CHARACTERIZATION OF SPATIAL VARIABILITY OF SOIL PHYSICAL PROPERTIES AT UTP CAMPUS

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CIVIL ENGINEERING
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by

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD FAIZ FAHMI BIN ABU BAKAR

ABSTRACT

Studies on the spatial variability of soil physical properties are limited in the south-east Asia. This study examines the spatial variability of soil physical properties in a flat region under subtropical climate using geostatistical and statistical methods. Soil samples were taken from a 400 ha (1000acres) in the University Technology Petronas(UTP). The Global Positioning System (GPS) was used for locating the sample position. 50 soils sample were collected on the field from predefined geo-grid location. Samples were then taken to the laboratory for analysis. The laboratory analysis will be cover on soil physical properties (bulk density, moisture content, organic content and particle size distribution). Laboratory test result were then subjected to statistical and geostatistical analysis.
Large spatial variability of soil fines and moisture content were found to exist in the study area and the degree of variability was heterogeneous among different soil properties. About 58.37%−78.12% of the observed total variability in soil properties was due to spatial structure. All the soil properties tested, exhibited strong spatial dependency and were spatially dependent up to distances of 1122m−3781m. The geostatistical analysis in conjunction with conventional statistical analysis could reveal spatial variability nature of soil properties and causes behind the variability. This project will allow understanding and characterization of small scale spatial variability nature of physical properties of tropical at UTP campus area.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

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 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.).

Soil properties are usually studied by taking samples on some grid or other pattern with the assumption that properties measured at a point also represent the unsampled neighborhood. The extent to which this assumption is valid depends on the degree of spatial dependence that exists among the samples. The variability of soil properties within the field is often described by a classical method, which assumes that the variation is randomly distributed within mapping units.

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 deter-mines rainfall-runoff responses in many catchments (Anctil et at., 2002).

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

This proposed project will allow understanding and characterization of small scale spatial variability nature of physical properties at UTP campus area. This will also allow identifying the effects of land disturbances and catchments characteristics in UTP campus area.

1.2 Problem Statement

University Technology PETRONAS (UTP) is built on a 400 hectare (1000acre) site strategically located at Bandar Seri Iskandar, Perak Darul Ridzuan. This campus is used as the experimental about the characterization of spatial variability of soil physical properties. In this project the statistical and geostatistical methods will be use to examine the characterization of spatial variability of soil physical properties in UTP area.

All the soil physical properties which are moisture content, soil bulk density, organic content and fine content should be determined. With all of this, the characterization of spatial variability of soil physical properties can be determined using tools like semivariogram and kriging. Thus, from all the data, it can map the variation in soil physical properties at UTP campus.

1.3 Objectives

This project is essential to determine of characterization of soil physical properties at UTP campus. The main objectives of this research are:

1. To characterize spatial structure of soil physical properties under tropical climate in terms of semivariogram parameters.
2. To map the variation of soil physical properties in the study area that is affected by several factor bulk density, moisture content, organic content, and particle size distribution.
3. To evaluate the effect of land use changes on the variability of soil physical properties.

1.4 Scope of Study

This project also concentrate on the optimum size of spatial grids for distributed parameter hydrological model (Anctil et al., 2002), estimating point or spatially averaged values of soil properties that using kriging technique (e.g. Bardossy and Lehmann, 1988) and in designing sampling networks and improving their efficiency (e.g. Prakash and Singh, 2000).

Therefore, a field works laboratory test and analysis using geostatistical and statistical needs to be done to achieve this entire objective.

CHAPTER 2

LITERATURE REVIEW/THEORY

Spatial variability of soil physical properties are important analysis which to determine the optimum size of spatial for distributed parameter hydrological models, estimating point or spatially averaged values of soil properties that using kriging technique, in designing sampling networks and improving their efficiency .The Global Positioning System (GPS) is used for locating the sample position. Finding the variability of the soil properties is largely important to land management practices due to topographic features and land disturbances.

The experiment of the spatial variability of soil physical properties are already been made by Rezaur R.B., Balamohan B., & Ismail A, 2004 at USM campus. The semivariogram and statistical parameters has been characterized the spatial variability of soil physical properties. From the experimental they did, larger CV's (coefficient of variation) and sill (the total variance) for soil fines and moisture content indicates irregular distribution of these two properties compared to other soil properties. Both of land disturbances and topographic conditions contributed to the variability of soil properties. However the semivariogram model parameter showed relatively poor fit to the data as judge from the low r^2 due to the fact that the number of sampling points selected was less relative to the extent of the area studied.

In this experiment, there are 3 main study and works to be done, which are the study area, soil sampling & laboratory analysis, and statistical and geostatistcal analysis.

2.1 The Study Area

The study of the spatial variability of soil physical properties was conducted in the Universiti Sains Malaysia (USM), Engineering campus located on a flat plain in Nibong Tebal. The study area is in the state of Penang mainland and lies between latitude 5°8′30″ to 5°9′19″ N and longitude 100°29′12″ to 100°30′1″ E. The campus area is 137 ha (320 acres). The study area was originally an oil palm plantation but cleared partially during 1999 for construction of the campus. The soil within the study area is composed mainly of alluvium made up of sand and clay. The soil is defined as silty-clay and was classified as soft soil (HLA Associates & USM, 1998).

The climate at the study area is typical of the humid tropics and is characterized by year- round high temperature ranges from 26°-32°C and annual rainfall varies between 2000mm-4000mm.

2.2 Soil Sampling and the Laboratory Analysis

The grid-sampling method was used for this study on the premise that grid-sampling reduces the possibility of uneven or clustered samples. The campus area was divided by a number of regular geo-grids. The grid size was about 115m × 115m. Soil samples were collected at each grid-node.

Global Positioning System (GPS) was used for locating the sample position with an error of ±1m.Fifty (50) soil samples were collected at each location using a stainless steel auger. Then the soil samples were transferred to laboratory for analysis which to determine the soil physical properties; bulk density, moisture content, particle size distribution, and the organic content.

2.2.1 Bulk Density

The ratio of Sand, silt and clay of a soil will determine the amount and sizes of soil pore spaces; this in turn will determine the soil density. When determining soil density, there are two different densities to consider. First there is particle density which is the density of the individual particles making up the soil such as the density of sand vs. density of silt, etc. Secondly, soil has a bulk density which is the density of all of the particles making up the natural soil.

Soil bulk density expresses soil weight in terms of total soil space or volume. In the illustration below, a cm^3 of soil is shown as it appears in the field and also as it would appear if all of the solids were compressed to the bottom of the cube to show the percentage of pore space.

Figure 2.1: Field soil and compressed soil

Soil bulk density, like all density measurements, is an expression of the mass to volume relationship for a given material. Soil bulk density measures total soil volume. Thus, bulk density takes into account solid space as well as pore space. Soils that are loose, porous, or well-aggregated will have lower bulk densities than soils that are compacted or nonaggregated. This is because pore space (or air) weighs less than solid space (soil particles). Sandy soils have less total pore than clayey soils, so generally they have higher bulk densities. Bulk densities of sandy soils vary between 1.2 to 1.8 Mg m^{-3}. Fine-textured soil, such as Clays, silty clays, or clay loams, has bulk densities between 1.0 and 1.6 Mg m^{-3}.

Bulk density is an indirect measure of pore space and is affected primarily by texture and structure. As aggregation and clay content increase, bulk density decreases (Figure 2.1). Tillage operations do not affect texture, but they do alter structure (soil particle aggregation). Primary tillage operations, such as plowing, generally decrease bulk density and increase pore space, which is beneficial. Secondary tillage (cultivation) generally increases bulk density and decreases pore space. The compaction resulting from cultivation can be detrimental to plant growth. Cropped soils generally have higher bulk densities than uncropped soils. The movement of machinery over the field forces solid particles into spaces once occupied by water or air, resulting in less pore space and increased bulk density.

Table 2.1: Effect of type of soil on bulk density

→	BULK DENSITY INCREASE	→
Clayey	Loamy	Sandy
Well-aggregated	Moderately aggregated	Nonaggregated
High organic matter content	Moderate organic matter content	Low organic matter content
→	BULK DENSITY INCREASE	→

2.2.2 Moisture Content

Moisture content is the quantity of water contained in a material, such as soil (called soil moisture), rock, ceramics, or wood on a volumetric or gravimetric basis. The property is used in a wide range of scientific and technical areas, and is expressed as a ratio, which can range from 0 (completely dry) to the value of the materials' porosity at saturation.

Compared to other components of the hydrologic cycle, the volume of soil moisture is small; nonetheless, it of fundamental importance to many hydrological, biological and biogeochemical processes. Soil moisture information is valuable to a wide range of government agencies and private companies concerned with weather and climate, runoff potential and flood control, soil erosion and slope failure, reservoir management, geotechnical engineering, and water quality. Soil moisture is a key variable in controlling the exchange of water and heat energy between the land surface and the atmosphere through evaporation and plant transpiration.

As a result, soil moisture plays an important role in the development of weather patterns and the production of precipitation. Simulations with numerical weather prediction models have shown that improved characterization of surface soil moisture, vegetation, and temperature can lead to significant forecast improvements. Soil moisture also strongly affects the amount of precipitation that runs off into nearby streams and rivers. Large-scale dry or wet surface regions have been observed to impart positive feedback on subsequent precipitation patterns, such as in the extreme conditions over the central U.S. during the 1988 drought and the 1993 floods. Soil moisture information can be used for reservoir management, early warning of droughts, irrigation scheduling, and crop yield forecasting.

2.2.3 Particle Size Distribution (Fines)

The particle size distribution (PSD) of a powder, or granular material, or particles dispersed in fluid, is a list of values or a mathematical function that defines the relative amounts of particles present, sorted according to size. PSD is also known as grain size distribution. The method used to determine PSD is called particle size analysis. The PSD of a material can be important in understanding its physical and chemical properties. It affects the strength and load-bearing properties of rocks and soils. The way PSD is expressed is usually defined by the method by which it is determined. The most easily understood method of determination is sieve analysis, where soil is separated on sieves of different sizes.

Grain-size analysis is a process in which the proportion of material of each grain size present in a given soil (grain-size distribution) is determined. The grain-size distribution of coarse – grained soils is determined directly by sieve analysis, while that of fine-grained soils is determined indirectly by hydrometer analysis. The grain-size distribution of mixed soils is determined by combined sieve and hydrometer analyses.

A sieve analysis consists of passing a sample through a set of sieves and weighing the amount of material retained on each sieve, Sieves are constructed of wire screens with square openings of standard sizes. The sieve analysis is performed on material retained on a U. S. Standard No. 200 sieve. The sieve analysis, in itself, is applicable to soils containing small amounts of material passing the No. 200 sieve provided the grain-size distribution of that portion of the sample passing the No. 200 sieve is not of interest.

The hydrometer method of analysis is based on Stokes' law, which relates the terminal velocity of a sphere falling freely through a fluid to the diameter. The relation is expressed according to the equation:

$$v = \frac{\gamma_s - \gamma_f}{1800\,\eta} D^2 \qquad (2.1)$$

Where:

v = terminal velocity of sphere, cm per set

Ys = density of sphere, g per cm3

Yf = density of fluid, g per cm3

μ = viscosity of fluid, g-set per cm 2

D = diameter of sphere, mm

It is assumed that Stokes' law can be applied to a mass of dispersed soil particles of various shapes and sizes. The hydrometer is used to determine the percentage of dispersed soil particles remaining in suspension at a given time. The maximum grain size equivalent to a spherical particle is computed for each hydrometer reading using Stokes' law.

The hydrometer analysis is applicable to soils passing the No. 10 sieve for routine classification purposes; when greater accuracy is required (such as in the study of frost-susceptible soils), the hydrometer analysis should be performed on only the fraction passing the No. 200 sieve .

2.2.4 Organic Content

The organic content of soil greatly influences the plant, animal and microorganism populations in that soil. Decomposing organic material provides many necessary nutrients to soil inhabitants. Without fresh additions of organic matter from time to time, the soil becomes deficient in some nutrients and soil populations decrease. The amount of organic material can be determined by ignition.

Organic material is made of carbon compounds, which when heated to high temperatures are converted to carbon dioxide and water. In the ignition process, a dry solid_sample is heated to a high temperature. The organic matter in the soil is given off as gases. This results in a change in weight which allows for calculation of the organic content of the sample.

Soils that have developed under forest vegetation usually have comparably low organic-matter levels. There are at least two reasons for these levels: (1) trees produce a much smaller root mass per acre than grass plants, and (2) trees do not die back and decompose every year. Instead, much of the organic material in a forest is tied up in the tree instead of being returned to the soil. Soils that formed under prairie vegetation usually have native organic matter levels at least twice as high as those formed under forest vegetation.

Organic matters have many benefits such as:

- Nutrient Supply

  Organic matter is a reservoir of nutrients that can be released to the soil. Each percent of organic matter in the soil releases 20 to 30 pounds of nitrogen, 4.5 to 6.6 pounds of P_2O_5, and 2 to 3 pounds of sulfur per year. The nutrient release occurs predominantly in the spring and summer, so summer crops benefit more from organic-matter mineralization than winter crops.

- Water-Holding Capacity

  Organic matter behaves somewhat like a sponge, with the ability to absorb and hold up to 90 percent of its weight in water. A great advantage of the water-holding capacity of organic matter is that the matter will release most of the water that it absorbs to plants. In contrast, clay holds great quantities of water, but much of it is unavailable to plants.

- Soil Structure Aggregation

  Organic matter causes soil to clump and form soil aggregates, which improves soil structure. With better soil structure, permeability (infiltration of water through the soil) improves, in turn improving the soil's ability to take up and hold water.

- Erosion Prevention

  This property of organic matter is not widely known. Data used in the universal soil loss equation indicate that increasing soil organic matter from 1 to 3 percent can reduce erosion 20 to 33 percent because of increased water infiltration and stable soil aggregate formation caused by organic matter.

2.3 Statistical and Geostatistical Analysis

In the past, classical statistics have been widely used to assess the variability of various properties of soil (e.g. Biggar and Nielsen, 1976; Bresler, 1989; Brejda et al., 2000). Statistical characterization of spatial variability involves parameter estimation such as the mean and variance. Classical statistics assumes that observations in the field are random processes, regardless of their location. However, there is a significant volume of literature in various disciplines such as hydrology (Ali et al., 2000; Rezaur et al., 2002), geology (Davis, 1986), mining (Isaaks and Srivastava, 1989), environmental science (Vereeckern et al., 2000) and soil science (Dasselaar, et al., 1998) which shows that variation in earth science data tends to be correlated across space.

Therefore, classical statistical methods may be in-adequate for interpolation of spatially dependant variables, because they assume random variation and do not consider spatial correlation and relative location of samples (Goderya et al., 1996).

Geostatistical procedures recognize these difficulties and provide tools to facilitate the examination of spatial and temporal correlation in the data, thereby allowing the estimation of a physical property using measurements of that property made at close physical proximity.

One of the most efficient tools is the semivariogram, which measures the temporal and/or spatial behavior of a variable of interest. Geostatistical tools such as kriging allow estimation of spatially correlated data and are superior to other commonly used interpolation techniques such as, Inverse Distance Weighting (IDW) and Normal Distance Weighting (NDW) (Rouhani, 1996). Because of this, the geostatistical approach has received increasing attention in science and engineering during the last decade (Western et al., 1998)

However, geostatistical characterization of soil engineering properties from the humid tropics particularly, the south-east Asia has been scanty. Most previous studies from this region, particularly Malaysia have focused on geostatistical characterization of spatial variability of soil nutrients in relation to farming practices (e.g. Swapan et al., 2001). It also appears that no geostatistical study has been reported on evaluation of spatial variability of soil engineering properties at small and regional scale.

CHAPTER 3

METHODOLOGY/PROJECT WORK

The methodology for this project is to characterize spatial structure of soil physical properties under tropical climate in terms of semivariogram parameters, to map the variation in soil physical properties in the area and to evaluate the effect of land use changes in the variability of soil physical properties. This project will be done by doing the study area, laboratory analysis, and statistical and geostatistical analysis.

3.1 The Study Area

The study was conducted in the University Technology Petronas(UTP) which located in Bandar Seri Iskandar that established on January 10,1997. The campus area is 400 ha (1000acres). The study area is in the west part of Perak. It lies on latitude 4° 23.01' 30'' N and 100° 58' 41'' E. it is about 19 kilometers from Batu Gajah town. The campus is subdivided into two regions which are urbanized which consist of academic block, administration blocks, hostel and all the infrastructures. Another region is undeveloped area where all the tree and forest are remaining untouchable.

3.1.1 GPS (Global Positioning System)

The GPS device as shown in below figure has been installed in 2 locations. This will act as the reference point to determine the other longitude and latitude points. In setting the device, the procedure below:

1. Switch on the device by press the 'on' button
2. Prepare the device (wait for a while)
3. Set the device to show the longitude and latitude of the current location.
4. Place the device onto the desire location and leave it for 2 to 3 minutes.
5. After that, read the reading shown in the device and record the measurement.
6. Press the 'off' button to switch off the device.

Figure 3.1: The GPS device

Figure 3.2: Place device at location

Figure 3.3: Record reading from device

3.2 Soil Sampling and Laboratory Analysis

The grid sampling method will be used for this study on the premise that grid sampling reduces the possibility of uneven clustered samples. The campus will be divided by a number of regular geo-grids. Soil samples were collected at each grid-note. The sampling location which fell on paved area or on buildings or where the sampling location was inaccessible (wet areas) were omitted. In certain occasion where the sampling location fell at the corner of a building, soil samples were collected from the adjacent ground. During field sampling the grid-note locations were established by a portable Global Positioning System (GPS) unit with an error of ±1m.Fifty soil samples were collected during the sampling program.

Soil sample was collected at each location using a stainless steel soil auger. The length of the soil samples collected was about 20cm. Each core sample, after extrusion from the sampler will divide into two sub-samples to represent two samples from each location. Then the soil samples will seal into plastic bags and transfer to the laboratory for analysis. Laboratory will be done on two samples from each location and the mean result will be used for analysis. For each soil sample, four soil engineering properties will be determined in the laboratory analysis:

a) Bulk density
b) Moisture content
c) The organic content
d) Particle size distribution (fines)

3.2.1 Bulk Density

The soil bulk density can be determined from the ratio of sample mass and the volume. The sample volume can be known by measuring sample length and cross sectional area and the sample mass will be obtained from the dry weight of the sample subjected to oven drying at 110°C for 24 hours.

Figure 3.4: Measure bulk density

3.2.2 Moisture Content

The soil moisture content can be determined from the difference between the wet weight (field sample) and dry weight (subjected to oven drying at 110°C for 24 hours) of the sample and expressed as a percentage of the dry weight of the sample. The procedure for determination of moisture content is:

1. Clean and dry the moisture content tin and weigh it to the nearest 0.01g (m1). Take a sample of at least 30g of soil, crumble and place loosely in container, and replace the lid. Then weigh the container and contents to the nearest 0.01g (m2).
2. Remove the lid, and place the container with its lid and contents in oven and dry at 105°C to 110°C for a period of 24 hours. Do not replace the lid while the sample is in the oven.

3. After drying, remove the container and contents from the oven and place the whole in the desiccators to cool.
4. Replace the lid and then weigh the container and content to the nearest 0.01g (m3).
5. Calculate the moisture content of soil specimen:

$$\text{Moisture content, } W = \frac{(m2 - m3)}{(m3 - m1)} \times 100\% \qquad (3.1)$$

Where:-

m1 is the mass of container (in g)

m2 is the mass of container and wet soil (in g)

m3 is the mass of container and dry soil (in g)

3.2.3 Organic Content

The sample organic content is determined from the difference between the weight of the oven dried (at 110°C for 24hours) sample and the weight of the sample subjected to ignition in a muffler furnace at 440°C for 4 hours and expressed as a percentage of the oven dry weight of the sample.

Figure 3.5: The muffler furnace at 440°C

3.2.4 Particle Size Distribution (Fines)

The particle size distribution is determined using both, mechanical sieving and hydrometer analysis. Then the results of the two analyses are then combined to produce the complete particle size distribution of the soil samples. The fine content are used for statistical and geostatistical analysis.

The procedure to determination of particle size distribution is:

1. Weigh the oven dried sample to 0.1% to its total mass (m1).
2. Stack 8 numbers of test sieves on the mechanical shaker with the largest size test sieve appropriate to the maximum size of material present at the bottom of the stack followed by the smaller size test sieves and a receiver at the bottom of the sack.
3. Place the sample on the top sieve and cover the sieve with a lid. Agitate the test sieves on the mechanical sieve shaker for 5 minute. Weigh the amount retained on each of the test sieves to 0.1% of its total mass.

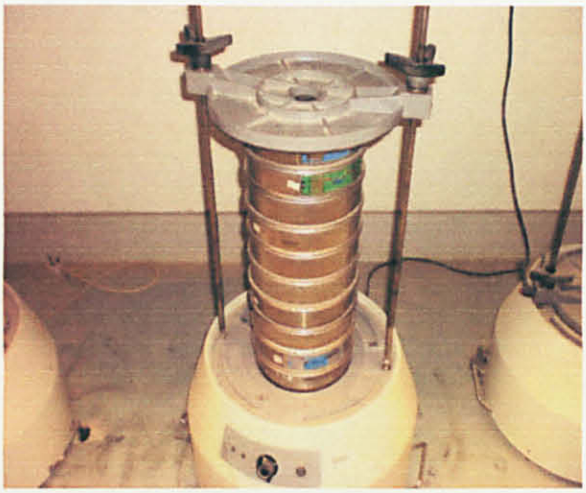


Figure 3.6: Mechanical sieving equipment

3.3 Statistical and Geostatistical Analysis

The results of the laboratory tests on soil engineering properties are subjected to two types of analysis:

I. Normal statistical analysis

II. Geostatistical analysis

3.3.1 Normal Statistical Analysis

Normal statistical analysis included determination of maximum, minimum, mean, standard deviation, and coefficient of variation of soil engineering properties over the study area.

3.3.2 Geostatistical Analysis

Geostatistical analysis included examining spatial variability nature of the soil engineering properties by determining semivariogram parameters namely the sill, nugget and range, establishing best fitted semivariogram models for the soil properties, and computing maps of distribution of soil engineering properties over the study area using the method of kriging.

Geostatistical characterization of the data was per-formed using GS+ (Gamma Design Software, Plainwell, MI, USA). The semivariance was estimated for all the four soil engineering properties. The semivariance is defined as (Goovaerts, 1997):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [\, z(x_i) - z(x_i + h) \,]^2 \qquad (3.2)$$

where $\gamma(h)$ is the semivariance, h is the lag, $N(h)$ is the total number of sample couples separated by the lag interval h; $z(x_i)$ is the measured sample value at point (x_i), and $z(x_i+h)$ is the measured value at point (x_i+h).

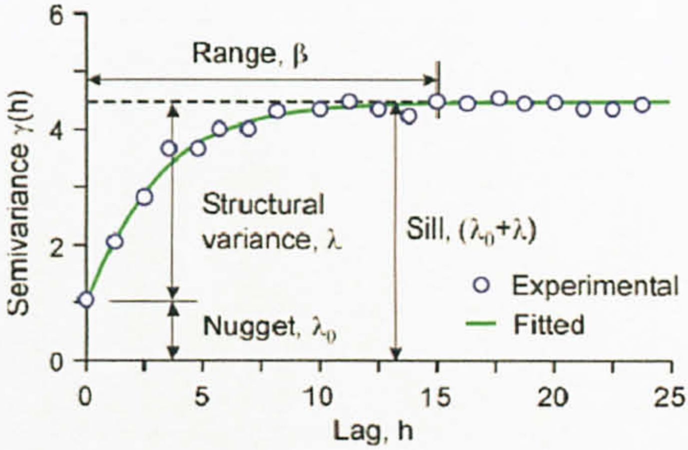


Figure 3.7: Semivariogram and its parameters

A property is called spatially dependent or auto correlated if the probability of similar data values is higher for neighboring sample points than for points far from each other (Warrick et al., 1986). Thus, $z(x_i)$ correlates to the neighboring $z(x_i+h)$, with h being the *lag*, between $z(x_i)$ and $z(x_i+h)$.

The correlation between $z(x_i)$ and $z(x_i+h)$ expresses the spatial structure of a variable of interest (Isaaks and Srivastava, 1989). The semivariogram displays the change in semivariance between sample points with increasing lag. Figure 9 schematically illustrates an experimental and fitted semivariogram with parameters. The semivariance rises with increasing lag then levels off.

The lag, at which the plateau is achieved, is called the 'range' β, and the semivariance value of the plateau is called the 'sill' $(\lambda_0+\lambda)$ (Figure 3.7). Points within the range are considered to be spatially or temporally auto-correlated, while points outside the range are spatially independent. Empirical semivariograms seldom pass the origin, but intersect ith the ordinate. This discontinuity is the 'nugget' λ_0, and consists of two parts; the spatial variance of scales less than the minimum sampling distance (if present), and measurement and sample location error.

The nugget represents all unaccounted spatial variability at distances smaller than the smallest lag while the semivariogram models the structural spatial dependence (Goovaerts, 1997). Therefore, the ratio of the nugget-to-sill gives a measure of the spatial or temporal dependence of the data. The smaller the ratio the stronger is the spatial dependence. Calculation of semivariance assumes stationarity. The existence of a sill in a semivariogram is an indication that the process is stationary (Western et al., 1998).

Five different models were examined to fit the semivariance data. These include the spherical, linear, linear-sill, exponential, and gaussian model. Optimal models were determined by examining the fit of the model to the semivariogram as judged by the coefficient of determination r^2 and RSS (residual sums of squares) values.

The two models that best fit the semivariograms of soil engineering properties data were spherical model and the exponential model, which are defined respectively by:

$$\gamma(h) = \lambda_0 + \lambda[1.5(h/\beta) - 0.5(h/\beta)^3] \qquad \text{for } h \leq \beta \qquad (3.3)$$

$$\gamma(h) = \lambda_0 + \lambda \qquad \text{for } h > \beta$$

$$\gamma(h) = \lambda_0 + \lambda\,[1-\exp(-h/\beta)] \qquad (3.4)$$

For each of these models, λ_0 represents the nugget variance, attributable to variance due to scales smaller than the sampling distance plus measurement errors. The structural variance, λ, is the variance attributable to the separation distance between observations.

The sum of λ_0 and λ is an estimate of the total variance. For the spherical model, β is the range and is the maximum separation distance for which sample pairs remain correlated. For the exponential model, β is not the range, but a parameter used in the model to provide the range. The range of the exponential model can be estimated as 3β (Isaaks and Srivastava, 1989).

3.4 Tools/Equipment Required

The tools and equipments which are required in this Final Year Project are:

i. GPS(Global Positioning System)
ii. Hoe
iii. Soil Auger
iv. Scope and Trowel
v. Polythine bags
vi. Mechanical Sieve
vii. Mufler furnace
viii. Oven
ix. Soil container
x. Digital calliper
xi. Cylinder container (for bulk density)
xii. Tray
xiii. GS+ Software
xiv. Surfer Software
xv. Digitizing Softwar

3.5 Project Flow Diagram

Project flow diagram is attached in the appendices (refer appendices 1)

3.6 Gantt Chart and Milestone of Project

Gantt chart and Milestone of Project is attached in the appendices (refer appendices 2)

CHAPTER 4

RESULT AND DISCUSSION

4.1 Reference Point Locations

Reference point location is an important task before the author can move to geo-grid sampling location. Using Global Positioning System (GPS), 2 points were selected to be the control point. These 2 points will be reading in Latitude and Longitude. After get the map of UTP campus, the author determine location that need to be the reference points which are block 13 and block I that located near the chancellor hall. The results of GPS data collection are showed in Table 4.1.

Table 4.1: Reference point

Point	Latitude (N)	Longitude (E)
Block 13	04° 22' 52''	100° 57' 51''
Block I	04° 23' 00''	100° 58' 10''

Figure 4.1: Reference point at UTP

4.2 Geo-grid Sampling Locations

The geo-grid sampling method was used for this study on the premise that grid-sampling reduces the possibility of uneven samples. After get the map of UTP campus that consist of all the building, road and pavement, trees, contours and also boundaries of UTP, then the author do the geo-grid sample location using CorelDRAW 9 software. The location for each soil sample collection points will be marked based on the intersection of grid lines. 50 points will be chosen from the generated campus map for soil sample testing. The result of the geo-grid sampling location showed as Figure 4.1.

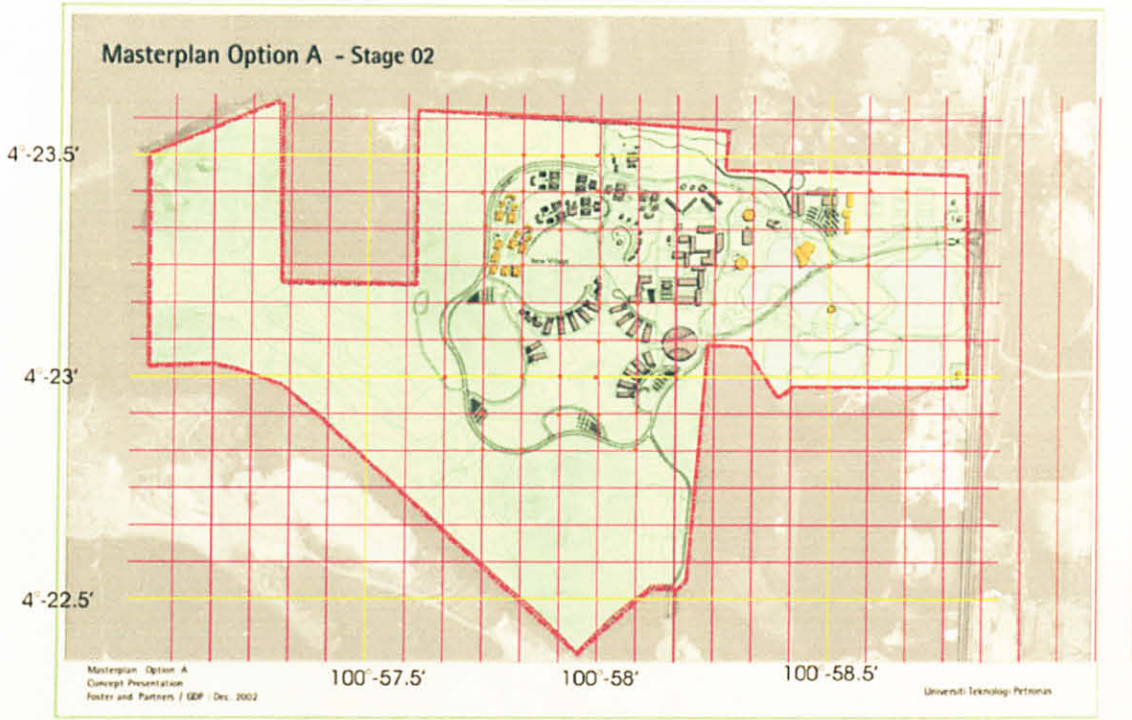


Figure 4.2: Geo-grid sampling location

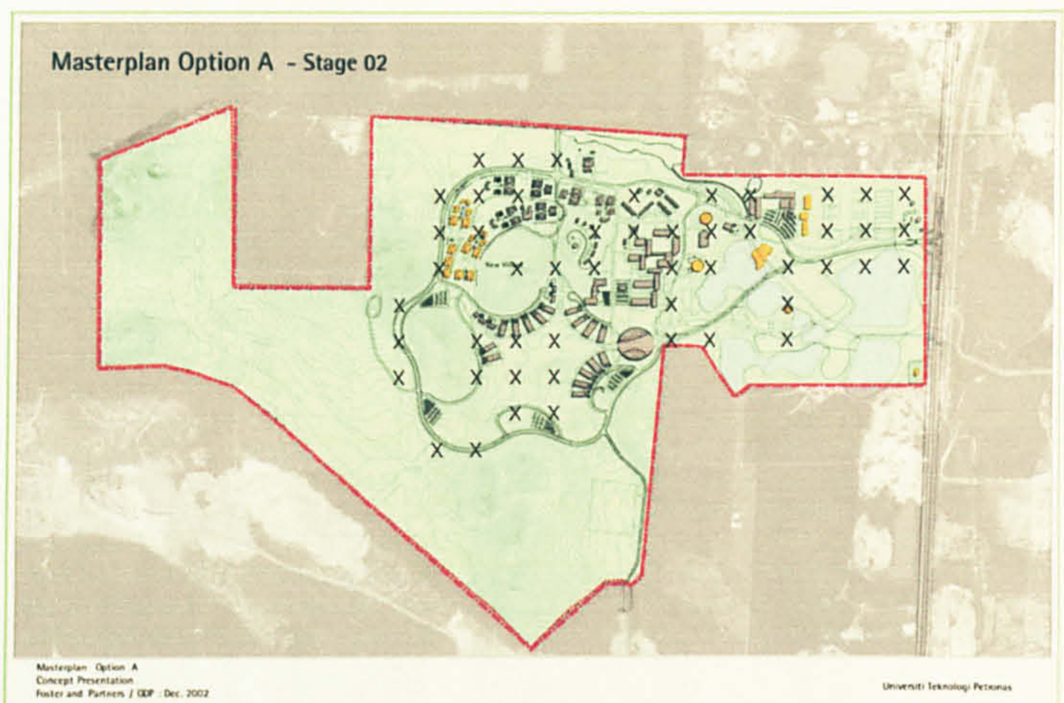


Figure 4.3: Sampling location

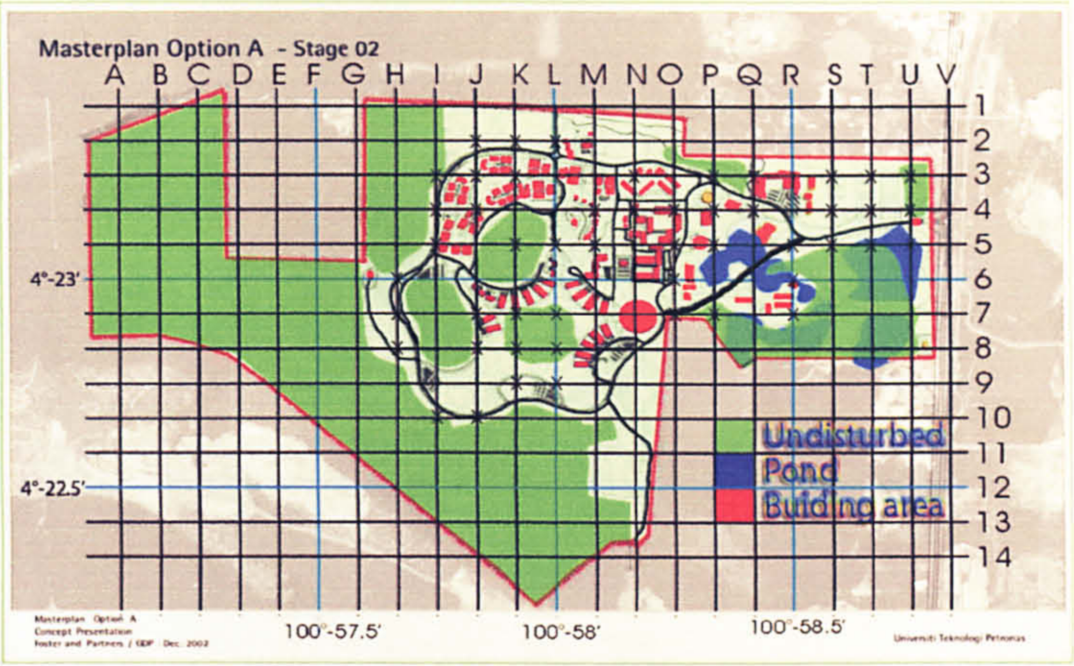


Figure 4.4: Site map with theoretical grid and zones

From Figure 4.4, disturbed area included areas where forest clearance and ground alteration have taken place for building, pavement and road construction. Undisturbed area comprised of forest area, lake area and low lying areas where no significant land alteration have occurred. Areas which only have landscaping activities also being assume as undisturbed.

4.3 Laboratory Result

After decided the 50 points for soil sample testing, laboratory work begin and take about 4 month to be finish. All the results for bulk density, moisture content, organic content and fines (particle size distribution) are calculated in Microsoft Office Excel. Below there are some calculations on bulk density, moisture content and organic content particle size distribution (fines) as examples. The full result of 50 samples can be referred in **Appendices** (refer appendices 3).

4.3.1 Bulk Density

Based on sample 5,

Diameter of cylinder = 5.465cm
Height of cylinder = 3.95cm
Volume of cylinder = 92.6547cm^3
Mass of cylinder = 20.0g
Mass of cylinder + soil = 145.2g
Bulk density = (145.2g – 20.0g) / 92.6547cm^3
= 1.351253633g / cm^3

4.3.2 Moisture Content

Based on sample 5,

Mass of container (m1) = 23.1g

Mass of wet soil + container (m2) = 43.8g

Mass of dry soil + container (m3) = 40.6g

Moisture content, W (%) = [(m2) – (m3) / (m3) – (m1)] x 100%

= [3.2 / 17.5] x 100%

= 18.28571429%

4.3.3 Organic Content

Based on sample 5,

Mass of container, a = 23.1g

Mass of oven dried soil + container

(at 110°C), X = 40.6g

Mass of dry soil + container

(at 440°C), Y = 40.1g

Organic content (%) = (40.6g - 40.1g) / (40.6g – 23.1g) x 100%

= 2.857142857%

4.3.4 Particle Size Distribution (Fines)

Based on sample 5,

Table 4.2: Percentage of fines

Sieve size	Mass of sieve, g	Mass of sieve + soil, g	Mass retained, g (m)	Percentage retained, % ((m/500) x 100)
3.35mm	483.8	508.1	24.3	4.86
2mm	380.5	407.4	26.9	5.38
1.18mm	425.4	459.2	33.8	6.76
600μm	304.9	351.9	47	9.4
425μm	369	402	33	6.6
300μm	355.7	409.5	53.8	10.76
212μm	341.2	407.1	65.9	13.18
150μm	269.2	327.8	58.6	11.72
63μm	326.6	432	105.4	21.08
Passing 63μm	245	297.6	52.6	10.52
			Percentage of Fines (%)	21.08 + 10.52 = **31.6**

4.4 Statistical Analysis

The summary of normal statistics of the soil physical properties obtained from 50 samples is shown in Table 4.3.

Table 4.3: Sample size (N), maximum, minimum, mean, standard deviation (SD), Coefficient of variation (CV) of tested soil physical properties

Soil properties	N	Max.	Min.	Mean	SD	CV (%)
Fines (%)	50	59.68	16.9	28.7892	8.275741003	28.75
Moisture content (%)	50	33.93939394	3.196347032	17.8958455	6.424041605	35.9
Organic content (%)	50	6.748466258	0.456621005	3.729534138	1.813023793	48.61
Bulk density (gm/cm^3)	50	1.735475912	1.169935254	1.421708775	0.136724499	9.62

The coefficient of variation (CV) is an indicator of variability. Among the four soil properties examined the organic content show the highest CV (48.61%), followed by moisture content (35.9%) and fine content (28.75%), while soil bulk density shows the lowest (9.62%) CV (Table 4.3).

The lowers CV for bulk densities are expected because the range over which soil density could vary is narrow compared to other soil properties. The range of CVs obtained (Table 4.3) suggests different degrees of heterogeneity between different soil properties examined in the study area. The large variance in soil properties in a large area could be linked to heterogeneity of land formation, land use pattern or erosion processes (Sun. et al., 2003).

4.5 Geostatistical Analysis

4.5.1 Spatial Dependence of Soil Properties

The best fitted semivariogram model parameters are shown in Table 4.4. The best fitted semivariogram of different soil properties are shown in Figure 4.5, Figure 4.6, Figure 4.7, and Figure 4.8. Thus, it is possible to examine the spatial structure and dependencies of the soil properties in terms of semivariogram parameters, the range, sill, nugget, and nugget-to-sill ratio after the semivariogram models and parameters for the soil properties are done.

Table 4.4: Characteristics parameters of fitted semivariogram of soil physical properties

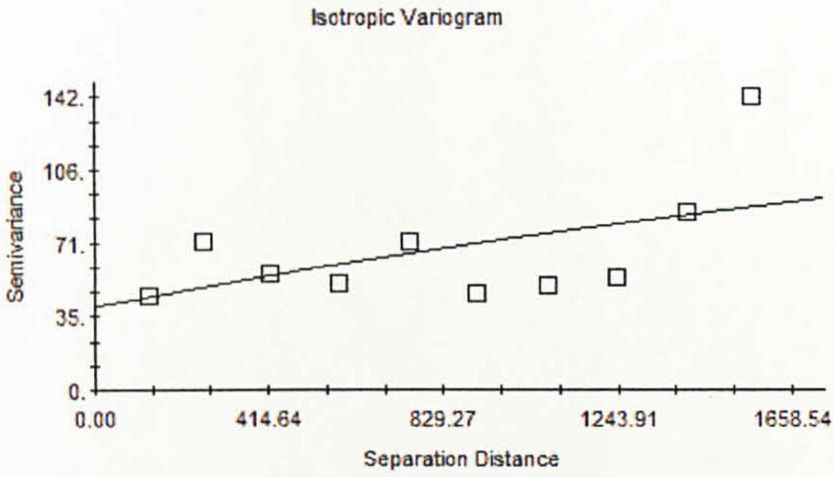
Soil properties	Model*	Range (m)	Nugget (λ_0)	Sill ($\lambda_0+\lambda$)	Sv (%) (λ)	Ratio (%) $\lambda_0/(\lambda_0+\lambda)$
Fines (%)	E	3781	40.1	183.3	78.12	21.88
Moisture content (%)	S	3702	23.9	76.53	68.77	31.23
Organic content (%)	S	2692	2.04	4.98	59.04	40.96
Bulk Density (gm/cm^3)	S	1122	0.00895	0.0215	58.37	41.63

Where:

E = Exponential

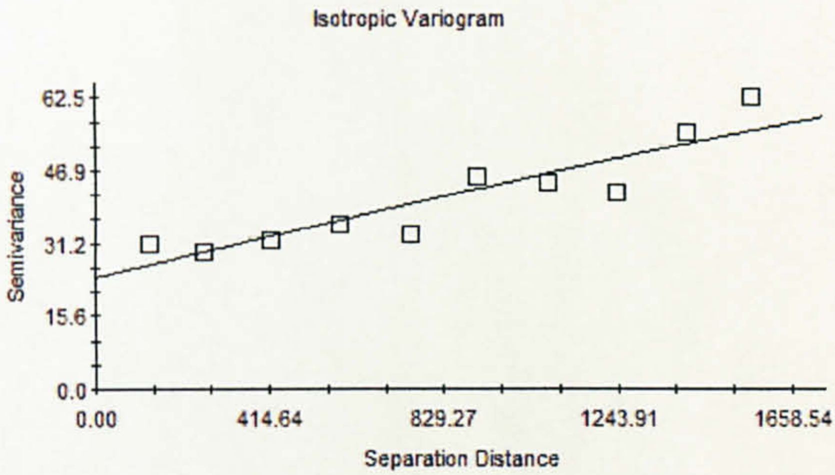
S = Spherical

Sv = Structural variance



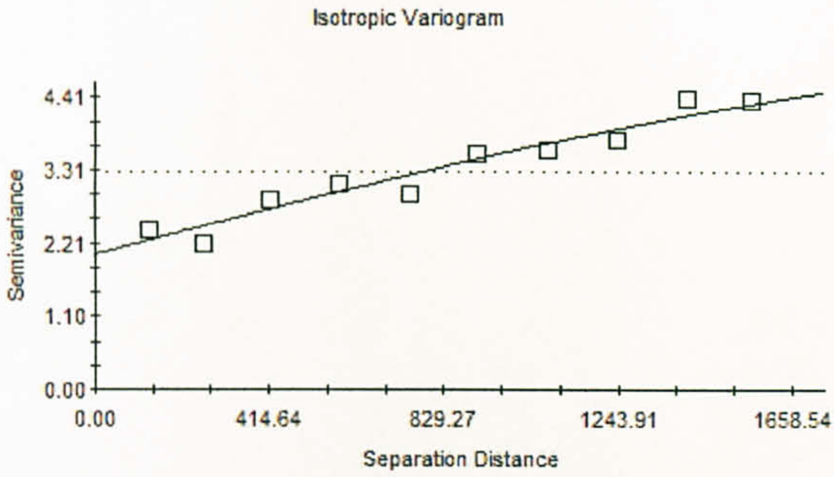
Exponential model (Co = 40.1000; Co + C = 183.3000; Ao = 3781.00; r2 = 0.306; RSS = 5328.)

Figure 4.5: Semivariogram and fitted model of fines



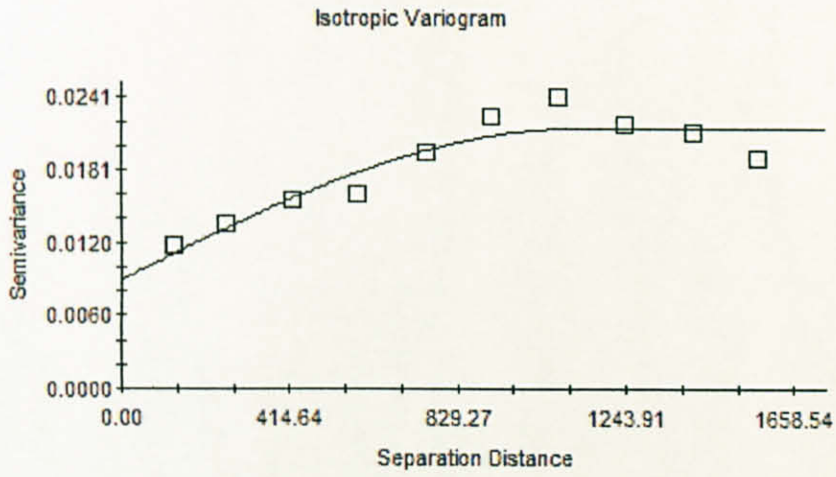
Spherical model (Co = 23.900000; Co + C = 76.530000; Ao = 3702.00; r2 = 0.833; RSS = 184.)

Figure 4.6: Semivariogram and fitted model of soil moisture content



Spherical model (Co = 2.040000; Co + C = 4.980000; Ao = 2692.00; r2 = 0.936; RSS = 0.322)

Figure 4.7: Semivariogram and fitted model of soil organic content



Spherical model (Co = 0.008950; Co + C = 0.021500; Ao = 1122.00; r2 = 0.871; RSS = 1.942E-05)

Figure 4.8: Semivariogram and fitted model of soil bulk density

From the Figure 4.5, 4.6, 4.7, and 4.8, C_o is represent as the nugget which is variation not spatially dependent over the range examined. $C_o + C$ is represent as the sill which is spatially-independent variance while for A_o is represent as the range which is considered as the distance beyond which observations are not spatially dependant. Regression Coefficient or r2 provides an indication of how well the model fits the variogram data. The r2 is indicates by the higher value of r2, the better the model fits the data. RSS is represent as residual sums of squares which is provides an exact measure of how well the model fits the variogram data; the lower the residual sums of squares, the better the model fits.

The range is considered as the distance beyond which observations are spatially dependant. The range also the separation distance over which sample locations are autocorrelated.In the study area of the UTP campus, the fine content showed the largest range (3781m), followed by moisture content (3702m), and organic content (2692m), while the bulk density showed the shortest range (1122m) (see Table 4.4).

The nugget is measure of all unaccounted spatial variability at distance smaller than the smallest lag (140 m in this study) while the structural variance accounts for variation due to spatial autocorrelation. The relatively smaller nuggets for soil organic content and bulk density (Table 4.4 and Figure 4.7 and 4.8) suggest that less variation existed for these two soil properties at distances shorter than the smallest lag. In contrast, the relatively larger nuggets for soil fine and moisture content compared to soil organic content and bulk density (see Table 4.4 and Figure 4.5, 4.6, 4.7, and 4.8) suggests that the variation of soil fines and moisture contents at distances shorter than the smallest lag are more than for organic contents and bulk densities.

The sill is a measure of the variability in the data.The highest sill was observed for fine content followed by moisture content and organic content, while bulk density showed the lowest sill (Table 4.4). Therefore, in the study area large variability are associated with fine and moisture content while relatively low variability are associated with organic content and bulk density.

The nugget-to-sill ratio gives an indicator of the spatial dependency of the data. A variable is considered to have a strong spatial dependence if the ratio is less than 25%, and a moderate spatial dependence if the ratio between 25% and 75%, and a weak dependence for ratio >75% (Goderya et al.,1996). The nugget to sill ratio for 3 properties moisture content, organic content and bulk density examined in this study range from 31.23% - 41.63% (Table 4.4) indicating moderate spatial dependence while fines content with 21.88% (<25%) has strong spatial dependence. The strong spatial dependency of the soil engineering properties provides indication of the influence of intrinsic or extrinsic factors.

4.5.2 Kriging Spatial Soil Properties

The spatial distribution of soil properties for unsampled locations in the study area were obtained from interpolation between sampled location by the method of kringing, based on semivariograms of the soil properties at sampled locations. Figure 4.9, 4.10, 4.11, and 4.12 illustrate the spatial distribution of fines, moisture content, organic content, and bulk density respectively, over the study area.

These maps of spatial distribution of soil properties in conjuction with the site map (Figure 4.4) now allow examining the closeness of association between variation in soil properties and topographic conditions.

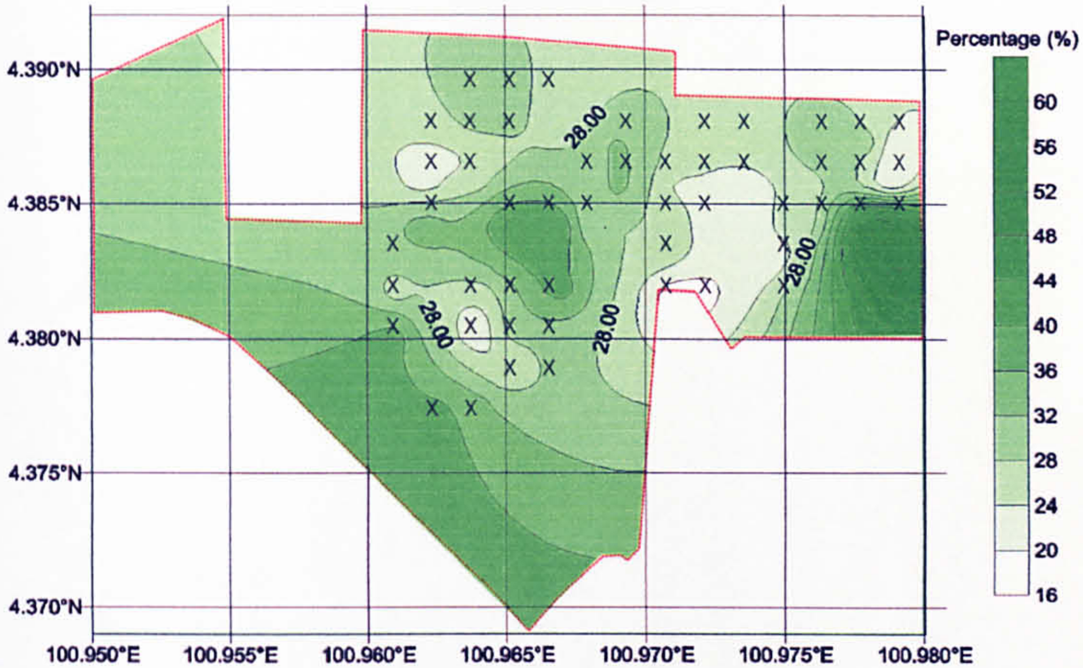


Figure 4.9: Spatial variability of soil fines

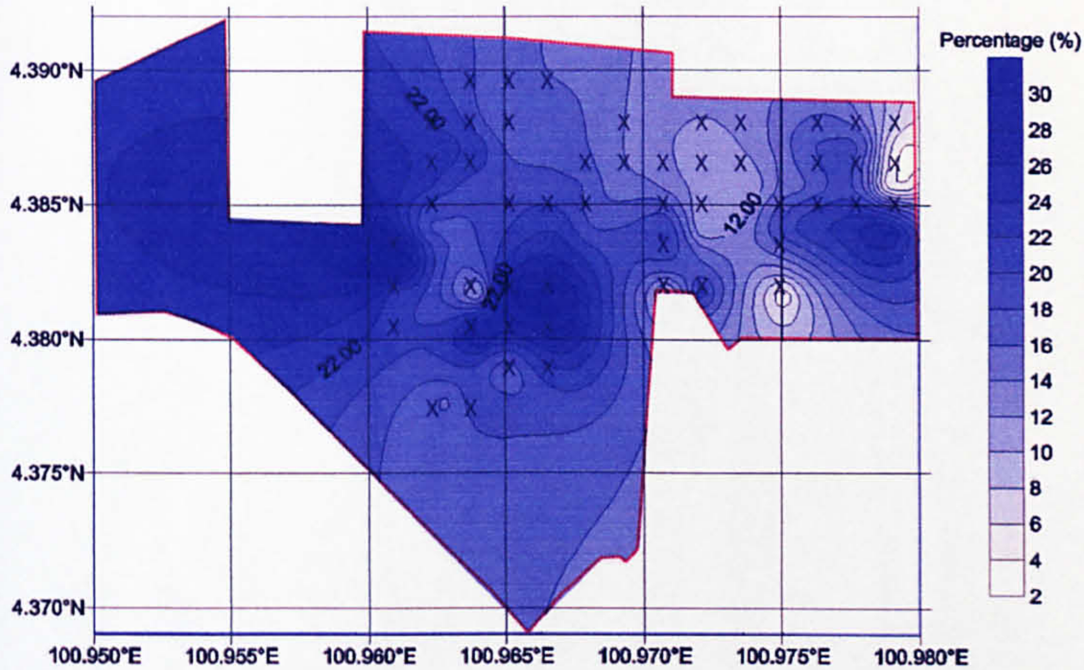


Figure 4.10: Spatial variability of soil moisture content

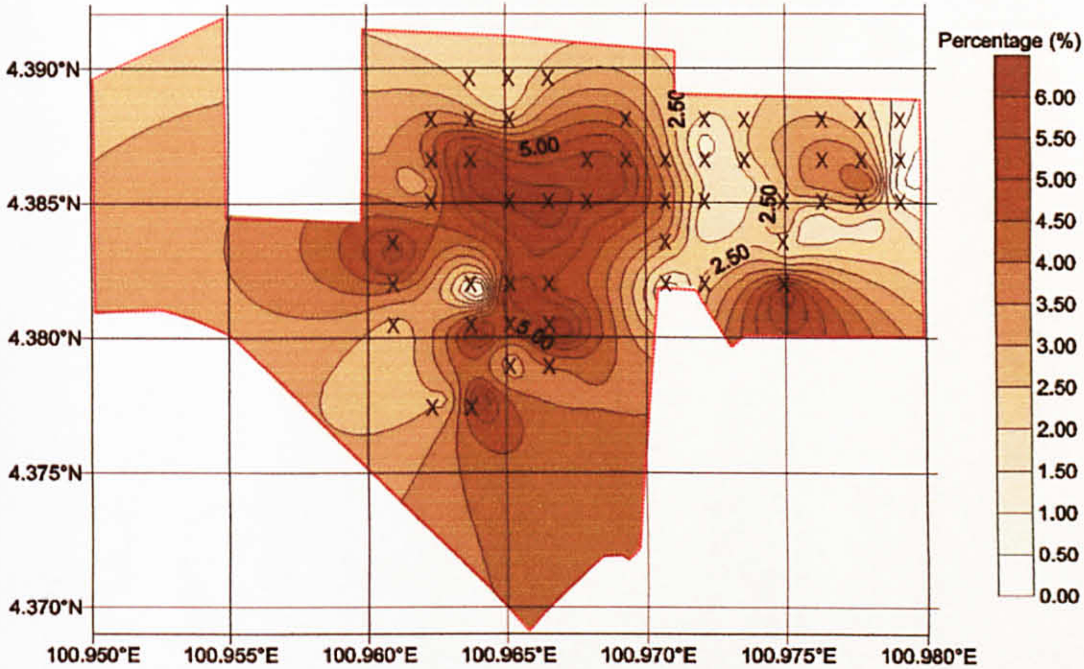


Figure 4.11: Spatial variability of soil organic content

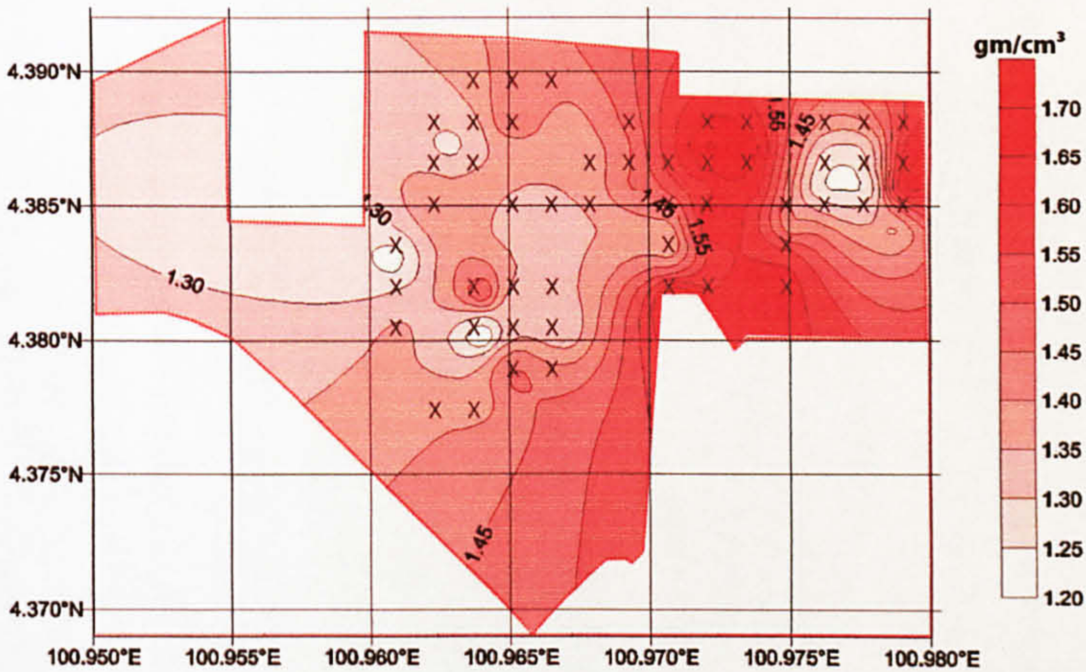


Figure 4.12: Spatial variability of soil bulk density

A comparison of Figures 4.9, 4.10, and 4.11, with Figure 4.4 reveals that higher fines, moisture content and organic contents appear to be associated with pond and forest areas (see Figure 4.4). The higher concentration of fines, moisture contents and organic contents near the (100.965°E-100.970°E, 4.380°N-4.385°N) and (100.975°E-100.980°E, 4.380°N-4.385°N) coordinate of the maps (Figures 4.9, 4.10, 4.11) are low lying areas (pond and forest zones) of the study area (see Figure 4.4). Thus it is reasonable to infer that the spatial variability of soil properties is induced partly by these topographic features present in the study area.

From Figure 4.12, bulk density has high concentration near the (100.970°E-100.975°E, 4.380°N-4.390°N) coordinate of the map. A comparison of Figures 4.12 with Figure 4.4 reveals that high bulk density can be associated with disturbed area that consist of academic building, hostel, road and pavement.

4.5.3 Variation of Soil Properties on Land Use Conditions

Statistical and geostatistical characterization of the soil properties provided strong evidence to the existence of influence from intrisic to extrinsic factors on the spatial variability of soil properties.To investigate into this aspect, the effect of land use changes was examined. To examine the effect of land use changes on the variability of soil properties, the study area was categorized by two zones which is disturbed and undisturbed area.

Disturbed zones included areas where forest clearance and ground alteration have taken place for building, pavement and road construction. Undisturbed area is where the ground is in its original condition such as the forest area. The mean of each soil properties investigated were computed for these two zones and compared as shown in Figure 4.13.

Mean soil properties

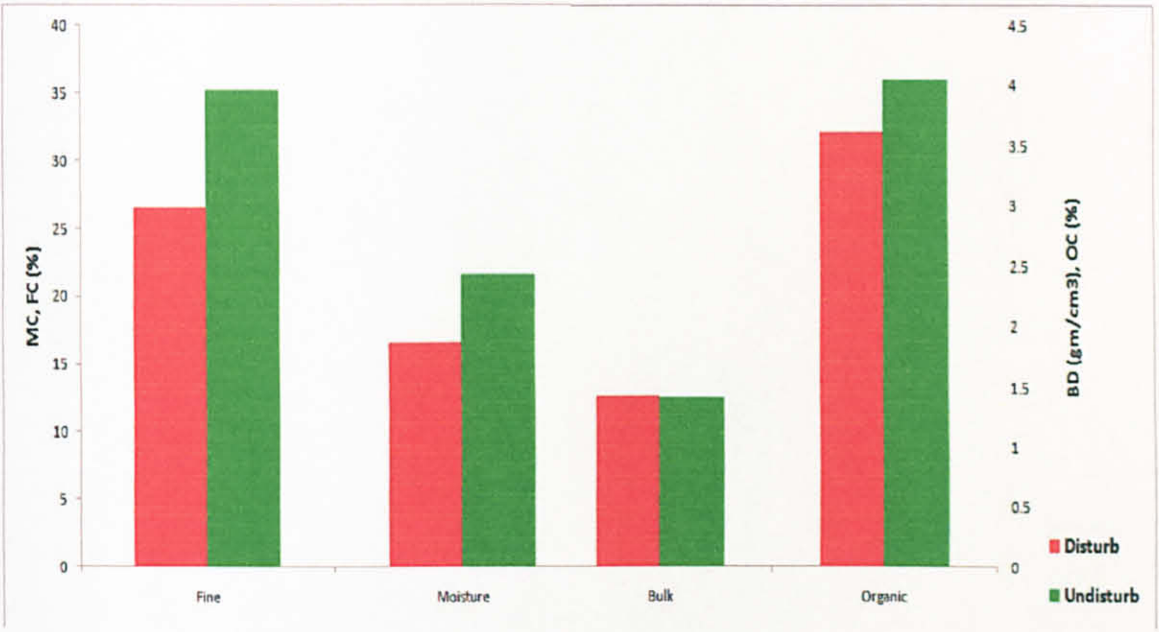


Figure 4.13: Effect of land use patterns on soil properties (FC: fine content; MC: moisture content; BD: bulk density; and OC: organic content)

Figure 4.13 indicates that the mean of soil fine content (FC), moisture content (MC), bulk density (BD) and organic content (OC) were higher in the undisturbed zones than compared to disturbed zones.

The relatively higher moisture and fine contents in the undisturbed zones are probably due to higher organic contents in soils which affect aggregate development and create macro-pores which enhance infiltration. Furthermore, when leaf litters are present, as found in undisturbed (forest) soil surface, runoff is delayed and there is more time for infiltration to take place, thus increasing the water intake of soils which contributes to higher moisture contents in the forest zones than in disturbed zones as seen in Figure 4.13.

The mean organic contents in undisturbed zones are higher than in disturbed zones as shown in Figure 4.13, because in forest zones the recycling of organic matter is more effective as there is no removal from the system (Mapa, 1995). In the disturbed zones, the net addition of organic matter is small and root activity is limited to shallow depths. For bulk density, it shows the result where disturbed area is relatively higher than undisturbed area. The higher bulk density in disturbed zones could be attributed to significant alteration of soil density by compaction induced by construction activities.

Thus it appears that the significant differences between soil engineering properties between the disturbed and forest zones are a consequence of disturbances cause by forest clearance and land alteration. It also appears that large variability of soil properties observed in the study area is probably a consequence of land use conditions.

CHAPTER 5

ECONOMIC BENEFITS

5.1 Cost

In this project, the total costs are considered from money that have been spent and time consuming from the beginning until the end of this project. Since this project involve with site work (taking sample), laboratory work, and analysis of laboratory result using software, so it takes time to finish it. The site and laboratory work for example take about 4 months to be finish while the result analysis take about 2 weeks (statistical and geostatistical). So the cost in term of time is slightly high for this project.

The cost in term of money spent for this project is small since most of tools and equipments required are available in laboratory. So the author just spent money for items that not available in laboratory and transportation. The costs (money) are shown in Table 5.1.

Table 5.1: Project costs (money)

Item / Description	Price/ Unit	Unit	Total price
Hoe	RM 22.00	1	RM 22.00
Polythine bag	RM 3.00	3	RM 9.00
Scope	RM 5.00	1	RM 5.00
Transportation	RM 2.80	50 litre	RM 140.00
		Total	RM 176.00

5.2 Economic Value

Studies on the spatial variability of soil engineering properties are limited in the south-east Asia including Malaysia. Understanding the spatial variability of soil physical properties would be helpful in the development of site-specific management. The study indicated geostatistical analysis in conjunction with conventional statistical analysis could reveal spatial variability nature of soil properties and causes behind the variability.

This project (spatial variability of soil physical properties) can be integrated with other project such as spatial variability of chemical properties to produce more economical precision farming, or site-specific farming. This can be achieving by controlling the usage of fertilizer in a farming area. Precision farming, or site-specific farming, can be defined as a management system with the flexibility to adjust agrochemical inputs to satisfy needs of specific areas in a field to achieve the soil's yield potential, rather than using uniform applications based on average field characteristics. With precision farming, producers have the ability to place crop nutrients where they are needed. As a result farmers can reduce their cost in farming and it is also environmental friendly.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

As conclusion, this project achieve its objectives to allow understanding and characterization of small scale spatial variability nature of physical properties (bulk density, moisture content, organic content, and fines content) of tropical soil at Universiti Teknologi Petronas (UTP). The author is also able to map spatial distribution of soil physical properties in UTP using Kriging. This project also allows identifying the effect of land use changes (disturb and undisturbed) on the variability of soil physical properties in UTP.

Significant variation of soil properties exists in the area studied. Larger CVs' and sill for soil fines and moisture content indicates irregular distribution of these two properties compared to other soil properties. Land disturbances and topographic conditions both contributed to the variability of soil properties.

Geostatistical characterization of the soil properties indicated distances over which different soil properties are correlated (range), the extent of variability (sill) between different soil properties, the degree of spatial dependencies (nugget-to-sill ratio) of various soil properties and enabled preparing maps for spatial distribution of soil properties. Whereas, conventional statistics helped in identifying causes of the variability in different soil properties.

Finally from this project, the author can conclude that the soil physical properties are varying spatially and are influenced by both the intrinsic and extrinsic factors.

6.2 Recommendation

For recommendation, the author suggests to have more closely spaced sampling data taken in order to make it relative to the area studied. For next time, more samples are taken and also the study is expand and continues for a lot of other applications in geotechnical studies.

The author also hope that this project can be integrated with other geotechnical studies in UTP such as soil strength, soil permeability and infiltration in order to understand the characterization of soil in this university.

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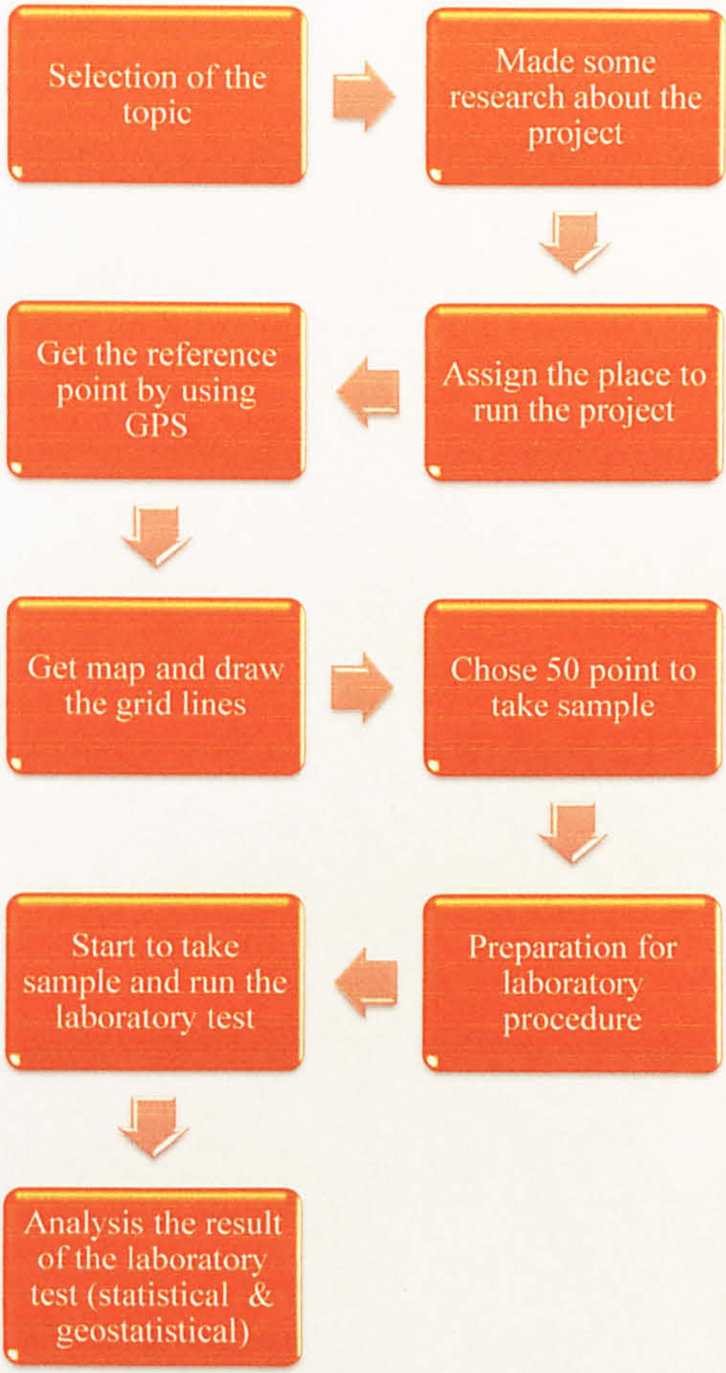
APPENDICES

APPENDICES

1. Project Flow Diagram



2. Gantt Chart

2.1 Suggested Milestone for the First Semester of Final Year Project

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Selection of Project Topic																
2	Preliminary Research work																
3	Submission of Premilinary																
4	Seminar (optional)																
5	Project Work																
6	Submission of Progress report																
7	Submission of Interim Report Final Draft																
8	Oral Presentation																

progress

suggested milestone

2.2 Suggested Milestone for the Second Semester of Final Year Project

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project work continue -soil sampling -laboratory analysis								Mid-semester break							
2	Submission of progress report 1															
3	Submission of progress report 2															
4	Project work continue - statistical and geostatistic analysis															
5	Preparing poster and oral presentation, dissertation report															
6	Poster Exhibition															
7	Submission Of Dissertation (soft bound)															
8	Oral Presentation															
9	Submission Of Dissertation (hard bound)															

Suggested milestone

Progress

3. Laboratory Result

3.1 Bulk Density

Sample	Longitude(E)	Latitude(N)	Mass(gm)	Volume	Bulk density
1	100°57'50"	4°22'55"	139.8	92.6547	1.508827939
2	100°57'50"	4°22'50"	108.4	92.6547	1.169935254
3	100°57'45"	4°23'10"	129	92.6547	1.392266124
4	100°57'45"	4°23'15"	118.3	92.6547	1.276783585
5	100°57'50"	4°23'20"	125.2	92.6547	1.351253633
6	100°57'55"	4°23'20"	135.5	92.6547	1.462419068
7	100°58'0"	4°23'20"	127.4	92.6547	1.374997707
8	100°57'50"	4°23'15"	123.8	92.6547	1.336143768
9	100°57'45"	4°23'5"	126.8	92.6547	1.36852205
10	100°57'45"	4°23'0"	112.6	92.6547	1.215264849
11	100°57'45"	4°22'55"	122	92.6547	1.316716799
12	100°57'45"	4°22'50"	126.4	92.6547	1.364204946
13	100°57'45"	4°22'40"	129	92.6547	1.392266124
14	100°57'50"	4°22'40"	127.1	92.6547	1.371759878
15	100°57'55"	4°22'45"	137	92.6547	1.478608209
16	100°58'0"	4°22'45"	130.2	92.6547	1.405217436
17	100°57'55"	4°22'50"	123	92.6547	1.32750956
18	100°58'0"	4°22'50"	119.9	92.6547	1.294052002
19	100°57'55"	4°22'55"	122.8	92.6547	1.325351008
20	100°58'0"	4°22'55"	123.6	92.6547	1.333985216
21	100°58'35"	4°23'15"	120.6	92.6547	1.301606934
22	100°58'40"	4°23'15"	121.2	92.6547	1.308082591
23	100°58'40"	4°23'10"	117.7	92.6547	1.270307928
24	100°58'35"	4"23'10"	116.5	92.6547	1.257356615
25	100°58'45"	4°23'10"	155.2	92.6547	1.675036453
26	100°58'35"	4°23'5"	149.8	92.6547	1.616755545
27	100°58'40"	4°23'5"	125.7	92.6547	1.356650013
28	100°58'45"	4°23'5"	123.8	92.6547	1.336143768
29	100°58'30"	4°23'5"	129.3	92.6547	1.395503952
30	100°58'35"	4°23'5"	132.5	92.6547	1.430040786
31	100°58'20"	4°23'15"	158.7	92.6547	1.712811115
32	100°58'25"	4°23'15"	153.2	92.6547	1.653450931
33	100°58'20"	4°23'10"	146.4	92.6547	1.580060159
34	100°58'15"	4"23'10"	142.6	92.6547	1.539047668

35	100°58'20"	4°23'5"	154	92.6547	1.66208514
36	100°58'25"	4°23'5"	148.3	92.6547	1.600566404
37	100°58'15"	4°23'5"	129.1	92.6547	1.3933454
38	100°58'15"	4°23'0"	127.7	92.6547	1.378235535
39	100°58'10"	4°23'15"	131.2	92.6547	1.416010197
40	100°58'10"	4"23'10"	133.6	92.6547	1.441912823
41	100°58'5"	4°23'10"	126.6	92.6547	1.366363498
42	100°58'5"	4°23'5"	124.5	92.6547	1.343698701
43	100°57'55"	4°23'15"	126.5	92.6547	1.365284222
44	100°57'50"	4°23'10"	128.8	92.6547	1.390107571
45	100°57'55"	4°23'5"	121.7	92.6547	1.313478971
46	100°58'0"	4°23'5"	124.9	92.6547	1.348015805
47	100°58'20"	4°22'55"	149.2	92.6547	1.610279889
48	100°58'15"	4°22'55"	160.8	92.6547	1.735475912
49	100°58'30"	4°23'0"	148.3	92.6547	1.600566404
50	100°58'30"	4°22'55"	150.2	92.6547	1.621072649

3.2 Moisture Content

Sample	Longitude(E)	Latitude(N)	Mass of wet soil + container (m2)	Mass of dry soil + container (m3)	Mass of containe r (m1)	Moisture Content, W (%)
1	100°57'50"	4°22'55"	40.89	38.9	20.7	10.93406593
2	100°57'50"	4°22'50"	43.6	39.2	23.2	27.5
3	100°57'45"	4°23'10"	38.8	35	18.5	23.03030303
4	100°57'45"	4°23'15"	39.1	35.3	18.6	22.75449102
5	100°57'50"	4°23'20"	43.8	40.6	23.1	18.28571429
6	100°57'55"	4°23'20"	41.3	38.5	20.7	15.73033708
7	100°58'0"	4°23'20"	39	36	18.5	17.14285714
8	100°57'50"	4°23'15"	39.3	35.6	18.6	21.76470588
9	100°57'45"	4°23'5"	41.4	38.7	23.1	17.30769231
10	100°57'45"	4°23'0"	42.8	37.2	20.7	33.93939394
11	100°57'45"	4°22'55"	40.3	36.6	18.6	20.55555556
12	100°57'45"	4°22'50"	41.7	37.7	18.7	21.05263158
13	100°57'45"	4°22'40"	42.5	39.9	23.1	15.47619048
14	100°57'50"	4°22'40"	42.7	39	20.7	20.21857923
15	100°57'55"	4°22'45"	40.2	37.3	18.6	15.50802139
16	100°58'0"	4°22'45"	40.5	36.5	18.7	22.47191011
17	100°57'55"	4°22'50"	44.6	40.4	23.1	24.27745665
18	100°58'0"	4°22'50"	41.5	37	20.7	27.60736196
19	100°57'55"	4°22'55"	40.5	35.7	18.5	27.90697674
20	100°58'0"	4°22'55"	40.4	35.6	18.6	28.23529412
21	100°58'35"	4°23'15"	42.7	39.7	23.1	18.07228916
22	100°58'40"	4°23'15"	42.5	39.4	23.1	19.01840491
23	100°58'40"	4°23'10"	42.9	39.8	20.7	16.23036649
24	100°58'35"	4"23'10"	42.2	39.3	20.7	15.59139785
25	100°58'45"	4°23'10"	41.1	40.4	18.5	3.196347032
26	100°58'35"	4°23'5"	41.7	40.8	18.5	4.035874439
27	100°58'40"	4°23'5"	41.3	36.9	18.7	24.17582418
28	100°58'45"	4°23'5"	41.5	36.8	18.7	25.96685083
29	100°58'30"	4°23'5"	40.3	37.2	20.7	18.78787879
30	100°58'35"	4°23'5"	40.7	37.1	20.7	21.95121951
31	100°58'20"	4°23'15"	42.3	40.4	23.1	10.98265896
32	100°58'25"	4°23'15"	42.8	40.6	23.1	12.57142857
33	100°58'20"	4°23'10"	42.4	40.2	20.7	11.28205128
34	100°58'15"	4"23'10"	42.9	40.3	20.7	13.26530612
35	100°58'20"	4°23'5"	41	39.1	18.6	9.268292683
36	100°58'25"	4°23'5"	40.7	38.6	18.6	10.5

37	100°58'15"	4°23'5"	41.3	37.5	18.7	20.21276596
38	100°58'15"	4°23'0"	41.8	38.1	18.7	19.07216495
39	100°58'10"	4°23'15"	42.2	39.8	23.1	14.37125749
40	100°58'10"	4"23'10"	42.7	40.2	23.1	14.61988304
41	100°58'5"	4°23'10"	42.4	39.1	20.7	17.93478261
42	100°58'5"	4°23'5"	41.7	38.6	20.7	17.31843575
43	100°57'55"	4°23'15"	39.7	36.5	18.6	17.87709497
44	100°57'50"	4°23'10"	39.1	35.9	18.6	18.49710983
45	100°57'55"	4°23'5"	39.4	36	18.6	19.54022989
46	100°58'0"	4°23'5"	40.2	36.4	18.6	21.34831461
47	100°58'20"	4°22'55"	45	41.2	23.1	20.99447514
48	100°58'15"	4°22'55"	42.9	41.2	20.7	8.292682927
49	100°58'30"	4°23'0"	40.9	38.2	18.5	13.70558376
50	100°58'30"	4°22'55"	39.9	39	18.6	4.411764706

3.3 Organic Content

Sample	Longitude(E)	Latitude(N)	Organic content (%)
1	100°57'50"	4°22'55"	0.549450549
2	100°57'50"	4°22'50"	6.25
3	100°57'45"	4°23'10"	3.03030303
4	100°57'45"	4°23'15"	5.389221557
5	100°57'50"	4°23'20"	2.857142857
6	100°57'55"	4°23'20"	2.247191011
7	100°58'0"	4°23'20"	4
8	100°57'50"	4°23'15"	5.882352941
9	100°57'45"	4°23'5"	4.487179487
10	100°57'45"	4°23'0"	6.060606061
11	100°57'45"	4°22'55"	3.888888889
12	100°57'45"	4°22'50"	2.631578947
13	100°57'45"	4°22'40"	2.976190476
14	100°57'50"	4°22'40"	6.010928962
15	100°57'55"	4°22'45"	2.673796791
16	100°58'0"	4°22'45"	3.93258427
17	100°57'55"	4°22'50"	4.624277457
18	100°58'0"	4°22'50"	6.748466258
19	100°57'55"	4°22'55"	5.813953488
20	100°58'0"	4°22'55"	4.705882353
21	100°58'35"	4°23'15"	3.614457831
22	100°58'40"	4°23'15"	3.067484663
23	100°58'40"	4°23'10"	4.712041885
24	100°58'35"	4"23'10"	3.76344086
25	100°58'45"	4°23'10"	0.456621005
26	100°58'35"	4°23'5"	0.896860987
27	100°58'40"	4°23'5"	1.648351648
28	100°58'45"	4°23'5"	2.209944751
29	100°58'30"	4°23'5"	3.03030303
30	100°58'35"	4°23'5"	1.219512195
31	100°58'20"	4°23'15"	1.156069364
32	100°58'25"	4°23'15"	2.857142857
33	100°58'20"	4°23'10"	2.051282051
34	100°58'15"	4"23'10"	3.571428571
35	100°58'20"	4°23'5"	1.463414634

36	100°58'25"	4°23'5"	2
37	100°58'15"	4°23'5"	3.723404255
38	100°58'15"	4°23'0"	2.577319588
39	100°58'10"	4°23'15"	5.389221557
40	100°58'10"	4"23'10"	5.847953216
41	100°58'5"	4°23'10"	5.97826087
42	100°58'5"	4°23'5"	5.027932961
43	100°57'55"	4°23'15"	5.027932961
44	100°57'50"	4°23'10"	6.358381503
45	100°57'55"	4°23'5"	5.747126437
46	100°58'0"	4°23'5"	6.179775281
47	100°58'20"	4°22'55"	2.762430939
48	100°58'15"	4°22'55"	0.975609756
49	100°58'30"	4°23'0"	2.030456853
50	100°58'30"	4°22'55"	6.37254902

3.4 Fines Content

Sample	Longitude(E)	Latitude(N)	Fines (%)
1	100°57'50"	4°22'55"	25.72
2	100°57'50"	4°22'50"	19.92
3	100°57'45"	4°23'10"	21.88
4	100°57'45"	4°23'15"	23.78
5	100°57'50"	4°23'20"	31.6
6	100°57'55"	4°23'20"	30.94
7	100°58'0"	4°23'20"	24.34
8	100°57'50"	4°23'15"	24.56
9	100°57'45"	4°23'5"	34.94
10	100°57'45"	4°23'0"	29.6
11	100°57'45"	4°22'55"	26.44
12	100°57'45"	4°22'50"	37.5
13	100°57'45"	4°22'40"	35.76
14	100°57'50"	4°22'40"	33.22
15	100°57'55"	4°22'45"	23.78
16	100°58'0"	4°22'45"	29.06
17	100°57'55"	4°22'50"	29.72
18	100°58'0"	4°22'50"	30.24
19	100°57'55"	4°22'55"	29.48
20	100°58'0"	4°22'55"	37.4
21	100°58'35"	4°23'15"	30.52
22	100°58'40"	4°23'15"	30.36
23	100°58'40"	4°23'10"	26.2
24	100°58'35"	4"23'10"	26.12
25	100°58'45"	4°23'10"	20.04
26	100°58'35"	4°23'5"	19.96
27	100°58'40"	4°23'5"	59.68
28	100°58'45"	4°23'5"	59.64
29	100°58'30"	4°23'5"	26.1
30	100°58'35"	4°23'5"	25.62
31	100°58'20"	4°23'15"	25.54
32	100°58'25"	4°23'15"	25.62
33	100°58'20"	4°23'10"	23.44
34	100°58'15"	4"23'10"	23.34
35	100°58'20"	4°23'5"	22.66
36	100°58'25"	4°23'5"	22.52
37	100°58'15"	4°23'5"	26.24

38	100°58'15"	4°23'0"	26.12
39	100°58'10"	4°23'15"	33.4
40	100°58'10"	4"23'10"	33.28
41	100°58'5"	4°23'10"	27.3
42	100°58'5"	4°23'5"	27.18
43	100°57'55"	4°23'15"	26.66
44	100°57'50"	4°23'10"	26.56
45	100°57'55"	4°23'5"	39.8
46	100°58'0"	4°23'5"	39.7
47	100°58'20"	4°22'55"	18.42
48	100°58'15"	4°22'55"	16.9
49	100°58'30"	4°23'0"	22.28
50	100°58'30"	4°22'55"	28.38

4. Isotropic Variogram Model

4.1 Bulk Density

Isotropic Variogram Model

Model	Nugget Co	Sill Co + C	Range Parameter Ao	Effective Range	Proportion C/(Co+C]	r2	RSS
Spherical	0.0089500	0.0215000	1122.0000	1122.0000	0.584	0.871	1.942E-05
Exponential	0.0062900	0.0219800	403.0000	1209.0000	0.714	0.807	2.903E-05
Linear	0.0130040	0.0232843	1565.5979	1565.5979	0.442	0.621	4.500E-04
Linear to sill	0.0096800	0.0215600	910.0000	910.0000	0.551	0.895	1.590E-05
Gaussian	0.0108300	0.0217600	992.0000	1718.1944	0.502	0.859	2.134E-05

4.2 Moisture Content

Isotropic Variogram Model

Model	Nugget Co	Sill Co + C	Range Parameter Ao	Effective Range	Proportion C/(Co+C]	r2	RSS
Spherical	23.900000(	76.530000(	3702.0000	3702.0000	0.688	0.833	184.
Exponential	22.700000(	86.400000(	2319.0000	6957.0000	0.737	0.801	220.
Linear	23.757348	56.253928(	1565.5979	1565.5979	0.578	0.846	3764.
Linear to sill	0.1000000	42.190000(	178.0000	178.0000	0.998	0.099	991.
Gaussian	0.1000000	42.340000(	207.0000	358.5345	0.998	0.107	983.

4.3 Organic Content

Isotropic Variogram Model

Model	Nugget Co	Sill Co + C	Range Parameter Ao	Effective Range	Proportion C/(Co+C]	r2	RSS
Spherical	2.0400000	4.9800000	2692.0000	2692.0000	0.590	0.936	0.322
Exponential	1.9200000	6.5270000	2171.0000	6513.0000	0.706	0.929	0.356
Linear	2.0928505	4.4000209	1565.5979	1565.5979	0.524	0.941	0.294
Linear to sill	2.0960000	4.3450000	1520.0000	1520.0000	0.518	0.942	0.292
Gaussian	2.3690000	4.7550000	2046.0000	3543.7760	0.502	0.935	0.325

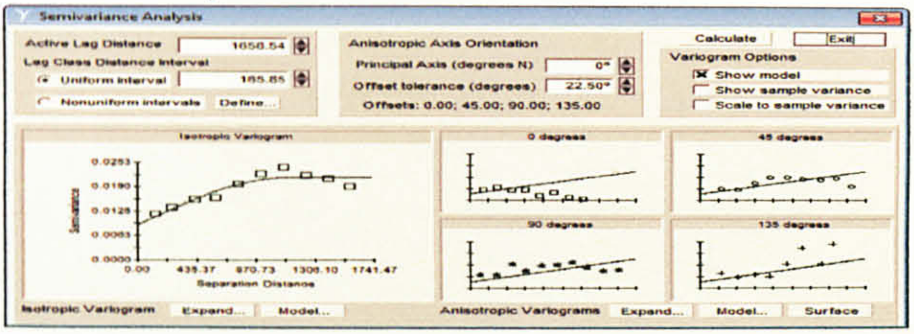
4.4 Fines

Isotropic Variogram Model

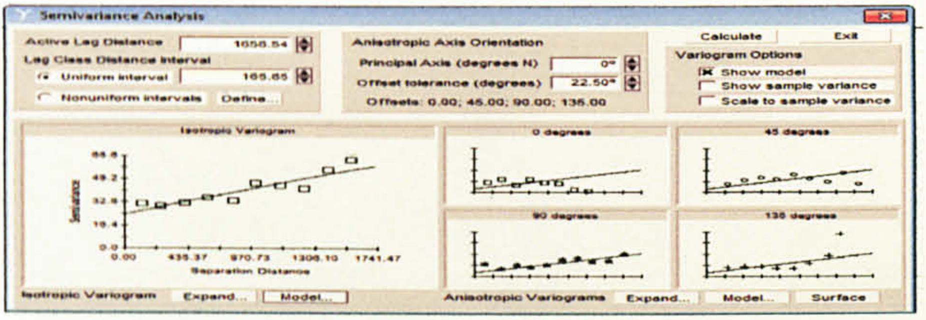
Model	Nugget Co	Sill Co + C	Range Parameter Ao	Effective Range	Proportion C/(Co+C]	r2	RSS
Spherical	0.10000	69.90000	273.0000	273.0000	0.999	0.068	7138.
Exponential	40.10000	183.30000	3781.0000	11343.0000	0.781	0.306	5328.
Linear	38.60690	92.90582	1565.5979	1565.5979	0.584	0.339	5057.
Linear to sill	0.10000	69.90000	200.0000	200.0000	0.999	0.068	7137.
Gaussian	0.10000	70.00000	218.0000	377.5871	0.999	0.067	7142.

5. Semivariance Analysis (Best Fitted Model)

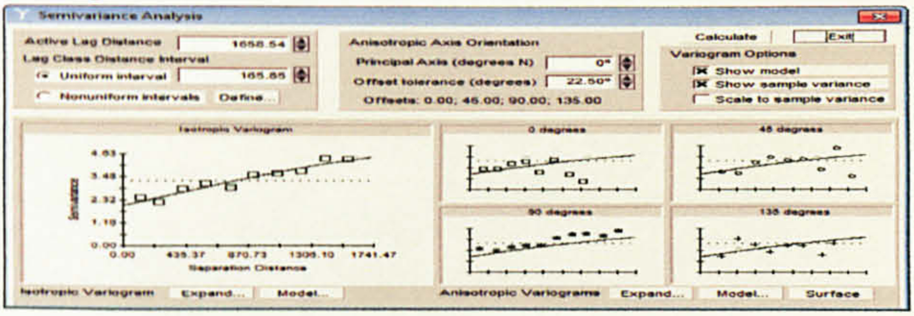
5.1 Bulk Density



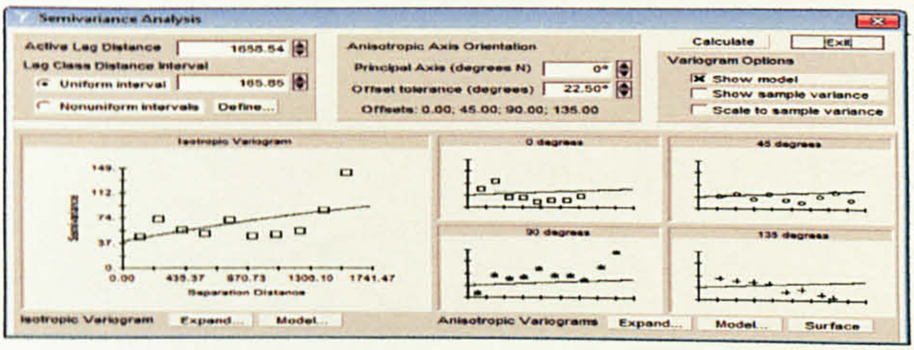
5.2 Moisture Content



5.3 Organic Content



5.4 Fines



6. Related Pictures

Site clearing

Take soil sample

Crush soil sample

Clean sieve

Measuring bulk density