ASSESSMENT OF POST-FIRE VEGETATION RECOVERY AND SOIL EROSION ON SLOPE CONTAINING NESOSILICATES

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ABSTRAK

Kebakaran hutan meningkatkan hakisan bukit dan larian permukaan. Kebakaran boleh mengurangkan kapasiti penyusupan air, menyebabkan tanah tidak menyerap air dan meningkatkan aliran dan hakisan. Kajian ini mengkaji kesan suhu di bawah keadaan semula jadi dan makmal sampel tanah yang diambil dari lereng bukit di Jalan Gambang. Sampel tanah yang tidak terbakar dan dibakar diperolehi daripada lapangan. Di samping itu, sampel tanah di bawah keadaan makmal telah dibakar pada tiga suhu, iaitu 440ºC, 800ºC dan 1350ºC. Pelbagai ciri tanah telah dikaji, termasuk graviti tentu, had Atterberg, indeks pengembangan dan kandungan bahan organik. Lengkung ciri tanah-air semua sampel cermin dan kaedah osmotik. Keputusan eksperimen menunjukkan bahawa suhu pada 440ºC, had cecair, kandungan bahan organik dan lengkung ciri tanah-air telah dikurangkan dan indeks pengembangan telah dihapuskan. Pemanasan tanah pada 800ºC menghapuskan had cecair, had plastic, pengembangan kandungan yang berpotensi dan organik tanah yang diuji. Kadar serapan air berkurang dengan peningkatan suhu. Daripada keputusan eksperimen keseluruhan, tanah di lapangan diramalkan telah mengalami kebakaran pada suhu 440ºC kebawah. Tambahan pula, penyingkiran tumbuh-tumbuhan seperti yang terjejas oleh kebakaran mengurangkan penutupan permukaan cerun dan menyebabkan hakisan cerun berlaku. Daripada permerhatian ditapak, pertumbuhan tumbuh-tumbuhan di tanah yang terbakar secara semulajadi adalah kurang berbanding di tanah yang tidak terbakar. Sebelum kebakaran terjadi, jumlah tumbuhan yang tumbuh di tanah terbakar adalah sebanyak tujuh jenis spesis manakala selepas kebakaran berlaku, jumlahnya berkurang kepada enam spesis sahaja.

ABSTRACT

Fires can reduce soil infiltration capacity induce soil water repellency and increase runoff and erosion. This study examines the effect of temperature under natural and laboratory condition of soil samples collected from hillside at Jalan Gambang. The unburned and burned soil samples were obtained from site. In addition, the soil samples under laboratory conditions were burned at three temperatures, which is 440ºC, 800ºC and 1350ºC. Various soil properties were studied, including specific gravity, Atterberg limits, swell index and organic matter content. The soil-water characteristic curve (SWCC) of all soil samples was also determined. The SWCC were established using chilled-mirror dew point technique and osmotic technique. Experiment results demonstrated that temperature at 440ºC, the liquid limit, organic matter content and SWCC were reduced and the swell index was eliminated. At 800ºC completely eliminated the liquid limit, plastic limit, swell potential and organic content of soil tested. The soil suction decreased with increasing temperature. From overall experimental results, the natural burned soil was predicted had experienced a fire at temperature below 440ºC. Furthermore, the removal of vegetation as affected by fire reduced the slope surface cover and caused erosion of the slope to occur. From the field work observation, the vegetation growths on natural burned soil are lesser compared to unburned soil. There are seven types of vegetation growth before the natural burned occurred but only six types of vegetation growth that are still growing even thought the amount is decreases.

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ºC	Degree Celsius

LIST OF ABBREVIATIONS

SWCC	Soil-Water Characteristic Curve
ASTM	American Society for Testing Material
BS	British Standard
FS	Free Swell

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Global surface temperature has increased ≈ 0.2ºC per decade in the past 30 years, similar to the warming rate predicted in the 1980s in initial global climate model simulations with transient greenhouse gas changes (Hansen et al., 2006). Climate change may bring about an increase in the frequency and intensity of extreme weather events, such as, droughts, storms and floods. Climate change, which will affect precipitation, temperature, and land cover, is likely to strongly influence the processes causing surface erosion. Surface erosion is the removal and transportation of soil by raindrop impact and overland flow (Foster & Meyer, 1977). Climate change is caused by the emission of heat-trapping gases – mostly carbon dioxide (CO_2) – from vehicles, industry, power plants and deforestation (Rahman, 2009). According to Malaysian Meteorological Department from updated record on February 2017 stated that, the total solar radiation and rates of evaporation were lower than average. However, the surface temperatures recorded were higher than average values.

Prolonged heat wave such as El Nino effect lead to a much drier forest and make fire ignition occur easier (Wotton & Flannigan, 1993). El Nino is the warming of the sea surface temperature in the eastern and central Equatorial Pacific Ocean that occurs every two to seven years. The strongest El Nino phenomenon that had swept Malaysia was in 1997/1998 with temperature of 40.1 degree Celsius in Chuping, Perlis (Bernama, 2016). According to the Meteorological Department, the hot and dry weather condition was caused by the El Nino phenomenon, which is expected to cause a reduction in rainfall intensity by 20 to 60 per cent and a temperature rise of between 0.5 to 2.0 degrees Celsius from between 28.6 and 35 degrees Celsius on normal day or from between 35 and 37 degrees Celsius on hot day (Bernama, 2016). The relationship between meteorological conditions and fire occurrence is well established. Forest fires tend to be more severe when temperature is high and air humidity and fuel moisture are low (Pinol, Terradas, & Lloret, 1998).

Forest fire, as a major disturbance agent in ecological community, yearly affects and even totally removes millions of hectares of forest land around the world (Zeng & Li, 2016). It is considered as a major cause of biodiversity reduction, soil fertility loss, gaseous pollutants emission, and other environmental impacts (Zeng & Li, 2016). Measurements of the post-fire damage levels over burned areas are critical to quantifying fire's impaction landscapes (Lutz, Key, Kolden, Kane, & van Wagtendonk, 2011) and improving post-disaster management (Veraverbeke et al., 2012), which have been widely used by environmental scientists, forest fire researchers, and policy makers. Fire can greatly increase the landscape's vulnerability to flooding and erosion events (Pierce et al., 2004). By removing vegetation, changing soil properties and inducing soil water repellence, fire increases the risk and erosive of overland flow. Since removal of fertile topsoil is often much faster than soil formation by weathering, fires can contribute to long-lasting degradation and even desertification (Neary, 2009; Shakeby, 2011).

Fire-induced water repellence in soils has been a continuous concern of watershed managers since its identification in the early 1960s. The formation of water repellent soil, its chemical nature, and its effect on filtration, runoff and erosion have all captured the attention of numerous scientists and managers worlds wide. Although much was known about the vegetation (Horton, 1960) and hydrologic responses (Rowe et al., 1954) of these watersheds following fire, little was known about the specific effects fire had on soil properties other than that the loss of vegetation directly exposed the soil surface to raindrop impact. The reason for the decreased infiltration after fire was initially believed to result from the loss of protective plant cover during combustion and the plugging of soil pores by ashy residue remaining on the soil surface. The decrease in filtration, however, was later found to be affected by a repellent layer formed during the fire (Debano, 2000).

Wildfire is an important disturbance factor in many ecosystems, especially in the Mediterranean Basin (Bento-Gonçalves et al., 2012; Keeley et al., 2012). It has been demonstrated that wildfires can modify soil post-fire runoff and erosion response according to changes made on water repellency (WR), soil aggregate stability (SAS) or soil organic matter (SOM) quantity and quality, all of them closely related (Certini, 2005). Burning severity can modulate the recovery of plant communities and the quantity and intensity of changes in fire-affected soil system, as shown by Bradstock et al. (1995) and Chafer (2008). While low severity burning does not affect soils in an important manner, severe burning can affect a wide range of soil properties (e.g., nutrient availability, organic matter content, etc,) (Certini, 2005). Fire-induced changes on soil properties can have an impact on soil productivity of burnt areas, in some cases in an irreversible way (Robichaud, 2009). In this study, the effect of fire on properties between burned and unburned soils were investigated.

Change in soil properties for burned and unburned soils will also give impact to the vegetation cover. Vegetation cover defines the percentage of soil which is covered by green vegetation. Leaf area index (LAI) is an alternative measure of plant cover which gives the area of leaves in square meters corresponding to an area of one square meter of land. In a wide range of environments, vegetation cover greatly affects both surface water runoff and sediment loss (Elwell and Stocking, 1976; Lee and Skogerboe 1985, Francis and Thornes 1990). A vegetation cover of 45-50% is considered a critical value since above this value soils are adequately protected from raindrop impact and soil erosion is significantly reduced. Vegetation cover can be measured in the field by assessing the percentage of the ground that it is covered by the existing annual or perennial vegetation.

In Malaysia for instance, approximately 2,940 forest, bush fire outbreaks were recorded within 10 days during dry season in April 2016 (Bernama, 2016). The event brought about severe depletion of vegetation (i.e. slope natural cover). Vegetation and trees on slope induced soil suction and absorb excess water during rainfall (Rees & Ali, 2012). A study conducted by Rees and Ali (2012) noted that, the presence of vegetation increased slope stability by about 8%. Thus, in absence of vegetation, direct contact of precipitation on burned of dried slopes lead to an increased in hill slope erosion and surface runoff. Moreover, the amount of precipitation is expected to be greater and longer during the Monsoon season between August and November. These two combinations prove to be ideal yet devastating on the disintegration of slopes.

Most studies on fire-induced changes have been conceived and designed “after the fact”, which means study areas are selected on burned areas and matched up with nearby unburned areas judged as being similar before the fire. Although this approach provides some insight into fire-related changes, uncertainty arises about the similarity of the burned and unburned sites (DeBano, Rice, & Conrad, 1979). A better method for obtaining study sites is to select paired plots and sample of burned and unburned soils to determine the wilting point for investigating the ability of burned soil to plant. During wildfires, little opportunity exists for obtaining paired plots in this manner. In contrast, prescribed burning provides a possible way for pairing sites according to pre-fire conditions, thereby assuring better comparability between the burned and unburned condition (DeBano et al., 1979). This paper reports data on wilting point of water ability to plant on burned and unburned soil in hillside on Jalan Gambang, Kuantan. Fire affects vegetation, litter and soils in several ways. It may directly consume part or all of the standing plant material and litter, as well as the organic matter in the upper layers of soil. Nutrients in the organic matter are either made more available or can be volatilized and lost from the site (e.g., gaseous loss of N) (DeBano et al., 1979).

1.2 Problem Statement

Global temperature shows warming trend for the past few decades and expected to increase continuously which will increase the frequency, duration and intensity of extreme weather events and associated droughts, wildfires and rainfall events. Forest become drier and make fire ignition occur easier as the global temperature increases. Many physical, chemical, mineralogical and biological soil properties can be affected by fire depends on the level of fire severity, combustion and heat transfer, magnitude and depth of soil heating, proximity of the soil properties to the soil surface and the threshold temperature at which the different soil properties change. Change in soil properties will also give impact to the vegetation cover. Vegetation cover is an important to prevent the soil erosion. Soil (or surficial) erosion is the removal of soil by wind, water and ice. In this study, the effect of fire on soil properties between burned and unburned soil were investigated. Other than that, the effect of fire on wilting point of water ability to plant and vegetation growth on burned and unburned soil were also established.

1.3 Research Objective

The objective of this research were as follows: (i) To determine the effect of fire on properties of burned and unburned soil at varying temperature of 440ºC, 800ºC and 1350ºC. (ii) To determine the effect of fire on wilting point of water ability to plants (iii) To evaluate effect of fire on vegetation growth.

1.4 Scope of Study

In this study, the soil sample obtained from hillside at Jalan Gambang, Kuantan was considered. Several laboratory tests were conducted in Soil and Geotechnical Laboratory in University Malaysia Pahang to investigate the soil properties of burned and unburned soil. The tests required for soil properties of burned and unburned soil were specific gravity, liquid limit, plastic limit, shrinkage limit, free swell, and loss on ignition. It is also to investigate the effect of fire on wilting point of water ability to plants on burned and unburned soil by using osmotic technique and chilled mirror technique.

1.5 Significant of Study

Vegetation cover plays a key role on land degradation and in fact, reduction in the perennial cover is regarded as an indicator of the onset of desertification. Extreme climate condition and human action can cause disequilibrium of these systems. Vegetation cover may be altered radically by Man within a short time, but physical and biological changes within the soil, affecting erosion rates, may take longer periods.

Vegetation and slope stability are interrelated by the ability of the plant life growing on slopes to both promote and hinder the stability of the slope. The relationship is a complex combination of the type of soil, the rainfall regime, the plant species present, the slope aspect, and the steepness of the slope. Knowledge of the underlying slope stability as a function of the soil type, its age, horizon development, compaction, and other impacts is a major underlying aspect of understanding how vegetation can alter the stability of the slope. There are four major ways in which vegetation influences slope stability: wind throwing, the removal of water, mass of vegetation (surcharge), and mechanical reinforcement of roots.

Studies in Malaysia have shown that there is a significant relationship between root length density, soil water content and ultimately slope stability. Slopes that had high root density (due to dense vegetation on the surface) were less likely to undergo slope failure. This is because a high root length density results in low soil water content which in turn results in an increase in shear strength and a decrease in soil permeability. It is suggested that root length density and soil water level could be used as indicators of slope stability and possibly could be used to predict future slope failure.

The mechanisms by which climate and vegetation affect erosion rates over various time scales lie at the heart of understanding landscape response to climate change. Plot-scale field experiments show that increased vegetation cover slows erosion, implying that faster erosion should occur under low to moderate vegetation cover.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the previous studies of burned soil were discussed.

2.2 Climate Change

Greenhouse gas emissions have significantly altered global climate, and will continue to do so in the future. Increases in the frequency, duration, and/or severity of drought and heat stress associated with climate change could fundamentally alter the composition, structure, and biogeography of forests in many regions.

Increasing emissions of greenhouse gases are now widely acknowledged by the scientific community as a major cause of recent increases in global mean temperature (about 0.5°C since 1970) and changes in the world's hydrological cycle (IPCC, 2007a), including a widening of the Earth's tropical belt (Seidel *et al*., 2008 ; Lu *et al*., 2009). Even under conservative scenarios, future climate changes are likely to include further increases in mean temperature (about 2–4°C globally) with significant drying in some regions (Christensen *et al*., 2007 ; Seager *et al*., 2007), as well as increases in frequency and severity of extreme droughts, hot extremes, and heat waves (IPCC, 2007a ; Sterl *et al*., 2008).

The effects of climate change on forests include both positive (e.g. increases in forest vigour and growth from CO2 fertilization, increased water use efficiency, and longer growing seasons) and negative effects (e.g. reduced growth and increases in stress and mortality due to the combined impacts of climate change and climate-driven changes in the dynamics of forest insects and pathogens) (Ayres and Lombardero, 2000; Bachelet et al., 2003; Lucht et al., 2006; Scholze et al., 2006 ; Lloyd and Bunn, 2007). The diverse instances of mortality reported here clearly illustrate that drought and heat can impact trees in many forest types (Auclair, 1993 ; Ciesla and Donaubauer, 1994). Climate variables affecting erosion include rainfall, wind and temperature.

2.3 Forest Fire

Fire is now recognized as an important agent of vegetation disturbance in tropical rain forest. The extensive destruction of rain forest across the Southeast Asia and New Guinea region during the severe 1997–98 El Niño event clearly demonstrated the susceptibility of large areas of rain forest to fire. Soil moisture generally remains at or wetter than field capacity for the whole year, except during severe El Niño years, when the low pressure system moves towards the eastern Pacific, limiting the southward penetration of the summer monsoon and significantly reducing rainfall across the Malesian sector. During the last two major El Niño years (1982–83 and 1997–98) fires were able to penetrate large areas of rain forest causing widespread destruction to these environments.

A forest fire is an uncontrolled fire occurring in nature. Sometimes, the forest fire is so large that it takes a long time for the fire fighting crews to gain control over the situation. This could result in massive destruction. In Norway, an average of about 1100 forest fires occurs each year. Most of these are small and relatively easy to control. Only two per cent of the registered forest fires in Norway are larger than 100 decades (100 000 m2).

In order to understand the effects of fire on ecosystems, it is crucial to understand fire itself. Vegetation fires are described in terms of fire behaviour, namely the amount and rate of heat released (fire intensity), the rate of spread, the residence time, and the fuel consumption (Alexander, 1982; Chandler et al., 1983a; Direccao Geral das Florestas, 2002). Fire behaviour is determined by the interaction between weather, ‘fuel’ (all burnable living and dead plant material) and topography (Chandler et al., 1983a). As such, fire behaviour varies with air temperature and relative humidity, both of which affect fuel ignitability, and with wind, which greatly influences fire spread. Furthermore, fire behaviour varies greatly between ecosystems because of the variation in physical and chemical characteristics of fuel (Stoof, 2011).

The fuel moisture index is a tool that is widely used to understand the fire potential for locations across the country. Fuel moisture is a measure of the amount of water in a fuel (vegetation) available to a fire, and is expressed as a percent of the dry weight of that specific fuel. For example, if a fuel were totally dry, the fuel moisture content would be zero percent. Fuel moisture is dependent upon both environmental conditions (such as weather, local topography, and length of day) and vegetation characteristics. When fuel moisture content is high, fires do not ignite readily, or at all, because heat energy has to be used to evaporate and drive water from the plant before it can burn. When the fuel moisture content is low, fires start easily and will spread rapidly - all of the heat energy goes directly into the burning flame itself. When the fuel moisture content is less than 30 percent, that fuel is essentially considered to be dead.

2.4 Effect of Fire on Soil Properties

The physical properties of soil which affect the detachment and transportation of soil particles due to erosion are soil texture, organic matter, moisture content, structure, density (due to compaction), chemical and biological characteristics of the soil. Many physical, chemical, mineralogical, and biological soil properties can be affected by forest fires. The effects are chiefly a result of burn severity, which consists of peak temperatures and duration of the fire. Climate, vegetation, and topography of the burnt area control the resilience of the soil system; some fire-induced changes can even be permanent.

Low to moderate severity fires, such as most of those prescribed in forest management, which promote renovation of the dominant vegetation through elimination of undesired species and transient increase of pH and available nutrients. No irreversible ecosystem change occurs, but the enhancement of hydrophobicity can render the soil less able to soak up water and more prone to erosion. Severe fires, such as wildfires, generally have several negative effects on soil. They cause significant removal of organic matter, deterioration of both structure and porosity, considerable loss of nutrients through volatilisation, ash entrapment in smoke columns, leaching and erosion, and marked alteration of both quantity and specific composition of microbial and soil-dwelling invertebrate communities.

Soil properties can experience short-term, long-term, or permanent fire-induced changes, depending chiefly on type of property, severity and frequency of fires, and post-fire climatic conditions. A plethora of recent works has investigated what type of modification selected properties of forest soils undergo following fire.

2.5 Effect of Fire on Soil Properties at Varying Temperature

The resilience against fire is affected by climate, vegetation and topography of the burnt area. Low to moderate severity fires eliminate undesired species which cause renovation of the dominant vegetation, impermanent increase of pH and available nutrients. Fire has also enhanced the hydrophobicity of the soil, which reduces the ability of soil to soak up water and increase the probability for soil erosion. Severe fires, for example wildfires, cause removal of organic matter, deterioration of both structure and porosity, loss of nutrients, ash entrapment in smoke columns, leaching and erosion, and alteration of both quantity and specific composition of the microbial and soil-dwelling invertebrate communities (Certini, 2005). Fire intensity is an integral part of fire severity in that it refers to the rate at which a fire is producing thermal energy in the fuel-climate environment where it occurs. It can be measured in terms of temperature, and heat release. During forests fires, maximum ground temperatures are typically in the range of 200°C to 300°C. In heavy fuels like slash, soil surface maximum temperatures are usually around 500°C to 700°C, but instantaneous temperatures in excess of 1500°C can occur (Neary et al., 1999). According to Beyers et al. (2008), temperature in the forest floor can easily reach 600 °C or higher during burning.

Sensitive soil properties are those that are changed at temperatures less than 100°C. Examples of sensitive materials are living microorganisms, plant roots, and seeds. Moderately sensitive soil properties which are sulphur, organic matter and soil properties dependent upon organic matter changed at temperatures between 100 and 400°C. Losses of organic matter can occur at temperatures below 100°C. Volatile constituents in organic matter are lost at temperatures up to 200°C. Destructive distillation destroys about 85% of the soil organic matter at temperatures between 200 and 300°C. Above 300°C, the greater part of the residual organic matter consists of carbonaceous material finally lost upon ignition. Heating the soil to 450°C for 2 hours or to 500°C for half an hour destroys about 99% of the organic matter. Relatively insensitive soil properties includes clays, calcium, magnesium, potassium and other minerals do not change until temperatures have reached over about 450°C. The most sensitive textural fraction is clay, which begins changing at soil temperatures of about 400°C when clay hydration and clay lattice structure begin to collapse. At temperatures of 700°C to 800°C, the complete destruction of internal clay structure can occur. However, sand and silt are primarily quartz particles that have a melting point of 1,414°C (Beyers et al., 2008).

A study conducted by Abu-Zreig et al. (2001) revealed that temperature had a significant effect on soil physical properties. However, the relative change in these properties was higher when temperature ranged from 100°C to 300°C. Soils were generally not affected by temperatures below 100°C. At 400°C, the average liquid limit was decreased by 80%. However, at 400°C, plastic limits were completely eliminated for all soils tested. The liquid limit decreases very rapidly with the temperature in the interval of 100°C and 300°C, while it decreases very slowly between 300°C and 1000°C. The plastic limit decreases rapidly with the temperature in the interval of 100°C and 300°C. Starting from 400°C to higher temperatures, the clays show non-plastically behaviour. The specific gravity decreases rapidly with the temperature in the interval of 100°C and 600°C, while this decrease is very slow in the interval of 600°C and 1000°C (Tan et al., 2004).

2.6 Effect of Fire on Vegetation

Vegetation cover defines the percentage of soil which is covered by green vegetation. Forest fire is a primary process that influences the vegetation composition and structure of any given location; fire helps shape the landscape mosaic and influence biogeochemical cycles such as the carbon cycle. Forest structure and composition, now and in the past, is influenced by the fire regime (Heinselman, 1973 ; Wright and Bailey, 1982). Seasonal phonological state of the plants burned will determine the characteristics of the vegetative or seed reproductive response and have a pronounced effect on the structure of post-fire ecosystems and landscapes.

Fire can act as an agent of change to hasten the modification of the vegetation landscape into a new equilibrium with the climate if species are able to migrate fast enough. This might be true where the fire activity is expected to increase in the next century and thus accelerate changes in vegetation. In those areas of America that experience a reduced fire frequency due to the altered climate or human activities, the transition of vegetation types may be retarded.

Fire impact on soils can greatly affect belowground ecosystem functioning, as the heat of the fire can alter a range of biological, physical and chemical soil properties. The extent of the change is generally determined to a large degree by the soil temperatures reached during the fire, and the length of time that high temperatures are sustained (Cerda and Robichaud, 2009; Neary et al., 1999). Fire effects on soils can range from microbe and seed mortality to the development of soil water repellence (DeBano, 2000b), soil structural changes, and nutrient votalization.

Surface vegetation cover reduces erosion as it acts as a buffer zone to dissipate the energy of falling raindrops, protecting the soils affected and reducing soil detachment and maximizing water infiltration. Vegetation roots assist in reducing the velocity of overland flow by increasing surface roughness and improve the aggregation and porosity of the soil by increasing the organic content of the soil. Vegetative transpiration reduces soil moisture thus encouraging infiltration of rain water which aids in reducing surface runoffs and the rate of erosion at potential unstable sites.

2.7 Effect of Fire on Soil Erosion

The fire regime at any given location is the result of complex interactions between fuel, topography, ignitions and weather. Fuel type, structure, moisture and spatial continuity are important aspects in determining the fire regime. The topography can influence the spread of fire through natural fire breaks such as lakes, rivers and ridges; also, slope and orientation influence the fire spread. The frequency and timing of ignitions, whether natural or human-caused, can play a role in the fire regime.

Topographic features affecting the rate of erosion include slope gradient, length of slope, elevation as well as the size and shape of the watershed. Steeper and longer slope increase the gravitational properties for the transportation of soil particles. Steep slopes result in high rainfall runoff velocities and low ground water retention properties.

From experiments, Loch and Silburn (1993) noted that there was an exponential increase in soil erosion with an increase in slope length. The velocity of runoffs generally varies with the square root of the slope gradient and doubling the slope gradient means increasing the soil quantity that can be transported by four times (IEAust-Qld, 1996).

Erosion is related to shear strength and critical shear strength. Kandiah (1974) conclude that the critical shear strength values at a site are a reliable index of susceptibility of the soil to erosion. Soil erosion is also influenced by soil properties, which include bulk density and shear strength. The bulk density determines the porosity and the infiltration rate of the soil type – compacted soil is more prone to water erosion than un-compacted soil. The advanced effects of soil erosion and landslides include:

a) Possible loss of lives and destruction of property due to slope failures / landslides;

b) Difficulty in the implementation of post rehabilitation site programmes;

c) Reducing the capability of future post-industrial land use options;

d) Reduction of soil structure stability due to the continuous loss of soil particles and vegetative cover at site; and

e) Economic losses due to delay in the transportation of goods possibly because of highways / roads being obstructed by debris / mudflows.

2.8 Nesosilicates

Nesosilicates are silica-alumina oxide having the chemical formula of Al_2SiO_5. The occurrence of nesosilicates in Malaysia was first reported by MacDonald. Nesosilicates may exist in three different phases (i.e. different mineralogical structure) depending upon surrounding temperature and pressure with mullite as the most stable form. Thus, in the event of wildfire, the changes in the mineral structure of nesosilicates are expected to occur given that wildfire could have a temperature exceeding 400^0C. It is anticipated that, these changes would resulted in increased soil erosion problems during heavy rainfall.

2.9 Soil Suction

Engineers are aware of the importance of soil suction in geotechnical applications. In addition, the engineering properties of unsaturated soils are significantly influenced by soil suction. The coefficient of permeability decreases with an increase in soil suction. The shear strength increases with increases in soil suction. An understanding of the flow behaviour through unsaturated soils is required for numerous applications in geotechnical and geo-environmental areas. The shear strength of a soil is also required for the prediction of the stability of slopes, the bearing capacity of foundations and pressure against earth retaining structures (Fredlund, 1995).

Soil suction can also be referred as the free energy state of the soil water (Mantri and Bulut, 2014) that can be found in all ground that lies above the water table (Hu Pan et al, 2010). In engineering practice, soil suction has two components namely matric suction and osmotic suction. The sum of matric and osmotic suction is defined as total suction of the soil (Krahn and Fredlund, 1971). Matric suction is defined as the solute component of the free energy (Mantri and Bulut, 2014).

2.9.1 Suction Measurement Technique

There are different methods to measure soil suction. There are methods which use another medium to determine soil suction and direct method. This paper reports on direct and indirect soil suction measurement methods. Direct suction measurement techniques mainly include axis-transition technique, tensiometer and suction probe. Indirect suction measurement techniques are divided into three categories, namely, measurement techniques of matric suction, osmotic suction and total suction. Indirect matric suction measurement techniques include time domain reflectometry (TDR), electrical conductivity sensors, thermal conductivity sensor (TCS) and in-contact filter paper technique. Indirect osmotic suction measurement techniques chiefly include squeezing technique and saturation extract method. Indirect total suction measuremet techniques include psyshrometer technique, relative humidity sensor, chilled-mirror hygrometer technique and non-contact filter paper method (Hu Pan et al, 2010).

2.9.1.1 Chilled Mirror Dew-Point Hygrometer Technique

The determination of the water retention properties in a wide suction range of natural and compacted soils is a fundamental issue in many geo-environmental and geotechnical applications, such as engineered barriers and liners, ground atmosphere interactions and compacted fills used in man-made structures – earth dams, road sub-grades and embankments.

In many processes moisture is a critical factor that needs to be monitored, and controlled. Chilled mirror is the humidity standard technology of choice for national standards laboratories worldwide. Chilled mirror has the highest attainable accuracy of any dew-point measurement technology, and provides excellent repeatability over a wide measurement range. It is a proven, well established and reliable measurement technique: the temperature at which condensation forms on a surface is measured directly, so there are no calculated variables that could change over time. This means chilled mirror does not suffer from drift or hysteresis.

A chilled-mirror dew-point psychrometer (WP4, Decagon Devices, Inc., Pullman, Washington, USA, www.decagon.com) which have been widely used and its reliability widely accepted. The latter equipment has been developed in recent years to accurately determine the relative humidity in a wide range and involving a reduced time of reading. This equipment or a similar one has been used by Loiseau (2001), Leong et al. (2003), Tang and Cui (2005), and Thakur and Singh (2005).

2.9.2 Suction Control Technique

The vapour equilibrium method and osmotic technique have gained widespread acceptance as reliable methods for controlling relative humidity and thereby suction in soil specimens. The ability to impose suction on soil specimens allows for drying and wetting stress paths to be imposed to evaluate resulting changes in strength, deformation and flow characteristics.

Soil suction is defined by Richards (1974) as the water potential in a soil-water system. Richards (1974) lists three components of suction in unsaturated soils, namely capillarity, adsorption of water on the surface of the clay minerals, and osmotic phenomena. Only two components of total suction are generally considered for engineering studies, the matric and osmotic components. Matric suction is generated by capillarity and the osmotic suction is generated by pore fluid chemistry and water adsorption (Fredlund and Rahardjo 1993). Matric suction is generally considered to be the dominant component of total suction in non-plastic cohesionless soils with a relatively pure pore fluid. Osmotic suction can be appreciable in high plastic clays that have high activity due to the clay mineralogy or in cases where the pore fluid activity is high due to the presence of dissolved salts. Osmotic suction is generally assumed to be insensitive to changes in water content as long as the pore fluid chemistry remains constant. However, this is not always true. In cases with active clay minerals, the water adsorption can be strongly dependent on the distance between the clay sheets and therefore the water content. As a general approach changes in total suction in unsaturated soils can generally be attributed to changes in the matric suction component (Fredlund and Rahardjo 1993).

2.9.2.1 Osmotic Technique

The osmotic technique was initially developed by biologists (Lagerwerff et al. 1961) and later adopted by soil scientists (Zur 1966). It was introduced in geotechnical engineering by Kassiff and Benshalom (1971). In this technique losses or uptakes of water are caused by the process of osmosis.

In osmotic technique, the specimen and osmotic solution are separated by a semi permeable membrane. Zur (1996) reported that semi permeable membrane only allows water molecules and ions to pass through the membrane but block the movement of large solutes molecules such as soil molecules. The suction in the specimen is lower than the suction in the polyethylene glycol (PEG) solution. In order to reach equilibrium, water molecule is moving through the semi permeable membrane from the specimen to the osmotic solution. When it reached equilibrium state, both sides has the same amounts of water and soil salts.

The main advantage of the osmotic technique is its ease in reaching high suctions in a safe manner. In addition, it applies a direct water potential to liquid water as opposed to the axis translation technique, therefore it is particularly well suited to high water content samples. The main disadvantage is the weakness of the membrane and its sensitivity to microbial attack. It is necessary to add some drops of penicillin in the solution before use to prevent from bacteria. The osmotic technique can be easily used to impose a suction value to a soil specimen under null stress.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The characteristic of unburned and burned soil were investigated though laboratory test. The physical properties of unburned and burned soil were determined by specific gravity, Atterberg limit test, and free swell test. The organic matter content was determined by loss on ignition test. Soil- water characteristic curve of unburned and burned soil were established by using osmotic technique. In this chapter, all the tests conducted were discussed.

3.2 Site Description

The sample of burned and unburned soils for this study were collected from the hillside slope at Jalan Gambang, Kuantan is shown in the Figure 3.1. From the information obtained, the fire began on October 2016. The slope is located in the Eastern Belt where andalusite deposits can abundantly be found. According to Hutchison (1983), andalusite deposits in the area extend approximately 50 km radius from Gambang to Sungai Lembing. The slope considered in this study was 315 m in length and a portion of the slope (about 131 m) was affected by wildfire. The height of the slope is 7.66m. In the Figure 3.2, shown that the surveying works is done to measured the height and the length of the slope.

Figure 3.1 Map of Gambang showing the location of the burned slope

Figure 3.2 Surveying works is done to measure the height and length of the slope

3.3 Selection of Material

Burned samples were obtained directly from the fire affected area, whereas unburned soil samples were collected on unaffected area about 1.8 m from the burned soil. Samples obtained were disturbed samples. Top layer of the soil contained ash and vegetation were removed. Using hand auger, disturbed soil samples were collected at burned site to a depth of about 20 cm below the ground surface. The samples were brought back to the laboratory in sealed bags.

3.4 Sample of Preparation

Natural burned sample were obtained directly from the fire affected area, whereas unburned samples were collected on unaffected area about 1.8 m from the burned soils. The disturbed soil samples were collected at burned site to a depth of about 20cm below the ground surface. All samples were crushed and sieved 425 µm before being kept in plastic seal bags for laboratory tested purpose. Some of each sample was added with deionised water to 1.2 times the liquid limit value to prepare slurry specimens. All the slurry specimens were kept in seal bags before being tested.

3.5 Heating Process

Some unburned soil samples were taken for heating process. Samples were oven dried for at least 24 hours**.** Samples were placed in porcelain crucibles and heated in muffle furnace at three different temperatures which are at 440°C, 800°C and 1350°C. Samples were held at the selected temperature for six hours and left to cool. Samples then stored in sealed bags.

3.6 Properties of Unburned and Burned Soil

The laboratory test included specific gravity test, Atterberg limit test, free swell test, and loss on ignition test. All the tests followed different standards as shown in Table 3.1.

Table 3.1 Standard used for the physical properties test

Physical Properties	**Method**
Specific gravity, G_S	Density bottle (Small pycnometer) (BS1377: Part 2 : 1990 : 8.3)
Liquid limit, LL	Cone penetration method (BS1377 : Part2 : 1990: 4.3)
Plastic limit, PL	(BS 1377 : Part 2 : 1990 : 5.3)
Shrinkage limit, SL	Standard test method for shrinkage factors of soil by the wax method (ASTM D 4943 – 08)
Swell index, Cs	Free swell test (ASTM D4829)
Determination of organic matter	
Loss on ignition	(BS 1377 : Part 3 : 4.3)

3.6.1 Specific Gravity Test

This test follow BS 1377: Part 2: 1990: 8.3. About 10 g oven dried soil sample that passed 2mm sieve was transferred to the density bottle. The distilled water was added about half to three-fourth of the density bottle and was placed in the vacuum desiccators. The soil sample was left in the desiccators for at least one hour until no further loss of air was apparent. The distilled water was added until the density bottle full and was left for an hour in room temperature. Then the soil and water was removed from the bottle. The density bottle was refilled with water until full and was left for an hour. The test was repeated twice for the same soil sample. The specific gravity can be calculated using Eq. 3.1.

$$Gs = (W2 - W1)/((W4 - W1) - (W3 - W2)) \tag{3.1}$$

Where;

W1 = Weight of bottle + Stopper

W2 = Weight of bottle + Stopper + Dry soil

W3 = Weight of bottle + Stopper + Soil + Water

W4 = Weight of bottle + Stopper + Water

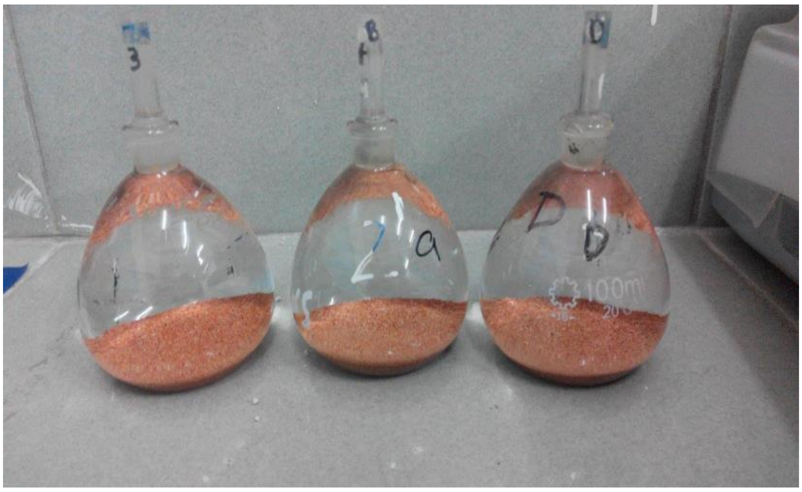

Figure 3.3 Apparatus setup for specific gravity test

3.6.2 Liquid Limit Test

This test was following the BS 1377: Part 2: 1990: 4.3. About 250 g oven dried soil passing 0.425mm were left air dried for at least 30 minutes. Distilled water were added to the soil sample to form paste and then transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air is trapped in the soil sample. The penetrometer was adjusted that the cone point touches the surface of the soil paste. The vertical clamp was released to penetrate into soil paste under its own weight for 5 seconds. The test was repeated for three times of values of penetration in the range of 13.5 to 27.5mm. The graph of water content versus cone penetration was plotted. The moisture content corresponding to cone penetration of 20mm was taken as liquid limit of the soil.

3.6.3 Plastic Limit Test

This test was following the BS 1377: Part 2: 1990: 5.3. The soil paste was rolled out a thread on a flat surface. The plastic limit is defined as the moisture content where the soil paste begins to break apart at diameter 3.2mm.

3.6.4 Shrinkage Limit Test

Shrinkage limit test follow ASTM D4943–08. The soil sample was added with distilled water until it reaches 1.2 times liquid limit of the soil sample. Weight of empty container is recorded. Then, grease is applied on internal of the container and weight again. The soil sample transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air is trapped in the soil sample and the weight is recorded. The soil sample was left air dried until no changes in the soil weight. The weights of metal cup with soil sample after oven dried were recorded. The dry soil sample is tied with thread and coated with wax. The weight of dry soil with thread and weight of dry soil with thread and wax were recorded. The dry soil with thread and wax is weight in air and in water. The graph of void ratio versus water content was plotted. The moisture content corresponding to void ratio of the soil was taken as shrinkage limit of the soil.

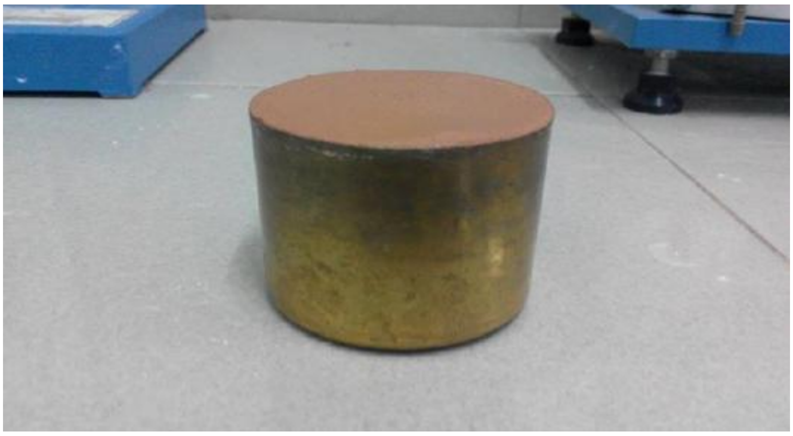

Figure 3.4 Shrinkage limit test apparatus setup

3.6.5 Free Swell Test

This test was following ASTM D4829. The 10ml soil sample was poured into a cylinder and distilled water was added until it reaches 50ml. The soil sample was left air dried until there is no change in its volume. The free swell test can be determined by using the Eq. 3.2.

$$FS = (v1 - v0)/ v \times 100 \ (3.2) \qquad 3.2$$

Where;

FS = Free swell, %

$v1$ = Soil volume after swelling, cm3

$v0$ = Volume of dry soil, 10 cm3

Figure 3.5 Free swell test apparatus setup

3.6.6 Lost on Ignition

This test follow BS 1377: Part 3: 1990: 4.3. The soil sample dried for at least one hour, cooled in desiccators for 30 minutes was added into the crucible until half full and weigh. The soil sample was oven- dried for 24 hours before it was cooled and reweight. Then, the soil sample was heated in a furnace with 440°C for three hours, cooled in a desiccators and weight again. The heating repeated until no further changes in the soil weight. The loss in ignition can be calculated by using Eq. 3.3.

$$\text{Loss in ignition} = (MS - MA)/(MS - MC) \times 100\% \, (3.3) \qquad 3.3$$

Where;

MS = Mass of crucible and oven dried soil sample

MA = Mass of crucible and soil sample after ignition

MC = Mass of crucible

3.7 Soil-Water Retention Curve

Soil-water characteristic curve defined as relationship between water content and soil suction. Water content can be presented in gravimetric water content, volumetric water content or degree of saturation. In this study gravimetric water content was used. The soil samples were added with deionizer water with increment of 2%. Then the soil sample was kept in sealed bag for at least seven days. Soil suction has two components namely metric suction and osmotic suction. The sum of metric and osmotic suction is defined as total suction of the soil. In this study, total suction is obtained by osmotic technique using Decagon WP4 PotentiaMeter device.

3.7.1 Chilled Mirror Dew-Point Hygrometer Technique

The capability of a chilled mirror device for measuring soil water retention curve was investigated on fine grained soils having plasticity indices ranging from 15 to 80. In Decagon's chilled mirror devices, a test specimen is inserted into a sealed chamber that contains a mirror together with means to chill and detect condensation on the mirror. The temperature at which condensation begins determines the water potential in the head space of the sealed chamber. When a test specimen is inserted into the chamber, moisture is transferred between the specimen and the head space until equilibrium is reached. At equilibrium, the water potential in the head chamber equals the water potential in the specimen. In soils, the water potential is usually called suction. The graph of gravimetric water content versus log total suction is plotted.

Figure 3.6 Apparatus set-up for Chilled Mirror Dew-Point Hygrometer Technique Test

3.7.2 Osmotic Technique

First of all, the 14,000 semi-permeable membranes were soaked in distilled water for about 30 minutes prior being used. Three type of solution of polyethylene glycol (PEG 20,000) powder (25g, 75g, and 125g) with 250ml of distilled water were prepared in beakers and magnetic stirrer was put into the beakers. The next steps, 4 g slurry sample was enclosed in the semi-permeable membrane and were immersed into the PEG solutions prepared earlier. The mass of the sample were obtained every day until no further changes occur. After the constant mass was reached, the samples were then oven dried for 24 hours and the resulted oven-dried mass of the sample were determined. The suction of PEG solutions at different concentration were measured using chilled-mirror dew-point technique.

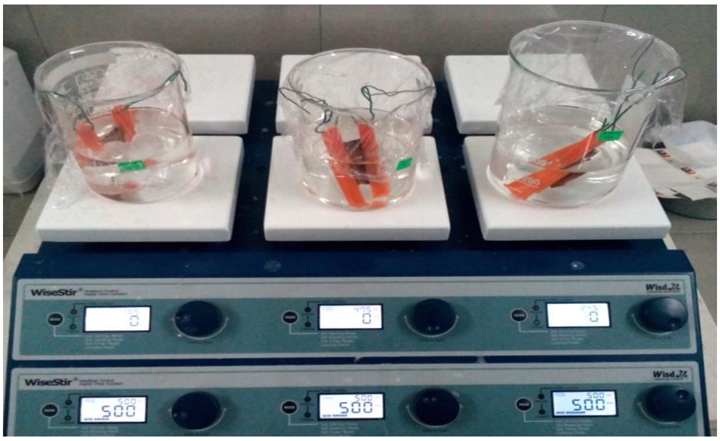

Figure 3.7 Apparatus set-up for Osmotic Technique Test

3.8 Measurement of Eroded Materials

A silt fence was installed at the base of burned soil plot to collect eroded sediment from the plot. Silt fences allow water to pass through the mesh (0.03 – 0.08 cm) and have a documented trapping efficiency of 68 to 93% (Spigel and Robichaud, 2007). After rainfall event, the collected sediment was removed from the deposition areas behind the silt fences and weighed.

3.9 Assessment of Vegetation Recovery

Field studies were conducted to evaluate the assessment of vegetation recovery on burned and unburned soil. The amounts of eroded material at the slope toe were measured to evaluate the effect of wildfire on slope erosion. Furthermore, the evaluation effect of fire on vegetation growth was observed. Evaluation on the qualitative analysis of fire that affect on vegetation cover on area that affected and unaffected by wildfire and type of vegetation were considered.

3.9.1 Qualitative Analysis of Fire Affect on Vegetation

In this study, images at the hillside slope at Jalan Gambang, Kuantan were captured to analyze the changes of vegetation on the slope that affected by wildfire. The images were captured after wildfire (i.e. 0 days), after 32 days, after 157 days, after 354 days and 729 days to evaluate the rate of vegetation growth after affected by wildfire. The difference in vegetation cover between the area affected by fire and unaffected by fire were also compared.

3.9.2 Types of Vegetation

The samples of vegetation at the natural burned site were taken at the hillside slope. Determinations of the type of vegetation that can growth at burned and unburned soils were compared.

Figure 3.8 Vegetation samples collection process

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Effect on Soil Properties

In this chapter, the results for all the tests were discussed. The soil properties of unburned and burned soil which are specific gravity, Atterberg limits, swell potential and organic matter content were also discussed.

Table 4.1 The effect of geotechnical properties of unburned and burned soil at varying temperature

Properties	Unburned	Natural Burned	Burned 440ºC	Burned 800ºC	Burned 1350ºC
Specific gravity, Gs	2.65	2.58	2.69	2.63	2.60
Liquid limit (%)	56.4	55	46.4	-	-
Plastic limit (%)	29.69	37.14	32.10	NP	NP
Shrinkage limit (%)	32	40	21.40	-	-
Free swell (%)	5	5	0	0	0
Organic matter content (%)	0.36	0.51	0.20	0.00	0.00

4.1.1 Effect of Temperature on Specific Gravity

From the Table 4.1, it shown that the effect of specific gravity on unburned and burned soil at varying temperature. Specific gravity for unburned soil is 2.65 while, for the natural burned soil is 2.58. Both of these values showed that it is reduced after the wildfire is occurred. In a study conducted by Young-Suk Song (2007), they suggest that specific gravity for natural burned soil is lower compared to unburned soil. In addition, the specific gravity for varying temperature at 440ºC and 800ºC are 2.69 and 2.63. From this laboratory result obtained, it showed that the specific gravity at 440ºC is more than the specific gravity for unburned and natural burned soil. This means it shows an increment at this temperature. However, it is reduced into 0.06 for temperature at 800ºC with the specific gravity of 2.63. It is contrast with study conducted by Tan et al, (2004) that stated specific gravity reduced rapidly from 100ºC to 600ºC and does not show significant decrease for interval of 600ºC to 1000ºC. Besides, the specific gravity at temperature of 1350ºC is 2.60 which is, it is slightly decreased into 0.03 from the temperature of 800ºC.

4.1.2 Effect of Temperature on Liquid Limit

From the Table 4.1 shown that the effect of liquid limit on unburned and natural burned soil at varying temperature. Liquid limit for unburned soil is 56.4% while, for the natural burned soil is 55%. Both of these values showed that it is slightly decreased about 1.4% after the wildfire is occurred. Furthermore, the value of liquid limit at temperature of 440ºC is also keep decreased into 46.4%. In addition, when the varying temperature is increased at 800ºC and 1350ºC, the liquid limit value is reduced until it is reached at zero. The result showed similar pattern with study conducted by Abu-Zreig (2001) which suggest that liquid limit decreased with increasing temperature. However, it in contrast with research conducted by Tan et al. (2004) which stated that liquid limit decreased rapidly at temperature between 100ºC to 300ºC and does not show significant changes between 400ºC to 1000ºC.

4.1.3 Effect of Temperature on Plastic Limit

The effect of temperature on plastic limit is shown in Table 4.1. From the table, it showed that there is an increment on plastic limit result for unburned soil and natural burned which are from 29.69% to 37.14%. The increment is about 7.45%. Furthermore, when the temperature is increased at 440ºC, the plastic limit is 32.10% which is reduced about 5.04% when compared with natural burned soil but it is more than 2.41% when compared with unburned soil. At temperature of 800ºC, the plastic limit reached non-plastic (NP) state and it is reduced to zero after burned at 1350ºC. The result contrast with study conducted by Tan et al. (2004) and Abu-Zreig (2001) which suggest that plastic limit reduced as temperature increase until it reached zero at 400ºC.

4.1.4 Effect of Temperature on Shrinkage Limit

The effect of temperature on shrinkage limit is shown in Table 4.1. From the table, the laboratory result obtained showed that there is a decrement on plastic limit result for unburned soil and natural burned which are from 32% to 42%. The decrement is about 8% which is the unburned soil plastic limit is less than natural burned soil. Furthermore, when the temperature is increased at 440ºC, the shrinkage limit is 21.40% which is reduced about 18.60% when compared with natural burned soil and decreased about 10.60% when compared with unburned soil. The shrinkage limit reached zero at temperature 800ºC and 1350ºC.

4.1.5 Effect of Temperature on Free Swell

The effect of temperature on free swell is shown in Table 4.1. The swell index in both unburned and burned soil samples are 5% which it is does not show any significant changes. However, the swell index is reduced to zero after burned at 440ºC, 800ºC and 1350ºC.

4.1.6 Effect of Temperature on Organic Content

From the result in Table 4.1, the organic matter increase to 0.51% in natural burned soil from 0.36% in unburned soil which may cause by the ash in natural burned soil sample (Ebel, 2012). At temperature of 400ºC, organic matter content is 0.2 and it reduced as the temperature increased until it reached zero at 800ºC and 1350ºC. According to a review on effect of fire on properties of forest soils conducted by Certini (2005), loss of organic matter is the most intuitive change soils experience during burning.

4.2 Drying Suction-Water Content SWCC

The suction of the unburned and natural burned soils at various water content is presented in Figure 4.1. Referring to Figure 4.1, the suction-water content SWCC of natural burned soil is below that of unburned soil. The lowest suction point for unburned and natural burned soil is 0.16MPa. The percent of the water content at the lowest suction for unburned and natural burned soil is 49.60% and 36.69%, which have the differences of 12.91%. A study conducted by Alauzis et al. (2004) measured major declines in organic matter content and soil-water retention resulting from wildfire. The suction-water content SWCC of burned soil at temperature of 440ºC is slightly lower compared to natural burned soil and unburned soil. The lowest suction point for burned soil at temperature of 440ºC is 0.16MPa with the water content of 35.23%. The differences of water content between burned soil at temperature of 440ºC and unburned soil is 14.37%, while slightly reduced into 1.46% when be compared with natural burned soil. Furthermore, burned soil at temperature of 800ºC is the second lowest suction-water content SWCC. In addition, the suction-water content SWCC of burned soil at temperature 1350ºC is the lowest due to non-plastic behaviour and zero organic matter content. According to Ebel (2012), the primary driver for differences in SWCC in unburned and burned soil is organic matter content.

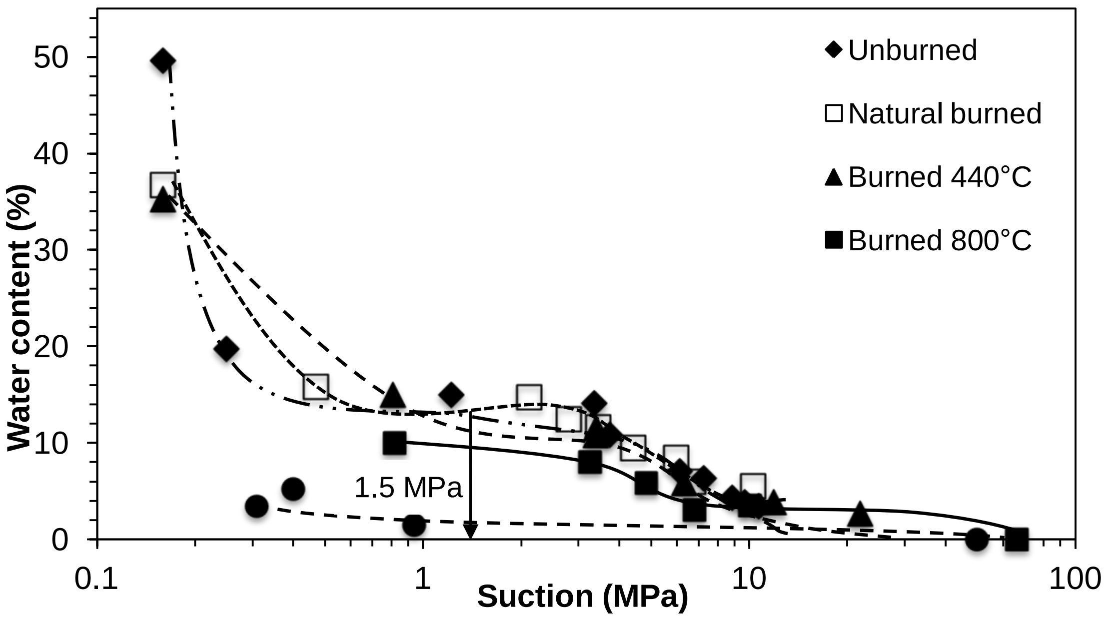

Figure 4.1 Drying Suction Water Content (SWCC)

4.3 Measurement of Eroded Materials

After rainfall event, the collected sediment was removed from the deposition areas behind the silt fences and weighed. The weight of eroded material is 21.46kg / m.

4.4 Assessment of Vegetation Recovery

The study after fire was observed by evaluation effect of fire on vegetation growth. Qualitative analysis of fire that affect on vegetation and type of vegetation were considered.

4.4.1 Qualitative Analysis of Fire Affect on Vegetation

In this study, images at the hillside slope at Jalan Gambang, Kuantan were taken to analyze the changes of vegetation on the slope that affected by wildfire. The images were taken after wildfire (i.e 0 days), after 32 days, after 157 days, after 345 days and after 729 days.

Figure 4.2 Image after wildfire captured on 22 November 2015 (i.e 0 days)

Figure 4.3 Image after wildfire captured on 23 December 2015 (32 days)

Figure 4.4 Image after wildfire captured on 27 April 2016 (157 days)

Figure 4.5 Image after wildfire captured on 10 November 2016 (354 days)

Figure 4.6 Image after wildfire captured on 20 November 2017 (729 days)

From the Figure 4.2, the image was captured at day of 0 on 22 November 2015 which is after the natural burned occurred at the natural burned site. The image showed that few types of vegetation, which is growth with none or thin stem at the slope such as *Dicranopteris Linearis, Nepenthes Spp, Rhodomyrtus Tomentosa Wight, Lygodium Microphyllum, Imperata Cylindrica* and *Brachiaria Mutica* were mostly burned in a huge amount while, the type of vegetation such as *Acacia Mangium* was also mostly burned but in a less amount. Besides, the function of the stem is to support for the leaves and the flower and carries water and minerals to them from the roots, while the function of the roots is to spread out and absorb the water. It can be concluded that the percent of vegetation on Figure 4.2 which is at the natural burned site was about 28% after the natural burned occurred. Furthermore, from the Figure 4.3, the image was captured on 23 December 2015 which is 32 days after the natural burned occurred. From the image, it showed that the observation result for vegetation growth was constant which is same as the result for natural burned that occurred at day of 0.

Moreover, in Figure 4.4 the vegetation were starts to growth but in a small amount. The amounts of the vegetation that can growth at the natural burned site were about 32%. The image of Figure 4.4 was captured on 27 April 2016, which at day of 157 after the natural burned occurred. Next, Figure 4.5 is the image that was captured at day of 354 on 10 November 2016 which after the natural burned occurred. From the figure, it showed that the vegetation is continuously growth. The amount of the vegetation that cans growth at the natural burned soil is about 35% with the same type of vegetations. The type and amount of vegetation at the natural burned and unburned site were compared and written at the next subtopic. Lastly, the latest image which is to achieve the third objective in this study was captured on 20 November 2017 which at day of 729 after the natural burned occurred. From the observation, the amount of the vegetation that cans growth is about 40%. The increment is only about 5% from the previous year.

4.4.2 Type of Vegetation

The samples of plants at the natural burned site were taken at the hillside slope. The details about the vegetation samples at natural burned and unburned soil are as shown in Figure 4.7. The types of vegetations growths are monitored at the natural burned site and were compared with the unburned site.

From the unburned site which is before the wildfire occurred, there are seven types of vegetation. There are including *Dicranopteris Linearis, Nepenthes Spp, Rhodomyrtus Tomentosa Wight, Acacia Mangium, Imperata Cylindrica, Lygodium Microphyllum* and *Brachiaria Mutica*. From the field work observation result, at the unburned site which is before the wildfire occurred, there are many amounts of *Dicranopteris Linearis* species while at the natural burned site are only moderate amount. *Nepenthes Spp* is found less at unburned site while there is no presence of this species at natural burned site. Furthermore, *Rhodomyrtus Tomentosa Wight* are found moderate in amount while after the natural burned occurred, the amount is reduced into very small amount. In addition, there are two type of species that many can be found at the unburned site while moderate amount at natural burned site. The two species are *Acacia Mangium and Imperata Cylindrica.* Next, *Lygodium Microphyllum* and *Brachiaria Mutica* are also have the same amount that growth at unburned site which is in moderate amount while there are reduced into less amount after the natural burned occurred.

From these field work observation, the vegetation that can growth at the burned soil are decreases after the natural burned occurred when compared with the unburned site. Furthermore, *Nepenthes Spp* is the only one species that is not growth again at the burned soil. The summarizations of the amount of vegetation growth are clearly stated in the Table 4.3.

Table 4.2 Comparison on the existing amount of vegetation growth at unburned and natural burned site

Type of Vegetations	**Unburned Soil**	**Natural Burned Soil**
Dicranopteris Linearis	Many	Moderate
Nepenthes Spp	Less	None
Rhodomyrtus Tomentosa Wiht	Moderate	Less
Acacia Mangium	Many	Moderate
Imperata Cylindrica	Many	Moderate
Lygodium Microphyllum	Moderate	Less
Brachiaria Mutica	Moderate	Less

a) *Dicranopteris Linearis*

b) *Nepenthes Spp*

c) Acacia Mangium

d) *Rhodomyrtus Tomentosa Wight*

e) *Lygodium Microphyllum*

f) *Imperata Cylindrica*

g) *Brachiaria Mutica*

Figure 4.7 Images of vegetation samples

CHAPTER 5

CONCLUSION

5.1 Summary

Wildfire affected the geotechnical properties of the soil. The changes to the overall geotechnical properties should be taken into consideration in the design of fire affected slopes to ensure long-term stability of the slopes. Vegetation is very important to less the occurrence of soil erosion during raining seasons and to increase the slope stabilization.

a) Temperature had significant effect on soil properties which consist of specific gravity, Atterberg limits, swell potential, organic matter content and SWCC. However, the changes in these properties were higher when the temperature ranged from 440°C to 800°C. At 440°C, the liquid limit, organic matter content and SWCC were reduced and the swell index was eliminated. At 800°C, liquid limit, plastic limit, swell potential and organic content were completely eliminated. Burned soil at temperature 1350ºC was completely eliminated due to non-plastic behaviour and zero organic matter content.

b) From overall study, the natural burned soil was estimated experienced fire at temperature below 440°C. Water retention curves were obtained for both soils at higher suctions, however at suctions lower than 1.5MPa, a much lower water retention characteristic was observed for natural burned soil.

c) The vegetation growths on burned soil are lesser compared to unburned soil. There are seven types of vegetation growth before the natural burned occurred but only six types of vegetation growth that are still growing even thought the amount is decreases. A study conducted by Rees and Ali (2012) noted that, the presence of vegetation increased slope stability by about 8%. Thus, in absence of vegetation, direct contact of precipitation on burned of dried slopes lead to an increased in hill slope erosion and surface runoff.

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