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MODELING SOIL EROSION AND LANDSCAPE METRIC ANALYSIS OF RIVER CATCHMENTS IN PULAU PINANG, MALAYSIA

马来西亚槟城槟榔岛的河流集水区土壤侵蚀模型和景观度量分析

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Abstract

To determine the soil erosion in ungauged catchments, the author used 2 methods: Universal Soil Loss Equation model and sampling data. Sampling data were used to verify and validate data from model. Changing land use due to human activities will affect soil erosion. Land use has changed significantly during the last century in Pulau Pinang. The main rapid changes are related to agriculture, settlement, and urbanization. Because soil erosion depends on surface runoff, which is regulated by the structure of land use and brought about through changes in slope length, land-use changes are one of many factors influencing land degradation caused by erosion. The Universal Soil Loss Equation was used to estimate past soil erosion based on land uses from 1974 to 2012. Results indicated a significant increase in three land-use categories: forestry, built-up areas, and agriculture. Another method to evaluate land use changes in this study was by using landscape metrics analysis. The mean patch size of built-up area and forest increased, while agriculture land use decreased from 48.82 patches in 1974 to 22.46 patches in 2012. Soil erosion increased from an estimated 110.18 ton/km^2/year in 1974 to an estimated 122.44 ton/km^2/year in 2012. Soil erosion is highly related (R^2 = 0.97) to the Shannon Diversity Index, which describes the diversity in land-use composition in river basins. The Shannon Diversity Index also increased between 1974 and 2012. The findings from this study can be used for future reference and for ungauged catchment research studies.

Keywords: Land-Use Change, Soil Erosion, Universal Soil Loss Equation, Metric Analysis, Shannon Diversity Index

摘要 为了确定未覆盖集水区的土壤侵蚀，作者使用了两种方法：通用土壤流失方程模型和采样数据。采样数据用于验证和验证模型中的数据。人类活动引起的土地利用变化将影响土壤侵蚀。上

个世纪，槟城岛的土地使用发生了巨大变化。主要的快速变化与农业，定居和城市化有关。由于土壤侵蚀取决于地表径流，而地表径流受土地利用结构的调节并通过边坡长度的变化而引起，因此土地利用变化是影响侵蚀造成土地退化的众多因素之一。通用土壤流失方程用于基于 1974 年至 2012 年的土地利用来估算过去的土壤侵蚀。结果表明，三种土地利用类别显着增加：林业，建成区和农业。在本研究中评估土地利用变化的另一种方法是使用景观度量分析。建成区和森林的平均斑块面积增加，而农业土地利用从 1974 年的 48.82 斑块减少到 2012 年的 22.46 斑块。土壤侵蚀从 1974 年的估计 110.18 吨/平方千米 /年增加到估计的 122.44 吨/平方千米 /年（2012 年）。土壤侵蚀与香农多样性指数高度相关（R2 = 0.97），该指数描述了流域土地利用成分的多样性。 1974 年至 2012 年之间，香农多样性指数也有所增加。本研究的结果可用于将来参考和未开展的流域研究。

关键词: 土地利用变化，土壤侵蚀，通用土壤流失方程，度量分析，香农多样性指数

I. INTRODUCTION

Land-use change refers to the changes in an area resulting from activities that directly modify or alter the surrounding landscape [1]. Changes in land use and land cover are one of the most significant challenges that alter the relationships among natural processes, such as soil productivity, animal diversity, climatic conditions, and biogeochemical and hydrological cycles [2]. Moreover, land use is one of the important factors that affect the quality and quantity of water [3], [4]. Therefore, examining the impact of land-use change on water quality and quantity is fundamental to sustainable development [5] and is an important component river basin health, related to catchment health. Changes in land use and vegetation cover in the catchment area could lead to major modifications to freshwater run-off, sediment transport, and nutrient fluxes to lake systems. Worldwide, studies have shown that agricultural practices have markedly increased the nitrate concentration in groundwater and surface waters during recent decades, mostly because of an increased use of artificial fertilizers in agriculture [6].

Soil erosion is a natural and inevitable phenomenon that can quickly become a serious economic and environmental problem [7]. Although erosion is a natural process, it can be accelerated through changes in land use which result in soil erosion and an increase in the amount or yield of sediment captured in catchment areas [8]. Following its independence in 1957, Malaysia began moving forward economically and socially, thereby increasing the proportion of people moving away from rural areas to towns and cities (i.e., urbanization). However, the impact of this progression also created significant problems such as ad hoc and irregular development consequently affecting the quality and nature of the physical environment [9]. Suspended sediment is important in determining water quality. A moderate amount of sediment in rivers is beneficial for aquatic habitats, provides nutrients, and enriches the floodplain ecosystems. Significant changes in land use can change the delivery and discharge of sediment in a river basin, impacting the geomorphological processes associated with the river system [10].

Soil degradation can be described as a decrease in the function and use of soil (i.e., quality and quantity) either physically, biologically, or chemically, resulting in the land becoming less useable for agricultural and development purposes and impacting the surrounding ecosystem [11], [12]. Disturbances caused by humans, such as deforestation, agriculture, roads, mining, and urbanization alter the timing, composition, and amount of sediment load to the downstream ecosystems. Change to land degradation is complex due to many natural and human interactions that accelerate soil erosion [13], [14]. In tropical regions, soil erosion is more prominent compared to milder climates because of the intense rainfall and weather conditions that contribute to environmental problems [15]. In fact, Asia is reported to have the highest rate of sediment loss when it comes to erosion, with an annual loss of sediment of about 166 tonnes/km^2 compared to 47, 43, and 93 tonnes/km^2 respectively in Africa, Europe, and South America [16], [17].

Soil erosion is a two-phase process in which soil particles (in mass) are transported by agents that cause erosion (i.e., water run-off) [18]. Both phases are closely related to the hydrological cycle and are influenced by various factors. Because the climate in Malaysia is dominated by high rainfall, the erosive effects are also high [19]. This causes the country to experience high soil erosion rates, which, in turn, affect the quality of water held in river basins [20]. Soil erosion caused by water is one of the most critical environmental degradation problems globally [15], [21], [22], [23]. Moreover, erosion is accelerated through human intervention and actions which contribute to environmental change, thereby causing increasing geomorphological processes and sediment fluctuations in most regions worldwide [24], [25], [26]. In other words, soil erosion and sediment deposition involve the removal, transportation, and deposition of significant amounts of soil particles caused by heavy rainfall conditions and rapidly flowing water [27], [28]. Therefore, spatial and time-related data with respect to water runoff, soil erosion, and sedimentary properties of an area provide useful information and perspectives on the availability of water and soil loss in a river basin [29]. Sediment yield (given as tonnes per year) can be defined as the amount of sediment reaching the catchment. The importance of studying sediment yields is to understand and be aware how much sediment is deposited in the catchment.

Interestingly, while spatial metrics are acknowledged as a useful tool in measuring the structure and style of a thematic map, the analysis of spatial structures and patterns is central to geographic research. Spatial primitives including location, distance, direction, orientation, linkage, and patterns are acknowledged as general spatial concepts used in geography that have been implemented in a variety of diverse ways. Landscape and spatial metrics are commonly used to quantify vegetation shapes and patterns in natural landscapes [30], [31]. Furthermore, the analysis of landscape metrics has been used in determining the number of Patches (NumP), Mean Patch Size (MPS), Edge Density (ED), Total Edge (TE), and determination of the Shannon Diversity Index (SHDI).

Accordingly, this paper aims to use metric analysis to assess the expanding uses of land between 1974 and 2012 and to relate land-use changes to erosional soil loss based on USLE calculations from past land-use activities in the catchment areas.

II. Study Area

The area of study selected for this work is the Barat Daya region of Pulau Pinang, Malaysia, which comprises 19 upstream and downstream river systems and catchment areas, as follows:

1. Teluk Bahang River;
2. Relau River; and
3. 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, and Titi Kerawang River.

Table 1 and Figure 1 show the geographic location of the catchment areas and sampling stations in the Barat Daya District of Pulau Pinang.

Table 1.
Morphological characteristics of the catchment area studied

No.	River and station name	Length (km)	Area (km^2)	Drainage density (km/km^2)	Order
1.	Relau River Upstream (RU)	10.05	2.53	3.97	3
2.	Relau River Downstream (RH)	46.24	11.55	4	5
3.	Ara River Upstream (AU)	15.25	4.93	3.09	3
4.	Ara River Downstream (AM)	17.0	5.1	3.33	3
5.	Bayan Lepas River (BL)	9	2.35	3.83	3
6.	Teluk Kumbar River (TK)	7.92	2.72	2.91	3
7.	Pulau Betong River (PB)	15.39	5.36	2.87	4
8.	Nipah River (SN)	3.07	0.92	3.34	2
9.	Burung River (BR)	30.54	10	3.05	4
10.	Kuala Jalan Baru River (KJB)	63.21	16.14	3.92	5
11.	Buaya River (BY)	22.78	7.65	2.98	3
12.	Titi Teras River (TT)	26.78	7.12	3.76	4
13.	Pak Long River (PL)	4.55	1.1	4.14	3
14.	Air Puteh River (AP)	10.98	3.05	3.6	3
15.	Rusa River (RS)	12.29	2.98	4.12	3
16.	Pinang River (SP)	43.37	8.84	4.91	4
17.	Titi Kerawang River (TTK)	28.79	6.71	4.29	4
18.	Teluk Bahang River Up (TBU)	4.37	0.98	4.46	2
19.	Teluk Bahang River (TBD)	50.19	11.96	4.20	4

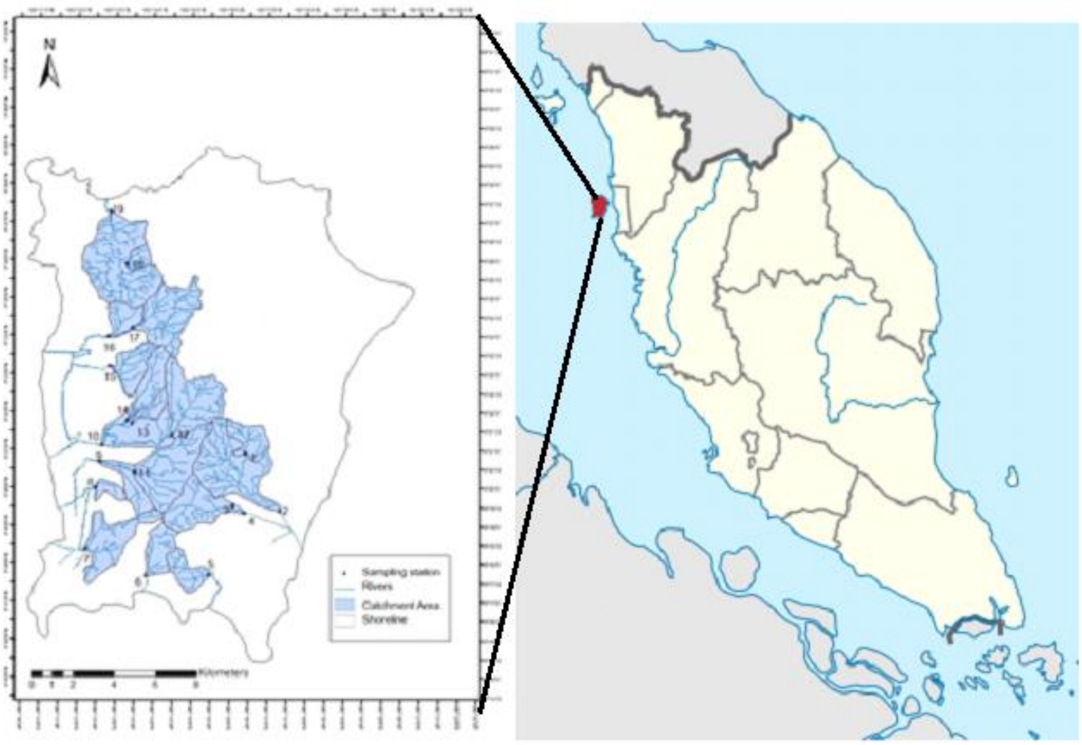


Figure 1. Location of 19 catchments and sampling stations

The Barat Daya area was selected as the location for this study because of the variety of land use in the area and the limited amount of current data with respect to the discharge of water and soil deposits in the area in comparison to the Timur Laut area, which has been subjected to greater land use and development. Additionally, no sediment research studies have been carried out in this area. The weather conditions in the northern area of Penang normally vary between 29°C and 32°C from April to June, with a relative humidity of around 65% and 70% between June and September each year. The island of Penang also experiences vast rainfall each year, averaging between 2,000 and 3,000 mm. The highest is usually recorded in September, which is estimated to be around 384.66 mm (at PPSF, USM). Whereas, at Bayan Lepas, the rainfall is typically around 376.9 mm per annum. The highest annual rainfall was recorded in September (384.66 mm) at the USM station, and 376.9 mm was recorded at the Bayan Lepas station. Figure 2 shows the monthly rainfall distribution at the USM (PPSF) and the Bayan Lepas stations in 2012.

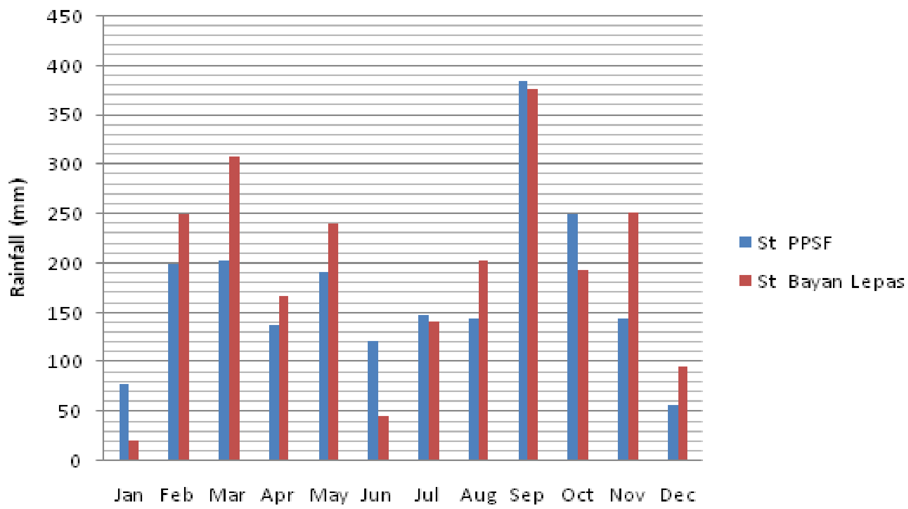


Figure 2. Rainfall distribution at USM (PPSF) and Bayan Lepas, Pulau Pinang

III. MATERIALS AND METHODS

A. Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) method was used in this study to predict soil erosion [27], [33]. USLE is a commonly used empirical formula for predicting long-term (i.e., annual/monthly) gross erosion used by soil conservationists [34]. The USLE method is a reasonably straightforward approach and a universally accepted method to assess and monitor soil loss. Additionally, the USLE model integrated with Geographic Information System (GIS) can be used to calculate soil erosion at any point in the catchment area to determine the net erosive effects (Figure 3). The equation is presented as shown below.

A (tons/ha/year) = R * K* LS * C * P where:
A = Annual soil loss
R = Rainfall and runoff erosivity factor
K = Soil-erodibility factor
L = Length of slope factor
S = Degree of slope factor
C = Cropping-management factor
P = Conservation practice factor

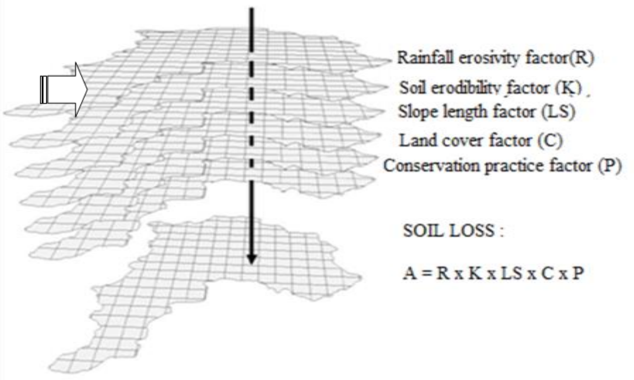


Figure 3. The layering of the USLE factor used in the modelling

B. Rainfall-Runoff Erosive Factor (R)

Rainfall data were obtained from the Bayan Lepas weather station operated and overseen by the Malaysian Meteorological Services Department, Malaysia. The monthly average rainfall data for 38 years (1974–2012) was used to calculate the R factor. The annual aerial precipitation, P (mm) was calculated using the Thiessen polygon average method [35]. The average or mean total rainfall for all stations in the catchment area was calculated using the following formula:

$$P = \frac{p1}{TA} \times rainfall\,1 + \frac{p2}{TA} \times rainfall\,2 + \frac{p3}{TA} \times rainfall\,3 \ldots \quad (1)$$

where: P1 = Area of the polygon, TA = Total Area.

Wischmeier and Smith [27] proposed the maximum intensity (I_{30}) value of 75 mm/h for tropical regions, and as many studies have shown a decrease in the size of raindrop erosive effects that occur when the intensity exceeds the threshold value. For the Penang station, the I_{30} was 100 mm that occurs once in five years. The various methods that can be employed to determine the rain index are based on Equations 2, 3, and 4 as given by [18], [36], [37]:

1) R = 9.28* P - 8838 (metric) (2)

2) R = 0.276*P*I_{30} (metric) (3)

3) R = 0.5*P* 1.75 (metric) (4)

where P = average annual precipitation (mm); I_{30} = Rain intensity for 30 min.

C. Soil Erodibility (K) Factor

Soil erodibility can be described as soil resistance against the process of disassembly and the transport of soil; it is an important index used to measure the tendency of soils to water erosion. It is also an important parameter in predicting soil erosion [38]. Soil (K) Factor shows the soil's effect on the nature and the nature and characteristics of the soil profile, such as soil texture, stability, aggregate stability, shear stress, infiltration capacity, and organic and chemical content in soil loss. The index of soil erodibility is based on the properties of soils as determined in the laboratory or in the field and the reaction of soil against rain [27], [39], [40], [41], [42]. Equation 5 [40] is used to estimate the (K) Factor for a series of soils and is recommended for the calculation of the (K) Factor as outlined in the guidelines issued by the Drainage and Irrigation Department, Malaysia [43]. The soil series in the study catchment areas of this study are shown in Table 2.

Table 2.
(K) factor for the different soil series in the study area [43]

Soil series	K value
Beriah clay	0.051
Chengai	0.057
Holyrood-Lunas	0.035
Keranji	0.051
Redua-Rusila	0.02
Renggam-Bukit Temiang	0.029
Renggam-Jerangau	0.038
Sedu-Parit Botak-Linau	0.045
Selangor-Kangkung	0.053
Sogomana-Setiawan-Manik	0.045
Steeplands	0.066
Urban	0.066
Telemung-Akob-Local Soil	0.051

The equation for the (K) Factor is given as follows:

$$K = [1.0x10 - 4(12 - OM)M^{1.14} + 4.5(s-3) + 8.0(p-2)]/100 \quad (5)$$

where:
K = Soil erodibility factor (ton/ha), (ha.hr/MJ.mm);
M = (% silt +% very fine sand) x (100 – % clay);
OM = % of organic matter;
S = Soil structure code; and
P = Permeability code.

D. Slope Length and Steepness Factor (LS)

Slope length factor is a combination of slope length (L) and slope steepness (S), which affect topography or soil erosion. The LS factor determines the length of the slope from the starting point of the surface runoff to the point where the slope is reduced, which will cause deposition, or the point where runoff enters into drainage [44]. Although the effect of slope sheerness with respect to erosion is reflected by the inclination of the slope in making the accumulated water travel much faster, making the accumulated water travel faster when the length (L) are longer. That is, the steeper the inclination (S factor), the faster the water will flow.

The development of a triangular irregular network (TIN) (30 m x 30 m resolution), using Environment System Research Institute (ESRI) ArcGIS software, and these topographic factors (L and S factor values) was derived from TIN and combined to a single LS factor. The LS factor was calculated based on equations 6 and 7 [27].

$$S = 0.065 + 0.045 + 0.0065S^2 \quad (6)$$

$$LS = (0.065 + 0.045S + 0.0065S^2Sx \sqrt{L}/22.13x \quad (7)$$

where
L = Slope length in meter;
S = slope angle in %
m = 0.2 if S < 1;
m = 0.3 if 1 ≤ S < 3;
m = 0.4 if 3 ≤ S < 5;
m = 0.5 if 5 ≤ S < 12; and
m = 0.6 if S ≥ 12%.

The calculations for the LS factor uses a map calculator using raster analysis based on Equation 8:

Pow(FlowAcc) x 30/22.1,0.6) x Pow(Sin[Slope]) x 0.01745/0.09,1.3) (8)

where:
30 = resolution,
0.6 = factor m,
0.09 = 9% or 5.16 slope gradient according to the standard plot (USLE).

E. Land Cover and Management Factor (C)

The ratio for soil loss is represented by the amount of vegetation cover as given by factor (C) to bare soil [38]. Reducing erosion depends not only on the efficacy of the vegetation cover but also on the persistence and height of the vegetation canopy related to both root growth and ground cover.

The vegetation cover plays an important role in preventing erosion by capturing rain before it hits the ground and dispersing its energy, thereby reducing the erosive effects caused by the rain [45]. In this study, the values representing factor (C) for the area under study, and for each basin, were determined by the Department of Agriculture (DOA), Malaysia [32] based on the proportion of land use as shown in Table 3.

Table 3.
The C value for each land use in the study area

Land use	C factor
Built-up area	0.15
Forest	0.003
Orchard	0.35
Rubber	0.25
Coconut/oil palm	0.2
Paddy	0.45
Scrub/others	0.03
Quarry	1
Water body	0.1

F. Conversation Practice Factor (P)

The conversion practice factor (P) depends on the conservation measure applied to the study area. In Malaysia, the most common conservation practice is contour terracing, which is practised on rubber and oil palm plantations. In this study, the P value was given as 1, which assumes no conservation practices were adopted.

G. Landscape Metrics Analysis

In this study, land use change analysis was conducted between 1974 and 2012 for the 19 river basins as described earlier, and land use maps were obtained from the DOA, Malaysia [32]. The land use map, in JPEG format, was registered in rectified skew orthomorphic (RSO) and in a digitised format. The land use classifications used in this study were based on the five categories developed by the DOA, namely forest, agriculture, built-up area, mining and others. Table 4 displays the land use categories and descriptions employed in this study. A set of landscape metrics was additionally employed for evaluating the landscape spatial pattern. Arc GIS 10.1 was used to identify changes using patch analysis. Using vector data, Statistical metric analysis was performed. Landscape metrics analysis or pattern analysis was then used to compare the changes in patterns between 1974 and 2012. FRAGSTATS is a computer software program designed to compute a wide variety of landscape metrics for categorical map patterns [31]. Table 5 displays a description of the landscape metrics employed in this study.

Table 4.
Classification of land use in this study [32]

Land use	Classification
Forest	Forest
Built-up area	Urban area & housing
Agriculture	Rubber, orchards, coconut, oil palm
Mining	Mining area, quarry
Others	Dam, schrub, grassland

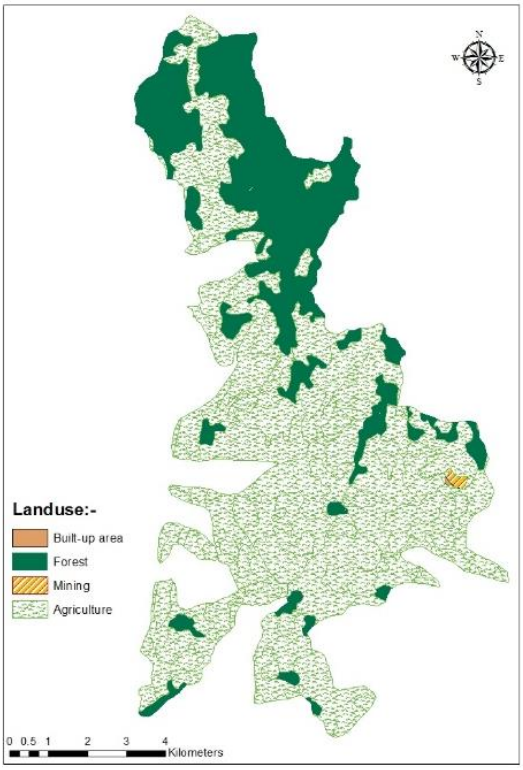
Table 5.
FRAGSTAT metrics [31]

Index	Formula	Description
NumP (Number of Patches)	$\sum_{i=1}^{n} Pi$	*Pi* refers to the number of patches for one class of land use.
ED (Edge Density)	$\frac{TE}{TLA}$	*TE* refers to the total perimeter of land use of the same class. TLA refers to the total area of land use of the same class. *Edge density* is a measurement of the multiple forms of patches involved. The higher the ED, the higher the degree of diversity and complexity.
SHDI (Shannon Diversity Index)	$\sum_{i=1}^{m} (Pi * \ln Pi$ m = the number of patches that are involved Pi = area by class	The SHDI value is increased if the number of patches also increases and if the wide distribution of borders between classes has increased over time. The value of this statistic is beneficial for the spatial study, especially for the landscaping basin which aims to evaluate the process of change resulting from development.

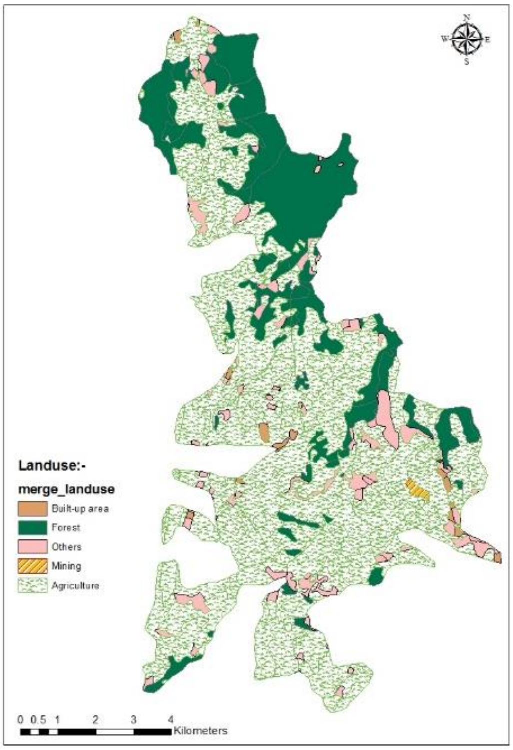
IV. Results and Discussion

A. Changing in Landscape 1974-2012

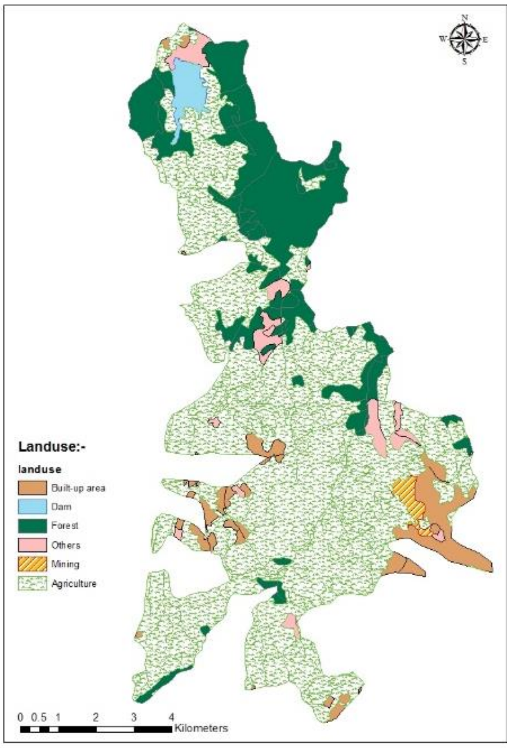
The average amount of sediment yield for all 19 catchments between 1974 and 1984 was estimated at 163.72 ton/km^2/year and 195.28 ton/km^2/year (19.3 per cent), respectively. In 2004, the amount of sediment increased slightly (0.5 per cent) averaging 196.18 ton/km^2/year, with a more substantial increase observed in 2012 (10.8 per cent) to 217.43 ton/km^2/year. The USLE estimated the soil loss at 110.18 ton/km^2/year and 116.89 ton/km^2/year between 1974 and 1984 respectively. In 2004, it slightly increased to 117.87 ton/km^2/year compared to 122.44 ton/km^2/year recorded in 2012. Figure 4 shows the change in land use of the study area over the past 38 years.



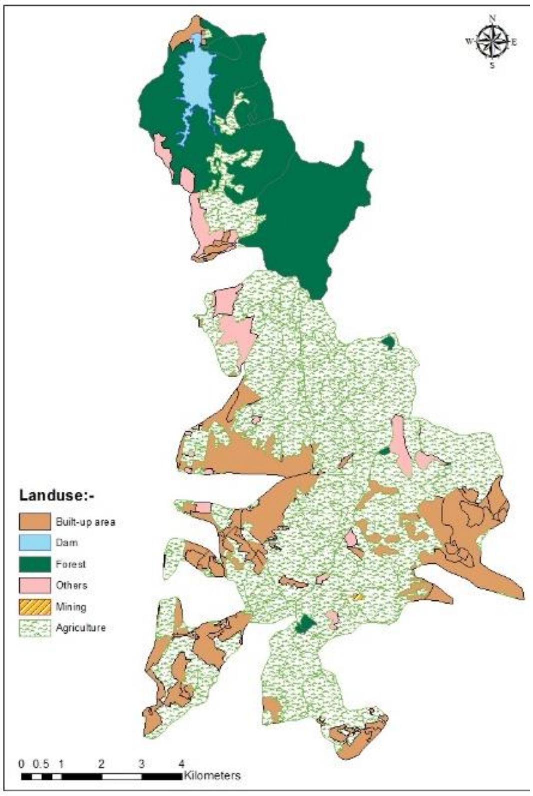
a) Land use (1974)



b) Land use (1984)



c) Land use (2004)



d) Land use (2012)

Figure 4. The changing landscape between 1974 and 2012 in the study area

In 1974, agriculture land use was dominant during this time based on the land use map. Here, the percentage of agriculture land use was 71.37%, with the remaining 28.4% attributed to forestry. While the built-up area only covered less than 1% of the total land area. In 1984, the percentage of agriculture land use was 68.06%, and the percentage of forest decreased to 24% with mining and the built-up area just beginning to develop. After 20 years, the land use pattern within the study area began to alter. Even though in 2004 land use was still dominated by agriculture the percentage of land use changed, increasing to 72.86% while forest land use reduced to 17.8%.

Similarly, the percentage of land use in the built-up area increased from 1% to 5.93%. Likewise, given the development and progress in the state of Penang, land use patterns also started to increase in 2012 with the percentage in the built-up area increasing to 18.87%, while agricultural land use decreased to 63.12%. Forest land use also decreased to 12% at this time including other land use activities. In the Barat Daya district region, the main activities were attributed to agriculture given the variety of land use and income associated with paddy, oil palm and orchards.

B. Soil Loss and the Shannon Index (SHDI) Relation

In 1974, soil loss based on the USLE model was estimated at 110.18 ton/km^2/year and 116.89 ton/km^2/year in 1984 respectively. However, in 2004, this slightly increased to 117.87 ton/km^2/year compared to 122.44 ton/km^2/year in 2012. Based on the analysis of the Shannon Diversity Index (SHDI), the value increased between 1974 and 2012 as shown by the changing trends in Figure 5. Therefore, this illustrates that the higher the SHDI value, the higher the composition of land use. Indeed, this is because the growing number of patches illustrates the land use pattern and it also refers to the diversity of land use activities within a river basin. For the river basin area of this study, in 1974, the SHDI was 0.61 and slightly increased in 1984 to 0.84. In 2004, the SHDI value was 0.94, increasing to 1.17 in 2012. The results from the SHDI analysis show that there is a significant relationship between land use changes and soil erosion, with $R^2 = 0.97$.

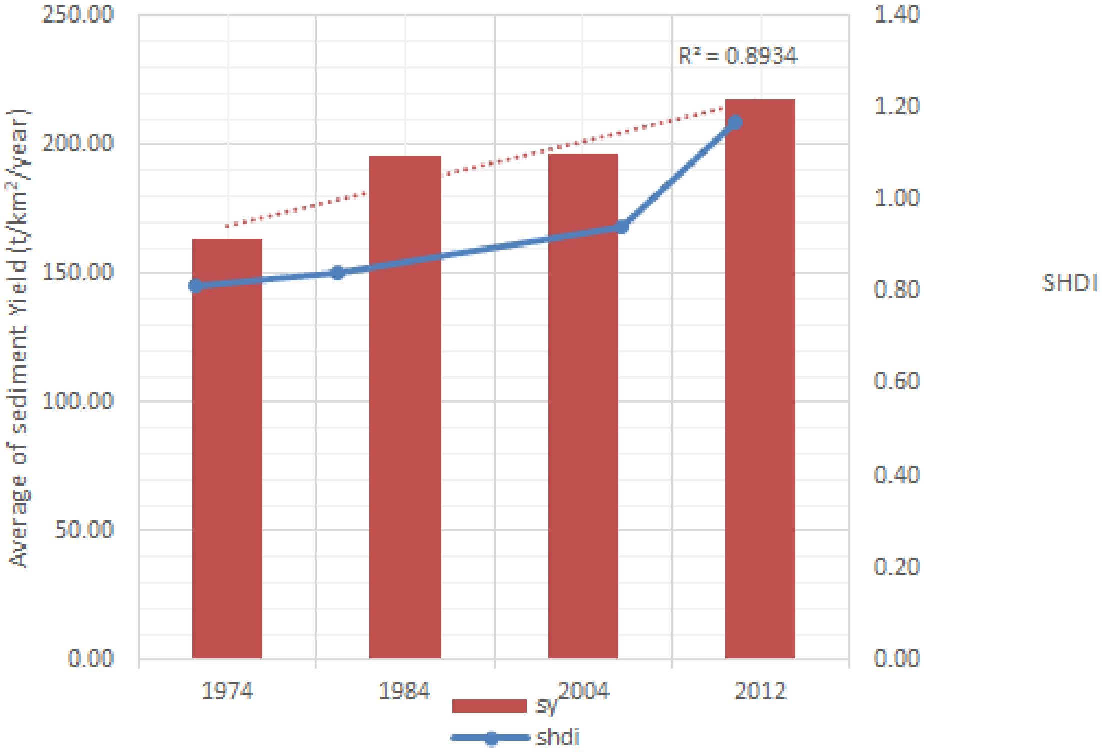


Figure 5. The relationship between the SHDI and past sediment yield

C. Metrics Analysis

The Number of Patches (*NumP)* in this study is represented as the total number of patches, while the Mean Patch Size (MPs) is represented as the average patch size, which includes analysis of Patch Density and Size Metrics. Accordingly, land use changes will depend on the number of patches where the higher the value, the higher the changes observed in a land use category. Therefore, based on the analysis of the study area (Table 6), the highest number of patches were from agriculture land use, with a total of 251 patches. The built-up area shows the value increasing from 1 patch in 1974 to 87 patches in 2012. Forest use is also seen to decrease from 60 patches to 9 patches, suggesting that human activities had minimal impact. Regarding mean patch size, the mean area of the built-up area and forest increased while agriculture land use in 1974 decreased from 48.82 to 22.46 in 2012. According to the mean patch size of agriculture land use, the value area of patches for mining peaked in 2004, before falling to its lowest in 2012.

Table 6.
Statistic of metric analysis, "Patch Analyst" – NumP & MPs

	Number patches (NumP)				**Mean patch size (MPs)**			
Land use	1974	1984	2004	2012	1974	1984	2004	2012
Built-up area	1.00	18.00	31.00	87.00	2.15	3.58	14.91	16.76
Forest	60.00	63.00	53.00	9.00	36.91	30.02	30.08	177.72
Agriculture	114.00	251.00	199.00	191.00	48.82	21.17	26.99	22.46
Mining	1.00	2.00	1.00	3.00	15.17	10.82	64.74	1.64

Others	x	98.00	16.00	24.00	x	5.29	11.71	13.57

Edge Density (ED) and Total Edge (TE) are analytical edge metrics for determining the diversity of the boundaries between land use categories. For instance, if the ED is high, then the degree of diversification of land use and its distribution will be uneven. This means that the higher the value of ED, the higher the degree of land use diversification in a river basin. Whereas, if ED is reduced, it illustrates limited or lack of land use in the area. Similarly, if the TE is high, then the composition of land use is also high and uneven. According to Table 7, the density of the ED value for the built-up area between 1974 and 2012 shows an increasing value, whereas the ED value for forest land use shows a decreasing value for the same period. Moreover, in 1984, the density of agriculture increased slightly, but decreased between 2004 and 2012. Overall landscape fragmentation was shown to be the highest in 1984.

Table 7.
Statistic of metric analysis, "Patch Analyst"-ED

Land use	**Edge density (ED)**			
	1974	**1984**	**2004**	**2012**
Built-up area	0.13	1.82	6.81	23.56
Forest	22.43	20.82	16.95	9.23
Agriculture	57.87	85.16	70.66	64.51
Mining	0.23	0.45	0.77	0.20
Others	x	12.93	3.17	5.21

V. Conclusion

Overall, land use changes and the expansion between 1974 and 2012 in the Barat Daya district region of Pulau Pinang did not develop as quickly as in the Timur-Laut district region. However, it is anticipated that, over the next few years, development pressures will increase concerning land use in this region, especially regarding the increasing demand for residential development. The increasing soil erosion loss is highly related to the Shannon Diversity Index (SHDI) of land use composition in the river basins. Therefore, the findings from this study provided a significant contribution to the currently available data and could act as a reference source for future ungauged catchment research studies.

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