INFILTRATION CHARACTERISTICS OF TROPICAL SOIL IN UNIVERSITY TEKNOLOGI PETRONAS (UTP) CAMPUS AREA

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UNIVERSITI TEKNOLOGI PETRONAS
JANUARY 2009

Infiltration Characteristics of Tropical Soil in University Teknologi PETRONAS (UTP) Campus Area

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

JANUARY 2009

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

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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 QAMAR RUSYDI B. RAMLAN

ABSTRACT

Infiltration characteristic of Tropical Soil is a study in 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 variation of soil hydraulic properties of different locations at the campus area of University Teknologi PETRONAS (UTP). The proposed project allowed understanding in describing the various characteristics of the nature of infiltration characteristics of tropical soil in the campus area of UTP. The aim of the study is to assess the difference in soil hydraulic characteristics around the campus area of UTP by performing double ring infiltrometer and evaluate the infiltration rate for every location. 50 infiltration test data obtained in different locations will be used in Horton's Infiltration equation to learn the characteristic of the soil. This allowed arriving at a generalized of Horton's infiltration equation for the campus area of UTP. Difference in soil hydraulic characteristics and determining field scale flow processes are complex due to the various natures of soil properties. The method of modeling this variety of nature of infiltration characteristics at the campus area of UTP comprises three parts which are determination of geo-grid locations, field data experiments where by the double ring infiltration tests are conducted at pre determined geo-grids locations and computer analysis on the soil infiltration data; to examine the spatial distribution of soil infiltration rates, to quantify the spatial correlation in the data in terms of semivariogram parameters and to prepare spatial distribution maps of soil hydraulic properties . Results from this project are expected to contribute to the understanding and characterization of small scale spatial variability nature of infiltration characteristics of tropical soil.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful

First and foremost, I would like to praise God the Almighty for His guidance. Though difficulties occurred, His guidance gave me the chance to still complete this challenging project successfully. Here, I would like to use this special opportunity to express my heartfelt gratitude to everyone that has contributed to the completing of my Final Year Project (FYP).

My deepest appreciation goes to my supervisor, Dr. Rezaur Rahman Bhuiyan who advised and guided me with moral supports throughout this project. I really acknowledge all the precious words from him and hope the moment working with him remains as valuable experience for my future undertakings. Obviously, without his cooperation and motivation I would not be able to fulfill the project requirements, as it needs a lot of commitment towards it.

Apart from that, I really appreciate the help given by the laboratory technologist from Civil department, for their advice and support that helps me ease my work. Also not to forget is En. Jani from Mechanical department, for his help and advice in fabricating the equipment has really helped me through the challenges in my work.

My high gratitude's' to all the lecturers of UTP especially lecturers from Civil department for their support that helps to keeps me up, my beloved family members for giving me the strength to finish my project, and also all my friends that gave feedback's and helped a lot through their useful ideas and advices.

Last but not least, for all the people that had give their cooperation directly or indirectly, thanks for being with me, for helping me and most of all for supporting me in completing our project.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Hydraulic conductivity in subsurface is affected by the inconsistency of soil hydraulic properties which are caused by natural factors such as soil formation process, composition of rocks and soil organisms, and activities such as vegetations, fertilizations, soil management practices and regional climate also leads to the inconsistencies.

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).

Soil infiltration is the process of water movement into soil and this process can lead to some effects such as surface runoff, soil erosion, and groundwater recharge which can occurred during this process. The process is much influenced by factors such as gravity, capillary action and porosity. But the most important factor of all is the soil porosity. The maximum speed of the water movement into the soil is known as the rate of infiltration. In the early part of infiltration process the rate of infiltration is reduced quickly and after a certain period of time the rate of infiltration reaches a constant value. This is because soil are made of small particles and between these particles there air voids and pores and when these small pores on the soil surface are filled with water the soil capillary forces ability to actively absorb water are reduced. The maximum speed of the water movement also gives a high impact on the large soil clumps and breaks it into smaller pieces which then clog the soil surface which also reduces the ability of the soil to absorb water.

In this study a procedure to differentiate systemically the statistical properties of each soil infiltration parameter and the parameter correlations involved are proposed. The procedure is known as the geostatistical analysis of spatial variability of nature infiltration characteristics.

It is very complex in understanding and describing the infiltration characteristics of soil as there are many uncertainties and differences in value of parameters measured due to various flow processes and errors related to the type of measurement.

In this study the double ring infiltrometer is used to measure the infiltration rate which consists of double metal cylinder that is driven to some extent of the soil and it is then filled with water and the rate at which the water moves into the soil is measured. The infiltration rate is controlled by the least permeable zone in the subsurface soils. With the double ring infiltrometer, testing several areas of large tract to find the infiltration rate would be an easy work. It also provides relative information that is useful for determining erosion rates, leaching and drainage efficiencies, irrigation patterns, and rainfall runoff.

1.2 Problem Statement

The soil hydraulics and flow dynamics are the main factors in plant growth, nutrient cycling and contaminant transport. In particular, infiltration is a dominant process controlling the soil water status for plants and 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 heterogenous (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 measurement of the 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 in University Teknologi PETRONAS (UTP) campus area. This will also allow in generalizing form of Horton's Infiltration equation for UTP campus area.

1.3 Objectives

1. The objective of the study is to find out and describe 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 using geostatistical approaches.
2. To map the variation in soil hydraulic characteristics in the study area that is affected by several factors such as soil texture, soil moisture content, bulk density, surface porosity and other biological activity.
3. To evaluate the effect of changes in land use that affects on the variability of infiltration characteristics in the study area.

1.4 Scope of Study

In this project, determining the inconsistency of infiltration rate of soil hydraulic properties inside UTP campus is the main topic of the study. In situ double ring infiltrometer test are performed at different sample locations as to examine the nature of infiltration characteristic hence, for calibrating the field data, the Horton's infiltration equation is to be used. 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 process of drainage, evaporation and transpiration (Reynold & Elrick, 1996).

Soil hydraulic properties can manipulate in many soil processes from process of controlling water movement, surface water runoff, soil erosion, soil water storage, plant growth and it is significantly vital to natural processes relevant to the hydrological cycle and human dealings relevant to soil water management.

These properties consist of hydraulic conductivity, flux potential, sorptivity and the macroscopic capillary length in which existed for all soil water contents.

2.2 Variations in Soil Hydraulic Properties

Hydrological and geological processes are known to vary in space (Nielsen et al., 1973; Delhomme, 1979). Variations in soil hydraulic properties play a major role in crop growth. In general, soil is not homogeneous and vast spatial soil texture variations can be noticed across the local area.

Soil texture has great influence in soil's water storage in which coarse textured soil has the ability to drain excess water more rapidly than fine textured soils due to high porosity and inversely to coarse soil the fine textured soils have varying percentages of silt and clay as the main components. Thus, these fine textured soils have a better moisture holding capacity compared to the coarse textured soil.

2.3 Soil Infiltration Characteristics

Soil infiltration is one of the key components of hydrological cycle. It effectively controls the quantity of water inflowing 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). In estimating the necessary parameter, such studies are very helpful and a general understanding of how different parameters rely with one another and the degree of 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 is important to:

1) Determine the optimum size of spatial grids for distributed parameter hydrological models (Anctil et al., 2002)
2) Estimate point of spatially averaged values of soil properties using kringing technique (Bardossy and Leh-mann, 1998)
3) Design sampling networks and improving their efficiency (Prakash and Singh, 2000)

The spatial distribution of soil moisture content effects infiltration of water into soil, lateral soil moisture redistribution as well as determines rainfall runoff responses in many catchments (Anctil et al., 2002). Thus, the inconsistency of infiltration characteristic in soil hydraulic properties should be monitored and quantified.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In studying the differences of infiltration characteristics in soil hydraulic properties within UTP campus area, there are three steps involved which include the preparation of the geo-grids for sampling for 50 different points. When the coordinate of the locations has been determined, then the in-situ double ring infiltrometer test will be performed as field experimental. After obtaining data from the field experiment the data will be analyze by using the statistical and geostatistical method from the GS+ and Surfer software.

3.2 Study Area

University Teknologi PETRONAS (UTP) campus area is located in Tronoh in the west part of Perak. It is about 19 kilometers from the Batu Gajah town. The UTP campus area 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 about 400 ha (934 acres). The campus is subdivided into two regions which are urbanized which consist of academic blocks, administration blocks, hostels and infrastructures. Another region is the undeveloped area where all the trees and forest are remained untouchable.

The area experienced warm and humid day all year round. The temperature is ranging from 23.9 to 33.1 degree Celsius (°C) with humidity exceeding 82.1 percent and abundant rainfall up to 3,217.00 millimeters a year.

Sources: http://wikimapia.org/

Figure 3.1: Topography map of UTP Campus

3.3 Geo-grids Sampling Location

A map of UTP will be use as the base map and using Google Earth software the map can be obtain. The map shall include all the buildings, roads, drainage, contours, buildings, fields, the boundaries around UTP Campus and will be traced by computer software. When all the features have been traced, the geo-reference (Latitude, Longitude) for two locations on the base map will be established by conducting a Global Positioning System (GPS) survey. The base map will then be digitalized to obtain map boundary data in digital form and in geo-grids reference system. From these digitalized data, the campus map will be generated with geo-references coordinate using surfer software.

On the generated map, the UTP Campus area will be subdivided by a number of regular geo-grids. 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.

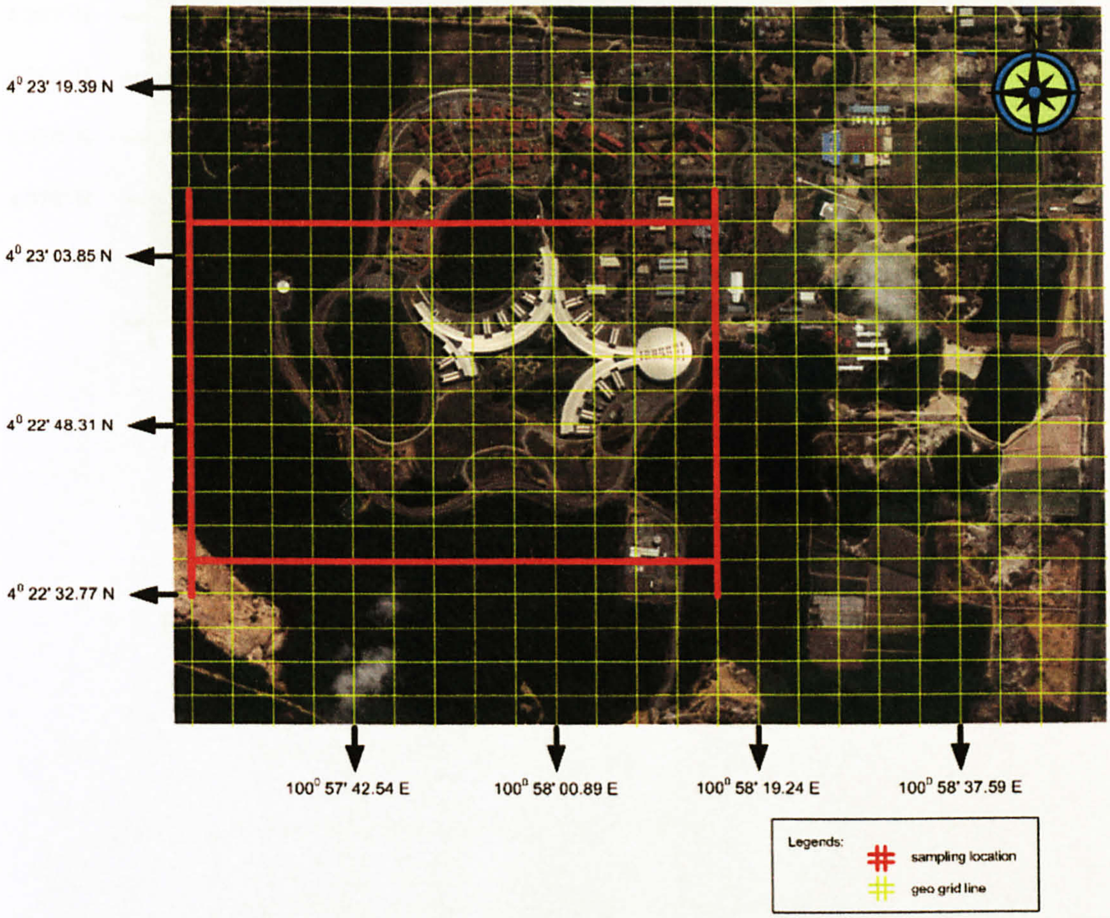

Figure 3.2: Geo-grid and Sampling Locations

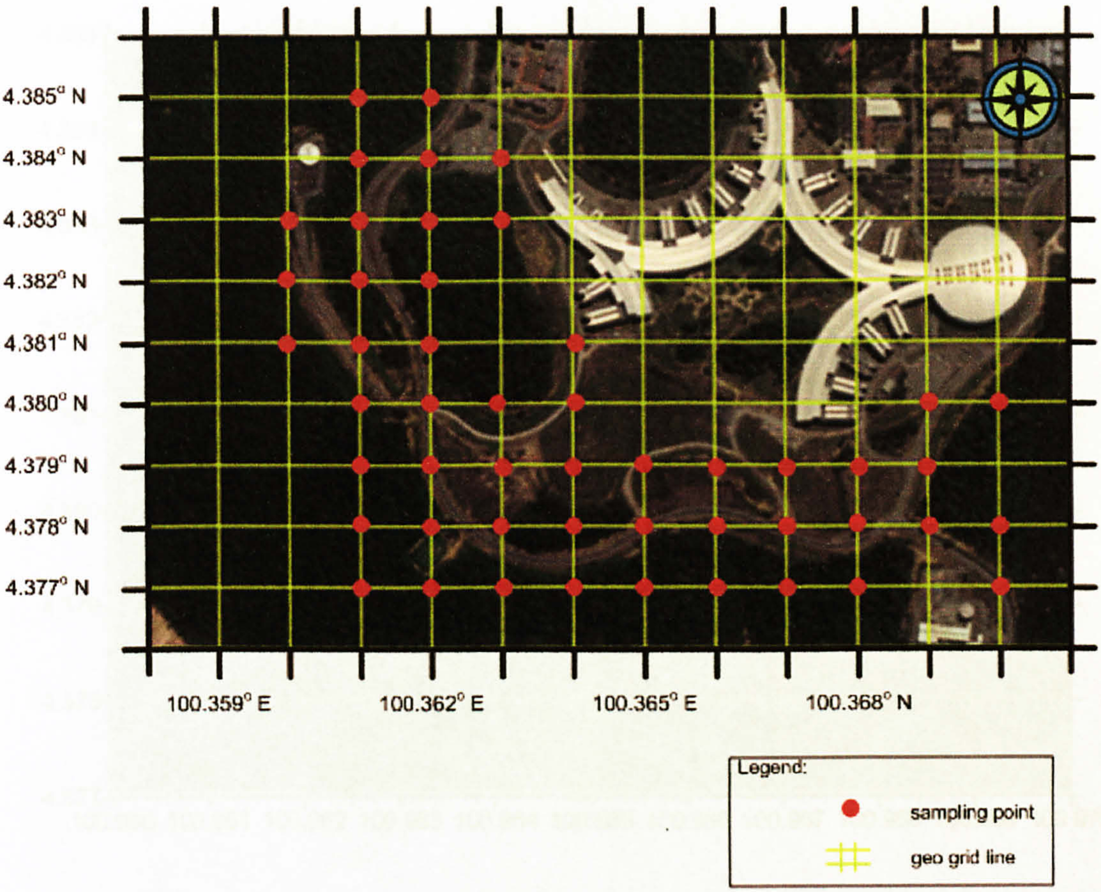

Figure 3.3: Details on sampling location and 50 sampling points

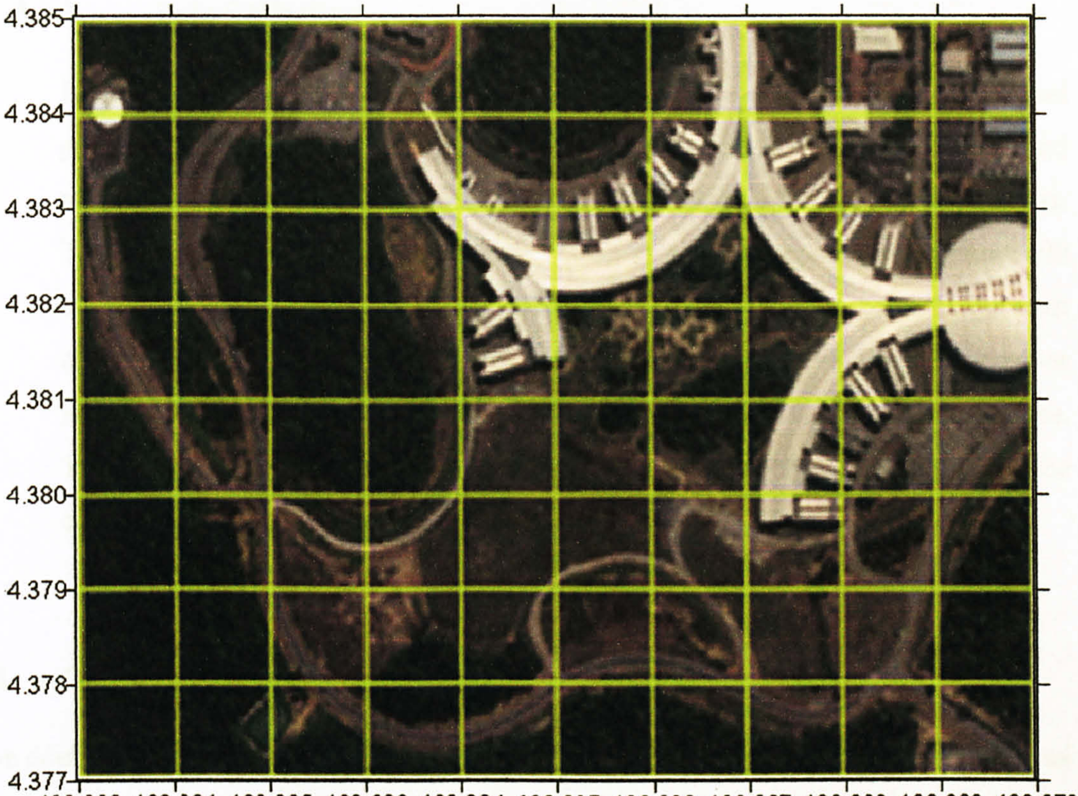

Figure 3.4: Base map of study area

3.3.1 Global Positioning System (GPS)

In setting up the equipment, the procedures below should be following:

i. Hammer a nail on a selected control point
ii. A tripod is set up exactly above the nail
iii. The bubble on the tripod is made sure on the centre of the circle to level the tripod.
iv. The GPS receiver is installed on the tripod
v. The receiver setting, GPS status, mode of positioning is check to be in correct and standby position.

3.3.2 Data Collection

Firstly, a control point is set as a base point while others are set as normal points. For the base control point, the GPS receiver and tripod is set up there and will not be moved and should be static during the entire data collection process. The balance of the GPS receivers are set up at different control points and will be moved out to another control points with the time gap of 15 minutes for each of the control point. This means that, after a 15 minutes period, the GPS receiver is moved to another control point and stays for the same period of 15 minutes. These steps are repeated until the receiver collects all the data for all of the control points that is to be determined.

3.4 Double Ring Infiltrometer Test

The double ring infiltrometer is a simple instrument that is used to determine the rate of infiltration of water into the soil.

The rate of infiltration is determined as the amount of water per surface area and time unit that penetrates the soil. This rate can be calculated on the basis of the measuring results using Horton's Equation.

The standard set of the double ring infiltrometer consists of sets of metal ring with different diameters (for reasons of transportation). Several measurements can be executed simultaneously, yielding a very reliable and accurate mean result.

As vertically infiltrated water runs away to the sides, the outer ring of the infiltrometer serves as a separation. The measurement exclusively takes place in the inner ring through which the water runs virtually vertical.

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To achieve good measuring result it is important to take into account several factors that may influences the measurement which includes:

- The surface vegetation
- The extent to which the soil has been compacted
- The soil moisture content
- Soil layer (strata).

The best measuring results are obtained at 'field capacity' of the soil.

The ring infiltrometer may be used for determining the rate of infiltration and capacity for irrigation and drainage projects, studying drainage, determining the intensity of artificial precipitation and the effects of treatment of the soil.

Figure 3.5: Double Ring Infiltrometer test

3.4.1 Procedures of Soil Infiltration Test

The methods of the test will be conducted as follows:

1. Any vegetation (grass) and all loose organic that covers over an area just larger than the outer ring shall be removed. The soil shall not be disturbed.
2. Starting with the smaller ring, the ring shall be twists and drive into the soil for 2 – 5 cm. A hammer may be used but a block of wood should be use between the top of the ring and the hammer to distribute the force of hammering. Try to not hammer so hard that the ring may be crumpled.
3. The height above the ground level of the bottom and top of the band shall be measured and marked inside of the small ring.
4. The following steps must be done as quickly as possible:
   a. Pour water into both rings, and the level in the outer ring must be maintained 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.
   b. Pour water into the inner ring, just above the upper reference mark.
   c. Start the stopwatch or note the time to the second and record it on the Infiltration Data Work Sheet.

      Note: Avoid water leaks from the outer ring to the surface outside of the outer ring. If it is, the test shall be redo in another location; push the outer ring deeper into the soil or pack mud around its base.
5. When the water level in the inner ring reaches the upper references mark, start the time and record the elapse time.
6. During the time interval, keep the water level in the outer ring approximately equal to the level in the inner ring, but careful not to pour water into the inner ring (using a funnel) or letting either both ring go dry.
7. As the water level in the inner ring reaches the lower reference mark the following steps shall be done:
   a. The time shall be recorded as the end time.

b. Calculate the time interval by taking the difference between the start and end times.

c. Pour water into the inner ring to just above the upper reference mark. The water level in the outer ring shall be raised so that the water level in the outer and inner ring is approximately the same.

8. Steps 5 -7 shall be repeated for 45 minutes or until two consecutive interval times are within 10 sec of one another.
9. Some clays and compacted soils are impervious to water infiltration and the water level will hardly drop at all within a 45-minute time period. In this case, the depth of water change shall be recorded, if any, to the nearest millimeters (mm). The time at which the observations are stopped shall be recorded as the end time. The infiltration measurement will consist of a single data interval.
10. Remove the rings (wait for about 5 minutes).
11. The near-surface (0 – 5 cm depth) soil moisture shall be measure from the spot where the rings were removed.

3.5 Infiltration Estimation

Horton's equation

Named after the same Robert E. Horton mentioned above, Horton's equation (John Wiley, 2005) is another viable option when measuring ground infiltration rates or volumes. It is an empirical formula that says infiltration starts at a constant rate, f_0, 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.

$$f_t = f_c + (f_0 - f_c)e^{-kt}$$

Where

f_t is the infiltration rate at time t;

f_0 is the initial infiltration rate or maximum infiltration rate;

f_c is the constant or equilibrium infiltration rate after the soil has been saturated or minimum infiltration rate;

k is the decay constant specific to the soil.

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

$$f_t = f_c + (f_0 - f_c)e^{-kt} \text{ .... (1)}$$

Taking log on both sides;

$$\log_{10}(f - f_c) = -Kt\log_{10}e + \log_{10}(f_0 - f_c) \text{ .... (2)}$$

$$-Kt\log_{10}e = \log_{10}(f - f_c) - \log_{10}(f_0 - f_c) \text{ .... (3)}$$

$$t = \frac{-1}{K\log_{10}}[\log 10\,(f - fc) - \log 10\,(f0 - fc)] \text{ .... (4)}$$

$$t = \left\{\frac{-1}{K\log_{10}}\right\}\{\log 10\,(f - fc)\} + \left\{\frac{1}{K\log_{10}}\log 10\,(f0 - fc)\right\} \text{ .... (5)}$$

Where from equation (5);

$$Y = t$$

$$m = \frac{-1}{K \log_{10}}$$

$$x = \log 10 \left(f - fc\right)$$

$$c = \frac{1}{K \log_{10}} \log 10 \left(f0 - fc\right)$$

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

Thus the slope is to be determined using the equation above and the equation for infiltration capacity can be written.

The other method of using Horton's equation is shown below. It can be used to find the total volume of infiltration, F, after time t.

$$F_t = f_c t + \frac{(f_0 - f_c)}{k}(1 - e^{-kt}) \quad \text{..(6)}$$

3.6 Statistical Analysis

The statistical analysis will be used in analyzing the results of double ring infiltrometer measurements on soil infiltration characteristics. The analysis involves the process of collecting and analyzing data and then the data will be summarized into a numerical form. All the measurement for all 50 sample locations will show variation in each different point as the soil infiltration characteristics of each point are different with another making it difficult to identify the parameters. The general statistical parameters for all the 50 sample location will be calculated which includes the maximum,

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 will be describing using semivariogram parameters. All semivariogram parameters in this study will be computed using the GS+ freeware and Surfer software. The relationship between the sample locations will be modeled to indicate the variability of the measure with distance of separation which known as 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 gives a smaller semivariances and a larger distance give a larger semivariances. The plot of the semivariances as a function of distance from a point is referred to as a semivariogram. The semivariances 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. (Noorhidayah, 2008).

From the point of interest to the distance where the flat region begins is termed the range or span 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 relativity 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:

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

where;

$\gamma_{(h)}$ = the semivariance

h = the lag

$N\,(h)$ = total number of sample couples separated by the lag interval h

$z\,(x_i)$ = the measured sample value at point (x_i)

$z\,(x_i + h)$ = the measured value at point $(x_i + h)$

If the semivariogram increases with distance and stabilizes at the a priori variance value, it means that the variable under study is spatially correlated and all neighbors within the correlation range can be used to interpolate values where they were not measured. Semivariograms may be scaled by dividing each semivariance value by a constant such as the square of the mean and the variance value, as it was suggested by Vieira et al. (1997).

When semivariograms are calculated using Equation 1, the result is a set of discrete values of distances along with the corresponding semivariances. Because any geostatistical calculation will require semivariances for any distance within the measured domain, there is a need to fit a mathematical model which would describe the variability. VIEIRA (2000) describes the model fitting process and the cross validation of the fitted models.

There are three characteristics semivariogram modeling; sill, range and nugget. The sill ($C + C_0$) 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 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.

There are five different semivariance models which are spherical, exponential, linear, linear to sill and the Gaussian where the best fitted semivariogram model is determined based on the r^2 and Residual Sum of Square (RSS) values. Spherical and Exponential model are two models that are best fit the semivariogram of soil hydraulic properties.

1. Spherical Model

$$\gamma_{(h)} = \lambda_0 + \lambda\,[\,1.5(\tfrac{h}{\beta}) - 0.5(\tfrac{h}{\beta})^3 \qquad \text{for } h \leq \beta \text{ .... } (2)$$

$$\gamma_{(h)} = \lambda_0 + \lambda \qquad \text{for } h \geq \beta \text{ .... } (3)$$

Where λ_0 is the nugget effect, λ is the structural variance and a the range of spatial dependence. These are the three parameters used in the semivariogram model fitting. Models were fit using least squares minimization and judgment of the coefficient of determination. Whenever there was any doubt on the parameters and model fit, the jack knifing procedure was used to validate the model, according to VIEIRA (2000).

2. Exponential Model

$$\gamma_{(h)} = \lambda_0 + \lambda\,[\,1 - \exp(-\tfrac{h}{\beta})] \text{ .... } (4)$$

Using the values interpolated by the Kriging method, contour or tri-dimensional maps can be precisely built, examined and compared for each of the sample location and soil hydraulic properties.

3.7.2 Analysis using the Contour Map (Kriging Analysis)

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

The 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 maps will be used to group sample observations and the variation in soil infiltration parameters will be separated into two parts:

a. Between soil types (i.e., soil type effect)
b. Within each soil type (i.e., residual)

A Kriging model combining with soil contour maps that includes the variation parameters of soil type effect and residual will be proposed (Noorhidayah, 2008).

3.8 Hazard Analysis

Table 3.1 Job Safety Analysis

Activity	Potential Hazards	Injury/ Damage	Risk	Controls
1. Global Positioning System for locating the control point	1.1. Climate change (weather)	- Injury to student. - Sun burn. - Damage to equipment	Low	1.1.1.Wearing proper shoes during field work. 1.1.2.Use umbrella or hat to avoid direct sun rays. 1.1.3.Hold GPS receiver tools tightly to avoid from falling. 1.1.4.Student works under supervision of Technician/ Graduate Assistants (GA)
2. Computer Analysis	2.1. Neck and Back strain	- May cause pain on the neck and the back	High	2.1.1.Sit-up straight 2.1.2.Posture check 2.1.3.Sit on chairs with cushion that can be tilt back on adjustments. 2.1.4.The monitor screen surface should be approximately 18 – 24 inches

				away from student torso. 2.1.5.Enough space for desktop and for work papers and other equipment.
	2.2. Eye Strain	- May cause eye fatigue, blurry eyes and even blindness due to imbalance light overexposure.	Mediu m	2.2.1.Install anti-glare screen. 2.2.2.Do not work in dark. 2.2.3.Adjust brightness control until comfortable with the eye. 2.2.4.The terminal was position at right angles to the window if possible and avoids facing directly into bright light (coming from behind computer screen)
	2.3. Carpal tunnel syndrome	- May cause pain to the bone joints.	Mediu m	2.3.1.The chair or table height was adjusted to have student elbow angle at 90 – 100 degrees. 2.3.2.Clinch the

				fists, hold on for one second, then stretch the fingers out wide and hold for 5 seconds. 2.3.3. The keyboard was position at correct place so that student doesn't have to bend the hands uncomfortably upwards to reach the keys; place a raised wrist rest on the table in front of the keyboard if necessary. 2.3.4. The mouse was hold loosely and clicks lightly.
3. Double Ring Infiltrometer test	3.1. Back pain	- May cause pain to the backbone and waist	High	3.1.1. Use trolley to carry the equipment. 3.1.2. Lifting up the equipment in correct posture (ergonomic)

CHAPTER 4

RESULTS 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 obtained from the 50 samples location, the summary of the soil Infiltration parameters is shown in Table 4.1. The parameters include the initial infiltration rate (f_0), final infiltration rate (f_c), constant value (k) and the type of soil in the sample location taken. (See Appendix B).

Table 4.1 Summary of 50 samples location for Soil Infiltration results.

Sample No.	Latitude	Longitude	f_0	f_c	k	Type of Soil
1	4.377 N	100.970 E	168.0	3.0	3.266	Disturbed
2	4.377 N	100.968 E	216.0	6.0	3.030	Undisturbed
3	4.377 N	100.967 E	204.0	5.5	3.038	Undisturbed
4	4.377 N	100.966 E	204.0	5.0	2.983	Undisturbed
5	4.377 N	100.965 E	216.0	5.5	2.564	Undisturbed
6	4.377 N	100.964 E	180.0	5.0	2.908	Undisturbed
7	4.377 N	100.963 E	192.0	6.0	2.949	Undisturbed
8	4.377 N	100.962 E	180.0	2.5	3.309	Disturbed
9	4.377 N	100.961 E	192.0	5.5	3.014	Undisturbed
10	4.378 N	100.970 E	228.0	6.0	2.968	Undisturbed
11	4.378 N	100.969 E	120.0	2.0	3.367	Disturbed
12	4.378 N	100.968 E	132.0	1.5	3.437	Disturbed
13	4.378 N	100.967 E	120.0	1.5	2.545	Disturbed

14	4.378 N	100.966 E	144.0	2.5	3.234	Disturbed
15	4.378 N	100.965 E	144.0	2.5	3.181	Disturbed
16	4.378 N	100.964 E	216.0	6.5	2.964	Undisturbed
17	4.378 N	100.963 E	180.0	4.5	2.949	Undisturbed
18	4.378 N	100.962 E	156.0	2.5	2.945	Disturbed
19	4.378 N	100.961 E	204.0	5.0	3.022	Undisturbed
20	4.379N	100.969 E	120.0	2.5	3.022	Disturbed
21	4.379N	100.968 E	132.0	2.0	3.190	Disturbed
22	4.379N	100.967 E	156.0	2.0	3.230	Disturbed
23	4.379N	100.966 E	156.0	3.0	3.038	Disturbed
24	4.379N	100.965 E	120.0	2.0	3.221	Disturbed
25	4.379N	100.964 E	156.0	2.5	3.337	Disturbed
26	4.379N	100.963 E	204.0	5.0	3.050	Undisturbed
27	4.379N	100.962 E	204.0	6.0	2.983	Undisturbed
28	4.379N	100.961 E	180.0	4.5	2.819	Undisturbed
29	4.380 N	100.970 E	192.0	5.0	2.975	Undisturbed
30	4.380 N	100.969 E	156.0	3.0	3.112	Disturbed
31	4.380 N	100.964 E	168.0	3.0	3.225	Disturbed
32	4.380 N	100.963 E	228.0	5.0	3.079	Undisturbed
33	4.380 N	100.962 E	240.0	6.5	2.956	Undisturbed
34	4.380 N	100.961 E	180.0	3.0	2.644	Disturbed
35	4.381 N	100.964 E	156.0	2.5	3.163	Disturbed
36	4.381 N	100.962 E	228.0	7.0	2.952	Undisturbed
37	4.381 N	100.961 E	168.0	2.5	3.142	Disturbed
38	4.381 N	100.960 E	180.0	2.5	3.018	Disturbed
39	4.382 N	100.962 E	240.0	6.5	2.850	Undisturbed
40	4.382 N	100.961 E	156.0	3.0	3.159	Disturbed
41	4.382 N	100.960 E	180.0	2.5	3.091	Disturbed
42	4.383 N	100.963 E	168.0	3.0	3.172	Disturbed
43	4.383 N	100.962 E	216.0	6.0	2.590	Undisturbed
44	4.383 N	100.961 E	192.0	3.5	3.225	Disturbed

45	4.383 N	100.960 E	156.0	3.0	3.054	Disturbed
46	4.384 N	100.963 E	144.0	2.0	2.611	Disturbed
47	4.384 N	100.962 E	168.0	3.0	3.198	Disturbed
48	4.384 N	100.961 E	156.0	2.0	3.030	Disturbed
49	4.385 N	100.962 E	156.0	2.0	3.030	Disturbed
50	4.385 N	100.961 E	216.0	5.0	3.018	Undisturbed

4.2 Statistical Analysis Parameters of Soil Infiltration Characteristics

In statistical analysis the general statistical parameter to be calculated includes the maximum, minimum, mean, median, standard deviation and the coefficient of variation for each soil infiltration parameters (f_0, f_c, k). Table 4.2 shows the statistical parameter for the Soil Infiltration tests carried out over the 50 samples location.

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_0 (mm/hr)	50	240.0	120.0	177.36	180.0	32.91	18.56
f_c (mm/hr)	50	7.0	1.5	3.79	3.0	1.64	43.27
k (constant)	50	3.4	2.5	3.04	3.0	0.20	6.60

Between the three soil properties observed, initial infiltration rate, f_0 showed the highest standard deviation (32.91 mm/hr) followed by the final infiltration rate, f_c (1.64 mm/hr) and the constant value, k showed the lowest (0.20) standard deviation (Table 4.2). The lowest standard deviation (0.20) shows the data points for constant value, k from the study area close to the mean values. Therefore the constant value, k has the smaller variation compare to other parameters in the study area.

When the variation of the soil infiltration parameters value are compared in terms of the coefficient of variance (CV), the parameters can be differentiate into; (i) parameter that

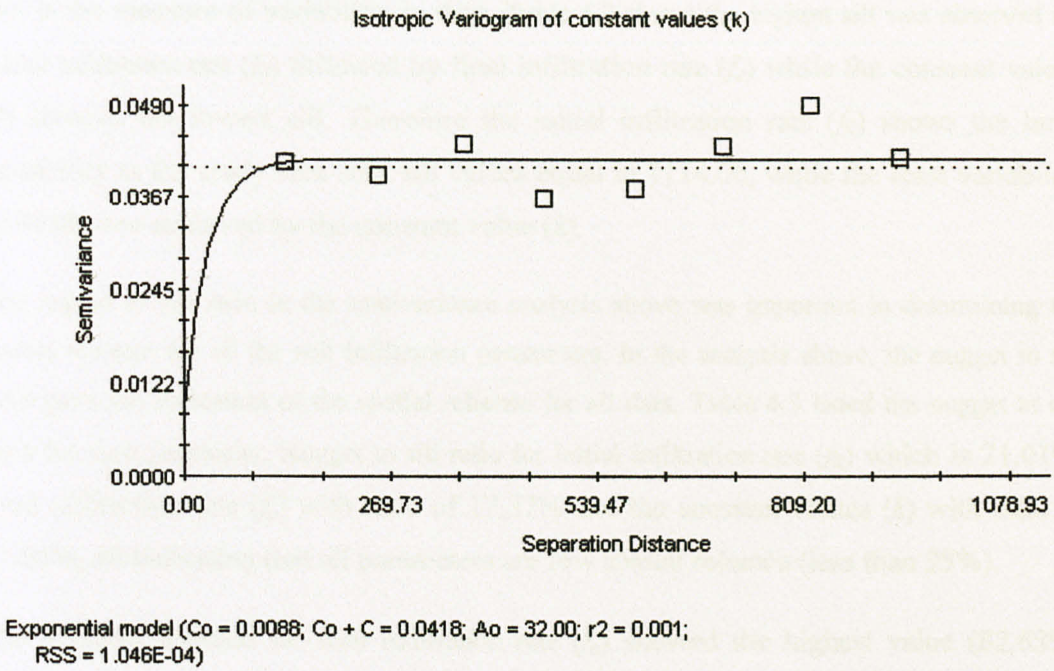


Figure 4.3: Isotropic Semivariogram of Constant Values (k)

Table 4.3 shows the geostatistical analysis in term of semivariogram modeling for the characteristics parameters, which proves that the soil hydraulic properties at UTP campus area are highly variable. Based on the understanding of the semivariogram modeling, most of the infiltration parameters at different sample locations show curved experimental semivariogram that could be described by two best models which are Spherical and Exponential models with a spatial range of 32.00 to 225.00 m.

The range is the measure of the lag distance at which the semivariogram reaches the sill value or the distance beyond which observations are not spatially reliance. Table 4.3 shows that the range values for all parameters are within the total lag distance which indicates that all parameters are spatially reliance.

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 shows the random variation. Table 4.3 shows that the nugget component (*Co*) ranges from 0.0088 to 234.00.

Sill is the measure of variability in data. Table 4.3 shows the highest sill was observed for initial infiltration rate (f_0) followed by final infiltration rate (f_c) while the constant values (k) showed the lowest sill. Therefore the initial infiltration rate (f_0) shows the large variability in the study area with sill values equal to 1114.00, while the least variability (0.0418) was achieved by the constant value (k).

The nugget to sill ratio in the semivariance analysis above was important in determining the spatial reliance for all the soil infiltration parameters. In the analysis above, the nugget to sill ratio gave the indication of the spatial reliance for all data. Table 4.3 listed the nugget to sill ratio for each parameter. Nugget to sill ratio for initial infiltration rate (f_0) which is 21.01%, final infiltration rate (f_c) with ratio of 17.37% and the constant values (k) with ratio of 21.05%, all indicating that all parameters are low spatial reliance (less than 25%).

The structural variance for final infiltration rate (f_c) showed the highest value (82.63%) followed by initial infiltration rate (f_0) and constant value (k) (78.99% and 78.95% respectively). This structural variance in the above analysis indicates that the variation in soil parameters is 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)

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 two other important information; spatial variation between soil types and the variability within each soil type.

Figure 4.4, 4.5 and 4.6 respectively illustrate the variability of spatial distribution of initial infiltration rate (f_0), final infiltration rate (f_c) and constant value (k) over the study area.

4.3.2.1 Variability in Initial Infiltration Rate, (f_0)

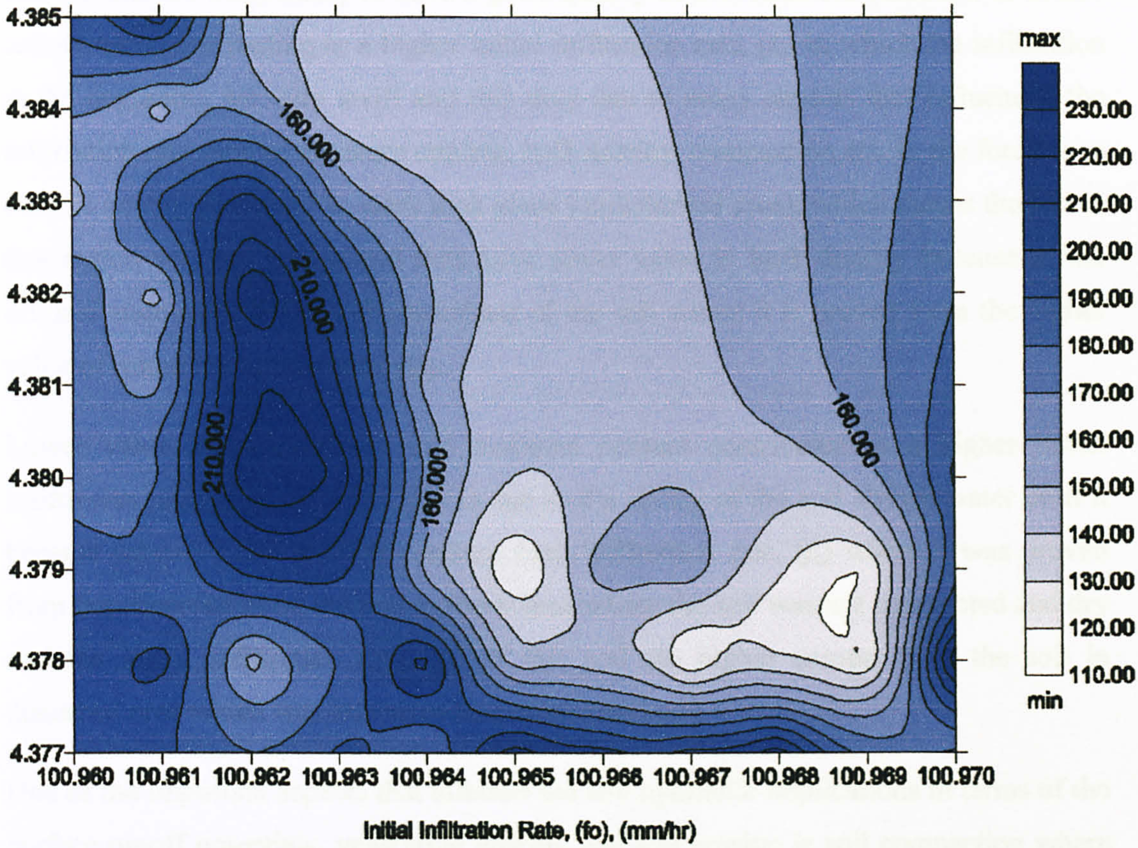


Figure 4.4: Spatial Distribution of Initial Infiltration Rate, (f_0)

As shown in Figure 4.4 above, it shows the variation of initial infiltration rate, (f_0) at the study area. Using Kriging analysis the variation is mapped by preparing the contour map which was used to map the variation of each different sampling location. The initial infiltration rate, (f_0) shown in figure 4.4 above is varies between the disturbed and undisturbed area.

At the east side of the area (4.379° N to 4.383°N, 100.962°E) which is the forest area showed higher initial infiltration rate, (f_0) while the lower initial infiltration rate, (f_0) was found at 4.378°N to 4.385°N, 100.964°E to 100.969°E. The variation of the initial infiltration rate, (f_0) at the study area is due to factors such as soil engineering properties and soil surface properties.

The topography map showed that the forest area where there is no construction work and the soil are most likely to have a good quality of soil structure (medium to coarse soil texture) contributing to a higher initial infiltration rate, (f_0) in which the infiltration at the beginning are very swift and this may due to many aspects that influenced the infiltration rate such as moisture content, bulk density, compaction etc. In the forest area there is no any construction work took place (undisturbed area), which means the soil in that region was not compacted thus have lower value in bulk density because of the original state and the good characteristic of the soil where it is proven from the higher value of initial infiltration rate, (f_0).

Lower value in bulk density and moisture content contributed to a higher initial infiltration rate, (f_0) in soil and this is due to the ability of the soil absorb water until it became saturated and reaches constant final infiltration rate, (f_c) where it was proven from the observation on the soil in forest area where the soil was not compacted and dry and the initial infiltration rate, (f_0) of this soil are higher compared to the soil in disturbed area which was known to be a compacted soil.

One of the important aspects that affected the soil hydraulic implications in terms of the surface runoff potentials, vegetative growth, and soil erosion is soil compaction where soil with stable structure and greater surface roughness such as in the forest area will have a greater infiltration rate thus increase the initial infiltration rate, reduce surface runoff and reduce soil erosion.

Large amount of macro pores presents in the soil resulting in the soil to become initially unsaturated can contribute to a high infiltration rate at the beginning due to the number and size of macro pores which can affect magnitude of the infiltration rate and gives great influence to the soils to absorb more water down to the soil water profile.

The initial infiltration rate, (f_0) varies and become lower when it reaches the developed (disturbed) area. This variability is shown in the contour map (Figure 4.4) at grid location 4.378°N to 4.385°N, 100.964°E to 100.969°E. From the topography map it is shown that this area is the developed area that consists of academic blocks and infrastructure components (roads, helipad). During the construction work of the building campus the original soil have been filling and dumped by other soil and it has been compacted for the construction work in which the air voids and pores that are so important for water and air movement in the soil are compressed and the soil became low in porosity and more denser causing the soil to have reduced in initial infiltration rate, (f_0) and may cause surface runoff which could lead to flooding and land erosion.

As a conclusion, there are differences in the initial infiltration rate, (f_0) between the disturbed and undisturbed area where by the disturbed area showed lower initial infiltration rate, (f_0) while the undisturbed area showed higher initial infiltration rate, (f_0) and the differences in this parameter of the two regions are much influenced by the type of land usage 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)

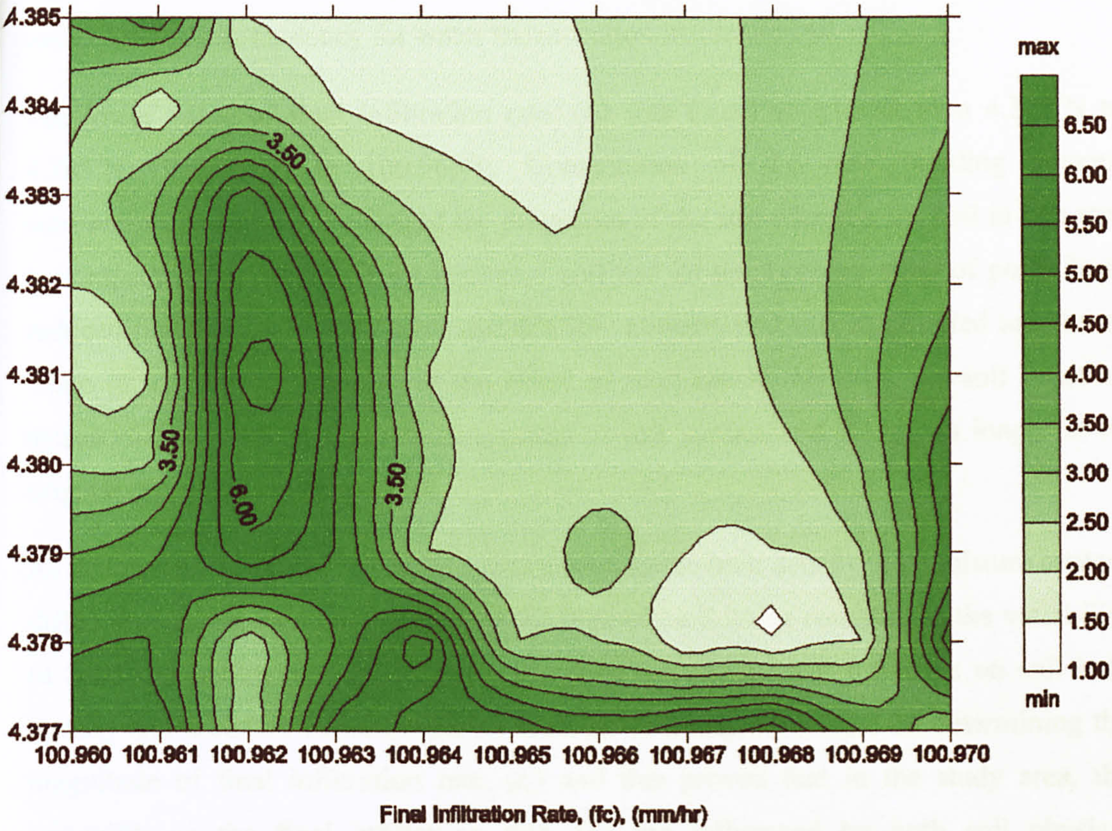


Figure 4.5: Spatial Distribution of Final Infiltration Rate, (f_c)

As shown in figure 4.5 above, it 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. Reduction in the rate of infiltration is probably caused by high soil bulk density and soil moisture content.

The higher value of final infiltration rate, (f_c) was found at grid location 4.379° N to 4.383°N, 100.962°E which is at the undisturbed area. Based on the topography map, that area is dedicated near the forest. From the observation of the land use pattern at the forest area shows that there are no development work take place thus the soil texture and the soil properties are in good condition and in its original type where the soils contain lower value of soil bulk density and soil moisture content and this land use pattern gave great significant to the infiltration rate and the soil are expected to have higher final infiltration rate, (f_c) and the soil in this region can be classified as healthy soil because of its tendency for water translocation inside the soil.

The lower value of final infiltration rate, (f_c) was found at grid location 4.378°N to 4.385°N, 100.964°E to 100.969°E. Construction of the new building campus surrounding the area has changed the properties of the soil whereby the soil in this area is compacted soil in which a compacted soil has its number and sizes of pores been reduced resulting in low porosity and this low porosity soil can contributed to a lower value of infiltration. Because of the effect of land use at this area, the soil becomes denser due to large amount of compaction at soil surface and it was no longer in its original types and characteristics.

As conclusion, the soil physical properties such as the bulk density and moisture content differ at different location affected by the type of land usage resulting in the variability of final infiltration rate, (f_c) whereby the land use gives great influence on soil bulk density and moisture content which contribute to a major outcome on determining the magnitude of final infiltration rate, (f_c) and this proved that in the study area, the variability in the final infiltration rate, (f_c) are influenced by both soil physical properties and topography.

4.3.2.3 Variability in Constant Value (*k*)

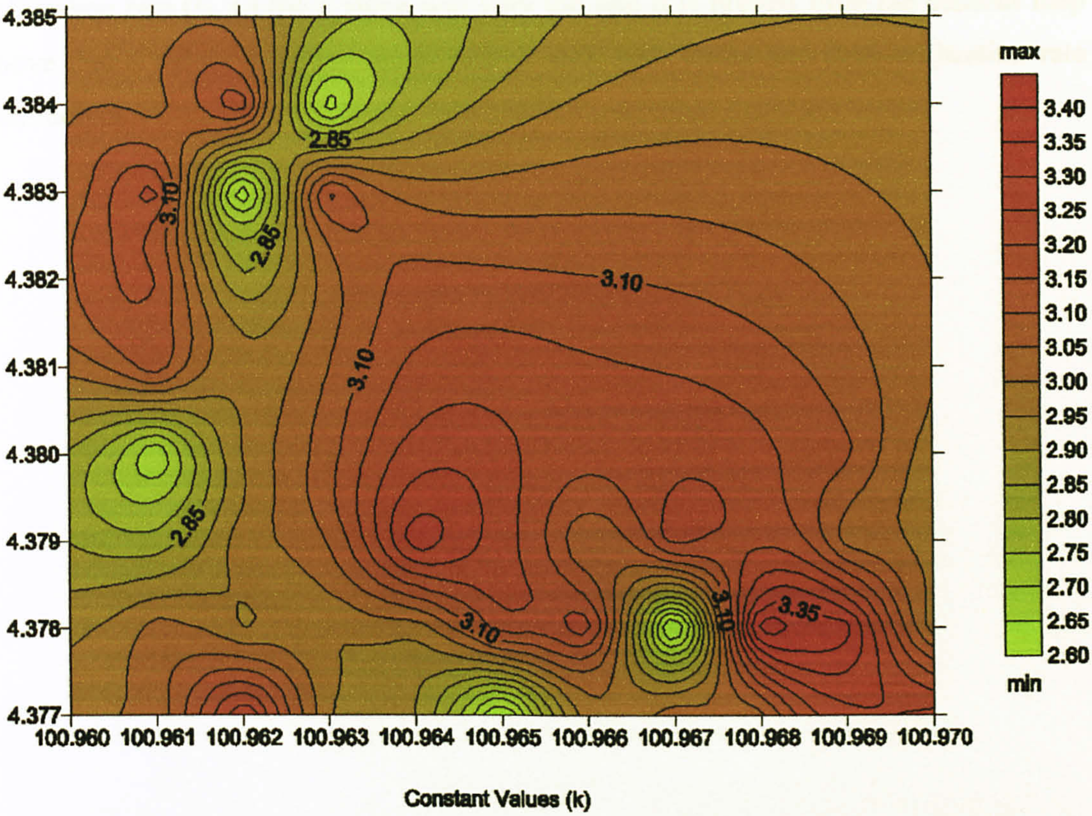
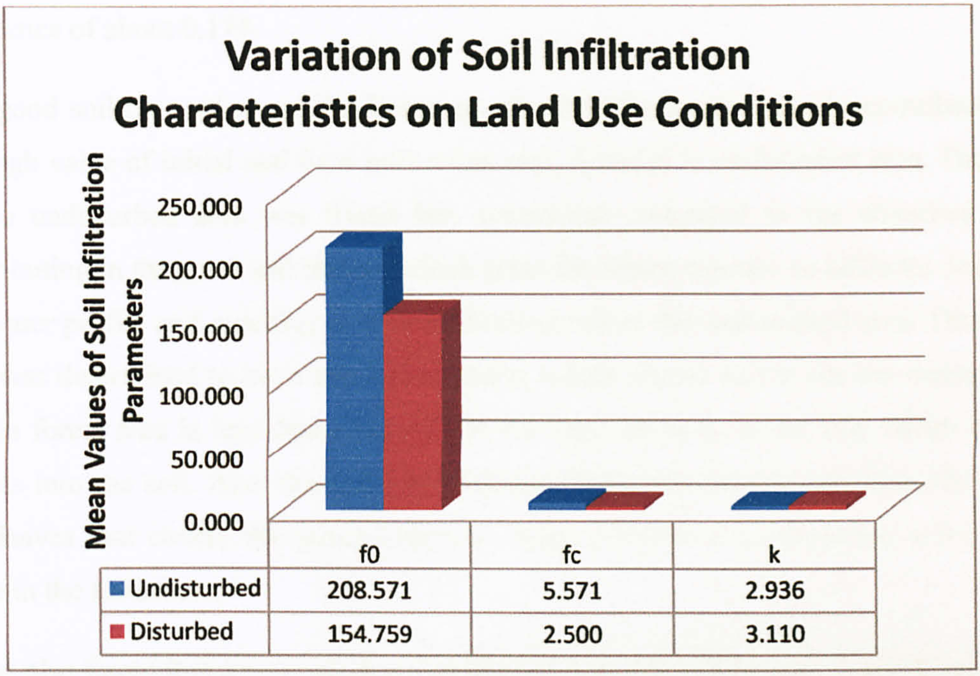


Figure 4.6: Spatial Distribution of Constant Value (*k*)

As shown in Figure 4.6 it shows the variability of the constant value, (*k*) where by using the Horton's infiltration equation the *k* values were determined. The variability in the infiltration rate was indicated from the contour map shown above, as the *k* values are varying spatially. *k* values varies when the parameters in the Horton's infiltration equation varies due to several factors affecting the parameters in the Horton's infiltration equation as the Horton's theory of infiltration is based on the fact that infiltration is more rapidly in dry ground, and the infiltration rate decreases as rain continues and the ground becomes wetter. The rate of infiltration is faster when the ground is dry is because there are air voids and spaces between the particles of the soil which the water fills up the gaps 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_0, f_c) the k value will vary too and it is proven from the contour map above 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_0: Initial Infiltration Rate (mm/hr); f_c: Final Infiltration Rate (mm/hr) Values)

Figure 4.7: Effect on Land Patterns on Soil Infiltration Characteristics

Various factors such as the soil physical properties, topography, ground surface cover and its land use pattern influenced the variation of the infiltration rate. The inconsistencies in infiltration rate at study area were given by these differences in soil physical properties at the study area. Therefore to further study on its land use pattern, the effect of land usage was observed in which the study area was divided into two regions; disturbed and undisturbed area (forest area). While disturbed area included the area consists academic blocks and infrastructure such as helipad, roads, surface drainage, parking lot and etc.

As shown in Figure 4.7 it shows the mean values of soil infiltration parameters; initial infiltration rate, f_0 (mm/hr), final infiltration rate, f_c (mm/hr) and constant values k. Both initial and final infiltration rate, f_0 and f_c (mm/hr) were higher in undisturbed or forest zones compared to disturbed zones. However the constant value, k, shows a very low difference of about 0.174.

The good soil properties and the freshness of soil in the particular area contributed to the high value of initial and final infiltration rate, f_0 and f_c in undisturbed area. The soil in the undisturbed area was found less compacted compared to the disturbed area contributing in the good soil texture which gives the water easiness to infiltrate down to the water profile and resulting in high infiltration rate in the undisturbed area. This area also was determined to have low bulk density, which means soil is not too dense. The soil in forest area is less dense because of the root action from the tree which create porous into the soil. Also the soil was protected from impounding rain from the trees and leaves that covers the ground surface. There are also no compaction work took place in the forest area.

It was also found that lower values of initial and final infiltration rate, f_0 and f_c (mm/hr) respectively experienced by the disturbed area. The disturbed area is the development area which consists of academic buildings, helipad, roads and etc. The soil in the disturbed area has loosened its freshness in properties and characteristics because of many construction works that took place in the area in which large amount of compaction at soil surface whereby 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 area becomes denser. The land pattern and the topography in this area have been changed by the construction works.

As conclusion, the differences between the disturbed area and undisturbed area are very significant. The consequence of disturbance such soil compaction and forest clearance that distorted the soil physical and soil surface properties causes the difference between the disturbed and undisturbed area. The inconsistencies in soil infiltration parameters studied are also contributed by the land use pattern.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

As conclusion, the natures of infiltration characteristics at UTP campus area are varying at different locations. After performing a total of 50 double ring infiltrometer in-situ measurements, 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 in the project objectives.

The variations and heterogeneity of infiltration parameters at UTP campus area was studied from the geostatistical analysis in term of semivariogram and statistical parameters and the analysis shows that the soil physical properties and its topography are both influencing the variation of the initial and final infiltration, f_0 and f_c respectively where larger coefficient of variation (CV) for the final infiltration rate, f_c shows that the variation in final infiltration rate, f_c is higher compared to other infiltration parameters. While the larger sill which belonged to the initial infiltration rate, f_0 shows large inconsistency compared to other parameters indicated in the semivariogram parameter.

The high values of initial and final infiltration rate, f_0 and f_c were found in the undisturbed area due to smaller soil compaction contributing to a lower value of soil bulk density as proven in the Kriging analysis of soil infiltration characteristics (contour map),. Therefore, the comparison of these soil infiltration parameters in term of contour map shows that is scale dependency and auto correlation between each parameter.

By evaluating the variation of soil infiltration characteristics on type of land usage it can be observed that the differences in soil infiltration characteristics were affected by the land use pattern and the topographic conditions where the analyses were used to develop the relationships of soil hydraulic properties between disturbed and undisturbed area where it shows that the undisturbed area has higher values of initial and final infiltration rate, f_0 and f_c and this is due the freshness of the soil properties and characteristics which has not been altered by any compaction or clearance work. While the disturbed area (development area), has lower values of initial and final infiltration rate, f_0 and f_c.

In order to obtained more accurate data for future study, it is important to take note of the weather since the weather controls the moisture content of the soil. This is due to the loss of moisture content of the soil through evaporation, ground water movement and translocation of water. The rainfall also can cause the soil become saturated thus reduce the rate of infiltration.

Proper equipment should be provided to perform the test. In this study a 60 centimeters (cm) ruler was used with the scale of cm. It is difficult to take readings of which in millimeters (mm) thus the reading taken was rounded up to cm and cause an inaccurate results. A bigger scale ruler should used in order to obtain more accurate data.

The number of samples locations also should be increase in order to obtain the best analyses results. 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 infiltration characteristic of tropical soil in UTP campus area has been characterized.

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APPENDICES

APPENDIX A

GEO-GRIDS SAMPLING PREPARATION

Table A-1: GPS Results of Reference Points

Point		Coordinates		
No	**Name**	**Latitude**	**Longitude**	**Height (m)**
1	Point 1 (base)	4° 22'53.45132" N	100° 57'56.26621" E	23.3024
2	Point 2	4° 22'42.09703" N	100° 58'00.89135" E	31.7466
3	Point 3	4° 22'48.31201" N	100° 57'42.53824" E	39.4431
4	Point 4	4° 23'00.91256" N	100° 57'44.32752" E	46.6125
5	Point 5	4° 23'13.13076" N	100° 58'19.58847" E	20.8723
6	Point 6	4° 23'00.01518" N	100° 58'16.31596" E	24.1477
7	Point 7	4° 23'10.17232" N	100° 58'09.99540" E	29.7622
8	Point 8	4° 23'09.16408" N	100° 58'01.74557" E	45.9108
9	Point 9	4° 23'20.05434" N	100° 57'59.84068" E	25.4407
10	Point 10	4° 23'12.36167" N	100° 57'45.67507" E	43.4025
11	Point 11	4° 23'19.52831" N	100° 58'06.54364" E	28.1317
12	Point 12	4° 23'17.22324" N	100° 58'26.46109" E	22.2736
13	Point 13	4° 23'11.56439" N	100° 58'29.18590" E	11.3449
14	Point 14	4° 23'15.41207" N	100° 58'33.10118" E	30.4750
15	Point 15	4° 22'54.66923" N	100° 58'27.36618" E	24.8039
16	Point 16	4° 23'16.15222" N	100° 58'45.33811" E	24.9866
17	Point 17	4° 23'08.79274" N	100° 58'44.83465" E	18.1858
18	Point 18	4° 23'02.08622" N	100° 58'46.71277" E	17.0331
19	Point 19	4° 22'55.93881" N	100° 58'41.99122" E	21.9708
20	Point 20	4° 22'56.55227" N	100° 58'36.28524" E	16.8022

Figure A-1: GPS Control Points

APPENDIX B

DOUBLE RING INFILTROMETER ANALYSIS TEST RESULT

SAMPLE 1: Here; f_0= 168.00 mm/hr and f_c = 3.00 mm/hr

Table B-1: Result of Soil Infiltration at 4.377° N, 100.970° E

Point 1					
Time (hr)	Water Level (mm)	Reduction (mm)	Rate (mm/hr)	$f - f_c$ (mm/hr)	$\text{Log}_{10} f - f_c$ (mm/hr)
0.00	300	0	0	0	0
0.08	286	14	168.00	165.00	2.22
0.17	275	11	66.00	63.00	1.80
0.25	264	11	44.00	41.00	1.61
0.33	254	10	30.00	27.00	1.43
0.42	244	10	24.00	21.00	1.32
0.50	234	10	20.00	17.00	1.23
0.58	225	9	15.43	12.43	1.09
0.67	216	9	13.50	10.50	1.02
0.75	207	9	12.00	9.00	0.95
0.83	198	9	10.80	7.80	0.89
0.92	190	8	8.73	5.73	0.76
1.00	182	8	8.00	5.00	0.70
1.08	174	8	7.38	4.38	0.64
1.17	167	7	6.00	3.00	0.48
1.25	160	7	5.60	2.60	0.41
1.33	154	6	4.50	1.50	0.18
1.42	148	6	4.24	1.24	0.09
1.50	142	6	4.00	1.00	0.00
1.58	136	6	3.79	0.79	-0.10
1.67	130	6	3.60	0.60	-0.22
1.75	124	6	3.43	0.43	-0.37
1.83	118	6	3.27	0.27	-0.56
1.92	112	6	3.13	0.13	-0.88
2.00	106	6	3.00	0.00	0.00

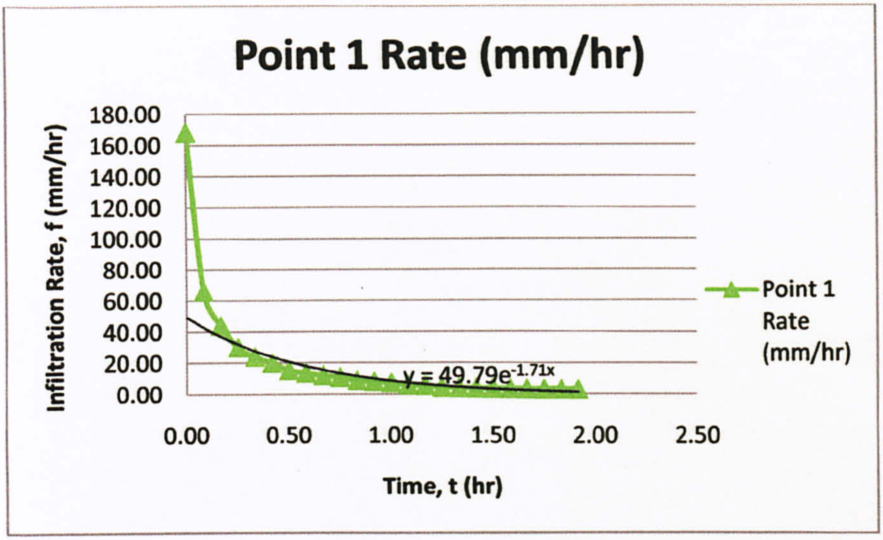

Figure B-1: Infiltration Capacity curve for 4.377° N, 100.970° E

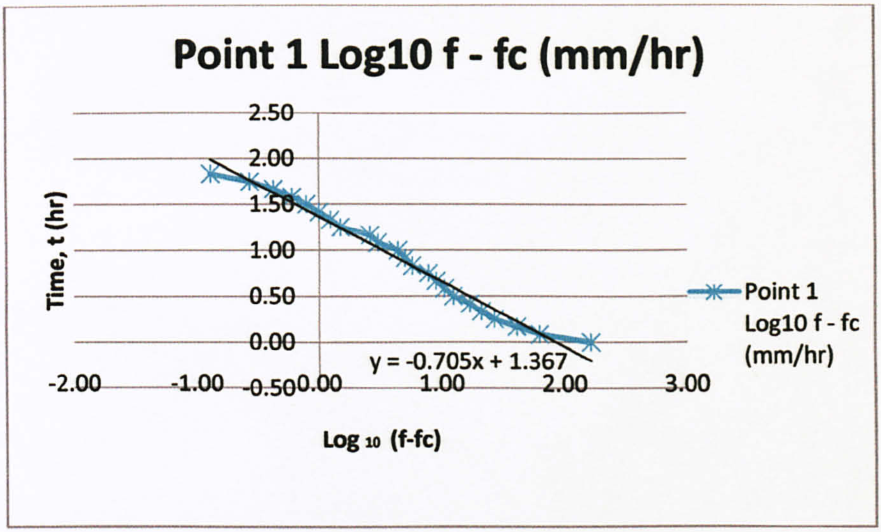

Figure B-2: Slope of the straight line for 4.377° N, 100.970° E

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