Research in Marine Sciences
Volume 9-Issue 2- 2024
Pages 423-441

Erosion Potential of Small Island: Case of Pulau Payar, Kedah (Malaysia)

Wan Ruslan Ismail[1,*], and Sumayyah Aimi Mohd Najib[2,*]

[1]KGA Engineering Sdn. Bhd., 576-B, 2nd. Floor, Jalan Sultan Azlan Shah, 11900 Sungai Nibong, Pulau Pinang, Malaysia.

[2]Department Geography and Environment, Faculty of Human Sciences, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia.

Received: 2024-05-21 *Accepted: 2024-06-24*

Abstract

Soil erosion refers to the soil removing process, from the terrain surfaces. It is the results of the combined effects of energy from rainfall and runoff, topography, soil properties and land uses. The process is greatly enhanced by human activities such as extensive agriculture, urbanization construction, and inappropriate farm and crop management practices. Soil loss from continent entering marine waters could affect marine fisheries. Erosion or soil loss on Pulau Payar was estimated using Revised Universal Soil Loss Equation (RUSLE) based on rainfall and site investigation of the soil and slope characteristics. Soil loss from a fully covered forest dominated by natural erosion process which was estimated about 3.52 ton/ha/year, which is considered as non-significant erosion to low erosion. While, for the worst case scenario of a fully disturbed area, land clearing and bare soils would give an estimates of 9,813 ton/ha/year. Medium disturbance, for example, will create a medium erosion of 801 ton/ha/year. Based on these scenario of land uses' activities, Pulau Payar should be kept at a minimal disturbance in order to minimize the impact of siltation on the surrounding marine environment.

Keywords: Soil erosion; Pulau Payar Marine Park; RUSLE; Small island; Kedah.

**Corresponding Author's Email: wruslan3@gmail.com; sumayyah@fsk.upi.edu.my*

1. Introduction

Soil erosion is one of the most significant forms of land degradation (soil truncation, loss of fertility, slope instability), greatly influenced by land use and management (Bini *et al*. 2006; Xu *et al*. 2011). Soil erosion is considered to be the results of the interplay and the combined effect of mainly three factors i.e.; a) energy of rainfall, or erosivity, b) resistance offered by the soil or erodibility, and c) protection offered by the vegetative cover (Morgan, 1979; Wischmeier and Smith, 1978). Hadley *et al*. (1985) stated that water erosion occurs if the combined power of rainfall and overland flow exceeds the resistance of the soil to detachment.

Erosion can occur naturally or be intensified primarily due to human activity, such as land clearance and forest disturbance (Bodo *et al*., 2021). The erosional patterns in the humid tropics are significantly influenced by the level of human disturbance, as stated by Juarez in 1990. Erosion and sedimentation are natural processes. These processes are caused by wind and water and happen every day on every terrain. On the other hand, natural erosion typically only becomes apparent over geologic time scales. Construction, farming, and logging are examples of activities that disturb the soil surface and significantly increase the amount of sediment lost from the site as a result of erosion (Price and Karesh, 2000).

Under humid tropical region, less water erosion when the natural protection offered by lush vegetation remains intact. Nevertheless, as a result of the intense rainfall, the erosion potential in this location is great and severe, and it will become evident when the vegetation is disturbed (El-Swaify and Dangler, 1982). Rainstorms in the humid tropics exhibit a significant level of intensity, often reaching 150-200 mm/hr (Lal, 1976). Due to human disturbances and the nature of the erosive power of humid tropical rainfall, Asia is regarded to have the highest rate of erosion with an overall annual sediment loss of about 166 t/km^2 as compared to 47,43 and 93 t/km^2 respectively for Africa, Europe and South America (Erman and Mahoney, 1983).

1.1. Siltation in rivers and marine environment

There is no question that the siltation of the coastal marine environment, watershed deterioration, and silty rivers are related. Nonetheless, this receives comparatively little scholarly attention. Scientists have only looked at a few instances of siltation harm to tropical coastal marine species, despite the substantial economic importance of coastal marine life (Hodgson and Dixon, 2018). Fish and invertebrate biomass and diversity will eventually decline as a result of siltation of the marine environment.

Rivers, coastal ecosystems, and marine environments are affected by erosion from land masses (Syvitsky *et al*., 2022; Morrison *et al*., 2009). Suspended sediment in water column influence the quantity of light that travels through water over a specific distance known as turbidity or clarity of water. The size of suspended particles influences the color and clarity of water. Both non-point sources such as storm-water runoff, stream erosion, agricultural runoff, urban runoff, and soil leaching; and point sources such as building projects and industrial or sewage treatment plant discharges, contribute suspended solids/sediments. Soil organic, for instance bacteria, algae, plankton, and zooplankton; and inorganic particles, such as clay, silt, and sand, are examples of suspended materials (Kennicutt, 2017). Understanding the mechanisms affecting these marine resources' very existence and survival is a step toward improving scientific knowledge of marine biodiversity for the sake of conservation and sustainable management in coastal and marine zones with turbid waters.

Total suspended solids (TSS) and chlorophyll-a (Chl-a) are the two main water quality metrics that have a major impact on the coral ecosystem both directly and indirectly (Maslukah *et al*., 2023). The TSSs are defined as that material indefinitely suspended in solution but retained on a sieve size of two micrometers (2 mm). Settleable solids refer to material that does not remain suspended or dissolved when water is motionless. Settleable solids may include large particulate matter or insoluble particles. The total inorganic and organic substances dissolved in water are called total dissolved solids (TDS) (Kennicutt, 2017). The distribution of total suspended solids (TSS) in surface waters is a common source of information for scientists and environmentalists on the health and state of a body of water (Anisah Lee and Yasin, 2000) and TSS provides a direct measurement of observable physical pollutants throughout time and space (Wirabumi *et al*., 2021).

The objective of this study is to estimate the probable impact of land use changes of the Pulau Payar on the potential soil erosion state using USLE model.

2. Material and Methods

2.1. Study Site: Pulau Payar Marine Park

Pulau Payar Marine Park has placed off the coast of Kedah, between Pulau Langkawi and Pulau Pinang (Figure 1). Pulau Payar is the largest (31.2 ha) of three islands in a group called the Payar-Segantang Groups of Island which consists of Pulau Payar, Pulau Kaca and Pulau Lembu (Aikanathan and Wong, 1994). It has located on the north west coast of Peninsular Malaysia and lies at latitude of 6^{o} 03’N-6^{o} 05’N; longitude 100^{o} 02’E – 100^{o} 04’E, approximately 35km off the coast of Kedah (De Silva and Ridzwan, 1982).

The average length of Pulau Payar is approximately 1.75km and width of 0.5km (Figure 2) and rise to some 80-90m above sea level at its highest point. The topography of the island is as such that it rises up a steep gradient from the shoreline. The entire island is covered with dense vegetation while it has been thinned out due to logging activities (De Silva and Ridzwan, 1982). Pulau Payar itself is a small island with very few low-lying areas and beaches, as the land rises at a steep gradient from the shore. Coupled with the lack of freshwater sources on the island, this seems to have deterred any accommodation development on the island (*https://www.fao.org/4/ X5626E/x5626e05.htm*).

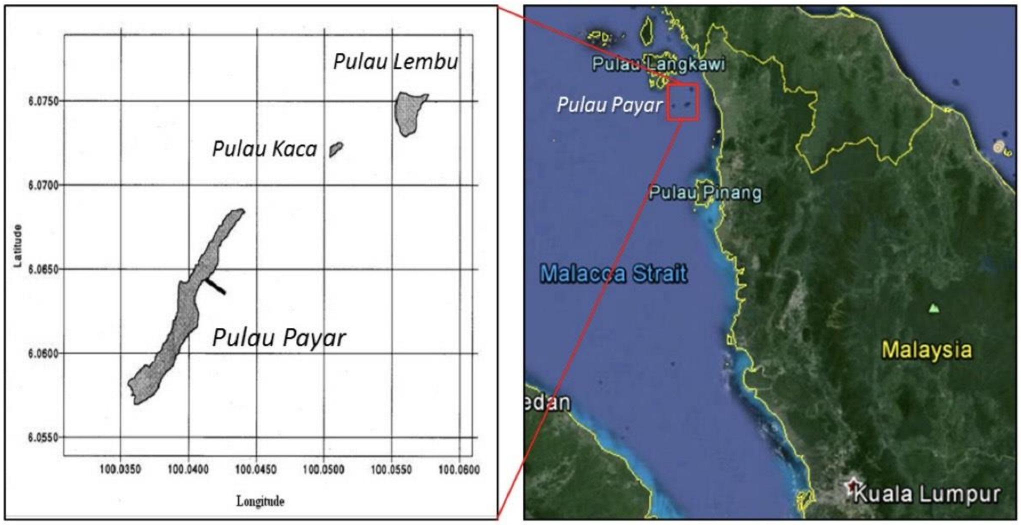

Figure 1. Pulau Payar Marine Park located off the coast of Kedah, between Langkawi and Pulau Pinang, consisting three islands (Source: Anisah Lee *et al*., 2016).

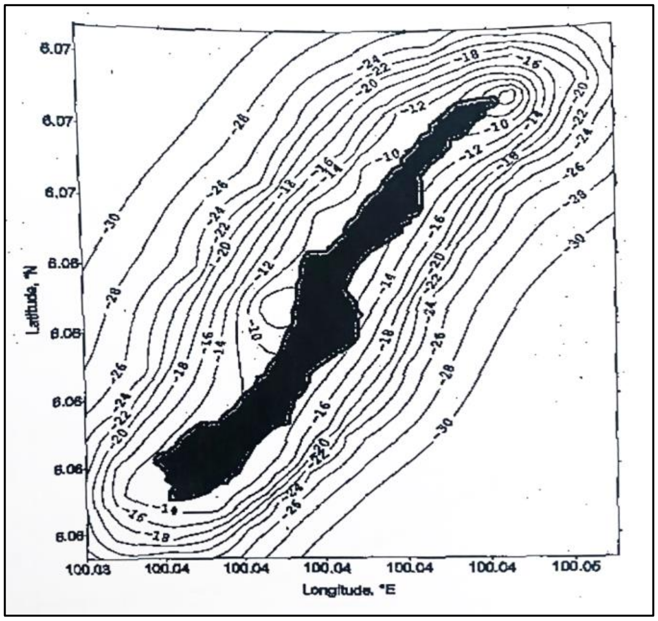

Figure 2. The topography of the Pulau Payar

2.1.1 Rainfall

Rainfall distribution for Pulau Payar could be regarded as similar in its distribution with Langkawi Island. Rainfall in dry period was observed in the January and February; each months having less than 40mm rainfall. January is the driest month with a mean rainfall of 18.2mm (Figure 3). The wet season started in southwest monsoon, where in May rain started be more than 200 mm per month. The rainfall peaked in October with the highest average 377.1 mm. It is noticeable that only one peak of rain was observed as compared to a two peaked distribution in other Malaysian sites (Ismail, 1997). The average 24-hour temperature ranges from 26.8 °C in October to 28.3 °C in March. The average annual rainfall is plotted in Figure 4. The mean long term rainfall at Langkawi is 1905.6 mm (1973-2015).

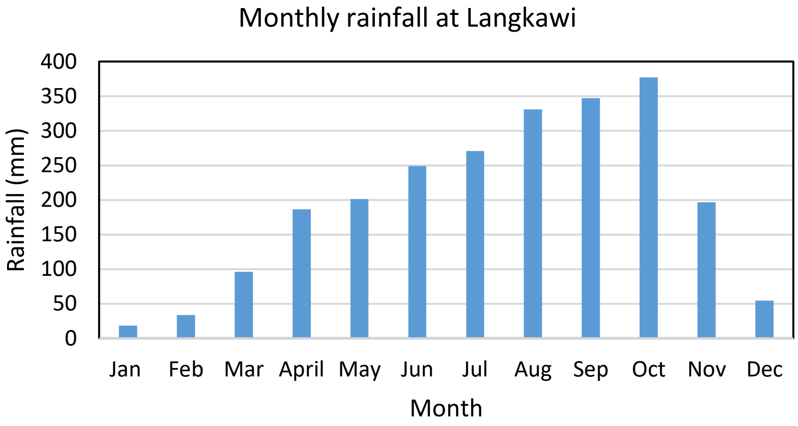

Figure 3. Monthly rainfall at Langkawi Island

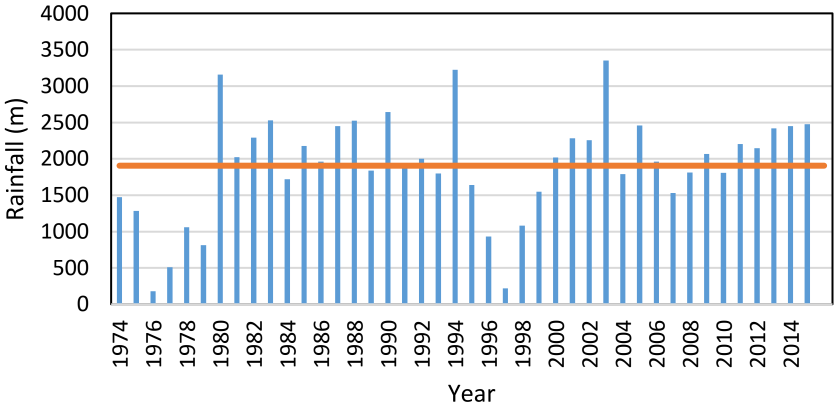

Figure 4. Annual Rainfall at Padang Matsirat, Langkawi from 1973-2015. Mean annual rainfall is 1906.5mm (red line).

2.2. Model description

One of the most common methods of estimating soil erosion is the Universal soil loss equation (USLE). USLE may be written as:

E = f (C, K, T, L)

where, E is the average annual erosion expressed in ton/ha/yr, C is the climatic factor (rainfall erosivity), K is the soil factor (erodibility), T is the topography factor comprised of slope gradient and slope length,and L is the land utilization factor that expresses the plant cover in relation to bare soil (Seckler, 2015).

The climate C factor is represented by rainfall erosivity R; soil factor is represented by the erodibility K,topography T could be represented by slope length (L) and slope gradient (S); and land utilization L could be represented by the cropping factor C, and management practice, P. USLE is therefore one of the methods used to estimate soil loss from land use category. The USLE method is based on the six factors above (Ştefãnescu *et al*., 2011).

So now, erosion is the product of all six parameters above,

$$E = R \times K \times (LS) \times C \times P \tag{1}$$

where;

E is soil loss in tons/ha/yr,

R is rainfall and runoff erosivity factor in MJ.mm /(ha.hr), K is soil erodibility in t.h/(MJ.mm),

LS is slope length and slope steepness, C is cover management, and P is support practice.

C is cover or crop management, and P is support practice factor.

The Universal Soil Loss Equation (USLE) predicts the long-term average annual rate of erosion on a hillslope based on rainfall pattern, soil type, topography, crop system and management practices. The USLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil loss that might occur from gully, wind, or tillage erosion (McKague, 2023).

3. Results

3.1. Rainfall erosivity factor (R)

The rainfall and runoff erosivity index (R) factor represents the erosivity occurring from rainfall and runoff at a particular location (Renard *et al*., 2011). Rainfall is one of the main drivers of soil erosion by water (Meusburger *et al*., 2012). In the USLE, the R factor quantitatively explains the impact of rainfall on the soil surface. R is the average of the annual summation of the erosion indices (EI) at maximum 30-minute rainfall intensity (Wischmeier and Smith, 1978).

In the original form of Revised Universal Soil Loss Equation (RUSLE), R factor is computed as the average annual sum of the erosivity of the individual storms, which is calculated as the product of total storm energy and maximum 30-min intensity (Wischmeier and Smith, 1958). Recent guidelines on erosion and sedimentation control in Malaysia (DID, 2010) have produced map of rainfall erosivity areas in Kedah, Perlis and Pulau Pinang (Figure 5).

3.1.1 Determination of Rainfall Erosivity, R, Factor

Rainfall is one of the main drivers of soil erosion by water (Meusburger *et al*., 2012). In the USLE, the R factor quantitatively represents the impact of rainfall on the soil surface. R is the average of the annual summation of the erosion indices (EI) at maximum 30-minute rainfall intensity (Wischmeier and Smith, 1978). Rainfall erosivity (R) map has been produced by the erosion study guidelines as shown in Figure 5. The R value for Langkawi and Pulau Payar fall between 10,000 -11,000 (MJ.mm)/ ha.hr (DID, 2010).

3.2. Rainfall erodibility factor (K)

Soil erodibility factor (K) is related to the combined effect of rainfall, runoff, and infiltration on soil loss. This represents the effect of soil properties and soil profile characteristic on soil loss (Renard *et al*., 2011). Soil type of the proposed site based on sample investigation following the slope transect above. The soil content was then used to calculate K factor.

Soil samples from the three transects were analysed using the soil hydrometer testing sedimentation method (ASTM D422-63, 2007). The method is based on Stoke’s Law, that calculates the particle' sizes from speed at which they settled out of suspension from a liquid, that gave the percentages of clay, silt and sand. The percentage of coarse sand and fine sand was estimated at 44% each, 7.3% silt and 4.7% for clay. These values are used for determining the structure of soil "s", in diagram Figure 6. The structure, "s" for the site is classified into a Class 3 for silty loam soil.

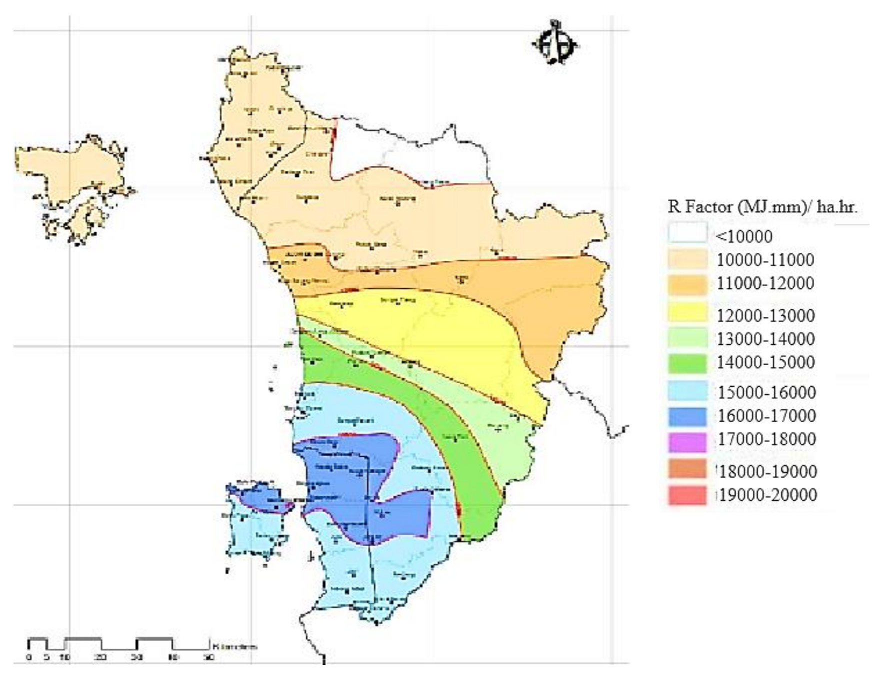

Figure 5. Rainfall erosivity map for Kedah, Perlis and Pulau Pinang. The R value for Pulau Langkawi area is 10000 -11000 (MJ.mm)/ ha.hr (DID, 2010)**.**

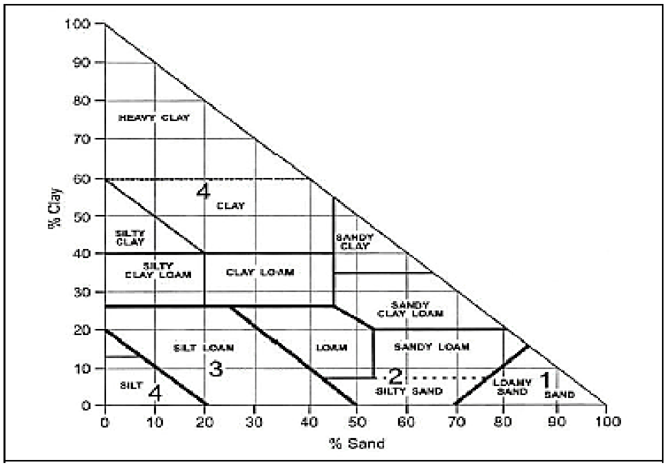

Figure 6. Diagram of soil structure, "s" (DID, 2010).

The calculation for K factor was done using the following formula

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

OM = between 3-6% from the literature, average value used is 4% (Azlan *et al.*, 2012).

M is calculated from the equation (%sand + % silt) x (100-%clay)

$M = (44 +7.3) x (100-4.7) = 51.3 x 95.3 = 4888.9$

For s=3, p=4

$K = [(0.0001x\ 8.0x\ 4888.9^{1.14}) + (4 x (3-3) + 8 (4-2)]/100 = 0.28$

$K = [(0.0001x\ 8.0x\ 16058.34) + (0 + 8(4-2)]/100$

$K = (12.847 + 16) /100 = 0.288$ (ton/ac.)*(100ft.ton.in/ac.hr)

For s=3, p=6

$K = [(0.0001x\ 8.0\ x4888.9^{1.14}) + (4 x (3-3) + 8 (6-2)]/100 = 0.32$

$K = [(0.0001x\ 8.0x\ 16058.34) + (0 + 8(6-2)]/100$

$K = [(12.043) + (32)]/100 = 0.44$ (ton/ac.)*(100ft.ton.in/ac.hr)

Minimum K= 0.28 (ton/ac.)*(100ft.ton.in/ac.hr)

= 0.288 x (1/7.59)

= 0. 038 (ton/ha)(ha.hr/MJ.mm)

Maximum K= 0.448 (ton/ac.)*(100ft.ton.in/ac.hr)

Max K = 0.448/7.59

= 0.059 (ton/ac.)*(100ft.ton.in/ac.hr)

Therefore, K values obtained is 0.038 (ton/ha)(ha.hr/MJ.mm) when permeability = 4 (medium) and 0.059 (ton/ha)(ha.hr/MJ.mm) when p = 6 (fast)

3.3. Length of slope

LS is the product of slope length and slope steepness.

3.3.1 Determining LS factor

The LS factor can be calculated using methodology suggested in Chapter 15, MSMA (DID, 2012), which applied the equation defined by Wischmeier (1975);

$$LS = (\lambda / \Psi)^{m} \times (0.065 + 0.046s + 0.0065s^2) \qquad (3)$$

where,

λ = sheet flow path length (m or feet)

Ψ = 22.13 for SI Units and 72.6 for English Units (BU)

s = average slope gradient (%)

$m = 0.2$ for $s < 1$,

$= 0.3$ for $1 \leq s < 3$,

$= 0.4$ for $3 \leq s < 5$,

$= 0.5$ for $5 \leq s < 12$ and

$= 0.6$ for $s \geq 12\%$

A survey of 3 slope profiles was carried out to obtain the slope of the terrain. The average steepness (S) from three slope transects was 46.9% while the average slope length was 62.7m. The slope of the area is shown by the transects in Figures 7.

The slopes of the area are more than 12% so the parameter ‘m’ to be used in the calculation of LS value is 0.6.

Length of flow path, λ, ranged in 73m; 90 m, and 28 m, with an average of 62.7m.

Now, the average LS factor is calculated as follow:

Average LS factor = $[(62.7/22.13)^{0.6} \times (0.065 + 0.046 \times 46.9 + 0.0065 \times 46.9^2)] = 30.859$.

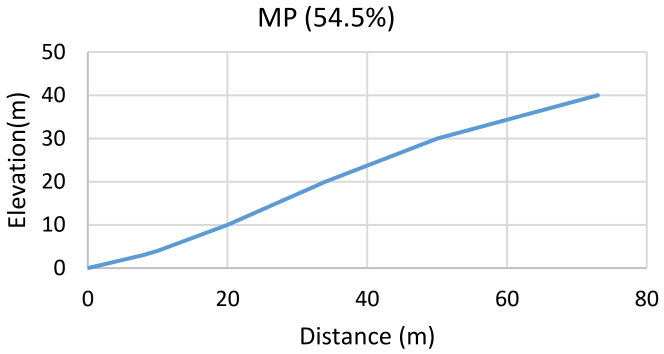

Figure 7a. Transect at Marine Park Centre slope was 54.5%.

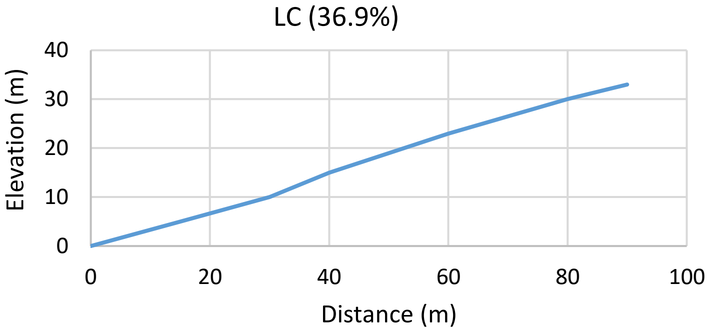

Figure 7b. Transect at Langkawi Coral (LC) slope was 36.9%.

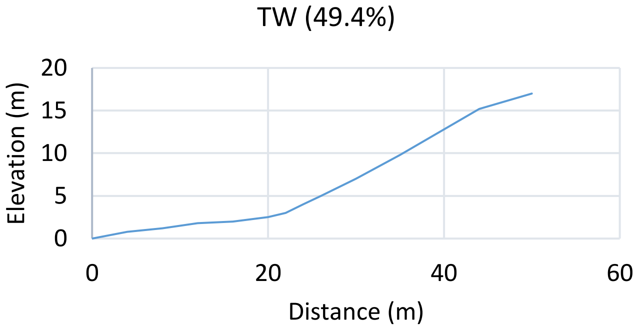

Figure 7c. Transect at Teluk Wangi Beach. The beach profile slope was 14.6% and the main hillslope behind the beach is 49.4%.

3.4. Crop and management (C) factor

The factor C is the cover management factor used to reflect the effect of cropping and management practices on erosion rates. The C is often used to compare the relative impacts of management options on conservation plans. It indicates the effect of the conservation plan to the average annual soil loss and distributed of soil loss potential during construction activities, crop rotations or other management schemes. The C values were applied to the land use map of 1997 (Figure 5). The value ranges from 0.003 in forest to 1.0 in a newly cleared land, other mining area and water (Table1).

Table 1. The adopted value of C factor for different land use

ID	Land use	C Value
1	Forest	0.003
2	Lalang	0.3
3	Newly cleared land	1.0
4	Scrub/Belukar	0.3
5	Unused land	0.45
6	Mining areas	1.0
7	Estate building and associated areas	0.35
8	Urban and associated areas	0.8

Source: Troeh *et al*., (1999)

3.5. Support Practice (P) factor

Factor P is the support practice element. The P reflects the impact of support practices on the average annual erosion rate. It indicates the fractional amount of erosion that occurs when any special practices are used compared with what would occur without them (Troeh *et al*., 1999). The P value in the study area ranging from 0.1 in the forest to 1.0 in the other mining areas, and urban and other associated areas (Table 2). The adopted value of P for different land use were adopted from Troeh *et al*., (1999) tabulated in Table 2.

Table 2. The adopted value of P for different land use

ID	Land use	P Value
1	Forest	0.1
2	Lalang	0.6
3	Newly cleared land	0.7
4	Scrub/Belukar	0.2
5	Unused land	0.45
6	Mining areas	1.0
7	Urban and associated areas	1.0

Sources: Troeh *et al*., (1999)

There were several possible scenarios of erosion rate estimated in this study and the results are tabulated in Table 3.

4. Discussions

The USLE calculates the total mass of sediments eroded from a specific area. It was originally set up to estimate sheet and rill erosion and it was designed for and empirically tested on the gently sloping, deep soiled, agricultural fields of the American Midwest and Eastern Seaboard (Calhoun and Fletcher III, 1999). In this study, the slope of Pulau Payar was between 35-45%. The results of the estimation are shown in Table 3.

Table 3. Erosion estimated using the USLE for Pulau Payar for three probable scenario of land use changes.

Phase		R MJ.mm/(ha.hr)	K	LS	C	P	Area Forested (ha)	Bare area (ha)	Annual erosion forested area (tons)	Annual erosion for bare area (tons)	Total Erosion (tons/yr)
1	Min	10000	0.037	30.86	0.003	0.1	31.2	0	109.76	0	109.76
Undisturbed	Max	11000	0.059	30.86	0.003	0.1	31.2	0	187.46	0	187.46
2	Min	10000	0.037	30.86	0.003	0.1	15.6	15.6	54.88	54.88	109.76
Medium disturbance of 50%	Max	11000	0.059	30.86	0.2	0.2	15.6	15.6	12,497.56	12,497.56	24,995.12
3	Min	10000	0.037	30.86	0.003	0.2	0	31.2	0	109.76	109.76
100% disturbed	Max	11000	0.059	30.86	0.7	0.7	0	31.2	0	306,190.2	306,190.2

Results of the estimation indicates that for fully covered forest with good soil conservation practice, the erosion rate was 109.76 tonnes (Table 3). This is equivalent to 3.52 ton/ha after dividing with the area of the island of 31.2 ha. This is close to the natural erosion rate and is considered none to slight erosion by FAO classification (Table 4). This erosion rate is considerable low to very slight and almost negligible associated with natural erosion under forested condition that would occur by slope wash and small disturbances by falling tree and burrowing animal. This erosion rate is also low based on categories of Langkawi erosion potential estimated by Ramli *et al*. (2004) as shown in Table 5.

Table 4. FAO Soil Erosion Classification

Erosion Class	Annual Soil Loss (t/ha)
None to slight	<10
Moderate	10-50
High	50-200
Very high	>200

Source: FAO (1965) in Suresh (2000)

Protection of the forest soil by the litter layer and the understorey lays a very important role in restricting further soil erosion loss. Both runoff and sediment yield fall exponentially as the percent vegetation cover increases (Francis and Thorne, 1990).

The maximum estimated erosion for category under forest, was 187.5 ton or 6.0 tons/ha which is under slight erosion in FAO category (Table 4). However, under Langkawi erosion category (Ramli *et al*., 2004), it falls under a moderate class (Table 5).

Under category 2, where there are 50% disturbance of the island, the minimum erosion was similar to the first category discussed earlier, however the maximum erosion was 24,995 tonnes or 801 tons/ha. This is considered very high according to both FAO and Ramli *et al*. (2004).

Table 5. Erosion potential categories for Langkawi Island (Ramli *et al*., 2004)

Erosion Class	Numeric Range (ton/ha/year)	Erosion Potential
1	0 –1	Very Low
2	1-5	Low
3	5-10	Moderate
4	10-20	High
5	20-50	Severe
6	50-100	Extreme
7	>100	Exceptional

Under category 3, when we expect all island is fully disturbed, or a worst case scenario, the maximum erosion rate was 306,190 tonnes (Table 3) or 9,813 tons/ha. This value is at very high and exceptional category according both to FAO (Table 3) and Langkawi erosion rate (Table 4). It is an increase of almost 1125 times from the second category to third category and 163,000 times compared to first (undisturbed). The worst case is when there is a total loss or removal of vegetation, or bare soil without any conservation practice, which yield the highest rate of erosion at 9,813 ton/ha/year. This extreme value could only happen when the land masses is totally bare where all vegetation is cleared by large land clearing activities that would leave the soil vulnerable to direct rainfall impact and high surface runoff (Douglas and Guyot, 2005).

The increase in erosion could increase the TSS concentration to a higher value than the TSS concentration of between 175-200 mg/l reported earlier (Anisah Lee *et al*., 2016; Figure 8). The Pulau Payar Marine Park was surrounded with waters with high levels of TSS (up to a maximum of 200 mg/L) during the satellite overpass on 9 December 2013. Figure 8 portrayed an overview of high TSS concentrations (depicted by the darker orange-red tones) along the immediate coastal strip of the peninsula. The range of TSS was >226 mg/L indicating very high values but an acceptable range because the coastal region lies within the rice bowl region of peninsular Malaysia. Erosion and runoffs of sediments as a result of continuous agricultural practices along the coast are highly probable (Anisah Lee *et al*., 2014).

Fluctuations of TSS levels are normal since the coastal and marine waters are very dynamic owing to the continuous tidal and current movement over the shallow zone of the continental shelf. A strip of lower TSS levels (<75 mg/l) running along the coastal region adjacent to the mainland seaward to approximately 15 km due to tidal mixing. Further out to the sea the range of TSS appeared to be higher. One possible explanation is the influx of water body during flooding tide carrying suspended materials from neighbouring south Thailand or Sumatera where land-use/land-cover change is rapid (Anisah Lee *et al*., 2016).

The Pulau Payar Marine Park was surrounded by waters with high levels of TSS (up to a maximum of 200 mg/L) during the satellite overpass on 9 December 2013. Considering the sensitivity of corals to environmental change particularly water quality, the duration of these reef organisms being exposed to the high levels of TSS may impact on its productivity, hence, the reef's overall health.

Generally, rate of soil erosion loss under forest are lower than in the open because rainfall interception by forest or tree canopy reduces impact on the forest floor and thus reduces the runoff forming on the forest floor. This is associated with high rate of infiltration cause by high aggregate soil and the opening of macropores in the soil by tree root growth (Mohammad and Adam, 2010; Li *et al*., 2019; Cheng *et al*., 2002).

All the above scenarios of land use changes cause increase in sedimentation and this could alter the physical properties of surrounding sea water such as turbidity, temperature and salinity that could lead to coral bleaching and in turn affect the marine fisheries (Zweifler *et al*., 2021; Otaño-Cruz *et al*., 2017).

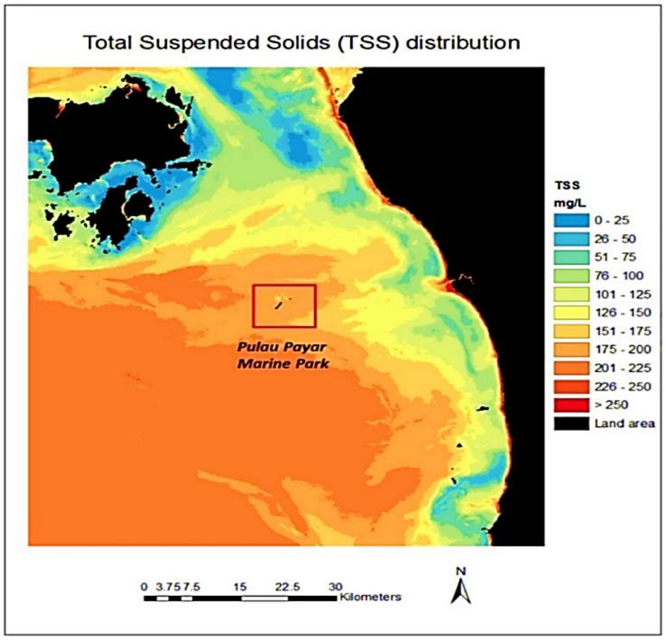

Figure 8. The TSS distribution on surface water in the northern Strait of Malacca. The TSS around Langkawi and Pulau Payar Marine Park was in the 175-200 mg/l zone. Source: Landsat 8 ETM+ on 9 Dec 2013 (Anisah Lee *et al*., 2016).

Table 6. Some erosional values from various island studies and from continents of the world.

Location/Condition	Methods	Area (ha)	Total rainfall (mm)	Elevation (m)	Erosion (ton/ha/yr)	Source
Marinduque, Philippines	RUSLE	92,624	2000	1200	Avg:107 Max: 10,338	Salvacione (2022)
Pulau Pinang, Malaysia	Gauging	28,500	2944	833	Min: 1.02 Max: 31.01	Ismail (1997; 2000)
Pulau Pinang, Malaysia	USLE	28,500	2944	833	75.7 (2005) 92.5 (2010)	Pradhan *et al* (2011)
Asia	Gauging		2000-3000		30	Pimentel *et al*., (1995)
South America	Gauging				40	Pimentel *et al*., (1995)
Undisturbed forest	Gauging				0.05	Pimentel *et al*., (1995)
Pulau Payar, Malaysia	$Qs = 0.323 A^{-0.28}$	31.2	2360	90	0.23	Khosla (1953)
Pulau Payar, Malaysia	USLE	31.2	2360	90	Min: 3.52 Max: 9,813	This study

Table 6 compares Pulau Payar's erosion to that of other islands and presents further findings about erosion from forested and disturbed areas. The estimates for the Pulau Payar study are low, at 3.52 t/ha for the undisturbed scenario, compared to 9,813 t/ha for the totally disturbed, cleared area. Even yet, the low case result is similar to other measurements, including 1.02 tons/ha for Sg. Air Terjun (Ismail, 2000) and 0.05 tons/ha for erosion of undisturbed forest (Pimentel *et al.*, 1995). Using the Khosla (1953) formula, we estimate the erosion for Pulau Payar at 0.23 t/ha/year (Table 6), which is less than previous estimates but nearly equal to Pimentel's estimates for undisturbed forest, which are 0.05 t/ha/year. In the worst statues, where all land was cleared, nearly similar results were obtained. The worst case scenario involving fully cleared land, produced almost comparable results to the maximum erosion of the Philippines by Salvacione (2022).

Conclusions

The combination of the steep topography and abundant rainfall on Pulau Payar allows for a significant level of natural erosion. The projected soil erosion of Pulau Payar, calculated using Langkawi's rainfall data, ranges from 3.52 tons/ha/year with minimal disturbance to a maximum of 9813 tons/ha/year in the most severe scenario. Therefore, any construction that encompasses extensive regions should be avoided, because it could cause increase in the TSS in the marine waters. To preserve the pristine condition of Pulau Payar for future generations and retain it as a viable tourist destination, it is important to prevent major clearing activities in order to reduce the influence of siltation on the surrounding marine environment, which could negatively damage the coral and fisheries. The status of Pulau Payar as a marine park should keep the island from "massive" future development and land clearing.

Acknowledgements

We would like to thanks Noor Hidayat Kamaruzaman and Khairul Rizal Abu Bakar for their assistance in the field; Salleh Bakar for laboratory analysis, and Zainuddin Othman for some useful discussion on USLE and lastly to the late Professor Ahyaudin Ali for inviting to make a contribution to the Payar Project. This paper is renewed version of a paper entitled "Estimating Possible Soil Loss on Pulau Payar Using Modified Soil Loss Equation", Proc. National Symposium on Pulau Payar Marine Park, Fisheries Research Institute, Batu Maung, Pulau Pinang ISBN 983-40863-5-0.

References

Aikanathan, S., and Wong, E. 1994. Marine park island management conceptual plan for Peninsukar Malaysia. Report produced under WWF Project MYS 256/93. Dept. of Fisheries Malaysia and the World Wildlife Fund for Nature (WWF) Malaysia, Kala Lumpur.

Anisah Lee, A., and Yasin, Z. 2000. Seasonal distribution of surface water total suspended solids and associated parameters of Tanjung Rhu, Pulau Langkawi, Malaysia. Malayan Nature Journal, 54(2): 109–125.

Anisah Lee, A., Lim, H.S., Yasin, Z., and Razali, N.M. 2014. Classification of chlorophyll-a concentrations in surface waters of Songsong Group of Islands using an optically-derived remote sensing model. ASM Science Journal, 8(1): 44–53.

Anisah Lee, A., Anscelly A.A., Mohamed, J., and Yasin, Z. 2016. Conservation of Pulau Payar Marine Park and Optical Remote Sensing Models. KEMANUSIAAN, 23: (1): 79–107.

ASTM D422-63. 2007. Standard Test Method for Particle-Size Analysis of Soils. American Standard for Testing and Materials, USA.

Azlan, A., Aweng, E.R., Ibrahim, C.O., and Noorhaidah, A.J. 2012. Correlation between Soil Organic Matter, Total Organic Matter and Water Content with Climate and Depths of Soil at Different Land use in Kelantan, Malaysia. The Journal of Applied Sciences & Environmental Management, 16 (4): 353-358.

Bini, C., Gemignani, S., and Zilocchi, L. 2006. Effect of different land use on soil erosion in the pre-alpine fringe (North–East Italy): ion budget and sediment yield. Science of the Total Environment, 369: 433–446

Bodo, T., Gimah, B.G., and Seomoni, K.J. 2021. Deforestation and Habitat Loss: Human Causes, Consequences and Possible Solutions. Journal of Geographical Research, 4(2): 22-30.

Calhoun, R.S., and Fletcher III, C.H. 1999. Measured and predicted sediment yield from a subtropical, heavy rainfall, steep sided river basin: Hanalei, Kausi, Hawaiian Islands. Geomorphology 30: 213-226.

Cheng, J.D., Lin, L.L., and Lu, H.S. 2002. Influences of forests on water flows from headwater watersheds in Taiwan. Forest Ecology and Management, 165(1-3): 11-28.

De Silva, M. W. R., and Ridzwan, A. R. 1982. Coral reef survey of Pulau Payar/Segantang group of islands, Kedah State, Malaysia: expedition report and recommendations for management. Report produced under WWF, project number MAL, 41., 84pp.

DID (Department of Irrigation and Drainage, Malaysia). 2012. Urban Stormwater Management Manual for Malaysia (MSMA), Second edition, Ministry of Natural Resources and Environment, Kuala Lumpur.

DID (Department of Irrigation and Drainage, Malaysia). 2010. Guideline for Erosion and Sediment Control in Malaysia. Ministry of Natural Resources and Environment, Kuala Lumpur.

Douglas, I., and Guyot, J. L. 2005. Erosion and sediment yield in the humid tropics. M. Bonell, L. A. Bruijnzeel (Eds) Forests, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management. Cambridge: Cambridge University Press.

El-Swaify, S.A., and Dangler, E.W. 1982. Rainfall erosion in the tropics: A state of the art. Soil erosion and Conservation in the Tropics ASAE Special Publication 43, 1-25. Fort Collins.

Erman, D.C., and Mahoney, D. 1983. Recovery after logging in streams with and without buffer-strips in Northern California. California Water Resource Center Contribution 186, University California Davis.

FAO. 1965. Soil erosion by water. Some measures for its control on cultivated lands. Rome.

Francis, C.F., and Thorne, J.B. 1990. The influences of lichens on slope processes in some Spanish Badlands. In J.B. Thorne(Ed.) Vegetation and Erosion, Chichester: John Wiley and Sons, 55-66.

Hadley, R.F., Lal, R., Onstad, C.A., Walling, D.E., and Yair, R.A. 1985. Recent development in erosion and sediment yield studies. Technical documents in Hydrology. Paris: UNESCO.

Hodgson, G., and Dixon, J.A. 2018. Sedimentation damage to marine resources: Environmental and economic analysis. In: Resources & Environment in Asia's Marine Sector (pp. 421-445). Routledge.

Ismail. W.R. 1997. The impact of hill land clearance and urbanization on runoff and sediment yield of small catchments in Pulau Pinang, Malaysia. In: Human Impact on Erosion and Sedimentation (Proceedings of Rabat Symposium S6, April 1997). IAHS Publication No. 245: 91-100.

Ismail. W.R. 2000. The hydrology and sediment yield of the Sungai Air Terjun catchment, Penang Hill, Malaysia. Hydrological Sciences Journal, 45(6): 897-910.

Juarez, A. 1990. Reduce erosion and sedimentation in a tropical watershed with a soil erosion simulation model. IAHS Publication, 192: 147-153.

Kennicutt II, M.C. 2017. Water quality of the Gulf of Mexico. Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill: Volume 1: Water Quality, Sediments, Sediment Contaminants, Oil and Gas Seeps, Coastal Habitats, Offshore Plankton and Benthos, and Shellfish, 55-164.

Khosla, A.N. 1953. Silting of reservoirs, Central Board of Irrigation and Power, New Delhi, India.

Lal, R. 1976. Soil erosion on Alfisols in Western Nigeria: III. Effects of rainfall characteristics. Geoderma, 16(5): 389-401.

Li, G., Wan, L., Cui, M., Wu, B., and Zhou, J. 2019. Influence of canopy interception and rainfall kinetic energy on soil erosion under forests. Forests, 10(6): 509.

Maslukah, L., Wirasatriya, A., Indrayanti, E., and Krisna, H. N. 2023. Estimation of Chlorophyll–a and Total Suspended Solid Based on Observation and Sentinel-2 Imagery in Coastal Water Teluk Awur, Jepara-Indonesia. International Journal of Geoinformatics, 19(8): 18-27.

McKague, K. 2023. Universal Soil Loss Equation (USLE). Factsheet No 23/005. Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), January 2023, 7pp.

Meusburger, K., Steel, A., Panagos, P., Montanarella, L., and Alewell, C. 2012. Spatial andtemporal variability of rainfall erosivity factor for Switzerland. Hydrology and Earth System Sciences, 16: 167-177.

Mohammad, A.G., and Adam, M.A. 2010. The impact of vegetative cover type on runoff and soil erosion under different land uses. Catena, 81(2): 97-103.

Morgan, R.P.C. 1979. Soil erosion and its control. New York: Van Nostrand Rheinhold.

Morrison, M.A., Lowe, M.L., Parsons, D.M. Usmar, N.R., and McLeod, I.M. 2009. A review of land-based effects on coastal fisheries and supporting biodiversity in New Zealand. New Zealand Aquatic Environment and Biodiversity Report No. 37. 100 p.

Otaño-Cruz, A., Montañez-Acuña, A. A., Torres-López, V., Hernández-Figueroa, E. M., and Hernández-Delgado, E. A. 2017. Effects of changing weather, oceanographic conditions, and land uses on spatio-temporal variation of sedimentation dynamics along near-shore coral reefs. Frontiers in Marine Science, 4: 249.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., and Blair, R. 1995. Environmental and Economic Costs of Soil Erosion and Conservation Benefits, Science, 267: 1117–1123, https://doi.org/10.1126/science.267.5201.1117, 1995.

Pradhan, B., Chaudhari, A., Adinarayana, J., and Buchroithner, M.F. 2011. Soil erosion assessment and its correlation with landslide events using remote sensing data and GIS: a case study at Penang Island, Malaysia. Environment, Monitoring and Assessment, 184(2):715-27. DOI 10.1007/s10661-011-1996-8.

Price, J.C., and Karesh, R. 2000. Tennessee Erosion and Sediment Control Handbook: A Guide for Protection of State Waters Through the Use of Best Management Practices During Land Disturbing Activities, Second Edition, Tennessee Department of Environment and Conservation, USA.

Ramli, M.F., Choo S.M., Yusoff, M.K., and Abdullah, A.M. 2004. Preliminary Assessment of Erosion Hazard using Open Source Geographical Resources Analysis Support System (GRASS) for Langkawi Island. Proceedings of the FOSS/GRASS Users Conference - Bangkok, Thailand, 12-14 September 2004.

Renard, K.G., Yoder, D.C., Lightle, D.T., and Dabney, S.M. 2011. Universal soil loss equation and revised universal soil loss equation. Handbook of erosion modelling, 137-167.

Salvacione, A.R. 2022. Delineating soil erosion risk in Marinduque, Philippines. GeoJournal. DOI: 10.1007/s10708-020-10264-7.

Seckler, D. 2015. Issues in the economic evaluation of soil and water conservation programmes. In Land Degradation and Society (pp. 84-96). Routledge.

Ştefãnescu, L., Constantin, V., Surd, V., Ozunu, A., and Vlad, Ş.N. 2011. Assessment of soil erosion potential by the USLE method in Roşia Montană mining area and associated natech events. Carpathian Journal of Earth and Environmental Sciences, 6(1): 35-42.

Suresh, R. 2000. Soil and Water Conservation Engineering. Delhi: Standard Publishers Distributors, 951pp.

Syvitsky, J., Ángel, J.R., Saito, Y., Overeem, I., Vörösmarty, C. J., Wang, H., and Olago, D. 2022. Earth's sediment cycle during the Anthropocene. Nature Reviews Earth & Environment, 3(3): 179-196.

Troeh, F.R., Hobbs, J.A., and Donahue. R.L. 1999. Soil and Water Conservation: Productivity and environment protection. New Jersey: Prentice-Hall.

Wirabumi, P., Kamal, M., and Wicaksono, P. 2021. Determining effective water depth for total suspended solids (TSS) mapping using Planet Scope imagery. International Journal of Remote Sensing, 42(15): 5784-5810.

Wischmeier W.H. 1975. Estimating the Soil Loss Equation's Cover and Management Factor for Undisturbed Areas, In Present and Prospective Technology for Predicting Sediment Yields and Sources, Proceedings Sediment-Yields Workshop, U.S. Department.

Wischmeier, W.H., and Smith, D.D. 1978. Predicting rainfall erosion losses-A guide to conservation planning. Agricultural Handbook No. 537. USDA, Washington, DC.

Wischmeier, W.H., Smith, D.D., and Uhland, R.E. 1958. Evaluation of factors in the soil loss equation. Agricultural Engineering, 39(8): 458-462.

Xu, Y., Luo, D., and Peng, J. 2011. Land use change and soil erosion in the Maotiao River watershed of Guizhou Province. Journal of Geographical sciences, 21: 1138-1152.

Zweifler, A., O'leary, M., Morgan, K., and Browne, N.K. 2021. Turbid coral reefs: past, present and future—a review. Diversity, 13(6): 251-274.