations and turbidity in Malaysia. For example, an earlier study conducted at Pasoh Catchment, Negeri Sembilan (Yusof 1990) was specifically to find correlation between turbidity and suspended sediment concentration under prelogging and postlogging conditions. This study, however, sought to explore the possibility of estimating suspended sediment concentrations in Malaysian streams by turbidity measurements.

STUDY AREA

The river water sampling was carried out in 23 catchments. Two catchments were located within the farms of Universiti Pertanian's Serdang campus (UPM) and the adjacent Malaysian Agricultural Research Institute, while the other 21 catchments were in the tributaries of Pahang River basin. The area of the catchments ranged from 3.4 km^2-4561 km^2.

The land use of the first catchment situated within the UPM farms included an oil palm and rubber plantation, a golf course, and grassland. The adjacent second catchment comprised active cultivated vegetation plots, construction sites, and bare spot areas. The soil type, topography, and rainfall distribution of the areas were considered the same.

The land use of the catchments on the Pahang River basin was diverse (*Fig. 1*). The soil types and topography also varied among the catchments.

MATERIALS AND METHODS

For a 6-month period (August 1991-January 1992), turbidity and suspended sediment measurements were made on water samples from two catchments on the farms of Universiti Pertanian Malaysia and Malaysian Agricultural Research Institute. A longer sampling period is preferable to reflect the monthly variations. However, due to time and budget constraints this was not possible. Samples from tributaries in the Pahang River basin (*Fig. 2*) were measured in June 1993.

The suspended sediment concentrations were sampled with standard US-DH-48 depth integrating sampler (Guy and Norman 1970). Turbidity was measured with a light scattering turbidity meter with operating range from 0 to 1000 NTU (Chemtrix Type 12). Water samples for the two catchments of the Universiti Pertanian's farm were gathered during storm and normal flow periods, while the samples from tributaries of Pahang River basin were sampled only during normal flow. Turbidity readings were also recorded for each repeated suspended sediment sample collected. The water samples were pumped under partial vacuum through 0.45 micron pore size glass fibre filters (Eaton

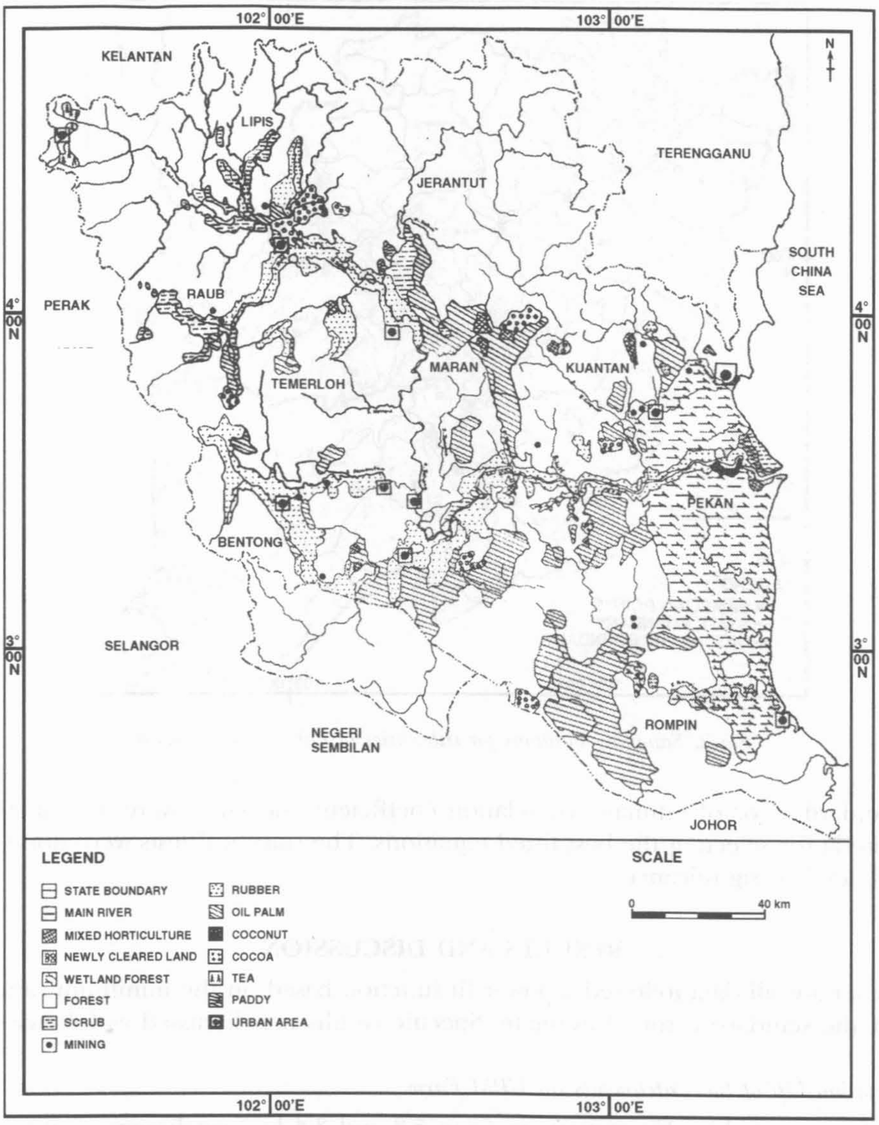

Fig. 1 Landuse of Pahang River basin

et al. 1969). Ashing of the organic material from the samples was done at 600° C for 2 h in a muffle furnace. The sediment was oven dried at 105° C for 24 h and weighed.

Data on suspended sediment concentrations were expressed in milligrams per litre (mg/l), while turbidity was measured in nephelometric turbidity units (NTU). All data sets were subjected to least square fitting for (1) simple linear, (2) power function, (3) logarithmic, and (4) exponential equations. The

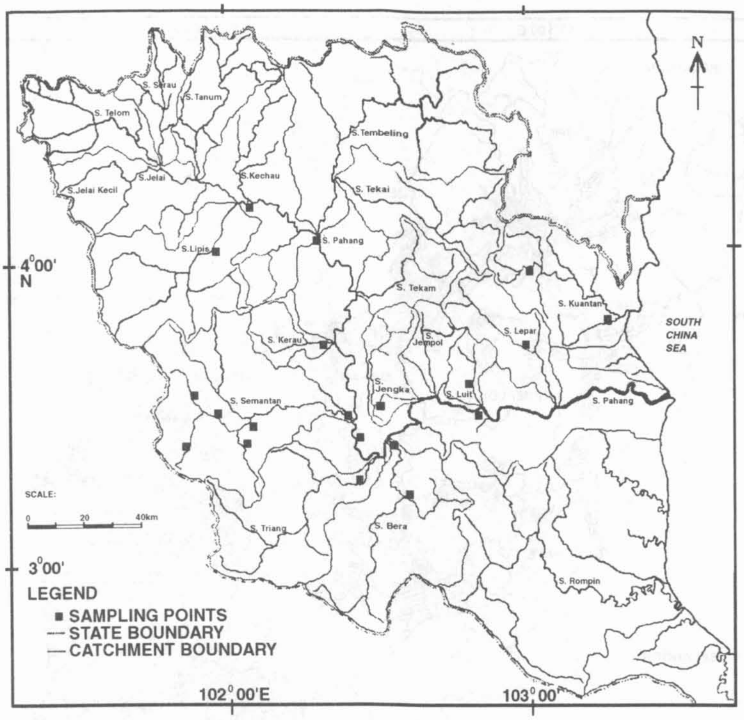

Fig 2. Sampling locations for tributaries of Pahang River basin

standard error of estimate, correlation coefficient and F-test were used as the criteria for selecting the best fitted equations. The statistical tests were done at 5% level of significance.

RESULTS AND DISCUSSION

Generally, all data followed a power fit function based on the minimum values for the standard error of estimate. Specific results are discussed as follows:

Relationship of the Catchments on UPM Farm

Data presented in this section are from 5.3 and 3.4 km^2 catchments that were designated catchment 1 and 2 respectively. Suspended sediment concentrations ranged from 1.0-2533 mg/l and turbidity ranged from 8-850 NTU. Once again, the data were collected during normal and storm flows. Suspended sediment and turbidity data from catchment 2 show a wider range in values than those of catchment 1, however. This may be due to the more disturbed nature of the soil surface of catchment 2.

Fig. 3-5 illustrate the samples' plot of the stage height versus time, together with the respective average suspended sediment concentrations taken during three storm events. There are no flow records pertaining to average long-term

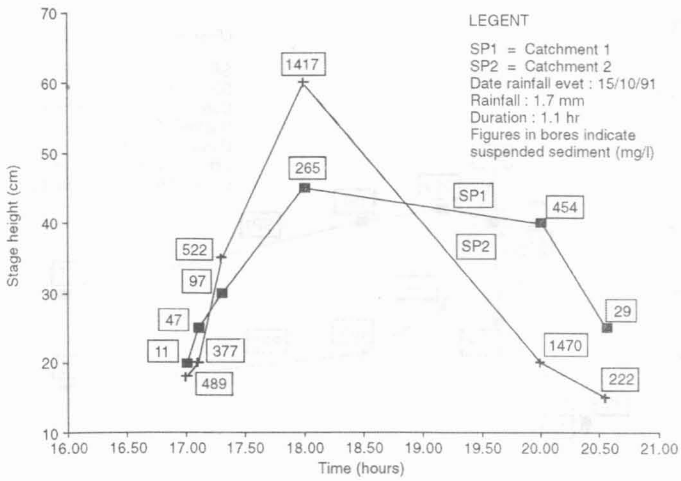

Fig. 3. Suspended sediment concentration and stage height at cotchments 1 and 2 of UPM farm

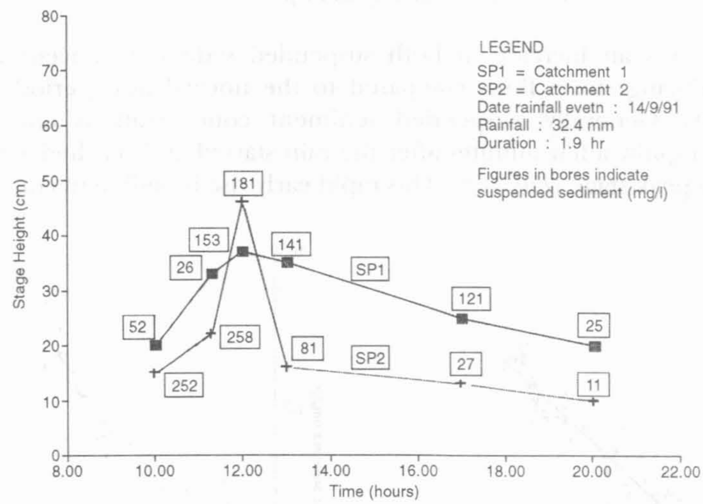

Fig. 4. Suspended sediment concentration and stage height at catchments 1 and 2 of UPM farm

minimum or maximum flow rates of these two catchments. *Fig. 3* suggests that a short high intensity rainfall event can produce a significantly (F-test, $P < 0.05$) higher sediment concentration than a less intense storm of relatively similar or longer duration as shown in *Fig. 4, 5*. *Fig. 3-5* also illustrate that for the sampled storm events dated 9, 14 August and 15 October 1991, the surge of suspended sediment concentrations receded to normal concentrations within 5-6 h after peak stage for both catchments.

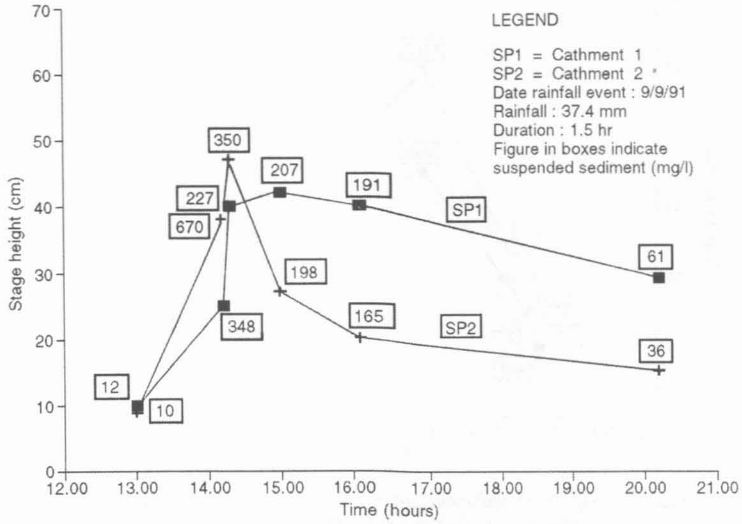

Fig. 5. Suspended sediment concentration and stage height at catchments 1 dan 2 of UPM farm

There was an increase in both suspended sediment concentration and turbidity during storm flows compared to the normal flow periods for both catchments. Generally, suspended sediment concentrations and turbidity increased rapidly a few minutes after the rain started and reached a maximum before the peak stage (*Fig. 4, 5*). This rapid early rise in sediment concentration

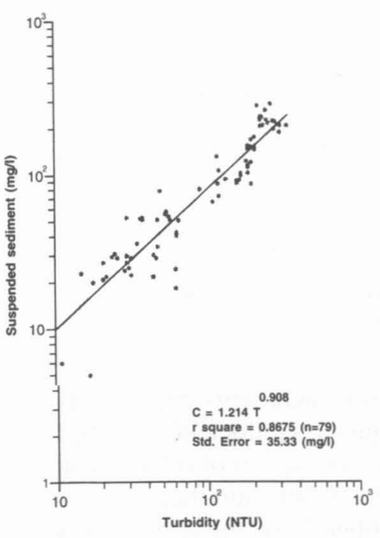

Fig. 6. Suspended sediment and turbidity relationships during rising stage for catchment 1 of UPM farm

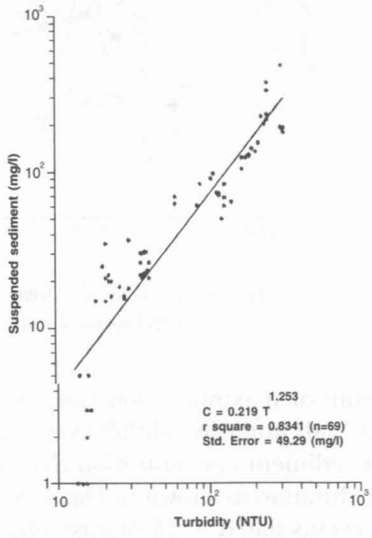

Fig. 7. Suspended sediment and turbidity relationships during rising stage for catchment 1 of UPM farm

may be due to the arrival of soil detached by rain drop impact that reached the streams by surface runoff, and sediment eroded from the stream banks with only 35% grass cover. In rare cases, the average maximum suspended sediment concentration appeared after the peak stage, as demonstrated in *Fig. 3*.

The least square fit of suspended sediment concentrations and turbidity for the rising and falling stages was plotted on a log-log scale and presented in *Fig. 6, 7* for catchment 1 and *Fig. 8, 9* for catchment 2, respectively. Statistically, best fit power function obtained from the least squares fitting was as follows:

$$C = 1.214\ T^{0.908}\ (r = 0.9314\ ;\ \text{Std. error}: 35.33\ \text{mg/l}) \quad (1)$$
$$C = 0.219\ T^{1.253}\ (r = 0.9133\ ;\ \text{Std. error}: 49.29\ \text{mg/l}) \quad (2)$$
$$C = 0.535\ T^{1.155}\ (r = 0.8999\ ;\ \text{Std. error}: 444.71\ \text{mg/l}) \quad (3)$$
$$C = 1.106\ T^{0.931}\ (r = 0.8709\ ;\ \text{Std. error}: 37.42\ \text{mg/l}) \quad (4)$$

The C and T values that appear in the equations and *Fig. 6-9* indicate suspended sediment concentration in mg/l and turbidity in NTUs, respectively. Equations (1) and (2) were obtained from data for the rising and falling stages of catchment 1, and (3) and (4) were derived from data for the rising and falling stages of catchment 2.

Fig. 6-9 suggest that individual measurements have higher correlation coefficients on the rising stage compared to the falling stage for both catchments (F-test, $P < 0.01$)). Similarly, using F-test ($P < 0.01$) the magnitude in terms

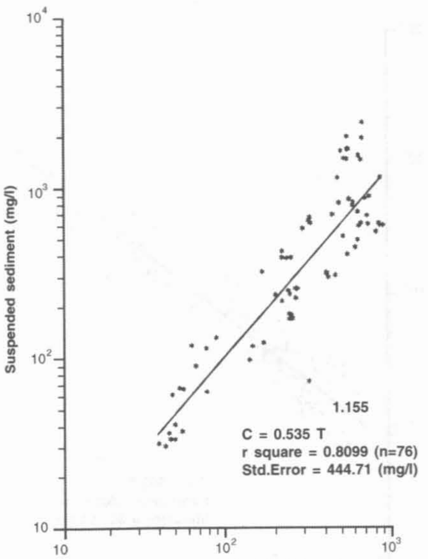

Fig. 8. Suspended sediment and turbidity relationships during rising stage for catchment 2 of UPM farm

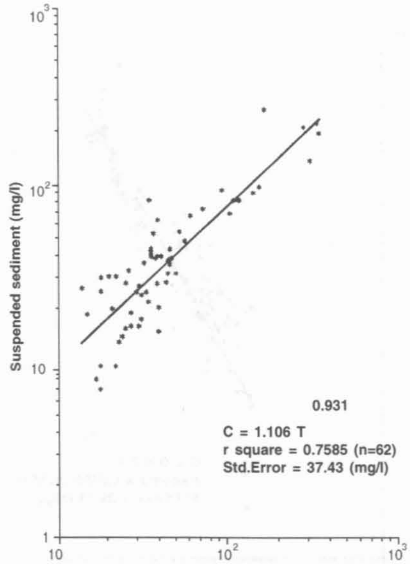

Fig. 9. Suspended sediment and turbidity relationships during falling stage for catchment 2 of UPM farm

of standard error of estimate was greater for the relationship obtained during the rising stage of catchment 2. This greater variation among individual data collected during the rising stage was expected due to the relatively unstable nature of catchment 2 compared to catchment 1. Generally, individual measurements for both catchments displayed more scatter at lower turbidity.

Analyses of suspended sediment and turbidity data in combination of both stages using F-test ($P < 0.01$) indicated that there was no significant change in the correlation coefficient for catchment 1 (*Fig. 10*). Data for catchment 2 (*Fig. 11*) did show a small improvement ($P < 0.05$) in the correlation, with a reduction in standard error to 308 mg/l (rising stage was 444.7 mg/l). Based on the analysis of variance (ANOVA), best fit equations of the power function obtained for the combined data of both rising and falling stages for both catchments, do not vary greatly ($P < 0.05$) as shown below:

$$C = 0.397\ T^{1.13} \qquad (r = 0.9168) \qquad (5)$$
$$C = 0.503\ T^{1.16} \qquad (r = 0.9488) \qquad (6)$$

Consistent correlation coefficients and power functions found in both catchments during rising and falling stages, and in combination of both stages, suggest that the optical property of the two stream was the sediment characteristic of both catchments.

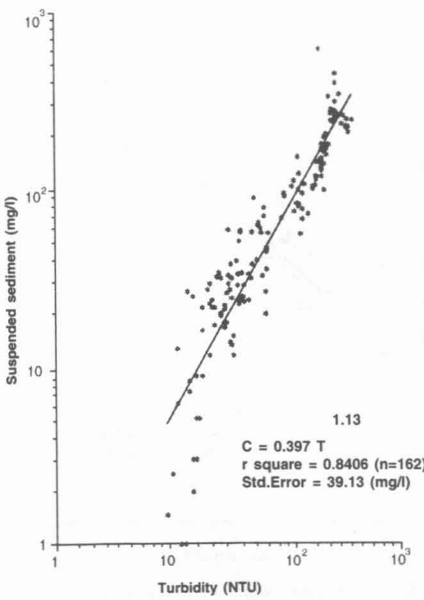

Fig. 10. Suspended sediment and turbidity relationships for catchment 1 of UPM farm

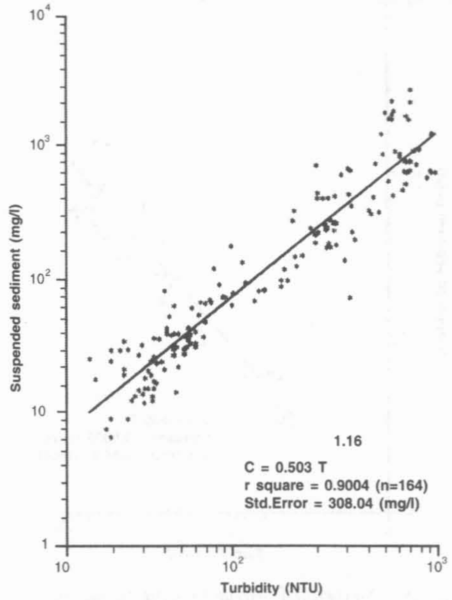

Fig. 11. Suspended sediment and turbidity relationships for catchment 2 of UPM farm

TABLE 1
Turbidity and suspended sediment concentrations of tributaries of Pahang River basin

Date of sampling	River	Longitude(E)	Latitude(N)	Average River Velocity (m/s)	Average Turbidity (NTU)	Average Suspended Sediment (mg/1)
14/6/93	Sg. Balok	103° 22" 19'	03° 56" 31'	0.01	6.32	58
14/6/93	Sg. Kuantan	103° 18" 19'	03° 47" 26'	0.01	10.40	10
15/6/93	Sg. Kuala Bera	102° 31" 50'	03° 23" 18'	0.01	27.37	4
15/6/93	Sg. Lepar	102° 58" 14'	03° 41" 57'	0.77	47.33	11
15/6/93	Sg. Lembing	103° 03" 00'	03° 55" 56'	0.68	47.83	46
15/6/93	Sg. Luit	102° 48" 55'	03° 35" 59'	0.13	51.63	14
15/6/93	Sg. Pahang (Cini)	102° 53" 09'	03° 27" 05'	0.36	72.00	57
15/6/93	Sg. Semantan	102° 25" 16'	03° 27" 25'	0.46	75.00	81
15/6/93	Sg. Jengka	102° 30" 44'	03° 31" 18'	1.18	138.00	15
16/6/93	Sg. Kuala Kerau	102° 21" 55'	03° 42" 59'	0.2	12.70	3
16/6/93	Sg. Lipis	101° 58" 27'	04° 01" 01'	0.67	28.00	11
16/6/93	Sg. Jelai (Tembeling)	102° 18" 44'	04° 44" 09'	0.88	87.60	66
16/6/93	Sg. Jelai (Lipis)	102° 03" 17'	04° 11" 16'	0.67	9.50	73
17/6/93	Sg. Bera	102° 36" 36'	03° 10" 01'	0.84	10.50	1
17/6/93	Sg. Lentang	101° 53" 13'	03° 22" 51'	0.1	30.60	19
17/6/93	Sg. Pertang	102° 04" 36'	03° 26" 50'	0.07	55.40	14
17/6/93	Sg. Benus	101° 55" 46'	03° 29" 38'	0.89	72.80	66
17/6/93	Sg. Bentong	101° 54" 52'	03° 31" 02'	0.77	78.30	38
17/6/93	Sg. Telemong	102° 02" 16'	03° 24" 50'	1.33	102.40	89
17/6/93	Sg. Triang	102° 24" 46'	03° 14" 33'	0.49	113.17	97
17/6/93	Sg. Pahang (Temerloh)	102° 25" 37'	03° 26" 35'	1.36	175.50	152

Relationship for Tributaries of Pahang River Basin

The results presented in this section were obtained from selected tributaries of the Pahang River basin (Table 1). Suspended sediment concentrations recorded during the four days' sampling ranged from 1.0-152 mg/l and turbidity ranged from 6.3 to 174.5 NTU. The power function obtained was:

$$C = 0.050\ T^{1.54} \qquad (r = 0.8684) \qquad (7)$$

The results of the least square fit are presented in *Fig. 12.* Data from two river tributaries (Sg. Balok and Sg. Kuantan) were not included in the regression analysis because of the influence of saline water in the relationship between suspended sediment concentration and turbidity. The plots indicated that for such a diverse soil type, topography and rainfall pattern the individual measurements data appeared to follow a statistically high correlation ($r = 0.8684$, $P < 0.05$). Although the range of suspended sediment concentration

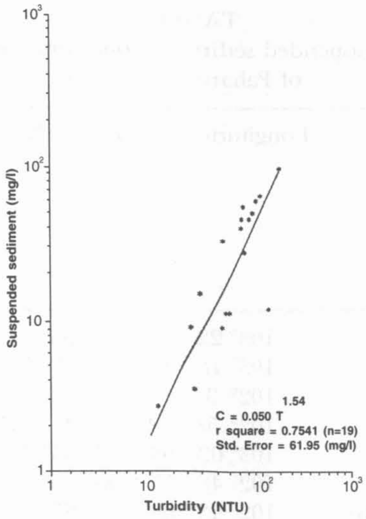

Fig. 12. Suspended sediment and turbidity relationships for major tributaries of Pahang River basin

and turbidity collected for the basin may be limited, the plot suggests that the data follow a pattern of a power function with relatively high correlation coefficient and low standard error. This correlation, however, could be further verified with more sampling to be made at different times of the year. Since the river basin is large, further detailed sampling at specific tributaries with respect to different land use, geological make-up, and seasons of the year may be needed. Nevertheless, it was postulated that this preliminary finding implies that most of the Pahang River's tributaries carry relatively similar ranges of suspended sediment particle size that influenced turbidity during the four consecutive days' sampling periods.

CONCLUSION

Sediment from non-point sources is the most widespread pollutant of surface water in Malaysia. The concentrations of suspended sediment in streams sampled were variable and may be influenced by rainfall duration and intensity, soil conditions, topography, geology, vegetation cover, and human activities taking place in the catchments. Despite many factors that influenced suspended sediment movements, the study suggested that it was possible to obtain an acceptable prediction equation within standard error of 35-500 mg/l based on the relationship between hourly or daily suspended sediment concentrations and turbidity for the study catchments. The regression analysis representing 21 catchments suggested that a good correlation (F-test, $P < 0.01$) exists between suspended sediment concentration and turbidity readings in all of the study catchments. The relationships between suspended sediment concentration and turbidity obtained in this study were, however, by no means universal. The relationships should be interpreted with caution. Physical environmental factors, such as geological characteristics of a particular area, may further influence the size of sediment particles produced. The equations were valid only for data from the catchments under study. The relationship should be used with caution and, where possible, can be applied only to small and relatively similar catchments.

Consistently high correlation coefficients (F-test, $P < 0.05$) obtained from the regression analysis of suspended sediment and turbidity data suggest that it is reasonable to postulate that for many Malaysian rivers where the suspended sediment loads are dominant, suspended sediment concentrations can be evaluated by studying correlations with turbidity instead of water discharge. Turbidity measurements can be an advantage, because they can be obtained directly in the field. The periodic and regular sampling can be more practical at a reduced cost then suspended sediment measurements, especially when dealing with large numbers of river tributaries. Even though at low turbidity the results may be less accurate due to problems in measuring suspended sediment at low concentrations, most erosion and sedimentation problems were usually encountered at high concentrations.

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