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Analysis of heavy metals as a key indicator to predict shallow slope failure

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Abstract

Degradation or decline of soil quality that cause shallow slope failure may occur due to physical or chemical processes. It can be triggered off by natural phenomena, or induced by human activity through misuse of land resources, excessive development and urbanization leading to deforestation and erosion of covered soil masses causing serious threat to slopes. The extent of damage of the slopes can be minimized if a long-term early warning system is predicted in the landslide prone areas. The aim of the study was to characterize chemical properties of stable and unstable slope along selected highways of Malaysia which can be manipulated as indicator to forecast shallow slope failure. The elements in soil chemical properties contributed to each other as binding agents that affected the existing soil structure. It could make the soil structure strong or weak. Indicators that can be used to predict shallow slope failure were low content in iron, lead, aluminum, chromium, zinc, low content of organic carbon and CEC.

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Introduction

In Malaysia, landslides have always pose threats to settlements and structures which are significant for transportations, natural resources and tourism. The issues regarding landslides have always been closely related to the soil factors (Harwant, 2006). Like all the acidic soils of humid tropics such as sandy soil, highly weathered soil (oxisols) are low in soil pH, which brings many potential problems, including heavy metal toxicity, Ca deficiency, low CEC, P fixation and low microbial activity (Tessens and Shamshuddin, 1983; Foy, 1984). The shallow top oxisols are highly susceptible to erosion, if they are not managed properly after clearing. They can also lose much of their original fertility and beneficial physical properties.

The chemical and physical properties of soil are very important for overall soil stability (Sidle and Ochiai, 2006). Degradation or decline in soil quality can occur due to physical or chemical processes that are triggered off by natural phenomena or human activity through misuse of land resources. There are numerous indicators of soil quality. Physical indicators can be measured by investigating some of the fundamental physical characteristics of soil such as water infiltration or field water holding capacity, while soils' chemical indicators of soil are determined by parameters arising from the presence of certain amounts and certain types of soil colloids, such as clays and organic matter (Brady and Weil, 2002). The chemical properties of soils are different in different areas, and depends on the state or region. The landslide problem might be caused by chemical properties inside the soil which causes shallow slope failure. Therefore, it is vital to identify and analyze the potential slope failure in the surrounding areas.

The study on the chemical properties of soil on hilly area that affects shallow slope failure focuses on heavy metal content in soils that create a hazard monitoring system to identify potential shallow slope failure areas. In the present study, an attempt has been made to characterize the changes in chemical properties of soil when soils were exposed to slope terracing. To achieve this, locations with terraced-saprolitic profiles of different geological areas and locations were selected in two states (Selangor and Perak) to forecast the potential of slope failure by chemical analysis of soil.

Materials and Methods

Study areas and sampling sites : Different sites in two different states of Malaysia were selected as study sites in this research situated in Perak and Selangor states. In Perak, 8 different locations were identified and the areas specifically focused on 4 for stable and 4 for unstable slopes; all the chosen sites were located along the highways (Tanjung Malim Route). Similarly in Selangor 13 locations were identified which consisted of 10 unstable slopes and 3 stable slopes. In total, 21 sites were studied from these 2 different localities in Peninsular Malaysia (Fig. 1 and 2).

Fig. 1 : 8 different locations in Perak along TanjungMalim Highway

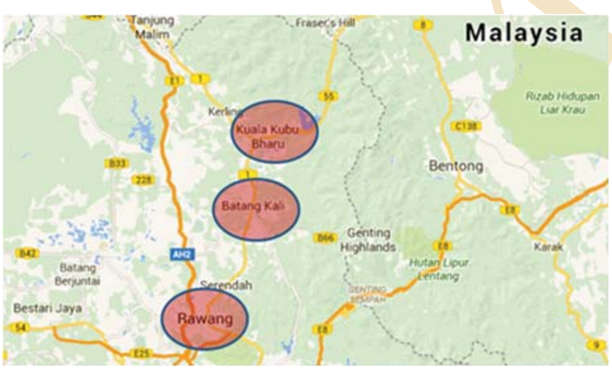

Fig. 2 : 13 different locations in Selangor along Rawang Highway

Method of soil sampling : Out of the 21 sampling points, 14 samples belong to unstable slope and 7 belonged to stable slope (0 to 200 mm depth). Soil samples were air dried at 80 ºC for 3 to 4 days and passed through a 2.00 mm (10 meshes) sieve and were stored in plastic bags. After that, about 0.2 g of sample were accurately weighed in a container made of PFA (peruoroalkoxy polymer), which was then placed in a microwave pressure vessel. After adding 2.5ml of concentrated nitric acid and 10 ml of concentrated hydrochloric acid, the samples were digested using microwave power that progressed to increase up to 400W for 40 mins. After cooling process, the solutions were accurately diluted in 50 ml water. The operating parameters for the working elements were set following standard protocol US EPA 3051A. All the solutions were further analyzed in laboratories by ICP-MS in triplicate for each sample.

Results and Discussion

Heavy metals concentration : In Selangor, the results obtained from T-test analysis showed significant difference in Fe, Al, Zn, Cr and Pb concentration in soil of stable and unstable slopes as shown in Table 1 and 2. The concentration of Fe was higher in stable slopes in comparison to unstable slopes. Moreover, a high concentration of Al also has been detected in soil at the stable slope areas. The concentration of Al and Fe possess significant relationship with oxisol soil; the degree of Al substitution in iron oxides. This can reflect the environment in which they are formed (Schwertmann and Kampf, 1985; Schwertmann, 1988b). The concentration of Cr was quite balanced between the stable and unstable slope. Furthermore, the results revealed that the concentration of Zn and Pb were higher in the stable slopes rather than in the unstable slopes. The concentration of Pb was higher in the stable slopes. These findings demonstrated an apparent influence of heavy metals in soils at stable and unstable slope areas.

Relationship between heavy metal content, CEC, soil texture, organic carbon and shallow slope failure : The analysis showed high content of heavy metals indicates that soils rich in organic carbon have high content of CEC activities, which is responsible for the additional stability level of soil. This was because of laterisation process in which the tissues from the existing plants growing on the slopes might have been deposited in the soil through leaf litters and built organic soil matters. The organic matter

Table 1 : Total heavy metals content in soil samples at stable and unstable slope areas in Perak along TanjungMalimHighway

Stable slope				
Heavy metal content	**S1-UPSI**	**S2-UPSI**	**S3-UPSI**	**S4-P.CITY**
Fe mg kg^{-1}	950±24	975 ± 19	975 ± 3	775 ± 13
Al mg kg^{-1}	954 ±32	263 ±193	279 ±403	281±451
Cr mg kg^{-1}	0.1 ±0.1	0.066 ±0.04	0.046 ± 0.06	ND
Zn mg kg^{-1}	0.067 ± 0.01	0.052 ± 0.006	0.039 ± 0.002	0.019 ± 0.003
Pb mg kg^{-1}	0.032± 0.01	0.052± 0.04	0.2± 0.031	0.020 ± 0.013
Unstable slope				
Heavy metal content	**S5**	**S6**	**S7**	**S8**
Fe mg kg^{-1}	11±19	14 ± 5	22 ± 8	27 ± 16
Al mg kg^{-1}	64 ±17.4	119 ± 60	93 ±8.6	29 ± 14
Cr mg kg^{-1}	0.056 ± 0.033	0.029 ± 0.07	0.034.6 ± 0.024	0.011 ± 0.001.3
Zn mg kg^{-1}	0.033 ± 0.01	0.051 ± 0.005	0.058 ± 0.018	0.039 ± 0.014
Pb mg kg^{-1}	0.030.7 +0.002	0.018 ± 0.009	0.018 ± 0.018	0.0025 ± 0.015

*ND: Not detected

Table 2 : Total heavy metals content in soil samples at stable slope and unstable slope areas in Selangor along Rawang Highway

Stable slope					
Heavy metal content	**S1**	**S2**	**S3**		
Fe mg kg^{-1}	87+39	187+ 236	110 + 185		
Al mg kg^{-1}	392 +214	254 +14.2	220 +256		
Cr mg kg^{-1}	0.225 +0.166	0.071 +0.015	0.0015 +0.0025		
Zn mg kg^{-1}	0.76 +0.022	ND	ND		
Pb mg kg^{-1}	0.035 +0.002	0.032 +0.021	ND		
Unstable slope					
Heavy metal content	**S4**	**S5**	**S6**	**S7**	**S8**
Fe mg kg^{-1}	13 +3.6	0.72 + 0.38	5.1 + 1.8	23 + 6.2	71 + 49.3
Al mg kg^{-1}	3.2 +3.1	3.8 + 2.1	3.4 +3.5	72.9 + 21.6	183 + 123
Cr mg kg^{-1}	ND	ND	ND	0.076 +0.021	0.199 +0.133
Zn mg kg^{-1}	ND	ND	ND	0.109 +0.04	0.143 +0.132
Pb mg kg^{-1}	ND	ND	0.021 +0.035	31 +10	11.4+8.4
Heavy metal content	**S9**	**S10**	**S11**	**S12**	**S13**
Fe mg kg^{-1}	42.6 + 37.2	33 + 13	30.8 + 4.2	31.9 + 9.3	36.7 + 1.2
Al mg kg^{-1}	125 + 74.5	148 + 64	201 + 15.9	144 +2.5	129 +5.1
Cr mg kg^{-1}	0.115 +0.099	0.094 +0.037	0.087 +0.007	ND	0.113 +0.005
Zn mg kg^{-1}	0.097 +0.037	0.094 +0.037	0.041 +0.024	0.104 +0.077	0.062 +0.005
Pb mg kg^{-1}	6.6 +5.6	5.6 +2.3	6.8 +0.4	4.6 +1.2	3.8+0.74

*ND: Not detected

content increased with the CEC activities and micronutrients in the soil. Therefore, lower content of heavy metals showed that soil possessed low organic carbon and CEC activities. This resulted in the instability of soil. This type of soil under went a rapid process of laterisation. In this process, the primary mineral was most probably absent and contributed to low CEC activities, low micronutrients and low moisture retention, or low water holding capacity. The soil eventually becames acidic, infertile and unstable.

The results showed that total aluminium, zinc, iron and lead content was higher in soils from stable slope as compared to soils from unstable slope from both the states. Moreover, heavy metal content usually decreased from clay to coarse silt due to high surface area of clay minerals and weak pH depending on the CEC activities. Soil with high amount of clay and organic matters can contribute more heavy metals than others. Hence, high clay content contributed to high CEC content in unstable slopes. This caused binding of positively charged heavy metals with the high clay content,

Table 3 : Key indicator to predict shallow slope failure based on soil chemical properties for 21 sites

Heavy metals (mg kg^{-1})	Unstable slope			
	High risk	Medium risk		Low risk
	I	II (A)	II (B)	III
Fe	20	50	100	150
Al	200	250	350	400
Zn	0.1	0.2	0.3	0.35
Pb	0.05	10	20	28
Cr	0.08	0.09	0.1	0.2
		Stable slope		
	Less stable	Stable	Most stable	
	I	II (A)	II (B)	III
Fe	500	1000	1500	3500
Al	600	800	1000	1600
Zn	0.05	0.06	0.08	0.09
Pb	30	35	40	46
Cr	0.3	0.4	0.5	0.6

which are negatively charged (Dube, 2000). The conditions contribute to the stability of soil since negative clay ions and positive ions of heavy metals are bonded to each other. Jamal and Nuranina (2005) stated that nitrogen and CEC contents were significantly correlated to aggregate stability due to the clay content in soil. The key indicator to predict shallow slope failure based on soil chemical properties for 21 sites are clearly summarized in Table 3.

Highly significant differences were observed between the heavy metal content, the locations, the slope stability, and all combinations of interactions. These variations indicate that changes in heavy metal composition are unique and the responses are prominent between stable and unstable slopes. The effects of soil chemical properties cannot be denied and should be further investigated. Therefore, by identifying the key factors controlling slope failure a greater understanding of how soil chemical actions influence slope stability in response to interactions with environmental factors will emerge.

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