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Seasonal Variations and Yearly Trend Evaluations of Sedimentation Loads: A Case Study at Chalok River, Terengganu, Malaysia

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Abstract

The aims of this study were to determine the relationship between seasonal variations (wet and dry periods) on sedimentation loads and to identify the yearly trend of sedimentation loads at Chalok River, Terengganu, Malaysia from 2003 to 2008. It was found that wet and dry periods influenced the transportation of suspended sediment into the river significantly. The highest suspended sediment loads at Chalok River occurred during the wet period when the intensity of rainfall is high. Besides, the rainfall, water level, stream flow and suspended sediment loads also were analysed using Spearman correlation to identify their relationships. The results showed significant positive relationship between suspended sediment loads with rainfall ($r = 0.664, p<0.05$), water level ($r = 0.923, p<0.05$) and stream flow ($r = 0.919, p<0.05$). Multiple linear regressions revealed 63% of high suspended sediment loads at Chalok River can be explained by rainfall, water level and stream flow. The trends of rainfall, water level, stream flow and suspended sediment loads were analysed by using Mann-Kendall trend test where the results showed that there is a significant increasing trend for suspended sediment loads but no significant increase trend for rainfall, water level and stream flow over the studied periods. It is evident that the evaluations conducted in this study are useful in providing better understanding and reliable conclusion on the basis of seasonal variations and other environmental variables that affect the sedimentations loads in the river. Such effort provides holistic information for effective and wise management policy of river basin management in the future.

Keywords: rainfall; sedimentation loads; spearman correlation; Mann-Kendall trend test; multiple linear regressions

1. Introduction

Seasonal variation of precipitation can affect the physical, biological and chemical characteristics of hydrological systems (Billota and Brazier, 2008; Prathumratana *et al*., 2008). An example can be illustrated through the high intensity and long duration of rainfall which affected the river system by increasing the sedimentation loads in the river (Wang *et al*., 2007; Ya-ning *et al*., 2007; Prathumratana *et al*., 2008; Zhang *et al*., 2008; Bogen, 2009). The increasing of sedimentation loads in the river has caused many environmental problems such as degrading water quality by (i) carrying pollutants (i.e. heavy metals and pesticides) and nutrients (i.e. phosphorus and nitrogen), (ii) reducing the penetration of light because of turbidity and (iii) decreasing the river depth when sediments are deposited in the river (Singh *et al*., 2007; Billota and Brazier, 2008; Ward *et al*., 2009; Nu-fang *et al*., 2011; Park *et al*., 2011). High suspended sediment concentrations in the river also can affect the aquatic organisms by clogging the gill of the fish, interfering in their natural movement and migration and disturbing the development of eggs and larvae by reducing the concentrations of dissolved oxygen in the river (Watts *et al*., 2003; Billota and Brazier, 2008).

The transportation of sediment to the river can be classified into three types; (i) overland flow, (ii) rainfall impact, and (iii) combination between overland flow and rainfall impact (Beuselinck *et al.,* 2002). The rate of soil detachment is depending on the rainfall intensity, diameter of rain drops and erodibility of soil surface. The smaller drops and lower rainfall intensity will lead to less efficient in sediment removal from the soil surface. The small particles of sediment that detached by rainfall impact become suspended in the overland flow and transported downslope while larger particles of sediment are transported to the river by rolling over the bed. Human activities and changes of land use have potential to cause the variability of sediment loads recorded at the river (Walling and Fang, 2003; Le *et al*., 2007; Ward *et al*., 2009; Peng *et al*., 2010; Naik and Jay, 2011; Miao *et al*., 2011; Thothong *et al*., 2011). The changes of land used can alter the velocity of

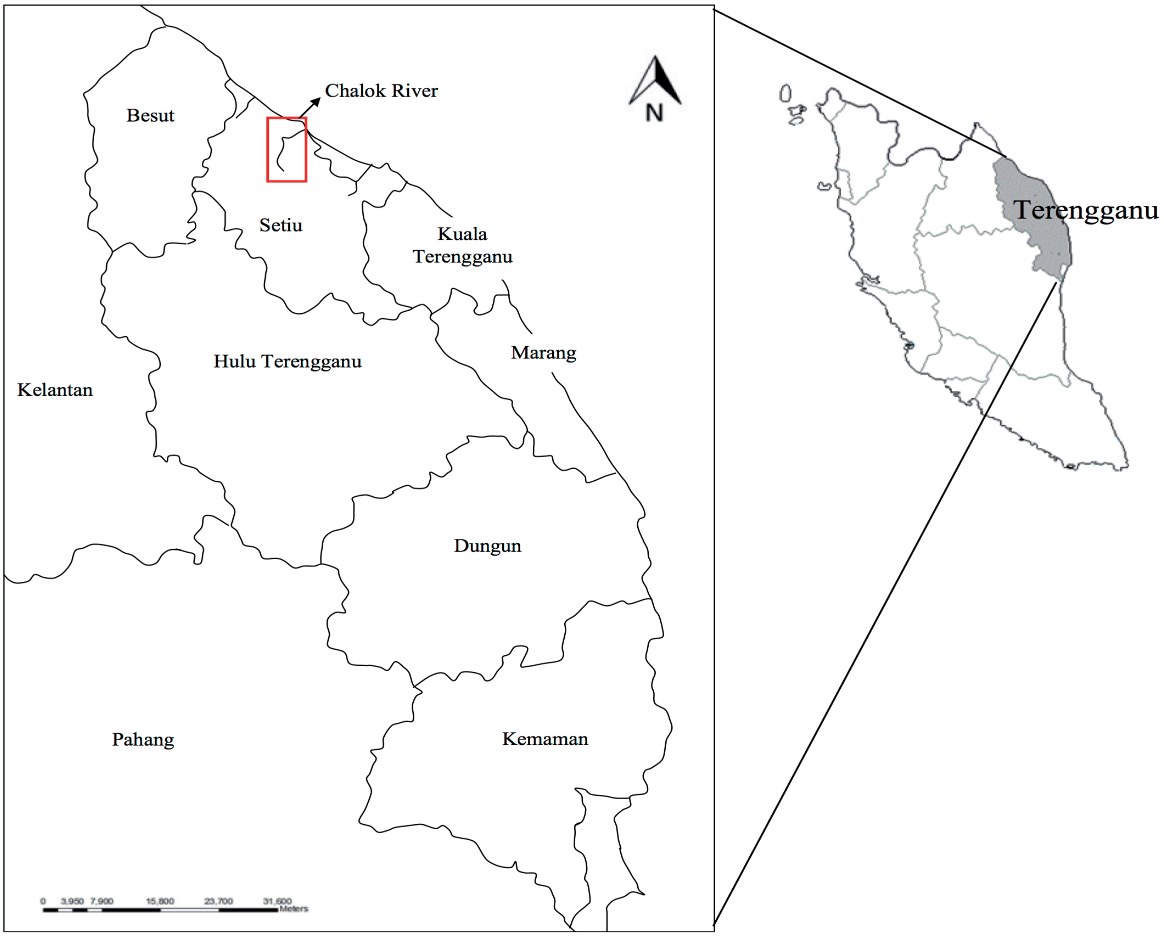


Figure 1. Location of Chalok River, Setiu, Terengganu

water, whether in the form of streams or overland flow, by changing the slope or gradient and the roughness encountered by the flow which affects sediment loads (Chen *et al*., 2007). Moreover, removal of vegetative cover and the breakdown of soil structures through compaction and loss of organic matter often reduced the infiltration, thus accelerate runoff and transportation of sediment to the river. The amount and size of soil particles transported increase as the volume and velocity of runoff increases (Beuselinck *et al*., 2002).

Investigating and understanding the processes of suspended sediment transport are necessary and imperative in controlling the soil erosion by applying suitable mitigation practices to reduce the suspended sediment loads in the river, hence it will improve the surface water quality (Nu-fang *et al*., 2011). In addition, detection of temporal trends of rainfall intensity and sediment loads is the most important objectives of environmental monitoring since trend detection provides useful information for sustainable development and long term planning of water resources (Ya-ning *et al*., 2007). The purposes of this study are to determine the possible effects of seasonal variations of rainfall on sedimentation loads and to identify the yearly trend of sedimentation loads at Chalok River from 2003 to 2008. This study also analyse the relationship between stream flow and water level with sedimentation loads.

2. Materials and Methods

2.1. Site description

The study was conducted at Chalok River which is situated in the Setiu catchment area, Terengganu, Peninsular Malaysia. The Chalok River is located between latitudes 5º 23’ 45” and 5º 27’ 15” North and longitudes 102º 48’ 10” and 102º 50’ 45” East. The average annual rainfall at Chalok River was 3673 mm for the year 2003 to 2008. The Chalok River is a small coastal basin area (20.5 km^2) and approximately 6.0 km x 3.5 km wide (Fig. 1). The length of the river is 6.9 km and flow to the north to meet the Bari River before discharging into the South China Sea. The area is covered mainly by rubber plantation and some agricultural crops such as vegetable farms (Fig. 2).

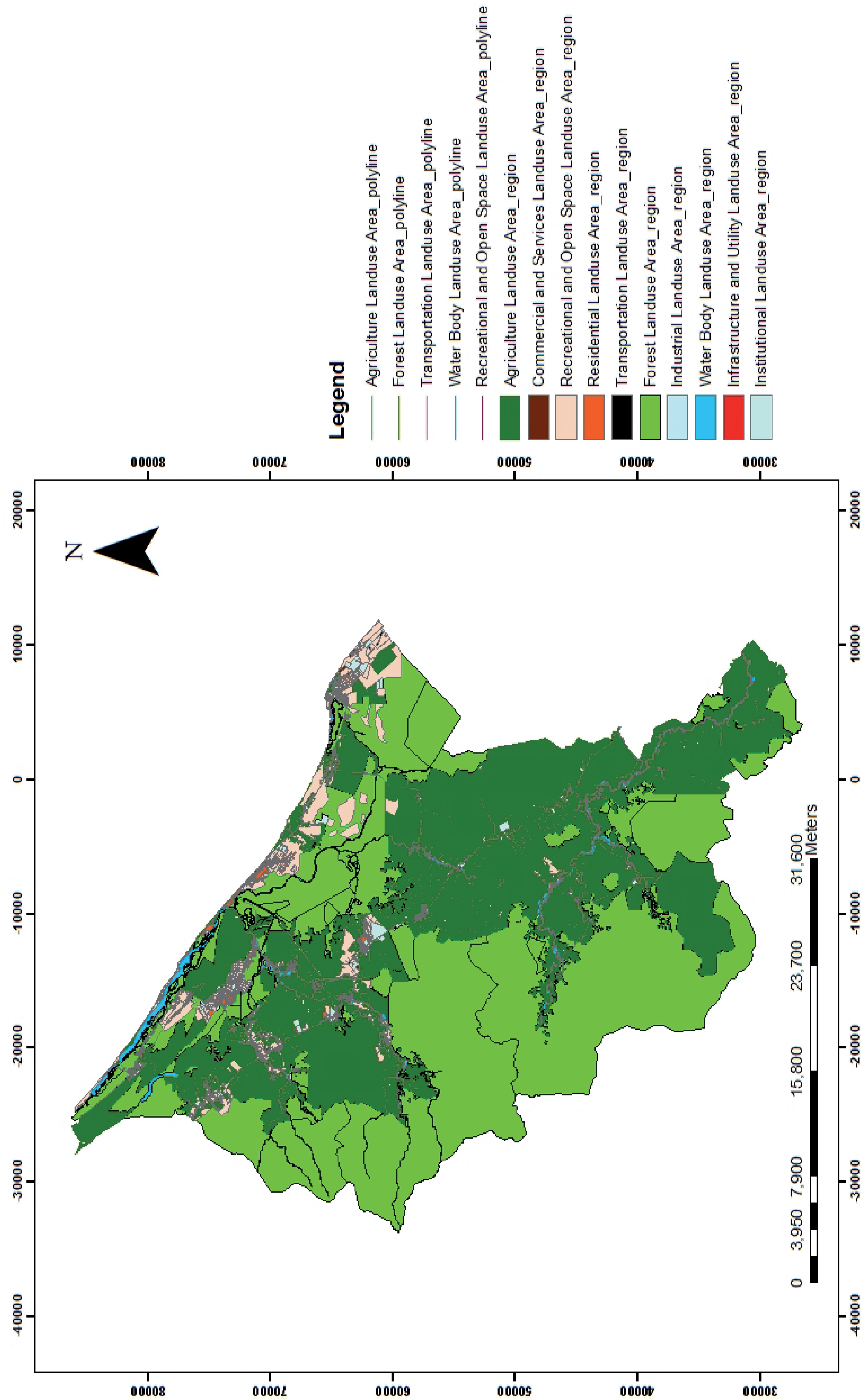


Figure 2. Land use of Setiu (Source: Ministry of Natural Resources and Environment)

2.2. Sample collection and analyses

Data used in this project are rainfall, suspended sediment load, water level and stream flow of Chalok River, Terengganu. All the data were obtained from Department of Irrigation and Drainage Malaysia (DID). Data was analysed by using XLSTAT. Seasonal and monthly rainfall, water level, stream flow and suspended sediment loads at Chalok River were analysed within the study period from 2003 to 2008.

From cluster analysis, the months with the highest rainfall intensity were considered as wet period. While months with the lowest rainfall intensity were considered as dry period. Relationship between the dependent variable (suspended sediment loads) and independent variable (rainfall intensity) were analysed by using Spearman correlation. Besides, water level and stream flow were also analysed to investigate the relationship with the suspended sediment loads at Chalok River. Analysis of relationship between suspended sediment loads with rainfall, water level and stream flow can assist in identifying the factors and processes that involve in sedimentation loads (Nu-fang *et al*., 2011). Additionally, multiple linear regressions were also used in this analysis. It was carried out to predict the values of a suspended sediment loads (y) given by a set of rainfall intensity, water level and stream flow (x_1, x_2, x_3). The relationship between suspended sediment loads with rainfall intensity, water level and stream flow are represented by the following equation:

$$y_i = \beta o + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + e_i \qquad (1)$$

Where the βo is a constant term and β1 to β3 are the coefficient related to the rainfall, water level and stream flow to the variables of interest. ANOVA also was used to identify the mean differences of suspended sediment and rainfall within years (2003 to 2008) and seasons (wet and dry periods). The null hypothesis stated that there are no mean differences of variables while the alternate hypothesis stated that there are mean differences between the groups.

2.3. Trend analysis

The Mann-Kendall trend test was used in order to define the trends in suspended sediment loads, as well as intensity of rainfall, water level and stream flow of Chalok River. This test was used in this study because a non-parametric test is more suitable for non-normally distributed data, not affected by the actual distribution of the data and less sensitive to the outlier compared to parametric test (Yue *et al*., 2002; Ya-ning *et al*., 2007; Juahir *et al*., 2010; Yenilmez *et al*., 2011).

The null hypothesis in Mann-Kendall trend test states that there is no trend of the data in the time of series. This test is based on the statistic *S* and defined as followed,

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} sgn(x - x_i) \qquad (2)$$

where the x and x_i are the sequential data values and and *n* is the length of the data set, and

$$sgn(\theta) = \begin{cases} 1 & if \quad \theta > 0 \\ 0 & if \quad \theta = 0 \\ -1 & if \quad \theta < 0 \end{cases} \qquad (3)$$

If the data set is identically and independently distributed, then the mean of *S* is zero and the variance of *S* is:

$$Var(S) = \frac{\lfloor n(n-1)(2n+5) - \sum_t t(t-1)(2t+5) \rfloor}{18} \qquad (4)$$

where *n* is represent for the length of the data set, *t* for the extent of any given time and ∑ for summation over all times. The magnitude of the trend is given as:

$$\beta = \text{Median}\left(\frac{x_i - x_j}{i - j}\right), j < i \qquad (5)$$

in which $1<j<i<n$ and β is the slope of trend. A plus sign is recorded when a value of a given variable in time is larger than the preceding one while the minus sign is recorded when the value is smaller than the preceding one. The plus or positive sign indicates an increasing trend. In contrast, minus or negative sign which stand for a decreasing in the variables at a given time. The zero sign indicates no change over the time. The null hypothesis is accepted when the zero sign is recorded. The significance level at 0.05 is used in this study.

3. Results and Discussion

3.1. Seasonal and monthly variation of rainfall, suspended sediment loads, water level and stream flow

Fig. 3 shows the monthly rainfall intensity and suspended sediment loads at Chalok River during the study period from 2003 to 2008. It can be observed that the rainfall intensity influenced the suspended sediment loads at the Chalok River. The monthly mean evaluation of the rainfall and suspended sediment loads from 2003 to 2008 at the Chalok River is demonstrated

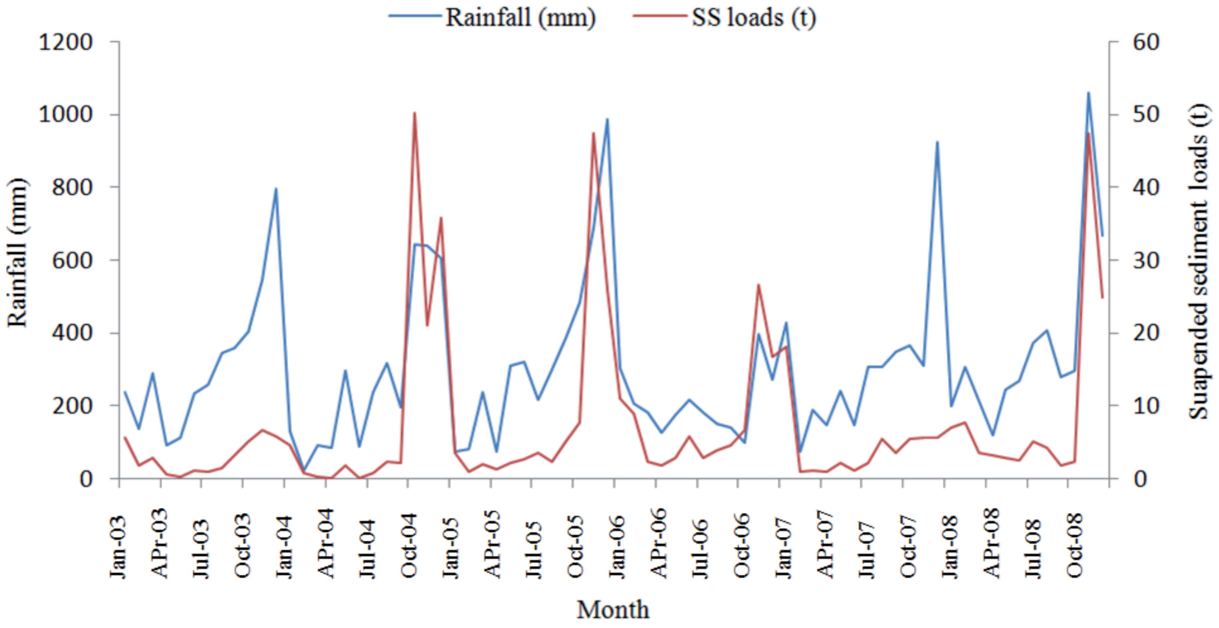


Figure 3. Monthly rainfall and suspended sediment loads at Chalok River (2003-2008)

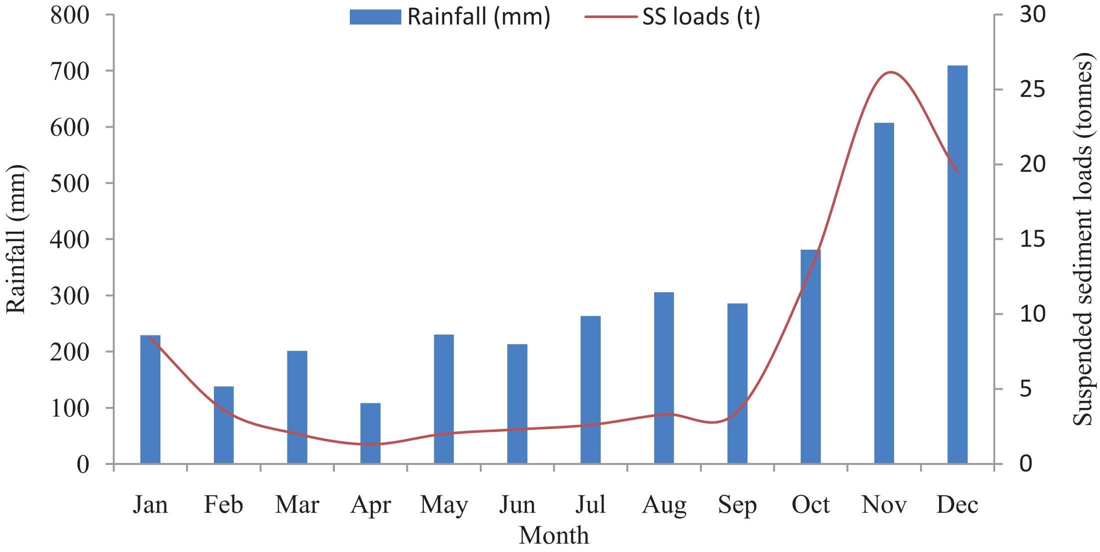


Figure 4. Monthly mean evolution of rainfall and suspended sediment loads (2003-2008)

in Fig. 4. In this study period, the total mean of annual rainfall was 3672.64 mm, when distributed among the twelve months in 2003 to 2008. The months with the highest rainfall intensities were recorded during November (607.20 mm) and December (709.27 mm). The lowest mean of rainfall intensities were observed during February (138.12 mm) and April (108.18 mm). From the cluster analysis, November and December were classified as the wet period which contributed to the highest mean of rainfall intensity while February and April as dry period which contributed to the lowest mean of rainfall intensity within study period (2003 to 2008). The highest mean of the total annual suspended sediment loads were recorded during the wet period (November, 26 tonnes). However, the suspended sediment loads have been decreased from 26 tonnes (November) to 19.5 tonnes (December). April recorded the lowest mean of total annual suspended sediment loads with 1.30 tonnes.

Figs. 3 and 4 clearly show that, the suspended sediment loads had increased during the wet periods and decreased during the dry periods. Meanwhile during December, the suspended sediment loads had decreased because of the dilution by the high rainfall intensity (Park *et al*., 2011). Further, the decrease of suspended sediment loads in December is also can be

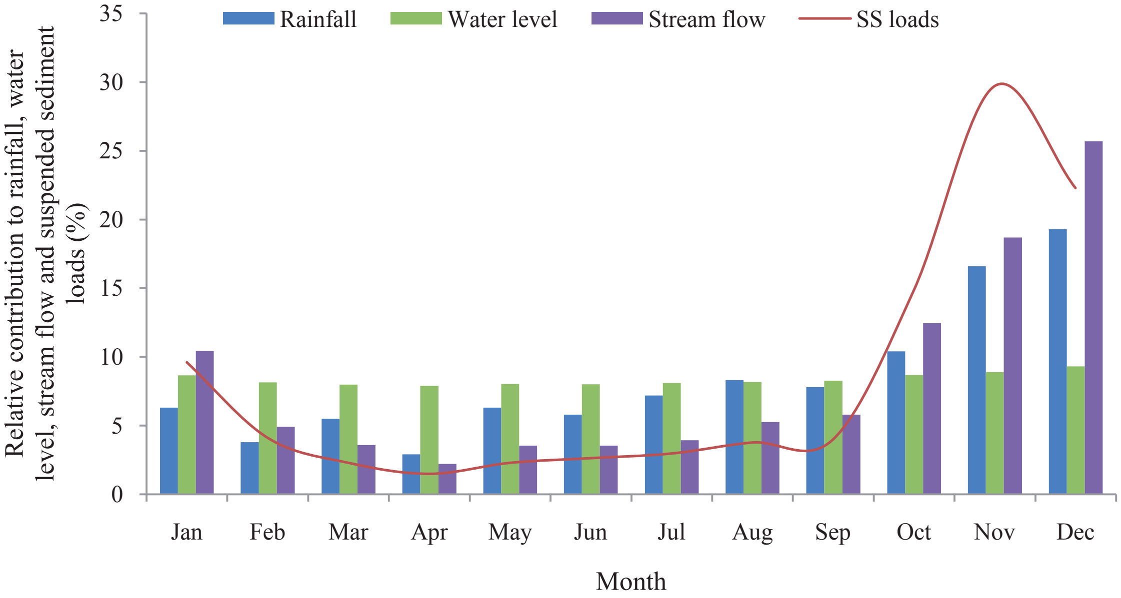


Figure 5. Relative monthly distribution of rainfall, water level, stream flow and suspended sediment loads (2003 – 2008)

Table 1. Descriptive analyses rainfall, water level, stream flow and suspended sediment loads separated into wet and dry periods

	n	Wet period				Dry period			
		Min	Max	Mean	Std. Dev	Min	Max	Mean	Std. Dev
Rainfall (mm)	72	274.05	1060.5	658.23	254.67	22.7	308.75	123.15	74.57
SS loads (t)	72	5.6	47.6	22.52	15.36	0.1	9	2.46	2.89
Water level (m)	72	6.2	6.85	6.63	0.22	5.48	6.19	5.83	0.19
Stream flow (m^3/s)	72	1.4	6.27	3.84	1.62	0.04	1.89	0.61	0.54

*Std. Dev=standard deviation; SS loads=suspended sediment loads

due to the increasing of soil surface protection by water layer. The impact of the rainfall on the soil surface is decreased when critical depth of soil is reached and exceeded which resulted an accumulation of water on soil surface (Beuselinck *et al*., 2002; Hogarth *et al*., 2004). During the wet period, high intensity and long duration of rainfall can cause flood event.

The percentage of relative monthly distribution of rainfall, water level, stream flow and suspended sediment loads at Chalok River for the whole study period is shown in Fig. 5. The high intensity of rainfall during the wet period increased the water level and stream flow at Chalok River. At the same time, the suspended sediment loads also increased. Table 1 summarises the main characteristics of rainfall, water level, stream flow and suspended sediment loads within the wet and dry periods.

ANOVA also was carried out to identify the mean differences between suspended sediment loads and rainfall from 2003 to 2008. For the suspended sediment loads, results show that F value ($F = 0.855$) is smaller than $F_{critical} = 2.353$ with $p\text{-value} > 0.05$. Therefore, the null hypothesis is accepted in which the mean of suspended sediment loads from 2003 to 2008 are same. The results for rainfall from 2003 to 2008 also show that there is no significant difference between years. The *p-value* (*0.515*) also shows greater than 0.05, indicating that there is no significant difference of mean in rainfall intensity from 2003 to 2008. The mean differences in suspended sediment loads and rainfall intensity within wet and dry periods also were identified. The results for suspended sediment shows F value ($F = 19.762$) was greater than $F_{critical} = 4.301$ with $p<0.05$. Therefore, there was a significant difference in suspended sediment loads within the wet and dry periods. This results show that there is a significant difference in rainfall intensity within wet and dry periods ($F = 48.793$) which is greater than $F_{critical} = 4.301$ and $p<0.05$. Since F value is greater than the critical value, the null hypothesis is

Table 2. Spearman correlation

Variables	Rainfall (mm)	SS loads (tonnes)	Water level (m)	Stream flow (m^3/s)
Rainfall (mm)	1	0.664	0.683	0.703
SS loads (t)	0.664	1	0.923	0.919
Water level (m)	0.683	0.923	1	0.955
Stream flow (m^3/s)	0.703	0.919	0.955	1

Significant at alpha = 0.05

rejected and alternate hypothesis is accepted. The wet and dry periods can increase or reduce the transportation of suspended sediment into the river. The lowest suspended sediment loads in the dry period is attributed by the reduction of rainfall intensity occurring in this period. The highest concentration of suspended sediment transported during wet period because of high intensity and long duration of rainfall at a very high discharge (Le *et al*., 2007; Lin *et al*., 2012). The high intensity and long duration of rainfall can increase the impact of rainfall on the soil and will lead to the increase soil erosion. It has proven from previous study which reported that suspended sediment loads during the wet period increased about five times higher compared to the dry period (Le *et al*., 2007).

3.2. Relationships between rainfall, water level and stream flow with suspended sediment loads

3.2.1. Spearman correlation

The correlation analysis had been used to identify the relationship between the suspended sediment loads with the rainfall intensity and other variables such as the water level and the stream flow. All variables showed significant relationship with each other at 0.05 confidence level (Table 2). The results show a positive significant relationship between the rainfall intensity and the suspended sediment loads ($r = 0.664, p<0.05$). An increased of rainfall intensity during the wet period had resulted in an increase in suspended sediment loads. The rainfall not only transports the suspended sediment to the river, but also influences the sediment detachment process. The high intensity and long duration of rainfall can detached more sediment from the soil surface and transported them to the river (Lin *et al*., 2012). The high intensity of rainfall also can cause land sliding events which could supply huge amount of suspended sediment to the river.

Furthermore, the correlations between suspended sediment with other variables such as water level and stream flow also identified. The suspended sediment loads presented strong significant positive correlations with water level ($r = 0.923$, $p<0.05$) and stream flow ($r = 0.919$, $p<0.05$). The transportation of suspended sediment increase when the stream flow increases. The suspended sediment becomes deposited when velocity of the stream flow decreased. The deposition of suspended sediment leads to raise the riverbed and reduce the depth of the river. The increasing of sedimentation loads in the river caused the rising of riverbed by several centimetres per year (Miao *et al*., 2011).

The correlation results indicate that increase of suspended sediment loads at Chalok River caused the increase in water level and stream flow. The increase of suspended sediment loads can lead to reduce the depth of river and as a consequence, the water level of river increases. The reduction in depth of the river can affect the river systems by reducing the capacity of the river to route water through the drainage basin and can caused to increase the flood events during wet periods. In addition, high concentration of suspended sediment also can affect aquatic organisms and degrade the water quality (Billota and Brazier, 2008; Prathumratana *et al*., 2008).

Results also showed that rainfall intensity has significant positive relationship with water level ($r = 0.683, p<0.05$) and stream flow ($r = 0.703, p<0.05$). When rainfall increases, the river water level also increases. High water level followed by increasing in flow velocity and discharge. Other factors such as the area of the basin, the slope of the ground, the erodibility of the soil, and the area of impervious surface within the basin also can influenced the relationship between rainfall intensity with water level and stream flow (Prathumratana *et al*., 2008). The large amount of impervious soil surface and steeper slopes will increase the surface runoff and reduce the amount of rainfall infiltrate into the soil and becomes groundwater. The results shows a strongest positive correlation between water level and stream flow ($r = 0.95, p<0.05$) compared to the other parameters.The increase of water level will significantly increase the stream flow.

3.2.2. Multiple linear regressions analysis

The multiple linear regressions were used to gain further understanding of relationship between suspended sediment loads with rainfall, water level and stream flow. Equation 6 showed the multiple linear regressions analysis with adjusted R^2 value of *0.633*.

$$SS\,loads = -66.526 + 3.948E03 * Rainfall + 11.291 * Water\ Level + 2.795 * Stream\ Flow \quad (6)$$

The multiple linear regressions result shows 63% of the variation loads of suspended sediment at Chalok River is influenced by the rainfall intensity, water level and stream flow. The remaining 37% of the variations may have been due to other factors such as topography of the basin, soil types, land use and vegetation cover. The flood peak discharge has been shown as the most significant factor, which controls the supply and delivery of suspended sediment to the river (Nu-fang *et al*., 2011).

3.3. Trend analysis

Fig. 6 displays the mean of annual rainfall at Chalok River (2003 to 2008). The mean of annual rainfall intensity for 2003 to 2008 has slightly increased. For 2006, it shows the lowest rainfall intensity (2458.35 mm) and the highest mean of annual rainfall intensity was observed during 2008 (4441.00 mm). Besides, Fig. 7 shows increasing trend for annual minimum rainfall intensity. The lowest minimum rainfall intensity was observed during 2004 (22.70 mm). For 2008, it shows the highest minimum rainfall intensity with 199.75 mm. Figure 8 shows the annual maximum rainfall at Chalok River from 2003 to 2008. The highest annual maximum rainfall intensity is observed in 2008 (1060 mm). Besides, the lowest annual maximum rainfall intensity is observed during 2006 (397.55 mm). The annual mean, minimum and maximum rainfall intensity (2003 to 2008) showed increasing trends.

The mean of annual suspended sediment loads also shows a slight increasing trend for 2003 to 2008 (Fig. 9). Year 2006 shows the lowest mean (94.4 tonnes) compared to the other years simultaneously with the lowest mean annual for rainfall intensity. The highest mean of annualwas observed during 2004 (10.02 tonnes). From the Figs. 9 – 11, the straight line shows a slightly increasing trend in mean, minimum and maximum suspended sediment loads at Chalok River.

Table 3 shows the result of Mann-Kendall trend test for suspended sediment loads, rainfall intensity, water level and stream flow series for Chalok River. The results show increasing trend of rainfall intensity, water level and stream flow from 2003 to 2008 at Chalok River but not at the significance level ($p>0.05$). The slightly increasing trend of rainfall intensity, water level and stream flow still existed at Chalok River although it is insignificant because the slope of trends show the value greater than 0, showing that they were increased monotonically (Ya-ning *et al*., 2007). For suspended sediment load, a significant increasing trend was detected from 2003 to 2008 ($p<0.05$).

This study showed an increasing trend of rainfall intensity and suspended sediment loads at Chalok River from 2003 to 2008. This indicates that increase in rainfall amount affect the sedimentation loads at Chalok River. The rise of land clearance, changes of land use, population increased and others human activities in this area can influence the increasing trend of suspended sediment loads. Population growth would boost the exploration of forest area for agricultural activities within study periods from 2003 to 2008, thus enhancing the suspended sediment loads into Chalok River. Although agriculture is a dominant cause of catchment disturbance and accelerated erosion in most areas, other forms of land disturbance such as logging can also be a cause of significant impact on sediment transportation to the river. The previous study reported that Dnestr River showed increasing trend of sediment because of forest clearance (Walling and Fang, 2003). Their

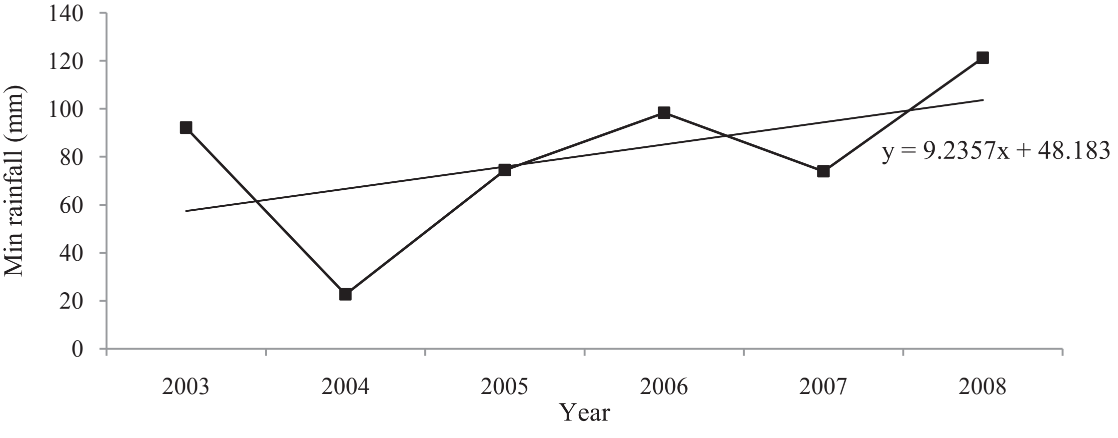
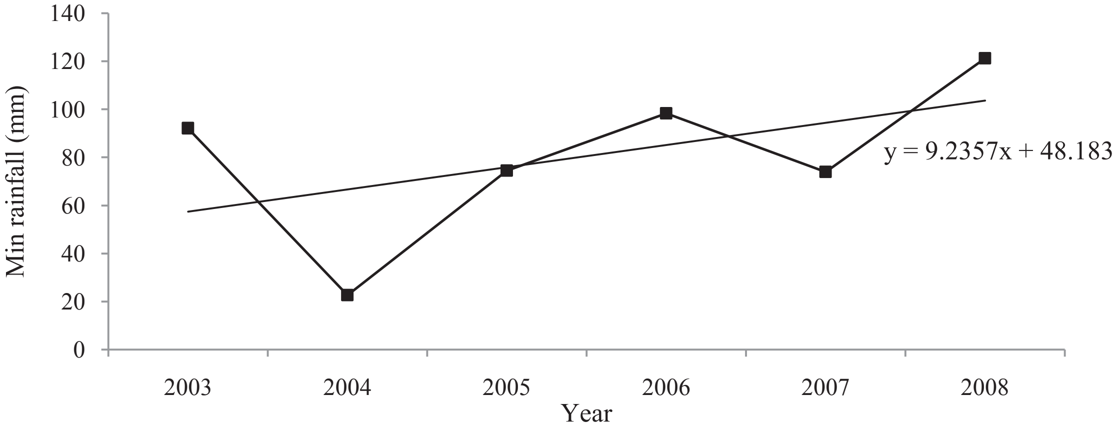


Figure 7. Minimum rainfall at Chalok River (2003 – 2008)



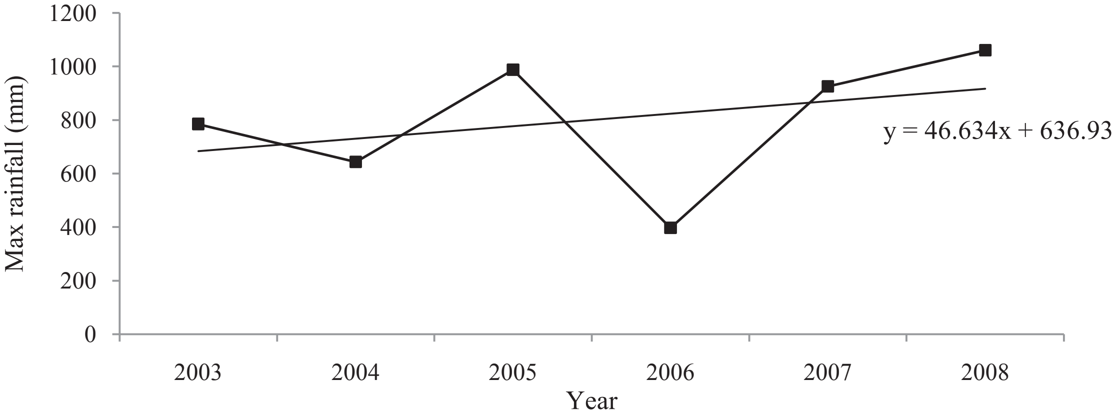


Figure 8. Maximum rainfall at Chalok River (2003 – 2008)

Table 3. Mann-Kendall trend test for rainfall, SS loads, water level and stream flow at Chalok River (2003 – 2008)

	Kendall's tau	S	Var (S)	*p-value* (two tailed)*	Trend
Rainfall (mm)	0.127	325	42315.000	0.115	Increasing
SS loads (t)	0.210	534	42283.333	0.010	Increasing
Water level (m)	0.133	339	42284.333	0.100	Increasing
Stream flow (m^3/s)	0.075	191	42301.667	0.356	Increasing

*alpha = 0.05

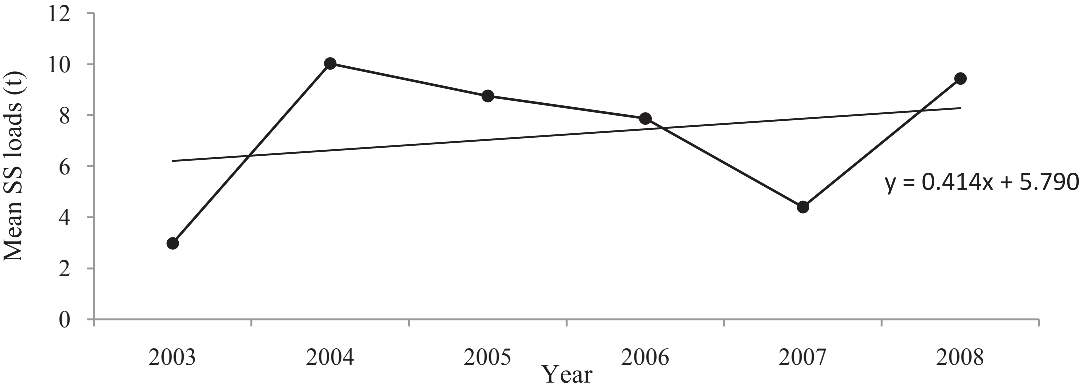


Figure 9. Mean suspended sediment loads at Chalok River (2003 – 2008)

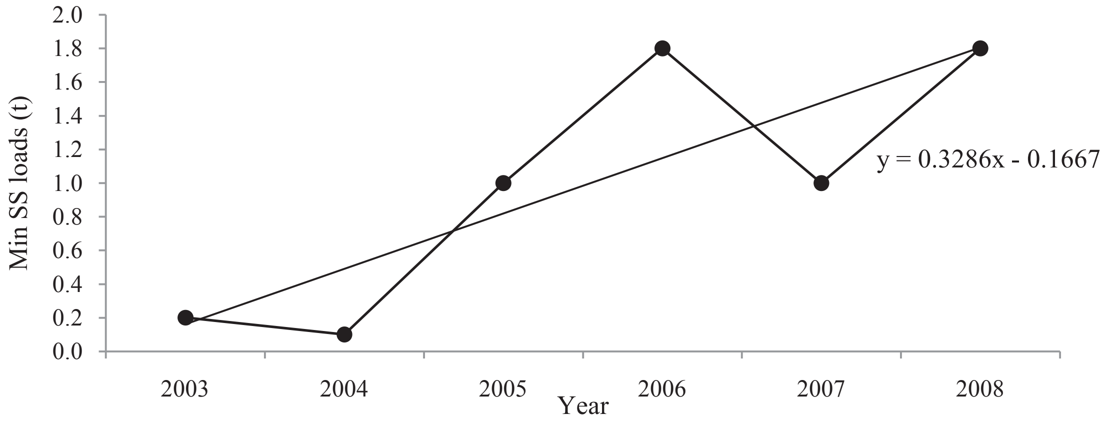


Figure 10. Minimum suspended sediment loads at Chalok River (2003 – 2008)

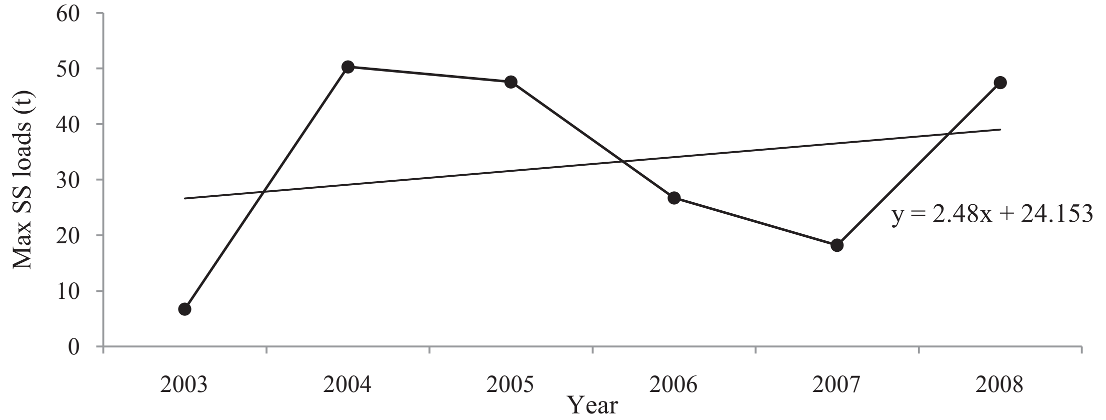


Figure 11. Maximum suspended sediment loads at Chalok River (2003 – 2008)

study indicated that the sediment load increased by five times over the period extending from 1950s to the mid-1980s. Yet other factor can decrease sedimentation loads in the river. For example, sediment load of Yellow River in China showed a substantial decline with mean annual sediment load decreased from 1600 x 10^6 tonnes in the 1950s and 1960s to 800 x 10^6 tonnes in the 1980s (Wang *et al*., 2007). Perhaps some reduction of sediment loads can be explained by reflection of decreasing in precipitation.

4. Conclusion

This study has examined the relationship of suspended sediment loads with rainfall, water level, and stream flow at Chalok River from year 2003 to 2008. The results showed the response of suspended sediment loads towards the seasonal variations of rainfall. November and December were considered as wet period when the highest rainfall intensities were recorded, while February and April as dry period when the lowest rainfall intensities were recorded. The highest suspended sediment loads were observed during the wet period while the lowest suspended sediment loads were recorded during the dry period. Wet period contributed 35.9% of the rainfall and 52% of the suspended sediment loads while dry period contributed 6.7% of the rainfall and 5.6% of the suspended sediment loads at Chalok River during the study periods (2003 to 2008). From the correlation results, there is a significance positive relationship between suspended sediments loads with rainfall intensity, water level and stream flow. The relationship between suspended sediment loads with water level was the strongest positive relationship compared to rainfall intensity and stream flow. The Mann-Kendall trend test also showed an increasing trend of rainfall and suspended sediment loads from year 2003 to 2008 although insignificance for rainfall trend. Human activities and changes of land use along the river stream also contributed to alter the trend of suspended sediment loads at Chalok River. The results obtained from this study provided some information about the dependency of sediment loads on rainfall, stream flow and water level. The results supported the evaluations of real time forecasting schemes and for practical purposes some criteria should be developed to validate the computed forecasts and correct it if necessary.These evaluations provided a more objective interpretation of seasonal changes on sedimentation loads and identification of the major process affecting the environmental variables trends as part of the effort toward the management of a sustainable river basin.

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