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.

NOORHIDAYAH BINTI MAHAMUD

ABSTRACT

Spatial variability of soil hydraulics is a study of determining representative infiltration rate parameters for use in modeling infiltration characteristics of soil under tropical climate in terms of geostatistical analysis. This study deals with the spatial variability of soil hydraulics properties at University Teknologi Petronas (UTP) campus area. The proposed project allowed understanding and characterization of small scale spatial variability nature of infiltration characteristics of tropical soil in the UTP campus area. The aim of the study is to evaluate the variation in soil hydraulic characteristics around the UTP campus area by performing the double ring infiltrometer and make a comparison of infiltration rate for each location. Horton's infiltration equation was calibrated with the data of 50 infiltration tests performed in different locations. This allowed arriving at a generalized for of Horton's infiltration equation for the UTP campus area. Variation in soil hydraulic characteristics and determining field scale flow processes are difficult because of the spatial variability of soil properties. Methodology of this modeling the spatial variability nature of infiltration characteristics at UTP campus area includes three parts which are determination of geogrid locations, field data experiments and computer analysis. The statistical parameters from the infiltration tests will be presented in statistical and geostatistical analysis.

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Variability in the soil hydraulic properties affects the behavior of water and solutes in the subsurface. When these properties are described by parametric functions, subsurface heterogeneity can be quantified by variations in the parameters of these functions. Different studies have exhibited different spatial correlation structures for soil hydraulic properties such as saturated or unsaturated hydraulic conductivity, saturated and residual soil water content, sorptivity, and pore-size distribution parameter (Dirk Mallants et al., 1996). This study proposes a procedure to characterize systematically the statistical properties of each soil infiltration parameter and the parameter correlations involved. The procedure is known as the geostatistical analysis of spatial variability of nature infiltration characteristics.

Soil infiltration is the process of water entering the soil. This process affects surface runoff, soil erosion, and groundwater recharge. The rate of infiltration is the maximum velocity at which water enters the soil surface. When the soil is in good condition or has good soil health, it has stable structure and continuous pores to the surface. This allows water from rainfall to enter unimpeded throughout a rainfall event. A low rate of infiltration is often produced by surface seals resulting from weakened structure and clogged or discontinuous pores.

The soil hydraulic parameters can be measured by more than one method, but there are often some uncertainties or differences in values of the parameters measured with different methods owing to variations in the flow process and errors associated with the particular method of measurement. Also, several empirical and theoretical equations which are currently used to describe the characteristics and the parameters of some equations appear to be similar. The aspects mentioned above further add to the complexity of understanding and describing infiltration behaviors of soil.

Being able to measure the surface infiltration rate is necessary in many disciplines. In this study the double ring infiltrometer is used for measuring infiltration rates. Double ring infiltrometers consist of double metal cylinder that is driven partially into the soil. The rings are filled with water, and the rate at which the water moves into the soil is measured. This rate becomes constant when the saturated infiltration rate for the particular soil has been reached. The double ring infiltrometer test is a well recognized and documented technique for directly measuring soil infiltration rates.

1.2 Problem Statement

Soil hydraulics and flow dynamics in soils are primary drivers of crop growth, nutrient cycling, and contaminant transport. In particular, infiltration is a dominant process controlling the soil water status for plants and the vadose zone transport of pesticides and nutrients. The infiltration rate is dictated by such factors as soil properties, initial and boundary conditions at the soil surface, landscape features, and agricultural management. All of which can be spatially and temporally heterogeneous (Sun et al., 2003).

The variability of soil engineering properties has significant impact on many hydrological processes. Spatial variability causes difficulty in representing a soil with a deterministic or precisely defined set of characteristics and precludes characterization of soil hydrological response. 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 (Cromer, 1996).

This proposed study will allow understanding and characterization of small scale spatial variability nature of infiltration characteristics of tropical soil at UTP campus area. This will also allow in arriving at a generalized form of Horton's Infiltration Equation of the UTP campus area.

1.3 Objectives

The objective of the study is to determine and characterize spatial structure of infiltration characteristics of soil under tropical climate in terms of semivariogram parameters. The characterization of the spatial variability and scale dependence of infiltration rate is performed by using geostatistical approaches.

To map the variation in soil hydraulic characteristics in the study area that is affected by various factors such as soil texture, soil moisture content, bulk density, surface porosity, and other biological activity.

To evaluate the effect of land use changes on the variability of infiltration characteristics in the study area.

1.4 Scope of Study

For this project, the scope of study are determined the spatial variability of soil hydraulic properties within UTP campus. In this study, the nature of infiltration characteristics is examined by performing the in-situ double ring infiltrometer test at different sample locations. Thus, the Horton's infiltration equation is used to calibrate the field data. The parameters obtained from the Horton's equation will further used in the statistical and geostatistical analysis.

CHAPTER 2
LITERATURE REVIEW

2.1 Soil Hydraulic Properties

Soil hydraulic properties control the rate of water entry into the soil during the process of infiltration, the rate of water translocation within the soil during the process of redistribution, and the rate of water removal from the soil during the processes of drainage, evaporation, and transpiration (Reynolds & Elrick, 1996). Through their control of water movement, soil hydraulic properties also exert a strong influence on many other soil processes, such as soil water storage, soil gas accumulation and flux, surface water runoff, soil erosion, groundwater recharge, leaching of solutes (e.g., crop nutrients, pesticides, contaminants), plant growth, and the accumulation or loss of soil organic matter. Consequently, soil hydraulic properties are critically important to natural processes associated with the hydrologic cycle, and to a vast range of human activities associated with soil water management.

Soil hydraulic properties include hydraulic conductivity, flux potential, sorptivity, and the sorptive number or its inverse known as the macroscopic capillary length. These parameters exist for all soil water contents.

2.2 Variability of Soil Hydraulic Properties

Hydrological and geological processes are known to vary in space (Nielsen et al., 1973; Delhomme, 1979). Variability of soil hydraulics properties plays a significant role in crop growth. Generally, soil is not uniform and immense spatial soil texture variability can be noticed across the regional area.

Soil texture is a key factor in influencing soil's water holding capacity. Coarse textured soils have a lower moisture holding capacity due to high porosity and ability to drain excess water quicker than fine textured soils. On the other hand, fine textured soils have varying percentages of silt and clay as the main components. Therefore, these fine textured soils have a higher moisture holding capacity.

2.3 Soil Infiltration Characteristics

Soil infiltration is one of the major components of hydrology cycle. It essentially controls the amount of water entering the soil, as well as the generation of overland flow. Studies in the past have attempted to relate the soil physical parameters such as porosity to the soil hydraulic parameters (e.g., hydraulic conductivity). While such studies are useful in estimating the required parameters, a general understanding of how different parameters relate with one another and the extent of their interrelation is required for a better understanding of infiltration. Water movement into soil is influenced by several soil hydraulic parameters that are often interrelated. (Maheshwari, 2000).

Infiltration is a complex process that depends upon physical and hydraulic properties of the soil moisture content, previous wetting history, structural changes in the layers and air entrapment (Delhomme, 1979).

2.4 Spatial Variability of Soil Hydraulic Properties

Characterization of spatial structure of soil hydraulic properties are important for several form of analysis: (i) to determine the optimum size of spatial grids for distributed parameter hydrological models (Anctil et al., 2002), (ii) estimating point or spatially averaged values of soil properties using kriging technique (Bardossy and Leh-mann, 1998), (iii) in designing sampling networks and improving their efficiency (Prakash and Singh, 2000)..

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). Therefore, spatial variability of soil hydraulic properties should be monitored and quantified

CHAPTER 3
METHODOLOGY

3.1 Introduction

There are three steps involved in this study of spatial variability of soil hydraulic properties in UTP Campus area. The first step is the preparation of the geo-grids sampling. After all the longitude and latitude for the 50 sample locations is determined, the next step is the field experimental by performing the double ring infiltrometer test. The last step is the analyzing the data that obtained from the field experimental by using the statistical and geostatistical method. The geostatistical analysis is done by using GS + and Surfer software.

3.2 Study Area

Figure 3.1: Topography Map of UTP Campus

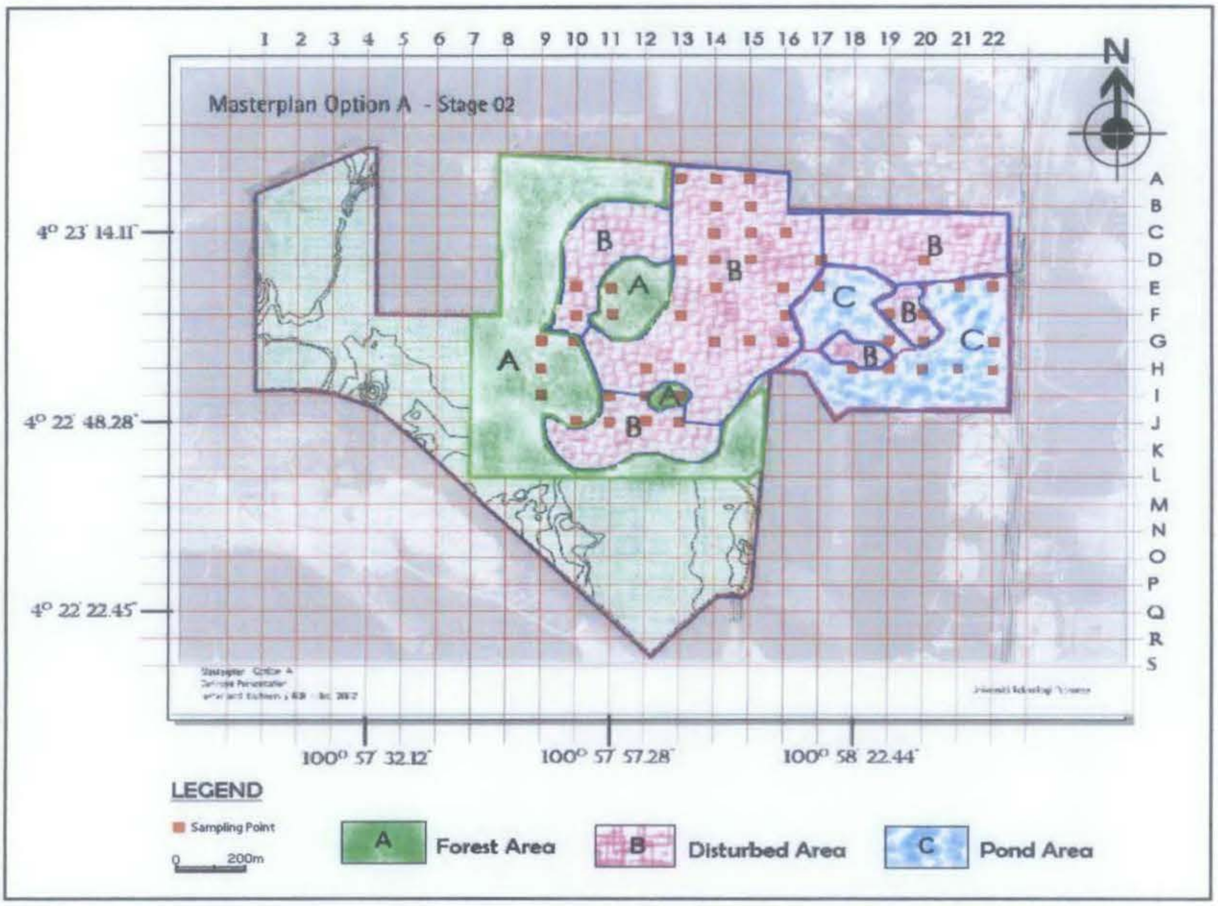


Figure 3.2: UTP Campus Map and Soil Sampling Location

Universiti Teknologi Petronas (UTP) campus area is located in Tronoh which is the west part of Perak. The UTP campus is about 25 kilometers from Ipoh city. The UTP campus area is lies between latitude 4° 22' 16.91637" N to 4° 23' 25.7225" N and longitude 100° 57' 28.18015" E to 100° 58' 34.20999" E. The overall study area is 400 ha (934 acres). The UTP campus is subdivided in two regions which are developed and undeveloped area. The development area mainly consists of academic blocks, administration blocks, hostels and also infrastructures component such as roads, covered sidewalk, open sidewalk, etc. and the undeveloped area is the forest area surrounding the UTP campus.

Perak experienced warm and humid day all year round. Perak State registers its temperature ranging from 23.7 to 33.2 degree Celsius (°C) with humidity exceeding 82.3 percent and abundant rainfall up to 3,218.00 millimeters a year.

3.3 Geo-grids Sampling

3.3.1 Tracing and Digitizing UTP Campus Map

The CorelDRAW 9 software is used to trace all the boundaries in the UTP campus area map in order to produce the campus base map. In determining the sampling area, all the roads, drainages, contours, buildings, fields, etc being traced using this software. After all the features in map have being traced, the geo-reference (Latitude, Longitude) for two locations on the base map was established by conducting the Global Positioning System (GPS) survey (see Appendix A). The base map was then digitalized with DigXY software to obtain map boundary data in digital form and in geo-grids reference system. From the digitalized data, the campus map was generated with geo-references coordinate using Surfer software.

On the generated map, the UTP Campus area was subdivided by a number of regular geo-grids. The location for each soil sample collection points is marked based on the intersection of the grid lines. 50 points was chosen from the generated campus map for soil sample testing.

3.4 Double Ring Infiltrometer Test

Double ring Infiltrometer is commonly used for in-situ measurement of soil infiltration characteristics. The double ring infiltrometer test is a well recognized and documented technique for directly measuring soil infiltration rates. The infiltrometer can employ one or two concentric rings, and correspondingly it is called a single or double ring infiltrometer. The double ring infiltrometer is preferred because it minimizes the error associated with the single ring method because the water level in the outer ring forces vertical infiltration of water in the inner ring.

There are two operational techniques used with the double ring infiltrometer for measuring the flow of water into the ground. In the constant head test, the water level in the inner ring is maintained at a fixed level and the volume of water used to maintain this level is measured. In the falling head test, the time that the water level takes to decrease in the inner ring is measured. In both constant and falling head tests, the water level in the outer ring is maintained at a constant level to prevent leakage between rings and to force vertical infiltration from the inner ring.

Figure 3.3: Fabricated Double Ring Infiltrometer

Figure 3.4: In-Situ Double Ring Infiltrometer Test

3.4.1 Procedures of Soil Infiltration Test

The methodology of conducting the test as stated below:

1. Clip any vegetation (grass) to the ground surface and remove all loose organic cover over an area just larger than your largest ring. Try not to disturb the soil.
2. Starting with the smaller ring, twist the rings 2 - 5 cm into the soil. A hammer may be used to pound the ring into the surface. If you must use a hammer, a block of wood should be used between the hammer and the top of the ring to distribute the force of the hammering. Do not hammer so hard that the ring crumples.

3. Measure the height above ground level of the bottom and top of the band you marked on the inside of the smaller ring.
4. As quickly as possible, do the following:
   i. Pour water into both rings, and maintain a level in the other ring approximately equal to the level in the inner ring. Note that the water level in the outer ring tends to drop more quickly than that of the inner ring.
   ii. Pour water into the inner ring, to just above the upper reference mark.
   iii. Start the stopwatch or note the time to the second and record it on the Infiltration Data Work Sheet.

      Note: The outer ring should not be leaking water to the surface around its rim. If it is, start over in another location; push the outer ring deeper into the soil or pack mud around its base.
5. As the water level in the inner ring reaches the upper reference mark, record the elapsed time as your start time.
6. During the timing interval, keep the water level in the outer ring approximately equal to the level in the inner ring, but be careful not to pour water into the inner ring (using a funnel can help) or to let either ring go dry.
7. As the water level in the inner ring reaches the lower reference mark:
   i. Record the time as your end time.
   ii. Figure the time interval by taking the difference between the start and end times.
   iii. Pour water into the inner ring to just above the upper reference mark. Raise the water level in the outer ring so that they are approximately equal.
8. Continue repeating steps 5 - 7 for 45 minutes or until two consecutive interval times are within 10 sec. of one another.
9. Some clays and compacted soils will be impervious to water infiltration and your water level will hardly drop at all within a 45-minute time period. In this case, record the depth of water change, if any, to the nearest mm. Record the

time at which you stopped your observations as the end time. Your infiltration measurement will consist of a single data interval.

10. Remove the rings. (Must wait five minutes)
11. Measure the near-surface (0 - 5 cm depth) soil moisture from the spot where you just removed the rings.

3.5 Infiltration Estimation using Horton's Infiltration Equation

Horton's Infiltration Equation is used to tabulate the data that obtained from the double ring infiltrometer measurement. Soil infiltration parameters including the initial infiltration rate (f_o), final infiltration rate (f_c), and constant value (k) is determined using Horton's Infiltration Equation.

The infiltration capacity curve is plotted for each sample location to represent the variation of infiltration capacity with time (see Appendix B). Since the curve reached a constant value and therefore it is a curve of the exhaustion type. Horton has suggested a mathematical form by which this curve generally represented. It is an empirical formula that says that infiltration starts at a constant rate, f_o, and is decreasing exponentially with time, t. After some time when the soil saturation level reaches a certain value, the rate of infiltration will level off to the rate f_c.
Horton's Infiltration Equation;

$$f = f_c + (f_o - f_c)e^{-Kt}$$

where;

f = infiltration rate at any time, t

t = time from the beginning the waters infiltrate

f_c = final infiltration rates after it reaches a constant value

f_o = initial infiltration rate

k = a constant

The constant values, k is determined for each sample location by using the steps below:

$$f - f_c = (f_o - f_c)e^{-Kt} \quad \text{.......(1)}$$

Taking log on both sides;

$$\log_{10}(f - f_c) = -Kt\log_{10} e + \log_{10}(f_o - f_c) \quad \text{.......(2)}$$

$$\log_{10}(f - f_c) - \log_{10}(f_o - f_c) = -Kt\log_{10} e \quad \text{.......(3)}$$

$$t = \frac{-1}{K\log_{10}}[\log_{10}(f - f_c) - \log_{10}(f_o - f_c)] \quad \text{.......(4)}$$

$$\underset{\text{Y}}{t} = \underbrace{\left\{\frac{-1}{K\log_{10}}\right\}}_{\text{m}}\underbrace{\left\{\log_{10}(f - f_c)\right\}}_{\text{X}} + \underbrace{\left\{\frac{1}{K\log_{10}}\log_{10}(f_o - f_c)\right\}}_{\text{C}} \quad \text{.......(5)}$$

The equation (5) above represents a straight line having a slope $= \dfrac{-1}{K\log_{10}}$

Thus the slope is determined using the above equation, the equation for infiltration capacity can be written (see Appendix B).

3.6 Statistical Analysis

The statistical analysis is used to analyze the results of double ring infiltrometer measurements on soil infiltration characteristics. Statistical analysis involves the process of collecting and analyzing data and then summarizing the data into a numerical form. All the measurement for all 50 samples location show variation from one point to another making it difficult to identify its parameters. The general statistical parameters were calculated for all the 50 samples location. These statistical parameters including the maximum, minimum, mean, standard deviation and coefficient of variation (CV) for each soil infiltration parameters.

3.7 Geostatistical Analysis of Spatial Variability of Soil Hydraulic Properties

3.7.1 Analysis using the Semivariogram Modeling

Spatial variation of steady state soil infiltration rate is described using semivariogram parameters. All semivariogram parameters in the study were computed using the GS+ freeware and Surfer Software. Modeling of relationship among sample locations to indicate the variability of the measure with distance of separation is called Semivariogram Modeling.

Semivariance is a measure of the degree of spatial dependence between samples. The magnitude of the semivariance between points depends on the distance between the points. A smaller distance yields a smaller semivariance and a larger distance results in a larger semivariance. The plot of the semivariances as a function of distance from a point is referred to as a semivariogram. The semivariance increases as the distance increases until at a certain distance away from a point the semivariance will equal the variance around the average value, and will therefore no longer increase, causing a flat region to occur on the semivariogram called a sill.

From the point of interest to the distance where the flat region begins is termed the range or span of the regionalized variable. Within this range, locations are related to each other and all known samples contained in this region also referred to as the neighborhood and must be considered when estimating the unknown point of interest.

Basic semivariance analysis theory and procedures to define relatedness between samples of spatially varying soil properties have been outlined in numerous texts. Normally semivariance is defined as $\gamma(h)$, of all samples separated by a Vector h as:

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

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; $z(xi)$ is the measured sample value at point (xi), and $z(xi+h)$ is the measured value at point $(xi+h)$.

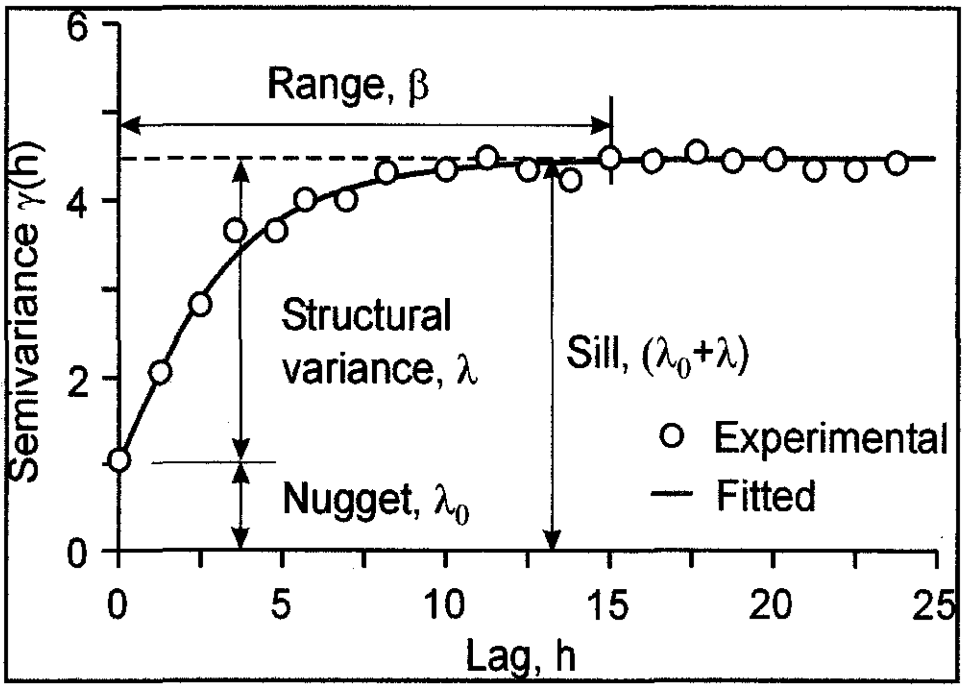


Figure 3.5: Schematic Diagram of a Semivariogram Model and its Parameters

There are three characteristics semivariogram modeling; sill, range and nugget. The sill ($C+C_o$) is a measure of the variability in the data and also used to refer to the amplitude of a certain component of the semivariogram. The lag, at which the plateau is achieved, is called the range or the lag distance at which the semivariogram component reaches the sill value. While the nugget (C_o) is a measure of all unaccounted spatial variability at distances smaller than the smallest lag including measurement error.

In the GS+ software there are five different semivariance models (spherical, exponential, linear, linear to sill, Gaussian). The best fitted semivariogram model is determined based on the r^2 and RSS (Residual Sums of Square) values. Spherical and Exponential model are two models that best fit the semivariogram of soil hydraulic properties. The results of the auto-correlation analysis are given in the Chapter 4; Result and Discussion

i) Spherical Model

$$\gamma(h) = \lambda_0 + \lambda\left[1.5\left(\frac{h}{\beta}\right) - 0.5\left(\frac{h}{\beta}\right)^3\right] \quad \text{for } h \le \beta$$

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

ii) Exponential Model

$$\gamma(h) = \lambda_0 + \lambda\left[1 - \exp\left(-\frac{h}{\beta}\right)\right]$$

3.7.2 Analysis using the Contour Map (Kriging Analysis)

Kriging interpolation is frequently used for mapping soil properties in the analysis and interpretation of spatial variation of soil. Kriging analysis is the estimation procedure used in geostatistics using known values and a semivariogram to determine unknown values. The procedures involved in kriging incorporate measures of error and uncertainty when determine estimations. The contour map was prepared to map the variation of soil infiltration parameters for all sample locations.

Soil contour maps will show the variability at the boundaries between different soil types which can provide valuable categorical information for interpreting variation in soil properties. In this study, contour map units were used to group sampled observations and the variation in soil infiltration parameters was separated into two parts: (i) between soil types (i.e., soil type effect) and (ii) within each soil type (i.e., residual).

A kriging model combined with soil contour maps, taking into account the variation parameters of soil type effect and residual was proposed.

3.8 Hazard Analysis

Table 3.1: Job Safety Analysis

JOB STEPS	POTENTIAL HAZARDS	WHO MIGHT INJURED (PERSON / EQUIPMENT)	RISK RATING	CONTROLS
1. Global Positioning System for locating the references points	1.1 Fall and Hot Weather	Student, equipment	Low	1.1.1 Proper shoes worn during the field work. 1.1.2 Umbrella was used during hot weather to avoic direct sun rays. 1.1.3 The GPS receiver tools were hold tightly to avoid it from falling. 1.1.4 The students was assisted by supervisor during the work execution.
2. Soil sampling	2.1 Sharp edge and heavy equipment	Student	Medium	2.1.1 Proper shoes worn during the field experimental 2.1.2 Umbrella was used during hot weather to avoic direct sun rays. 2.1.3 Drinking water was bring during the experimental to avoid from dehydration. 2.1.4 Hand glove worn during the work execution. 2.1.5 Equipments were handdle carefully to avoid the sharp

				edge. 2.1.6 The equipment was used as stated in the procedure.
3. Computer analysis	3.1 Eye Strain	Student	Medium	3.1.1 An anti-glare screen was installed. 3.1.2 The terminal was position at right angles to the window if possible and avoids facing directly into bright light (coming from behind compute screen). 3.1.3 The brightness controls were adjusted on the screen until they are comfortable to student eyes.
	3.2 Carpal Tunnel Syndrome	Student	Medium	3.2.1 The chair or table height was adjusted to have student elbow angle at 90-100 degrees. 3.2.2 Clinch the fists, hold for one second, then stretch the fingers out wide and hold for 5 seconds. 3.2.3 The keyboard was position at correct place so that student doesn't have to bend the hands uncomfortably

				upward to reach the keys; place a raised wrist rest on the table in front of the keyboard if necessary. 3.2.4 The mouse was hold loosely and clicks lightly.
	3.3 Neck and Back Strain	Student	High	3.3.1 The posture was check - sit up straight. 3.3.2 The monitor screen surface should be approximately 18-24 inches away from student torso. 3.3.3 Preferably chairs should be on wheels, have backrest tilt adjustment, and have arms. 3.3.4 Student must be sure to have enough desktop space for work papers and other equipment.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Results of Soil Infiltration Test

4.1.1 Infiltration Estimation using Horton's Infiltration Equation

Based on the Double Ring Infiltrometer Test results, the summary of the soil infiltration parameters obtained from 50 samples location is shown in Table 4.1. Soil infiltration parameters including the initial infiltration rate (f_o), final infiltration rate (f_c), and constant value (k) was tabulated using Horton's Infiltration Equation. (See Appendix B).

Table 4.1: Summary of Soil Infiltration Results at 50 Samples Location

Sample No.	Coordinate	Longitude	Latitude	f_o (mm/hr)	f_c (mm/hr)	k
1	(15,A)	100.9699	4.3893	166.25	4.53	6.148
2	(14,A)	100.9689	4.3893	197.50	4.70	5.100
3	(13,A)	100.9679	4.3893	202.50	6.30	5.624
4	(15,B)	100.9699	4.3883	180.00	5.05	5.401
5	(14,B)	100.9689	4.3883	192.50	5.89	5.970
6	(16,C)	100.9709	4.3873	190.00	5.73	5.970
7	(15,C)	100.9699	4.3873	191.25	5.38	5.351
8	(14,C)	100.9689	4.3873	191.25	5.75	5.674
9	(20,D)	100.9749	4.3862	192.00	6.20	5.857
10	(17,D)	100.9719	4.3862	153.75	4.28	5.418
11	(15,D)	100.9699	4.3873	191.25	5.40	5.785
12	(14,D)	100.9689	4.3862	202.50	5.72	5.368
13	(13,D)	100.9679	4.3862	176.25	5.25	5.692
14	(22,E)	100.9769	4.3852	168.75	5.52	5.800

15	(21,E)	100.9759	4.3852	192.50	6.10	5.588
16	(17,E)	100.9719	4.3852	191.25	6.10	5.570
17	(16,E)	100.9709	4.3852	195.00	5.48	5.368
18	(14,E)	100.9689	4.3852	201.25	5.43	5.435
19	(11,E)	100.9659	4.3852	177.50	4.42	5.552
20	(10,E)	100.9649	4.3852	215.00	5.96	5.401
21	(20,F)	100.9749	4.3842	207.00	6.54	5.287
22	(19,F)	100.9739	4.3842	195.00	5.44	4.878
23	(16,F)	100.9709	4.3842	192.50	5.53	5.368
24	(13,F)	100.9679	4.3842	190.00	5.15	5.857
25	(11,F)	100.9659	4.3842	146.25	2.74	6.066
26	(10,F)	100.9649	4.3842	161.25	3.61	5.819
27	(22,G)	100.9769	4.3832	146.25	4.79	5.800
28	(20,G)	100.9749	4.3832	208.75	6.18	4.593
29	(19,G)	100.9739	4.3832	183.75	6.46	5.674
30	(16,G)	100.9709	4.3832	207.50	6.35	5.637
31	(15,G)	100.9699	4.3832	191.25	5.45	5.767
32	(14,G)	100.9689	4.3832	217.50	6.75	5.624
33	(10,G)	100.9649	4.3832	205.00	5.70	5.809
34	(9,G)	100.9639	4.3832	215.00	6.35	5.711
35	(22,H)	100.9769	4.3821	192.50	5.67	5.285
36	(21,H)	100.9759	4.3821	188.75	5.85	5.624
37	(20,H)	100.9749	4.3821	193.75	6.15	5.896
38	(19,H)	100.9739	4.3821	216.25	6.83	5.385
39	(18,H)	100.9729	4.3821	193.75	6.82	5.655
40	(13,H)	100.9679	4.3821	127.50	3.02	6.419
41	(12,H)	100.9669	4.3821	200.00	5.10	5.588
42	(9,H)	100.9639	4.3821	202.50	5.24	5.517
43	(13,I)	100.9679	4.3811	190.00	5.43	5.334
44	(12,I)	100.9669	4.3811	216.25	5.96	5.418

45	(11,I)	100.9659	4.3811	192.50	5.19	5.435
46	(9,I)	100.9639	4.3811	175.00	5.00	6.066
47	(13,J)	100.9679	4.3801	163.75	3.22	5.970
48	(12,J)	100.9669	4.3801	151.25	3.15	6.330
49	(11,J)	100.9659	4.3801	178.75	4.90	6.169
50	(10,J)	100.9649	4.3801	171.25	4.95	6.066

4.2 Statistical Analysis Parameters of Soil Infiltration Characteristics

In statistical analysis, the general statistical parameters including the maximum, minimum, mean, standard deviation and coefficient of variation for each soil infiltration parameters (f_o, f_c, k) were calculated. The statistical parameters for the soil infiltration tests conducted over the 50 samples location are given in Table 4.2.

Table 4.2: Sample Size (N), Maximum, Minimum, Mean, Median, Standard Deviation (SD) and coefficient of variance (CV) of Tested Soil Infiltration Characteristics

Soil Properties	N	Max.	Min.	Mean	Median	SD	CV (%)
f_o (mm/hr)	50	217.50	127.5	187.78	191.625	19.9248	10.61
f_c (mm/hr)	50	6.83	2.74	5.37	5.465	0.9675	18.02
K (constant)	50	6.419	4.593	5.642	5.631	0.3448	6.11

Among the three soil infiltration parameters examined, the initial infiltration rate, f_o showed the highest standard deviation (19.9248 mm/hr), followed by the final infiltration rate, f_c (0.9675 mm/hr) and the constant value, k showed the lowest (0.3448) standard deviation (Table 4.2). The lowest standard deviation (0.3448) shows that the data points for constant value (k) from the study area very close to the mean values. Therefore the constant values (k) have the smaller variation among other soil infiltration parameters in study area.

When the variability of the soil infiltration parameters values was expressed in term of the coefficient of variance (CV), three groups could be distinguished among the soil infiltration parameters; (i) parameters that are extremely variable (f_c) with a maximum CV of 18.02%, (ii) moderately variable parameters (f_o) with a CV of 10.61%, (iii) parameters with a weak variability (constant *k*) showing a minimum CV of 6.11%. Statistical analysis clearly showed that the constant parameters (*k*) have the minimum variation among other parameters.

4.3 Geostatistical Analysis of Soil Infiltration Parameters

4.3.1 Semivariogram Modeling of Soil Infiltration Parameters

Spatial variability of three soil infiltration parameters (f_o, f_c, *k*) was investigated using the semivariance analysis. The structure of the spatial dependence (autocorrelation) which is the semivariance is calculated for different distance intervals (range, ***m***) and characteristics parameters are given in Table 4.3.

Table 4.3: Characteristics Parameters of Fitted Semivariogram of Soil Infiltration Parameters

Soil Properties	Model*	Nugget (C_o)	Sill (C_o+C)	Range (A_o, m)	Ratio (%)	S_v (%) (C)
f_o(mm/hr)	S	34.000	403.50	164.00	8.43	91.57
f_c (mm/hr)	S	0.5850	1.1820	1238.00	49.49	50.51
k (constant)	E	0.0963	0.2556	3110.00	37.68	62.32

(*S = Spherical; E = Exponential; S_v = Structural Variance)

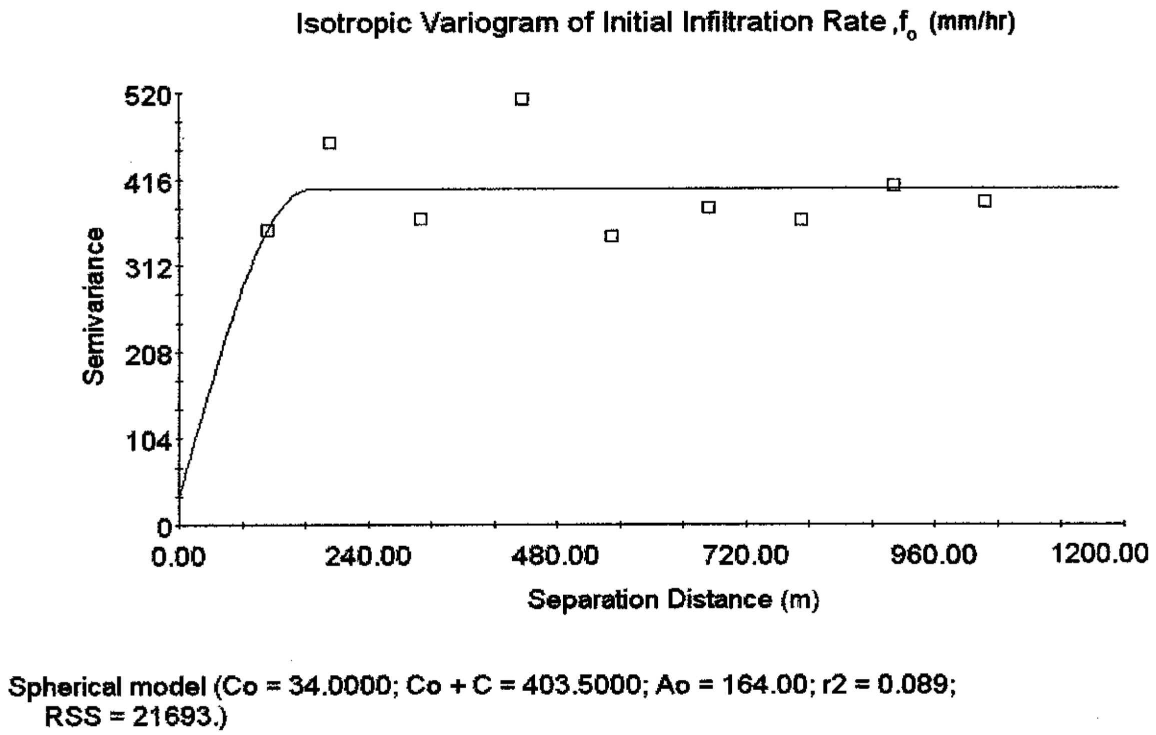


Figure 4.1: Isotropic Semivariogram of Initial Infiltration Rate (f_o)

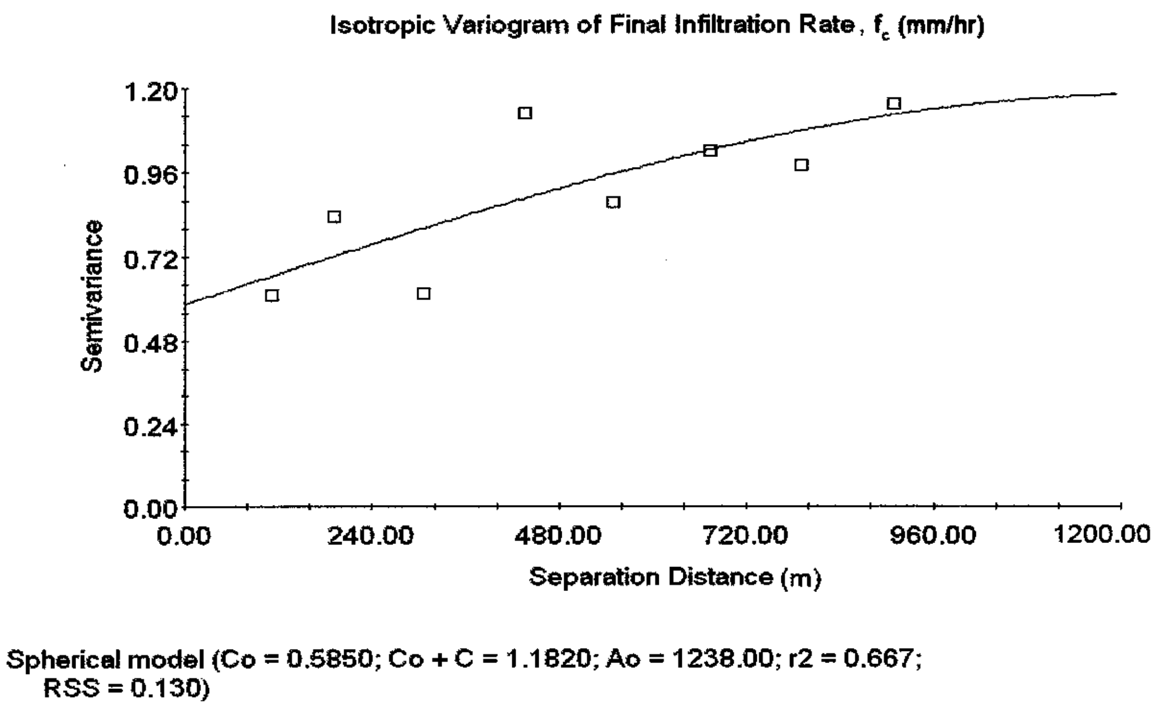


Figure 4.2: Isotropic Semivariogram of Final Infiltration Rate (f_c)

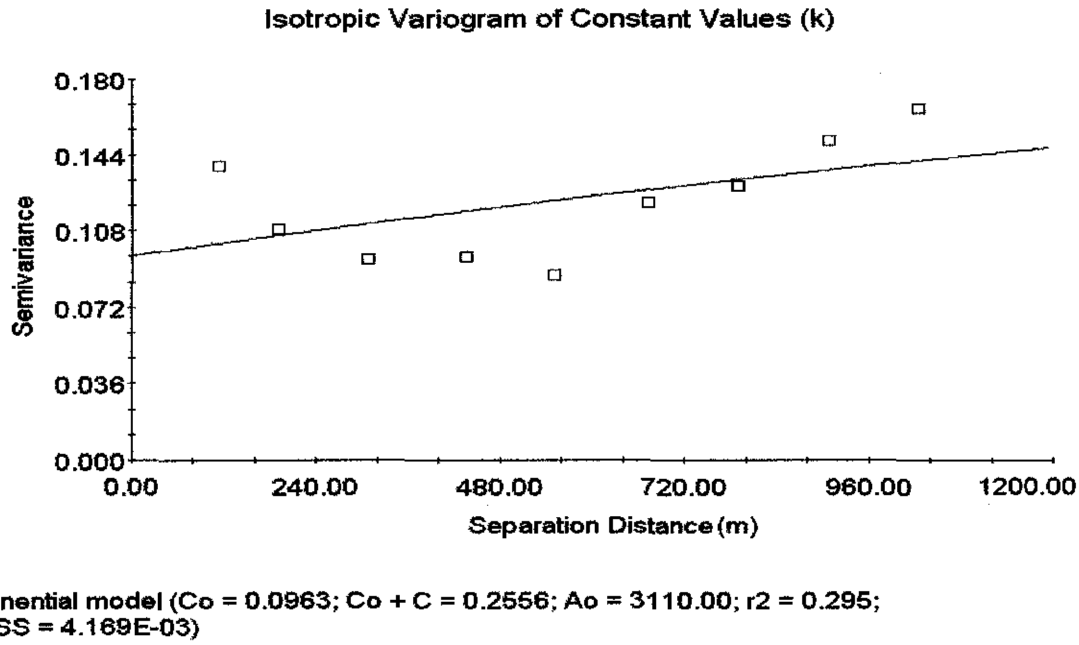


Figure 4.3: Isotropic Semivariogram of Constant Values (k)

From the characteristics parameters obtained in the geostatistical analysis in term of the semivariogram modeling (Table 4.3), it is proven that the soil hydraulic properties at UTP Campus area are highly variable. Based on the interpretation of the semivariogram modeling, most of the infiltration parameters at different samples location exhibited convex experimental semivariogram that could be described by two best models which are Spherical and Exponential models with a spatial range of 164.00 to 3110.00 m.

The range is a measure of the lag distance at which the semivariogram reaches the sill value or the distance beyond which observations are not spatially dependent. Table 4.3 shows that the range values for constant values (k) are exceeding the total lag distance which is indicated that the semivariance analysis are not suitable to analyze this parameters.

The nugget represents of all unaccounted spatial variability at distance smaller than the typical sample spacing including the measurement errors (smallest lag). Nugget models which are equal to overall sample variance (Table 4.3) only exhibiting the random variation. Table 4.3 revealed that the nugget component (C_o) range from 0.0963 to 34.00.

Sill is the measure of the variability in data. Table 4.3 shows the highest sill was observed for initial infiltration rate (f_o) followed by final infiltration rate (f_c) while the constant values (k) showed the lowest sill. Therefore the initial infiltration rate (f_o) that only showed the large variability in the study area with sill values equal to 403.50. While the least variability (0.2556) was achieved by the constant values (k).

The nugget to sill ratio in the semivariance analysis above were crucial important in determine the spatial dependence for all the soil infiltration parameters. In the analysis above, the nugget to sill ratio gave the indication of the spatial dependence of all data. Table 4.3 listed the nugget to sill ratio for each parameter. Nugget to sill ratio for initial infiltration rate (f_o) which is 8.43% indicating strong spatial dependence. Meanwhile the nugget to sill ratio for final infiltration rate (f_c) and constant values (k) ranged from 49.49% to 37.68% respectively (Table 4.3) (more than 25%) indicating moderate spatial dependence.

The structural variance for initial infiltration rate (f_o) showed the highest value (91.57%) followed by constant values (k) and final infiltration rate (f_c) (62.32% and 50.51% respectively). This structural variance in the above analysis indicates the variations in soil parameters due to spatial structure. Spatial variation of soil infiltration rate above indicates that there was spatial auto correlation among all the parameters involved.

4.3.2 Kriging Interpolation (Contour Map)

Kriging interpolation is frequently used for mapping soil properties in the analysis and interpretation of spatial variation of soil. Figure 4.4, 4.5 and 4.6 respectively illustrate the variability of spatial distribution of initial infiltration rate (f_o), final infiltration rate (f_c) and constant value (k) over the study area.

There are complex spatial changes in the study area, even for the same soil type. While showing the different types of soil infiltration parameters in the study area, a detailed kriging map also includes other two important information; spatial variation between soil types and the variability within each soil type.

4.3.2.1 Variability in Initial Infiltration Rate, (f_o)

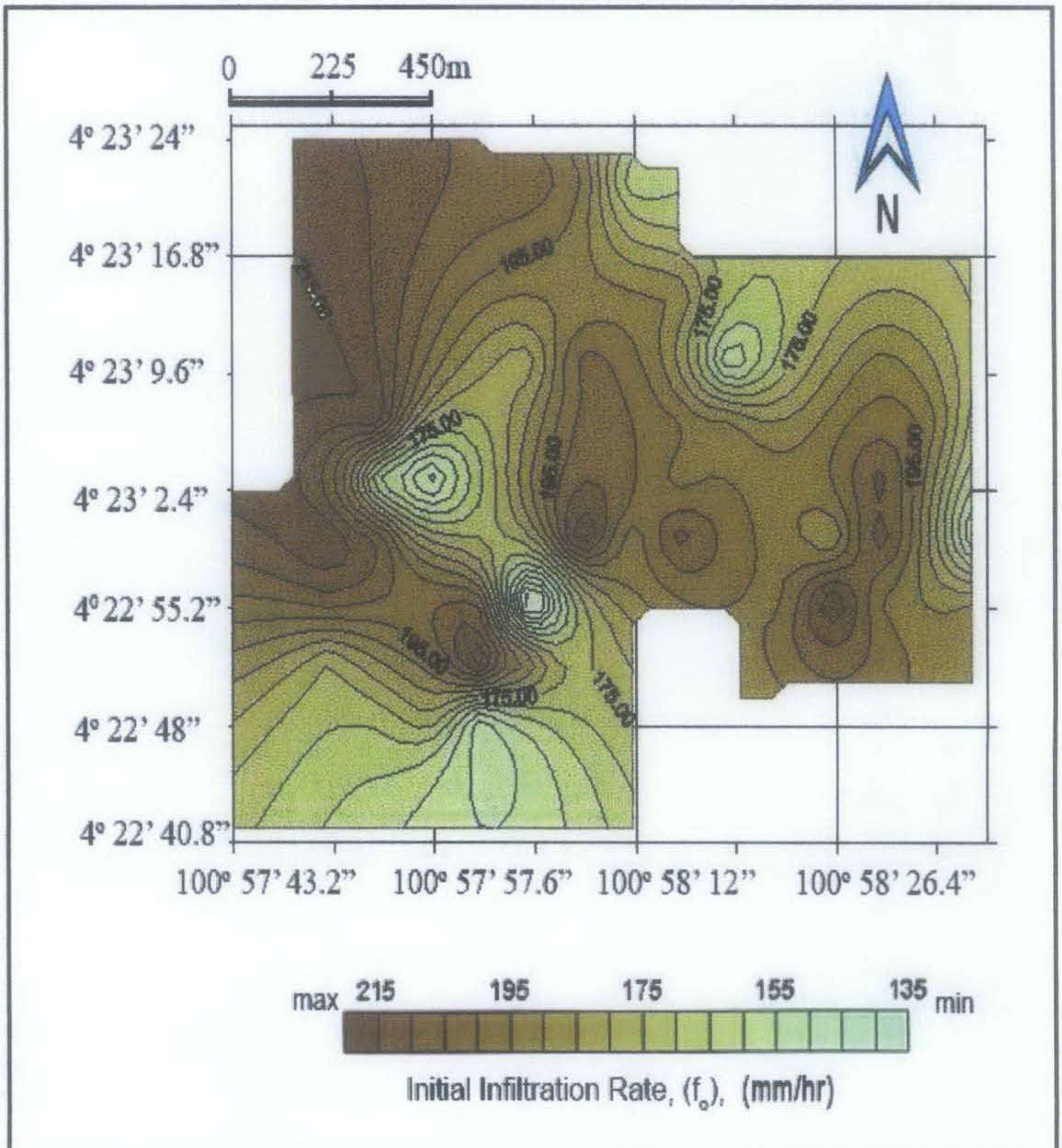


Figure 4.4: Spatial Distribution of Initial Infiltration Rate, (f_o)

Figure 4.4 shows the variation of initial infiltration rate, (f_o) at the study area. The variation is mapped by performed the kriging analysis. The contour map is prepared to map the variation of each different sampling location. The initial infiltration rate, (f_o) shown in Figure 4.4 above is varies between the developed and undeveloped area. At the north side of the study area (4° 22' 55.2" N to 4° 23' 2.4" N, 100° 57' 43.2" E) which is undeveloped (undisturbed) area showed higher initial infiltration rate, (f_o) while the lower initial infiltration rate, (f_o) was found at 4° 23' 9.6" N to 4° 23' 24" N, 100° 57' 57.6" E (develop area). The variation of the initial infiltration rate, (f_o) at the study area is due to factors such as soil engineering properties and soil surface properties.

The topography map showed the area that experienced higher initial infiltration rate, (f_o) is near the forest which there is no construction work took place. Therefore the rapid infiltration rate at beginning, (f_o) is most probably due to the presence of good soil structure (medium to coarse soil texture) and number of factors that affect the infiltration rate such as soil moisture content, bulk density, compaction etc. In that region there is no any construction work took place (undeveloped area), which is means the soil there is the original soil. The higher initial infiltration rate, (f_o), indicated that the soil at the area was not compacted or lower value in soil bulk density.

Higher initial infiltration rate, (f_o) were due to the lower bulk density and lower moisture content because the soil has the capability to absorb water until it saturated and reaches constant final infiltration rate, (f_c). Therefore the higher initial infiltration rate, (f_o) took place at undisturbed area which is the soil was not compacted and dry.

Soil compaction is one of important aspect that affected the soil hydraulic implications in terms of the surface runoff potentials, vegetative growth, and soil erosion. On soils such as these, the infiltration rate is very great because it relatively have stable structure and greater surface roughness. Therefore less compacted soil can increase the initial infiltration rate, reduce runoff and reduce the soil erosion.

Since the ground surface was already covered by crop, the rate of infiltration becomes slower because the water had the resistance to flow into the soil layers.

As a conclusion, the initial infiltration rate, (f_o) varies greatly between the disturbed and undisturbed area. The disturbed area indicated the lower initial infiltration rate, (f_o) while the undisturbed area showed the higher initial infiltration rate, (f_o).The differences between this two values are much affected by the land use conditions and soil physical characteristics (e.g. soil texture, ground surface, vegetative cover and soil pores).

4.3.2.2 Variability in Final Infiltration Rate, (f_c)

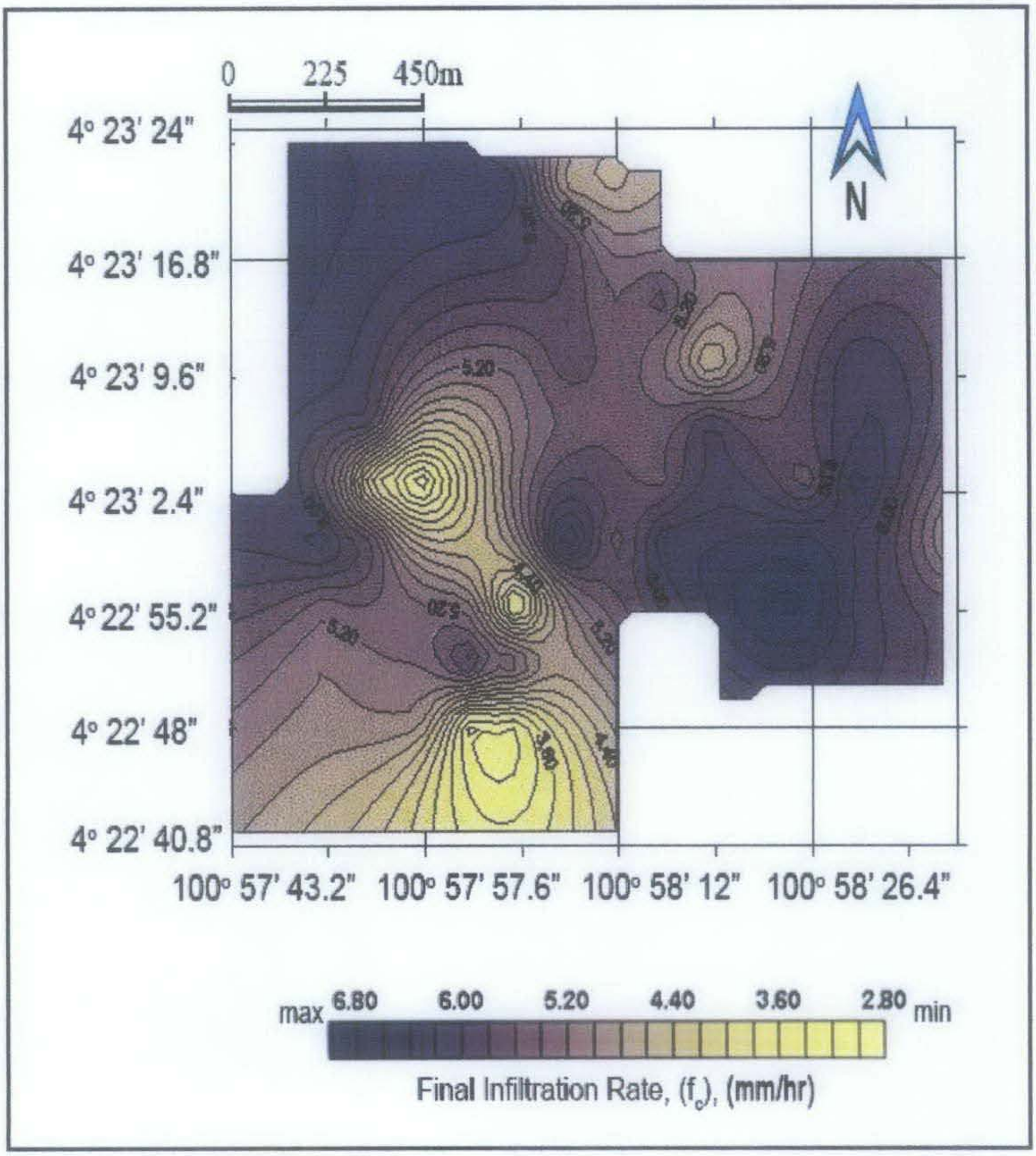


Figure 4.5: Spatial Distribution of Final Infiltration Rate, (f_c)

Figure 4.5 above shows that the final infiltration rate, (f_c) in the study area is varying spatially depend on the soil physical properties (e.g. soil bulk density and soil moisture content, etc.) and its land use pattern. Higher values of soil bulk density and soil moisture content are likely to decrease the rate of infiltration.

The higher value of final infiltration rate, (f_c) was found at grid location 4° 23' 9.6" N to 4° 23' 24" N, 100° 57' 43.2"E to 100° 57' 57.6" which is at the undisturbed area. Based on the topography map, that area is dedicated near the forest. Evaluating the soil physical properties and land use structure at the field area shows that the soils contains lower value of soil bulk density and soil moisture content which are likely to increase the final infiltration rate, (f_c). The influence of land use pattern (structure) gave great significant to the infiltration rate whereby at this area there is no development work take place. Therefore the soil texture and soil type at this area were classified as healthy soil that had the tendency to allow the water to flows through it.

The lower value final infiltration rate, (f_c) was found at grid location 4° 22' 55.2" N to 4° 23' 2.4" N, 100° 57' 57.6" E .This area is surrounding by the construction of the new building campus whereby the soil in this area is compacted soil. Soil compaction has reduced the number and sizes of soil pores resulting in the low porosity. Soil with low porosity can be expected to yield lower value of infiltration. Besides reducing the infiltration rate, soil compaction also reduces soil health and environmental quality (Andrew et al., 1998). Because of the effect of land use at this area, the soil was no longer in its original types and characteristics. The soil in this disturbed area becomes denser due to large amount of compaction at soil surface.

As conclusion, the above analysis proved that the soil physical properties such as the bulk density and moisture content that varies jointly land use pattern result in the variability of final infiltration rate, (f_c). The influence of land use on soil bulk density and moisture content has significant impact on determined the magnitude of final infiltration rate, (f_c). In the study area, soil physical properties and topography continue to jointly influence the variability in the final infiltration rate, (f_c).

4.3.2.3 Variability in Constant Values (*k*)

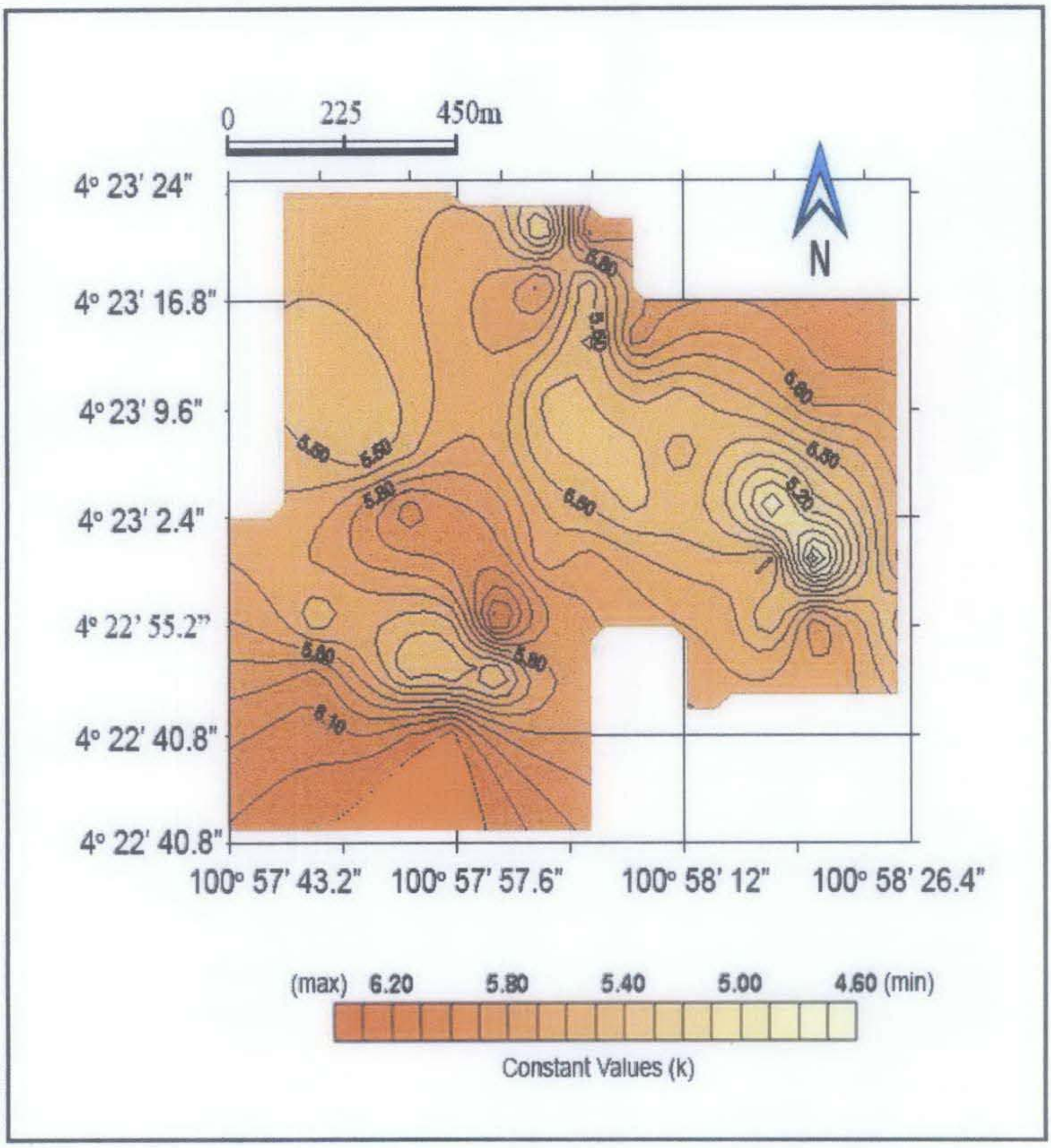
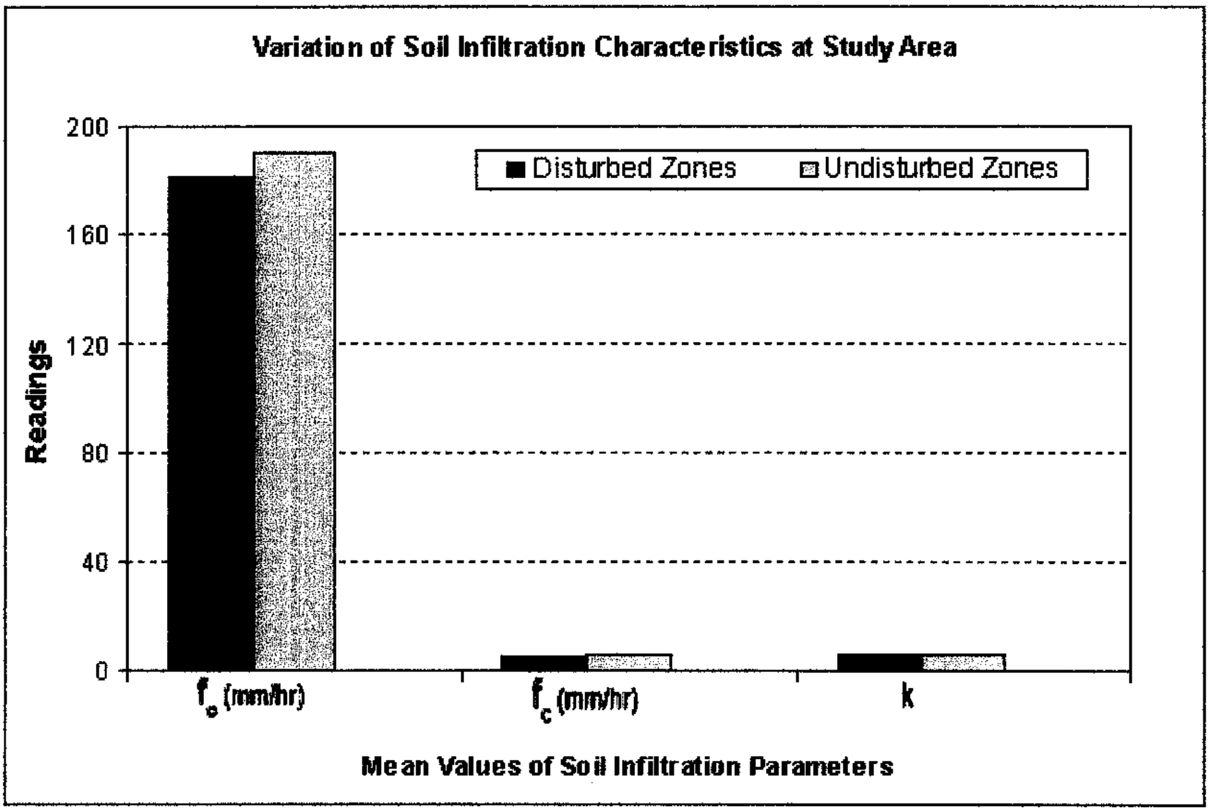


Figure 4.6: Spatial Distribution of Constant Value (*k*)

Figure 4.6 showed the variability of the constant value, (*k*). *K* values were determined by using the Horton's infiltration equation. In the contour map shown above, the *k* values is varying spatially indicate the variability in the infiltration rate. There are number of factors that affect these values. *K* values varies when the parameters in the Horton's infiltration equation varies. This is due to the several factors that affect the parameters in the Horton's infiltration equation. Horton's theory of infiltration is based on the fact that infiltration is faster in dry ground, so as rain continues and the ground becomes wetter, the infiltration rate decreases. The reason that infiltration is faster when the ground is dry is that there are more spaces for the water to fit so capillary forces that pull the water down into the ground are stronger. Therefore when there were differences in both initial and final infiltration rate (f_o, f_c) the *k* value will varies too. The contour map above proved that *k* values are very much related with both initial and final infiltration rate parameters.

4.4 Evaluation on Variation of Soil Infiltration Characteristics on Land Use Conditions



(*f_o : Initial Infiltration Rate(mm/hr); f_c: Final Infiltration Rate (mm/hr); k:Constant Values)

Figure 4.7: Effect on Land Patterns on Soil Infiltration Characteristics

The infiltration rate variability is influenced by various factors such as the soil physical properties, topography, vegetative cover and its land use pattern. These differences in soil physical properties at the study area can be expected to yield variations in infiltration rate. Therefore the effect of land use changes was examined to further investigate on its land use pattern. The study area was divided into two zones; disturbed and undisturbed zones (forest areas, Area A; see Figure 3.2). While disturbed zones included the area consists of academics blocks, administration blocks, hostels and also infrastructures component such as roads, covered sidewalk, open sidewalk, etc. (Area B; see Figure 3.2).

Figure 4.7 indicates that the mean values of soil infiltration parametes; initial infiltration rate, f_o (mm/hr), final infiltration rate, f_c (mm/hr) and constant values k. The initial and final infiltration, f_o and f_c (mm/hr) respectively were higher in undisturbed or forest zones compared to disturbed zones. However constant values k, does not show any variations between the undisturbed and disturbed zones. The higher initial and final infiltration rate infiltration rate, f_o and f_c in undisturbed zones could be attributed by the good soil properties and the originality of soils in that particular region. The soil in this region was found less compacted compared to the disturbed zone. Due to the good soil texture, the water can easily infiltrate down to the water profile and resulting in higher infiltration rate. This area also was determined to have lower value in soil bulk density, which means the soil is not too dense. The soil found in this area is less dense because there is no compaction work took place in the forest area. In the undisturbed zones (forest area), the soil pores most probably were not fully saturated at beginning due to dry weather and it had the tendency to infiltrate more water compared to the area that near the lakes or ponds area.

Meanwhile, the disturbed zones experienced lower values of initial and final infiltration rate, f_o and f_c (mm/hr) respectively. This area is the development area that consist the academic buildings, hostels, pavement, sidewalks, etc (Area B, Figure 3.2, page 8). Due to many construction works that took place in the area, the soil was no longer in its original types and characteristics. In this area the original soils have been compacted and dumped by foreign soils in order to build up the land and consequently the soil in this disturbed area becomes denser due to large amount of compaction at soil surface. The construction works had changed the land pattern and the topography in this area.

As conclusion, the differences between the disturbed and undisturbed zones were very significant. The difference is much affected by the consequence of disturbance such soil compaction and forest clearance that altered the soil physical and soil surface properties. Beside than that, the variability of soil infiltration parameters observed in the study area is most probably attributed by its land use pattern.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

As conclusion, the natures of infiltration characteristics at UTP campus area are varying spatially. After a total of 50 double ring infiltrometer in-situ measurements were performed, the variation of the natures of infiltration characteristics has been characterized in terms of geostatistical (semivariogram) and statistical parameters. Based on both analysis of the soil infiltration test result, this study was able to meet all of three goals as articulated in the project objectives.

From the geostatistical analysis in term of semivariogram and statistical parameters, the variability and heterogeneity of infiltration parameters at UTP campus area was observed. The variation of the initial and final infiltration, f_o and f_c respectively were influenced by the soil physical properties and its topography. The larger coefficient of variation (CV) for the final infiltration rate, f_c indicates that the variation in this parameter is higher compared to other infiltration parameters. While the semivariogram parameter indicates that the larger sill is belonged to the initial infiltration rate, f_o which is showed large variability compared to other parameters.

Meanwhile, the kriging analysis of soil infiltration characteristics (contour map), the higher values of initial and final infiltration rate, f_o and $f_{c,}$, were found in the undisturbed area that associated with lower value of soil bulk density due to lesser soil compaction. Therefore, the comparison of these soil infiltration parameters in term of contour map shows that is scale dependency and auto correlation between each parameter.

The land use pattern and the topographic condition also influenced the variability of soil infiltration characteristics. The analyses were used to develop the relationships of soil hydraulic properties in a range of disturbed and undisturbed area. The undisturbed zone has higher values of initial and final infiltration rate, f_o and f_c due to the originality of soil at the area that was not experienced any compaction work. While in the disturbed area (development area), has lower values of initial and final infiltration rate, f_o and f_c.

For future work recommendation, the automatics double ring infiltrometer should be used in performing the in-situ measurements to achieve the most accurate results. This automated double ring infiltrometer mainly consists of inner and outer rings, water-level sensors, water container, depth sensor, solenoid valves, 12 V car batteries and a laptop computer with software to perform recording and basic analysis of the infiltration data. The infiltration in-situ measurement is time and labor consuming therefore by using the automatics double ring infiltrometer, the infiltration in-situ measurements requires little attention once the test is started and the computer provides an up to the minute summary of infiltration results while the test is still in progress.

The number of samples locations also should be increase in order to produce the best analyses results in term of the best fitted curve in the semivariogram modeling. In this study only 50 double ring infiltrometer tests could be performed due to time constraints and raining seasons. By the end of the study, the spatial variability nature of infiltration characteristics at UTP campus area has been characterized.

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APPENDIX A

GEO-GRIDS SAMPLING PREPARATION

GLOBAL POSITIONING SYSTEM (GPS)

Locations of References Point

Adjustment type: Plane + Height, Minimal constraint
Confidence level: 95 %
Number of adjusted points: 4
Number of plane control points: 1
Number of used GPS vectors: 6
A posteriori plane UWE: 0.7374291 , Bounds: (0.4546061 , 1.551881)
Number of height control points: 1
A posteriori height UWE: 0.8755238 , Bounds: (0.2683282 , 1.766352)

Table A-1: GPS Results of Reference Points

Used GPS Observations					
Name	**dN (m)**	**dE (m)**	**dHt (m)**	**Horizontal Precision (m)**	**Vertical Precision (m)**
Chancellor-Heli Pad	-255.667	-541.969	1.992	0.001	0.002
Chancellor-Kantin	617.044	-293.195	3.349	0.002	0.003
Chancellor-MPH	198.234	13.470	2.518	0.001	0.002
Heli Pad-Kantin	872.710	248.775	1.353	0.003	0.004
Heli Pad-MPH	453.902	555.442	0.531	0.001	0.002
Kantin-MPH	-418.810	306.664	-0.830	0.002	0.003
GPS Observation Residuals					
Name	**dN (m)**	**dE (m)**	**dHt (m)**	**Horizontal Precision (m)**	**Vertical Precision (m)**
Chancellor-Heli Pad	-255.667	-541.969	1.992	0.001	0.002
Chancellor-Kantin	617.044	-293.195	3.349	0.002	0.003
Chancellor-MPH	198.234	13.470	2.518	0.001	0.002
Heli Pad-Kantin	872.710	248.775	1.353	0.003	0.004
Heli Pad-MPH	453.902	555.442	0.531	0.001	0.002
Kantin-MPH	-418.810	306.664	-0.830	0.002	0.003

Table A-2: Control and Adjusted Points for GPS

Control Points				
Name	**Latitude**	**Longitude**	**Ell.Height (m)**	**Code**
Chancellor	4°22'56.60467N	100°58'14.85808E	23.096	
Adjusted Points				
Name	**Latitude**	**Longitude**	**Ell.Height (m)**	**Code**
Heli Pad	4°22'48.28137N	100°57'57.28015E	25.088	
Kantin	4°23'16.69270N	100°58'05.34877E	26.444	
MPH	4°23'03.05825N	100°58'15.29499E	25.616	

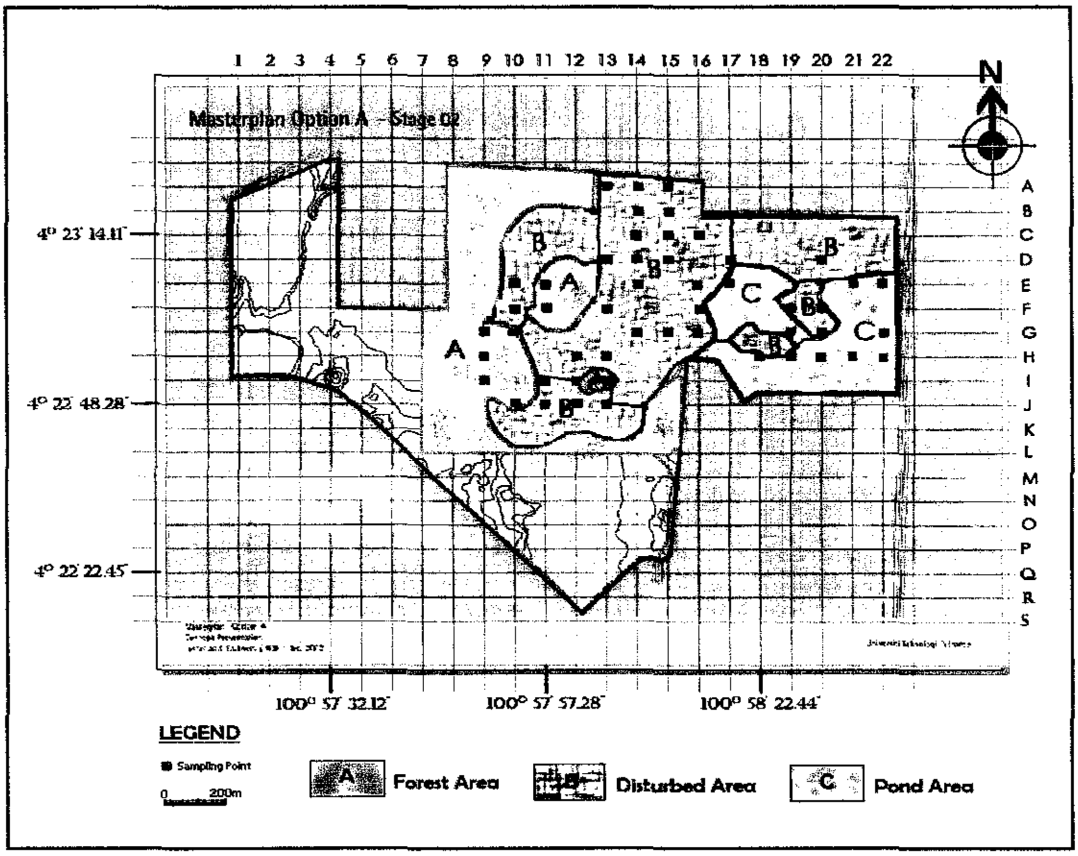

Figure A-1: Soil Sampling Locations

APPENDIX B

DOUBLE RING INFILTROMETER ANALYSIS TEST RESULT

(HORTON'S INFILTRATION EQUATION)

SAMPLE 1

Here; f_c = 4.53 mm/hr and f_o = 166.25 mm/hr

Table B-1: Results of Soil Infiltration at 4.3893°N, 100.9699°E

Time,t (hr)	Rate, f (mm/hr)	f-f_c (mm/hr)	Log_{10} (f-f_c)
0	0	0	0
0.08	166.25	161.72	2.209
0.17	74.12	69.59	1.843
0.25	47.20	42.67	1.630
0.33	33.94	29.41	1.468
0.42	25.24	20.71	1.316
0.50	20.20	15.67	1.195
0.58	16.72	12.19	1.086
0.67	14.03	9.50	0.978
0.75	12.40	7.87	0.896
0.83	11.08	6.55	0.817
0.92	9.89	5.36	0.729
1.00	9.10	4.57	0.660
1.08	8.43	3.90	0.591
1.17	7.61	3.08	0.488
1.25	7.12	2.59	0.413
1.33	6.69	2.16	0.335
1.42	6.20	1.67	0.222
1.5	5.87	1.34	0.126
1.58	5.57	1.04	0.017
1.67	5.27	0.74	-0.131
1.75	4.97	0.44	-0.355
1.83	4.75	0.22	-0.650
1.92	4.53	0	0

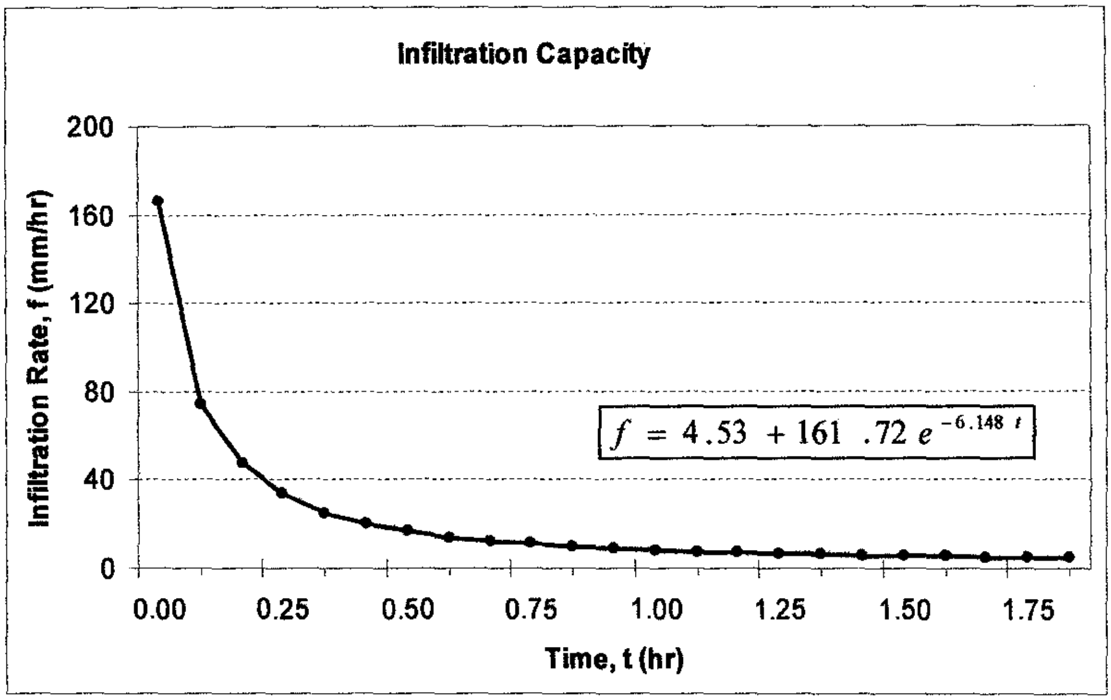

Figure B-1: Infiltration Capacity Curve for 4.3893°N, 100.9699°E

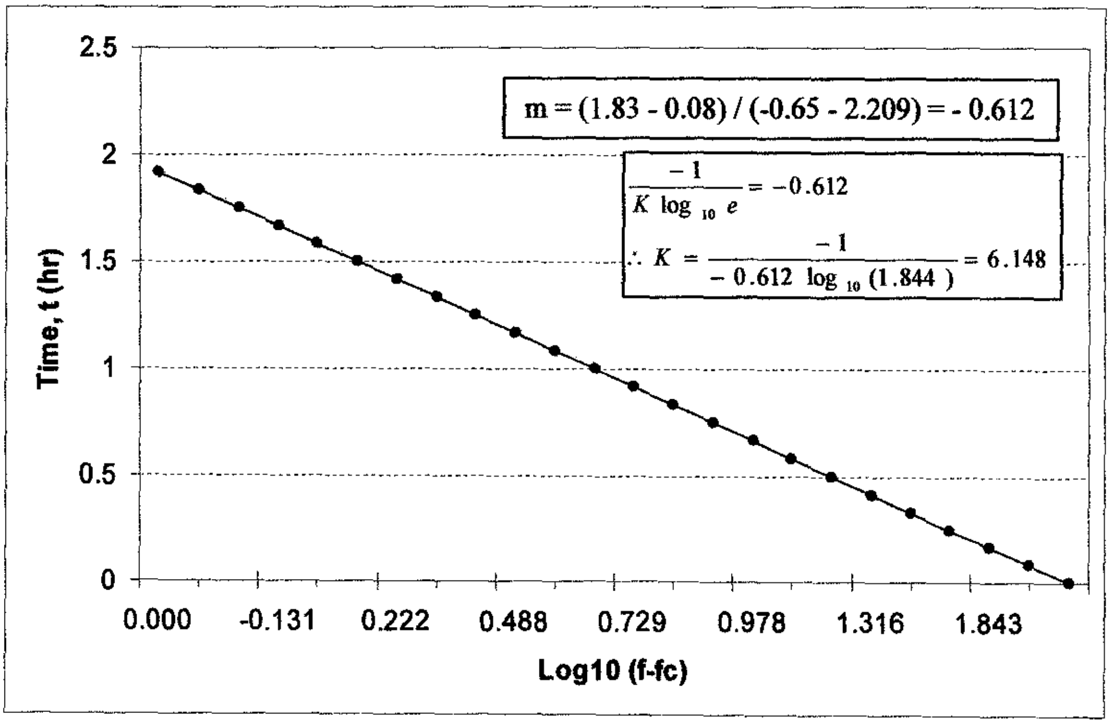

Figure B-2: Slope of the Straight Line for 4.3893°N, 100.9699°E

(*Same procedures of analyzing for all 50 field data of double ring infiltrometer test)