STUDY ON HEAVY METAL CONTENTS OF HIGHLY WEATHERED SOIL AS EARLY WARNING SYSTEM INDICATOR TO PREDICT SHALLOW SLOPE FAILURE

BY

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A thesis submitted in fulfilment of the requirement for the degree of Master of Science (Built Environment)

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AUGUST 2014

ABSTRACT

The soils of the tropics have long been considered problem soils compared to their counterparts in temperate areas. Malaysia has a hot humid climate which these high temperatures and heavy rainfall acting over a wide variety of parent materials, have produced a wide range of soils. Problem soils are defined as those which require special management practices for their economic use in agricultural production. In general, problem soils are of the lowest priority for agricultural use. However, when population pressure demands it, such soils have to be utilised. There are four groups of problem soils found in Malaysia which are Oxisols, acid sulphate soils, sandy soils and organic soils. Unfortunately, In Malaysia, most of these types of soils are prone to erosion and landslides. Slope stability has always been the interest of civil engineers, geotechnique experts, soil mechanists and therefore the principles of soil physics, soil mechanics, and geotechnique, have been applied to explain slope failures and to find ways of improving slope strength. The chemistry of slope instability and landslides has not been the main concern of many landslide researchers. The aim of this research is to bring forward a study on the problem of slope stability from the physico-chemical point of view, such as to explore the capabilities of heavy metal (micronutrients) concentration in soil as shallow slope failure indicator. The second objective of this study is to determine the concentration of heavy metals namely Aluminium (Al) lead (Pb), Ferum (Fe), Zinc (Zn) Chromium (Cr) in highly weathered soil that significantly relevant to stable slope. The third objective is to determine the concentration of heavy metals in highly weathered soil that significantly relevant to unstable slope and to identify key factors to predict shallow slope failure using chemical properties. In order to achieve this goal, in chapter 3, 21 sampling points of stable and unstable slope in Selangor and Perak were chosen and 21 soils samples were collected for labatory test.Analysis on each of 93 samples data confirmed the findings by exhibiting highly significant differences between heavy metal (micronutrients) content, slope stability, and the location .This clearly demonstrates that concentration of heavy metal in different slope condition can have an important influence on the shallow slope failure. The results of the study from soil samplings both in Perak and Selangor sites show that a higher content of heavy metal (micronutrients) is an indication that the soil has higher content of organic carbon and higher content of CEC activities which result in the stability of the soil while a lower content of heavy metal (micronutrients) is an indication that the soil has lower content of organic carbon and lower content of CEC activities which result in the instability of the soil.

Keywords: Oxisols, Stable slope, Unstable slope, Heavy Metal (micronutrients)

خلاصة البحث

طالما اعتبرت التربة في المناطق المدارية تربة ذات مشكلة مقارنة مع نظيراتها في المناطق المعتدلة. يتميز مناخ ماليزيا بأنه حار رطب، أين تؤثر درجة الحرارة المرتفقة والأمطار الغزيرة على إيجاد تنوع واسع للمواد الأصلية، وهنا أنواع كثيرة من التربة. تعرف التربة المشْكلة بأنها تلك التي تتطلب أساليب إدارة خاصة لأجل استخدامها استخداما اقتصاديا في الإنتاج الزراعي. تعتبر التربة المشكلة بشكل عام من أدنى الأولويات في الاستخدام الزراعي، لكن عندما يكون هنالك ضغط سكاني لاستخدامها، فهنا يستلزم الاستفادة منها. هناك أربع مجموعات من التربة المشكلة الموجودة في ماليزيا؛ وهي: التربة المأكسدة، والتربة البكتيرية الحامضة، والتربة الرملية، والتربة العضوية. للأسف، فإن معظم هذه الأنواع من التربة في ماليزيا هي اليوم عرضة للتآكل والإنهيارات الأرضية، ذلك أن استقرار المنحدرات بات دائما مستعملا لفائدة المهندسين المدنيين، وخبراء تقنية الجغرافيا، وميكانيكي التربة. ولذلك فقد تم تطبيق مبادئ فيزياء التربة، وميكانيكا التربة، وتقنية الجغرافيا من أجل تفسير فشل المنحدرات وإيجاد سبل لتحسين قوة المنحدر. لم تكن كيمياء المنحدرات اللامستقرة والانهيارات الأرضية يوما ما الشغل الشاغل لكثير من باحثي الانهيارات الأرضية. إن الهدف من هذا البحث هو الخروج بدراسة عن مشكلة استقرار المنحدرات من وجهة نظر فيزيوكيميائية لاستكشاف قدرات المعادن الثقيلة (تركيز المغذيات الدقيقة) في التربة كمؤشر لفشل المنحدرات الضحلة. الهدف الثاني من هذه الدراسة هو تحديد تركيز المعادن الثقيلة في التربة؛ وهي الألمنيوم، والرصاص، والحديد، والزنك، والكروم في التربة المعرضة للعوامل المناخية العالية، وتقرير بأن لها علاقة متينة باستقرار المنحدرات. فيما يقوم الهدف الثالث على تحديد تركيز المعادن الثقيلة في التربة المعرضة للعوامل المناخية العالية وأنه لها علاقة متينة بالمنحدرات اللامستقرة، وذلك لتحديد العوامل الرئيسية التي يمكن أن تساعد على تنبؤ فشل المنحدرات الضحلة، باستعمال خواص كيميائية. من أجل تحقيق هذا الهدف، كما هو مبين في الفصل الثالث، فقد تم اختيار 21 نقطة في ولايتي "سيلانجور" و"بيراك" كعينات للمنحدرات المستقرة وغير المستقرة، كما جمعت 21 عينة للتربة لأجل التحليلات المخبرية. وقد أكدت تحليلات كل من العينات الـ 93 على النتائج التي توصلت اليها الدراسة وذلك بإظهار فروق ذات دلالة إحصائية عالية بين محتوى المعادن الثقيلة (المغذيات الدقيقة)، واستقرار المنحدرات، والموقع. وهذا ما يبين بوضوح أن تركيز المعادن الثقيلة في وضعيات منحدرات مختلفة يمكن أن يكون لها تأثير مهم على فشل المنحدرات الضحل. كما تشير نتائج الدراسة المجراة على عينات التربة من كلا الموقعين "بيراك" و"سيلانغور" أن المحتوى العالي للمعادن الثقيلة (المغذيات الدقيقة) هو إشارة إلى أن التربة تحتوي على مستوى عال من الكربون العضوي ومن أنشطة السعة التبادلية الكاتيونية التي تؤدي إلى استقرار التربة، في حين أن محتوى أقل من المعادن الثقيلة (المغذيات الدقيقة) هو إشارة إلى أن التربة لديها محتوى أقل من الكربون العضوي ومحتوى أقل من السعة التبادلية الكاتيونية التي تؤدي إلى عدم استقرار التربة.

الكلمات المفتاحية: التربة المؤكسدة، المنحدرات المستقرة، المنحدرات اللامستقرة، المعادن الغنية (المغذيات الدقيقة).

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science Built Environment.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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ACKNOWLEDGEMENTS

First and foremost, my utmost gratitude goes to Allah s.w.t, The Most Merciful and The Most Compassionate for His blessing and guidance which enabled me to complete my research and thesis.

I wish to thank my family for their tremendous contribution and support, both morally and financially, towards the completion of this research. I am also grateful to my project Supervisor, Dr Rashidi Othman, and internal examiner Dr Hanafi who without whose help and guidance this research would not have been completed. I owe my profound gratitude to our project guide, who took keen interest in our study by providing all necessary information for developing a good system.

I heartily thank the MOHE (Ministry of Higher Education) for the financial sponsorship to complete this research, and my Department of Landscape Architecture, the Kulliyyah of Architecture and Environmental Design for facilitating and furnishing me with the equipment and facilities required for my research.

Last but not least, my gratitude to my friends and all who contributed in one way or other in the course of this study.

Thanks and regards

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CHAPTER 1

INTRODUCTION

The soils of the humid tropics have been shown to be managerially problematic, particularly with regard to their fertility. In an undisturbed environment, these soils are inherently infertile. Like all acid soils of the humid tropics, these soils are low in soil pH, which brings with it many potential associated problems, including H, Al, and Mn toxicity, Ca deficiency, low CEC, P fixation and low microbial activity (Tessens and Shamshuddin, 1983; Foy, 1984). Their shallow top soils are highly susceptible to erosion and, if not managed properly after clearing, can lose much of their original fertility and beneficial physical properties. Reviews on the characteristics and management of these soils did not take into account the effect of terracing in exposing saprolites or C horizon. With the surface soils and subsoils already being considered problematic, one could only imagine what impact the saprolites pose to the fertility of these soils. In this paper, we attempt to characterize the changes in soil chemical properties when these soils are exposed for slope terracing. To achieve this, two states Perak and Selangor- places of terraced-saprolitic profiles of different geology and locations were selected for further investigation in order to forecast the potential of slope failure by soil chemical analysis.

1.1 RESEARCH BACKGROUND

The soils of the tropics have long been considered problem soils compared to their counterparts in temperate areas. Malaysia has a hot humid climate where these high temperatures and heavy rainfall, acting over a wide variety of parent materials, have produced a wide range of soils. Problem soils are defined as those which require special management practices for their economic use in agricultural production. In general, problem soils are of the lowest priority for agricultural use. However, when population pressure demands it, such soils have to be utilised. There are four groups of problem soils found in Malaysia which are Oxisols, acid sulphate soils, sandy soils and organic soils.

The rapid weathering in the tropical environment of Malaysia results in soils dominated by kaolinite, iron oxides and aluminium oxides. Such soils have been classified as Oxisols according to the Soil Taxonomy (Soil Survey Staff, 1975). These soils are often deep, friable red soils, which appear at a glance to be excellent for agriculture. However, they are often rich in iron and aluminium oxides, are somewhat excessively drained and have a low to very low cation exchange capacity. Most of the physico-chemical properties of these soils are related to their mineralogy which takes place during soil formation (Tavernier and Eswaran, 1972). Such soils are in the oxic (haplic and acric) stage of soil formation and are dominated by oxides and oxyhydrates-gibbsite, goethite and hematite, with kaolinite as the dominant aluminosilicate mineral. As these minerals have low nutrient retention properties, this implies that with progressive weathering, the soil is reduced almost to an inert medium. In addition to this low fertility status, many such soils also have a high iron content. This is inherited from the iron-rich rocks, such as serpentines, basalts and andesites, from which the soils have developed. The high iron content of these Oxisols causes aggregation of the clay fraction to form pseudosilts and pseudosands and even the formation of clay balls. Such an aggregation of the clay results in a soil that is excessively drained and highly porous, with a low moisture content (Eswaran and Sys, 1975). Chemically these Oxisols also present problems, as the mineralogical composition gives special charge characteristics to the soils. In some Oxisols of Malaysia (Paramananthan and Lim, 1978) the net charge is low or even positive, indicating that the nutrient retention capacity is low. The charge in these Oxisols is dominated by high pH dependent or variable charges while aluminium saturation often exceeds 60%. Occasionally some micronutrients toxicity, such as nickel and chromium, has been reported (Paramananthan, 1977). As a consequence of all these properties, the highly weathered Oxisols of Malaysia can be considered problem soils and the potential of soil failure at slope areas is high.

1.2 AIM

The aim of the study is to understand the potential and limitation of highly weathered soil (Oxisols).

1.3 OBJECTIVES

1. soils that is significantly relevant to stable slopes. To determine the concentration of heavy metals, namely Aluminium (Al), lead (Pb), Ferum (Fe), Zinc (Zn), copper (Cu), Calcium (Ca), Natrium (Na), Manganese (Mn), and Chromium (Cr) in highly weathered
2. To determine the concentration of heavy metals in highly weathered soil that is significantly relevant to unstable slopes.
3. To identify key factors to predict shallow slope failure using chemical properties.

1.4 ISSUES

In Malaysia, slope terracing is an unavoidable procedure in the preparation of crop plantation, oil palm cultivation or highway construction. The cutting for a terrace bench can be more than a meter deep, which exposes the upper saprolite (commonly cited as the C horizon) to the surface or near to the surface. The plants or crops planted on hilly and upland areas will eventually be utilizing saprolite as the growing substrate. Oil palm is one of the major plantation crops in Malaysia, and is cultivated on inland areas especially in these type of soils, some rugged, hilly and steep (Hamdan *et al.,* 2000)**.** According to the Malaysia Land Conservation Act (1960), the utilization of slopes >20° for agriculture is not recommended. Owing to increasing land pressure and also the lack of enforcement, this Act has not been strictly followed (Aminuddin *et al.*, 1990). Some observations have shown that where slopes are >10°, terracing will expose saprolites directly to the surface (Burnham, 1978; Hamdan, 1995). These observations, however, noted that the tendency towards saprolite exposure would depend upon the soil depth and terracing techniques. The soils of the humid tropics have been shown to be managerially problematic, particularly with regard to their fertility. Reviews of research work and crop yields on current plantations in Malaysia, Thailand and Indonesia have significantly shown that such fertility constraints could be improved. Poor fertility of the saprolite is more complex, and could impose a serious limitation to crop production in the upland areas. However, their chemical and physical properties and the potential problems related to these properties is a greater cause for concern. Unlike ordinary soil materials, which can be amended and improved to suit crop requirements, saprolites are more difficult as they are partly weathered parent materials. At even deeper zones, these materials are composed of rock fragments and corestones. The root permeability, moisture availability, poor drainage, compaction, crust formation and runoff are some of the potential problems of saprolites that limit crop productivity and cause vulnerability to slope landslide (Hamdan *et al.,* 2000). At present, no work has been done that deals with the properties, utilization, problems and management of exposed saprolite in sloppy areas. Eswaran and Wong (1978) noted that in such steep terraced areas where saprolites are exposed, their characterization and interpretation of agricultural potential based on soil information become less meaningful. Future work on the amelioration of exposed saprolite materials to improve their sustainability for agriculture production and also for landslide prevention is necessary.

1.5 CONCLUSION

This chapter aims to briefly discuss an introduction to the research, some background, objectives, and scope of the study and main issues of the research.

CHAPTER 2

LITERATURE REVIEW

A thorough literature review is needed to show the interrelation between shallow slope landslide, Oxisol soil and heavy metal elements as a slope failure indicator.

2.1 SHALLOW SLOPE FAILURE

In recent years there has been an increasing concern over soil erosion throughout Malaysia. Accelerated soil erosion is either seen as the result of logging activities, the introduction of rubber plantations, tin mining activities or deforestation associated with land conversion for agriculture, development and construction. There has been much research conducted on landslides, but most of them focused on how the land falls were caused by physical reactions of soil affected by nature (Rickson & Morgan, 1995). Nevertheless, the chemical and physical properties of the soil are very important for overall soil stability (Sidle & Ochiai, 2006). Understanding the initiation of landslides or other mass wasting events, i.e. soil failure due to mechanical reasons connected with water saturation or gravity, is a primary factor for prediction. Five functional categories of mass movements were identified by Sidle and Ochiai (2006), which are:

1. Shallow, rapid landslides (debris slides, avalanches, flows)
2. Rapid, deep slides and flows
3. Slower, deep-seated landslides (slumps, earth flows, lateral spreads)
4. Slow flows and deformations (soil creep)
5. Surficial mass wasting (not by water, only gravity)

The main physical factors which influence landslide occurrence are:

1. Geological factors (rock characteristics, weathering, bedrock structure, tectonics)
2. Soil engineering, chemical and mineralogical factors (soil shear strength)
3. Geomorphic factors (slope gradient, slope shape, aspect, altitude, soil depth, etc.)
4. Hydrologic factors (precipitation, infiltration, soil water flow processes, etc.)
5. Vegetation influences (woody vegetation)
6. Seismicity and volcanic effects

Some factors are predisposing factors and some are triggering factors of landslides.

In addition, from 1973 to 2007, some 440 landslides were reported. Of these, 31 cases involved fatalities. There have been slightly less than 600 deaths due to landslides in Malaysia since 1973; there are thousands more ‘unreported’ minor slope failures and landslides (National Slope master plan, 2009-2023). Moreover in December 2012, Malaysia suffered a very impressive failure in an engineered slope at Bukit Setiawangsa near Kuala Lumpur. Furthermore, in May 2013 at least five areas in the city were hit by landslides following heavy rains. The landslides resulted in traffic chaos as motorists had to be diverted following several road closures. The affected areas were the Bukit Nanas Forest Reserve in Jalan Ampang near the Bukit Nanas monorail station; Mahameru highway, Jalan Sultan Salahuddin, Jalan Kasah in Medan Damansara and Lorong Anggur, and Taman Shanghai in Jalan Klang Lama. During the 6.30pm incident on a Tuesday in Jalan Ampang, nine cars parked at a private parking lot near the Jalan Dang Wangi intersection were buried under the rubble (see Figure 2.1, The Star, 2013).

Figure 1.1**:** Buried**:** The landslide buried nine cars at a carpark near Jalan Ampang in recent case at Kuala Lumpur city.

Apart from the tragedies in Setiawangsa, there were many cases reported on engineered slope failure, one of which was in 2009, at MRSM Bentong (Figure 2.2).

Figure 1.2: Photo on soil nailed wall failure at MRSM Bentong in 2009

This shows that in certain cases, eventhough soil nail was designed in line with international practice, slope failure still occurred (National Slope master plan 2009-2023).

Nevertheless, small slope failures like erosion and small localized failures still happen due to rainfall. The familiar locations of landslide are Hulu Kelang in Selangor, Cameron Highlands and Bukit Fraser in Pahang, the East Coast area of Penang Island, Gunung Raya in Langkawi Island, Kapit and Miri in Sarawak, Sandakan and the foot of Mount Kinabalu area in Sabah. The normal statistics show that landslides normally occur from the months of April to June and August to December.

2.2 OXISOL SOIL

There is diversity in the types of soils we find in the humid tropics, but the most distinctive and common soils found are termed Oxisols. Processes such as hydrolysis, hydration, dissolution, oxidation, leaching, desilication, acidification and lessivage occur at constantly high rates in these soils. This means that the soils contain few weatherable minerals, have high levels of secondary minerals, low pH, deep profiles and high levels of available aluminium. The clays they contain are kaolinitic clay minerals and clay sized oxides and hydroxides of metals such as iron and aluminium, which have reduced abilities to retain plant nutrients. As these soils are acidic, certain elements such as aluminium, which is toxic to many crop species, become mobile and the sesquioxides in these soils fix phosphorous, making it unavailable for plant uptake. Some of these soils have stable aggregates made up of clays and sesquioxides bound together and are approximately 1-10 mm in size. These aggregates are water-stable and provide excellent drainage and also accelerate leaching process through the profile. Where drainage is impeded at depth and there is a concentration of sesquioxides and clays a hard 'laterite' (from the latin 'later', meaning brick) (also called plinthite) pan can develop inhibiting rooting depth and aeration. The figure below shows the global distribution of Oxisols.

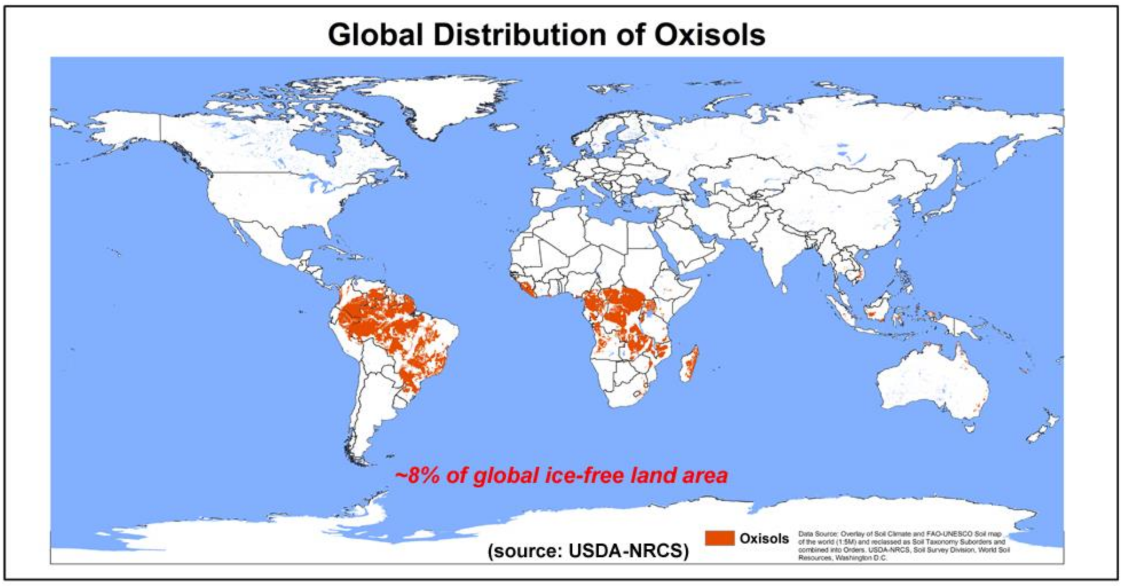

Figure 1.3: Oxisols make up about 8% of the world’s ice free land surface

In Malaysia, many of the soils in the upland areas are highly weathered. These soils which are classified as Oxisols are dominated by kaolinite, gibbsite, goethite and hematite in the clay fraction (Tessens & Shamshuddin, 1983). These minerals are termed as variable-charge minerals (Uehara & Gillman, 1981). Oxisols in the country are developed on shale, schist, basalt, andesite, granodiorite, serpentinite and limestone, but the most weathered of them all are those formed on basalt, andesite and serpentinite.

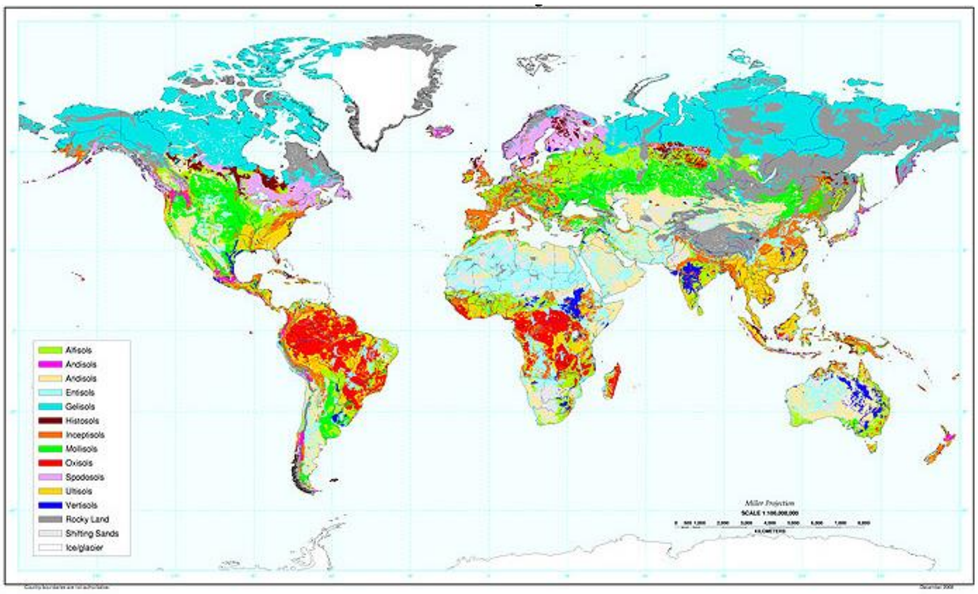

Figure1.4: Global Classification of soil shows that soil in Malaysia is mostly oxisol and Ultisols.

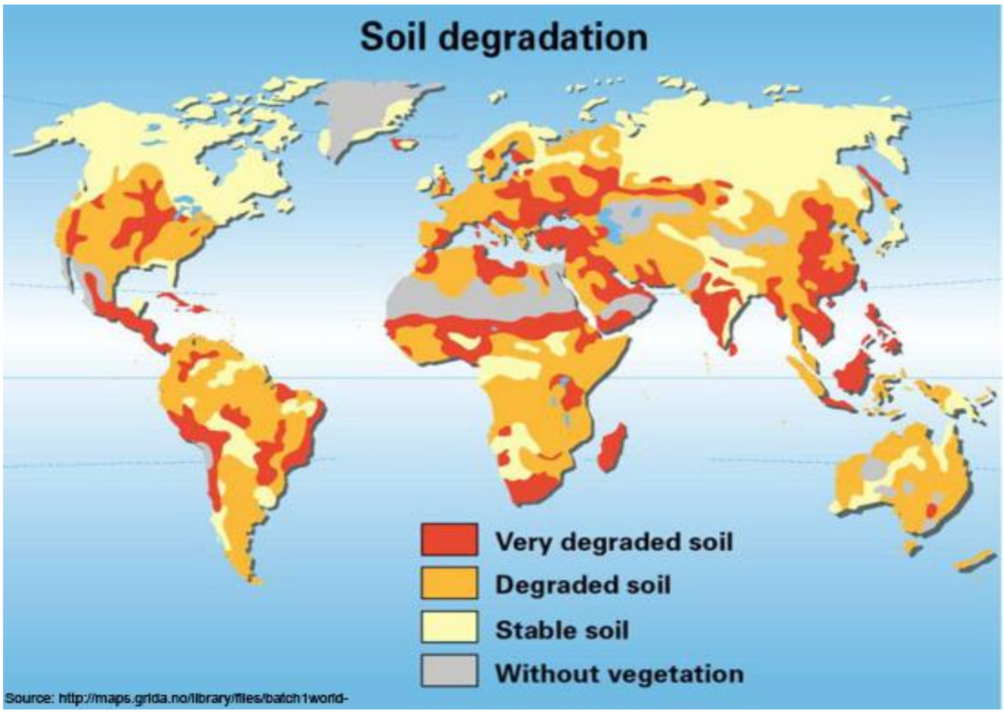

Figure 1.5: Soil degradation map, Malaysia soil falls under very degraded and degraded soil.