AN ESTIMATION OF SEDIMENT YIELD USING UNIVERSAL SOIL LOSS (USLE) AND RATING CURVE IN BARAT DAYA DISTRICT OF PENANG, MALAYSIA

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ABSTRACT: Sediment yield estimation in rivers at the regional or local scale is very important especially in term of managing the water resources in the catchment area. The sediment yield usually calculated either from direct measurement of sediment concentration in rivers or from sediment transport equation at a particular outlet point in the catchment. A total of 19 rivers were selected as sampling sites located at the Barat Daya District of Penang. The Universal Soil Loss Equation (USLE) was used to estimate the sediment yield in the study area by integrating with the Geographic Information System (GIS) to generate maps of the USLE factors, which are rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), crop management (C), and conservation practice (P) factors. A sediment rating curves of the study area was developed to verify the accuracy as well as comparison to the sediment yield estimated by USLE. The results show good correlation between the sediment yield estimated by USLE and observed data (r^2 is 0.62). The sediment yield estimated in the year 1974 was 1300 ton/km^2/year, 1984 was 1921 ton/km^2/year, 2004 was 1919 ton/km^2/year and 2012 was 2336 ton/km^2/year. Based on the land use analysis, agricultural activity was dominant in the Barat Daya area and contributes much of the sediment into the river system.
Keywords: estimation sediment yield, USLE, Barat Daya District of Penang, Malaysia

INTRODUCTION

Soil erosion is a worldwide problem because of its economic and environmental impacts. Many human-induced activities, such as mining, construction, and agricultural activities disturb land surface, resulting in accelerated erosion (Lim et al., 2005). Over the past 40 years, 30 per cent of the world's arable land has become unproductive. Erosion also reduces the ability of the soil to store water and support plant growth, thereby reducing its ability to support biodiversity (Lal, 1990). Sediment yield is the amount of sediment load passing the outlet of a catchment and is the net result of erosion and deposition processes within a basin. It can be expressed in absolute terms (t yr^{-1}) or per unit area (t km^{-2} yr^{-1}) (Jain et al., 2010). The amount of sediment yield generated within a catchment is a function of a number of anthropogenic and physical factors including farming, mining, construction, slope, basin area and rainfall intensity. Information on sediment yield of a river basin is an important requirement for water resources development and management (Akrasi, 2011), because high sediment loads affect water quality, water supply, flood control, reservoir lifespan, irrigation, navigation, fishing, tourism, hydro-power generation, river channel morphology and stability (Schwartz and Greenbaum, 2009). During the last decades, many different models have been proposed to describe and predict soil erosion by water and associated sediment yield, varying considerably in their objectives, time and spatial scale involved, as well as in their conceptual basis (De Vente and Poesen, 2005). Hence, the main objective of this study is to estimate sediment yield using Universal Soil Loss Equation (USLE) and Rating Curve Method and to estimate past sediment yield for the year of 1974, 1984, 2004 and 2012, for 19 catchments in the Barat Daya District of Penang, Malaysia.

MATERIALS AND METHODOLOGY

Study area

Barat Daya District of Penang was selected as the study area, consists of 19 river catchments. Figure 1 and Figure 2 show the location and land uses of each catchment, and the morphological characteristic of the respective catchment is shown in Table 1. The list of the selected rivers are the Upstream and Downstream of Relau River, Upstream and Downstream of Ara River, Bayan Lepas River, Teluk

Kumbar River, Pulau Betong River, Nipah River, Burung River, Kuala Jalan Baru River, Buaya River, Titi Teras River, Pak Long River, Ayer Puteh River, Rusa River, Pinang River, Titi Kerawang River, and Teluk Bahang Upstream and Downstream River. Barat Daya District was were selected as research area due to the lack of data in terms of sediment and discharge, and also the diversity of land uses compared to the Timur Laut District which is dominated by build-up land use. In addition, there is no comprehensive sediment study of the Barat Daya District. According to the Malaysian Meteorological Department data, the temperature of the northern part of Penang ranges between 29^{o}C and 32^{o}C and the mean relative humidity between 65 per cent and 70 per cent. The highest temperature is during April to June while the relative humidity is lowest in June, July and September. Rainfall on Penang Island averages between 2,000 and 3,000 mm per annum respectively. Figure 3 shows the rain gauged data for the stations of Bayan Lepas and School of Physics, USM for 2012. The highest 376.9 mm annual rainfall was recorded in September; which is 384.66 mm (School Of Physics) and Bayan Lepas.

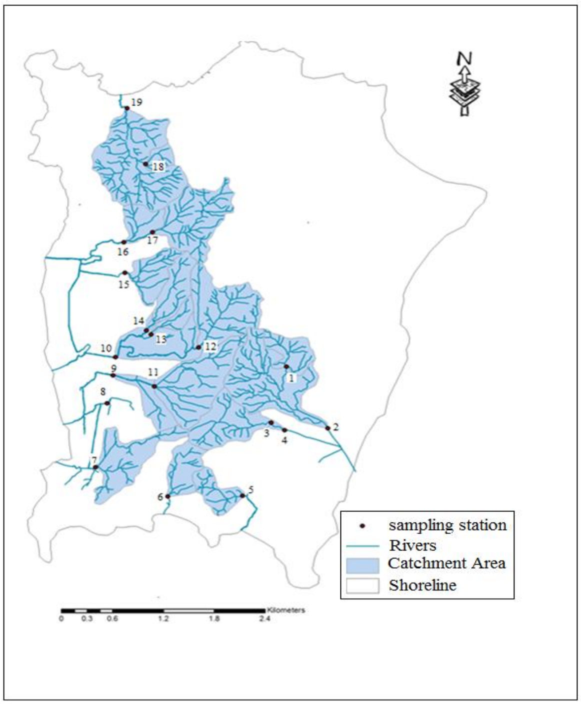

Figure 1: Location of sampling stations

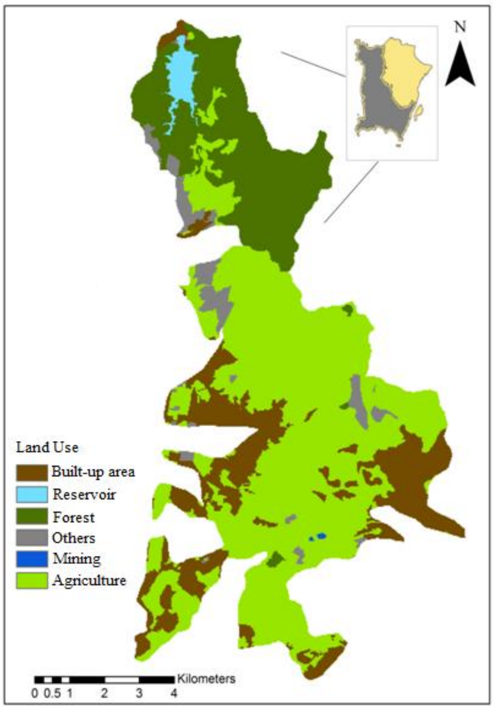

Figure 2: Land use for 2012

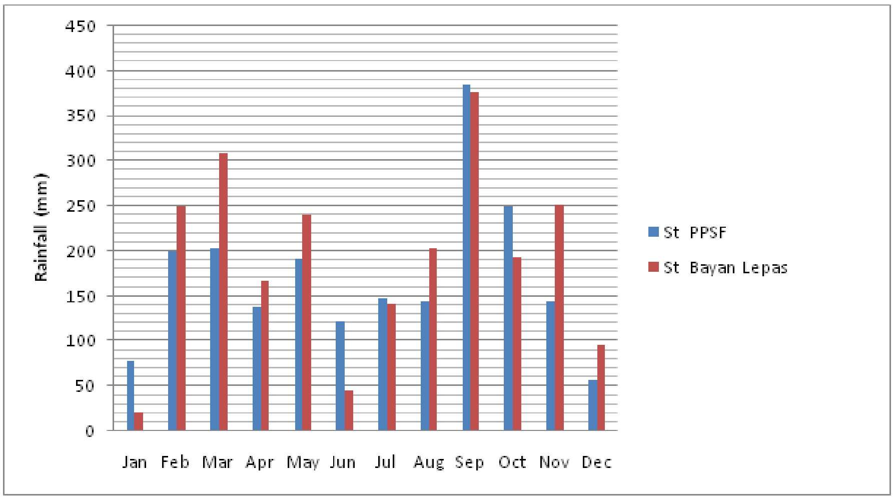

Figure 3: Monthly Rainfall data for 2012

Table 1: Location and morphological characteristic of catchments in the study area

Rivers/ Sampling location	River Length (km)	Catchment area (km^2)	Drainage density (km/km^2)	River Order	Latitude	Longitude
1. Relau River Upstream(RU)	10.05	2.53	3.97	3	N 5° 20.94”	E° 100 16.32’’
2. Relau River Downstream (RH)	46.24	11.55	4	5	N 5° 19.27”	E° 100 16.88’’
3. Ara River Upstream (AU)	15.25	4.93	3.09	3	N 5° 19.48”	E° 100 15.86’’
4. Ara River Downstream (AM)	17	5.1	3.33	3	N 5° 19.34”	E° 100 16.33’’
5. Bayan Lepas River (BL)	9	2.35	3.83	3	N 5° 17.8”	E° 100 15.6’’
6. Teluk Kumbar River (TK)	7.92	2.72	2.91	3	N 5° 17.5”	E° 100 13.8’’
7. Pulau Betong River (PB)	15.39	5.36	2.87	4	N 5° 18.42”	E° 100 12.17’’
8. Nipah River (SN)	3.07	0.92	3.34	2	N 5° 19.9”	E° 100 12.38’’
9. Burung River (BR)	30.54	10	3.05	4	N 5° 20.68”	E° 100 12.49’’
10. Kuala JalanBaru River (KJB)	63.21	16.14	3.92	5	N 5° 21.12”	E° 100 12.55’’
11. Buaya River (BY)	22.78	7.65	2.98	3	N 5° 20.23”	E° 100 13.24’’
12. TitiTeras River (TT)	26.78	7.12	3.76	4	N 5° 21.21”	E° 100 13.77’’
13. Pak Long River (PL)	4.55	1.1	4.14	3	N 5° 21.63”	E° 100 13.32’’
14. Air Puteh River (AP)	10.98	3.05	3.6	3	N 5° 21.75”	E° 100 13.22’’
15. Rusa River (RS)	12.29	2.98	4.12	3	N 5° 23.18”	E° 100 12.75’’
16. Pinang River (SP)	43.37	8.84	4.91	4	N 5° 23.94”	E° 100 12.7’’
17. TitiKerawang River (TTK)	28.79	6.71	4.29	4	N 5° 24.2”	E° 100 13.35’’
18. Teluk Bahang River (TBU)	4.37	0.98	4.46	2	N 5° 25.43”	E° 100 13.21’’
19. Teluk Bahang River (TBD)	50.19	11.96	4.20	4	N 5° 27.25”	E° 100 12.81’’

Sediment rating curves

The framework for the estimation of sediment yield is shown in Figure 4. The samplings were carried out every fortnight to develop the sediment rating curves for the river catchments. The rating curve will then be used to estimate the sediment yield during the ungauged period. The sediment rating curves were developed based on Ismail (1995). It was based on the relationship between the rainfall and sediment loading. Two rating curves were developed, one for rainfall amount that is less than 20mm, and the other is for rainfall of more than 20mm. The sediment rating curve equation as shown in Table 2 were used to obtain the sediment yield for each river catchment. Based on the estimation of sediment yield from the sediment rating curve, the relationship of the obtained sediment yield are used to verify the accuracy of sediment yield estimated from the USLE.

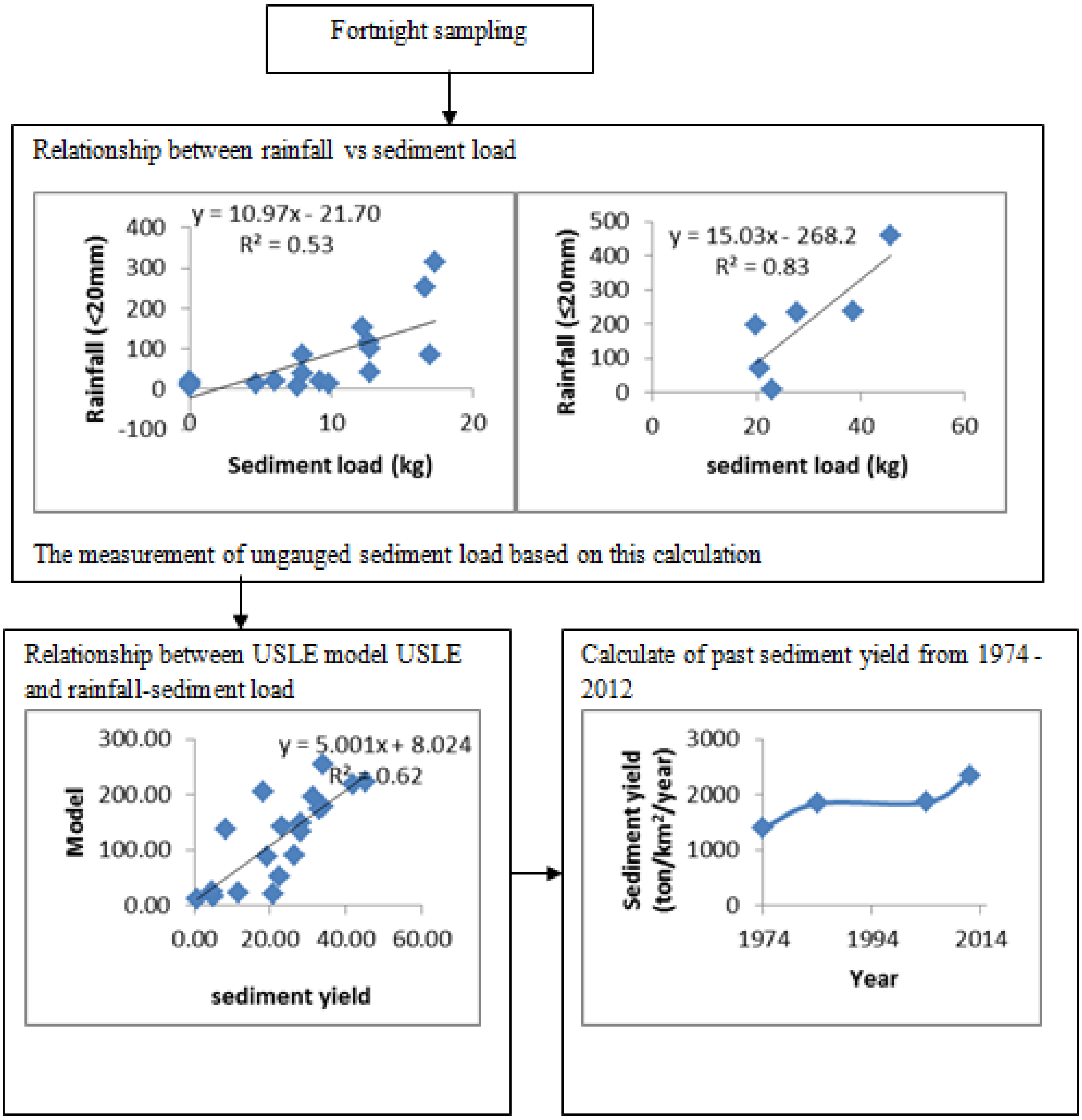

Figure 4: The framework for the estimation of sediment yield

The sediment yields estimation from Universal Soil Loss Equation (USLE)

For estimation of sediment yield, USLE method is also used to compare the gauging data. GIS is an efficient tool to integrate various datasets and assess any dynamic system such as soil loss/ soil erosion and there have been many studies of soil loss by various methods (Adinarayana et al.,1999; Lee, 2004; Millward and Mersey, 2001). The USLE model integrated with GIS could be used to calculate soil erosion at any point in catchment experiencing net erosion. It is an easy and simple approach, efficient method of soil loss assessment and universally accepted method for monitoring soil loss. The USLE is an empirical model developed by Wischmeir and Smith (1978) to estimate soil erosion. Figure 5 and Figure 6 show the steps for obtaining the soil loss map from USLE. Mathematically, the equation is denoted as:

A (tons/ha/year) = R x K x LS x C x P (1)

Where, A denotes the average annual soil loss caused by sheet and rill erosion (t ha-1 yr-1); R is the rainfall erosivity factor; K is the soil erodibility; LS is the slope length and steepness factor (dimensionless); C is the land cover and management factor (dimensionless, ranging between 0 and

1); P is the support conservation practice factor (dimensionless, ranging between 0 and 1) (Chander and Zullyadini, 2014).

Table 2: The calculation of Rating Curve

Rivers catchment	Rainfall relation < 20 mm		Rainfall relation ≥ 20 mm	
	R^2	Regression	R^2	Regression
Relau River Upstream(RU)	0.53	y = 15.03x-268.2	0.83	y =10.97x-21.7
Relau River Downstream (RH)	0.72	y = 288.2x-7745	0.87	y =27.18x+54.48
Ara River Upstream (AU)	0.86	y = 18.25x-390.3	0.76	y =22.39x+ 50.68
Ara River Downstream (AM)	0.83	y = 257.2x-6017	0.98	y =11.20x+37.18
Bayan Lepas River (BL)	0.52	y = 23.5x-126.6	0.56	y = 33.49x+ 78.69
Teluk Kumbar River (TK)	0.58	y = 121.8x-3774	0.70	y = 10.01x+98.62
Pulau Betong River (PB)	0.75	y = 5.26x-47.83	0.85	y = 5.38x+30.85
Nipah River (SN)	0.80	y = 0.73x-15.56	0.80	y = 78.97x-130.7
Burung River (BR)	0.97	y = 42.07x-1170	0.78	y = 40.81x+50.12
Kuala JalanBaru River (KJB)	0.93	y = 236.6x-6046	0.78	y = 59.05x+293.3
Buaya River (BY)	0.86	y = 49.92x-1076	0.88	y = 63.61x+54.72
TitiTeras River (TT)	0.57	y = 117.3x-3152	0.95	y = 7.46x+23.12
Pak Long River (PL)	0.93	y = 7.14x-173.9	0.78	y = 33.1x+29.31
Air Puteh River (AP)	0.7	y = 4.33x-14.96	0.59	y = 4.35x+22.35
Rusa River (RS)	0.78	y = 44.18x-876.2	0.99	y = 3.5x+19.67
Pinang River (SP)	0.77	y = 0.43x+77.82	0.89	y = 41.22x+129
TitiKerawang River (TTK)	0.77	y = 8.35x-114	0.69	y = 31.66x+29.47
Teluk Bahang River (TBU)	0.5	y = 20.33x-432.7	0.98	y = 18.72x+23.70
Teluk Bahang River (TBD)	0.64	y= 23.20x-480.3	0.98	y = 10.57x+42.95

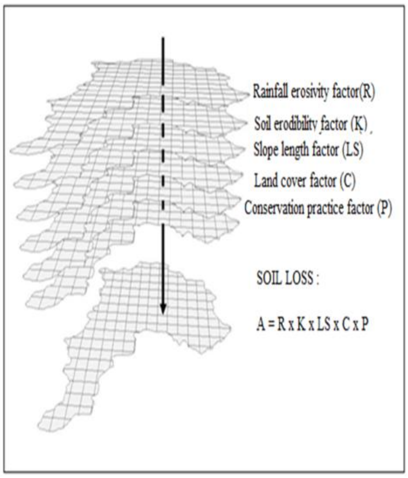

Figure 5: The layering of USLE factor

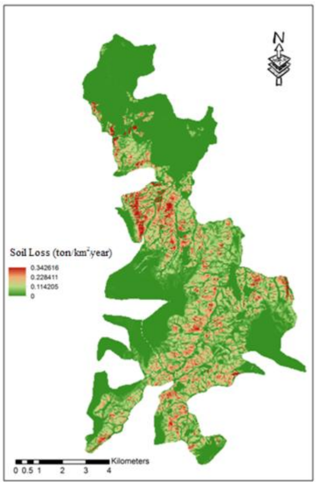

Figure 6: Soil erosion map (2012)

RESULTS AND DISCUSSIONS

The most common way of combining intermittent concentration data with continuous discharge data uses a rating curve to predict unmeasured concentrations from the discharge at the time (Ndomba et al., 2008). A suspended sediment rating curve or transport curve is usually presented in one of two basic forms, either as a suspended sediment concentration/streamflow or as a suspended sediment discharge/streamflow relationship (Walling, 1977). In most cases, rating curves are constructed from instantaneous observations of discharge and either sediment concentration or load, but several specific variants have been proposed (Walling, 1977). Colby (1956) has classified rating relationships, according to temporal resolution of the data, into instantaneous, daily, monthly, annual and flood period curves and, according to particle size criteria, into clay-silt ratings and sand-sized ratings.

Other researchers have subdivided instantaneous data according to stage and season, constructing separate rating relationships for rising and falling stages (Loughran, 1976) and for various times of the year (Hall, 1967) as reported in Walling (1977). From this rating curve method, an estimation of sediment yield was obtained.

Table 3 and Figure 7 shows the result between the sediment yield estimated by USLE and observed data (r^2 is 0.62) and the equations were used to estimate past sediment yield. The estimated sediment yield from 1974-2012 shows an increasing trend (Figure 8). The highest sediment yields for gauging data was 221.94 ton/km^2/year recorded at Sungai Rusa catchment while the lowest sediment yields was 10.99 recorded at Sg. Nipah. The average amount of sediment yields for all 19 catchments were estimated at 163.72 ton/km^2/year and 195.28 ton/km^2/year (19.3 per cent) for 1974 and 1984, respectively. Then it increased slightly (0.5 per cent) to an average of 196.18 ton/km^2/year in 2004 and a larger increase was noticeable (10.8 per cent) to 217.43 ton/km^2/year in 2012. USLE estimated the soil loss at 110.18 ton/km^2/year and 116.89 ton/km^2/year for 1974 and 1984 respectively, then also increase slightly to 117.87 ton/km^2/year in 2004 then 122.44 ton/km^2/year in 2012.

Sediment availability in the study area is related to the land use and agriculture was the most dominant activities. In Penang Island, natural elements particularly weather elements are highly erosive (Goh and Hui, 2006). Geomorphological processes such as rain splash erosion and surface runoff erosion have been shown to be extremely high in wet equatorial areas (Pradhan et al, 2012; Ismail, 1995).

Table 3 : Estimated sediment yield from gauging data and USLE method 2012

Rivers catchment	Gauging 2012 (ton/km^2/year)	USLE (ton/km^2/year)
Relau River Upstream(RU)	178.55	178.48
Relau River Downstream (RH)	87.10	103.75
Ara River Upstream (AU)	173.38	173.33
Ara River Downstream (AM)	196.00	165.18
Bayan Lepas River (BL)	205.53	99.73
Teluk Kumbar River (TK)	254.07	178.67
Pulau Betong River (PB)	21.86	111.81
Nipah River (SN)	10.99	11.49
Burung River (BR)	52.80	119.84
Kuala JalanBaru River (KJB)	141.33	123.43
Buaya River (BY)	89.33	140.91
TitiTeras River (TT)	149.82	148.27
Pak Long River (PL)	132.77	149.30
Air Puteh River (AP)	217.82	217.62
Rusa River (RS)	221.94	234.06
Pinang River (SP)	23.96	66.14
Titi Kerawang River (TTK)	16.94	33.90
Teluk Bahang River (TBU)	138.00	49.33
Teluk Bahang River (TBD)	24.76	31.62

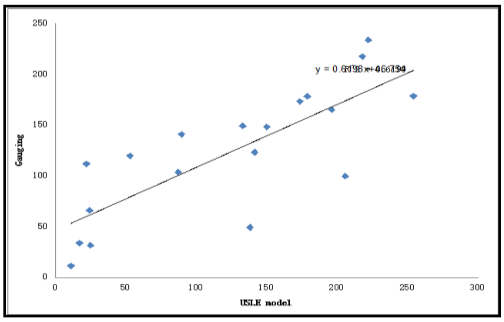

Figure 7: Verify Gauging and USLE

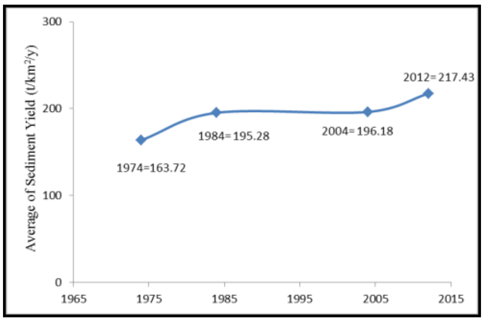

Figure 8: The trend of past sediment yield from 1974-2012

CONCLUSION

The rating curve method was used because of insufficient hydrological and sediment data in Barat Daya District. This study has successfully estimated the past sediment yield for 19 ungauged catchment in the Barat Daya District of Penang, using existing conceptual methods and GIS. This method can be used for the identification of sediment source areas and the prediction of sediment yield from an ungauged catchments.

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