CHARACTERIZATION OF SPATIAL VARIABILITY OF SOIL ENGINEERING PROPERTIES AT USM ENGINEERING CAMPUS

By

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ABSTRACT

Studies on the spatial variability of soil engineering properties are limited in the south-east Asia. Understanding the variability of soil properties is significant to land management practices including planning and adopting conservation works for soil erosion, slope stability, landslide control and soil hydrological response modeling. This study examines the spatial variability of soil engineering properties (moisture content, bulk density, particle size distribution, organic content and specific gravity) in a flat region under tropical climate using geostatistical and statistical methods. Soil samples were taken from a 137 ha area of the Universiti Sains Malaysia. The study area was divided into a number of geo-grid reference points and soil samples were collected at grid intersection points. The Global Positioning System (GPS) was used for locating the sample position. Large spatial variability of soil fines content and moisture content were found to exist in the study area and the degree of variability was heterogeneous among different soil properties. About 74–84% of the observed total variability in soil properties was due to spatial structure. All the soil properties tested, exhibited strong spatial dependency and were spatial dependent up to distances of 181–256m. The study indicated geostatistical analysis in conjunction with conventional statistical analysis could reveal spatial variability nature of soil properties and the causes behind the variability. The variability of the soil properties observed is largely due to topographic conditions and land disturbances.

ABSTRAK

Kajian mengenai perubahan sifat-sifat fizikal tanah terhadap ruang hanya dihadkan di kawasan Asia Tenggara sahaja. Pemahaman mengenai perbezaan dan perubahan sifat fizikal tanah adalah penting dalam aspek pengurusan tanah termasuk merancang dan mengenalpasti kerja-kerja pemulihan dalam mengatasi masalah hakisan tanah, kestabilan cerun, kawalan terhadap keruntuhan tanah dan permodelan kesan tanah terhadap hidrologi. Sifat-sifat fizikal tanah (termasuk kandungan lembapan, ketumpatan, analisis saiz zarah, kandungan organik dan graviti tentu) di kawasan tropika akan diuji dalam kajian ini dengan menggunakan kaedah geostatistik dan kaedah statistik. Sampel tanah dikumpul dari kawasan seluas 137 hektar di Universiti Sains Malaysia. Lokasi pengumpulan sampel ditentukan berdasarkan titik-titik rujukan grid-geo yang ditetapkan di kawasan kajian. Peralatan GPS (Global Positioning System) digunakan untuk mengenalpasti kedudukan sebenar lokasi pengumpulan sample tersebut. Perubahan kandungan lembapan dan kandungan tanah liat megikut ruang adalah drastik di kawasan kajian dan darjah perubahan adalah berlainan untuk setiap sifat fizikal tanah. Struktur ruang mendominasi 74–84% daripada perubahan keseluruhan sifat fizikal tanah. Daripada analisis yang dijalankan terhadap tanah, perubahan sifat fizikal tanah terhadap ruang diperhatikan dalam julat 181–256m. Analisis geostatistik bersamaan dengan analisis statistik telah diaplikasikan untuk mengkaji perubahan sifat fizikal tanah mengikut ruang dan sebab yang menjurus kepada perubahan tersebut. Keadaaan topografi dan keadaan semasa tanah merupakan penyumbang utama kepada perubahan tersebut.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Soil is a complex heterogeneous mixture of organic and inorganic mineral compounds formed by weathering of rocks. Soil properties vary spatially and temporally from a field scale to a large regional scale (Sun *et al.*, 2003) and influenced by both intrinsic (e.g. soil formation process, composition of parent rocks, soil organisms) and extrinsic factors (e.g. regional climate, vegetation, soil management practices, fertilization, etc.). This variability may be random or systematic. Contrary to the random variation, a systematic variation has a consistent spatial pattern which allows one to estimate a particular property at subjected locations (Ersahin *et al.*, 2005). Common engineering properties of soil include moisture content, bulk density, particle size distribution, specific gravity and organic content.

The variability of soil engineering properties has significant impact on many hydrological processes. For example, the spatial distribution of soil moisture content effects infiltration of water into the soil, lateral soil moisture redistribution as well as determines rainfall-runoff responses in many catchments (Anctil *et al.*, 2002).

Spatial variability causes difficulty in representing a soil with a deterministic o precisely defined set of characteristics and precluded characterization of soil hydrological response. One of the major issues in distributed parameter hydrological modeling is how to estimate attributes of spatially varying soil properties (Sun, *et al.*, 2003). Characterization of spatial structure of soil engineering properties is important for several form of analysis:

i. To determine the optimum size of spatial grids for distributed parameter hydrological models.
ii. Estimating point or spatially averaged values of soil engineering properties using kriging technique.
iii. In designing sampling networks and improving their efficiency.

This proposed project will allow understanding and characterization of small scale spatial variability nature of physical properties of tropical soil at Universiti Sains Malaysia Engineering campus area. This will also allow identifying effect of land disturbances and catchment characteristics in Nibong Tebal area. Apart from that, this study will also enhance the understanding of the spatial variability in soil engineering properties and its effects on the hydrological processes.

1.2 PROBLEM STATEMENT

The heterogeneity and variability of soil engineering properties has important influence on processes such as erosion (Western *et al*., 1998), solute transport (Netto *et al*., 1999), soil-water retention, shrinking, soil swelling, seepage (Mapa, 1995; Guan & Fredlund, 1999), CO_2 emission from soil (Scala *et al*., 2000), various soil-inhabiting biota (Brukner *et al*., 1999) and soil fertility (Delcourt *et al*., 1996). Under tropical climates, properties of soils will exhibit more spatial variability due to their greater exposure to harsh climatic conditions (Mapa & Kumaragamage, 1996).

There are two main statistical approaches can be used in study of engineering soil properties variability depend on the way that data is analyzed. Classical statistics have been widely used to assess the variability of various properties of soil (Biggar & Nielsen, 1976; Bresler, 1989; Brejde *et al*., 2000). Statistical characterization of spatial variability involves parameter estimation such as the mean, variance and coefficient of variation. Statistical analysis requires the validity of some basic hypotheses, such as the independence between observations, due to the randomness of variations from one place to another and do not consider spatial correlation and relative location of samples (Vauclin *et al*., 1983; Goderya *et al*., 1996). In contrast, geostatistical analysis, based on the theory of regionalized variables, enables the interpretation of results based on the structure of their natural variability, taking into consideration spatial dependence within the sample space. The analysis of dependence is based on the structure of the semivariogram, which demonstrates the existence of spatial dependence (Carvalho, 1991; Vieira, 1997; Goovaerts, 1997).

1.3 OBJECTIVE

The primary objectives of this study are:

1. To characterize spatial structure of soil properties under tropical climate in terms of semivariogram parameters
2. To map the variation in soil properties in the study area, and
3. To evaluate the effects of land use changes on the variability of soil properties

1.4 SIGNIFICANT OF THE STUDY

i. This project will help identifying spatial variability of soil engineering properties under the tropical climates. Properties of soils under tropical climates exhibit more spatial variability due to their greater exposure to harsh climatic conditions. In many instances, spatial variation of soil properties is not random but tends to follow a pattern of variability decreases as distance diminishes between points in space (Youden & Mehlich, 1937; Warrick & Nielson, 1980).

ii. Soil properties vary from place to place, even for the same soil type. Variability of soil engineering properties has significant impact on many hydrological processes. The common engineering properties of soil such as moisture content, bulk density and organic content are greatly influence the hydrological processes such as infiltration of water into soil, rainfall-runoff response and precipitation. Apart from that, changes in soil properties due to change in atmospheric deposition inputs, vegetation or land use may affect long-term stream response (Neal, 1992; Anderson *et al*., 1993; Sanger *et al*., 1996).

iii. Human activities have had pronounced impacts on soil properties. Human activities are most frequently related to changing patterns of land use (Grieve, 2001). Changes in land use have made changes in the land-atmosphere fluxes of heat, moisture and momentum. These changes in turn impact weather and climate through influences on atmospheric dynamic, thermodynamic, convection, clouds and rainfall. Therefore, identifying the spatial variability in soil engineering properties can be used to predict the consequences of the human activities on the hydrological processes such as precipitation, surface water runoff flood and etc.

iv. Soil organic matter is essential to erosion control, water infiltration, water holding capacity in soil and conservation of nutrients (Franzluebbers, 2000). Apart from that, organic matter will take effect in promoting soil granulation and thus maintaining large pores through which water can enter and percolate downward.

v. Soil compaction increased bulk density, decreased porosity and shifts in pore shapes and size distributions (Flowers & Lal, 1998). Changes in these basic soil properties alter the soil’s water retention and hydraulic conductivity characteristics, which in turn affect the infiltration ability of the soil and available water storage capacity. Consequently, soil compaction can have serious effects in changing of soil properties and hence, on crop growth and environmental quality.

vi. Soil moisture content is a key state variable for understanding a large number of hydrological processes involved in a broad variety of natural processes (geomorphological, climatic, ecological) that act at different spatio-temporal scales (Entin *et al*., 2000). Soil moisture is also one of the main factors in infiltration or runoff dynamic. It participates directly in the separation of net radiation between sensible and latent heat; it determines the amount of water available for evapotranspiration and it controls subsurface flow and the migration of chemicals to aquifers. Antecedent soil moisture in a basin is a key factor in hydrology and erosion modeling and knowledge of the behavior of soil moisture and its spatial distribution affords essential information for climatic and hydrological models (Beven, 2001).

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Soil is a complex heterogeneous mixture of organic and inorganic mineral compounds formed by weathering of rocks. Concept of soil has been changing from a static point of view towards a more dynamic and complex understanding. Properties, characteristics and attributes are considered (Montero, 2005). Soil can be characterized as a natural body comprised of solids (minerals and organic matter), liquid and gases that occur on the land surface occupy space. There are five soil forming factors (parent material, climate, topography, organisms and time) affect the properties of the soil in its natural (Murray *et al.*, 1975).

Soil physical properties vary spatially and temporally from a field scale to large regional scale (Sun *et al.*, 2003) and are influenced by both intrinsic (e.g. soil formation process, composition of parent rocks, soil organisms) and extrinsic factors (e.g. regional climate, vegetation, soil management practices, fertilization, etc.).

Extrinsic factors are environmental controls on the soil that relate mainly to the components of the *clorpt* model (Jenny, 1941). The model's name is an acronym where: *cl* refers to the climate conditions, *o* to the effect of biotic factors (organisms), *r* is the relief, *p* is the parent material and *t* refers to time effect. Jenny (1961) argues that the *clorpt* model variables define the state of the soil system within which pedogenetic processes occur. However, the extrinsic factors are insufficient to explain fully the spatial variability of soil physical properties (Ibanez *et al*., 1998; Philips, 1998).

Intrinsic factors provide complementary information that can be related to variation in the initial conditions and their perturbations that increase over time and make the soil system dynamic and variable (Seydel, 1988). Intrinsic factors are also related to soil attributes which might be the outcome of long term pedogenetic process (Phillips, 2001). The importance of intrinsic factors to understand soil variation has already been acknowledged and was linked to patterns of physical and chemical soil properties (Phillips, 1999; Skidmore & Layton, 1992).

Soil is one of the most important engineering materials and determinacy of soil conditions and soil properties are the initial work of any type of civil engineering work. Engineers think of soil as material to build on and are concerned with moisture conditions and the ability of soil to become compacted and hold weight (Murray & Tedrow, 1975).

2.1.1 Soil Profile

The soil profile is the vertical display of soil horizons. Soil physical parameters vary in respect to both time and position in the soil profile (Letey, 1985). Erosion, deposition and other forms of disturbance might affect the way a soil profile looks at a particular location (Murray & Tedrow, 1975). The important characteristics of the various horizons are:

i. Soil horizons differ in color, texture, structure, consistence, porosity and soil reaction.
ii. Soil horizons may be several feet thick or as thin as a fraction of an inch.
iii. Generally, the soil horizons merge with one another and may or may not show sharp boundaries. Horizons in a soil profile are like the parts of a layer cake without the clear bonds of frosting between them.

2.1.2 A Typical Soil Profile (Oberlander & Muller, 1987)

O Horizon

From the Figure 2.1, the top layer of the soil profile is the O horizon. This horizon consists mainly of organic matter from decomposing process which accumulates under conditions of free aeration.

A Horizon

Beneath the O horizon is the A horizon which marks the beginning of the true mineral soil. In this horizon organic material mixes with inorganic products of weathering. The A horizon typically is dark colored horizon due to the presence of organic matter. Eluviation process occurs in this horizon where the organic and inorganic substances are removed from a horizon by leaching. Eluviation is driven by the downward movement of soil water.

E Horizon

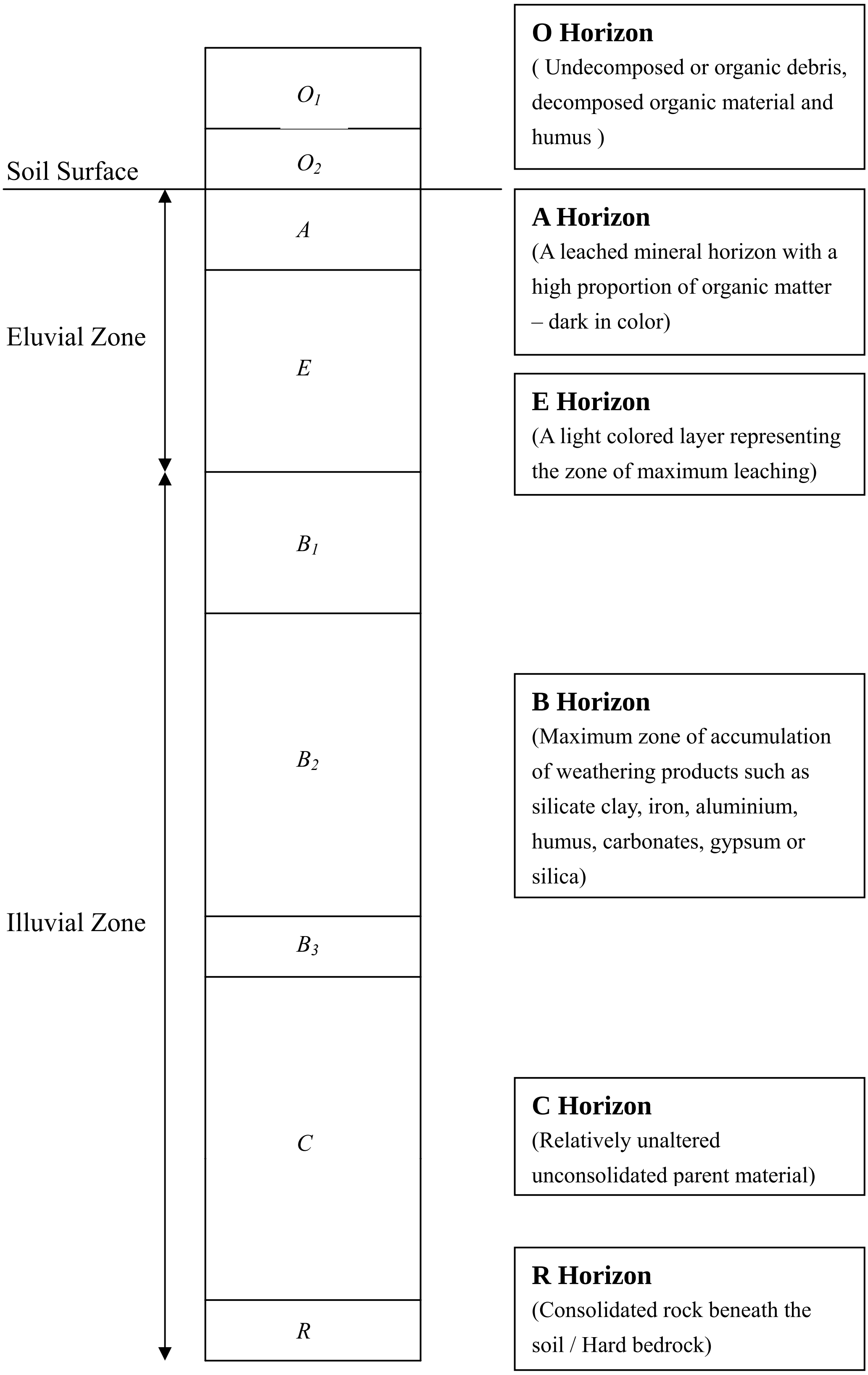
The E horizon generally is a light-colored horizon with eluviation being the dominant process. Leaching or the removal of clay particles, organic matter and oxides of iron and aluminium is active in this horizon. Under coniferous forests, the E horizon often has high concentration of quartz giving the horizon an ashy-gray appearance.

B Horizon

Beneath the E horizon is the B horizon which is acknowledged as illuviation zone where downward moving, especially fine material is accumulated. The accumulation of fine material leads to the creation of a dense layer in the soil.

C Horizon

The C horizon represents the soil parent material, either create in situ or transported into its present location. Beneath the C horizon is consolidated or hard bedrock which is the lowest layer of soil profile.



O Horizon
(Undecomposed or organic debris, decomposed organic material and humus)

A Horizon
(A leached mineral horizon with a high proportion of organic matter – dark in color)

E Horizon
(A light colored layer representing the zone of maximum leaching)

B Horizon
(Maximum zone of accumulation of weathering products such as silicate clay, iron, aluminium, humus, carbonates, gypsum or silica)

C Horizon
(Relatively unaltered unconsolidated parent material)

R Horizon
(Consolidated rock beneath the soil / Hard bedrock)

Figure 2.1: Schematic presentation of soil profile

2.2 SOIL PROPERTIES

Soil properties are usually recognized as important soil quality indicators (Karlen & Stott, 1994; Arshad *et al*., 1996; Boix-Fayos *et al*., 2001). Soil properties change from one place to place, even for the same soil type (Warrick & Nielsen, 1980). Changes in soil properties are due to changes in atmospheric deposition inputs, vegetation or land use (Neal, 1992; Anderson *et al*., 1993; Sanger *et al*., 1996). A major problem in many studies of soil properties has been the inherent spatial variability (Beckett & Webster, 1971; Webster & Oliver, 1992). This has resulted in the need for complex sampling strategies and statistical procedures aimed to minimizing site variability to allow the assessment of temporal changes (Domberg *et al*., 1994; Papritz & Webster, 1995). Soil properties are complex and depend on site, horizon and depth to an extent which depends upon the property studied. Consequently rates of change may also vary with the property measured and also with depth (Miller *et al*., 2001).

2.2.1 Importance of Soil Engineering Properties

Soil properties are important for drawing impacts to hydrological balance. The common engineering properties of soil such as moisture content, bulk density and organic content are greatly influence the hydrological process. The moisture content of soil is very important in the processes of precipitation and infiltration. The higher of moisture content can cause rapid precipitation. Apart from that, bulk density of soil also will influence the infiltration rate. Soil with low density will caused higher infiltration rate compare with the soil with high density. Beside that, organic matter in soil is essential to erosion control, water infiltration and conservation of nutrients (Franzluebbers, 2002). A high contains of soil with organic content will available the soil to storage more water.

2.3 VARIABILITY IN SOIL PROPERTIES

Many soil properties show great variation from place to place in such way that they exhibit an enormous complexity which soil spatial studies aim to understand. Many factors influence soil variation, operating and contributing together to the final result summarized in an experimental data set (Caniego *et al*., 2005).

The heterogeneity and variability of soil properties has important influence on process such as erosion (Western *et al*., 1998), solute transport (Netto *et al*., 1999), soil water retention, soil swelling, shrinking, seepage (Mapa, 1995; Guan & Fredlung, 1999), CO_2 emission from soil (Scala *et al*., 2000), various soil inhabiting biota (Brukner *et al*., 1999) and soil fertility (Delcourt, 1996).

The common engineering properties of soil include bulk density, moisture content, organic content, particle size distribution and specific gravity.

2.3.1 Bulk Density

The bulk density of soil expresses the relationship between its mass and the volume it occupies including the pore space. Bulk density is often regarded as the most useful parameter of soil structure and is used as an indicator of soil compaction or loosening because it is directly related to total soil porosity (Hernanz, 2000). However, it is an insensitive measurement of pore-size distribution and pore continuity (Hamblin, 1987). Apart from that, bulk density is considered to be a measure of soil quality due to its relationships with other properties (eg., porosity, soil moisture, hydraulic conductivity, etc.) (Dam *et al.*, 2005).

Compaction is the compression of a non-saturated soil resulting in reduction of the volume and increase in the density of a given mass of soil (Bodman & Constantin, 1965; Gupta *et al.*, 1989). Soil compaction has important hydrologic implications in terms of its contribution to reduced plant growth, reduced infiltration rates and increased runoff potentials (Gifford *et al.*, 1977). A higher bulk density is important to obtain a suitable soil for construction. Meanwhile, the lower bulk density can obtain a high infiltration rate.

Bulk density of soil can be dividing to:

1. Wet bulk density (ρ), which is the mass including any water present per unit volume in the field.
2. Dry density (ρ), which is the mass per unit volume of field soil after oven drying.

These parameters are related to the soil gravimetric water content (w) as below:

$$\rho_s = 100\left(\frac{\rho}{100+w}\right)$$

Where *w* is the mass of water expressed as a percentage of the mass of dry soil.

Variation in bulk density is attributable to the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil. More of the mineral soils have a bulk density between 1.0 and 2.0.

Soil bulk density is measured using both direct and indirect methods (Hernanz, 2000). Direct method involves measurement of the sample mass and volume. Meanwhile, indirect method is radiation method which is more accurately and precisely than direct method.

2.3.1.1 Methods of Soil Bulk Density Measurement

i. Direct Method

- *Core Sampling*, a cylindrical sampler is hammer or press into the soil. As the volume of the cylinder is known, trimming of the soil core and allows the bulk density can be calculated.
- *Rubber Balloon Method*, the sample is excavated, weighted and it water content is determined.
- *Sand Replacement*, the method as in the Rubber Balloon Method.
- *Cold Method*, a cold is weighted and its volume is determines.

ii. Indirect Method (Radiation Method)

- Several users have designed and built gamma-ray gauges to suit specific purposes.

2.3.2 Moisture Content

Soil moisture is a key state variable for understanding a large number of hydrological processes involved in a board variety of natural processes (geomorphological, climate, ecological) that act at different spatial-temporal scales (Entin *et al.*, 2000). Soil moisture is also one of the main factors in infiltration and runoff dynamic. It participates directly in the separation of net radiation between sensible and latent heat; it determines the amount of water available for evapotranspiration and it controls subsurface flow and the mitigation of chemicals to aquifers (Bevon, 2001). Through the process of evaportranspiration, soil moisture provides a significant source of moisture for the formation of clouds and precipitation over land (Famiglietti *et al.*, 1998). Antecedent soil moisture in a basin is a key factor in hydrology and erosion modeling and knowledge of the behavior of soil moisture and its spatial distribution affords essential information for climatic and hydrological models (Bevon, 2001).

Temporal and spatial variations of soil moisture are receiving increased attention in climate studies because soil moisture is an essential element in processes that drive land surface water and energy fluxes, which affect ecosystem dynamic and biogeo-chemical cycles in the land-atmosphere system. The total groundwater loss in form of supply to soil moisture depends on the soil type, precipitation, potential evaporation and depth of the groundwater table. Because of the groundwater effects on soil moisture and the local water cycle, spatial variations in the groundwater table depth can result in spatial heterogeneity in soil moisture and, subsequently, surface moisture flux across a region. (Xi Chen & Qi Hu, 2004)

Water held in soil in two ways; as a thin coating on the outside of soil particles and in the pore spaces. Soil moisture in the pore spaces can be divided into two different forms which is gravitational water and capillary water. Gravitation water generally moves quickly downward in the soil due to the force of gravity. Capillary water is the most important for crop production because it is held by soil particles against the force of gravity. As water infiltrates into a soil, the pore spaces will be fill with water. When the pores are filled by water, water moves through the soil by gravity and capillary forces. Water will continues move downward until a balance is reached between the force of gravity and the capillary forces. Water is pulled around soil particles and through small pore spaces in any direction by capillary forces.

2.3.2.1 Factors Influence the Variability of Soil Moisture Content

Soil moisture variability is influenced by a number of factors. These include variations in topography, soil properties vegetable type and density, mean moisture content, depth to water table, precipitation depth, solar radiation and other meteorological factors (Famiglietti *et al*., 1998).

i. Topography

Variation in slope, aspect, curvature, upslope contributing area and relative elevation all affect the distribution of soil moisture near the land surface. Slope angle influences infiltration, drainage and runoff; steeper slopes are likely to be drier than flat areas owing to lower infiltration rate, rapid subsurface drainage and higher surface runoff. Hills and Reynolds (1969), Moore *et al.* (1988) and Nyberg (1996) all found that slope angle influences soil moisture variability. Aspect or slope orientation influences solar irradiance and thus evapotranspiration and soil moisture. Reid (1973) found a significant correlation between aspect and soil moisture content.

ii. Soil properties

Soil heterogeneity affects the distribution of soil moisture through variations in texture, organic matter content, structure and the existence of macroporosity, all of which affect the fluid transmission and retention properties of the soil column. Additionally, soil color influences its albedo and thus the rate of evaporative drying. Reynolds (1970), Henninger *et al.* (1976) and Crave and Gascuel-Odoux (1997) all found that variations in soil moisture were related to variations in soil texture. Hawley *et al.* (1983) noted that differences in soil moisture content due to differences in soil texture were more pronounced under wet conditions rather than dry. Niemann and Edgell (1993) found that macroporosity exerted a controlling influence on moisture movement and thus soil moisture variability.

iii. *Vegetation*

Vegetation influences soil moisture variability by the pattern of through fall imposed by the canopy; by shading the land surface and affecting the rate of evaporative drying; by generating turbulence and enhancing evapotranspiration rates; by affecting soil hydraulic conductivity through root activity and the addition of organic matter to the soil surface layer; and by extracting moisture for transpiration from the soil profile. The degree to which these factors effect the soil moisture distribution varies with vegetation type, density and season (Lull & Reinhart, 1955; Reynold, 1970; Hawley *et al.*, 1983; Francis *et al.*, 1986).

iv. *Mean moisture content*

Several investigations have noted that the variance of soil moisture decreases with decreasing mean moisture content (Hills & Reynold, 1969; Reynold, 1970; Henninger *et al.*, 1976; Bell *et al.*, 1980; Hawley *et al.*, 1982; Robinson & Dean, 1993).

2.3.2.2 Methods of Soil Moisture Content Measurement

Measurement of the moisture content of soil and the unsaturated zone is fundamental to many investigations in agriculture, forestry, ecology, hydrology, civil engineering and others environment fields. In practice, the value of soil moisture content, w is determined gravimetrically as the difference between the total weights of the sample when it is oven dried to a constant weight at 105 ^{o}C and when it is wet (Hall & Djerbib, 2004). There are two methods in measurement the soil moisture content:

i. Direct Method (Gravimetric Method)

   The oven-drying technique is probably the most widely used of all gravimetric methods for measuring soil moisture and is the standard for the calibration of all other soil moisture determination techniques. This method involves removing a soil sample from the field, and determining the mass of the water contained in a soil relative to the mass of dry soil.

ii. Indirect Method (Time-Domain Reflectometer)

   Time-domain reflectometer (TDR) determinations involve measuring the propagation of electromagnetic (EM) waves or signals. Propagation constants for EM waves in soil, such as velocity and attenuation, depend on soil properties, especially water content and electrical conductivity. The dielectric constant, measured by TDR, provides an accurate measurement of soil water content and is essentially independent of soil texture, temperature, and salinity.

2.3.3 Organic Matter

Organic matter is the plant and animal residue in the soil at various stages of decomposition. The content of organic in a soil can be maintained or increased by returning crop residue to the soil. Organic matter affects the available water capacity, infiltration rate and tilth. It is a source of nitrogen and other nutrients for crops. The capacity (for water storage) varies, depending on soil properties that affect the retention of water.

Organic matter and organic matter fractions are important attributes of soil quality (Gregorich *et al*., 1994). Thus the impact of changing land use on soil organic matter needs to be assessed in specific agroe-cosystems. However, estimation of soil organic matter contents is often based on large scale variation climate and soil type (Post *et al*., 1982; Zinke *et al*., 1984; Eswaran *et al*., 1993).

Soil organic matter sustains many key soil functions by providing the energy, substrates, and biological diversity to support biological activity which affects soil aggregation and water infiltration. Aggregation is important in:

i. Facilitation water infiltration
ii. Providing adequate habitat space for soil organisms
iii. Adequate oxygen supply to roots and soil organisms
iv. Preventing soil erosion

Meanwhile, infiltration is an important soil feature that controls leaching, runoff, and crop water availability. Surface organic matter is essential to erosion control, water infiltration and conservation of nutrients (Franzluebbers, 2002).

Organic matter contributes to plant growth through its effect on the physical, chemical and biological properties of the soil. It has a:

i. Nutritional function it serves as a source of N and P for plant growth.

ii. Biological function in that it profoundly affects the activities of micro flora and micro faunal organisms.

iii. Physical function in that it promotes good soil structure, thereby improving tilt, aeration and retention of moisture and increasing buffering and exchange capacity of soils.

2.3.4 Particle Size Distribution

Soil particle distribution is one of the most important physical attributes due to its great influence on soil properties related to water movement, productivity and erosion (Rieu & Sposito, 1991; Perfect *et al.*, 1996; Gimenez *et al.*, 1997). Apart from that, particle size distribution of soil has been frequently used to estimate the soil hydraulic properties (Arya & Paris, 1981; Haverkamp & Parlange, 1986; Hwang & Powers, 2003a). Particle size distributions arise as a result of complex geological and geophysical processes which mostly used in soil classification as well as for estimating various related soil properties (Hillel, 1980). The classification of soils in terms of particle size stems essentially from the work of Atterberg (1916). He built on the work of Ritter Von Rittinger (1867) in relation to rationalization of sieve apertures as a function of particle volume.

Soil is generally called gravel, sand, silt or clay depending on the predominant size of particles within the soil. The United States Department of Agriculture (USDA) defines particle sizes as: sand 2.0 mm – 0.05 mm in diameter, silt 0.05 mm – 0.002 mm in diameter and clay less than 0.002 mm in diameter. Meanwhile, The International Soil Science Society (ISSS) defines particles size of soil as: sand 2.0 mm – 0.02 mm in diameter, silt 0.02 mm – 0.002 mm in diameter and clay less than 0.002 mm in diameter.

2.4 SPATIAL VARIABILITY OF SOIL PROPERTIES

Soil properties variation within a field often has been described by classical statistical methods assuming a random distribution (Goovaerts, 1999; Webster, 2000; Conant & Paustian, 2002). Spatial variability of soil properties in nature occur primarily from pedogenetic factors (Trangmar *et al*., 1985). In addition, variation can occur as a result of land use and management (Paz-Gonzalez *et al*., 2000; Stenger *et al*., 2002).

The variability of soil properties has significant impact on many hydrological processes. For example, spatial variability of soil moisture content has a major influence on a range of hydrological processes including flooding, erosion, solute transport and land-atmosphere interactions, as well as a range of geographic and pedogenic processes. Soil moisture content is highly variable in both time and space. This variability has a significant impact on the above processes due to nonlinearities involved. Therefore, knowledge of the characteristics of soil moisture variability is important for understanding and predicting the above processes (Western *et al*., 2004).

As known, soil properties exhibit a complex degree of variability in both space and time. This variability is both continuous and scale-dependent. The understanding and incorporation of this variability, or the associated uncertainly, into modeling approaches relies on the availability of detailed sampling information and this place a limitation on the development of spatially distributed models concerning a range of environmental processes (Burrough, 1993; Goovaert, 2001; Park & Vlek, 2002).

2.4.1 Causes of Spatial Variability of Soil Properties

There are many causes influence the spatial variability in soil properties. Properties of soil under tropical climates exhibit more spatial variability due to their greater exposure to harsh climatic conditions (Mapa & Kumaragamage, 1996). The climate of Malaysia is typical of the humid tropics and is characterized by year-round high temperature and seasonal heavy rain. This will cause the soils to be dry and wet though the year. The soil swelling and shrinking processes will be easily to cause.

Apart from that, soil compaction will also cause the spatial variability of soil properties. The detrimental effects of soil compaction include increased bulk density, decreased porosity and shifts in pore shapes and size distributions (Flowers & Lal, 1998; Radford *et al.*, 2000; Richard *et al.*, 2001; Pagliai *et al.*, 2003).Changes in these basic properties alter the soil's water retention and hydraulic conductivity characteristics, which in turn affect the infiltration ability of the soil and its plant-available water storage capacity. Consequently, soil compaction can have serious