International Journal of Latest Research in Humanities and Social Science (IJLRHSS)
Volume 06 - Issue 07, 2023
www.ijlrhss.com || PP. 23-30

Role of Landscape Vegetation in Treating Slope Failure

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Abstract: Slope failure is becoming one of the world's environmental issues, including in Malaysia, that may affect the community and change the earth's surface. The decreased amount or the removal of forest vegetation species, especially on hillside areas because of hillside clearing, cutting, and fill processes, affect the slope stability. Many options exist to treat slope failure, including biological or landscape vegetation measures, which may offer the best option to cater to this problem for long-term benefit. Thus, this research aims to investigate the role of landscape vegetation in treating slope failure. For this purpose, a questionnaire survey, non-participant observation, and semi-structured interviews are performed to gain insights. The findings suggest vegetation plays a vital role in treating the slope, supported by the findings of the suitable characteristics of vegetation being able to protect against slope failure. As potential slope vegetation, the vegetation can protect the slope by absorbing moisture, strengthening the soil structure, and preventing surface water runoff through its mechanical and hydrological characteristics. Large canopy, deep root system, and fast-growing and native vegetation characteristics are needed for ecological treatment to sustain the long-term solution.

Keywords: Biological measure, forest removal, the role of vegetation, slope stability, vegetation's characteristics

Introduction

Slope failure is known as one of the natural phenomena disasters that may affect the community and environment. It may occur in a residential area, road, and other places. In the worst scenario, slope failure can also lead to a landslide disaster, which brings massive damage or changes to the earth's surface. According to Rahman and Mapjabil (2017, p.58), slope failure or landslide refers to the "movement of a mass of rock, debris or earth (soil) down a slope under the influence of gravity". They also stated that slope failure frequently happens in Malaysia, which can be proved from 1993 to 2011, in which 28 cases of slope failure or landslide were reported in Malaysia. This case caused more than 100 lives to be affected by it. One of the reports includes Highland Tower, Ulu Klang Selangor, which became a slope failure tragedy with a total loss of 48.

The decreased amount or removal of forest vegetation species and human activity to develop construction, especially in hillside areas, may affect slope stability (O'Loughlin, 1985). According to O'Loughlin (1985), there is a relationship between forest disturbances and slope stability. Similarly, this statement was also agreed upon by Vanacker (2019), who stated that the increase in population pressure and economic development made the authority decide the residents to move to the unstable hillside areas. For instance, in Ecuador, and South America, the Agrarian population must move to the prone to erosion area because of limited land use for new residential (Vanacker, 2019). Consequently, the demand to establish new development on the hillside area causes the removal of forest vegetation species or deforestation, leading to forest disturbance. The forest disturbances lead to slope instability as no more tree root reinforcement holds the soil structure. Besides, the type of vegetation characteristics that are not suitable to be planted on the slope might decrease the possibility of slope stability.

In response to the slope stability, the need for a sustainable approach should be highlighted where the natural or landscape vegetation measure may offer the best option to cater to this problem. According to Osman et al. (2014), the bioengineering practice refers to using vegetation combined with engineering, which can produce low cost of slope maintenance, high biodiversity, and self-sustainability if the slope is planted with the appropriate vegetation species and planting technique. However, there is insufficient research regarding landscape vegetation measures for slope treatment, especially in Malaysia. Thus, it is essential to perform this research to gain some insights to be a reference in the future for those who worked in the built environment field.

Literature Review

Historically, slope failure and landslide events are familiar everywhere, including Malaysia. As stated in The Star Online (Leoi et al., 2018), Malaysia is among the countries prone to landslides even as it sits among the

top ten countries with 171 landslides between 2007 and March 2016. Moreover, Malaysia experienced 18.5 landslides annually over the past ten years (The Star Online, Leoi et al., 2018). According to Rahman and Mapjabil (2017), the first slope failure or landslide event happened on 1 May 1961 at Ringlet, Cameron Highland, Pahang, killing at least 16 people. After that, this disaster continued from 1993 till today.

Factors of Slope

Failure Kazmi et al. (2016) mentioned three typical causes of the landslide, which are geological, morphological, and human causes, as stated in Table 1. Kazmi et al. (2016) indicated that human factors and human error cause slope failure in Malaysia due to human activities such as agriculture, deforestation, and so on contrast with human errors, which are due to design errors and the improper construction of the slope applied by humans that leads to the landslide.

From Table 1, the removal or cutting of forests belongs to both morphological and human causes groups, as referred to by the World Wildlife Fund (WWF, 2019). 40% of forest loss worldwide makes the number of degraded areas higher yearly. The demand for timber products, food, fuel construction, and building material cause humans to do illegal logging, exploitation of woods for fuel and charcoal, agriculture, farming, and hunting activities for their interest without having less awareness that it may create a harmful impact. Thus, it may harm the forest and lead to disaster or erosion (WWF,2019). Other than that, the factor that makes it contrast to the other countries is the weather. Malaysia is known as a tropical region with a humid climate which means Malaysia almost has the rainy season all over the place. The prolonged heavy intensity of rainfall with deforestation activity triggered the soil properties and caused trees to fall and leading to erosion. (Rahman and Mapjabil, 2017). Besides, the wrong selection of vegetation also may not provide treatment for the slope. For instance, the luxuriant vegetation might create the sliding force of the slope and therefore generate the instability of the slope. The deep root anchorage of the vegetation cannot extend to the stable rock soil, and it might not bring much positive impact in protecting the slope (Wang and Liu, 2018).

Table 1 The cause of the landslide
(Source: Kazmi et al. (2016) and National Geographic (2019)

Type of Causes	**Description**	**Examples**
Geological	Geology usually happens because the substance itself, such as the earth maybe fractured	• Splitting, jointing, shearing in materials • Poor or susceptible materials • Negatively acquainted (faults/bedding)
Morphological	The morphology is happening because of the structure of the land that might be triggered by something	• Weakening of the earth due to the high water table • Loss of vegetation • Weathering effects
Human Causes	The human cause includes the common activities on the slope or hillside	• Agriculture • Excavation • Construction • Deforestation

Vegetation as a Slope Treatment

According to Stokes et al. (2014), one of the best approaches to solving the slope failure issue is vegetation. Their journal, "Ecological Mitigation of Hillslope Instability: Ten Key Issues Facing Researchers and Practitioners", stated that vegetation could improve surface erosion and shallow landslide with proper management. These practices have already been applied in other countries. However, this environmental practice only started in Malaysia in a few years as professionals who worked in a built environment and the community became aware of this green technology. This practice which uses vegetation combined with engineering, is also known as bioengineering (Osman et al., 2014). Figure 1 illustrates the role of vegetation in reducing erosion and stabilizing slopes.

FIGURE 1. ROLE OF VEGETATION IN REDUCING EROSION AND STABILIZING SLOPES. (MENASHE, 1993)

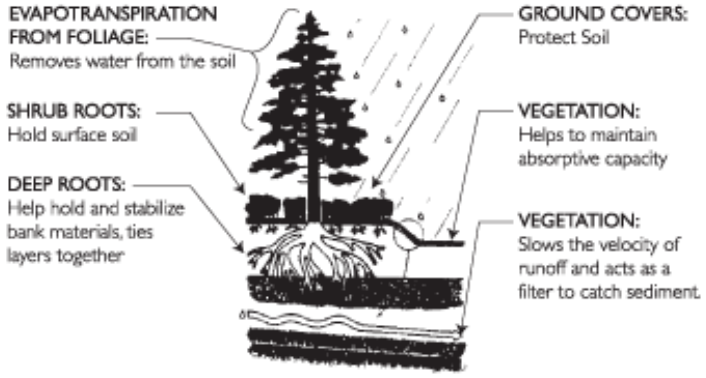


Figure 1 Role of vegetation in reducing erosion and stabilizing slopes
(Source: Google Images-Online)

According to Wang and Liu (2018), vegetation has a hydrologic effect where the foliage or canopy absorbs moisture and reduces water in the soil. Its ability to absorb water improves the shear strength of the soil and thus leads to slope stability. Other than that, the dense canopy intercepts the rainfall from directly falling to the ground and thus reducing the infiltration of rainwater (Wang & Liu, 2018). They added that the deep root system could effectively enhance the shear strength of the slope soil and hold it in place. Therefore, prevent it from being blown or washed away. Meanwhile, Asri (2007) mentioned that the more the weight of vegetation, the more it can hold the downhill force component. In general, soil loss will decrease exponentially with increased vegetation coverage.

Methodology

The methodological approach used mixed methods such as a questionnaire survey, semi-structured interview, and non-participant observation to gain qualitative and quantitative data.

Table 2 Summary of research questions, objectives, methods, and techniques to analyze data

Research Questions	**Research Objectives**	**Methods Of Data Collection**	**Techniques To Analyze Data**
1) What is the factor that causes the slope failure to have occurred?	1) To identify the factor that causes the slope failure to have occurred	Qualitative research: • Semi-structured interview Quantitative research: • Questionnaire survey	Qualitative research: • Content analysis (coding and theme) Quantitative research: • Statistical and descriptive analysis
2) How the role of vegetation helps in increasing slope stability, especially in hillside areas?	2) To investigate the role of vegetation in treating the slope failure, especially in the hillside area	Qualitative research: • Semi-structured interview Quantitative research: • Questionnaire survey	Qualitative research: • Content analysis (coding and theme) Quantitative research: • Statistical and descriptive analysis
3) How the suitability of vegetation characteristics contributes to stabilizing the slope failure?	3) To recommend suitable vegetation characteristics as slope treatment	Qualitative research: • Semi-structured interview • Non-participant observation Quantitative research: • Questionnaire survey	Qualitative research: • Content analysis (coding and theme) • Visualization technique analysis Quantitative research: • Statistical and descriptive analysis

Regarding this research, Table 2 summarizes a research methodology that states the research question and where it supposes to meet the research aim and objectives. Other than that, Table 2 also lists the technique to analyze the obtained data for each qualitative and quantitative research. The first research question was addressed to present explanatory research information on the perception, awareness, and understanding of the factor of slope failure. Meanwhile, the second and third research questions indicate the level of agreement, engagement, and relationship of the role of vegetation and vegetation characteristics contribute to slope stability.

Research Population

According to Majid (2018), research population refers to its target population, whom it wants to examine or treat. From the researcher's perspective, it comprises a group of individuals, institutions, and objects with common characteristics that would interest the research. The researcher identified several potential respondents that could give the feedback that the researcher wanted. In this case, the research population selected is listed below:

- There should be someone with experience and knowledge about slope treatment, such as landscape architects, engineers, environmentalists, architects, contractors, and academicians.
- Someone with experience in the slope treatment field must work for a government or private agency such as FRIM or DBKL

Besides, the population for the site observation also has similar characteristics, such as the area must have slopes with vegetation and natural surroundings or any artificial slopes with a combination of the natural setting as the research's interest. Overall, the research population is one of the critical elements in determining the success of the data collection process.

Qualitative Data Collection

The qualitative part consisted of semi-structured interviews and non-participant observation. The semi-structured interview was done online with five interviewees who were experts or had experience in managing the slope. Semi-structured interviews aim to understand better and perspective their opinions on this research. Mixed expert respondents from both private and government sectors were asked about their understanding of slope failure, the practices of slope treatment that had been done, and the role of vegetation helps in stabilizing the slope. Meanwhile, the non-participant observation was conducted at Jalan Lelangit residential area Bukit Jelutong, Shah Alam. The site observation was done to discover and visualize the approach applied to the site. The site was selected as it used the bioengineering measure to retain the slope condition and as a prevention measure.

Quantitative Data Collection

The questionnaire survey was done online to collect quantitative data. The respondents were selected from those who worked in the built environment fields, such as architects, landscape architects, engineers, environmentalists or academicians. Overall, there are four sections to be completed: demographic information, understanding and perception of slope failure, the conception of vegetation as a slope treatment, and lastly, the preference for the vegetation approach vs geotechnical engineering for slope. The purpose of having questionnaire surveys is to gain respondents' perceptions and general feedback towards the role of vegetation.

Results and Discussion

To understand the factors that cause a slope failure, 133 respondents from different backgrounds in the built environment field participated in the survey and accomplished all the questions given, which is plenty for this research to be analyzed and gain some results.

Factors that Lead to Slope Failure

Table 3 Chi-square test on the relationship between factors of slope failure with gender

Factors of Slope Failure	Observed Frequency		Expected Frequency		df	p-value
	Female	Male	Female	Male		
Prolonged heavy rainfall led to slope failure	3	16	9	10	4	.014
Slope failure happened due to design errors & the improper construction of the slope	13	14	12.7	14.2	4	.014

Slope failure happened due to poor slope management	8	11	9	10	4	.014
Slope failure is caused by human activity such as deforestation, and agriculture	39	29	32.2	35.7	4	.014
Total (*n*=133)	63	70	63	70		

Chi-square= 10.536; df= 4; p= .014; Critical value= 7.841

Table 3 indicates X2 (3, N=133) =10.536, p= .014, which shows a significant relationship between gender and factors of slope failure. The factor of human activity, such as deforestation, and agriculture, reach the highest frequency. 51.1% of respondents, which refer to 39 female respondents and 29 male respondents, agree and chose this finding as the main factor. All genders from different built environment fields seem aware of this environmental issue, as the researcher argues it might be because this factor is more exposed on the media mass or any medium compared to other factors. The second highest frequency comes from design errors and improper slope construction, of which 20.3% of respondents agreed to this finding. In contrast, factors such as prolonged heavy rainfall and poor slope management show the balance frequency, with 14.3% of respondents choosing this finding. It is due to the limitation of knowledge as there are many types of research related to slope in Malaysia, and experts reported heavy rainfall and poor slope management become the main triggering factors of slope failure.

The Role of Vegetation

It can be seen through the data gathered from semi-structured interview findings, which highlight the importance of the role of vegetation helps in increasing slope stability. Table 4 shows an expert's opinion on vegetation's role, which is analyzed through content analysis.

Table 4 The role of vegetation towards slope stability from expert's opinion

Interviewees	**Excerpt**
IN1	"…the leaf will capture all the rain and disperse it slowly through the outside of the tree trunk or move down when it hits the leaf and falls into a small part on the ground. Therefore, it can easily be absorbed in the soil when it becomes a small molecule. The fewer trees or leaves make, the more rain directly falls into the soil. Furthermore, fewer trees make the soil hardened as we know the effect of tree roots help in loosening the soil."
IN3	"Yes, definitely, the role of vegetation contributes to the slope. As we know, so much research shows vegetation can prevent erosion with its mechanical and hydrological character. In addition, its roots play a vital role in holding the soil. The same goes for the leaf, which helps capture the rain from falling directly into the soil. It is to prevent the water level in the soil from increasing. In other words, it also slows the movement of water surface runoff. The role of vegetation also can be seen where it can imitate the surrounding so that the slope or any side view does not look too concrete and bulky. Still, the effectiveness can only be shown after using the right vegetation, root characteristics and planting technique."
IN4	"I agreed with that statement. Vegetation has its role in the slope. First, it prevents erosion and creates aesthetic value. For instance, the slope appearance will be too concrete if we disregard the aesthetic value. Besides, vegetation protects the slope surface and prevents surface water runoff."
IN5	"I admit that the contribution of the vegetation role can strengthen the slope mainly with low risk as it helps prevent soil erosion. Moreover, it develops aesthetic value towards the slope appearance when vegetation combines with architecture design."

From Table 4, all the interviewees agreed and shared similar opinions that vegetation's role helps increase slope stability. The role of vegetation in preventing soil erosion can be observed through its hydrological ability to absorb water in the soil and control surface water runoff. Furthermore, this finding cannot be denied as all of them and previous researchers have the same thought on the hydrological role of vegetation, as stated by Wang and Liu (2018), that the ability in absorbing water improves the shear strength of the soil and thus leads to slope stability. Other than that, the mechanical part can be seen through its root which holds the soil to prevent erosion, as well as vegetation, provide some aesthetic value towards the slope appearance as the researcher argues the form, texture, colour, and size of the vegetation provide variety and add beauty appeal to

the surrounding despite having a concrete or bulky design. After all, the proper selection of vegetation is essential as it can determine the effectiveness of vegetation as a slope treatment.

The Vegetation Characteristics

Regarding the role, the researcher highlighted several characteristics that should act as adequate slope stability vegetation. Table 5 indicates the level of agreement of vegetation characteristics among three professions in the built environment.

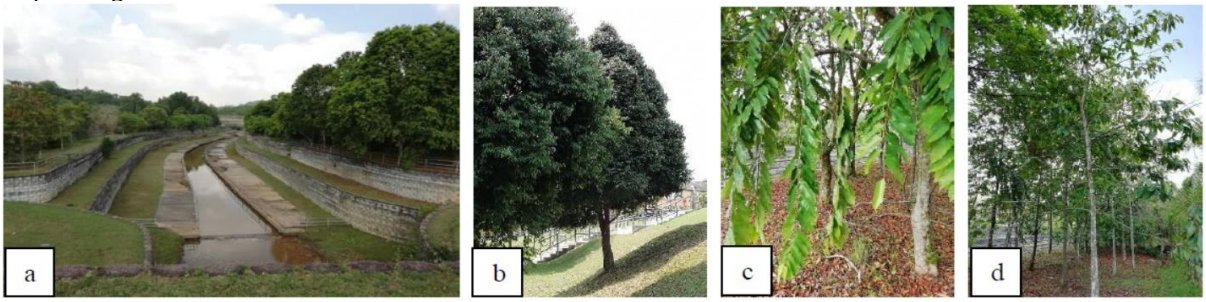
Table 5 Level of agreement of vegetation characteristics with the profession

Characteristics	Profession	Level of Agreement (n=82)		
		Disagree	**Undecided**	**Agree**
Native vegetation	Landscape Architects	4	6	18
	Architects	2	16	11
	Civil Engineers	2	16	15
	Total / Percent (%)	**8/ 9.8%**	**30/ 36.6%**	**44/ 53.6%**
Large canopy	Landscape Architects	3	1	24
	Architects	2	2	25
	Civil Engineers	2	5	18
	Total/ Percent (%)	**7/ 8.5%**	**8/ 9.8%**	**67/ 81.7%**
Fast-growing	Landscape Architects	3	2	23
	Architects	2	2	25
	Civil Engineers	2	7	16
	Total/ Percent (%)	**7/ 8.5%**	**11/ 13.4%**	**64/ 78.0%**
Deep root system	Landscape Architects	3	1	24
	Architects	2	2	25
	Civil Engineers	2	5	18
	Total/ Percent (%)	**7/ 8.5%**	**8/ 9.8%**	**67/ 81.7%**

The researcher used a Likert scale rating to observe the respondent's level of agreement towards the vegetation characteristics so that the researcher could identify the highest and lowest scores. As evaluated from Table 5, the highest frequency, 81.7%, equivalent to 67 respondents from these three backgrounds, agrees that the large canopy and deep root system characteristics are adequate slope vegetation. Wang and Liu (2018) also agree with these findings, who mention that the large canopy becomes an excellent interceptor in absorbing moisture. Osman et al. stated that a deep root system creates enough strength to avoid shear stress. The second highest percentage goes to the fast-growing characteristic, with 78.0% of respondents agreeing with this finding. To add up, Menashe (2001) stressed that vegetation takes several years to develop on the site successfully and because of this, fast-growing characteristic also plays a vital role.

Conversely, native vegetation characteristics got a minor percentage, with only 53.6% of respondents agreeing to this finding, while another 36.6% are undecided, and 9.8% disagree. The researcher argues this might be because there is a limitation of knowledge as native characteristics are essential in determining the effectiveness of the vegetation's role in treating the slope. This finding is supported by Stokes et al. (2014), which mention that native species have a higher rate of success resisting erosion and can reduce the maintenance cost in the future.

Moreover, the researcher made some observations at Taman Lelangit to observe the abovementioned vegetation characteristics. As illustrated in Figure 2, vegetation and engineering approaches were applied on the slope along the river.



a) Taman Lelangit's slope area b) Mesua ferrea l. c) Brownea grandiceps d) Dipterocarpus sp.
Figure 2 Vegetation combined with engineering approach for slope at Taman Lelangit

The authority used a gravity-type stone retaining wall to restrain the soil from sliding down and planted vegetation at the top and toe of the slope to protect the slope surfaces. Furthermore, most of the vegetation planted is native to the country, which can adapt to Malaysia's climate and grows in lowland tropical rainforests. The dense canopy from Brownea grandiceps, Mesua ferrea l., and Dipterocarpus spp. can absorb moisture. The deep taproot and fibrous root system from Messua ferrea l. can hold the soil structure, while Dipterocarpus spp. can grow faster with an open canopy.

Conclusion

After all, the research findings suggest vegetation plays a vital role in treating the slope, supported by the findings of the suitable vegetation characteristics to protect against slope failure. As potential slope vegetation, it protects the slope by absorbing moisture and preventing surface water runoff through its hydrological characteristics, such as extensive canopy vegetation. Besides that, the root system, such as deep taproot and fibrous root, provides mechanical stabilization of slopes through its tensile strength and ties the soil layers together to prevent it from being blown or washed away. Meanwhile, fast-growing characteristics help vegetation establish its role at an early stage on the slope, and native vegetation characteristics have significant benefits on the slope as they grow in harmony with the environment, such as climate and soil condition, and even require minimal maintenance. Again, the researcher wants to stressed-out that vegetation is miraculous in its invisible ability. Even though vegetation might start weak, it will grow stronger over time, and thus, it is considered a tremendous ecological treatment that can sustain the long-term solution.

To sum up, this research reveals that the impact of the role of landscape vegetation is adequate to be recognized as an eco-friendly soil slope stabilization treatment. It cannot be denied that when vegetation treatment combines with an engineering approach, it becomes the best solution to cater to the slope problem if a suitable selection of vegetation with erosion control characteristics is established on the site. Undoubtedly, this research contributes as a guideline to selecting proper vegetation for the profession in the built environment, mainly for those who manage slope construction. It also acts as a theoretical review guide for those who want to do future research on this topic.

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