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Soil related factors controlling erosion and landslides in Malaysia

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Abstract: The high temperature and rainfall in Malaysia results in intensive tropical weathering and depending on the parent material, the resultant soil can have deep or shallow soil profiles. Thus, a variety of soils can form with different textures (clay content), structure and porosity. With the high rainfall, soils in steep terrain are subjected to surface erosion when exposed or landslides if the rainwater percolates into the soil profile. Key soil-related factors controlling soil erosion and landslides include local climate, parent material of soils and depth of the weathered profile. Slope and geomorphology, vegetation and land use as well as land management practices also influence erosion and landslides. Measures used to control soil erosion and stabilize slopes require improved understanding of soil weathering, erosion, landslide and their linkages in steep terrain.

Keywords: Tropical weathering, soil, landslides, erosion, disaster prevention

Abstrak: Suhu dan hujan yang tinggi di Malaysia mengakibatkan luluhawa tropika yang intensif dan bergantung kepada bahan induk, tanah yang terhasil boleh mempunyai profil tanah dalam atau cetek. Oleh itu, pelbagai jenis tanah boleh terbentuk dengan tekstur (kandungan lempung), struktur dan keliangan yang berbeza. Dengan taburan hujan yang tinggi, tanah di kawasan curam akan mengalami hakisan permukaan apabila terdedah atau tanah runtuh jika air hujan meresap ke dalam profil tanah. Faktor utama berkaitan tanah yang mengawal hakisan tanah dan tanah runtuh termasuk iklim tempatan, bahan induk tanah dan kedalaman profil terluluhawa. Cerun dan geomorfologi, tumbuh-tumbuhan dan guna tanah serta amalan pengurusan tanah turut mempengaruhi hakisan dan tanah runtuh. Langkah-langkah yang digunakan untuk mengawal hakisan tanah dan menstabilkan cerun memerlukan pemahaman yang lebih baik tentang luluhawa tanah, hakisan, tanah runtuh dan kaitannya di kawasan tanah tinggi yang curam.

Kata kunci: Luluhawa tropika, tanah, tanah runtuh, hakisan, pencegahan bencana

INTRODUCTION

Historically, Man has always been linked to soil and the land on which he lived, as he depended upon hunting, fishing or the resources provided by wild fruits and grains for his subsistence, and to the use of stones as his weapon and caves for his dwelling place. As Man learned to use fire and till the soil in order to increase and stabilize his food supply, his dependence on the soil increased. Much of the early studies on soil focussed on increasing food productivity. The soil map now provides information for non-agricultural purposes covering a wider range of sectors such as engineering, forestry, conservation and recreation, industry and finance including appraisal and acquisition (Figure 1). In the engineering sector, aspects covered include seeking foundation materials for engineering structures or storage basins for water retention to minimise flooding. The importance of the soil as part of the landscape to use for construction of houses, buildings and their resultant impact on the environment is also becoming increasingly important.

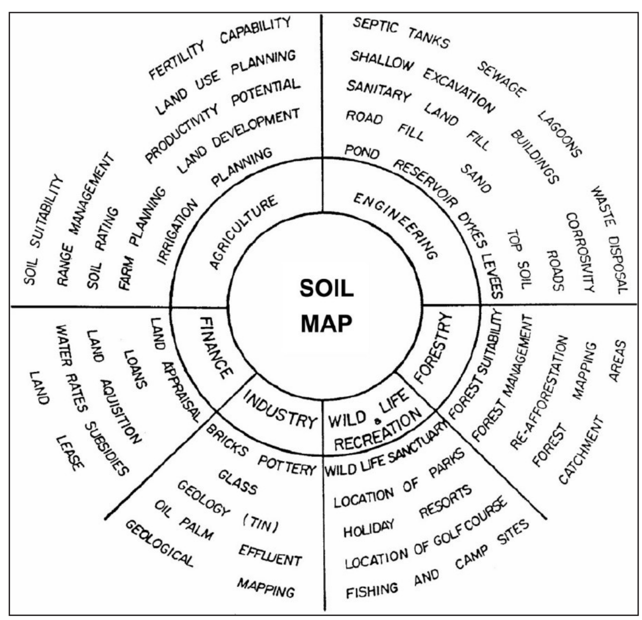

Figure 1: Soil map as a basic resource.

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Soils represent the top most layer of the land surface. There are many different types of soils. They come in a range of colours with different proportions of clay, silt and sand. They can occur on level, hilly or steep land up to various depths. A soil can be well or poorly drained. It can be sandy, clayey or consist of mixtures of both. It can be organic or mineral. Soils are formed by the action of climate (rainfall and temperature) and plants with their associated organisms on the parent materials over a period of time. This action is greatly influenced by the relief or slopes or shape of the land on which the soil is found. This can be represented as follows:

s = f (c, o, p, r, t)

where	s	=	soil
	c	=	climate
	o	=	organisms/vegetation
	p	=	parent material
	r	=	relief
	t	=	time

Where all the five soil forming factors are the same, the resultant soil will be the same. All of these factors are interrelated. Because these factors can vary widely, different kinds of soils can develop. For example, a steep area allows the rain to runoff the surface resulting in severe erosion and shallow soils result. Temperature and moisture influence the kind of vegetation and hence different soils support different types of crops. Parent material or rock type influences the texture and some chemical properties of the soils. Sandy soils are formed from sandstones while granites often give rise to soils with coarse sandy clay textures and shales and basalts form clay textured soils. Basalts give rise to soils rich in iron while granites to soils with low free iron oxides. Similarly, the fertility, clay mineralogy and soil structure of a particular soil is also influenced by the parent rock or the parent material as modified by climate and time. These properties also influence the use of soil in engineering works and other sectors (Paramananthan, 1980).

Erosion is a geological process where water wears away and transports earth material. The main forms of erosion include surface erosion, fluvial erosion, river bank erosion and mass movement erosion, which is essentially the downslope movement of loose mixture of soil and rock particles by the force of gravity. Landslides, also referred to as landslips, are influenced by geology (bedrock characteristics), morphology (shape of the land) and human activities such as irrigation, poor surface drainage. Landslides are often initiated by heavy rainfall and erosion as well as poor land management and construction practices.

The role of water with respect to surface and subsurface flow characteristics as well as pore water pressure response is critical in the initiation of both shallow and deep-seated landslides. Shallow landslides such as debris flow are rapid and constitute a major risk to human life, compared to the slower deep-seated landslide (Sidle *et al*., 2006). The size of a landslide including its depth, length, width, area, volume, and their multiple ratios and dependencies, which influence the magnitude and impact in terms of destructiveness is a major challenge. The concept of landslide-event magnitude scale has recently been introduced to predict the size of a landslide event (Lombardo *et al*., 2021). This statistical approach, which has been demonstrated for earthquake-influenced landslides has yet to be tested for erosion-induced landslides.

Accelerated surface erosion and episodic landslides are common in mountainous terrain that are altered by human activities, which contribute to increased sediment delivery to streams (Sidle *et al*., 2006). Water plays an important role that influences and intricately links soil erosion and landslides in the tropics. Excessive cultivation in steep slopes accompanied by frequent rainstorms contribute to increased soil erosion and landslides in the tropics. The relationship between erosion and landslides also depends on factors such as the slope angle, slope shape and soil depth, which provides important insights to their prediction in critical landscapes (Yu *et al*., 2019).

Malaysia is located in a tropical environment characterized by high temperature and high intensity of rainfall. Landslides are a common phenomenon especially along the many road cuts along the highways. Among the natural hazards, landslides are the major cause of loss of lives in the country (Government of Malaysia, 2021). Erosion-induced landslides are common in the Cameron Highlands (Abdullah *et al*., 2019). The high rainfall results in most soil profiles having depths that are for the greater part controlled by the original rock from which the soil is developed (Paramananthan, 1977; 1980). Consequently, many of the soil properties determine to a large extent the type of soil erosion and the size of landslides that occur at a particular site. A sound understanding of the linkages between soil properties, erosion, landslides and the factors that influence them will support the identification of proper corrective measures to minimise disasters.

This paper outlines key factors that influence soil erosion and landslides. The factors include regional climate, local climate, parent rock or material, slope and geomorphology, vegetation and land use as well as land management practices. The differences in soils formed under temperate and tropical environments is provided in this context. The variety of rock types that influence many of the soil properties such as the depth of soil, texture and structure, water holding capacity, porosity and clay mineralogy, which directly or indirectly influence erosion and landslides are also briefly mentioned. Much of the observation is based on the vast field experience of the first author and supplemented with information from the literature. The intent is to provide a descriptive narrative to stimulate future work on the soil-erosion-landslide nexus in steep terrain, to control soil erosion and stabilize slopes.

SOIL RELATED FACTORS AFFECTING EROSION AND LANDSLIDES

There are many factors that control erosion and landslides in Malaysia and these relate to soil and land characteristics. Key factors include regional climate, local climate, parent rock or material, slope and geomorphology, vegetation and land use as well as land management practices (Table 1).

Regional climate

Tropical climate strongly influences the formation of the different soils in Malaysia. Both the regional and local climate – in particular temperature and rainfall influence differences in soil formation in the temperate and tropical regions (Paramananthan, 1977; Brady & Weil, 1999). The temperature and rainfall in temperate regions are distinctly different from those of tropical areas.

Temperate areas have clear winters and summers i.e. seasonally cold or low temperatures and seasonal hot temperatures. The temperate rainfall is also often seasonal, with wet or dry seasons. Temperature controls the rate of weathering while rainfall controls the rate of leaching of the weathered products. Consequently, temperate soils are seldom intensely weathered or intensely leached. The alternating high and low temperature, wet and dry season with seasonal weathering and leaching results in fersiallitic weathering, with partial leaching of bases or silica and weathering zones that are often less than 2 m.

Tropical areas generally have continuously high temperatures and are mostly wet throughout the year.

Table 1: Overview of soil and land related factors affecting soil erosion and landslides.

No.	Factor	Sub-Factors	Implications	Remarks
1.	Regional Climate	Temperate vs. Tropical	• Cannot directly apply temperate solutions to tropical soils. Need to modify solutions to suit tropical soils.	• Temperate soils are shallow. • Tropical soils are deep. • Temperate areas have less rainfall that is seasonal and hence less erosion takes place. • Tropical areas have more continuous rainfall and hence more erosion.
2.	Local Climate	• Temperature (Elevation) • Rainfall pattern	• High and uniform in the tropics – fast reaction and breakdown. • Heavy rainfall – soils prone to soil erosion/landslip.	• Granitic areas – deep soils – deep slips e.g. Bukit Lanchang. • Sedimentary rocks – moderate to shallow slips.
3.	Parent Rock/ Material	• Depth of soil • Texture/ Structure • Chemical characteristics • Clay mineralogy	• Depth depends on type of rocks/slope position. • Influence physical, chemical and mineralogical properties of soils.	• Granites with deep profiles – large slips. • Sedimentary rocks – small slips. • Variation in texture, structure, porosity, infiltration, etc. • Surface erosion common. • Expanding clays in Lahad Datu – landslips along cracks due to clay mineralogy.
4.	Slope/ Geomorphology	• Surface runoff • Infiltration/ Rate • Porosity • Aspect	• Controls surface erosion. • Rate of infiltration/runoff. • Siltation of rivers.	• Slope determines surface runoff and erosion. • Soil texture controls landslip through its porosity and infiltration rate.
5.	Vegetation/ Land Use	• Natural vegetation cover crop • Cover crop • Rubber/Oil Palm • Bare soil • Organic soil layer	• Helps protect soil from erosion. • Maintains soil at equilibrium state. • Cover crops provide temporary protection of soil surface.	• High surface litter minimizes soil erosion e.g. surface organic layer. • Slides higher on bare soil. • Cover crop prevents surface erosion but increases porosity and possibility of slips.
6.	Land Management Practices	• Terraced • Not terraced • Engineering structures	• Correct solution? • Position of weep holes. • Maintenance of drains and no siltation hampering water flow. • Type of engineering structure.	• Terracing breaks surface runoff. • Need to maintain drains from silting-up.

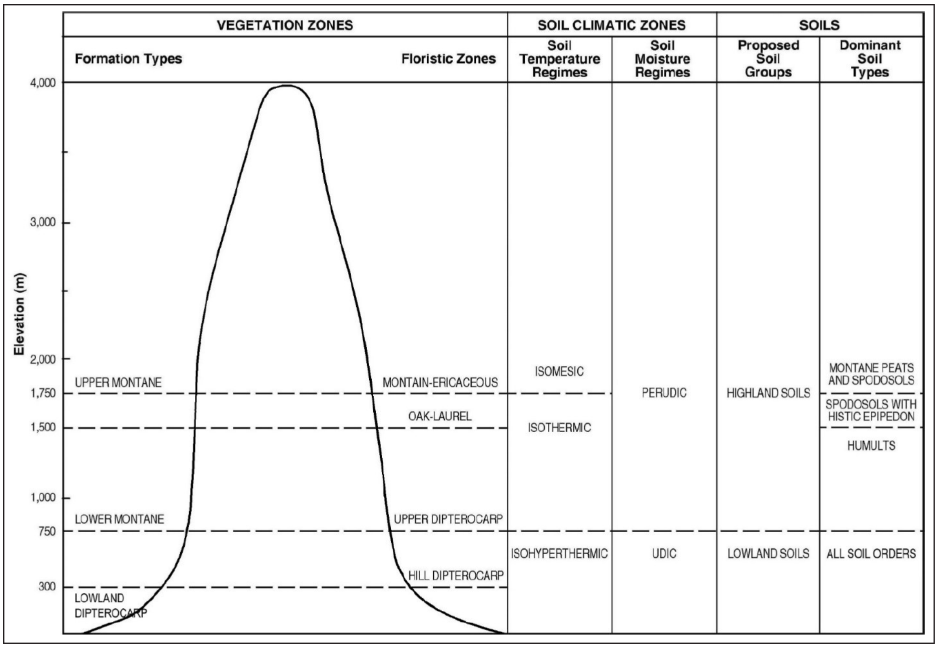

Figure 2: Vegetation, soil climatic zones and proposed soil groupings in Malaysia (Vegetation distribution after Burgess, 1969, soil climatic zones after Paramananthan, 1977).

Tropical soils are mostly both intensely weathered and leached (Paramananthan, 1977). Ferallitic weathering, with intensive weathering and leaching of bases and silica are characterised by weathering zones exceeding 10 m in depth. The dissimilarity in climate conditions invariable result in differences between temperate and tropical soils.

Local climate

Differences in local climate, specifically temperature and rainfall, can also affect vegetation and soils, and exert influence over erosion processes and landslide occurrences in an area. Local climate also influences crop selection. Temperature variation within a small country like Malaysia is mainly due to differences in elevation. This results in variations in vegetation, soil temperature and moisture regimes, and soils. Climo-topo sequences have been reported over granites of the Main Range in the Cameron Highlands of Peninsular Malaysia (Figures 2 and 3), and over sedimentary rocks in the Crocker Range of Sabah (Paramananthan, 1977; Wong *et al*., 2020). It appears that elevation controls not only the vegetation type but also strongly influences the soil temperature, moisture regimes and soil types.

At high altitudes, a perudic soil moisture regime (where rainfall exceeds evapotranspiration) prevails, and due to low temperatures highland organic soils occur. Tea, flowers and temperate vegetables are planted at the altitudes around 1,200 m. The cultivation of these crops requires the removal of the protective natural organic layer. Removal of the protective layer makes an area susceptible to severe soil erosion and landslides in steep terrain of the tropics (Sidle *et al*., 2006). This condition has also been reported in the Cameron Highlands, resulting in erosion-induced landslides (Abdullah *et al*., 2019). It has been observed that due to erosion, the coarse sand in the granite soils are washed and transported onto the generator blades of the National Electricity Board in Cameron Highlands. This may contribute to reducing their life-span. Siltation of the rivers by the sediments washed from the highlands could

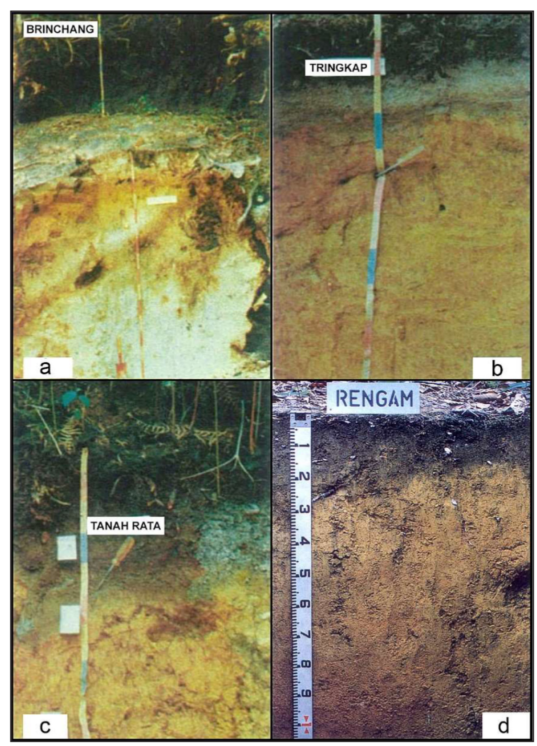

Figure 3: Soil profiles at selected elevations over granites in Peninsular Malaysia. (a) Brinchang Series (1,900 m), (b) Teringkap Series (1,700 m), (c) Tanah Rata Series (1,500 m), (d) Rengam Series (70 m) (Source: Paramananthan, 1977).

also contribute to extensive flooding and loss of lives and property.

Rainfall distribution over a ten-year mean varies in Peninsular Malaysia (Figure 4). For example, Johor Bahru experiences good monthly rainfall distribution. Dry months (<100 mm) are common on the east coast (Kuantan) and in the northern regions (Alor Setar). An important factor for assessing soil erosion is rainfall erosivity, which is available for the whole of Peninsular Malaysia (Figure 5). The rainfall erosivity factor has been used in combination with other parameters to model incidences of soil erosion, landslides and erosion-induced landslides in the Cameron Highlands (Abdullah *et al.*, 2019).

Surface erosion and landslides are easily distinguishable. It has been reported that for every unit of area disturbed, roads contribute to the largest surface erosion and landslide losses (Sidle *et al.*, 2006) in steep terrain. Rainfall after a prolonged dry period will make the upper soil weathering profile moist and heavy while the underlying soil profile at depth is dry. Clay migration can increase in this moist/dry interface and a slip-zone due to clay migration can develop. In this scenario, any trigger such as a heavy vehicle passing close to the road cut could trigger a landslide.

Parent rock and material

A variety of rock types occur in Malaysia. A rock weathers to form the parent material (weathered rock/saprolite) which eventually becomes the soil. Different rocks have different rates of weathering resulting in soils of different depth classes for saprolite. The term isomorphic parent materials can be used to describe rocks like granite

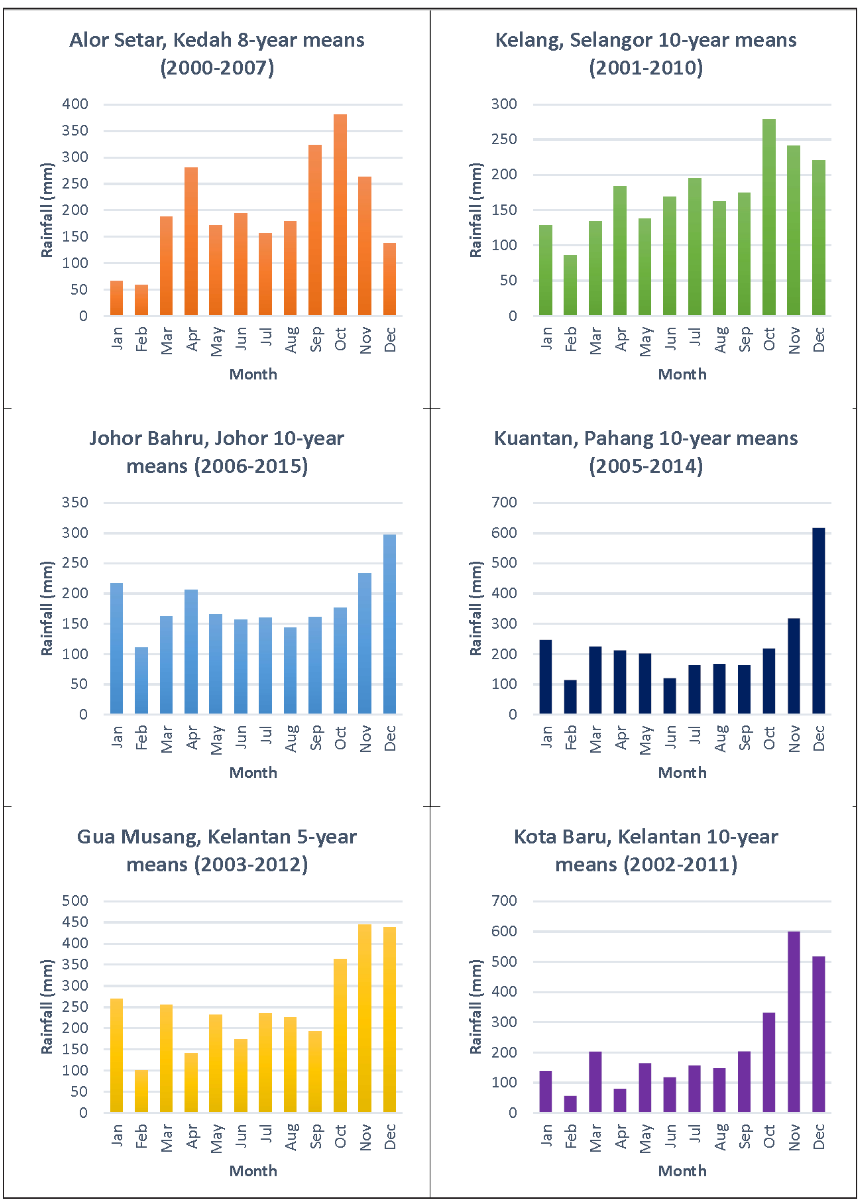

Figure 4: Rainfall histograms of selected stations in Peninsular Malaysia (Source: MetMsia).

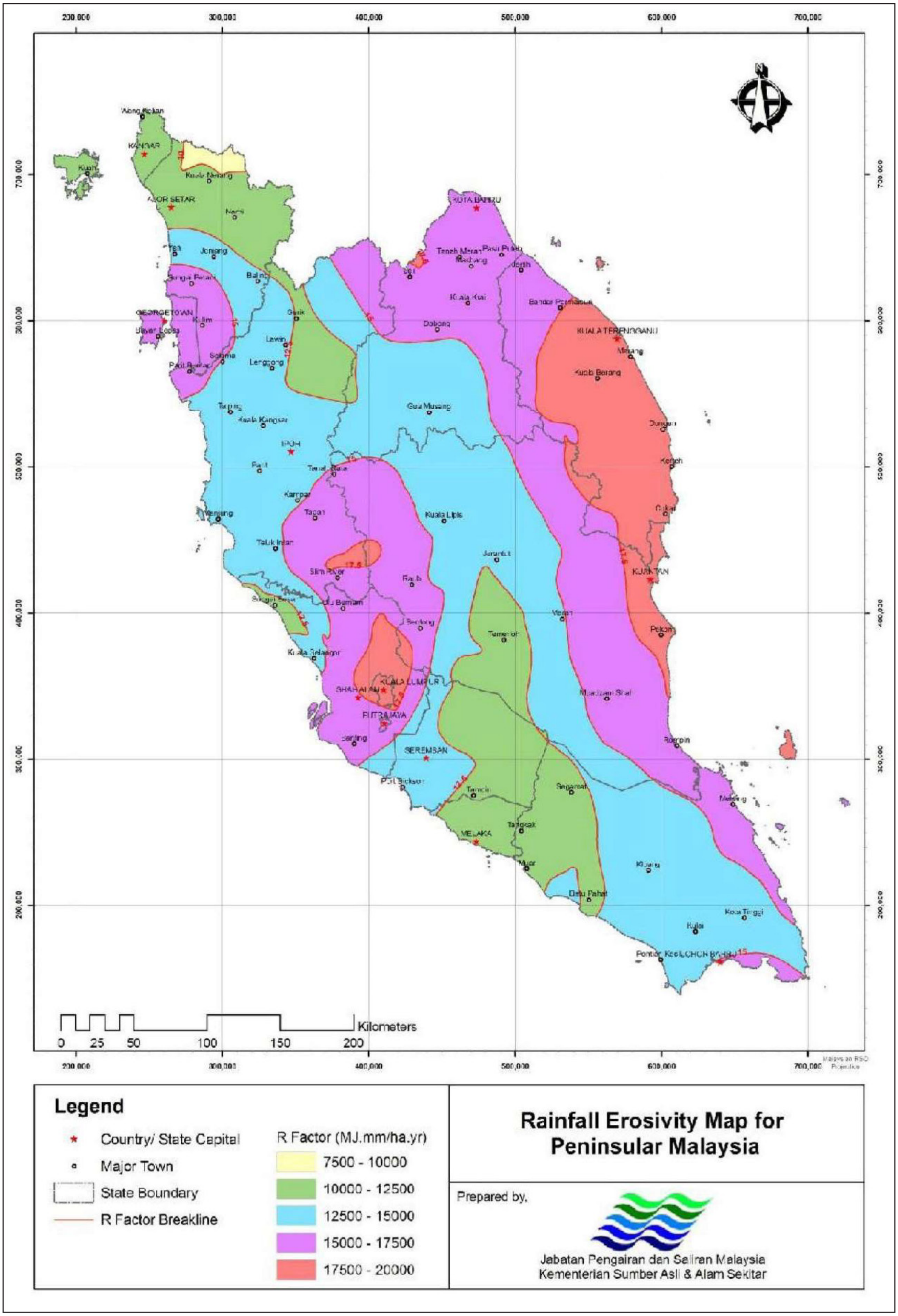

Figure 5: Erosivity map of Peninsular Malaysia (Department of Irrigation and Drainage (DID), 2010).

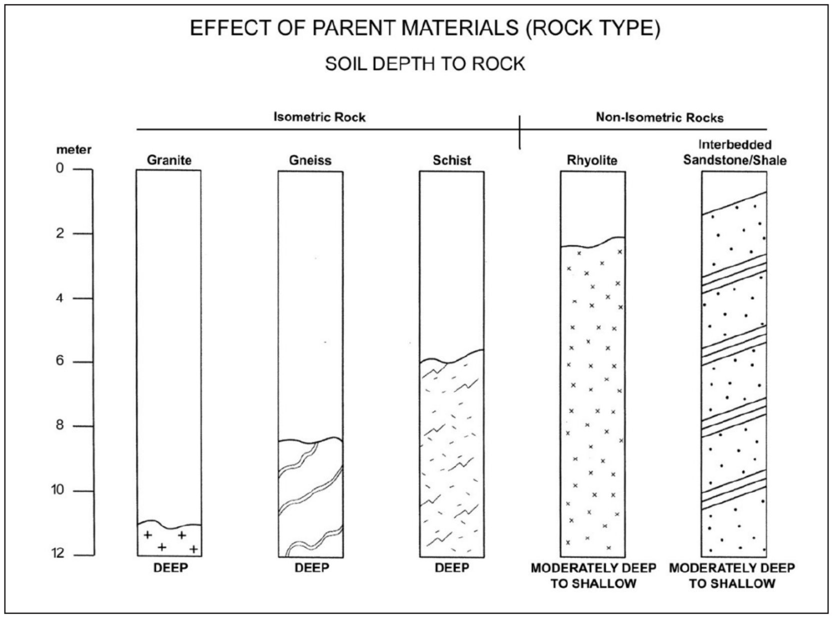

Figure 6: Effects of parent material (rock type) on soil depth to hard rock.

which do not have different rock types and hence weather to form deep soil profiles up to more than 10 metres. Sandstone interbedded with shales are non-isomorphic as the weathering of the different interbedded rock types vary and often form shallow to moderately deep soils (Figure 6). When landslides occur, the magnitude of the slides is influenced to some extent on the parent rock type. Rainfall is an important triggering mechanism that induces shallow landslides (Sajinkumar *et al*., 2011).

The rock type also to a large extent controls the physical and chemical properties of the resultant soils. A granite, for example, give rise to a soil with coarse sandy textures (35-60% clay) while andesites or basalts being made up of more weatherable olivine, pyroxenes and amphiboles give rise to soils with clay textures (>60% clay). Basalts and andesites have higher iron giving the soil a red colour, while soil from granite is of yellowish brown colour and has only 2-3% free iron. High iron in a soil causes the clay particles to aggregate forming pseudosands and pseudosilts increasing the soil's porosity (Maene *et al*., 1975a; 1975b). The rain falling on such soils mostly enters the soil. Silty clay textured soils have structure that is coarse angular blocky, where the percolation rate is slow and the resultant soils shallow. Such differences in structure and textures result in differences in porosity and determine if rainwater will percolate into the soil, or will result in surface flow causing surface erosion and deposition of the soil downslope (Brady & Weil, 1999). Despite differences in parent material, deep weathering profiles of basalt, granite and schist, with depths to fresh rock of 16, 27 and 10 m, respectively display similar physico-chemical properties (Hamdan & Burnham, 1996).

Soil profile depths in the tropics is influenced by the speed of weathering, geological age and geomorphological history, including erosion and landslides. Landslides extend to a considerable depth and can involve pedological soil (saprolite or completely weathered bedrock), saprock (slightly to highly weathered bedrock) and bedrock, indicating the important role of weathering in its occurrence (Sajinkumar *et al.,* 2011). Saprolites have been uncovered by erosion, landslips and human activity but they have been found resistant to water erosion upon exposure (Hamdan & Burnham, 1996; 1997). The top-most pedological soil, intermediate saprock and bottom bedrock within the profile of a rhyolite outcrop has been classified into three major weathering zones, based on factors such as the ratio of clay to silt and clay contents in Malaysia (Raj, 2018). The textural weathering index has been proposed to describe the progress of weathering to inform road excavation works.

Slope and geomorphology

Slope plays an important role in determining if the rainwater will runoff on the surface of the soil or it will percolate into the soil. The amount of soil loss and runoff from the various treatments was determined over an experimental period of 60 days (Maene *et al*., 1975a; 1975b). Soil loss was found to increase with the steepness of the slope (Table 2). However, when the soil surface was heated with bitumen emulsion, soil loss was reduced significantly on all slopes (Table 3). The cumulative soil loss over the experimental period was reduced by a factor 3.5 on the gentlest slope (S_1) and 2.8 on the steepest slope (S_3), as a result of such treatment. No significant difference in soil loss was found between treatments S_1B_1 and S_2B_1 (Table 3). The amount of runoff water for the 60-day period was significantly reduced on all slopes by treatment with bitumen emulsion. This indicates that soil conditioning

Table 2: Runoff soil loss – effect of slope and soil types (Source: Maene *et al*., 1975a).

Treatment	Slope (°)			Soil Type		
	25	15	5	Durian	Serdang	Rengam
Runoff soil loss (g/m^2)	1,081	910	645	1,072	977	587
Total soil loss (g/m^2)	2,223	2,233	2,135	2,684	3,714	1,193
Runoff water loss (% of rainfall)	35.2	33.6	32.4	43.7	38.4	19.1

Table 3: Soil loss (kg/ha) and runoff water (% rainfall) during a 60-day period for the different treatments (Source: Maene *et al*., 1975b).

Date			9.9	12.9	19.9-21.9	1.10	12.10-13.10	23.10	24.10	1.11	2.11	4.11	Cumulative 9.9-4.11
Rainfall (mm)			45.7	13.5	74.2	17.3	10.2	17.0	23.4	14.5	17.7	30.5	264.0
Soil Loss (kg/ha)	S_1	B_o	2,518	8,320	13,043	4,057	107	6,476	3,757	624	1,328	3,277	43,507
		B_1	1,144	391	2,372	616	84	2,806	1,309	547	999	2,043	12,311
	S_2	B_o	6,901	5,763	13,754	4,473	65	7,965	4,254	706	1,444	3,362	48,687
		B_1	1,315	1,098	2,804	1,584	122	3,286	1,705	760	1,092	2,243	16,009
	S_3	B_o	11,448	10,116	17,522	5,320	102	7,988	4,849	1,238	1,592	3,410	63,585
		B_1	2,899	1,963	6,264	799	115	4,240	2,067	979	1,293	2,484	23,103
Runoff Water (%)	S_1	B_o	16.1	66.9	11.7	28.2	18.8	34.7	31.0	16.7	30.8	45.1	30.0
		B_1	13.8	53.8	8.9	24.5	16.5	28.8	29.6	13.4	24.9	40.5	25.5
	S_2	B_o	16.8	68.5	12.3	32.8	10.5	38.0	32.7	17.3	31.2	48.1	30.8
		B_1	14.6	56.4	11.5	30.6	15.5	30.4	31.1	14.9	30.6	42.8	27.8
	S_3	B_o	23.2	71.0	13.0	33.4	13.9	39.1	35.4	20.6	34.8	54.1	33.9
		B_1	15.0	57.7	12.4	28.0	18.8	32.8	30.2	15.7	32.5	43.8	28.7

has increased the infiltration of water into the soil, thereby reducing surface runoff. The average reduction factor for water runoff on the three slopes was 1.2 after conditioner treatment.

The steeper the slope, the more the surface runoff and surface soil erosion as manifested by rill and gulley formation. Recent studies indicate that the characteristics of the slope material and corresponding stress state play a relatively more important role than rainfall and slope steepness in triggering slope debris flows (Du *et al.,* 2021). This calls for further investigation on the link between soil related factors, erosion and slope stability. The soil texture/structure will prevail for the same slope class (Paramananthan, 2010). The geomorphology and drainage pattern can also assist to determine the nature of the parent rock/material; and indirectly its susceptibility to erosion and landslides. The slope aspect determines the amount of sunshine a particular slope will receive and how quickly the slope will dry up. The aspect of a slope is generally less critical in tropical environments. However, it is important as one moves away from the equator.

Vegetation and land use

Under natural vegetation, with its soil surface litter and humus-rich topsoil, one would expect the land to be in equilibrium. However, this equilibrium will be upset if there is any change of land use e.g. land clearing or planting of crops (Paramananthan, 2010). A variety of land use has been recommended for the slope classes used in Malaysia (Table 4). The Land Conservation Act 1960 (Revised 1989) forbids any land clearing for slopes above 25° (Government of Malaysia, 1989). Development of a land above 25°

Table 4: Slope classes used in Malaysia (Source: Paramananthan, 2010).

Slope Class	Map Symbol	Slope Range (%)	Slope Range (°)	Recommended Land Use
Level	C1	0–4	0–2	Plantation/Cash crops
Undulating	C2	4–12	2–6	Fruit trees/ Plantation crops
Rolling	C3	12–24	6–12	Fruit trees/Plantation crops with terracing and soil conservation practices
Hilly	C4	24–38	12–20	
Somewhat steep	C5	38–50	20–25	
Steep	C6	50–60	25–30	CONSERVATION AREA (Retain as Forest)
Very steep	C7	>60	>30	

slopes requires special approval from the Land Office and Department of Environment (DOE) Malaysia.

Land management practices

Land management practices influence the rate of weathering and soil erosion and accelerate landslide occurrences in the tropics (Sidle *et al*., 2006; Sajinkumar *et al*., 2011). In Malaysia, the Environmental Quality Act (1974) and the Environmental Quality (Prescribed Activities) (Environmental Impact Assessment Order 1987) require owners of agriculture land to ensure that proper soil conservation measures are taken to minimise soil erosion (Government of Malaysia, 2000; 2001).

Cover crops are normally planted to ensure that the soil surface is covered and soil erosion minimised. In addition to planting cover crop, soil terraces are also made to minimise soil erosion. The cover crop is temporary as once the crop's canopy closes the cover crop gradually dies; but the closing of the canopy means that there is little or no rainfall that falls directly on the land surface. Most plantations will plant a hardy cover crop (creeper) such as *Mucuna bractiata* to protect the road cuts from soil erosion (Paramananthan, 2010). Information is limited on tree root systems to stabilize hillslopes to reduce the risk of landslides in the tropics. Findings indicate that a mix of tree species with deep roots and grasses with intense fine roots provides the highest stability for hillslopes (Hairiah *et al*., 2020).

In the case of engineering projects, a variety of measures are used. These include use of concrete slab with weep holes for drainage, use of cement plaster, fibre-mats with turf plantings or even grass or legume cover. Terraces with drains are also commonly used. However, the construction of these preventive structures are generally not properly followed-up with monitoring and maintenance.

SOIL EROSION CONTROL TO PROMOTE SLOPE STABILITY

A number of soil erosion control actions are currently applied in Malaysia to minimise and prevent soils from being eroded by splash by rainwater, transported and deposited downslope or in rivers causing floods. These practices are outlined in the "Guideline for Erosion and Sediment Control in Malaysia (Department of Irrigation and Drainage (2010)). These include:

- Seeding of grasses, trees and shrubs or other ground covers;
- Mulching;
- Runoff control structures – earth bank;
- Geotextiles and mats;
- Drainage outlet protection; and
- Temporary waterway crossing.

In addition, sediment control structures to collect the sediments being washed down can also be constructed. Such structures include check dams, silt fence, sediment traps and sediment basins. A prevalent issue associated with these control structures is the lack of regular inspection and maintenance.

The impact of vegetation on slope stability needs further understanding as it may be detrimental in some cases, depending on the slope size and soil properties. Models have been developed for bioengineering solutions to ensure optimum vegetation cover type and configuration, to estimate risks to support engineers offset shallow landslides in the tropics (Collison *et al.*, 1995). As a slope stabilizing measure, soil bioengineering solutions are found to be most effective for low and moderate risk slopes (Dorairaj & Osman, 2021). Further investigation is called for to stabilize steep slopes.

The socio-economic impacts of landslides are generally given relatively more attention than its effects on the ecology (Pravalie, 2021). The ecological effects of landslides in combination with erosion give rise to the creation of degraded depositional environments, removal or displacement of upper fertile soil layers, habitat loss and degradation for soil biota, or the reduction of soil biodiversity and its overall functioning. This aspect warrants further investigation given the projected increase in intensity and frequency of rainfall for Southeast Asia due to global warming (IPCC, 2021).

CONCLUSION

The soil properties in tropical terrain is differs from that in temperate regions due to differences in climate and weathering. Intensive weathering and leaching of bases and silica result in weathering zones exceeding 10 m in depth in the tropics. Soil profile depths in the tropics is also influenced by the speed of weathering, geological age and geomorphological history. Steep terrain is susceptible to severe soil erosion and landslides where the protective upper layer is removed during crop cultivation. Measures used in temperate areas to control soil erosion and stabilize slopes cannot be directly used in the tropics. The measures have to be modified and this requires improved understanding of soil weathering, erosion, landslides and their linkages in a tropical environment.

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AUTHOR CONTRIBUTIONS

SP: Preparation of original draft, field work. NM: editing, data curation. JJP: conceptualization, review and funding acquisition.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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