Poll Res. 41 (1) : 17-29 (2022)

ISSN 0257–8050
DOI No.: http://doi.org/10.53350/PR.2022.v41i01.002

PAST LAND-USE ACTIVITIES IN RELATION TO THE LONG-TERM SUSPENDED SEDIMENT YIELD OF KINTA RIVER, PERAK, MALAYSIA

M. HASHIM[1] AND W. R. ISMAIL[2,3*]

[1]*Department of Geography and Environment, Faculty of Human Sciences, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia*
[2]*Environmental Consultant, KGA Engineering Sdn. Bhd., 576B, Jalan Sultan Azlan Shah, 11900 Sg. Nibong, Pulau Pinang, Malaysia*
[3]*Formerly at Section of Geography, School of Humanities, Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, Malaysia*

(Received 26 July, 2021; Accepted 12 August, 2021)

ABSTRACT

Soil erosion and the suspended sediment yield (SSY) of Kinta river catchment were investigated using river and sediment discharge data of Kinta River and its tributaries available from 1961-2006. A long-term annual SSY for the Kinta River basin recorded an average of 2417.6 t/km^2/year, with a maximum SSY of 8,757.3 t/km^2/year in 1973 and a minimum SSY of 720.4 t/km^2/year in 2005. The Mann-Kendall test was conducted to analyse the long-term SSY trends, which revealed an overall decreasing trend of SSY for the Kinta River basin. This 46-year period was divided into four phases of different SSY trend. The second phase from 1970–1985 recorded the highest average of 4,062 t/km^2/year, as a result of the rapid development process that occurred in the drainage basin. The declining trends in SSY were observed after many mining operations ceased after 1960 and dam construction start in 2003. Some increasing trends in the early 1970s to 80s were due largely to the initial implementation of the New Economic Policy (NEP) and Green Book Plan. It involved a large-scale conversion of forest areas into agricultural lands with the expansion of urban areas and improvement of infrastructures.

KEY WORDS : Land use change, Suspended sediment yield, Mann-Kendal, Kinta River

INTRODUCTION

Urban areas, which serve as land cover in the form of built-up or paved-over areas, occupy less than 2% of the total land surface (Grubler, 1994; United Nations, 2001). Therefore, any changes in the urban areas do not significantly affect the land cover, but urbanisation has caused land-use changes and land degradation. Urbanisation itself is a complex process of converting rural land use to urban land use, which causes various implications on the structure, functions, and dynamics of the ecosystem (McDonnell *et al.*, 1997; Lambin *et al.*, 2001; 2003). The pervasiveness of land-use changes and land-cover changes, when aggregated globally, significantly affect the key aspects of Earth System functioning.

Apart from directly affecting the biotic diversity worldwide (Sala *et al.*, 2000) and contributing to the local and regional climate change (Chase *et al.*, 1999) and global warming (Houghton *et al.*, 1999), these changes are the primary source of soil degradation (Tolba *et al.*, 1992). The land-use changes and deforestation leads to soil degradation, which is manifested as sediment. The sediment loads of many rivers undergo changes owing to various cases of land clearance or land-use changes (increasing the suspended sediment loads) as well as the construction of dams (trapping sediment that would otherwise be discharged to the oceans) (Walling, 2006). Nevertheless, the production of sediment yield from a drainage basin to the oceans through the rivers is deemed vital in the global geochemical cycles (Walling and Fang, 2003). Essentially, the resulting sediment yield in the drainage basin system is related to the effect of clearing the land surface processes in certain areas as well as a key measure for land degradation and land resources deterioration.

The analysis of long-term suspended sediment yield (SSY) trend demonstrated the sensitivity of drainage basin due to various human activities, such as the construction of dams, sand mining, forest exploration, and changing the original drainage design and diverting rivers. Human disturbance increases the production of SSY, which affect the drainage system. It may also reduce the SSY when the sediment is blocked or deposited in dams. Evidently, any type of development and human activities, such as mining, logging, and construction of roads and housings, increase the sediment loads in the drainage basin (Syvitski *et al.,* 2005). Moreover, the production of sediment in the drainage basin is significantly high in the tropics, particularly within the Asian region (Milliman and Meade, 1983), due to the tropical climate with high temperature and overwhelming rainfall. Such climate is in favour to the weathering process, which, in turn, catalyses the soil erosion process. This is worsened by the lack of vegetation to protect the land surface from the direct impact of rainfall.

Accordingly, studies on sediment yield trends are usually studied together with the discharge and other hydro-meteorological factors, such as rainfall, temperature, evaporation, and evapotranspiration. Some studies on long-term sediment yield trends include the work of Milliman (1991); Walling and Fang (2003); Yang *et al.* (2005); Liu *et al.* (2007). In addition, studies on long-term sediment yield trends in China were also widely documented, especially in the Yangtze River and Yellow River basins (Chen *et al.,* 2001; Saito *et al.,* 2001; Zhang *et al.,* 2004; Chen *et al.*, 2005; Yang *et al.*, 2006; Lu *et al.*, 2007; Wang *et al.*, 2007; Yang *et al*., 2007; Chen *et al.,* 2008; Wang *et al.*, 2008). In view of the above, this study aimed to examine the long-term SSY trend and its relationship with land-use changes in the Kinta River basin, Perak (Malaysia) based on the river discharge data of between 1961 and 2006 and sediment discharge data of between 1977 and 1998.

MATERIALS AND METHODS

Study Area: Kinta River Catchment

Kinta River basin, which covers an area of 2,566 km^2, is one of the rapidly developing sub-basins in the Perak River compared to the other sub-basins of Perak River (Figure 1). The sub-basins of Kinta River include the basins of Pari River, Raia River, Kampar River, Chenderiang River, and Tumboh River (Figure 2). Kinta River is the largest tributary of Perak River with a basin perimeter of 266.7 km,which stretches from north to south. The drainage density (Dd) of the river basin is 2.23 km/km^2. Based on Strahler's (1957) method the Kinta River is a seventh ordered river. The drainage pattern of Kinta valley has been described by Ingham and Bradford (1960) as "roughly in the form of a herringbone and is governed by the shape of the valley which is closed in to the north and open to the south".

The geological structure of Kinta River basin consists of limestone-type (46%) and acid and undifferentiated granitoids (39%). Kinta river basin situated in belts of tin in Permo-Triasic granite mountain ranges, and Ipoh tin field is located on the west of the Main Range granite, underlain by limestone bedrock (MohamadandHassan, 1996). Meanwhile, the types of soil at the Kinta River basin include steep land (40.3%), land mines (22.8%), and Holyrood-Lunas (14.2%) (http://www.jmg.gov.my,

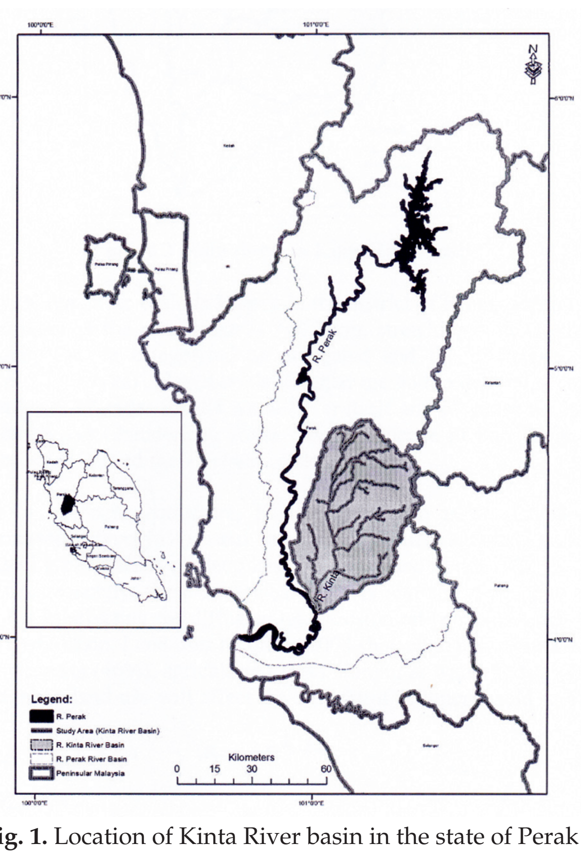


Fig. 1. Location of Kinta River basin in the state of Perak

2011). These geological features and types of soil provide insights on the significance of these attributes in affecting the diffusion rate, erosion rate, and sediment yield rate in the Kinta River basin.

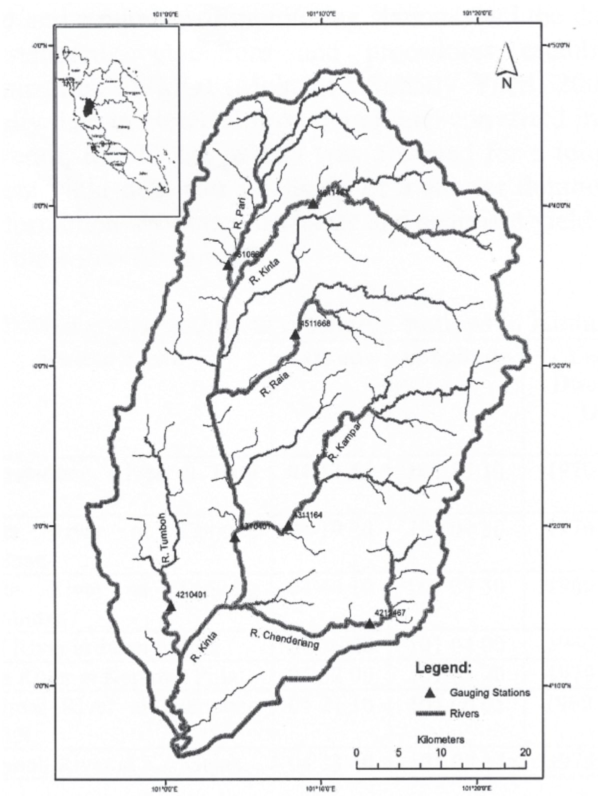


Fig. 2. Main river tributaries in Kinta River basin

The land use records in 2004 (Figure 3) revealed that Kinta River basin were dominated by forests (46%), followed by agriculture (28%), mining and water bodies (16%), and built-ups (10%). Table 1 shows the land-use changes from 1974 to 2004, which demonstrated the impact of land-use changes on the amount of SSY in the Kinta River basin. The percentages of relative changes in the land uses were based on the land uses between 1974 and 2004 (see Figure 3). Most significant changes is the increasing area of developed or built up area (pink colour) by almost 120% (Table 1).

Data and Analysis

The main data for this study were river discharge data of between 1961 and 2006 and sediment discharge data of between 1977 and 1998, which were obtained from the Information Management Unit, Hydrology and Water Resources Division, Department of Irrigation and Drainage (DID) Malaysia. The DID has maintained their data collection according to the standards, guidelines, and procedures established by the World Meteorological Organisation (WMO) at several gauging stations in Perak (Che Ngah, 2007). The DID monitors the discharge data at seven river discharge stations in Kinta River basin on a daily basis. These recorded data from each station provide very valuable information on the characteristics of river discharge and sediment discharge in a basin or sub-basin.

The obtained daily data for this study were in Notepad format, which was then converted into Excel format in time series form. Table 2 shows the information of the river discharge data and sediment discharge data according to the respective stations in the Kinta River basin. There were certain cases of missing data for a certain period of time, which highlighted the need for this study to perform additional analysis. Therefore, the data from the adjacent or nearby sub-basins (paired catchment) were analysed to address the missing data problem in this study.

In this study, linear regression analysis and Mann-Kendall test were selected to determine the significance of the river discharge and sediment discharge trends in the Kinta River basin. The linear regression analysis was conducted to assess the long-term trends of river discharge and sediment

Table 1. Historical land-use changes of Kinta River basin from 1974 to 2004

Year/Land Use	1974	%	1984	%	1990	%	1997	%	2004	%	Δ in % Relative 1974-2004 (%)
Forest	1350	53	1326	52	1293	50	1204	47	1184	46	-12.3
Agriculture	659	26	656	26	611	24	691	27	721	28	9.4
Water bodies	445	17	484	19	452	18	463	18	417	16	-6.3
Built up area	111	5	100	4	210	8	207	8	244	10	119.8
Total	2566	100	2566	100	2566	100	2566	100	2566	100	

Source: Hashim (2014)

Table 2. River discharge and sediment discharge stations in Kinta River basin

Station No.	Station Name	Latitude (North)	Longitude (East)	Year of River DischargeData	Year of Sediment Discharge Data
4212467	Chenderiang River at 32 mile road	04° 3′ 55"	101° 13′ 10"	1970–2006	1977–1996
4310401	Kinta River at TanjungTualang	04 °19′ 20"	101° 04′ 30"	1976–2006	1977–1995
4611463	Kinta River at TanjungRambutan	04 °40′ 10"	101° 09′ 30"	1960–2006	No data
4610466	Pari River at JalanSilibin	04° 36′ 20"	101° 04′ 00"	1960–2006	1977–1998
4511468	Raia River at KeramatPulai	04° 32′ 00"	101° 08′ 20"	1978–2006	1979–1998
4311464	Kampar River at KampungLanjut	04° 21′ 10"	101° 06′ 05"	1960–1992	No data
4210401	Tumboh River at Kg. Gajah	04 °13′ 40"	101° 00′ 15"	1978–1985	No data

discharge (i.e., it can either be an increasing or decreasing trend or no trend exists). The trends were displayed in the form of annual river discharge and sediment discharge in the sub-basins of Kinta River, of between 1961 and 2006.

Mann-Kendall test is normally conducted to further verify the trend changes in time-series data, especially for rainfall, temperature, discharge, SSY, water quality, and other environmental data (Burn and Elnur, 2002; Yue *et al.*, 2003; Shaharuddin and Hashim, 2006). Besides that, the Mann-Kendall test is also used to identify whether the occurring trend is significant. Mann-Kendall test was used in numerous studies to identify the hydro-meteorological trends, particularly rainfall (Hirsch and Slack, 1984; Burn, 1994; Lettenmaier *et al.*, 1994; Gan, 1998; Suppiah and Hennessey, 1998; Zhang *et al.*, 2001; De Jongh *et al.*, 2006; PartalandKahya 2006; Bae *et al.*, 2008; Luo *et al.*, 2008; Basistha *et al.*, 2009; Kwarteng *et al.*, 2009; Shahid, 2010; Caloiero *et al.*, 2011).

For this non-parametric analysis, the obtained data are organised in time-series form. Each data is compared with the subsequent data. Basically, the initial data from the Mann-Kendall test (S) is assumed as zero (0), which indicates that no trend exists. If the data from the following period is higher than its predecessor, S increases by 1. On the

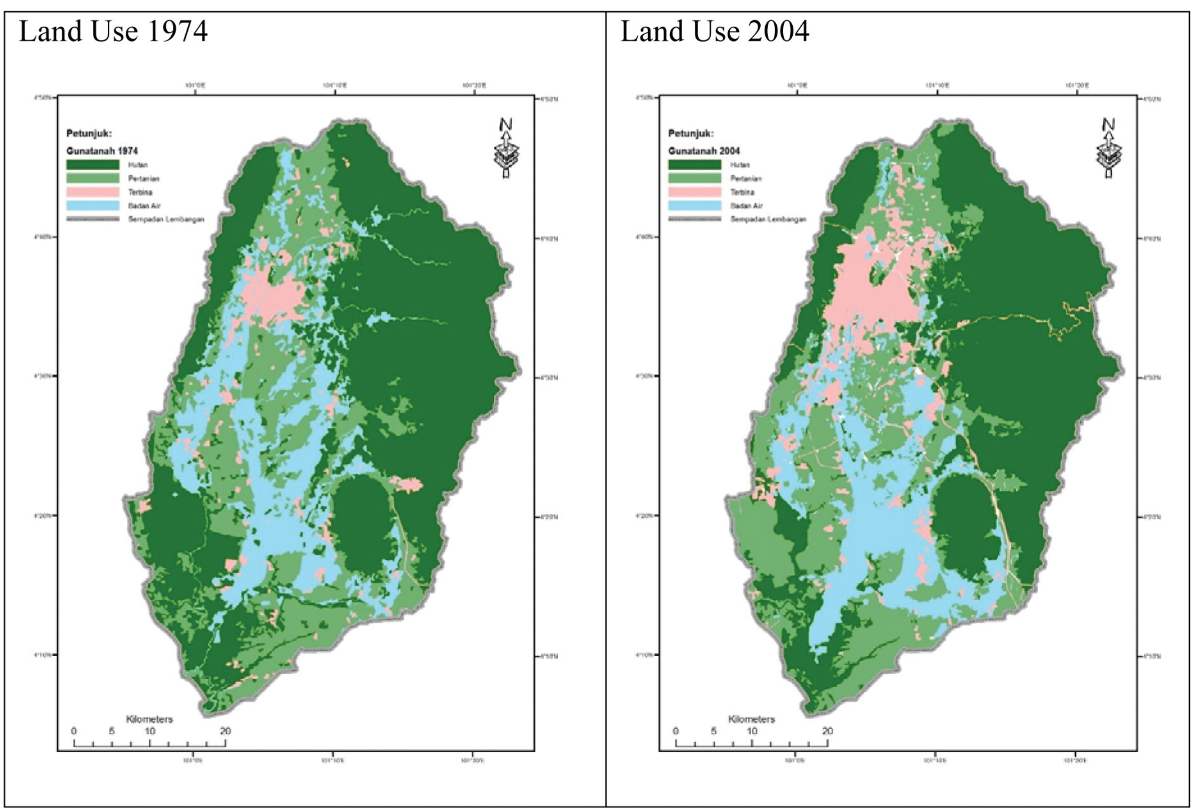


Fig. 3. The land-use changes in Kinta River basin from 1974 to 2004.

contrary, if the data from the following period is lesser than its predecessor, *S* decreases by 1. The results of the increasing and decreasing trends in a data sequence then produce the final value for *S*. If $x_1, x_2, x_3,\ldots,x$, represent the data points of *n* where x_j is the data point of time *j*, then *S* is expressed as follows:

$$S = \text{'' ''} \sum_{k=l}^{n-1} \sum_{j=k+l}^{n} sign\,(x_j \% x_k) \quad (1)$$

where

$$sign(x_j \% x_j) = \begin{cases} +1, \text{ if } (x_j \% x_k) > 0 \\ 0, \text{ if } (x_j \% x_k) = 0 \\ -1, \text{ if } (x_j \% x_k) < 0 \end{cases}$$

RESULTS AND DISCUSSION

Suspended Sediment Yield (SSY) of Kinta River Catchment

According to Manokaran (1979), the tropical rain forest can intercept between 21% and 31% of the total rain from directly hitting the ground, which minimises the rate of soil erosion. Deforestation contributes the most significant impact on the production of SSY, especially in the tropical rain forest areas. High rainfall in the tropics exposes all materials on the Earth's surface and carries the sediment to the water bodies.

According to Milliman and Syvitski (1992) a third of the estimated contemporary global flux of about 20 Gt yr^{-1} of fluvial suspended sediment from the continents to the oceans is transported by the rivers of southern Asia. Areas experiencing active erosion and having high sediment yields are from the Southeast Asian archipelagos and peninsulas (Gupta, 1996).

The long-term annual SSY in the Kinta River basin recorded an average of 2,417.6 t/km^2/year with a maximum annual SSY of 8,757.3 t/km^2/year in 1973 and a minimum annual SSY of 720.4 t/km^2/year in 2005 (Table 3). Meanwhile, referring to Figure 4c, high SSY was recorded in 1970 (5,041 t/km^2/year), 1972 (4,699 t/km^2/year), 1976 (6,305 t/km^2/year), 1980 (6,524 t/km^2/year) and 1985 (5,476 t/km^2/year), which were related to the La Niña phenomenon (except for 1980) (Nicholson and Selato,2000; de Souza et al. 2000) and fragile landform of the tin mining landscape.

In this case, the analysis of long-term SSY trend was required to determine whether the drainage basin experiences an increasing or decreasing trend. Figure 4 depicts the annual SSY trends of the three segments of Kinta River basin, specifically at the upstream part of Kinta River at Tanjung Rambutan (TR), the middle segment of Kinta River at Tanjung Tualang (TT), and the Kinta River mouth before entering the Perak River.

The Kinta River basin at Tanjung Rambutan (TR) is located at the upstream part of Kinta River (Figure 1). The annual SSY at the TR station recorded an average of 2.4 t/km^2/year with a maximum SSY at 8.1 t/km^2/year in 1994 and a minimum SSY at 0.2 t/km^2/year in 2005. As shown in Figure 4a, the long-term SSY trend showed a downward trend. In addition, high SSY was recorded for this basin in 1995 (6.32 t/km^2/year). The SSY trend slightly decreased from 1961 to 1993 with an average of 2.4 t/km^2/year before it increased to an average of 7.19 t/km^2/year from 1994 to 1995. Following in 1995, the SSY trend declined steeply with an average of 1.66 t/km^2/year.

Meanwhile, the Kinta River basin at TanjungTualang (TT) received SSY input from the basins of Pari River, Kinta River at TR, Raia River, and Kampar River. The production of SSY at TT station recorded an average of 879 t/km^2/year with a maximum SSY of 2,397.4 t/km^2/year in 1994 and a minimum SSY of 414 t/km^2/year in 1986. Figure 4b reveals the decreasing trend of SSY in the Kinta

Table 3. Descriptive statistics of the annual SSY (t/km^2/year) for Kinta River basin and sub-basins from 1961 to 2006

Sub-basins/Basin	Mean	Standard Error	Minimum	Maximum	Range	Standard Deviation	Coefficient Variation	No. of Data
Chenderiang	1069.1	243.7	18.1	7219.1	7201.1	1652.9	1.55	46
Kampar	0.7	0.1	0.1	2.4	2.4	0.5	0.76	46
Raia	151.2	10.6	18.1	426.3	408.2	71.8	0.48	46
Kinta@ TanjungRambutan	2.4	0.2	0.2	8.1	7.8	1.3	0.53	46
Pari	314	46.7	10.8	1293.0	1282.2	316.5	1.01	46
Tumboh	0.8	0.1	0.07	2.8	2.7	0.6	0.78	46
Kinta @TanjungTualang	87	50.7	414.0	2397.4	1983.5	343.5	0.39	46
Kinta River basin	2417.6	259.7	720.4	8757.3	8036.9	1761.2	0.73	46

River at TT. Additionally, high SSY records were obtained in 1969 (1,278 t/km^2/year), 1980 (1,434 t/km^2/year), 1994 (2,397 t/km^2/year), and 1996 (1,299 t/km^2/year). The SSY trend fluctuated from 1961 to 1992, but the recorded values exceeded 500 t/km^2/year with an average of 876 t/km^2/year. The SSY increased to 1,131 t/km^2/year from 1993 to 2000 and decreased again to 558 t/km^2/year from 2001 to 2006.

The long-term SSY trend of Kinta River was in decreasing trend from 1961 to 2006 (Figure 4c) possibly related to the decline in mining industry post 1960. After World War II, production of tin remained constantly above 50,000 tonnes annually (ITC 1974; 1984). However, Malaysia's contribution to global tin production declined progressively from over 40 percent in the early 1960s to just over 20 percent in 1990s (Balamurugan, 1991). It has been reported that export of tin has reached from 39, 569 tonnes in 1898 and rose to a peak 72, 620 tonnes in 1972, but decline to 37 874 tonnes in 1983. The total acreage of mining areas in Perak also declines to 5388 ha in 1996 (Malaysian Mines Department, 1996). Recent estimates of tin production from mines output were 7339 tonnes in 1999; reduced to 6307 tonnes in 2000, and declining to 3539 tonnes in 2003 (Wu, 2003).

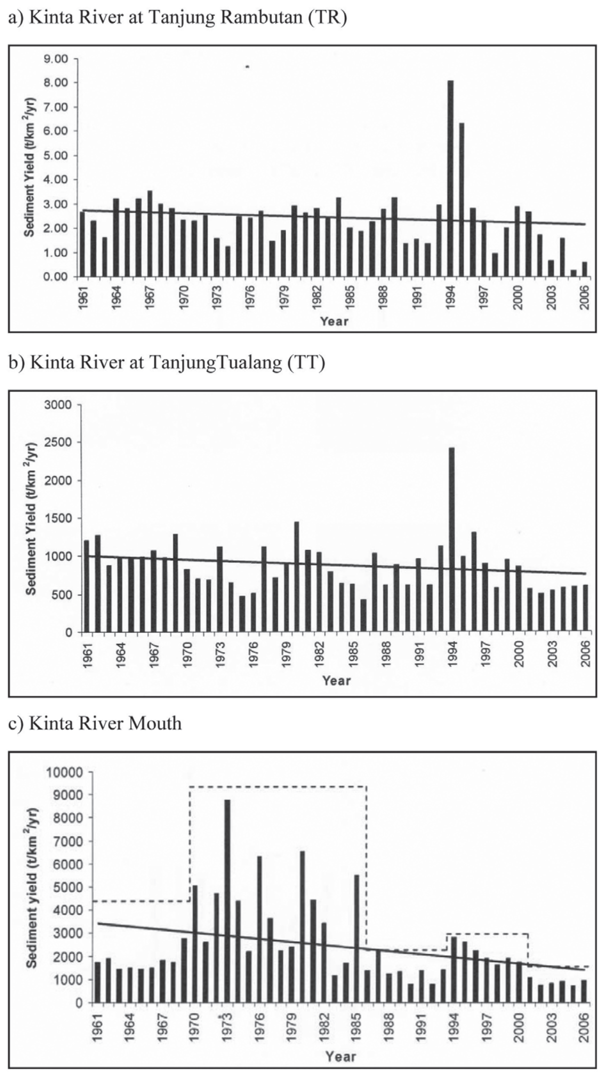


Fig. 4. The total annual SSY at (a) the upstream part of Kinta River at Tanjung Rambutan (TR), (b) the middle segment of Kinta River at Tanjung Tualang (TT), and (c) the Kinta River mouth before entering the Perak River

Closer scrutiny of the long-term data, this 46-year period (1961–2006) can be divided into five different phases according to the SSY trend. The total annual SSY in the first phase, which was between 1961 and 1969, recorded a low average of 1,757 t/km^2/year. Following that, the total annual SSY recorded an increased average of 4,062 t/km^2/year in the second phase of between 1970 and 1985. The total annual SSY subsequently decreased to an average of 1,306 t/km^2/year (1986–1993) before it increased again to an average of 2,109 t/km^2/year in the next phase (1994–2000). Lastly, the fifth phase (2001–2006) recorded an average of 865 t/km^2/year only.

Essentially, the SSY trend is significantly related to the land-use changes, thus human activities in the drainage basin. This scenario is closely linked to different human activities that cause various amounts of discharge, which increase SSY and subsequently affect the different aspects of land management in the drainage basin. Therefore, the various trends of the annual SSY found in this study were very likely to be related to the occurrence of land-use changes—certain areas of the drainage basin were explored for various purposes that were related to human activities.

Furthermore, the development process that took place in the Kinta River basin was in line with the initiated development plans by the Malaysian government in 1970 through the introduction of New Economic Policy (NEP) (Jomo 2004) and Green Book Plan (Courtenay, 1984). As depicted in Figure 3, large forest areas were cleared for agricultural purposes with the expansion of urban areas and improvement of facilities and infrastructures. The rapid development from 1970 to 1985 led to soil erosion where all materials on the earth's surface were exposed and washed to the water bodies, resulting in an increased amount of SSY during that period.

SSY of River Tributaries

Chenderiang River

Referring to Figure 5a, the trend analysis also included the annual SSY trend for the sub-basins of Kinta River basin from 1961 to 2006. Overall, the annual SSY trend for this basin demonstrated a downward trend. The production of SSY at the Chenderiang River basin recorded an average of 1,069.1 t/km^2/year with a maximum annual SSY of 7,219 t/km^2/year in 1973 and a minimum annual SSY of 18 t/km^2/year in 1990 and 1992. Apart from the recorded maximum SSY in 1973, huge amount of SSY was produced over the years, specifically in 1970 (3,765 t/km^2/year), 1972 (3,718 t/km^2/year), 1976 (5,495 t/km^2/year), 1980 (4,312 t/km^2/year), and 1985 (3,502 t/km^2/year). In other words, these data depicted a wide range of SSY readings for the sub-basin, which amounted to 7,201.1 t/km^2/year.

The coefficient of variation (CV) value exceeded 1 (Table 3), which reaffirmed that the amount of SSY in this basin had high variance. In particular, the fluctuating trend of SSY in Chenderiang River basin can be divided into three phases. The first phase was between 1961 and 1969, which revealed low amount of SSY with an average of 433 t/km^2/year. However, the overall SSY trend during the first phase demonstrated an increasing trend. Despite the fluctuating readings, the second phase from 1970 to 1985 showed a significant, increasing SSY trend with an average of 2,720 t/km^2/year, which was five times higher than the prior phase. However, the SSY trend from 1986 to 2006 demonstrated a significant, decreasing trend with an average of about 84 t/km^2/year.

Kampar River

Figure 5b presents the annual SSY in Kampar River basin, which is a large sub-basin of the Kinta River basin. However, the production of SSY at the Kampar River basin was relatively small compared to the other sub-basins, with an average of 0.7 t/km^2/year. The river basin recorded a maximum SSY of 2.4 t/km^2/year in 1988 and a minimum SSY of 0.1 t/km^2/year in 2005. Besides that, high amount of SSY was also observed in several years, specifically in 1962 (1.26 t/km^2/year), 1969 (1.39 t/km^2/year), 1985 (1.36 t/km^2/year), and 1987 (2.12 t/km^2/year). In particular, the overall SSY trend for this river basin depicted a downward trend from 1961 to 2006 with four phases of different SSY trend. The first phase (1961–1973) showed an increasing SSY trend with high sediment discharge of an average of 0.83 t/km^2/year. High amount of SSY appeared to be significantly related to the extensive tin mining activities in the area of Kampar during the 1970s and the 1980s. Meanwhile, the second phase (1974–1983) showed a slight decreasing trendof SSY with an average of 0.43 t/km^2/year. However, it increased in the next phase (1985–1991) with an average of 1.41 t/km^2/year, which was attributed to the land-use changes following the conversion of former tin mines to residential and urban areas in the area of Kampar. The SSY trend in the fourth phase of between 1992 and 2006 showed a downward trend with a relatively high sediment discharge (average of 0.37 t/km^2/year).

Raia River

The annual SSY trend for the Raia River basin also showed a downward pattern from 1961 to 2006 (Figure 5c). Furthermore, the average SSY (151.2 t/km^2/year) in this Raia River basin was considerably high (compared to Kampar, Kinta TR, and Tumboh) with a maximum SSY of 426.3 t/km^2/year in 1981 and a minimum SSY of 8.1 t/km^2/year in 2005. The production of SSY was high in certain years, especially during the 1990s, specifically in 1994 (200

Table 4. Mann-Kendall test of the annual SSY trend at Kinta River basin and sub-basins from 1961 to 2006

Sub-basins/Basin	No.of Data (n)	Mann-Kendall Statistics (S)	Normal Statistical Test(Z)	Probability (P)	Trend (at 99 % Confidence Level)
Chenderiang	46	-390	-3.684	0.0002	Decreasing
Kampar	46	-323	-3.050	0.0023	Decreasing
Raia	46	-212	-1.999	0.0456	Decreasing
Kinta @TanjungRambutan	46	-234	-2.207	0.0273	Decreasing
Pari	46	254	2.396	0.0166	Increasing
Tumboh	46	-11	-0.095	0.9245	Decreasing
Kinta@ TanjungTualang	46	-303	-2.860	0.0042	Decreasing
Kinta River Basin	46	-393	-3.712	0.0002	Decreasing

t/km^2/year), 1995 (306 t/km^2/year), 1998 (281 t/km^2/year), and 1999 (285 t/km^2/year). Despite the downward trend, the overall SSY trend of SSY from 1961 to 1980 appeared to be relatively stable and high with an average of 161 t/km^2/year. However, there was an exceptional increase of sediment discharge in 1981. Meanwhile, the average SSY from 1982 to 1992 (113 t/km^2/year) was slightly lower than the average SSY from 1961 to 1980. Nevertheless, it increased to an average of 230 t/km^2/year from 1993 to 1999 before it decreased again to an average of 65 t/km^2/year from 2000 to 2006.

Pari River

Pari River basin, which is located at the northwestern part of the Kinta River basin, experienced rapid development process, particularly in the area of Kinta Valley. The production of SSY at this river basin recorded an average of 314.3 t/km^2/year (Figure5d) with a maximum SSY of 1,293 t/km^2/year in 1995 and a minimum SSY of 10.8 t/km^2/year in 1964. Therefore, the range between the minimum and the maximum values was deemed high at 1,282.2 t/km^2/year. In addition, there were also high SSY readings in 1981 (953 t/km^2/year), 1985 (1,206 t/km^2/year), and 1987 (1,008 t/km^2/year). Overall, the long-term SSY trend for this river basin depicted an increasing trend. In this case, it is plausible that the diversity of land-use activities, such as massive deforestation, caused high amount of sediment and soil to enter the drainage system of Pari River, or in other words, increased SSY. Accordingly, there were five phases with different SSY trend. The first phase (1961–1976) recorded an average SSY of 123 t/km^2/year and it increased sharply to 524 t/km^2/year during the second phase of between 1977 and 1987. However, there was a shortfall in the third phase (1988–1994) with an average of 149 t/km^2/year. Following that, it increased dramatically to 761 t/km^2/year in the subsequent phase (1995–2000) before it declined sharply to 185 t/km^2/year from 2001 to 2006.

Tumboh River

Meanwhile, the annual SSY trend for Tumboh River basin showed a downward trend (Figure 5e) with an average of 1.0 t/km^2/year. The maximum SSY of 2.8 t/km^2/year was recorded in 1988 whereas the minimum SSY of 0.07 t/km^2/year was recorded in 1990. The other high values of SSY recorded were 2.03 t/km^2/year in 1984, 2.08 t/km^2/year in 1985, and 2.8 t/km^2/year in 1988. In particular, there were three phases with different SSY trend for this river basin. The first phase (1961–76) recorded an average of 0.42 t/km^2/year before it increased to 1.33 t/km^2/year during the second phase (1977–87). The third phase (1990-2006) recorded a lower average of 0.39 t/km^2/year.

Mann Kendall Test

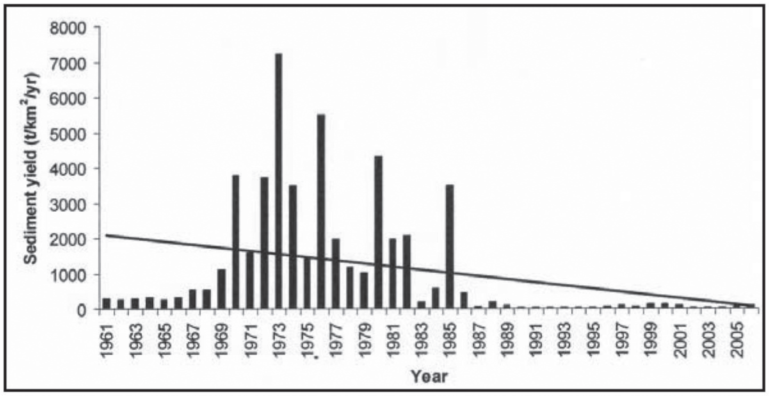
The Mann-Kendall test was applied in this study to verify the significance of long-term annual SSY trend for the Kinta River basin. Compared with the annual discharge trend that mostly showed an increasing trend, the trend of SSY showed the opposite trend except for Pari River basin (Table 4). The overall SSY trend of the Kinta River basin showed a highly significant reduction at 0.01 level (S = -393).

Thus the decreasing long-term SSY trend for a drainage basin could be influenced by several human activities, for instance, the construction of dams and lakes will potentially reduces the amount of SSY in the downstream area (Trimble, 1999; Rahaman, 2004; Ismail *et al.,* 2010, Gao *et al.,* 2012; Memarian *et al.,* 2012; Toriman *et al.,* 2012; Sani *et al.,* 2012). Ulu Kinta dam was completed in 2006 and began operation in 2007 (Ismail *et al.,* 2017). The second factor that could have impacted the SSY of the Kinta River basincould related to the decreased mining areas in the catchment which has been reported earlier (ITC, 1974; 1984).

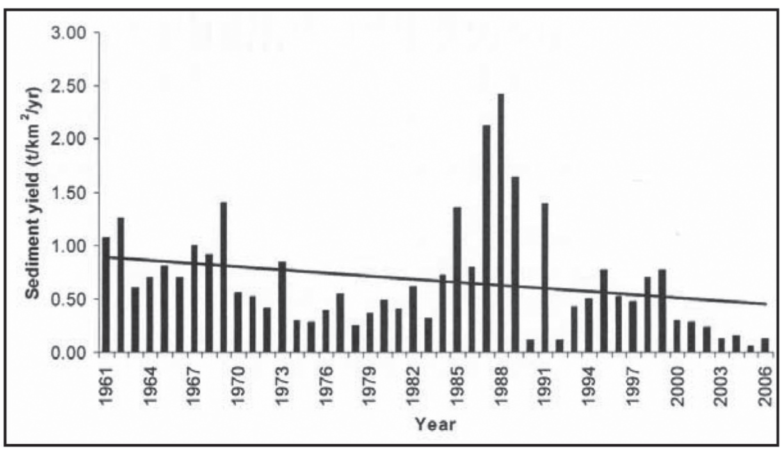
This study demonstrated that the decreasing long-term SSY trend for the Kinta River basin is with the value of S= -393. With an average of 2,417.6 t/km^2/year, the maximum SSY of 8,757.3 t/km^2/year was recorded in 1973. High SSY readings were also recorded in 1970 (5,041 t/km^2/year), 1972 (4,699 t/km^2/year), 1976 (6,305 t/km^2/year), 1980 (6,542 t/km^2/year), and 1985 (5,476 t/km^2/year). These data demonstrated the impact of rapid development process in this basin on the (high) amount of SSY over these years.

Clearly, the national development policy, particularly the NEP, promoted the conversion of forest areas into large-scale agricultural estates, such as rubber and oil palm plantations. In order to process the raw materials of these agricultural products and to provide for the downstream industries, new industrial areas and other facilities, such as residential areas, business hubs, and other infrastructures, were built. The massive deforestation led to the problem of increased SSY in the drainage basin. This follows Abernethy's (1990) analysis of sediment yield based on reservoir sedimentation in Southeast Asia's reservoirs impacted by land use change during the twentieth century who observed that the annual rate of sediment yield increase between 2.48 – 6.02% per year. The sediment yield increase is paralleled with the rate of population growth in the areas concerned. He also suggested that the annual suspended sediment yields in many developing countries were currently increasing at a rate

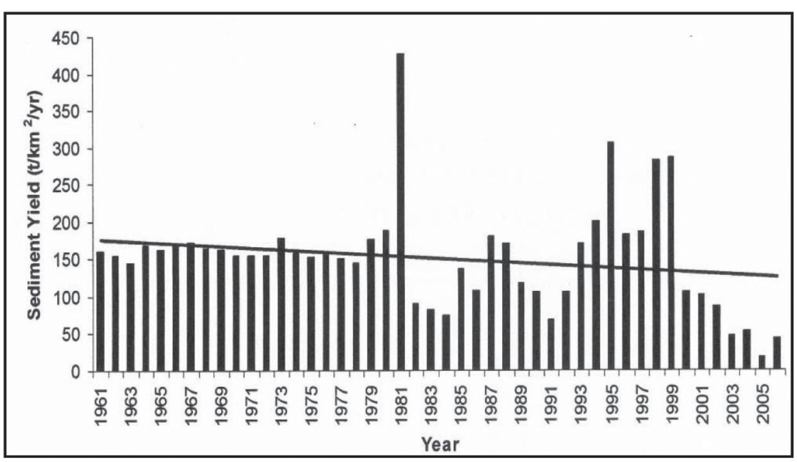
a) Chenderiang River



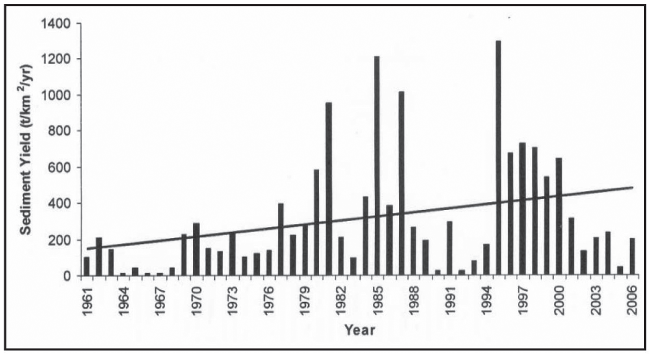
b) Kampar River



c) Raia River



d) Pari River



e) Tumboh River

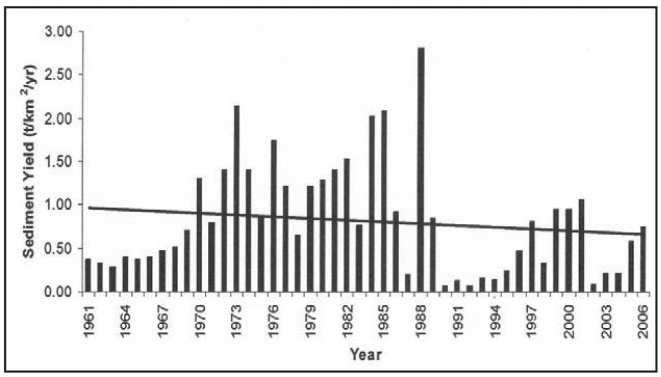


Fig. 5. The annual SSY of the tributary rivers: (a) Chenderiang River, (b) Kampar River, (c) Raia River, (d) Pari River, and (e) Tumboh River.

equivalent to 1.6 times the rate of population increase (Walling and Webb, 1996). The combination of anthropogenic alteration and fragile landforms in Southeast Asia give rise to very high local sediment yields (Gupta, 1996).

CONCLUSION

The trend of SSY of Kinta River basin were analysed and presented. The SSY is closely associated with the land-use development activities, including the clearance and opening of such areas for various human activities, such as for the purposes of agriculture, residential, new township, and others.The SSY trends for Kinta River basin and sub-basins demonstrated a declining trend, except for Pari River basin. The Pari River basin is a rapidly growing downstream area of where the Ipoh city lies. With respect to the increasing demands of the population, the rapid urbanisation in this area has resulted in the development of numerous urban areas in Ipoh city and its peripheral areas. Large forest areas and agricultural plantations were converted into township areas, which further increased the amount of SSY in this basin. Nevertheless, the decreasing SSY trend for the Kinta River basin did not exclusively imply the absence of land-use activities altogether, but more of an indication that the development process in this area may have been at a slower and staggering pace. In particular, the forest land-use changes appeared to have affectingsome part of the total Kinta River basin area, resulting in the downward trend of SSY. The changing development phases would continuously affect the forested land uses and contribute to higher SSY, especially when there are no control measures in place. The main reduction in SSY was due to declining mining areas since 1960, and the creation of Ulu Kinta dam is partially responsible for the reduction in SSY of Kinta River basin starting 2005.

ACKNOWLEDGEMENTS

We would like to thank the Department of Irrigation and Drainage (DID) Malaysia, specifically the

Information Management Unit, Hydrology and Water Resources Division, for providing the necessary hydrological data for this study. We would also like to acknowledge the scholarship and financial support provided by the Ministry of Education, Malaysia to MH throughout his Postgraduate study at Universiti Sains Malaysia.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

Abernethy, C. 1990. The use of river and reservoir sediment data for the study of regional soil erosion rates and trends. Paper presented at the *International Symposium on Water Erosion, Sedimentation and Resource Conservation*, Dehradun, India, October 1990

Balamurugan, G. 1991. Tin mining and sediment supply in Peninsular Malaysia with special reference to the Kelang river basin. *The Environmentalist*. 11(4): 281-291.

Basistha, A., Arya, D.S. and Goel, N.K. 2009. Analysis of historical changes in rainfall in the Indian Himalaya. *International Journal of Climatology*. 29: 555-572.

Burn, D. H.1994. Hydrological effects of climate change in West Central Canada. *Journal of Hydrology.* 160: 53-70.

Bae, D.-H., Jung, I. W. and Chang, H. 2008. Long-term trend of precipitation and runoff in Korean River Basins. *Hydrological Processes.* 22 : 2644-2656.

Brookfield, H., Potter, L. and Byron, Y. 1995. *In place of the forest: Environmental and Socio-economic transformation in Borneo and the eastern Malay Peninsula.* Tokyo: United nation university Press, 310pp.

Burn, D. H. and Elnur, M. A. H. 2002. Detection of hydrologic trends and variability. *Journal of Hydrology.* 255 : 107-122.

Caloiero, T., Coscarelli, R., Ferrari, E. and Mancini M. 2011. Trend detection of annual and seasonal rainfall in Calabria (Southern Italy). *International Journal of Climatology.* 31(1): 44-56.

Chase, T.N., Pielke, R.A., Kittel, T.G.F., Nemani, R.R. and Running, S.W.1999. Simulated impacts of historical land cover changes on global climate in northern winter. *Climate Dynamics.* 16 : 93–105.

CheNgah, M. S. Y. 2007. *Impact of Landuse Change on Water Yield and Water Quality in Peninsular Malaysia*. Unpublished Ph.D. Thesis, Department of Geography, Loughborough University.

Chen, Z., Li, J., Shen, H. and Wang, Z. 2001. Yangtze River of China: Historical analysis of discharge variability and sediment flux. *Geomorphology.* 41 : 77-91.

Chen, X., Zhang, E., Mu, H. and Zong, Y. 2005. A preliminary analysis of human impacts on sediment discharges from the Yangtze, China into the sea.*Journal of Coastal Research*. 21 (3) : 515-521.

Chen, X., Yan, Y., Fu, R., Dou, X. and Zhang, E. 2008. Sediment transport from the Yangtze River, China into the sea over the post-Three Gorge Dam period: A discussion. *Quaternary International.* 186 : 55-64.

Courtenay, P. P. 1984. The diversification of Malaysian agriculture, 1950-80: Objectives and achievements. *Journal of Southeast Asian Studies.*15 : 166-181.

Department of Environment, DOE.2013. Environment Quality Report 2012. Putrajaya: Department of Environment, Ministry of Natural Resources and Environment.

De Jongh, I. L., Niko, E. C., Verhoest, N. E. C. and De Troch, C. P. 2006. Analysis of a 105-year time series of precipitation observed at Uccle, Belgium. *International Journal of Climatology*. 26 : 2023-2039.

de Souza, E. B., Kayano, M. T., Tota, J., Pezzi, L., Fisch, G. and Nobre, C. 2000. On the influences of the El Nino La Nina and Atlantic dipole pattern on the Amazonian rainfall during 1960-1998. *Acta Amazonica*. 30(2): 305-318.

Gan, T. Y. 1998. Hydroclimatic trends and possible climatic warming in the Canadian Prairies. *Water Resources Research.* 34 : 3009-3015.

Gao, Z. L., Fu, Y. L., Li, Y. H., Liu, J. X., Chen, N. and Zhang, X. P. 2012. Trends of streamflow, sediment load and their dynamic relation for the catchments in the middle reaches of the Yellow River over the past five decades. *Hydrology and Earth System Sciences.* 16 : 3219-3231.

Gupta, A. 1996. Erosion and sediment yield in Southeast Asia: a regional perspective. In: Walling, D. E. and Webb, B. W. (Eds) Erosion and Sediment Yield: Global and Regional Perspectives (*Proceedings of the Exeter Symposium, July 1996*). *IAHS publ.* 236 : 215-222.

Grubler, A. 1994. Technology. In: Meyer WB and Turner BL II. (Eds.), *Changes in Land Use and Land Cover: A Global Perspective*. Univ. of Cambridge Press, Cambridge, pp. 287-328

Hashim, M. 2014. *The impact of rainfall and land use changes on the water discharge and suspended sediment discharge of Kinta River Basin* (in Malay). Unpublished PhD Thesis, Department of Geography, School of Humanities, Universiti Sains Malaysia, Pulau Pinang, 438pp.

Hirsch, R. M. and Slack, J. R. 1984. A nonparametric trend test for seasonal data with serial dependence. *Water Resource Research.* 20(1) : 727-732.

Houghton, R. A., Hackler, J. L. and Lawrence, K. T. 1999. The U.S. carbon budget: contribution from land-use change. *Science.* 285 : 574–578.

http://www.jmg.gov.my2011. Geosciences and Mineral

Department of Malaysia Portal. Accessed on 20 December 2011.

Ismail, W. R., Rahaman, Z. A., Najib, S. A. M. and Othman, Z. 2010. Sediment impact on aquatic ecosystem of Bukit Merah Reservoir, Perak. In: Banasik, K., Horowitz, A. J., Owens, P. N., Stone, M.and Walling, D. E. (eds.), Sediment dynamics for a changing future. *Proceedings of the ICCE Symposium. The Warsaw University of Life Sciences-SGGW, Poland*. *IAHS Publications*. 337 : 258-263.

Ismail, R., Kamsani, M. H. and Mohd Nadzri, N. I. 2017. Seismic Analysis of Concrete Dam by Using Finite Element Method. *MATEC Web of Conferences.* 103: *02024* (2017). DOI: 10.1051/matecconf/ 20171030 ISCEE 2016 2024.

Ingham, F. T. and Bradford, E. F.1960. Geology and Mineral Resources of the Kinta Valley, Perak. *Federation of Malaya Geological Survey District Memoirs 9*, Kuala Lumpur: Government Printer.

ITC. 1974. Tin statistics 1963-1973. International Tin Council. London.

ITC. 1984. Tin statistics 1973-1983. International Tin Council. London.

Jomo, K. S. 2004. The new economic policy and interethnic relations in Malaysia. *United Nation Research Insitute for Social Development, Identities Conflict and Cohesion Programme Paper No 7*.

Kwarteng, A. Y., Dorvlo, A. S. and Vijaya Kumar, G. T. 2009. Analysis of a 27-year rainfall data (1977-2003) in the Sultanate of Oman. *International Journal of Climatology*. 29 : 605 -617.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A. and Vogel, C. and Xu, J. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change.* 11 : 261-269.

Lambin, E. F., Geist, H. J. and Lepers, E. 2003. Dynamics of land use and land cover change in tropical regions. *Annual Review of Environment and Resources.* 28 : 205-241.

Lettenmaier, D. P., Wood, E. F. and Wallis, J. R. 1994. Hydro-climatological trends in the continental United States, 1948-88. *Journal of Climate.* 7(4): 586-607.

Lins, H. F. and Slack, J. R.1999. Streamflow trends in the United States.*Geophysical Research Letters.* 26(2): 227-230.

Luo, Y., Liu, S., Fu, S., Liu, J., Wang, G. and Zhou, G. 2008. Trends of precipitation in Beijing River Basin, Guangdong Province, China. *Hydrological Processes.* 22 : 2377-2386.

Liu, J. P., Xu, K. H., Li, A. C., Milliman, J. D., Velozzi, D. M., Xiao, S. B. and Yang, Z. S.2007. Flux and fate of Yangtze River sediment delivered to the East China Sea. *Geomorphology.* 85: 208-224.

Lu, X. X., Zhang, S. R., Xie, S. P. and Ma, P. K. 2007. Rapid channel incision of the Lower Pearl River (China) since the 1990s as a consequence of sediment depletion. *Hydrology and Earth System Sciences.*11: 1897-1906.

Malaysian Mines Department.1996. *Annual Report 1996*: Ipoh, Malaysia

Manokaran, N.1979.Steamflow, throughfall and rainfall interception in a lowland tropical rainforest in Peninsular Malaysia.*Malayan Forester*. 42(1): 174-201.

McDonnell, M. J., Pickett, S. T. A., Groffman, P., Bohlen, P., Pouyat, R. V., Zipperer, W. C., Parmelee, R. W., Carreiro, M. M. andMedley, K.1997. Ecosystem processes along an urban-to-rural gradient. *Urban Ecosystems.* 1: 21-36.

Memarian, H., Balasundram, S. K., Talib, J. B. andSood, A. M.2012. Trend analysis of water discharge and sediment load during the past three decades of development in the Langat basin, Malaysia. *Hydrological Sciences Journal*. 57(6): 1207-1222.

Milliman, J. D. and Meade, R. H. 1983. World-wide delivery of river sediment to the oceans. The *Journal of Geology.* 91(1): 1-21.

Milliman, J. D.1991. River sediment discharge to the sea: New analysis of old data. *Proceedings of the COMAR Interregional Scientific Conference UNESCO*, Paris. 21-25 Mei 1991, 56-66.

Mohamad, H. and Hassan, W. F.1996. Mining: What Environmental Impact? Compilation of papers presented at the *CAP-SAM National Conference*, 5-9 January 1996, Penang, 303-313.

Nicholson, S. E. and Selato, J. C.2000. The influence of La Nina on African Rainfall. International *Journal of Climatology*. 20: 1761-1776.

Strahler, A. N.1957. Quantitative Analysis of Watershed Geomorphology. *American Geophysical Union Transactions.* 38: 913-920.

Tolba, M. K. and El-Kholy, O. A. (Eds.) 1992. The World Environment 1972-1992:Two Decades of Challenge. Chapman & Hall, London.

Toriman, M. E., Kamarudin, M. K. A., Abd Aziz, N. A., Md Din, H., Ata, F. M., Gasim, M. B. and Mokhtar, M. 2012. Managing sediment towards integrated water resource: A case of Chini River, Pekan, Pahang (in Malay). *Jurnal e-Bangi.* 7(1): 267-283.

Partal, T. and Kahya, E. 2006. Trend analysis in Turkish precipitation data.*Hydrological Processes.* 20: 2011-2026.

Rahaman, Z. A. 2004.*Sediment balance and sedimentation of TimahTasoh Reservoir, Perlis, Malaysia*. Unpublished PhD Thesis, Department of Geography, UniversitiSains Malaysia, 350pp.

Shahid, S. 2010. Rainfall variability and the trends of wet and dry periods in Bangladesh. *International Journal of Climatology.* 30(15): 2299-2313.

Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Walker, M. and Wall, D. H. 2000.

Biodiversity: global biodiversity scenarios for the year 2100. *Science.* 287: 1770-1774.

Suppiah, R. and Hennessy, K. J. 1998. Trends in total rainfall, heavy rain events and number of dry days in Australia, 1910-1990. *International Journal of Climatology.* 18(10) : 1141-1164.

Saito, Y., Yang, Z. and Hori, K. 2001. The Huanghe (Yellow River) and Changjiang (Yangtze River) Deltas: A review on their characteristics, evolution and sediment discharge during the Holocene. *Geomorphology.* 41: 219-231.

Sani, S. F. M., Ismail, W. R., Najib, S. A. M. and Omar, M. A. 2012. Evaluation of sediment budget of Bukit Merah Reservoir and its catchment area, Perak, Malaysia. *Malaysian Journal of Environmental Management.* 13(1) : 69-76.

Shaharuddin, A. and Hashim, N. M. 2006. Analysis of pattern and direction of rainfall in Negeri Sembilan Using GIS Polygon Thiessen Method and Isohyet. *Geografia.* 3(2) : 1-12.

Syvitski, J. P., Vörösmarty, C. J., Kettner, A. J. and Green, P. 2005. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science.* 308(5720) : 376-380.

Trimble, S. W. 1999. Decreased rates of alluvial sediment storages in the Coon Creek Basin, Winconsin 1975-93. *Science.* 285 : 1244-1246.

United Nations, 2001. *The state of the world's cities*. United Nations Centre for Human Settlements, Nairobi, Kenya.

Walling, D. E. 2006. Human impact on land-ocean sediment transfer by the world's rivers. *Geomorphology.* 79 : 192-216.

Walling, D. E. and Webb, B. W. 1996. Erosion and sediment yield: a global overview. In: Erosion and Sediment Yield: Global and Regional Perspectives *(Proceedings of the Exeter Symposium, July 1996). IAHS Publ.* 236 : 3-19.

Walling, D. E. and Fang, D. 2003. Recent trends in the suspended sediment loads of the World's rivers. *Global and Planetary Change.* 39 : 111-126.

Wang, H., Yang, Z., Saito, Y., Liu, J. P., Sun, X. and Wang, Y. 2007. Stepwise decreases of the Huanghe (Yellow River) sediment load (1950-2005): Impacts of Climate Change and Human Activities. *Global and Planetary Change.* 57 : 331-354.

Wang, W., Chen, X., Shi, P. and van Gelder, P. H. A. J. M. 2008. Detecting changes in extreme precipitation and extreme streamflow in the Dongjiang River Basin in Southern China. *Hydrology and Earth System Sciences.* 12 : 207-221.

Wu, J. C. 2003. *Mineral of Malaysia.* USGS Publication: Washington.

Yang, S. L, Gao, A., Hotz, H. M., Zhu, J., Dai, S. B. and Li, M. 2005. Trends in annual discharge from the Yangtze River to the sea (1865-2004). *Hydrological Sciences Journal.* 50(5) : 825-836.

Yang, Z., Wang, H., Saito, Y., Milliman, J. D., Xu, K., Qiao, S. and Shi, G. 2006. Dam Impacts on the Changjiang (Yangtze) River Sediment Discharge to the Sea: The Past 55 Years and After the Three Gorges Dam. *Water Resources Research.* 42 : W04407, doi: 10.1029/2005 WR003970.

Yang, G., Chen, Z., Yu, F., Wang, Z., Zhao, Y. and Wang, Z. 2007. Sediment Rating Parameters and their Implications: Yangtze River, China. *Geomorphology*. 85 : 166-175.

Yue, S., Pilon, P. and Phinney, B. 2003. Canadian streamflow trend detection: Impacts of serial and cross-correlation. *Hydrological Sciences Journal.* 48(1) : 51-63.

Zhang, X. B. and Wen, A. B. 2004. Current changes of sediment load in the Upper Yangtze River and its two biggest tributaries, China. *Global and Planetary Change.* 41 : 221-227.

Zhang, X., Hogg, W. D. and Mekis, F.2001. Spatial and Temporal Characteristics of Heavy Precipitation Events over Canada. *Journal of Climate.* 14 : 1923-1936.