KEY INDICATOR TOOLS FOR SHALLOW SLOPE FAILURE USING SOIL CHEMICAL PROPERTIES SIGNATURES AND SOIL COLOR VARIABLES

BY

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ABSTRACT

Slope failure has become a major concern in Malaysia due to the rapid development and urbanization in the country. It poses severe threats to any highway construction industry, residential areas, natural resources, as well as tourism activities. The extent of damages resulted from this catastrophe can be lessened if a long-term early warning system to predict landslide prone areas is implemented. Thus, this study aimed to develop key indicator tools to predict shallow slope failure based on soil chemical properties and soil color variables. The concentration of each soil properties and chromaticity in both stable and unstable slope soil samples was evaluated using ICP-MS and Remote DRA Cary-50 chroma meter from two different localities that consist of 120 soil samples located along the South Highway (PLUS) and the East Coast Highway (LPT). This study established a marked difference ($P<0.0001$) of positive correlation between soil properties concentrations and slope failures. Soil texture, total organic carbon (TOC), soil pH, iron oxide and aluminium concentration were the environmental variables that strongly correlated with soil color variables at the studied area. Indicators that could be used to predict shallow slope failure were high value of L* (62), low values of c* (20) and h* (66) with indication between 5 YR to 10 YR, low concentration of iron (53 $mgkg^{-1}$) and aluminium oxide (37 $mgkg^{-1}$), low soil total organic carbon (0.5%), low soil cation exchange capacity (3.6 cmol/kg), slightly acidic (pH 4.9), high amount of sand fraction (68 %) and low amount of clay fraction (20%) in soil particles. The reactions and distinctive changes of soil properties between stable and unstable slopes were emphasized as results of highly significant differences were perceived between soil properties, the locations, slope stability and combinations of all interactions. By identifying the key factors controlling slope stability, a greater understanding of how the properties of Oxisols influenced the slope stability in response to interactions with environmental factors would be gained. Besides, the control of such damaging effects would require proper soil conservation strategies such as proper land leveling, afforestation, fallowing, terracing and inclusion of restorative vegetation on the slopes. Therefore, new rating system for shallow slope failure can be developed by implementing these findings as key indicators. The approach of using soil properties to predict the landslide prone areas has never been verified in highway construction industry and also in other industries in Malaysia. This approach is appropriate to be implemented as an indicator to categorize the prospective areas of unstable slopes and simultaneously helps in improving slope stability and safety for future development. Additionally, the mass movement also can be avoided by identifying the areas with the probability of experiencing slope failures at the preliminary phase of development.

ملخص البحث

أصبح انهيار المنحدرات مصدر قلق كبير في ماليزيا والذي نتج بسبب التطور السريع والتحضر في البلاد. تشكل انهيار المنحدرات تهديدا خطيرا على قطاع بناء الطرق السريعة، والمناطق السكنية، والموارد الطبيعية، وبالإضافة إلى الأنشطة السياحية. بالإمكان تقليل مدى الأضرار الناتجة عن هذه الكوارث عن طريق تطبيق أنظمة إنذار مبكر طويل الأمد للتنبؤ بالمناطق المعرضة للانهيارات الأرضية. هدفت هذه الدراسة إلى تطوير أدوات للمؤشرات الرئيسية من أجل التنبؤ بانهيار المنحدرات المنخفضة بالاعتماد على الخواص الكيميائية للتربة ومتغيرات ألوان التربة. تم تقييم تركيز كل من خصائص التربة ولونيتها في عينات تربة المنحدرات المستقرة والغير المستقرة باستخدام المطياف الكتلي البلازمي بالتقارن الحثي (ICP-MS) ومقياس DA Cary-50 لمنطقتين مختلفتين والتي تكونت من ١٢٠ عينة ترابية تقع على طول الخط الجنوبي السريع (PLUS) و خط الساحل الشرقي (LPT). أثبتت هذه الدراسة فرقاً واضحاً (P <0.0001) للارتباط الإيجابي بين تراكيز خصائص التربة، وانهيار المنحدرات. كانت متغيرات قوام التربة، والكربون العضوي الكلي (TOC)، ودرجة الحموضة التربة، وتراكيز أكسيد الحديد والألمنيوم البيئية مرتبطة بقوة مع متغيرات لون التربة في المنطقة المدروسة. المؤشرات التي بالامكان استخدامها للتنبؤ بانهيار المنحدرات المنخفضة كانت: قيمة L *(٦٢)، وقيم c *(٢٠) و h* (٦٦) منخفضة مع مؤشر بين ٥ YR إلى ١٠ YR ، وتركيز منخفض للحديد (٥٣ مغ/كغم) وأكسيد الألومنيوم (٣٧ مغ/كغم) ، وإجمالي الكربون العضوي المنخفض للتربة (٠,٥٪) ، وسعة تبادل الكاتيون المنخفض (٣,٦ سنتيمتر/كجم) ، والحمضية قليلا (٤,٩ درجة حموضة) ، وكمية كبيرة من أجزاء الرمل (٦٨%)، وكمية منخفضة من أجزاء الطين (٢٠ ٪) في جزيئات التربة. تم التركيز على التفاعلات والتغييرات المميزة لخصائص التربة بين المنحدرات المستقرة وغير المستقرة كنتائج بفروق ذات دلالة معنوية بين خصائص التربة، والمواقع، وثبات المنحدرات، ومزيج جميع التفاعلات. سيتم فهم كيفية تأثير خصائص الأوكسيسولات على استقرار المنحدر استجابة للتفاعلات مع العوامل البيئية بشكل أفضل من خلال تحديد العوامل الرئيسية التي تتحكم في استقرار المنحدرات. وبالإضافة إلى ذلك فإن التحكم في هذه التأثيرات الضارة يتطلب استراتيجيات سليمة للمحافظة على التربة مثل التسوية المناسبة للأراضي، والتحريج، والإراحة، وعمل المصاطب، وإدراج النباتات الداعمة على المنحدرات. لذلك بالإمكان تطوير نظام تصنيف جديد بانهيار المنحدرات المنخفضة عن طريق تطبيق هذه النتائج كمؤشرات رئيسية. لم يتم من قبل استخدام خصائص التربة للتنبؤ بالمناطق المعرضة للانهيارات الأرضية واختبارها في قطاع بناء الطرق السريعة وفي القطاعات الأخرى في ماليزيا. هذه الطريقة مناسبة للتطبيق كمؤشر لتصنيف المناطق المحتملة لحوادث المنحدرات الغير مستقرة، وتساعد في الوقت نفسه في تقوية استقرار المنحدرات وتحسين السلامة للتنمية المستقبلية. بالإضافة إلى ذلك فإنه بالإمكان تجنب الحركة الكتلية عن طريق تحديد المناطق المحتمل انهيار منحدراتها في المراحل الأولية من التطوير.

APPROVAL PAGE

The dissertation of Mohd Shah Irani Bin Hasni has been approved by the following:

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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.

Mohd Shah Irani Bin Hasni

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This dissertation is dedicated to my beloved parents

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In the Name of Allah, the Most Beneficent and the Most Merciful,

All the praises and thanks to Allah (SWT), to whom ultimately we depend for sustenance, guidance and the Creator who is ultimate source of knowledge and wisdoms endowed to mankind.

It is my ardent hope that the thesis I wrote will be benefited by others who possess the interest and passion to study on slope soil properties. All the methods and techniques had been explained in detail with diagrams and features. I wish one day my findings will contribute to a significant use for the state government especially relating to catastrophe management of slope failure. It also can generate other novel ideas to prevent slope failure by controlling soil properties index either by engineering or other technologies.

Special thanks goes to my enthusiastic supervisor, Associate Professor Dr. Rashidi bin Othman and Co-supervisor, Assistant Professor Dr. Zainul Mukrim bin Baharuddin. My research has been an amazing experience and I thank them wholeheartedly, not only for their tremendous academic support, but also for giving me plenty of wonderful opportunities and always dedicated to assist me in solving the confusions and guide me to the right path towards the final result of the thesis.

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LIST OF ABBREVIATIONS

%	Percent	mL	Mililiter
<	Less than	ICP-MS	Inductively coupled plasma mass spectrometry
>	More than	IETC	International Environmental Technology Center
°C	Degree celcius	IUCN	International Union for the Conservation of Nature
MΩ	Mega-ohm	KED	Kinetic energy discrimination
		Kg	Kilogram
Al	Aluminium	KOH	Potassium hydroxide
$Al_2O_{12}S_3$	Aluminium sulfate	L	Liter
ANOVA	Analysis of Variance	mg/kg	Milligram per kilogram
BOD	Biochemical Oxygen Demand	mg/L	Miligram per liter
CCOHS	Canadian Centre for Occupational Health and Safety	Mg	Magnesium
Cd	Cadmium	MgO	Magnesium Oxide
CEC	Cation exchange capacity	MHLG	Ministry of House and Local Government
CO_2	Carbon dioxide	Mn	Manganese
COD	Chemical Oxygen Demand	$MnSO_4$	Manganese (II) Sulfate
Cr	Chromium	M_1	Stock concentration
Cu	Copper	M_2	Desired concentration
DI	Deionized	MS	Murashige and Skoog
DNA	DeoxyriboNucleic Acid	NEB	Nebulizer
DO	dissolved oxygen	NH_3-N	Ammoniacal Nitrogen
EPA	Environment Protection Agency	Ni	Nickel
Fe	Iron	Pb	Lead
$FeSO_4.7H_20$	Ferrous sulfate heptahydrate	PFA	perfluoroalkoxy polymer
G	Gram	pH	Potential of hydrogen
H_2O_2	Hydrogen peroxides	ppb	Parts perbillion
H_2O	Water	ppm	Parts permillion
HNO_3	Nitric acid	PSII	photosystem II
H+	Hydrogen ion	USEPA	United States Environmental Policy Agency
HCl	Hydrochloric acid	UV	ultraviolet
QC	Quality control	V_1	Volume of stock needed

STD	Standard mode	V_2	Final volume
TDS	Total dissolve solid	WWF	World Wide Fund For Nature
U	Uranium	Zn	Zinc
μg/L	Microgram perliter		
USD	United States Dollar		

CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND: SOIL EROSION AND GLOBAL AGENDA

United Nations (UN) and other international organizations have produced numerous reports in relation to the need to emphasize on soil studies and the establishment of adequate soil information. World leaders had adopted the United Nations Millennium Declaration in September 2000 to set out the Millennium Development Goals (MDGs). Series of references and recommendation regarding soil health and the relationship between unhealthy soil and poor soil management were made and reinforced in the MDG reports (UN Millennium Project, 2005). An annual report of Human Development was published by UNDP to measure and evaluate the developmental progress since 1990. The information regarding soils only started to be reported in 2003 Human Development Report and soils were only mentioned in few parts of the report which generally directed on the soil degradation and nutrient depletion and other issue such as indigenous soil was also stated in the sequential reports. Moreover, the latest report regarding soils discussed on the significance of soil to perform as sinks and sources of greenhouse gases, soil fertility failure, soil erosion and the effects to the future development (UNDP, 2007). Essentially, the information on soils with other related information and their revolution such as new technologies to solve problems regarding soils in the reports are very crucial as this global agenda is frequently asked and utilized by the other scientific disciplines, society, decision and policy makers.

Healthy soils are needed by all communities and societies for various reasons such as for economic and social well-being and provision of ecosystem goods and services (Millennium Ecosystem Assessment, 2005). Thus, it is essential to monitor the quality of soils and to gather the information on their functions and properties. With these information, numerous benefits can be gained including protection of the environment via interactions between soils, water and air, maintenance of habitats and biodiversity, preservation of archaeological residues, establishment of a platform for structure and provision of raw resources (Blum, 2005). The European Communities Framework Directive has formed the foundation for the proposed legislative protection of soils and has recognised the necessities for soil protection and management within the UK policy framework via the recognised implication of these functions (Commission of the European Communities, 2006a, b; SEPA, 2001; Defra, 2004; Environment Agency, 2004; Towers, 2006). However, these policies face several challenging scientific issues as soils are amongst the most complex systems on the planet.

Soils have been categorised as one of the main features of the natural resources in terrestrial ecosystems. In order to manage and monitor soils at local, regional and national-scales, there is a need to improve the list of requirements in the policy. Yet, it remains unclear which properties of soils are most appropriately monitored due to the extensive series of goods and services and the inherent chemical, physical and biological complexities contained in soils. The physio-chemical properties of soils have hitherto provided the fundamental context in which such functions operate and have clear utility in assessing ecological status and the majority of soil processes are driven by the soil biota. Nevertheless, a mechanistic understanding of the interactions between soil biodiversity and its role is indisputably complex and continuously indescribable both in relation to the soil as an ecosystem in itself or as part of a greater ecosystem (Bardgett et al., 2005; Fitter et al., 2005; Hooper et al., 2005).

Generally, industrialized and developing countries give great impacts to Nature such as soil erosion and land degradation resulting from the increasing population and enlargement of settlements and life-lines which are located at hazardous areas. To supervise these natural hazards, major forces and rational land-use procedures by the third world countries are necessary. But, they are causing difficulties to them since the costs for the works are expensive. Same goes to the industrialized societies as they are unwilling to pay the costs in structural procedures that can minimize natural risks. In addition, the soil erosion trend has increased significantly owing to improper changes in land usage and ranked10th among the most devastating natural disasters in the world occurring across almost all terrains with steep slopes singled out as the most susceptible to sliding (Schuster and Highland, 2003; Highland and Bobrowsky, 2008; Leroy and Grachera, 2013). Marques (2007) reported an annual rate of soil erosion of 30–40 tonne/ha in developed countries of Asia, Africa and South America. On a global scale, the annual loss of 75 billion tons of soil costs the world about US$400 billion per year or approximately US$70 per person per year (Eswaran, 2008). Soil erosion from catchments with natural forests is minimal, but levels of soil erosion tend to increase when natural forest is changed to tree crop plantations. Significant dissimilarities usually depend on the soil properties, site influences and management practices (Towers, 2006).

1.1.1 Soil Erosion and Highway Construction Industry

One of the factors increasing the soil loss is the road construction that involves the processes of cutting and filling the slopes, removal of forest vegetation and