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EFFICIENCY OF GRASS PATTERNS ON SLOPE EROSION CONTROLS DUE TO RUNOFF

by

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MALAYSIA

DECEMBER 2013

DECLARATION OF THESIS

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DEDICATION

I dedicate this work to my late father Syed Subhan Ali Shah, my mother Nur un Nisa my siblings Syed Rahil Hussain Shah, Syed Najaf Ali Shah, and my uncle Syed Imtiaz ul Haq Shah.

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ABSTRACT

Soil erosion is a serious environmental, social, and economic problem which is not only responsible for the loss of soil productivity and severe land degradation but it also threatens the sustainable development of a society. It is associated with the on-site impacts which occur when the land is degraded due to the loss of nutrient rich top layer causing adverse impacts to the soil quality. The off-site impacts are liable to water contamination and increased turbidity which are responsible for the environmental degradation and economic losses.

During the phase of roads construction, the nutrient rich top soil is removed which is necessary for the plant re-growth. Due to the lack of top soil cover, the soil is easily eroded and the detached soil sediments are directed towards the stream channels by means of surface runoff which aggrades the channel capacity, contaminates water quality, and leads to the increased turbidity. This study aimed to recommend the optimum percentage of partially covered grass patches necessary to protect the exposed soil as an immediate protection cover against the soil loss during the phase of embankments construction. The study further aimed to observe the soil erosion and the water quality parameters such as turbidity and total suspended solids (TSS) over the exposed soil surface, covered with the different percentage of native grass cover for the newly constructed embankments.

A full scale field test was conducted on four plots which resembles the road embankments (approximately 30°) provided with the different percentage of land covers namely, Plot A (fully grass covered surface), Plot B (bare surface), Plot C (50% of the grass covered surface), and Plot D (30% of the grass covered surface). The soil type was determined, prior to running the experiments. The sediment loss was observed manually at the catchment outlet of each plot whereas; the volume rate of water flow was observed in the designed bottom container. The water samples were

collected to study the water turbidity, and the concentration of TSS. The simulated rainfall intensities opted for the experimental runs were 40 mm hr^{-1} and 52 mm hr^{-1}. The optimum and immediate percentage of grass cover required in retaining the soil loss was observed to be 50% of the grass covered surface which grew naturally and reached almost 80% in a period of two months. The closely spaced grass patches performed well to scatter the generated runoff and acted as a filter to retain the soil particles. Moreover, the average turbidity and TSS values from this plot were observed to be very low when compared with the bare soil surface and 30% of the grass covered surface.

ABSTRAK

Hakisan tanah adalah masalah alam sekitar, sosial dan ekonomi yang serius menyebabkan bukan sahaja kehilangan produktiviti tanah dan kemerosotan tanah yg teruk malah ia juga mengancam pembangunan mampan sesebuah masyarakat. Ia berkait dengan impak di tapak yg berlaku apabila kualiti tanah direndahkan akibat kehilangan lapisan atas yg kaya dengan nutrien dan menyebabkan kesan buruk terhadap kualiti tanah. Impak-impak luar tapak pula boleh mengakibatkan pencemaran air dan peningkatan kekeruhan yang menyebabkan kemerosotan alam sekitar dan kerugian ekonomi.

Dalam fasa pembinaan jalan, lapisan atas tanah yg kaya dengan nutrien yang terhakis, juga merupakan satu keperluan bagi penumbuhan semula tumbuhan. Akibat kekurangan lapisan atas tanah, tanah tersebut boleh terhakis dengan mudahnya dan sedimen-sedimen tanah tersebut akan terhakis ke arah saluran air dan akan memenuhi saliran, mencemari kualiti air dan meningkatkan kekeruhan. Sasaran kajian ini adalah untuk mengesyorkan peratusan optimum tampalan rumput yang diperlukan untuk melindungi tanah yang terdedah sebagai perlindungan segera untuk mengatasi hakisan tanah semasa fasa pembinaan cerunan tebing di lebuhraya. Sasaran kajian yg lebih lanjut adalah untuk memerhatikan hakisan tanah dan parameter kualiti air seperti kekeruhan dan jumlah pepejal terampai (*total suspended solids*, TSS) ke atas tanah yg terdedah, dilindungi dengan peratusan rumput tempatan yang berbeza bagi tebing yang baru siap dibina.

Ujian skala penuh telah dilakukan ke atas 4 bidang tanah yang menyerupai tebing jalan (lebih kurang 30°) dengan peratusan perlindungan tanah yang berbeza yang dinamakan Plot A (perlindungan rumput penuh), Plot B (tanah terdedah), Plot C (50% perlindungan rumput) dan Plot D (30% perlindungan rumput). Jenis tanah telah ditentukan sebelum menjalankan eksperimen. Sedimen-sedimen yg terhakis

diperhatikan secara manual di setiap *outlet* plot tanah manakala isipadu kadar aliran air diperhatikan pada bekas di bawah setiap plot. Sampel-sampel air dikutip untuk tujuan kajian kekeruhan air dan kepekatan TSS. Intensiti simulasi hujan yg digunakan untuk ujian eksperimen adalah 40 mm jam^{-1} and 52 mm jam^{-1}. Peratusan perlindungan rumput optimum dan segera yang diperlukan untuk menahan hakisan tanah adalah diperhatikan sebanyak 50% perlindungan rumput yang tumbuh secara semulajadi dan boleh mencapai hampir 80% dalam masa 2 bulan. Jarak di antara tampalan rumput yang sangat rapat memberi kesan yang baik untuk meneraburkan limpasan air dan menjadi penapis untuk menahan partikel-partikel tanah. Tambahan pula, nilai purata kekeruhan dan TSS dari plot ini adalah diperhatikan sangat rendah apabila dibandingkan dengan permukaan tanah terdedah dan permukaan 30% perlindungan rumput.

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CHAPTER 1

INTRODUCTION

1.1 General Description

Malaysia is located in the Southeast Asia with the area of approximately 330,000 square kilometers. The average rainfall is between 2000 to 4000 mm with the temperature ranging between 26°C to 32°C all over the country (Suhaila et al., 2011). Being a humid tropical region, this area has suffered a lot from the soil erosion which is a geological process. The triggering factors that are considered responsible for the soil particles detachment are intense prolonged rainfalls and the seismic activities (Chou and Wu, 2010). Malaysia is considered away from the active fault line which makes it immune to earthquakes (Mukri, 2003). However, the prolonged rainfalls are therefore considered to be the main source of soil erosion in this region which leads to the running water that erodes various landforms (Taha and Kaniraj, 2011).

Soil is termed as "limited and irreplaceable resource" by the International Soil Science Society (Shah et al., 2012), which is necessary for the atmosphere of the earth and for the region of surface where living organism, exists. Thus, it is appropriate to say that imagining life without soil is impossible (Zuazo et al., 2011). It is the major source of food production (Wycherley, 1969). It keeps carbon dioxide and other greenhouse gases in the soil organic matter which amend soil structure, enhance water quality, bear weather impacts, allow microbial habitats and even the antibiotics taken to cure infection are received by the soil organism (Glasener, 2013). It is one of the essential natural resource which is being degraded with an alarming rate. Its shelter is therefore obligatory.

To promote economic development, the need of roads is among the major infrastructures. It influences the local environment (Dong et al., 2012) and is considered responsible to induce the higher rates of erosion (Cerdà, 2007). The loss of cover crop during the road construction makes the soil surface bare which leads to the risk of slope instability (De Oña et al., 2009). This causes both on-site and off-site effects by undermining the roads utilities, loss of fertile top soil, high cost for the maintenance, instability to the stream channels, and siltation in the reservoirs resulting in the loss of water capacity of the water channels (Sekitar, 1996).

Erosion is such a process which worn away the earth over a specific time period and occurs often by water and wind that leads to undesirable effects on soil which carries away the bits of soil sediment and causes land degradation, resulting in the loss of fertile top soil (El Kateb et al., 2013; Wang et al., 2013). It has eternal list of harmful effects and water is one of the most significant factors of soil erosion. It tears apart the sediments by rain drop impact and generates runoff which carries away the detached soil particle from their place of origin. This process then leads to gully floor which makes the land unstable and permit the affected sediments to enter the water body causing unwanted siltation and contamination (Bhattarai et al., 2011). Figure 1.1 shows the phases of erosion that how the impact of raindrop leads to the process of soil detachment. The rain drop when comes in contact with the bare soil surface, it splashes away the soil from its point of origin which is transported down the slope by means of surface runoff and the process of deposition occurs (Derpsch, 1991).

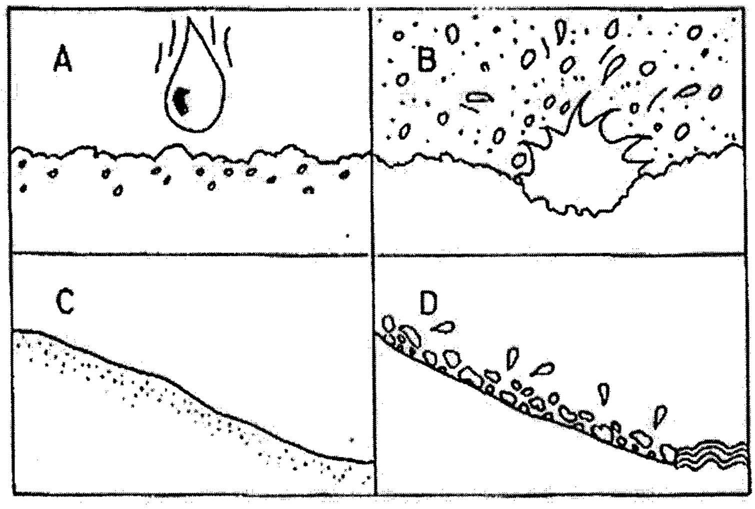


Figure 1.1 Phases of erosion

Wind erosion is also a natural process that usually occurs in bare areas where the soil consists of loose fine particles. The strong wind blows over and carries these finest particles which are usually exposed and affects the top layer of the fragile soil. It is a common cause of land degradation in arid and semi-arid regions, although not usually a problem in Malaysia (Sekitar, 1996).

Asia, Africa, and South America contributes to the highest rates of soil erosion averaging 30 to 40 tons ha^{-1} $year^{-1}$ whereas; for United States and Europe the soil erosion rates are low averaging about 17 tons ha^{-1} $year^{-1}$ (Pimentel et al., 1995). Table 1.1 shows different regions affected by the water and wind erosion. Among all the regions shown in the table, the continent Asia has suffered a lot by water erosion and Malaysia is located in that region (Ng, 2003).

Table 1.1 Different regions affected by water and wind erosion

	Land area affected by Erosion (10^6 ha)	
Region	***Water Erosion***	***Wind Erosion***
Africa	227	186
Asia	441	222
South America	123	42
Central America	46	5
North America	60	35
Europe	114	42
Oceana	83	16
World	1094	548

Once the soil is detached from its point of origin, the process of sedimentation starts which includes transportation and deposition of the sediments. Deposition is the reverse process of erosion which is directly related to the carrying capacity of the flow as shown in Figure 1.2 (Shah et al., 2013). If the flow is inadequate to carry the sediments, the process of deposition occurs. Not all the detached soil particles reach the streams (Fu et al., 2010) but it usually ends up in the water ways which deteriorates the water quantity and quality, affects the marine life, and contributes to the higher costs of water maintenance (Verma et al., 2012).

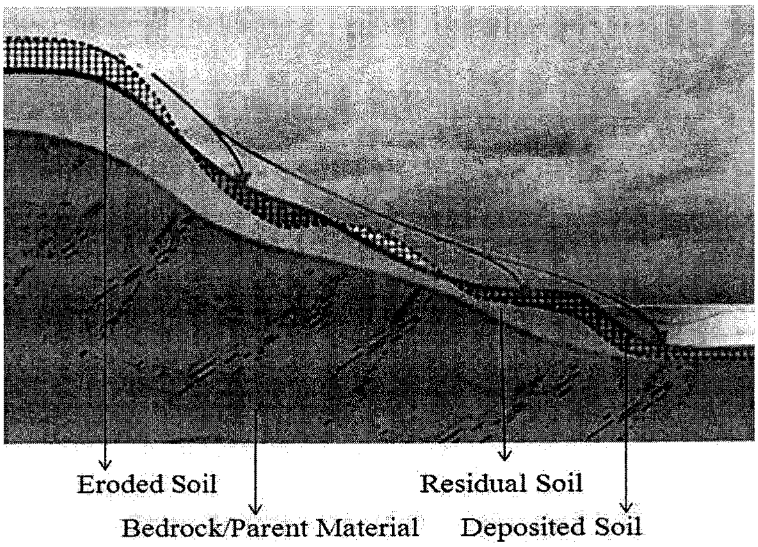


Figure 1.2 Phases of deposition process

Drastic change can be observed when the slow and steady erosion accumulates and erodes away a large portion of soil. For example if rainstorm detaches 2/5" of soil over 2.5 acres of land then the time it takes to recover those 13 tons of the top soil will take about 20 years of natural process. The soil which is lost is usually the nutrient rich upper layer of the soil which bears nutrients and high concentration of microorganism that helps improving the soil structure. However, the issue is considered problematic and is recommended to be prioritized (Shah et al., 2014).

Covering the exposed soil from the impact of rain drop by providing an adequate cover of vegetation is best recommended as a "first golden rule" (Wycherley, 1969). It has been suggested by the Agriculture Department, Ministry of Agriculture and Agro-based Industry Malaysia that planting grass and covering crops are among the agronomic practices for the immediate soil protection of the degraded lands (DOA, 2013).

Figure 1.3 shows the risk management framework which is necessary for the systematic functioning of a project. Concerning the thesis, this framework identifies the dominant factors responsible for the soil loss, estimates the impact of those agents towards the environment, mitigates the risk to an extent by using soil conservation techniques, and monitors the framework for the improvement of the project (Shong, 2010).

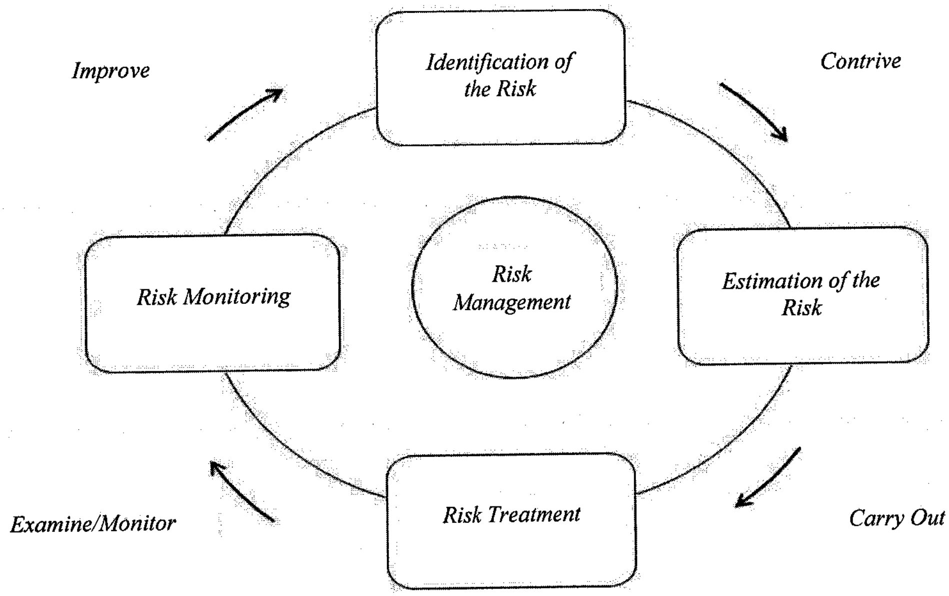


Figure 1.3 Risk management framework

1.2 Background of Research

The necessity of the fresh water has aroused in the last few decades due to the tremendous increment in the population growth. On the other side the impairment of the aquatic systems through several polluting sources in the form of effluents and runoff from the surrounding areas has raised (Muhammad Barzani et al., 2006). Rivers are the vital source of irrigation. It is essential for the industrial water supply and is the only source of domestic water supply. Consequently, controlling the river pollution is mandatory for the effective water management (Al-Badaii et al., 2013).

In the year 2010, the river water quality status of the Malaysian rivers was monitored. Out of 1055 monitoring stations, 10% of the stations were reported polluted, 40% of the stations were reported slightly polluted, and the remaining 50% were found clean. The status of clean rivers was 54% in year 2009, which slightly declined by the year 2010. Several pollutants were accounted for the decrement in the clean rivers among which the concentration of the suspended solids (SS) was found to be a threatening agent. The source of these SS was mainly the land clearing activities and the earthworks (DOE, 2010).

Among the polluting sources, the land use activities that is deforestation, overgrazing, urbanization, industrials activities, and roads construction possess serious threats to the aquatic system (Blanco-Canqui et al., 2008). However, this thesis relates to the soil loss obtained from the bare embankments during the construction phase and its consequences towards the surrounding environment in the form of water erosion, turbidity, and total suspended solids (TSS). The study was conducted to notice the contributions made by the bare embankments in worsening these parameters.

1.3 Problem Statement

It is convenient to control erosion at the source rather than removing the sediments from the storm water runoff. As a sediment source, the significance of roads construction cannot be disregarded as it may induce the similar rate of soil loss as attained from the agricultural lands (Ziegler and Giambelluca, 1997). The phase of highway construction removes the topsoil which is essential for the plant growth and makes the subsoil exposed and available for the detachment (De Oña et al., 2011). To reduce the impact of rain splash erosion which is the most common type of soil erosion on the exposed soil surfaces, re-vegetation is suggested to be the most viable erosion control technique which takes time to grow (Taha and Kaniraj, 2011). Therefore, the use of grass sod to control the surface erosion on the disturbed lands associated with the highways, is very common as an immediate soil shelter (Dollhopf et al., 2008).

No doubt, the fully grass covered surface provides the best protection. This study aimed to observe the immediate response of a partially covered native grass patches against the soil loss during the phase of embankments construction. If an optimum percentage of cover provides nearly the same results as for the fully grass covered surface for a particular rainfall event, then it would be best recommended as an economical and immediate soil conservation approach.

1.4 Research Objectives

The study aimed to provide such an approach that can immediately protect the bare embankments with the following specific objectives:

1. To compare the behavior of detached soil particles at different percentages of grass cover.
2. To estimate the presence of turbidity and total suspended solids caused by soil loss.
3. To propose the optimum percentage of cover suitable for the immediate soil protection.

1.5 Scope of Research

The research has been narrowed down to fulfill below scope:

- When rainfall occurs, water penetrates (infiltrate) the soil that fills the water capacity of the soil causing surface runoff. For this study infiltration is not calculated but to observe the similar effects on the experimental run and to allow the water to perforate some initial soil wetting was done using rainfall simulators to obtain the natural conditions on the slopes.
- This study was observed for the moderate rainfall events whereas; in Peninsular Malaysia the month of April, October, and November are considered to be the months of intense rainfall events. January usually remains dry which contributes to only 4.57% of the mean annual rainfall (Leong, 2007). Therefore, while considering the soil conservation practice

recommended in this study, climatic conditions should be taken into consideration.

- The slope angle chosen for the study represents the usually constructed road side slopes along the highways which limits that the result achieved are suitable for the slopes of 30° and less only.

- The study was purely based on the comparative analysis between the different plots. The results were attained directly from the experimental site which cannot be equated with the other sources.

- During the test run, it was observed that the turbidity rates were quite inappropriate at different intervals of time for which the reason was considered to be the disturbance of the settled sediments while collecting the water samples. For the experimental runs the water samples were collected from the top of the surface without disturbing the settled sediments (Murphy, 2011; Shah et al., 2013).

- The soil loss was manually observed by collecting the detached soil sediments received at the catchment outlet, while conducting the runs.

- The grass species selected for the experimental runs (non-structural soil conservation practice) was cow grass which is commonly available in Perak.

- The rainfall data used for conducting the experiments was collected from the Metrological Department Malaysia for Perak. The data obtained includes the past rainfall records from the year 1994 to 2011 for Lubuk Merbau station, from the year 1951 to 2011 for Sitiawan station, and from the year 1951 to 2011 for Ipoh station. Some missing data were observed which had probably caused by the human or instrumental error. However, the data analyzed for the study involves the recent rainfall records from the year 2005 to 2011 only.

1.6 Thesis Structure

This thesis contains five chapters as shown in Figure 1.4 which are arranged as explained below.

Chapter One includes the general description, background of research, problem statement, research objectives, and the scope of study. The purpose of this chapter is to over view the concept of the research and to lightly discuss that why the study is conducted.

Chapter Two thoroughly explains soil fundamentals, flow cycle, erosion phenomenon as affected by raindrop and overland flow (runoff). The background studies which relates to the soil loss generated from the embankments and the control practices commonly used to cope with the erosion setback were also studied.

Chapter Three explains the method of conducting research to obtain the objectives of the study which involves the study area, plots description, detailed drawings of the experimental area, the construction phases involved in making of the structure, soil sampling procedures, the way rainfall data used for Perak, and the frame work of the study which summarizes the experimental setup, performed.

Chapter Four explains the findings of the research which were obtained by the comparative field analysis between all the plots. Furthermore, it contains the discussions based on what was observed while running the experiments.

Chapter Five summarizes the entire study. In concluding the research, recommendations and possible future study were also presented.

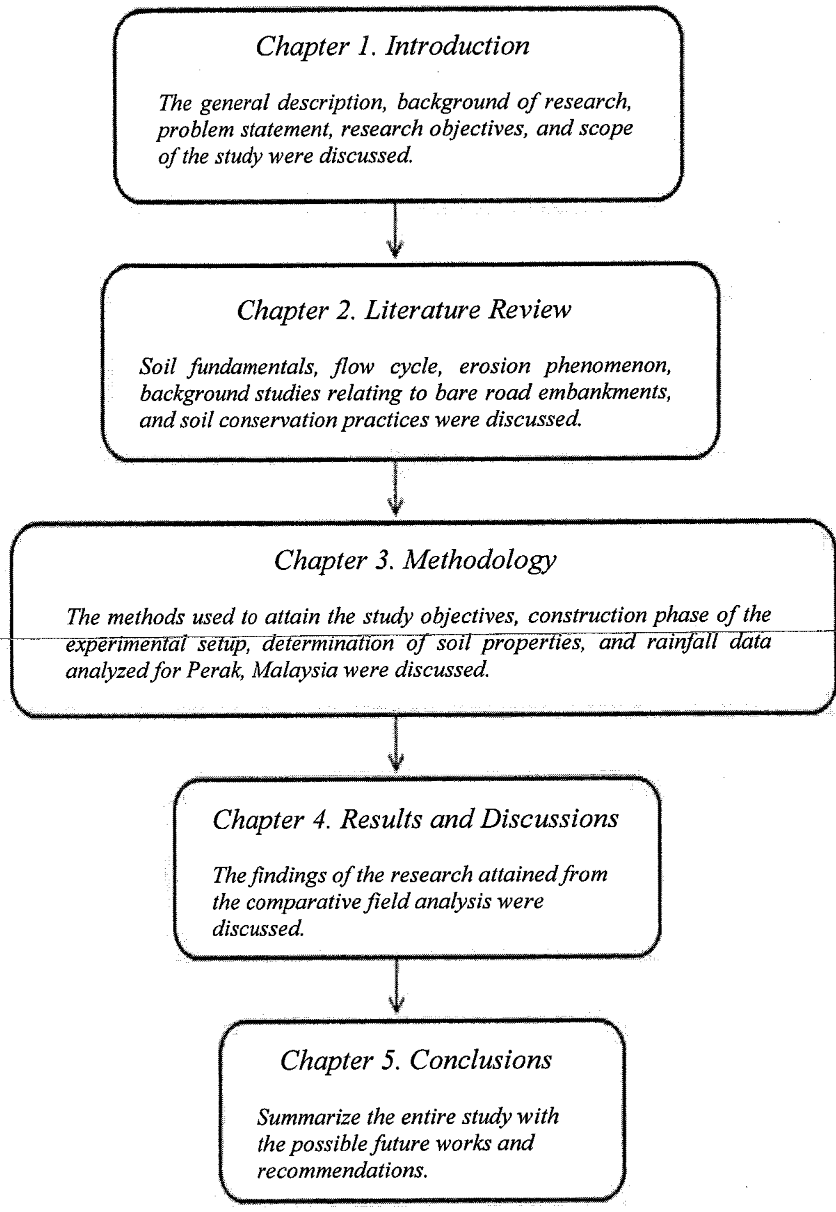


Figure 1.4 Thesis structure

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explores the basic soil fundamentals including soil composition and texture. The influence of hydrology of flows on land which affects the soil particles by means of rain drop erosion and the effects of overland flow on the soil surface leading to the notable problems have also been reviewed which ultimately ends up in streams and rivers causing adverse effects to the water-related activities. This study emphasizes the aspect of bare highway embankment on soil erosion, which usually remains exposed during the construction phase and is considered to be the primary source of sediment delivery to the streams. It further reviews the merits and demerits of several erosion control practices and focuses on the environmental friendly and immediate soil conservation practices. Lastly, based on the information gathered from the background studies, suggestions attained from the Department of Agriculture Perak, Malaysia (DOA), and the site visits conducted for the native soil conservation practice in Perak, the entire chapter was framed.

2.2 Preliminary Study

The excessive soil erosion is responsible for majority of the causes and is among the serious environmental problem the world faces. Several off-site and on-site impacts are linked with this issue leading from the soil particle detachment to the deterioration of the water quality.

Soil loss may occur through several means but this thesis concerns with the road embankments which belongs to the road constructions that usually remains bare and unprotected thus accumulates to the soil loss. Immediate protection is required to cover the exposed soil surface for which it is difficult to grow natural vegetation as the nutrient rich upper soil layer is already disturbed. Several studies have attempted to observe the soil loss from the road side slopes with the different parameters which are further discussed in this chapter to broaden the study scope.

The purpose of reviewing several soil conservation techniques was to come out with the concerns and observation of the researchers regarding their experiences. Every of the technique has been found prominent with the merits and demerits which vary with the soil type, slope inclination, slope type, and the climatic impacts. The practices reviewed cannot only be considered during the construction phase of the bare embankments as it has been found promising in controlling the soil loss even for the existing embankments.

The study was conducted in Perak, Malaysia for which the rainfall data from the year 2005 to 2011 was obtained from the Meteorological Department Malaysia. The focus of the study was to recommend such an approach which should be immediate and compatible with the existing environment. The slope instability increases with the steepness which is one important parameter of soil loss; however this study was only observed for the slope angle of 30° which is the representative of newly constructed road side slopes. The soil type observed was the sandy loam as the soil is mainly sandy in Perak.

The literature was reviewed in two parts that is Mulches and Vegetation Cover. Mulch covers with the different percentages have been reported adequate to conserve soil loss on the exposed soil surface. Its application is considered suitable for the "dry areas" where vegetation takes several years to establish (McLaughlin, 2007) whereas; vegetation cover showed significant results in controlling the soil loss for almost every climatic zone (Smets et al., 2008). This made the author more focused towards the vegetation cover. The study was conducted in a humid tropical region where rainfall is intermittent. Several studies witnessed the efficiency of shrubs and vetiver grass in diminishing the soil loss upon their maturity which takes several years to establish. This left the author with the option of grass cover only which germinates quickly and has been reported efficient by several researchers at different percentages.

To broaden the research area and to discuss this matter on the real ground conditions, it was decided to visit the Department of Agriculture (DOA) Perak, Malaysia in the presence of supervisor as shown in Figure 2.1. The aim of the visit was to determine the cover features being used to cope with the detachment of soil particles. However, planting grass (native grass cover) and cover crops were reported among the agronomic practices being commonly and widely used to control soil detachment on the road embankments by DOA (DOA, 2013).

Next, a survey was conducted which helped finding the common grass species available in Perak. The locations surveyed for this purpose were Simpang Pulai, Parit, Batu Gajah, Nursery Lahat Lama, and Nursery Station 18 Ipoh as shown in Figure 2.2. The purpose of the survey was to observe the agronomic practices which are being applied to the embankments, hill-slopes, constructions sites and roadsides for the erosion control as shown in Figure 2.3. The most commonly found grass species observed were the cow grass and vetiver grass species.

Based on the literature reviewed, surveys conducted in Perak, and the visit made to the DOA a discussion was held with the supervisor and co-supervisors which ended with the conclusions that to be within the frame work of the master's study different **percentage of native grass cover** must be observed as an immediate soil conservation approach as it grows quickly and is suitable for the immediate soil protection on the bare embankments.

Meeting with the Agriculture Officer

Discussions

Suggestions noted

Vetiver grass sample

Figure 2.1 Visit to the Department of Agriculture, Perak Malaysia

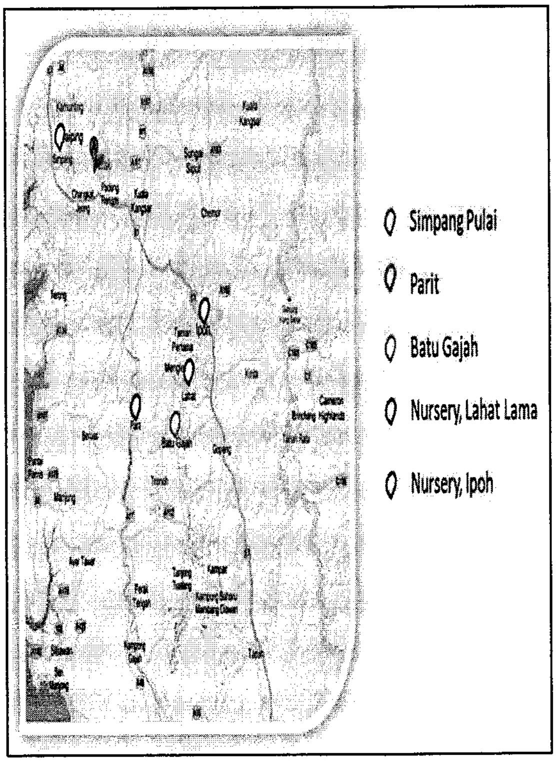
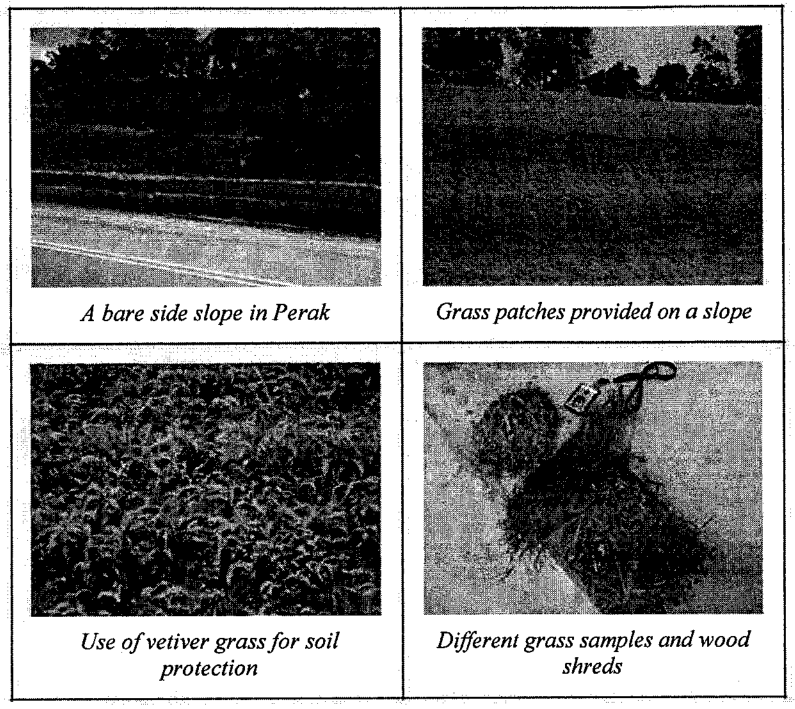


Figure 2.2 Survey locations in Perak, Malaysia



A bare side slope in Perak

Grass patches provided on a slope

Use of vetiver grass for soil protection

Different grass samples and wood shreds

Figure 2.3 Different vegetation covers for soil conservation

2.3 Soil Fundamentals

Soil is a structured porous medium, described as the skin of the earth which is biologically active and is found below the continental land surface on our earth. It nurtures various species of living organisms and acts as a necessary medium for the plant growth. It is closely engaged with the hydrological cycle of the earth and helps decomposing the waste products into the nutrients which are necessary for the revival of life on earth (Hillel, 1998).

The earth envelope where soil occurs and its formation is active is called "pedosphere" which is formed by the long term interaction of the four major spheres that is atmosphere (the layer of gases surrounding the earth), biosphere (the portion of earth's environment where living organisms exist), lithosphere (the phase containing minerals), and hydrosphere (the entire water body existing on or close to the earth surface) as illustrated in Figure 2.4. The pedosphere serves as a most vital sphere which correlates with all the other spheres that controls, regulates, and sustains various material cycling and flow (Qiguo, 2002).

Soil is composed of air (20-30%), mineral (45%), organic matter (1-5%), and water (20-30%) as illustrated in Figure 2.5. The physical properties of soil are greatly influenced by the composition of these components which affects soil texture, structure and porosity (McCauley et al., 2005). Soils are classified according to its texture which is composed of the proportion of clay, silt, and sand particles and is distinguished by its size. It is important to know the soil texture as it influences the water holding capacity of the soil, soil temperature, and the soil loss. The particles between 2 to 0.05 mm in diameter are termed as sand. Silt ranges between 0.05 to 0.002 mm in diameter and the clay particles are smaller than 0.002 mm in diameter as shown in Figure 2.6 (Brown, 2003). The water holding capacity of the coarse-textured soils (sand) is low so their response to the soil detachment is also low. The medium-textured soils have good water holding capacity (silt) and are highly erodible whereas; the fine-textured soils have high water holding capacity (clay) and their susceptibility to water erosion depends on the aggregation of the soil particles (Brady and Weil, 1999).

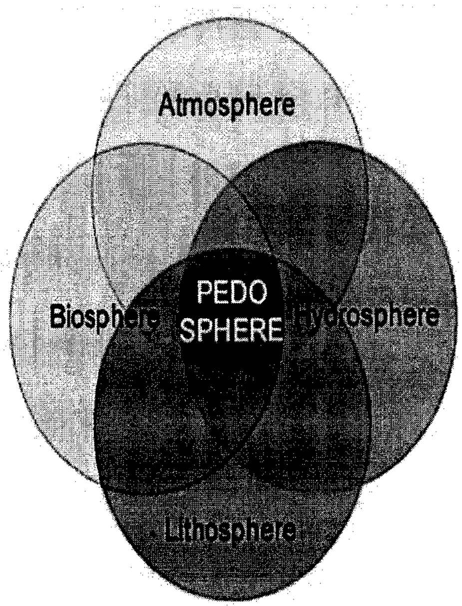


Figure 2.4 Relationship between spheres

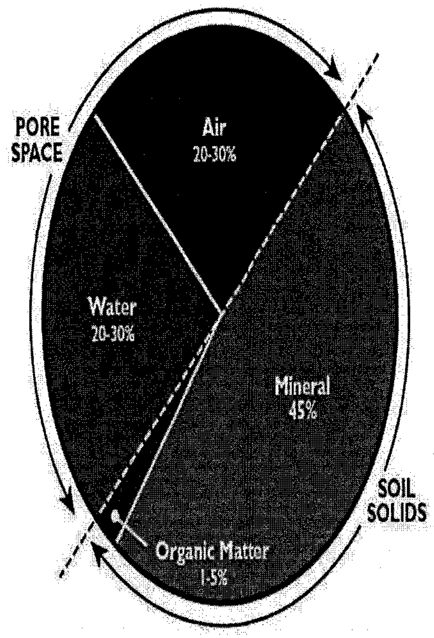


Figure 2.5 Soil composition

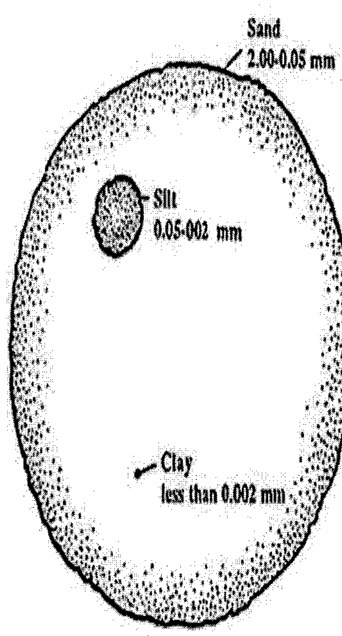


Figure 2.6 Size comparison between sand, silt, and clay

2.4 Hydrology of Flows on Land

To understand the concept of water erosion, the parameters of the hydrological cycle must be explained. The water cycle describes the movement of water above and below the ground surface as illustrated in Figure 2.7. The water that percolates into the ground surface through the soil pores is termed as infiltration. However, the water which is taken up by the trees and plants roots evaporates and released to the atmosphere in the process of transpiration. The process of evaporation occurs when water coverts from its liquid form to the vapor form and these vapors then condense, forming clouds which restart the cycle. The concern of this thesis relates to the water that falls to earth in the form of precipitation and flow towards the streams affecting the soil particles as runoff. These flowing particles accumulate to the streams and lakes and the process of deposition occurs (Peirce et al., 1998; David Nyman, 2002).

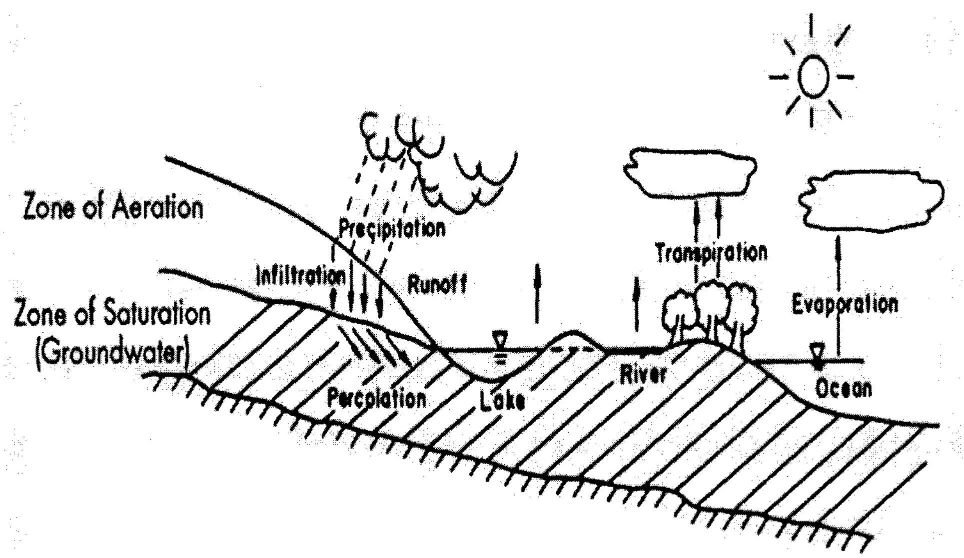


Figure 2.7 The hydrologic cycle

2.5 Soil Erosion

Soil erosion is a global environmental, social, and economic issue which is a widespread problem that is not only liable for the loss of fertile top soil and severe land degradation but it has been a major threat to the sustainable development of a society (Wang et al., 2013). It is a gradual process which occurs when the soil particles are eroded away from their point of origin by means of detachment and transport through water and wind. Water is considered to be the most forceful and prime factor of soil erosion which results from the occurrence of rainfall (Sekitar, 1996). During rainfall, the force of the falling drop is directed towards the surface of the soil which splashes-out and detaches the soil particle. The pore space in the soil allows water to percolate until it arrive the saturated zone which then contributes to the surface runoff and is responsible for the soil particles displacement to the water channels (Mukri, 2003). It is an inevitable process which cannot be disregarded (Bakr et al., 2012), as it contributes to the process of sedimentation which is accountable for one of the major off-site problems (Toy et al., 2002). It varies with the different topographies, soil type, and erosion pattern which raise the concentration of impurities in the water bodies therefore; its treatment at the source is recommended (Deletic, 2001).

2.5.1 Classification of Erosion

The erosion that occurs due to the natural environment, mainly due to the climatic conditions is termed as geological erosion which is caused by the action of wind, water, gravity, and temperature variations whereas; accelerated erosion occurs when the soil erodes at much more rapid pace by human activities than under natural conditions or when the equilibrium of soil structure is disturbed and intensified by the human activities. This is mainly due to the de-forestation, cultivation, roads construction, and housing developments (Mukri, 2003).

2.5.2 Types of Erosion

Soil erosion may occur at an alarming rate or it may continue relatively unnoticed. Several factors including soil texture, slope steepness, land cover, and the intensity of severe rainfall are considered to be the vital agents in affecting the magnitude of the water erosion (Ng, 2003). Erosion by water comprises a number of forms such as rain splash erosion, sheet erosion, rill erosion, gully erosion, river bank erosion, tunnel erosion, land slide, mass movement, and wind erosion.

When the soil particles are dislodged under the force of falling raindrop then the process is considered to be the evidence of rain splash erosion which is the first stage of water erosion process. When these loose soil particles move laterally in a uniform layer, sheet erosion occurs. Rills are shallow channels that can be meters long but not more than 30 cm deep. Gullies are considered to be wide and deep, in other words the depth is twice the width and can be easily seen as illustrated in Figure 2.8 (EI-swaify et al., 1982). River bank erosion erodes the bank of a stream or river under the natural conditions which constantly adjust the channels shape. Tunnel erosion occurs when the weathered rock and soil texture changes. It usually develops beneath the surface and is predicted as an insidious form of erosion. Land sliding usually occurs in the terrain of steep mountainous region caused by the heavy rainfall events. Unstable slopes contribute huge quantity of sediments to the channels in the form of mass movement and wind erosion occurs usually on the dry lands where the soil surface is bare and exposed containing loose fine materials (Sekitar, 1996).

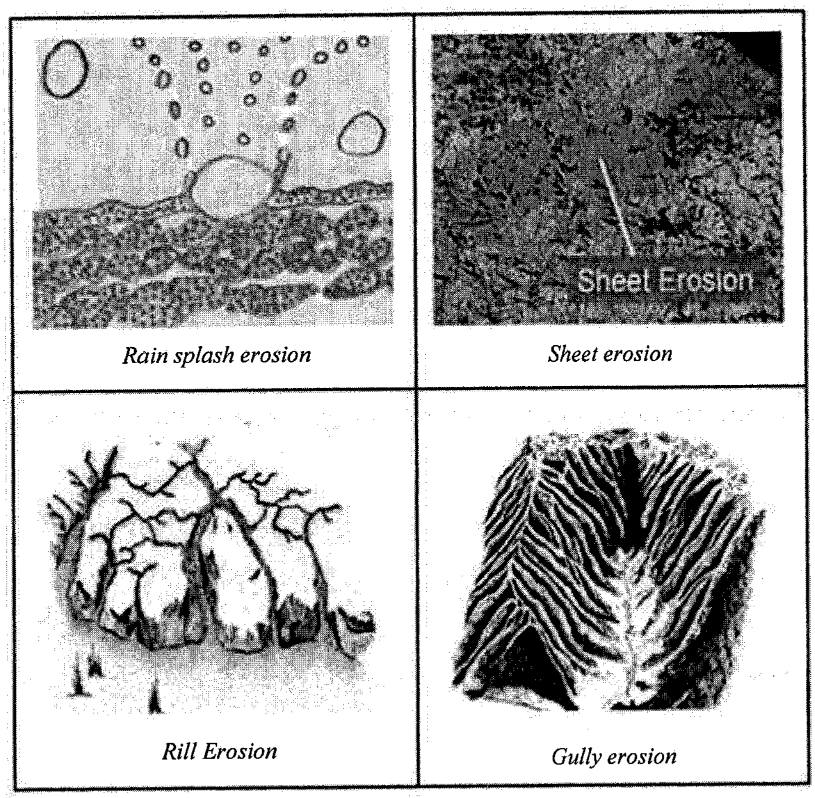


Figure 2.8 Types of erosion

2.5.3 Affects of Erosion

The affects of erosion are rarely acknowledged as it has both on-site and off-site negative impacts. Water erosion's main on-site impact (at the place where the soil is detached) is the loss of nutrient rich top layer of the soil which affects the soil productivity resulting in the decline of crop production. In addition to the on-site affects these detached soil particles may transport to the considerable distances raising the off-site problems (where ever the soil ends up). This causes water contamination, increased turbidity, and disruption of ecosystem of the lakes which are responsible for the economic losses and environmental degradation (Delmas et al., 2012).

2.5.4 How Raindrop and Runoff Dislodge Soil Particles

The detachment process of soil particle relates with the energy required to soak the soil surface (Rienzi et al., 2013). The raindrop ability to detach the soil particles relies on the mass and velocity of the raindrop striking the soil surface (Angulo-Martinez et al., 2012). Raindrop impact induced erosion begins when the raindrop energy initiates soil particles detachment from the soil surface. It loosens the soil particles which are then splashed and lifted into the surface flow to the downstream (Kinnell, 2005). The steps in drop-cater formation when rainfall occurs and the effects of overland flow on the soil surface are further elaborated under this heading.

Figure 2.9 illustrates the way how rain drop comes in contact to the soil particles when the soil surface is bare which then disperse the soil particles with the passage of time and results in the separation of the soil from its origin (Schwab et al., 1992).

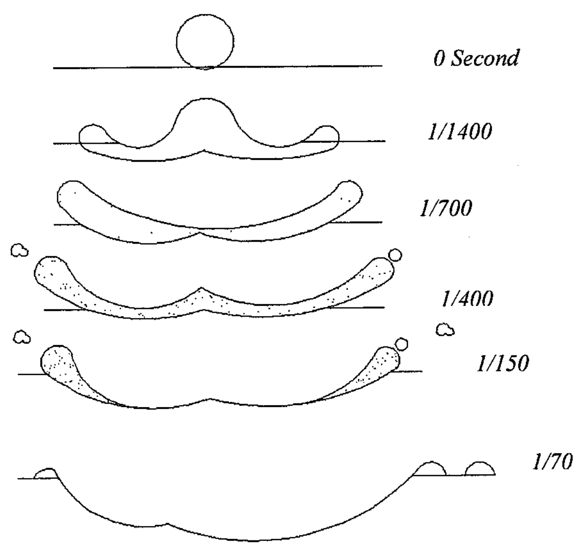


Figure 2.9 Raindrop impact induced erosion (adapted and modified using Auto-cad)

Figure 2.10 illustrates the occurrence of the overland flow which happens when the water carrying capacity of the soil pores is filled. It strikes the soil particles with the flow velocity and forms depression which further develops the head wall and scours at the base that impairs the soil structure and results in the formation of gully floor (Morgan, 2009).

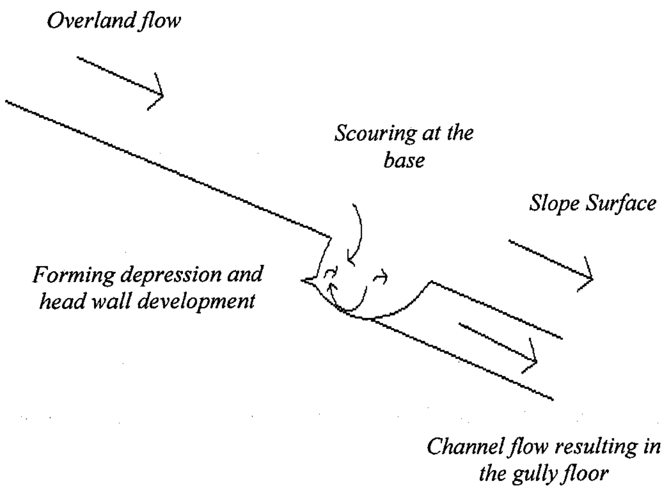


Figure 2.10 Affects of overland flow (adapted and modified using Auto-cad)

2.6 Sedimentation

Soil erosion is considered responsible for the concentration of sediments in the water channels. The process of sedimentation takes place once the soil particles are eroded, transported, and deposited to another place (Ji, 2008). The time a particle takes to remain in suspension depends on its size. The lighter the soil particle, the higher would be its stay in suspension. When these carried soil particles find their way to bottom of a water body, several problems associated with the water quantity and quality are raised (Franklin, 2003) among which the major highlighted issues are worsening of the potable water and deposition in the water reservoirs (Enters, 1998). These problems are linked with the factors like particle size, water color, and other minerals which influence the water turbidity and the concentration of the suspended sediments in the water channel (Sun et al., 2001).

2.6.1 Total Suspended Solids

To predict the presence of suspended sediments concentration in the water body it is significant to determine the presence of Total suspended solids (TSS) in it which measures the actual weight of the material per volume of water (Yahyapour and Golshan, 2013) .

2.6.1.1 Sediments settling process

Sediment size varies in the natural water bodies which are classified as cohesive or non-cohesive sediments. The inter-particle bonding forces among the cohesive sediments allow them to flocculate. These tiny particles stick each other as aggregates of thousands of particles. However, the diameter of the non-cohesive particles is large and the particles are easily separable. Silt particles possess both cohesive and non-cohesive properties which allow these particles to remain in suspension far longer than sand grains. These particles then form the bed load by moving near or on the bed as shown in Figure 2.11 (Ji, 2008; Floyd, 2012).

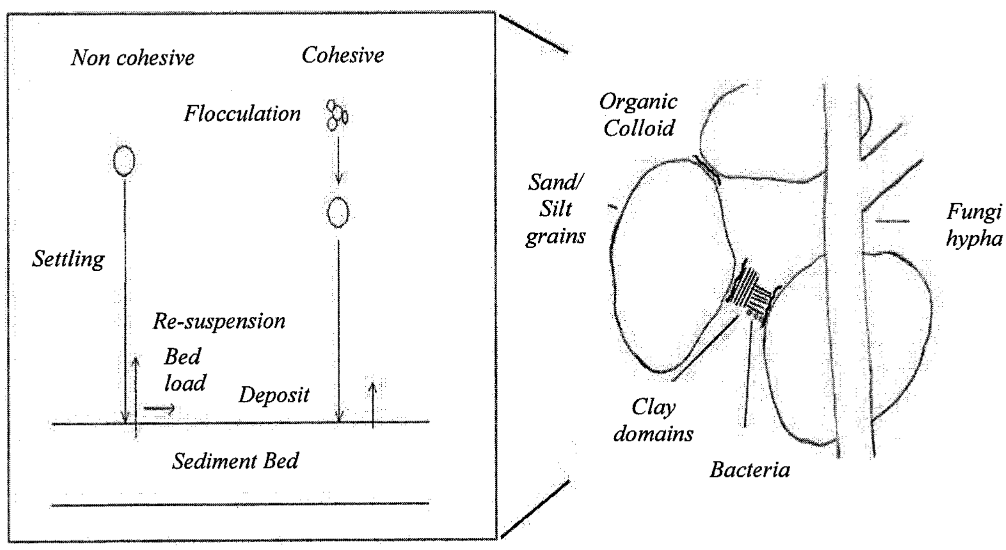


Figure 2.11 Sediment transport process (adapted and modified using Auto-cad)

2.6.1.2 Problems associated with the suspended particles

The sediment particles may attach with the toxic chemicals and nutrients on land and influx into the water body where these pollutants may either settle or become soluble with the water column (Ji, 2008; Chèvre et al., 2007). This deteriorates the water quality for which higher cost of water treatment is required (Bilotta and Brazier, 2008). It further influences the water temperature by reducing the capability of light to penetrate which affects the presence of dissolved oxygen in water. The sunlight absorbed by the suspended particles raise the water temperature which reduces the oxygen holding capacity of the warm water (SOM, 2013). These particles obstruct the penetration of sunlight which is necessary for the plant to produce dissolved oxygen hence the level of dissolved oxygen in the water is further reduced (Swietlik et al., 2003). The concentration of these particles is reported life threatening to the aquatic life population. Troublesome infection like abrasion of gills is very common among the fish species. Moreover, it influences the food finding ability of fishes due to the reduced visibility (Packman et al., 1999).

2.6.2 Turbidity

Turbidity is one of the physical characteristics of the water which does not allow light to transmit in a straight line and relates to the darkness of water due to the presence of the suspended matter and impurities in the form organic matter (algae, bacteria, etc.), inorganic matter (silt, clays, etc.), and other contaminants (nutrients, heavy metals, etc.) (Dieter, 1990). The way how light scatters the suspended matter is illustrated in Figure 2.12 which shows that light can either be transmitted or reflected when it comes in contact with the a suspended matter (Davies-Colley and Smith, 2001).

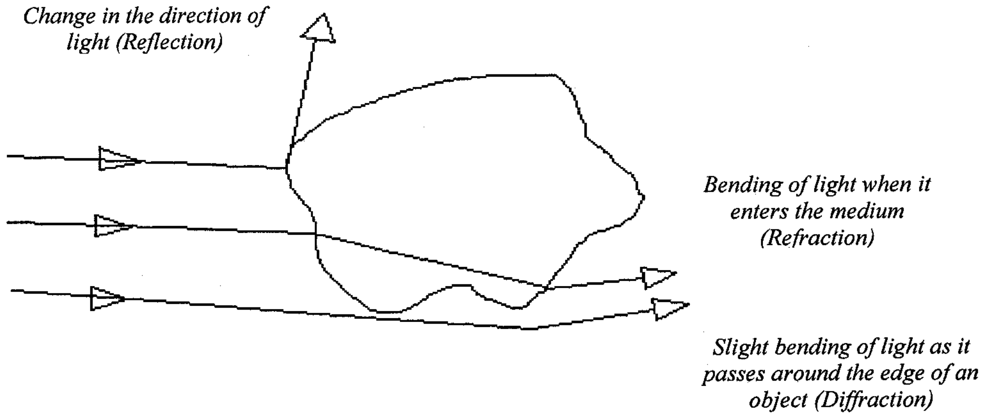


Figure 2.12 Scattering of light by a suspended particle (adapted and modified using Auto-cad)

2.7 Contribution of Embankments towards Soil Loss

When cities grow new highways are constructed which contributes to the severe soil loss and runoff from the construction activities that are among the most problematic non-point source of water pollution. It is such a process which cannot be eliminated completely; however it can be mitigated by applying several structural and soil bio-engineering management practices (Bakr et al., 2012).

Roads, regardless of their small areal periphery cannot be neglected when compared with the agricultural lands in generating erosion (Ziegler and Giambelluca, 1997). Erosion measured from the barren lands are similar to the one measured at the road embankments (Cerdà, 2007). By the year 2050 it is predicted that the urban population would reach the plateau by about nearly 9.5 billion and the majority of the increase is expected in the developing countries like Africa and Asia which are severely affected by the water pollution. The construction activities like roads development contributes to the significant amount of pollutants like suspended solids by means of runoff which affects the management of the urban water ecosystems (Chow et al., 2011).

Both human activities and natural conditions are reported responsible for the occurrence of soil loss. The man-made erosion occurs through agricultural activities, logging roads, construction and public works (Wycherley, 1969; de Panamá, 2012). The newly constructed highways are regarded as the primary agent of soil loss which remains bare during the construction phase and are rarely covered that makes them susceptible to surface erosion (De Oña et al., 2009). While constructing a highway in China, the construction spoils obtained per 100 km were 2-5 million m^3 (Dong et al., 2012). Figure 2.13 illustrates the view of newly constructed embankment which remained bare and induced higher erosion rates. The development of road networks results in high erosion rates which spoils natural environment. Unfortunately, the awareness to this issue is still very limited (Cerdà, 2007). On the other side, the need of roads for the economic development of the country is necessary whereas; it detrimental impact to the local environment cannot be disregarded (Dong et al., 2012). However, immediate protection in the form of surface cover can mitigate this problem but the soil on the newly constructed road embankments is poorly structured, infertile, and low in nutrients which restrict plant growth that shelters the soil against soil erosion (De Oña et al., 2011).

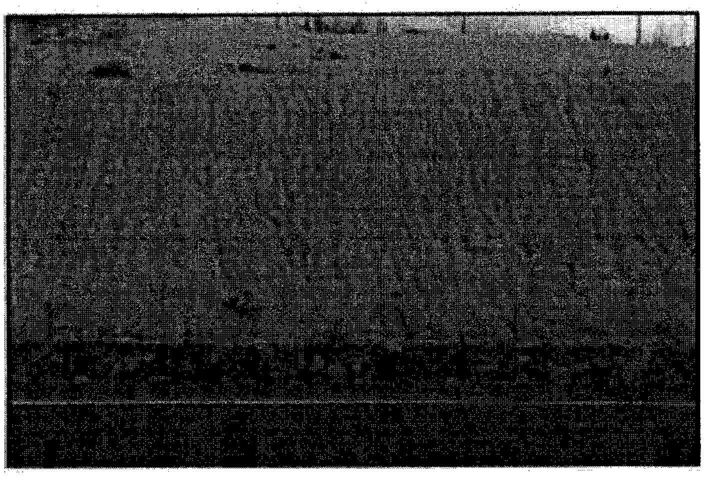


Figure 2.13 View of the newly constructed road embankment

Erosion from road surfaces accounts for the drastic influx of sediments into the streams which contributes by nearly 50 % of the sediment load (Hogans et al., 1986). River sediment loads have been greatly influenced by the rapid development during the last few decades for which human activities are reported responsible for nearly

80% of the total sediment load which contributes to the catchment basins (Fatt, 1985). The sediment concentration in the basin is mainly due to the development phase (Lai et al., 1996). There has been an increasing concern on the problematic issue of soil erosion for many river systems, which not only impairs soil productivity but is also considered responsible for the sediment yields in the river channels that give rise to the siltation problems and deteriorates water quality (Gregersen et al., 2003). However, among the general causes responsible for the worsening of the embankments are the imprecise construction of the embankment gradients, rain splash erosion and the inadequate maintenance practice (Islam et al., 2013).

Various issues have been pointed by several studies concerning sediment transport in the recent years. The runoff flow from the construction site washes away the sediments which causes detrimental impacts on fauna and flora (Yahyapour and Golshan, 2013). The storm water runoff which flows toward the water channel by means of roads carries sediments along with the toxic contaminants associated with the road vehicles (Coffin, 2007). The deposition process also reduces the water carrying capacity of the drain which then leads to the overflow of the drain (Sharma, 2012). A study reported that the maximum amount of suspended solids accumulated in the river basins is due to the negligible ground coverage. The study further estimated that during the year 1965-1990, Ubolratana dam received the mean yearly siltation of 1.50 million tons $year^{-1}$ which worsened the capacity by 32.90 million m^3 (Sthiannopkao et al., 2007).

The embankments usually get damaged by water erosion on the road side slopes which is difficult to maintain and is very costly therefore the prediction of erosion rates and its remediation measures are necessary (Xu et al., 2009).

2.8 Soil Conservation Practices

Soil is degrading at rates faster than its formation and seeks attention for its conservation (Blanco-Canqui et al., 2008). The purpose of providing soil conservation practices is to mitigate the accelerated rates of soil erosion which can be conserved either by traditional way or by means of structural controls (de Panamá, 2012). This study concerns towards the traditional soil conservation techniques which are useful to stabilize shallow slopes. These techniques are durable, economical, native, and compatible to the local environment (Giuseppe Bonati, 2013).

To prevent soil from washing away, professionals, planners, and landscape designers are provided with the variety of methods at the disposal to retain soil on the surface. It is therefore required to key out the most feasible practice which can assist in controlling erosion rates and runoff as per the requirement and suitability of the land geography and the climatic condition (Shah et al., 2012).

Several soil conservation techniques are being used all around the world to shelter soil from water and wind erosion. However, the traditional soil conservation practices studied in this literature were limited, based on the guidelines recommended for the prevention and control of soil loss and siltation in Malaysia (Sekitar, 1996) as shown in Figure 2.14. The literature was reviewed in two parts that is mulches and vegetative cover. Mulches were further sub divided into organic and in-organic mulches. The agricultural straws, wood strands, hydro mulching, and wood shreds were among the organic mulches which decay over time and are not permanent. The gravel-sand mulch and the plastic mulch were among the in-organic mulches which last longer but it does not decompose. For the vegetative cover, plant materials like shrub cover, vetiver grass, and native grass species were among the most commonly used soil conservation practices used for the gradual slope protection and its stabilization.

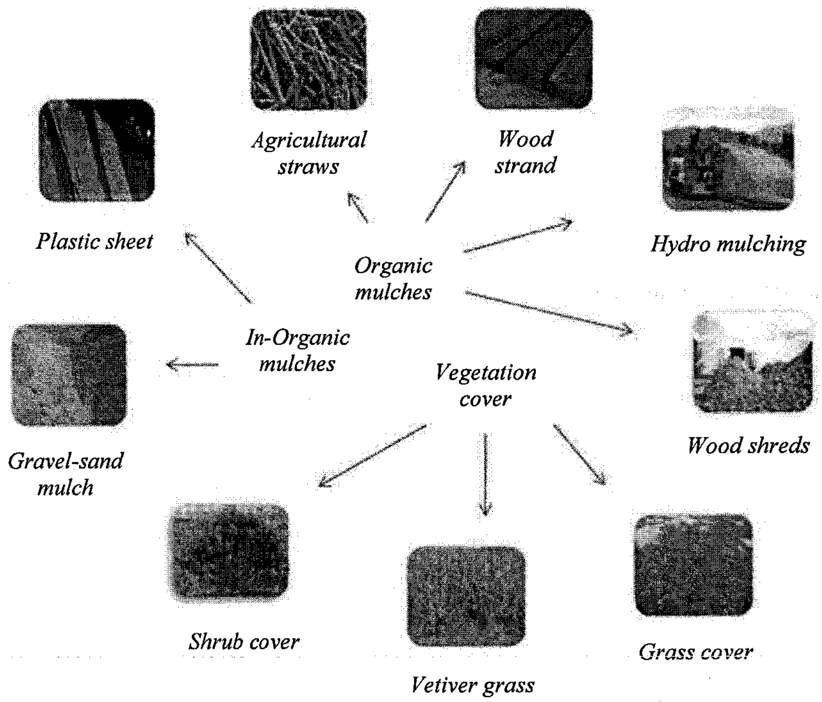


Figure 2.14 Erosion control practices studied in the literature review

2.8.1 Mulches

A proficient method to conserve soil on the exposed area by coating the soil surface is termed as mulching which enhances water infiltration, moderates soil temperature by conserving soil water, reduces surface runoff, and hinders soil erosion (Adekalu et al., 2007; Singer and Martin, 2005). It acts as roughness elements which slow down the flow velocity and trap the detached soil particles by forming mini-dams (Foltz, 2012) however, when subjected to erosive concentrated flow, it may float away (Sekitar, 1996). There are two basic kinds of mulches which are discussed below with the merits and demerits.

2.8.1.1 Organic mulches

Organic mulches are those which get decomposed with the passage of time and require excess amount of nitrogen for their decomposition. It adds nutrients to the soil, and attracts micro-organisms whose by-product improves the soil structure (Bajorienė et al., 2013).

For road related construction projects, agricultural straws have been favored to diminish rain splash erosion (Peterfeso, 2012). The soil loss from forest road cut and fill inclinations can be reduced by 80% if the soil surface is protected by 96% of the straw cover (Burroughs Jr and King, 1989). The cornstalk residue reduced soil loss from a silt loam by 75% under simulated rainfall event of 56 mm hr^{-1} and an additional concentrated flow of 9 L min^{-1} (Brown et al., 1989). Straws are considered effective, cheap, readily available, and easy to implement. Although it is a convenient approach but its implementation causes serious health risk to the workers as it gets shattered carrying dust particles (Foltz and Copeland, 2009). Furthermore, its potency is affected by the different climatic conditions which may decompose it ahead of time (Foltz and Dooley, 2003).

For the production of wood strands wood veneer material is used for which controlled dimensions are required in the manufacturing process. The strands are cut to accurate width and length (Foltz, 2012). Strands are considered equally effective as straws in conserving soil loss and reducing runoff. It does not contain weeds and dust particles like straws and are obtained from the stuff that would otherwise be wasted. A three-dimensional layer of strands have a high structural integrity which obtains a secure matrix that prevents rill formation (Foltz and Copeland, 2009). It showed remarkable results in controlling dust emissions from the disturbed soil areas and has been found prominent in reducing wind induced-erosion. Depending on the strand's length, thickness, and width it was found stable to the wind speed of 18 m s^{-1} (Copeland et al., 2009). The soil loss conserved at 67% of straw cover is as effective as applying 48% of the strand cover (McLaughlin, 2007). Similarly, an optimal strand cover of 50% performed well in controlling soil loss both for sandy loam and gravelly sand (Foltz, 2012).

Hydro mulching contains a mixture of shredded wood fiber and a stabilizing liquid, which is desirable for the soil disturbed areas. It is suitable for the immediate and temporary soil protection. It dries in about 24 hours and is recoated to remain effective throughout the rainy season (BMP, 2011). Its application is feasible to any site (Fay et al., 2012). Therefore it has been widely practiced during the formation of highway and road construction activities which involve bare road side slopes, and the embankments that remain exposed to water erosion. Its application has been reported effective for the moderate rainstorms and not for the extreme rainfall events (>70 mm hr^{-1}). Furthermore, it is reported suitable for the post fire soil conservation measures (Wohlgemuth et al., 2011). A study investigated that the soil detachment can be reduced from the impact of raindrop by immediately applying hydro mulch to the exposed soil areas. They further inspected that its application reduced soil loss by 90% for the first year, which was then decreased by 50-77% next year whereas; for the third year there was not observed any significant reduction in soil loss (Kwok et al., 2008). Furthermore, it is reported to be less effective in the dry seasons as it require large quantity of water to assure vegetation formation (CTIP, 2013).

Wood shreds are formed when small diameter tree branches are shredded on-site (Foltz and Wagenbrenner, 2010). Its production does not require specific dimensions as for the wood strands. Shreds forms small dikes which traps sediment particles and retain water (Foltz and Copeland, 2009). A study proposed that during the road construction phase, trees and woody debris which is removed should be rigged on-site to make its use more valuable for mitigating soil loss which reduces the transportation cost as well (Groenier and Showers, 2004). It restricts weed growth and produces less dust than straws. 30% of the shred cover is reported equally effective to 70% of the straw cover (Groenier et al., 2005). A study investigated the response of sandy loam and gravelly sand on a small scale at different percentage of cover with the slope inclination of 30%. It was recommended that 50% of the shred cover is adequate for the fine grain soil and 70% of the shred cover is appropriate for the coarse grain soil. However, the mixture obtained from the grinded shreds produces majority of the fine materials which cannot resist the runoff event (Foltz, 2012). Furthermore, it was investigated that the ground coverage of 29-36% was lost in a year-long study when wood shreds, and straws were applied for conserving soil in an exposed area whereas; strands remained effective and intact to the ground surface (McLaughlin, 2007).

2.8.1.2 In-Organic mulches

Application of In-organic mulches is considered to be a permanent technique which does not decompose and gives zero nutritional value to the plants that affects the presence of microorganisms in the soil structure (Masciandaro et al., 2004).

Application of gravel-sand mulch is a traditional technique which modifies the hydrological process of the soil. Its presence acts as a roughness element which deflates surface runoff and water erosion. It further traps the dust particles and constantly reduces the process of wind erosion (Li et al., 2001). It is widely implemented for the road side slope stabilization. However, its seedbed is difficult to prepare for which proper compaction and care is required for not allowing the soil to mix with the gravel-sand layer (Li, 2003). It was experimentally examined that with the varying percentage of stone cover that is 0%, 5.1%, and 20.8% the flow velocity and sediment yield decreased. However, not only the percentage but also the size of the cover is an influential factor as in the fields, the mixture is composed of different thickness, sizes and random placement (Guo et al., 2010). At different wind velocities from 10 to 26 ms^{-1}, pebble mulch was found effective in reducing the wind erosion by 84 to 96 % (Li et al., 2001). The soil temperature significantly increases by using the gravel mulch which causes evaporation losses during the hot season. It was further observed that at the soil depth of 3 cm and 10 cm, the mean increase in the soil temperature was increased by 0.97°C and 1.5°C respectively which was measured for 20 days in a study (Nachtergaele et al., 1998).

For the temporary protection, non-erodible plastic sheets of hard wearing and specified thickness have been used to protect the exposed soil areas inclined to soil erosion. The approach is simple to implement which provides immediate soil protection (Sekitar, 1996). It further maintains soil temperature and curbs the weed growth (Wan and El-Swaify, 1999). However, its impervious nature does not allow air and water to penetrate the soil pores which stops the soil to breath, impedes infiltration, damages plant roots and the affects the microbes within the soil zone (Grandy and Conde, 2007). The minimum plastic thickness recommended should be 6 millimeters, the edges of which must be implanted 6 inches in the soil. It must be laid firmly on the top of the soil supported by the sand bags which must be placed no less than 10 feet apart (ITD, 2011).

2.8.2 Vegetation Cover

Road side slopes have been identified to induce severe water erosion and surface runoff for which re-vegetation is considered to be the most effective way to restore the degraded soil (Xu et al., 2006; Calvo-Cases et al., 2003; Arnaez et al., 2004; Garcia-Estringana et al., 2011). The significance of cover in controlling the soil loss especially on the slopes is due to its capability of improving the soil stability through both its belowground and aboveground biomass (Hudek, 2013). Furthermore, it absorb the raindrop energy, intercept the direct impact of the rainfall, reduce the runoff velocity which retards the erosion process, enhance biological activity of soil, and decrease the amount of water in soil by means of transpiration which results in reduced runoff (Thakore, 2006; Zuazo et al., 2011; Marques et al., 2007; Li et al., 2011). It further improves the mechanical strength of the soil due to the root system which binds the soil particles (Mishra et al., 2006). It is considered to be the main factor which influences the interrill erosion and surface runoff, which was agreed by the studies of *"Bedunah et al., 1986; Wood et al., 1987; Gutierrez et al., 1988; Johnson et al., 1988; Wilcox et al., 1989; and Blackburn et al., 1992"* (Gutierrez and Hernandez, 1996). In the short term, native vegetation cover mitigates the soil loss which intercepts and softens the raindrop impact whereas; in the long term, it enhances water infiltration and increases soil stability (Zuazo et al., 2011). However, for almost every climatic zone vegetation cover has been found significant in controlling the soil loss whereas; its effectiveness can only be realized once it is fully matured (Smets et al., 2008).

2.8.2.1 Agronomic practices

To reduce erosion rates, re-vegetation is widely used for road-fill restoration. Among the agronomic practices, the use of local selected species is common due to the quick germination and its compatibility with the local environment (Tormo et al., 2007). The use of vegetation covers like shrubs and grasses naturally recovers the road side gradients and provides valuable resistance to the surface runoff and soil erosion (Negishi et al., 2006). Comparatively, shrub covers are considered more effective to mitigate soil detachment than the grass covers (Xiao et al., 2011). It nullifies the wind impact and allows soil deposition around it (Ambatzis et al., 2003). Besides conserving soil loss, shrubs are capable of improving the soil quality due to its potential of fixing nitrogen which is necessary to revive organic matter within the soil zone (Garcia-Estringana et al., 2011). It further accumulates nutrient which improves soil fertility (Wezel et al., 2000; Ambatzis et al., 2003). A study stated that the soil loss and surface runoff obtained from the exposed soil surface were 150 and 82 times, respectively, of those for shrub covered plot in the Yanhe Watershed of the Loess Plateau (Shen et al., 2006). Another study analyzed the average runoff and soil loss rates from the shrub and grass covered surface under the rainfall events of 45 mm hr^{-1}, 87 mm hr^{-1}, and 127 mm hr^{-1}. For the rainfall event of 45 mm hr^{-1} the average runoff rates obtained from the shrub cover surface were higher than that of the grass covered surface whereas; for the rainfall events of 87 mm hr^{-1} and 127 mm hr^{-1} shrub covered surface performed well to slow down the average runoff rates. Moreover, reduced average soil loss rates were observed from the shrub covered surface for all the rainfall events (Xiao et al., 2011). However, shrubs were found ineffective during the establishment period as they were too small to deliver any significant output in reducing the soil loss (Marques et al., 2007).

The use of vetiver grass cover is very common for slope stabilization and erosion control on the road embankments in Malaysia due to its root reinforcement capability in the soil which enhances slope stability (Hengchaovanich and Nilaweera, 1996). The roots grab the soil particles firmly and once established it is very difficult to root out. It is a sturdy grass that originates up to 1 meter wide at its base (Sekitar, 1996) and descends vertically up to 2-3 meters in the first year which may extend up to 5 meters for the tropical regions whereas; above the ground surface it may reaches up to 2 meters (Truong and Loch, 2004). If planted across the slope the row spacing should not be less than 1 meter whereas; for bunches the spacing should be 10-15 centimeters (Sanguankaeo et al., 2000). In China, during the recent few years, the use of vetiver grass has been popularized on the highways and railways due to its ability of restricting the soil displacement (Truong and Loch, 2004). Similarly, its use is very common in Bangladesh for the soil protection on the road embankments (Islam et al., 2013). In humid regions it has been found effective for soil protection whereas; it cannot survive in the temperate regions. Moreover, it takes too long to germinate by nearly around two years for the development of thick grass hedges and to become fully effective (Xiao et al., 2010).

The use of grass cover is a common native technique to conserve soil and water on the inclined planes adjacent to the highways, roads, and railways in Japan, China, Western Europe, and United States. It is suggested to be the most advisable natural soil protective layer because of its relatively dense cover (Cao et al., 2006). Road surfaces are naturally recovered by the re-vegetation of grass and shrub species (Negishi et al., 2006). To ensure adaptability and economical approach for the desired stabilization and protection, use of native grass cover has been recommended for different slope angles whereas; on the inclinations where stronger protection is required the deep rooted shrubs and trees can be used (EPA, 2013). The quick germination of grass provides complete cover with a dense root system which strengthens the soil (De Baets et al., 2006). It hinders the direct impact of rain drop which does not allow the soil particles to scatter and acts as a filter which entraps the soil particles (Deletic, 2001). It further reduces the overland flow due to its high roughness which allows the water to infiltrate (Zuazo et al., 2011) and helps preventing surficial erosion (Schor and Gray, 2007). A study observed the erosion rates under the middle rain, heavy rain, rainstorm, and heavy storm for the grass covered plot (A), mulch covered plot (B), and bare plot (C). For the entire rainfall events bare plot performed worst. However, under the middle rainfall intensity mulch covered surface conserved more soil compared to grass covered surface whereas; for the heavy rain, rainstorm, and heavy storm the erosion rates obtained from the grass covered surface were comparatively lower than that of mulch covered surface (Li et al., 2011). The ground cover is usually established in three ways that is by hydro-seeding or hydro-mulching, standard seeding, and sodding. Hydro-seeding has been already discussed in the section of Organic mulches. Standard seeding is done when the seeds are mechanically scattered or by means of hand (Franklin, 2003) which nearly takes around 14 months to enhance the density of the cover (Elseroad et al., 2003) whereas; a sod is a section of a covered grass surface with the soil beneath it held together by the roots. It is such an approach which can be applied on the bare soil surface for the immediate protection (Franklin, 2003). The research data attained from the Montana State University, U.S stated that a newly built road gradient (1V:2.5H) treated with the native grass sod yielded a soil loss of 0.6 tons/hectare/year whereas; the similar gradient treated with hydro seed yielded a soil loss of 1-2 tons/hectare/year (DOT, 2013).

2.9 Selection of the Soil Conservation Practice

The study aimed to provide immediate shelter to the bare embankments for which it was necessary to select such an approach that should be readily available, easy to apply, establishes effective erosion control, and should meet the environmental sensitivity of the area. However, based on the merits and de-merits studied for different traditional soil conservation practices, surveys conducted in Perak, and the visit made to DOA. A frame work was prepared as illustrated in Figure 2.15 which concisely describes the link between the steps and clarifies that how the literatures were reviewed and on what basis the soil conservation technique was selected.

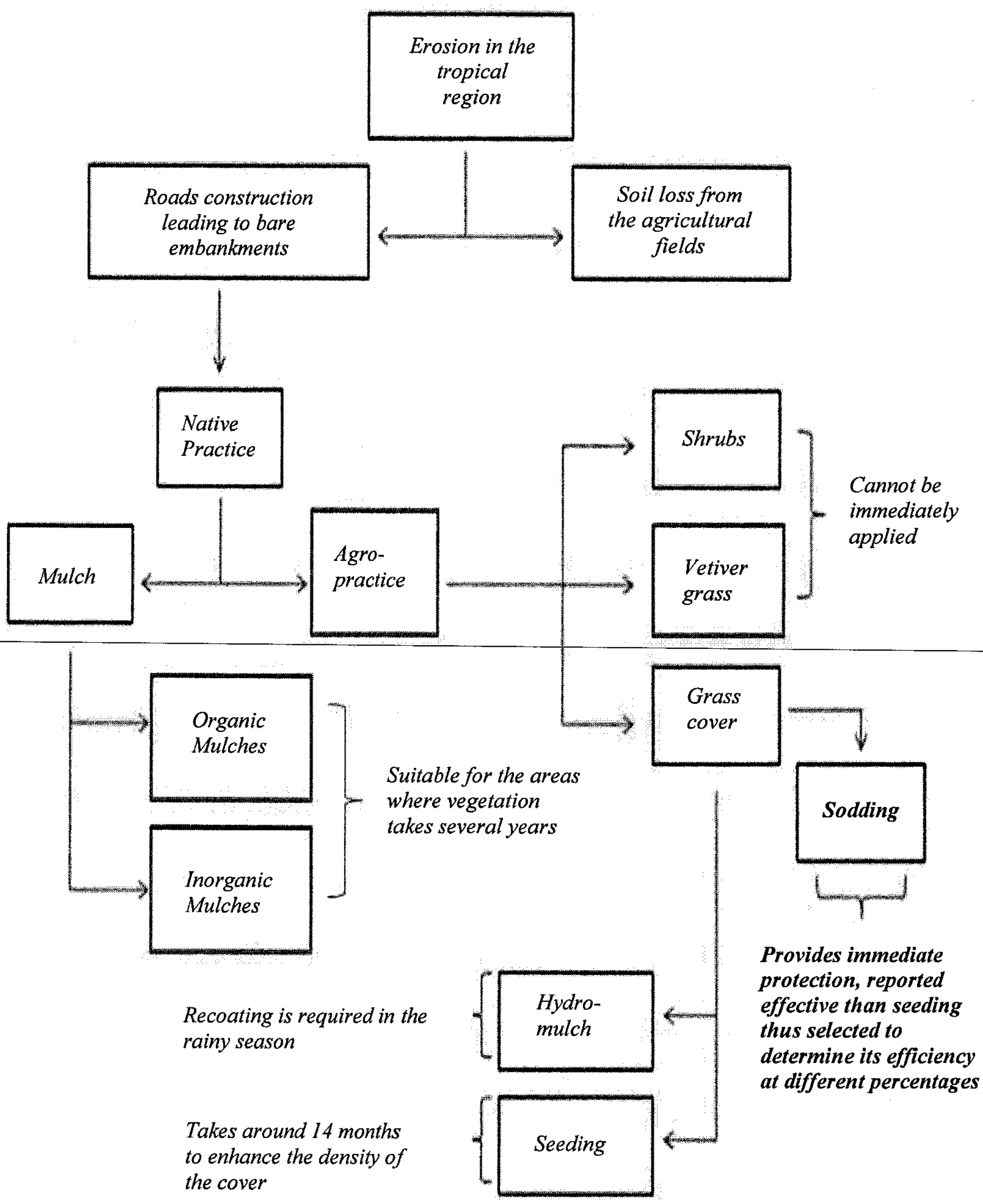


Figure 2.15 Selection of the soil conservation technique

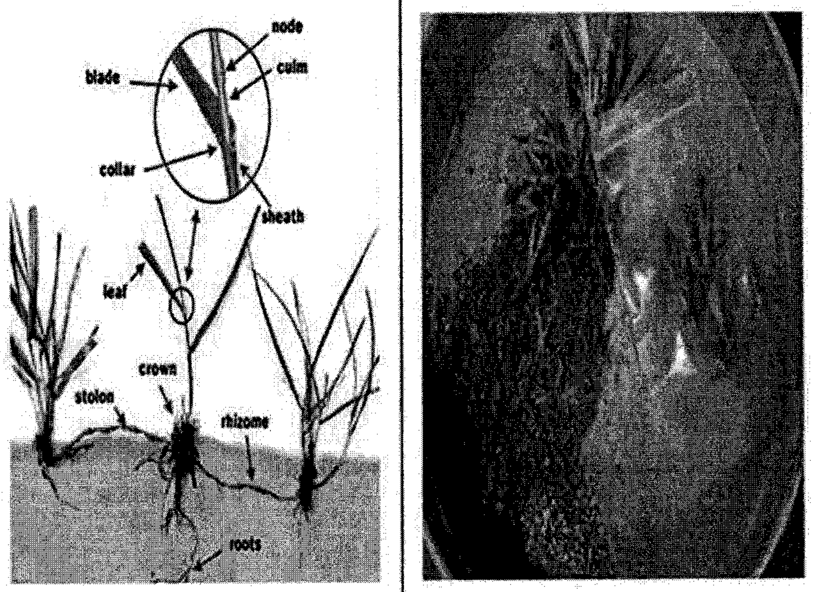
2.10 Description of the Grass Cover

In most areas grasses have produced desired and intended results for erosion control as they grow rapidly and provide complete protection layer to the ground surface.

Comparing the consequences of vegetation cover and the root area ratio of the grass roots on the relative soil displacement rates, it shows that grass roots are well capable of reducing soil detachment. Furthermore, roots have the quality to tie the soil particles at the soil surface and increases surface roughness, therefore soil particles barely get influenced by the rill erosion (De Baets et al., 2006).

2.10.1 The Grass Structure

The *Gramineae* family of plants for which the familiar name is "Grass" is among the biggest families on the universe having more than 9000 known species. The description of a simple grass cover as shown in Figure 2.16 explains the different components of a grass structure. It consists of fibrous roots at the base which are grabbed into the soil for collecting nutrients and protecting the plant. The grass stems, also known as "culms" originate from the crown, which are found rigid in many of the grass species except at the joints (nodes). The leaves originate in different directions like the first leave from right then left and so on. The upper and lower part of the leaf, are called "blade" and "sheath" and the connection between them is surrounded by a ligule which is in the form of thin membrane. The grass collects the energy from the sun through photosynthesis. The photosynthesizing chlorophyll is responsible for the green color of the grass in the leaf. The stems that grow below the grass are called "rhizomes" and the stems that crop along the ground are called "stolons" (Harris, 2013).



Grass cover description | *Original grass picture*

Figure 2.16 The grass structure

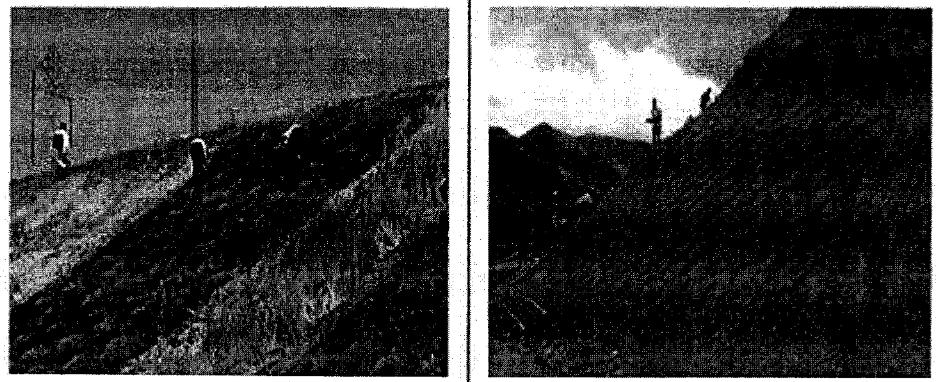
2.10.2 Influence of the Roots

The reduction in the soil loss is due to the combined effects of both the vegetation cover and the roots (Gyssels et al., 2005). The rooted soil enhances the soil strength which improves the stability of the vegetated covered slopes (Osano et al., 2008). The root zone which is considered to be the integral part of the plant is mostly disregarded because of it's out of sight nature (Reubens et al., 2007). Roots originating parallel to the soil surface improve the tensile strength of the soil mass whereas; the one penetrating perpendicular to the soil mass enhance the shear strength of the soil (Zhou et al., 1998). It absorbs the water and nutrients from the soil and is considered as a principle source for gibberellins and cytokinins which are necessary for the development of the shoot zone. It further restricts the soil particles from being washed away and makes the plant stable (Bingru Huang et al., 2013). Moreover, the surface residue and the roots play a defensive role against the soil loss even if the established vegetation dies (Giuseppe Bonati et al., 2013).

2.10.3 Percentage of Cover

Several studies have been conducted as discussed in the section of literature review to ensure the efficiency of an individual material in conserving soil at different percentages (Burroughs Jr and King, 1989; McLaughlin, 2007; Kwok et al., 2008; Groenier et al., 2005; Guo et al., 2010; Li et al., 2011). However, it has been stated that the percentage of cover matters a lot when compared to the erosion control materials for the slope stabilization (Foltz and Copeland, 2009).

The augment in the grass percentage create more roughness to the flowing water which resist the flow path and scatter the flow direction that diminish the impact of the surface runoff and protect the soil particles (Gutierrez and Hernandez, 1996). A study revealed that for reducing the surface runoff and soil loss, 50% of grass covered surface is considered essential whereas; it was found that 34% of the sparse grass cover is ineffective to control soil loss (Li et al., 2011). Furthermore, a study revealed that by establishing 60% of the grass covered surface, reduction of 90% in the soil loss was observed when compared with the bare lands (Gyasi-Agyei, 1998). Andres et al. (2001) observed that the ground cover of less than 25% is considered insufficient in reducing the soil loss whereas; a cover of greater than 50% is reported efficient to restrict the soil loss (Andrés and Jorba, 2000). Figure 2.17 shows the bare gradients which were fully and partially covered by using the grass sodding approach to counteract the impact of raindrop as an immediate soil conservation approach, once the embankments were completely constructed (DOT, 2013; DOR, 2012).



Slope treated with the native grass sod (fully covered), California

Partially covered gradient, Benapa-Sindhuli-Bardibas road, Nepal

Figure 2.17 Sodding example on slopes

The concern of the study was to recommend the optimum percentage of grass cover necessary to sustain the raindrop impact on the bare embankments in Perak, Malaysia. The results obtained are further discussed in Chapter 4 which gives the detailed analysis of the experiments that ended up with the conclusions and recommendations as discussed in Chapter 5.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the methodology section which explains the approach of conducting the experiments. It enlightens how the research problem was planned to deal. The brief description of the procedure for determining the erosion rates, water discharge, turbidity, and suspended solids has been discoursed. The study area, plots description, schematic diagrams, detailed drawing of the experimental plot, construction phase of the experimental site, meetings and site visits conducted by the supervisor and co-supervisor during the construction stage, problems faced while conducting the experiments, soil investigation and the rainfall data analyzed for conducting the experiments are also discussed in this chapter. Lastly, it mentions the frame work of the study which summarizes the phases involved in the methodology part.

3.2 Materials and Methods

3.2.1 Brief Description of the Study

A field investigation was carried out to observe the effects of modeled rainfall and the influence of bare embankments in transporting sediments to the water ways. The study area was constructed incompliance with the real road embankments having similar slope gradient which was observed by considering different percentages of native grass cover (cow grass) as a protection layer for the immediate protection of the exposed soil surface. The grass cover was selected because of its continuous growth with the passage of time and its availability in the locality. The study was observed for the rainfall data of Perak, Malaysia. However, the study was based on the hypothesis that if any of the grass percentage gives adequate and efficient results in conserving soil as an "immediate approach" then it would be best recommended for the newly constructed highway/road embankments within the mentioned limitations as stated in Chapter 1.

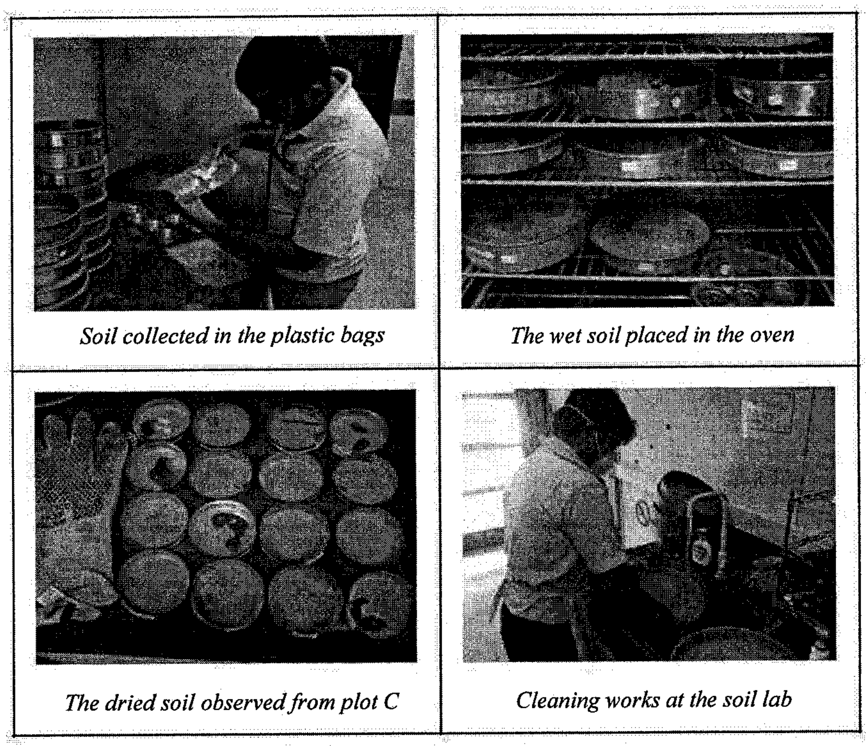
3.2.2 Experimental Setup

The plot-level studies are commonly being used to understand the relationship between soil loss and land management practices (Thomaz and Vestena, 2012). Even the small plots of 7 m^2 have been stated adequate to observe the soil loss and the runoff with the different vegetation covers and slope gradients (El Kateb et al., 2013). For this study, a field work comprises of four plots namely plot A (complete grass covered surface), plot B (bare surface), plot C (50 % of grass covered surface), and plot D (30 % of grass covered surface) with the analogous soil conditions and an area of 6 m length x 2 m width (12 m^2) each, having a slope angle of 30.61° were established. The experiments were conducted under the simulated rainfall events for around 2 hours as in general, the natural rainfall occurs in short duration which lasts within 1 or 2 hours (Leong, 2007).

Prior to running the experiments it was necessary to have a profound insight at the soil for which different soil tests were conducted including particle size distribution, water content, bulk density, and porosity.

Native grass cover was chosen for the study because of its rapid growth and accessibility. However, all the plots were equally observed under the same rainfall events to evaluate the behavior of the individual plot against soil erosion, water discharge, turbidity and total suspended solids at different time intervals.

The dissimilar rainfall events detached the soil from their point of origin and the generated runoff allowed the dislodged soil particles to move with the flow velocity which were collected at the catchment outlet on the plastic plates above the designed bottom container to determine the erosion rates (g m^{-2}) from each plot. The eroded soil was collected after every 15 minutes for 2 hours in the labeled plastic bags which was then dried in an air forced oven at 105° C to obtain the accumulated erosion rates (dry) as shown in Figure 3.1.



Soil collected in the plastic bags | *The wet soil placed in the oven*

The dried soil observed from plot C | *Cleaning works at the soil lab*

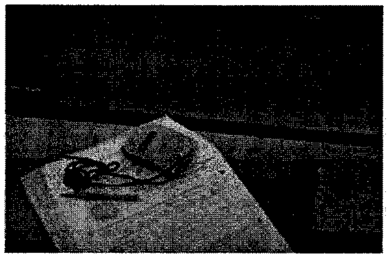
Figure 3.1 Estimation of accumulated soil loss

The discharged water from each plot, $Q_{experimental}$ (m^3 sec^{-1}) was collected in a designed container of known volume provided at the bottom drain with a V-notch weir which is the most accurate open channel constriction and a measuring scale (Fox, 1974). The time against the collection was noted at every 15 minutes for 2 hours (occurrence of artificial rainfall) and 40 minutes (no rainfall, only the generated surface runoff) which helped knowing the flow response as shown Figure 3.2. The water discharge was determined by using the basic V-notch weir formula:

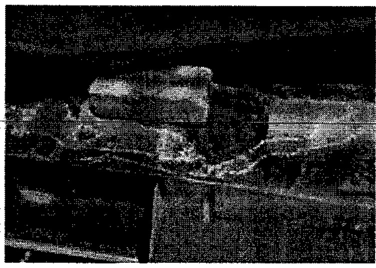
$$Q = C_d \, 8/15 \, (2g)^{1/2} \tan \Theta/2 \, h^{5/2} \quad (3.1)$$

Where Q is the flow rate, C_d is the discharge constant that is 0.581, g is the gravitational acceleration, Θ is the angle of V-notch that is 90°, and h is the head on weir.

The water collected in the container



The discharge observed from plot B



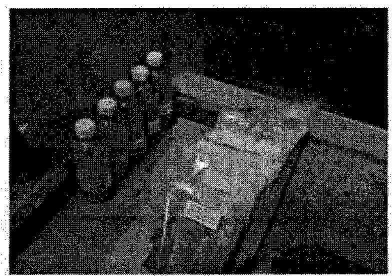
The plastic scale used for determining the water head

Water flowing out of the weir

Figure 3.2 Assessment of water discharge

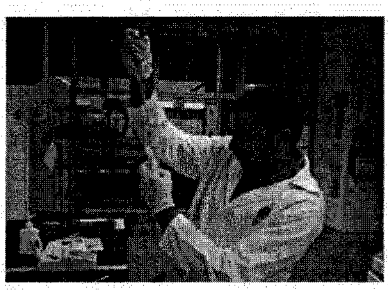
During the entire experiment, the water samples were collected at different intervals of time that is after every 15 minutes for 2 hours using the plastic bottles of known volume (350 ml), which were properly labeled. The volume of water collected was sufficient enough to ensure proper examining of the water turbidity (NTU) and the presence of total suspended solids (mg L^{-1}). The samples analyzed after the collection helped knowing the water muddiness and the concentration of total suspended solids in the each sample for a particular period of time.

For determining the water turbidity, the proper functioning of the turbidity meter was assured. The water samples collected from the bare soil surface were quite turbid which surpassed the turbidity meter range. However, for determining the turbidity rates, 1 in 50 dilutions were used for each sample analysis. 10 ml of the diluted sample was poured into the glass cuvette from the graduated cylinder which was then well cleaned and placed into the turbidity meter and the turbidity range was determined. The procedure was repeated thrice to get the average turbidity value of a given water sample as shown in Figure 3.3 (Shah et al., 2013).

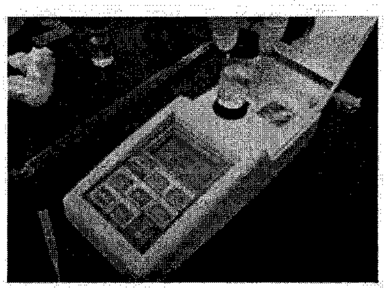


Water samples collected at the site

Turbidity meter and glass cuvettes



Diluting the water sample



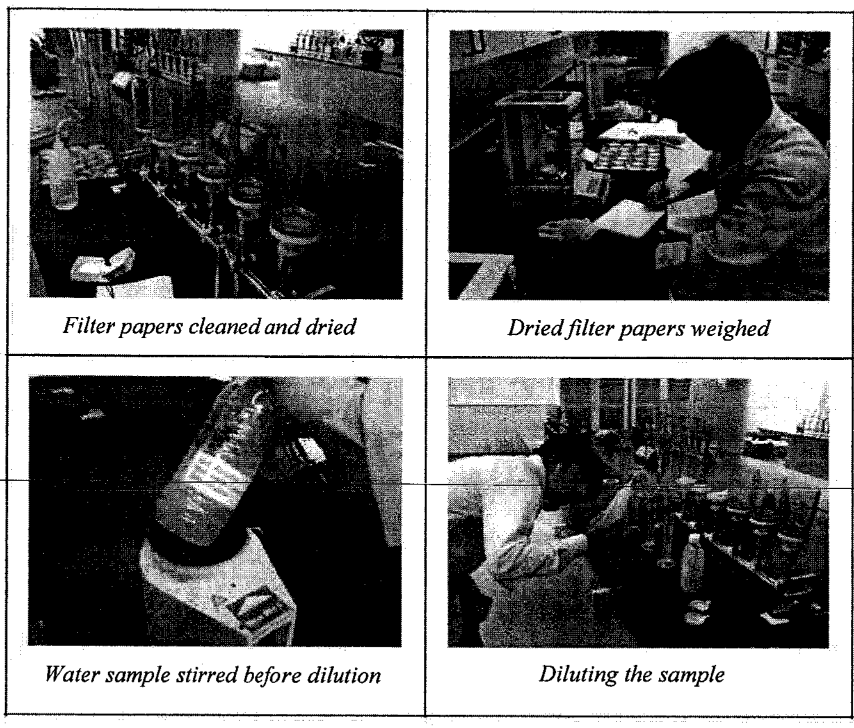
Determining the turbidity range

Figure 3.3 Observation of the turbidity range

For determining the total suspended solids (TSS), the filter papers were first rinsed with the distilled water and by applying vacuum to the flask. The cleaned filter papers in the labeled filter holder were dried in the oven at 105°C for 24 hours. The dried filter papers were kept in the desiccators for 20 minutes which allowed the filters to cool in a moisture free environment and weighed (W_1) on the analytical balance. 10 in 100 dilutions were used for each sample analysis. Three readings from each sample were taken to determine the average amount of total suspended solids present in the water. The filter papers containing suspended particles were then dried for 1 hour in the oven under the same temperature and placed in the desiccators for 20 minutes and weighed (W_2) as shown in Figure 3.4. The TSS was determined using:

$$TSS = W_2\ (mg) - W_1\ (mg) / 0.1\ (L) \quad (3.2)$$

Where TSS is the total suspended solids, W_1 is the weight of dried empty filter paper, W_2 is the weight of the dried filter paper containing suspended particles, and 0.1 is the sample volume in liters (Shah et al., 2013).

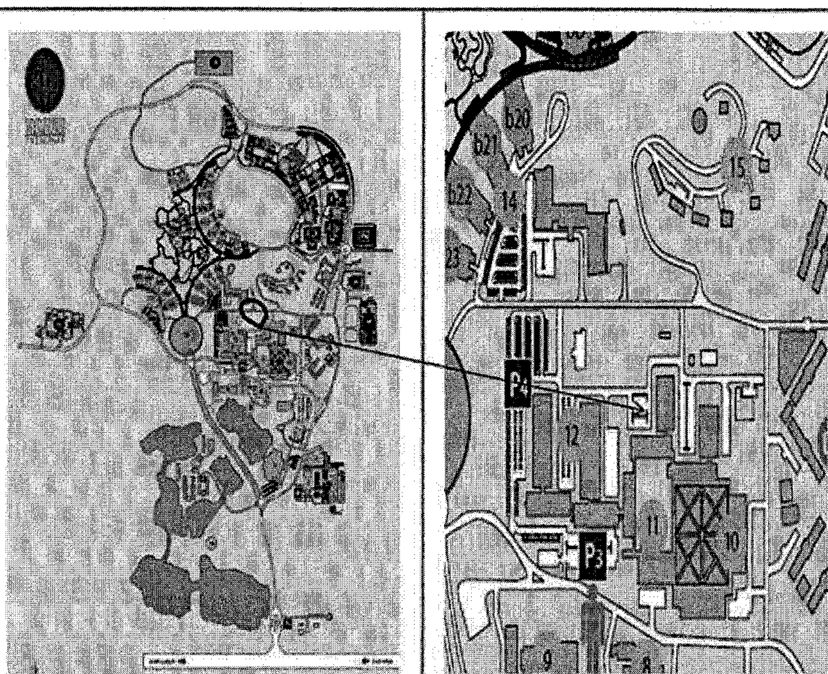


Filter papers cleaned and dried | *Dried filter papers weighed* | *Water sample stirred before dilution* | *Diluting the sample*

Figure 3.4 Determination of total suspended solids

3.2.3 Study Area

The study area is located at Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Tronoh Perak, Malaysia. It was necessary to identify such a slope within the University premises that would meet the requirements of study for which some pre-study visits were conducted and a slope located near block "J" as shown in Figure 3.5 was chosen to conduct the field work.



Universiti Teknologi PETRONAS | *Location of the study area*

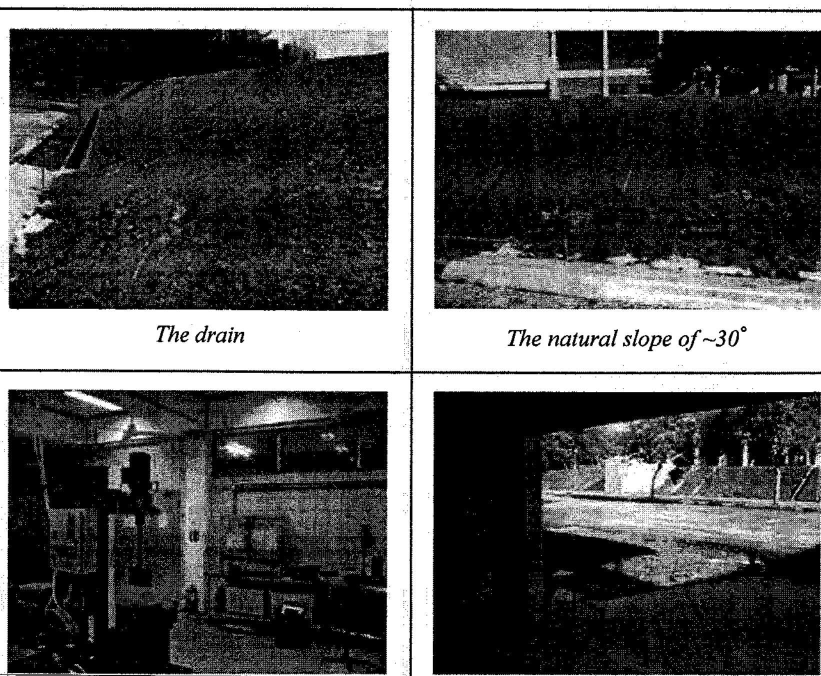
Figure 3.5 The study area

Figure 3.6 illustrates the cause of site selection. The bases for the selection are as follow.

- It was provided with an appropriate drainage which was necessary to place the designed container for the estimation of the water discharge, and collection of water samples for the determination of the turbidity rates and TSS.

- The natural slope angle of ~30° which is the representative of the road side slopes that are usually constructed with the gradient of 1V:1.5H was also among the major concerns of the study (JKR, 2010; DOR, 2012; Bayfield et al., 1993).

- The highway lab which was adjacent to the study area assured easy access to the lab equipment, guaranteed a comprehensive control of the research conditions, and facilitated the working phase.



The drain | *The natural slope of ~30°*

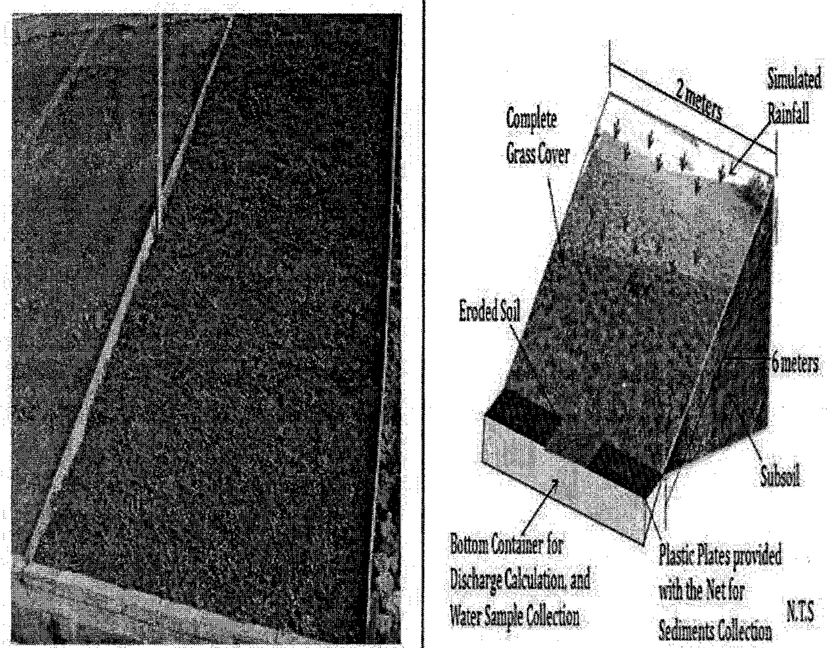
Oven used for drying soil | *Site location from Highway lab*

Figure 3.6 Reasons of site selection

3.2.4 Plots Description

The vegetation measures on the road embankments not only shelter the soil from soil erosion but it has been widely applied on road side slopes due to the rapid awareness of the environmental protection (Xu et al., 2006). The growth of vegetation on the newly constructed highways is worsened by the poorly structured soil which is infertile and low in nutrients that renders the roadbeds to erosion (De Oña et al., 2011).

A land cover is considered to be an effective way of stabilizing the road side slopes as it nullifies impact of direct rain and the intensity of runoff which is responsible for the soil detachment. However, to study and observe the similar conditions in practical, a complete grass covered surface as shown in Figure 3.7 was established and studied.



Fully grass covered surface | *Description of the plot*

Figure 3.7 Complete grass covered surface (Plot A)

High erosion rates have been induced by the road embankments which usually remain bare once the road is constructed. This spoils natural environment and leads to the several problems associated with the road degradation (Cerdà, 2007).

The bare surface **(control plot)** as shown in Figure 3.8 was supposed to have higher rates of soil erosion and runoff as it allows the direct impact of the rain drop to strike the exposed soil particles which are then dislodged and carried away by the generated runoff. The purpose of this plot was to compare the results and to determine the proficiency of the fully grass covered surface and other partially grass covered surfaces against soil erosion, water discharge, turbidity, and TSS.

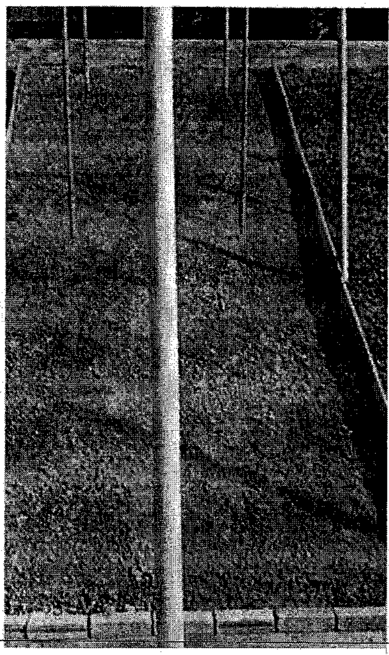
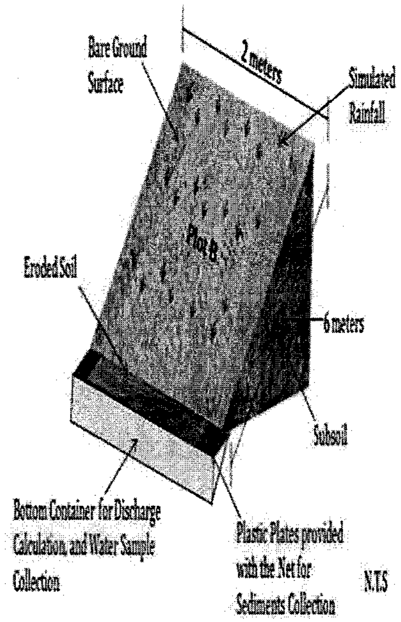
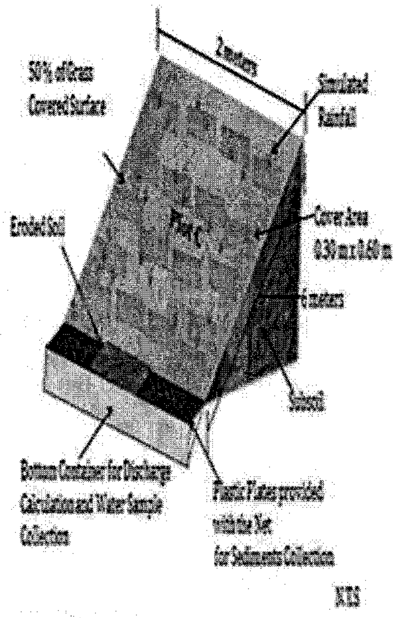
	
Bare soil surface	*Description of the plot*

Figure 3.8 Bare surface (Plot B)

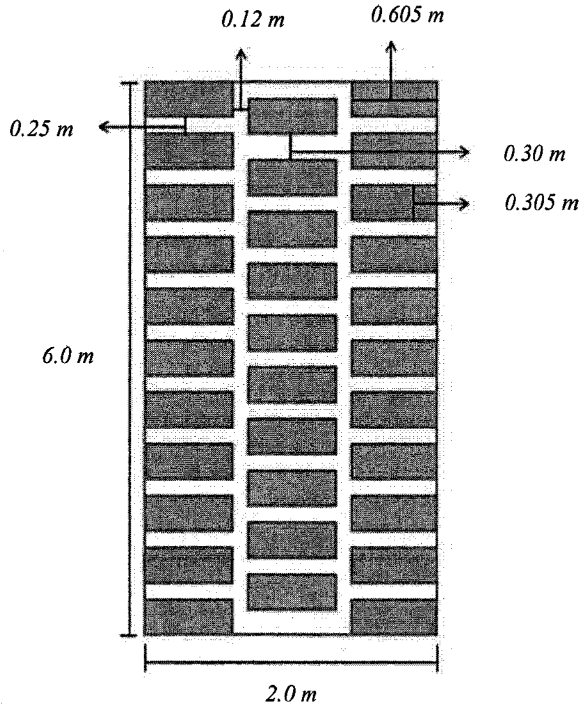
The purpose of 50 % of grass covered surface as shown in Figure 3.9 was to compare the difference among the values and to analyze the results more accurately. The aim of the plot was to observe its efficiency against soil loss as an immediate surface cover for the particular rainfall conditions.

To cover the plot area of 6 m length x 2 m width by 50%, the area of grass required was 6 m^2 for which a wooden box of 0.185 m^2 as shown in Figure 3.10 was prepared. A total of 32 wooden boxes, closely spaced and covered with the grass patches were used on the plot area to meet the requirement of the partially grass covered surface.

50 % of grass covered surface



Description of the plot



Spacing (N.T.S)

Figure 3.9 50 % of grass covered surface (Plot C)

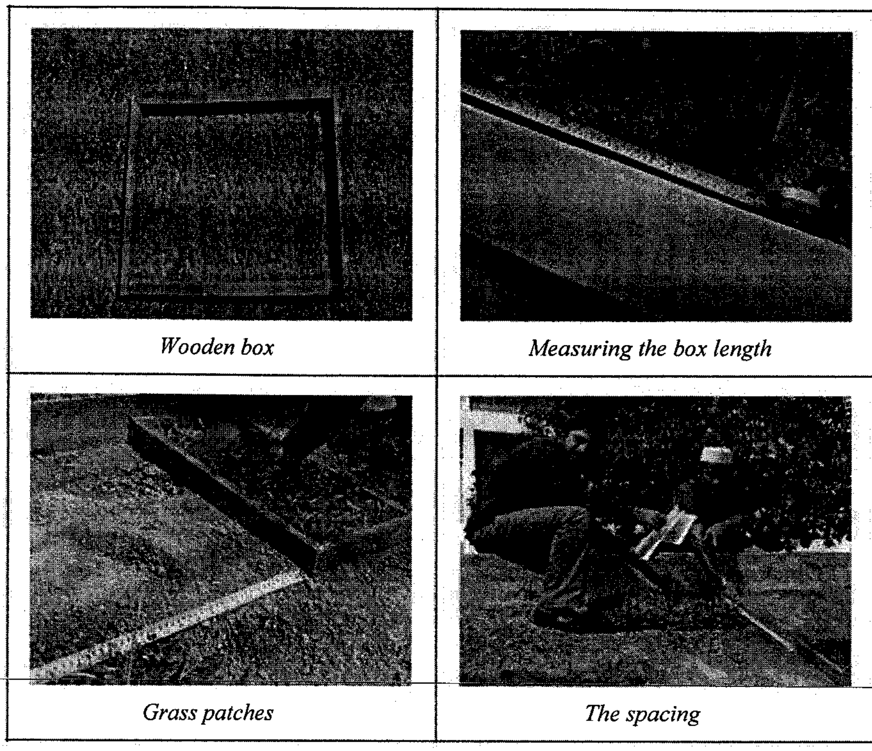
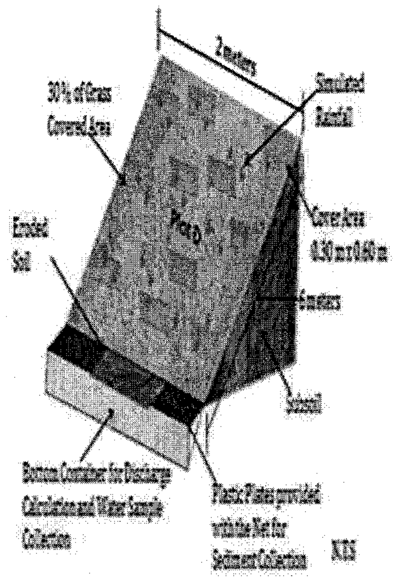


Figure 3.10 The wooden box of 0.185 m^2

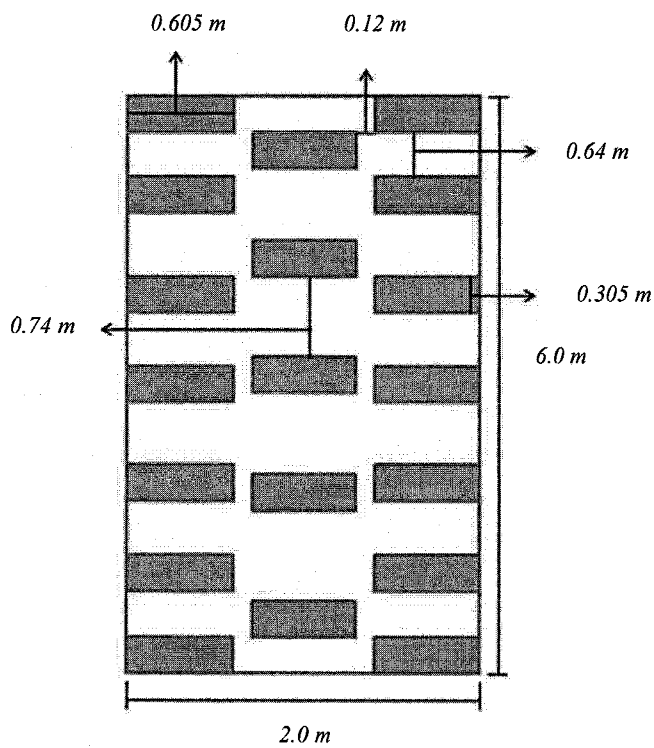
Likewise, observing the impact of moderate rainfalls on soil detachment, water discharge, turbidity, and total suspended sediment concentration for 50 % of the grass covered surface. It was also decided to observe the response of 30 % of the grass covered surface on all the mentioned factors. The concern was to recommend with the most adequate and economical approach that should be considered for the immediate soil shelter on the bare embankments for the opted rainfall events, soil type, and gradient.

To cover the plot area of 6 m length x 2 m width by 30%, the area of grass cover required was 3.6 m^2. A total of 19 wooden boxes of 0.185 m^2 grass were patched on the soil surface to meet the requirement of the plot. The spacing between the grass patches was decreased due to the reduced grass cover area as shown in Figure 3.11.

30 % of grass covered surface



Description of the plot



Spacing (N.T.S)

Figure 3.11 30 % of grass covered surface (Plot D)

3.2.5 Schematic Diagram

To visualize the study area, schematic diagrams of each section of the experimental setup were made. The purpose of making these diagrams was to capture all the geometric features of the study area. Figure 3.12 shows the front elevation of each plot along with the dimensions of the entire area (not to scale). Moreover, the application of the artificial rainfall, plastic plates for sediments collection, and the catchment basin are further pointed in the diagram. Figure 3.13 shows the layout of the study area from above (plan view) and Figure 3.14 shows the section view AB (Plot A), CD (Plot B), EF (Plot C), and GH (Plot D). The diagram was sectioned just to conceive the object by a plane that exposes the interior to the observer.

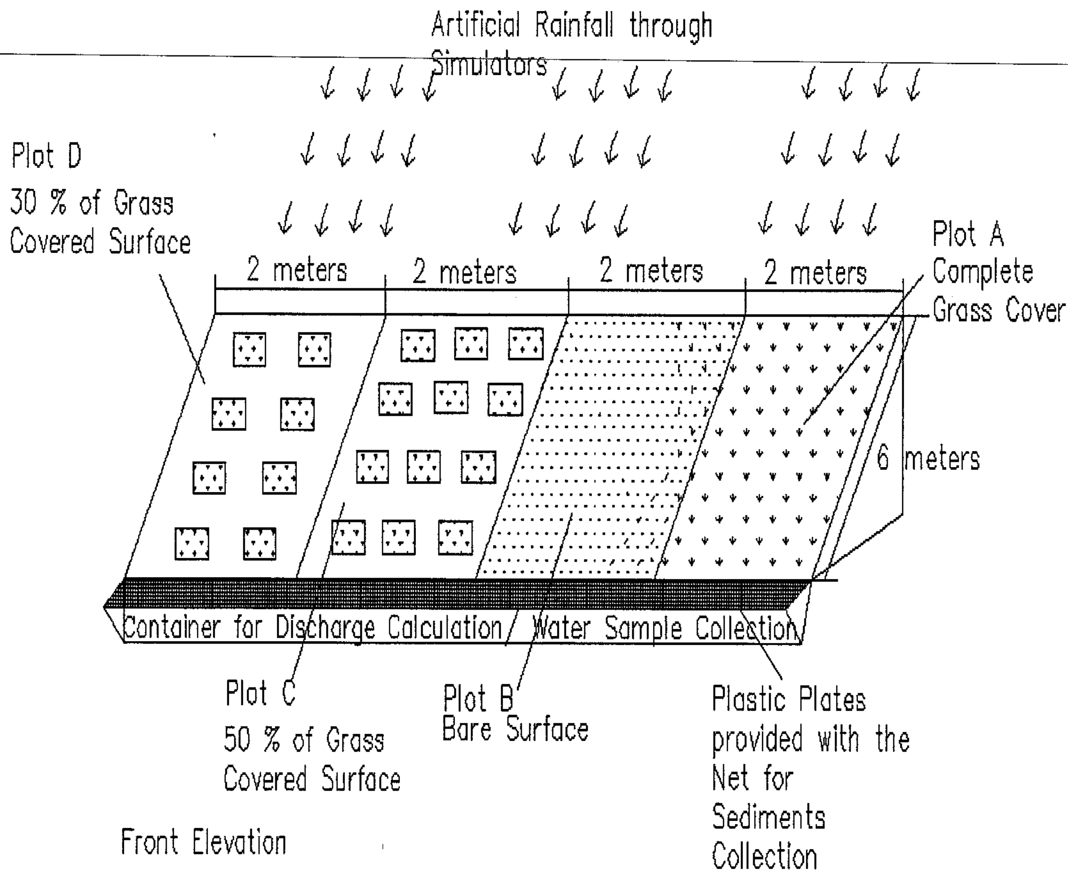


Figure 3.12 Front elevation of the experimental setup (Auto-cad)

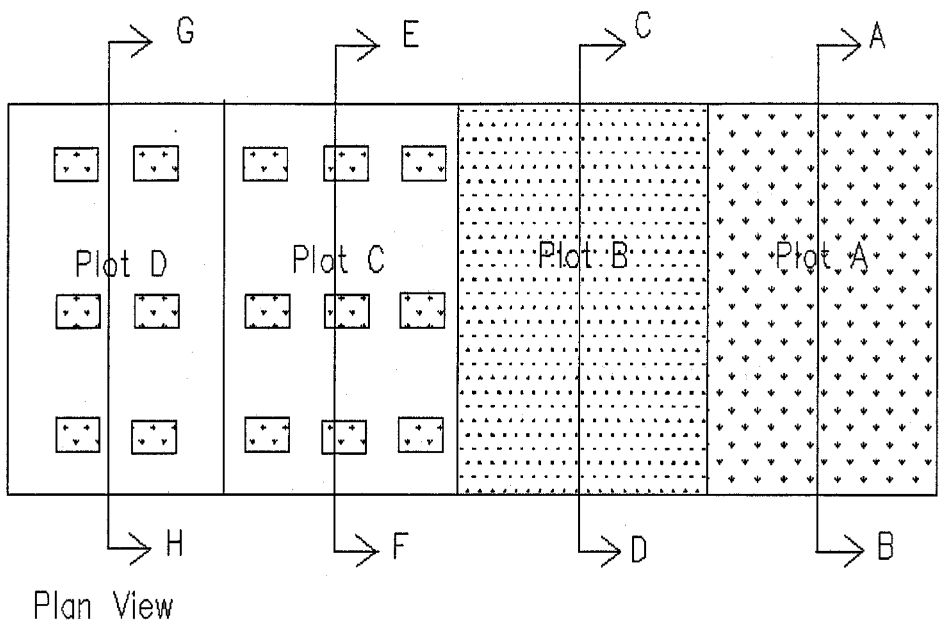


Figure 3.13 Plan view of the experimental setup (Auto-cad)

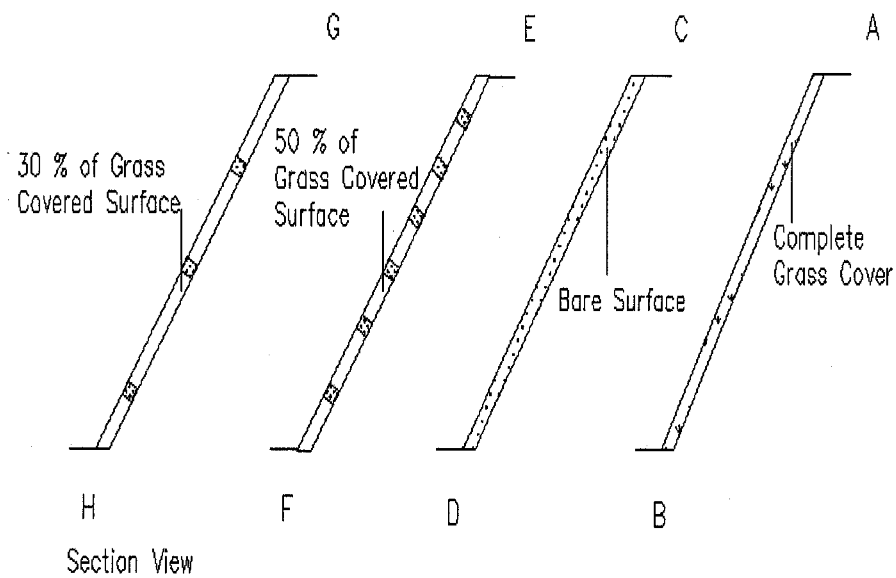


Figure 3.14 Schematic section view of the experimental setup (Auto-cad)

3.2.6 Detailed Diagram

The detailed drawings are mandatory for the start of any project which are made with precision and are considered to be the most efficient way to put the data in a simple form. Verbal or written instructions are not feasible during the phase of construction, which can be misunderstood or forgotten. Experimental drawings give the details of the experimental setup which may help finding the creative directions, and can be used for the critical analysis, discussion, and modification of the experimental framework.

The experimental setup for this study was carefully designed, taking into consideration the most feasible testing conditions and constraints. A detailed drawing was then prepared to comprehend the overall experimental setup which considered the investigation requirement as well as the available site condition as illustrated in Figure 3.15.

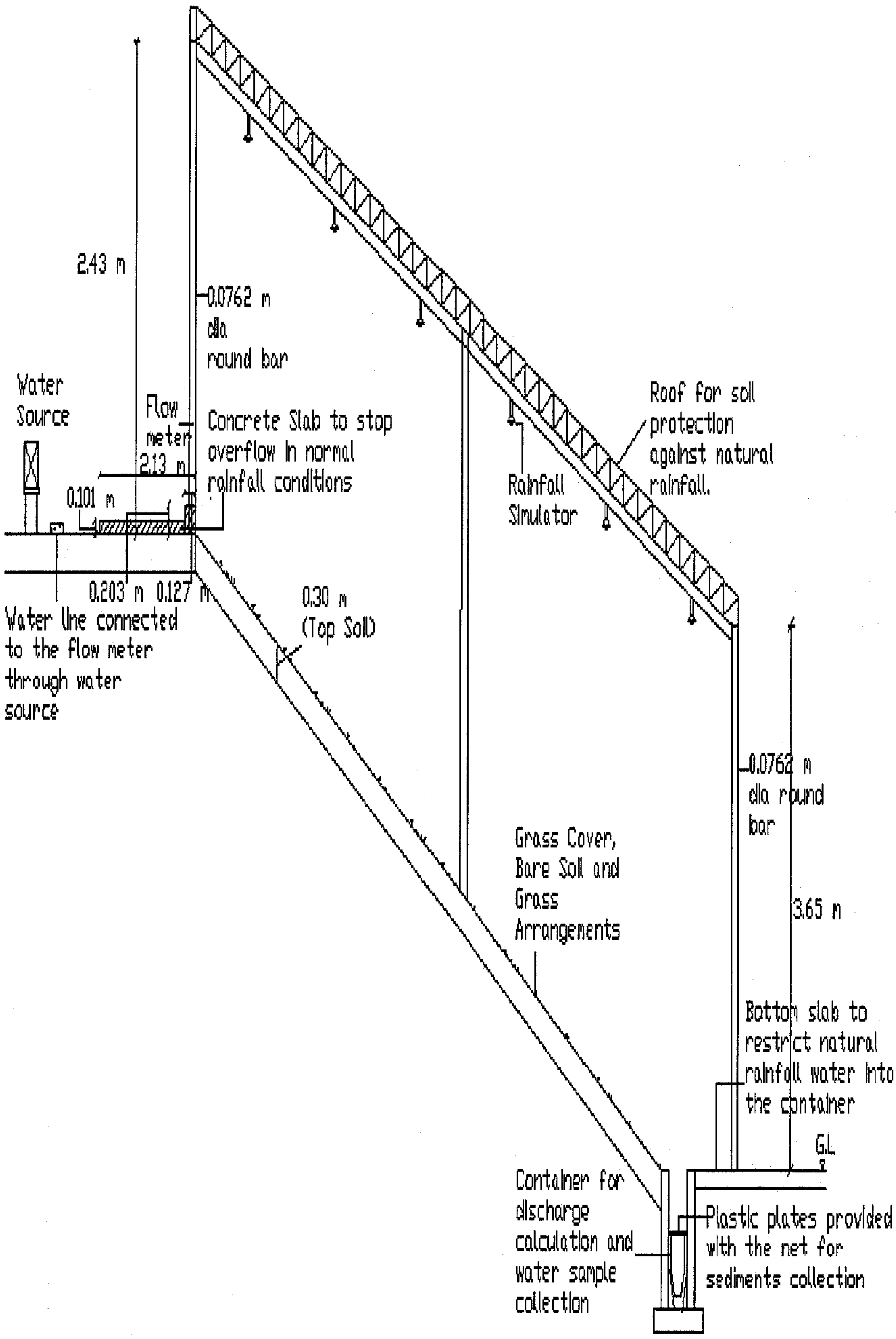


Figure 3.15 The detailed drawing of the experimental setup (Auto-cad)

3.2.7 Construction of the Experimental Site

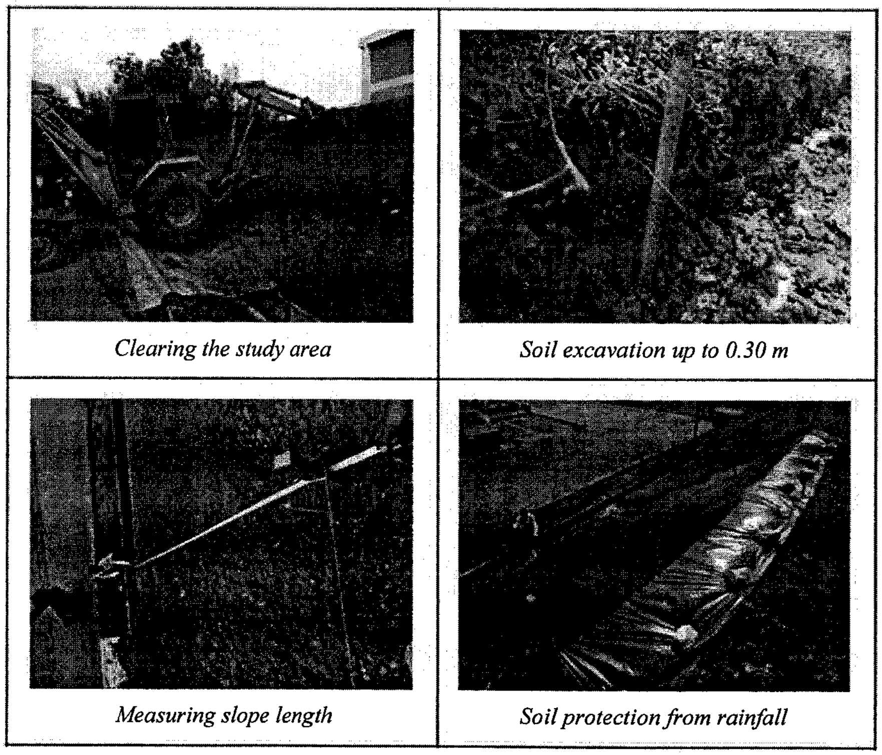
A construction phase goes through several steps. However the steps involved for the construction of the experimental site includes,

- Cleaning of the working site, excavation of the old soil up to 0.30 m and covering the bare soil from the impact of natural rain as shown in Figure 3.16, while comparing the efficiency of grass covered surface and mulch covered surface, the soil was excavated and set aside to a depth of 0.35 m (Li et al., 2011) whereas; while performing a laboratory test under the simulated rainfall conditions, the soil was filled to a depth of 0.35 m in a flume (Dong and Wang, 2012).
- Placement of the concrete slab to disallow the runoff water from the top (in case, natural rainfall occurs) to enter the study area as shown in Figure 3.17, to avoid outside water to affect the experimental runs, ditches were constructed on the top of the slope while studying the application of sludge on road embankments (De Oña and Osorio, 2006).
- Installing the plywood for the plots separation as shown in Figure 3.18, In a study of highway embankments, there were constructed 15 plots which were separated with a 0.1 m high wood wall (Pengcheng et al., 2008).
- Roof installment to avoid the raindrop affect and to shelter the working area with the thickness of 0.001 m and the size of 7.62 m x 10.36 m as shown in Figure 3.19.
- Compaction of the subsoil as shown in Figure 3.20, the subsoil is considered compacted with a fragile structure once the top soil is removed, which restricts water penetration into the soil and contributes to the surface runoff (Alfsen et al., 1996).
- Laying the new soil (top soil) on the compacted surface as shown in Figure 3.21, the top soil during the construction of embankments is not tamped (about 0.20 m depth) to allow the plant growth (Pengcheng et al., 2008).
- Making of the bottom slab to avoid the influence of the external water (in case, natural rainfall occurs) from disturbing the experiments as shown in Figure 3.22.

- The study was purely observed under simulated rainfall conditions. Therefore, plastic cover was provided to cover the sides of the experimental area to nullify the impact of natural rain as shown in Figure 3.23.
- Rainfall sprinklers were used to conduct the experimental study under the artificial rainfall conditions as shown in Figure 3.24, for which the rainfall data for Perak was obtained and analyzed from the Meteorological Department Malaysia which is further discussed in this Chapter, To study soil hydrology and soil erosion by water, rainfall simulations are being used since 30's by the researchers. The sprinklers give qualitative information about the data in a short period of time due to the facility of repetition (Martínez-Murillo et al., 2013).
- The rainfall simulators were adjusted at a height of 1.82 m from the soil surface. The concern of the height was to cover the complete area within the reach of the simulated rain as shown in Figure 3.25, To study the effects of vegetal cover on soil detachment and surface runoff under the light intensity events, the rainfall sprinklers were used, which were suspended at a height of 2.2 m above the ground surface (Marques et al., 2007).
- A flow meter was used to adjust the rainfall intensity during the experimental study as shown in Figure 3.26.
- Placement of the grass patches on the land model as shown in Figure 3.27.
- For the smooth movement of the water catchment container, rails were provided in the drain as shown in Figure 3.28.
- To study the water discharge there was designed a container provided with a V-notch weir, the details of which are shown in Figure 3.29.
- To collect the detached soil particles, plastic plates were used at the catchment outlet as shown in Figure 3.30.
- Together with the plastic plates, a "net" was provided to trap the detached soil particles with the particle size greater than 1.3 mm to enter the bottom container as shown in Figure 3.31, the nominal diameter of sand ranges between (2-0.6 mm) so the net nearly trapped the very coarse sand

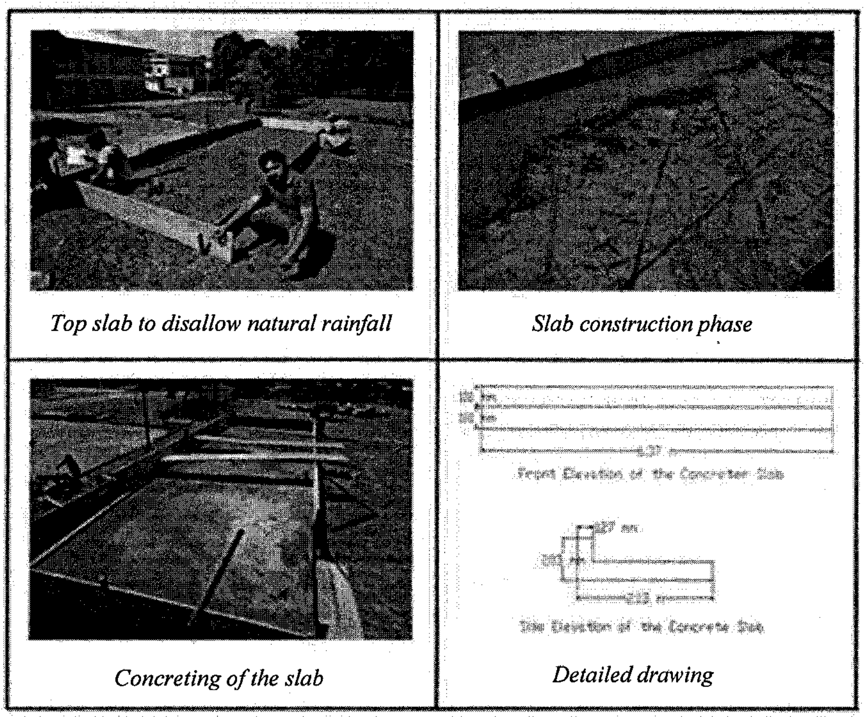
particles (1.0-2 mm) whereas; medium (0.6-0.2 mm) and fine (0.2-0.06 mm) sand particles were subjected to the bottom container (Mckenzie, 2013).

- A stone cage was affixed in the container to smoothen the water flow coming out of the V-notch for the accurate head measurement which was necessary for the accurate discharge calculation as shown in Figure 3.32.
- To observe the water head "h" from the V-notch weir, a plastic scale was stuck in the container as shown in Figure 3.33.
- Labeled plastic bags were used to collect the eroded soil samples. Similarly, labeled plastics bottles of known volume were used for collecting the water samples and to ensure the accurate measurement of elapsed time, a stop watch was used as shown in Figure 3.34.
- Lastly, after conducting the each experimental run it was necessary to clean the bottom container to make it ready for the next run, the way how it was cleaned is shown in Figure 3.35.



Clearing the study area | *Soil excavation up to 0.30 m* | *Measuring slope length* | *Soil protection from rainfall*

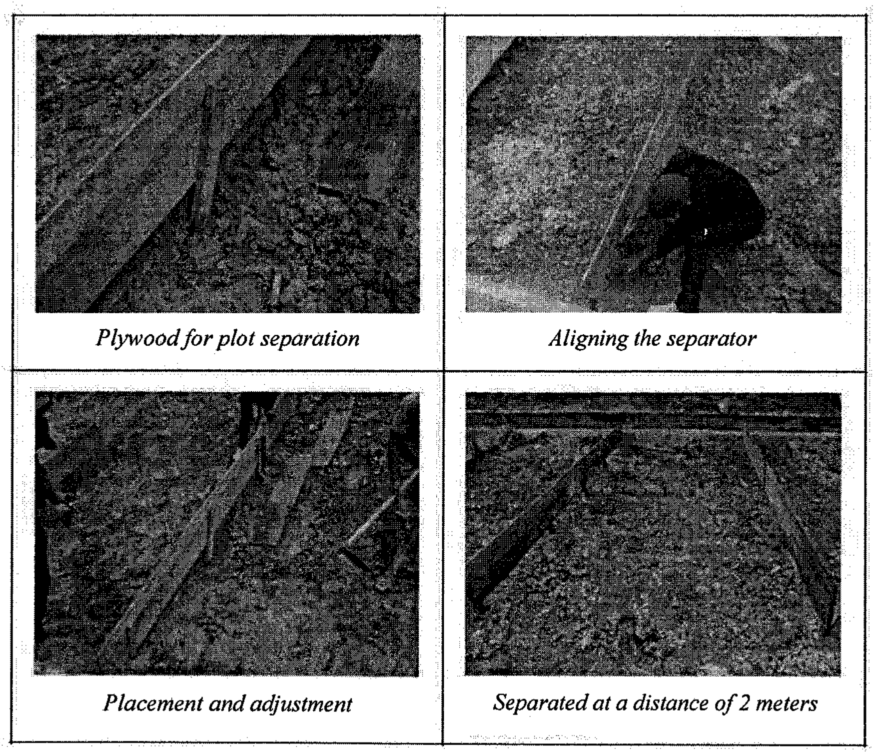
Figure 3.16 Excavation and covering of the exposed soil



Top slab to disallow natural rainfall | *Slab construction phase*

Concreting of the slab | *Detailed drawing*

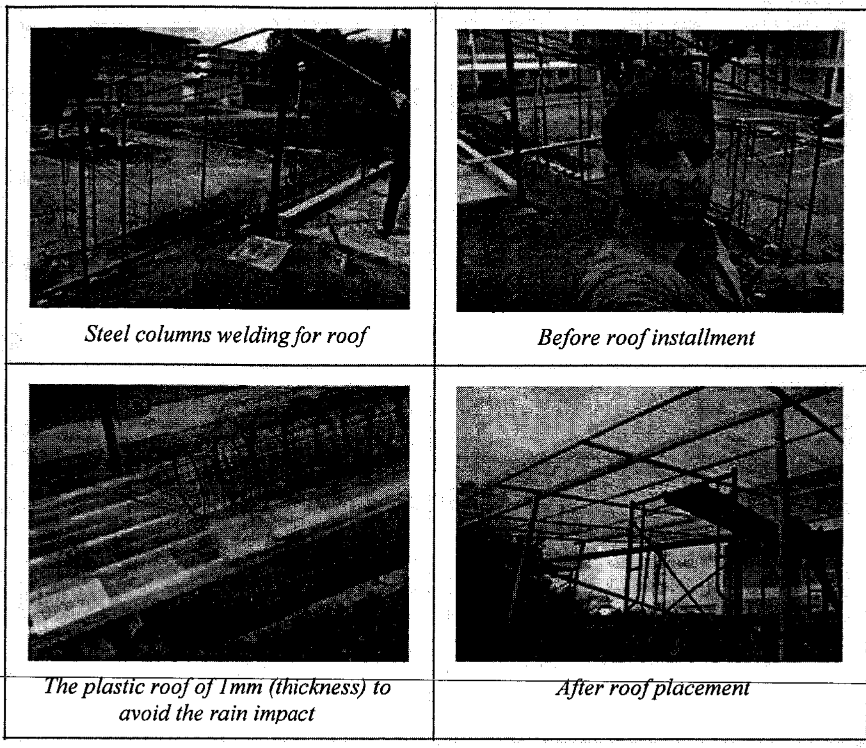
Figure 3.17 Placement of the concrete slab



Plywood for plot separation | *Aligning the separator*

Placement and adjustment | *Separated at a distance of 2 meters*

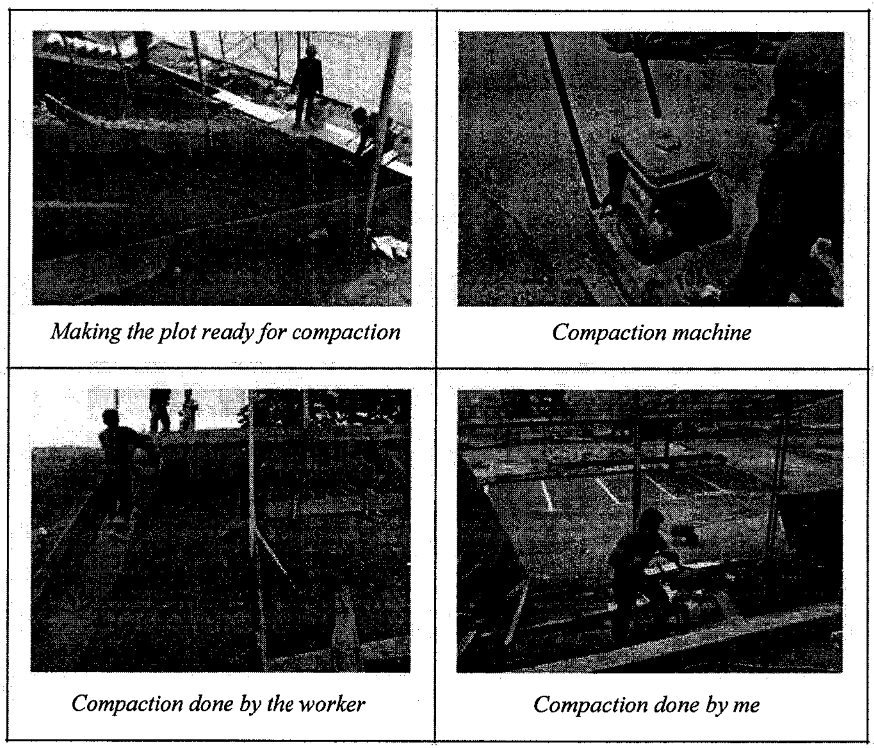
Figure 3.18 Plywood as a plot separator



Steel columns welding for roof | *Before roof installment*

The plastic roof of 1mm (thickness) to avoid the rain impact | *After roof placement*

Figure 3.19 The roof placement



Making the plot ready for compaction | *Compaction machine*

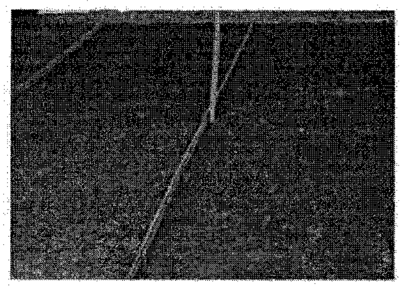
Compaction done by the worker | *Compaction done by me*

Figure 3.20 Soil compaction

The top soil

Top soil protection from rain

Compacted bottom soil

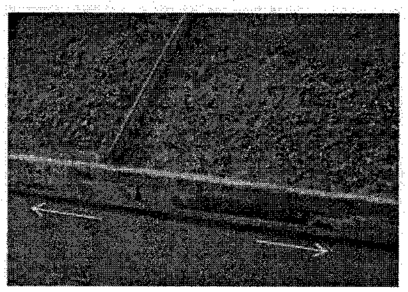


Top soil placed

Figure 3.21 Placement of the top soil

Concrete bricks for making the bottom slab

Making of the bottom slab to hinder rainfall water in the catchment



Water direction in case if rainfall occurs

Bottom slab finally constructed

Figure 3.22 The bottom slab

Cutting of the plastic as required

Putting up the plastic on the study area

Covered front and back side

The study area completely covered

Figure 3.23 The plastic cover

Observation of the flow by the Co-supervisor, before sprinklers selection

The lab technicians briefing the Supervisor regarding rainfall sprinklers

Drop size diameter

Sprinklers placement on the plot

Figure 3.24 The rainfall simulators

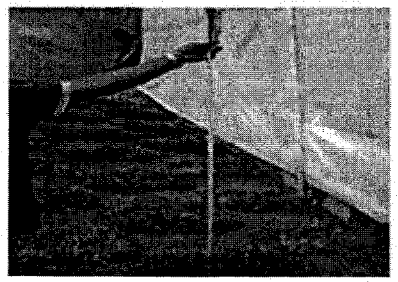
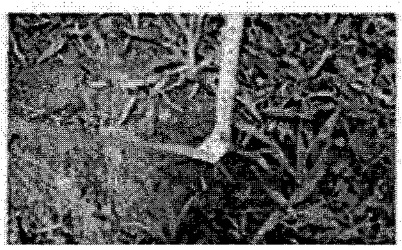
 *The contractor being suggested regarding sprinklers height*	 *The height selected to cover the entire area of the plot*
 *Sprinklers height at 1.82 m from the surface*	 *Final check after the placement*

Figure 3.25 The sprinklers height

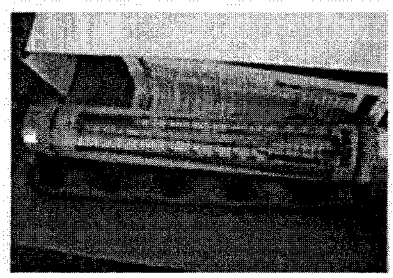
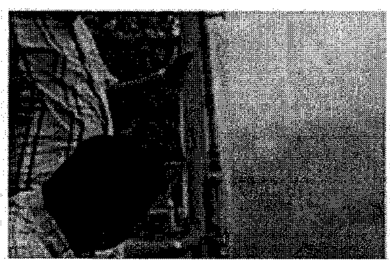
 *Discussion regarding purchase of the flow meter at the Hydrology lab*	 *The flow meter*
 *Providing connection with the water source*	 *Accuracy being checked by the lab assistant*

Figure 3.26 The flow meter used to adjust the rainfall intensity

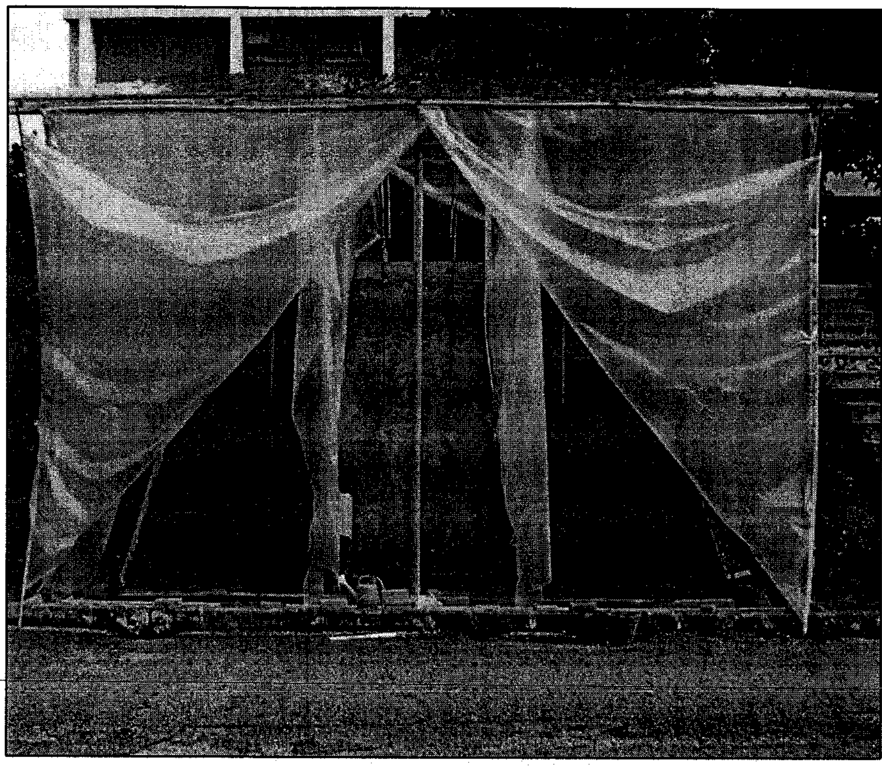
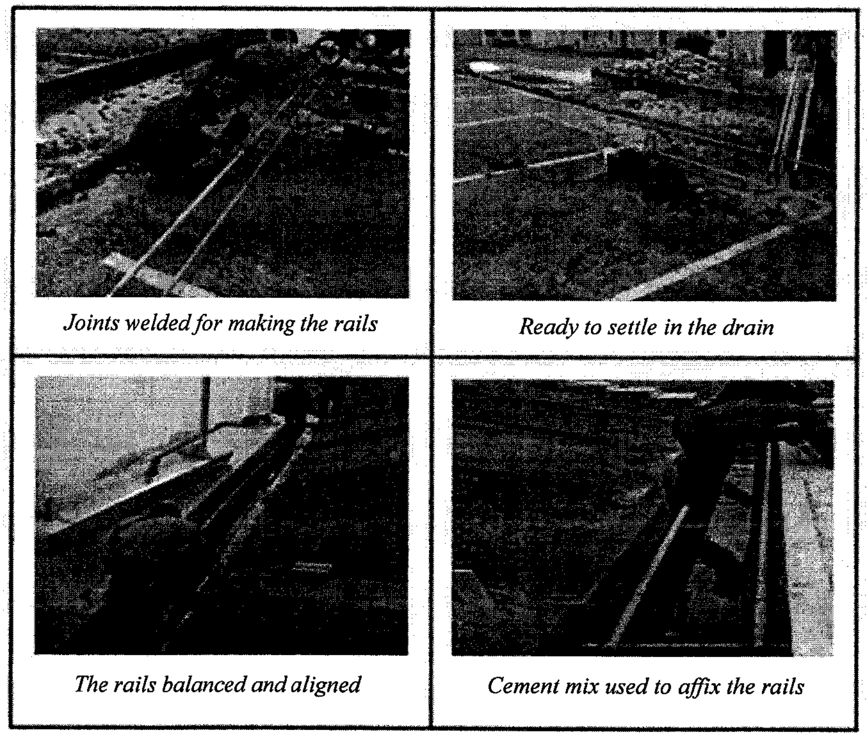


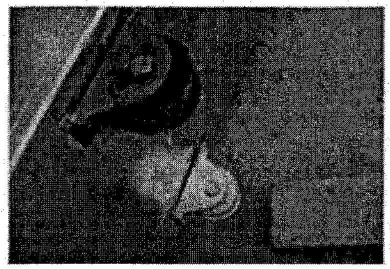
Figure 3.27 Grass placement on the land model



Joints welded for making the rails	*Ready to settle in the drain*
The rails balanced and aligned	*Cement mix used to affix the rails*

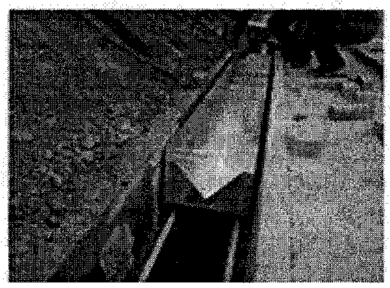
Figure 3.28 Rails provided in the drain

The designed V-notch weir



Rollers welded for smooth movement

V-notch weir aligned for the accurate discharge calculation



Ready for the discharge observation

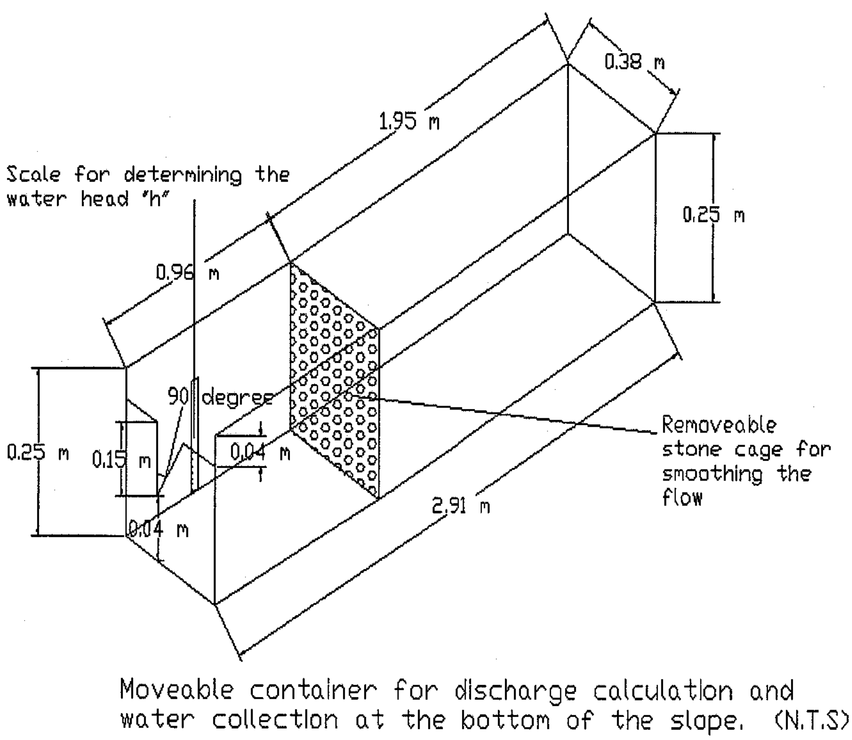
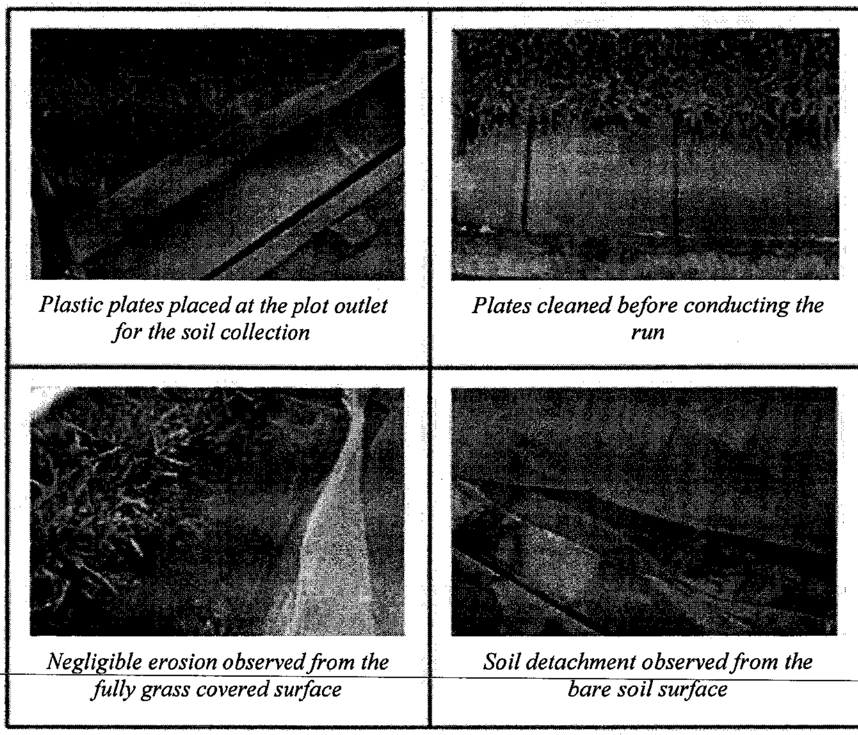


Figure 3.29 Moveable container for discharge calculation (Auto-cad)



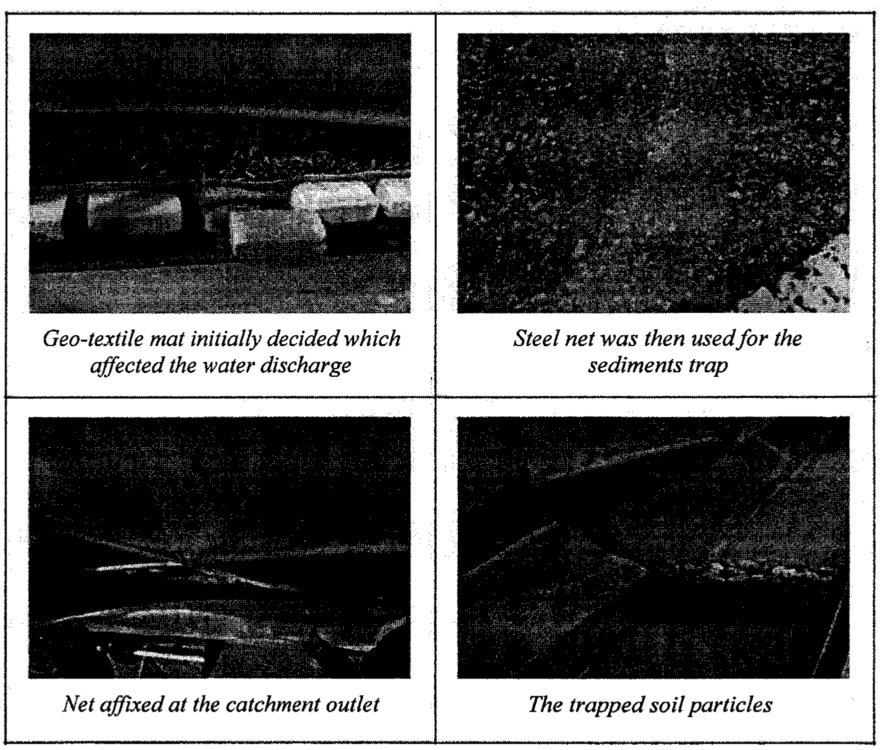
Plastic plates placed at the plot outlet for the soil collection

Plates cleaned before conducting the run

Negligible erosion observed from the fully grass covered surface

Soil detachment observed from the bare soil surface

Figure 3.30 Plastic plates for sediment collection



Geo-textile mat initially decided which affected the water discharge

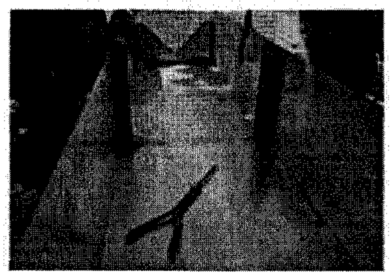
Steel net was then used for the sediments trap

Net affixed at the catchment outlet

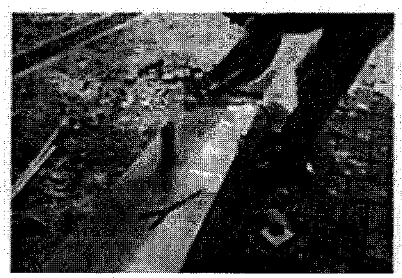
The trapped soil particles

Figure 3.31 The “net” used to trap very coarse soil particles

The weir crest sharpened for the smooth flow of the water



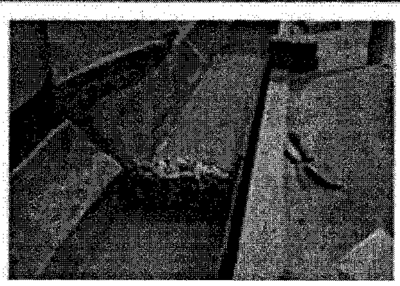
Placing the steel cage inside the container



The extra cage portion curtailed

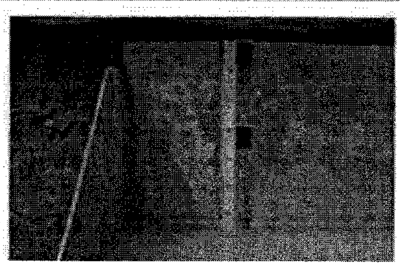
Stone cage finalized

Figure 3.32 Stone cage to uniform the flow for measuring the accurate head



Water volume in the designed container

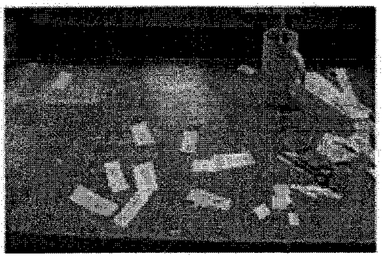
The flow coming out of the weir



The head, h measured above the weir crest

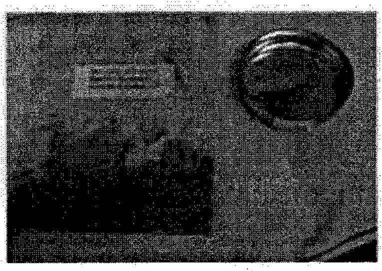
Observing the discharge at different time intervals

Figure 3.33 The scale for determining the water head



While labeling the plastic bags

Labeled empty plastic bag, plastic bottle, and stop watch

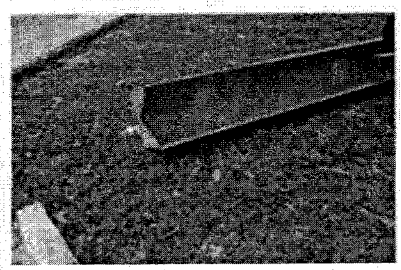


Plastic bag used for collecting detached soil particles

Plastic bags and bottles used for sample collection

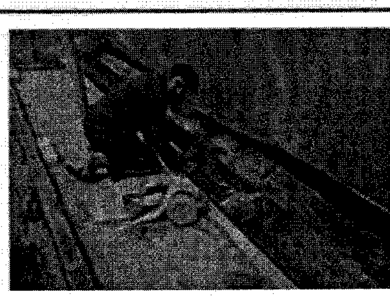
Figure 3.34 Plastic bags, plastic bottles, and stop watch

Bottom container cleaned before conducting each run



The cleaning process

Ready to use again

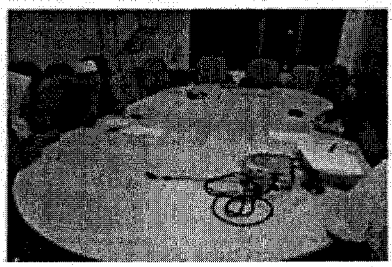


Placed back on the rails

Figure 3.35 Cleaning of the container

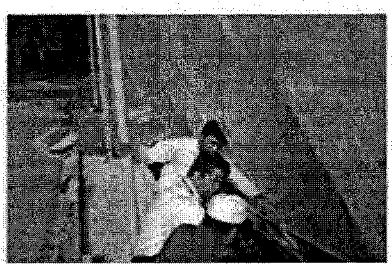
3.2.8 Site Visits Conducted by the Supervisor and Co-Supervisors

During the construction phase, regular meetings were arranged with the contractor in the presence of the supervisor and the co-supervisors to make sure that experimental site development is in compliance with the needs of the study. Continuous visits to the field area were conducted to assess the progress of the construction phase as shown in Figure 3.36.



Meeting arranged at the offshore lab to discuss the work progress

Site visit conducted by the Supervisor and Co-supervisor



Suggestions given by the Supervisor at the study field

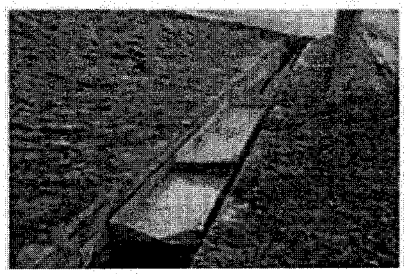
Suggestions given by the Co-supervisor at the study field

Figure 3.36 Site visits by the Supervisor and Co-supervisor

3.2.9 Problems Faced During the Experimental Phase

The study was performed on a prototype model which was constructed on a natural slope. While performing the runs, the experimental phase was affected by the occurrence of the natural rainfall. The bottom container designed to collect the water floated away in the drain during a high rainfall event as shown in Figure 3.37. The experiment encountered few hindrances as the height of the water and the flow pressure in the drain was such that it interrupted the discharge values and affected the water quality collected in the container. However, the experiment was repeated.

The container floated away of the study area



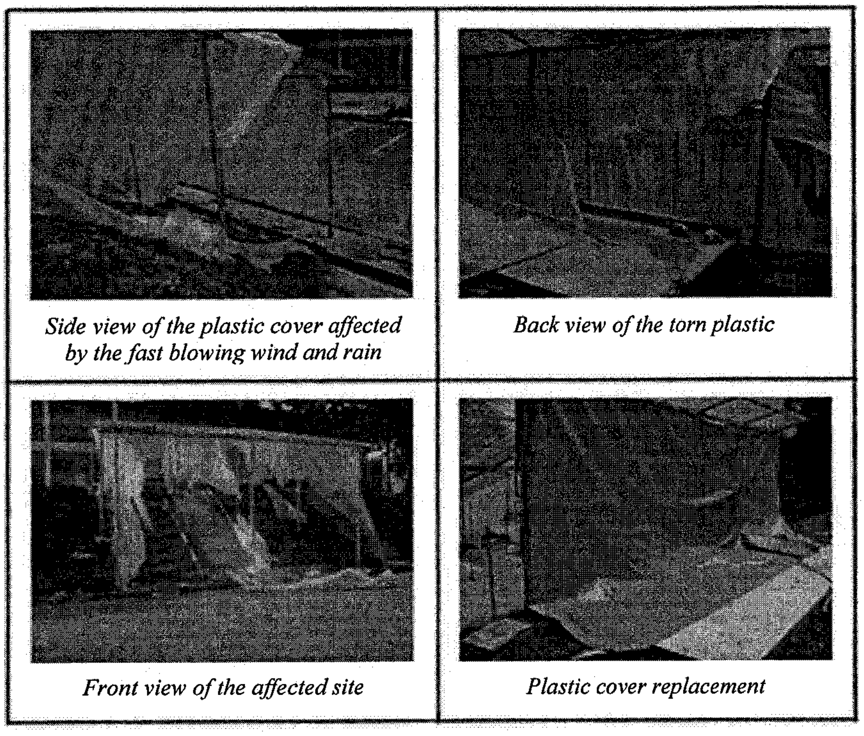
The container drifted away several meters by the flow pressure

Debris accumulated in the stone cage

The drain water taken out of the container which was then washed

Figure 3.37 The bottom container floated away

Similarly, the purpose of the plastic cover was to shelter the study area from the natural rainfall effects which worked, but somehow the fast blowing wind torn the plastic as shown in Figure 3.38 which delayed the experimental phase.



Side view of the plastic cover affected by the fast blowing wind and rain

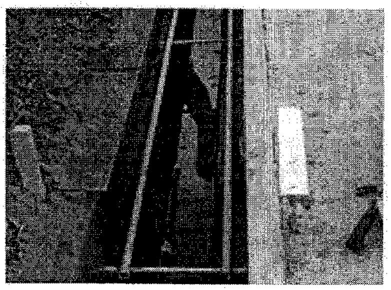
Back view of the torn plastic

Front view of the affected site

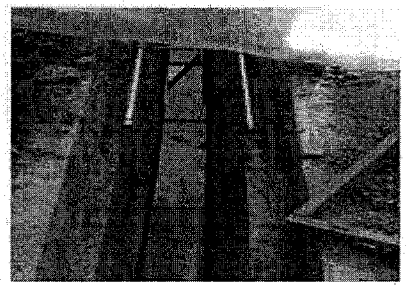
Plastic cover replacement

Figure 3.38 The plastic cover affected by the fast blowing wind

The bottom container was designed in such a way that it should receive all the suspended soil and the runoff that generates on the plot. The length of each plot was 2 meters whereas; the length of the container was designed for around 3 meters so that the stone cage can be placed in it and the water flows out of it smoothly without disturbing the water head. The length of the rails placed in the drain was 6 meters. However, when plot C was to be examined it was noticed that the container cannot be adjusted on the rails for which the rails were further extended as shown in Figure 3.39.



The rails length before extension



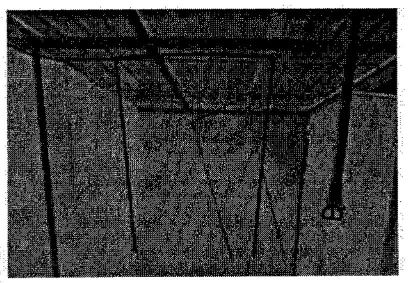
Extension of 1 meter

Top view of the extended rail

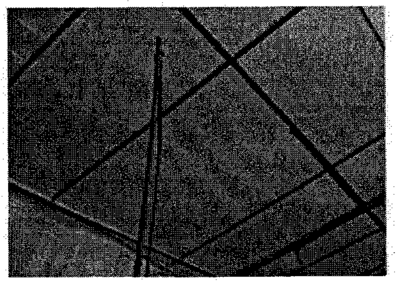
Ready for conducting the runs

Figure 3.39 The extension of rails

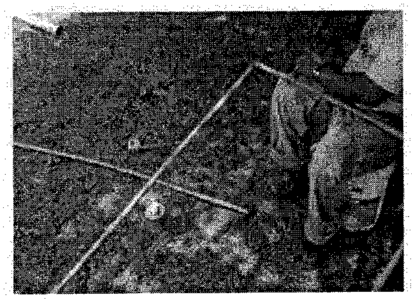
The PVC pipe attached to the rainfall simulator was found torn on one of the experimental plot due the fast blowing wind which was then repaired by the skilled workers to maintain the required discharge in the flow meter as shown in Figure 3.40.



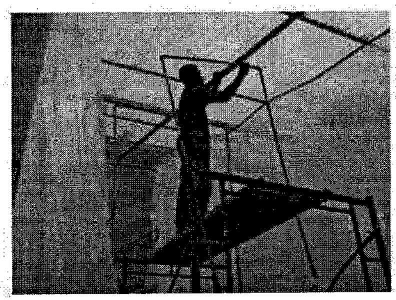
The simulators attached to the pipe network got torn



The wind force separated the simulators



The pipe connection repaired



Simulators affixed back to the place

Figure 3.40 PVC pipe collapsed

The study was further delayed for nearly around two weeks due to the smoke haze from the forest fires on the Indonesian island of Sumatra.

3.3 Soil Investigation

To determine the percentage of sand, clay, silt, and gravel particle size distribution (PSD) was performed. Soil water content (the amount of water present in the soil), bulk density (varies with the structural condition of the soil), and porosity (the measure of voids) were also determined.

3.3.1 Sampling Procedure for Determining Particle Size Distribution Test

Soil sample was taken and oven-dried for 24 hours at 105°C. The sample was then crushed and 501.2 gm (m_1) of the soil was taken to conduct the sieve analysis test.

Sieves were then cleaned and weighed. After weighing the sieves, they were arranged in the following aperture sizes 2 mm, 1.18 mm, 600 μm, 425 μm, 300 μm, 212 μm, 150 μm, 63 μm, and passing 63 μm .The sample was then placed on the top sieve and covered with the lid. The test sieves were then agitated for 15 minutes on the mechanical sieve shaker. The retained soil on each sieve was then weighed and calculated which has been shown in Table A.1 (APPENDIX A). The graphical representation of the particle size distribution chart is illustrated in Figure 3.41. The results attained showed that the soil was a sandy loam. Several other studies concerned with the soil type also found that the soil type in Perak is mainly sandy (Ghollasimood et al., 2012; Chew and Lee, 2006; Khairiah et al., 2009).

The soil sample

Crushing the soil sample

The mechanical sieve shaker

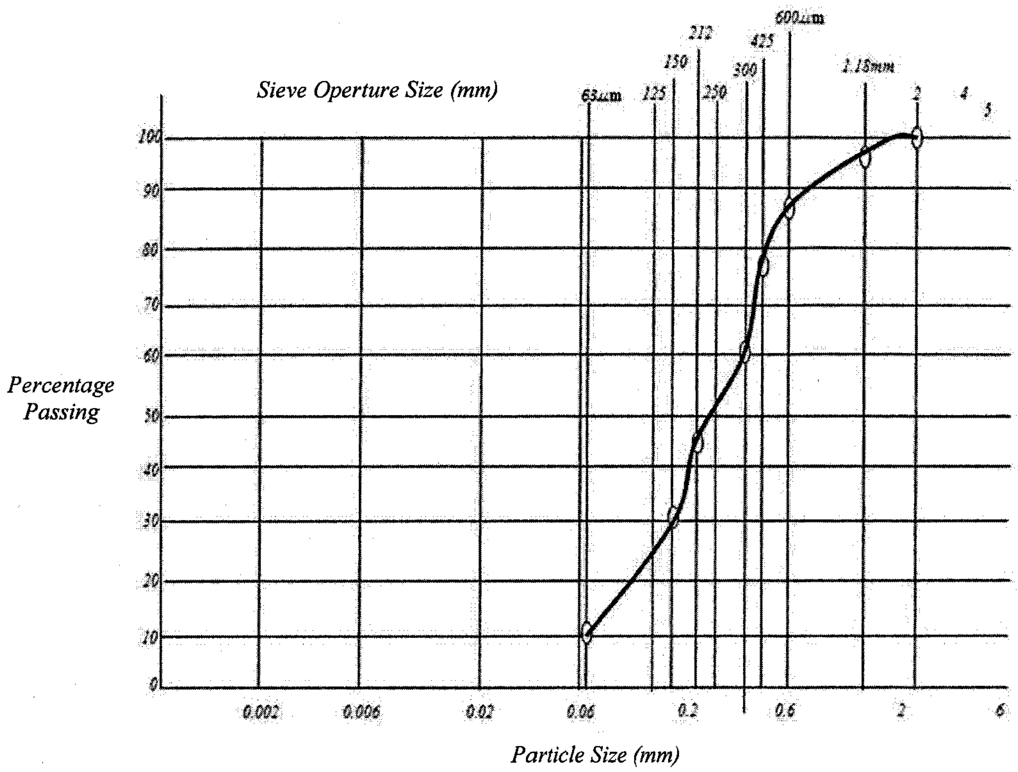
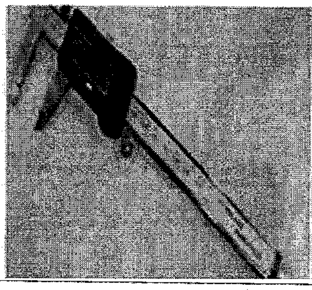


Figure 3.41 Particle size distribution chart

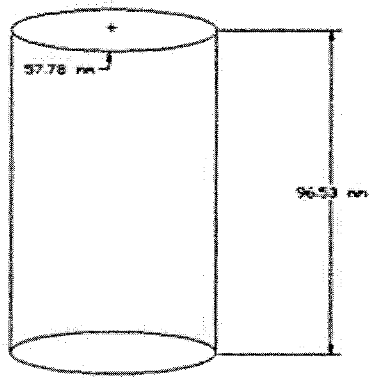
3.3.2 Sampling Procedure for Determining Water content, Bulk density, and Porosity

The cylindrical core method was used to calculate the soil water content, bulk density, and porosity. The ring was first driven into the soil using wooden block by means of hammer in a way that it should not disturb the soil structure. The ring was then lifted out carefully so that no soil loss occurs. The excess soil was removed using knife from the top and bottom of the ring which was then covered with the cloth. Later, the diameter and the height of the ring were measured to calculate the volume of the ring as shown in Figure 3.42.

The ring driven into the soil



Digital caliper for determining the height and the diameter of the ring



Dimensions of the ring

Figure 3.42 The use of ring method

The empty can was weighed along with the top cover. Next, the moist weight was recorded by emptying the soil into the can which was oven-dried for 24 hours and dried weight of the soil was determined.

Calculations

Wet weight of the soil, wet wt. = 639.5 g

Dry weight of the soil, dry wt. = 559.3 g

Inner diameter of the ring = 57.78 mm

Radius of the ring = 28.89 mm

Height of the ring = 96.53 mm

Volume of the ring $= \pi r^2 \times h$

$= 3.14 \times (28.89)^2 \times 96.53$

$= 252980\ mm^3$

Moisture Content (g/g) (%),

θg = [(wet wt. - dry wt.) / (dry wt. - can wt.)] x 100

= [(639.5g - 559.3g) / (559.3g - 189.2g)] x 100

= [80.2g / 370.1] x 100

= 21.66 %

A sandy soil can hold the moisture up to 30% (MEA, 2013).

Bulk Density (g/cm^3),

ρb = [(dry wt. - can wt.) / volume of the ring]

= [(559.3 - 189.2) / 252980]

= [370.1 / 252980]

$= 0.0014629\ g/mm^3$

$= 1.4629\ g/cm^3$

A sandy soil with the bulk density of less than 1.60 g/cm^3 is considered ideal for the plant growth whereas; it restricts the root growth if it contains the bulk density greater than 1.80 g/cm^3. For silty soil, the ideal bulk density suitable for the plant growth is less than 1.40 g/cm^3 and the bulk density that restricts root growth is greater than 1.65 g/cm^3. Similarly, for the clayey soil the ideal bulk density desired for the plant growth is less than 1.10 g/cm^3 and the bulk density that restricts root growth is greater than 1.47 g/cm^3 (USDA, 2008).

Soil Porosity,

Ø = [1 - (bulk density / particle density)], where particle density is assumed to be 2.65 g/cm^3

= [1 - (1.4629 / 2.65)]

= [1 - 0.55203]

= 0.448

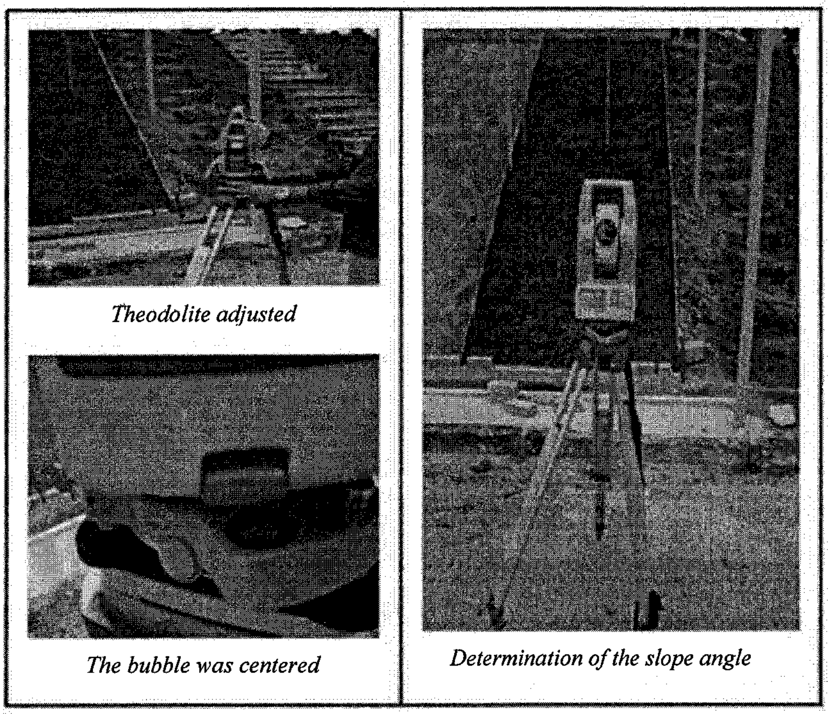
The soil volume detracted by the pore space is termed as porosity. For soils, it ranges in between 0.3 to 0.7. It depends on the variety of factors like packing density, particles binding, and particles shape. The porosity of an idealized soil with the uniform spheres lies in between 0.26 and 0.48 (Nimmo, 2004).

3.4 Determination of the Slope Angle

Procedure

Initially while selecting the experimental site estimation of the slope angle was among the major factors, which was manually determined. To make it more authentic the slope inclination was reconfirmed by using the equipment called "Theodolite". The apparatus helped finding the slope angle of the experimental surface by determining the slope height as shown in Figure 3.43.

The theodolite was adjusted and the bubble was balanced. The device was then turned "on" and the star (*) button was pressed. The option "laser from telescope" was selected and the icon of standard measure on the desktop of the screen was chosen. The laser point was then placed on the bottom end of the slope and the option "measure" was pressed. The horizontal distance was settled at zero by pressing F1 option after which the option "Yes" was selected. The vertical distance (V1) was then noted by selecting the triangle icon. The next step was to put the laser point on the top of the slope. No zero set was required this time. The vertical distance (V2) was then noted by pressing the triangle icon and the difference was taken to calculate the height.



Theodolite adjusted

The bubble was centered

Determination of the slope angle

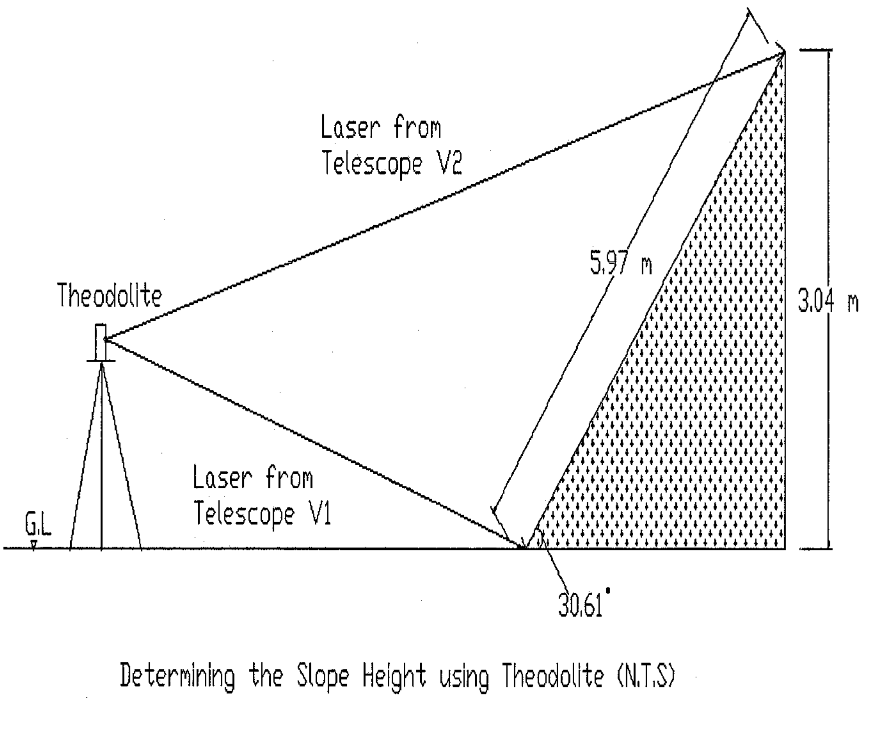


Figure 3.43 Determining the slope height for finding the slope angle (Auto-cad)

Calculations

The average height obtained from Plot A, B, and C = (3.055 + 2.995 + 2.988) / 3
= 3.04 meters

The Slope hypotenuse was already determined using measuring tape = 5.97 meters

$\sin \Theta$ = Perpendicular / Hypotenuse

$\Theta = \sin^{-1} (3.04 / 5.97)$

$\Theta = 30.61^{\circ}$

3.5 Rainfall Data Discussion

The South China Sea separates Malaysia into two land masses called Peninsular Malaysia and East Malaysia. The country covers an approximate land of 330,000 km^2 whose periphery meets with the border of Singapore, Thailand, Indonesia, Brunei, and Philippines. The Malaysian weather is quite hot and humid with the annual average rainfall of 2000 mm to 4000 mm and the uniform temperature which ranges between 25.5°C to 32°C (Suhaila et al., 2011).

In order to conduct the experimental study and to make it more realistic to the natural conditions, an authentic source of the rainfall data was required. The experimental field is located in the Peninsular Malaysia, Perak. Therefore, it was agreed to work with the rainfall data of the Perak for which the data was collected from the Meteorological Department Malaysia. The data includes the rainfall readings from the three stations located in Perak that is Lubok Merbau, Sitiawan, and Ipoh station as shown in Figure 3.44. The rainfall amount from all the stations is mentioned in mm for 15 minutes, 30 minutes, 45 minutes, 1 hour, 2 hours, 3 hours, 4 hours, 5 hours, 6 hours, 12 hours, 24 hours, 48 hours, 72 hours, and 98 hours.

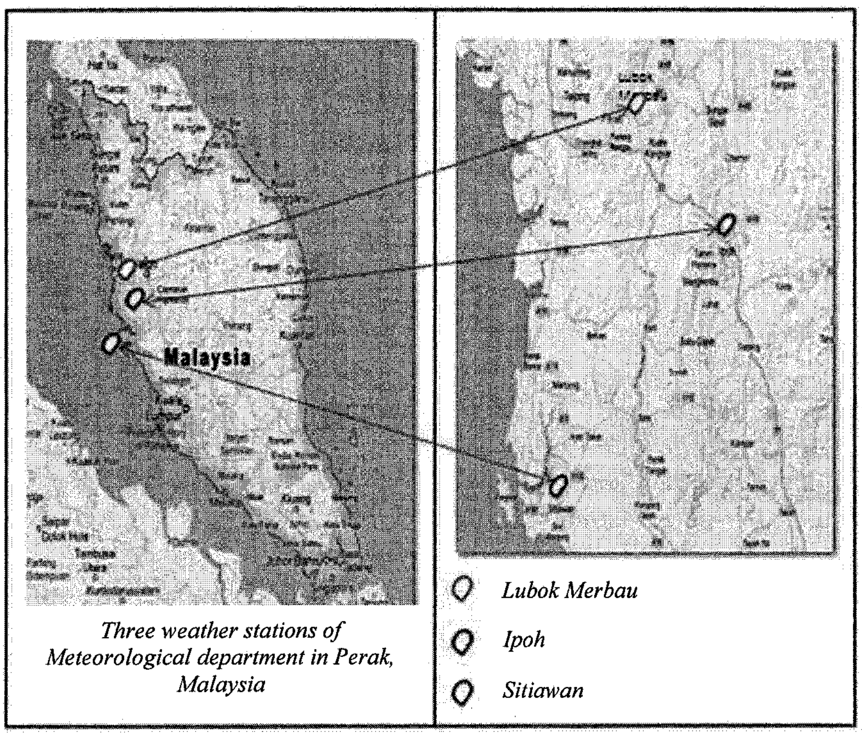


Figure 3.44 The three weather stations of Jabatan Meteorologi Malaysia in Perak

3.5.1 Highest Rainfall Amount in Millimeters Recorded for Various Durations

The highest rainfall amount in millimeters recorded for Lubok Merbau station has been shown in APPENDIX A, Table A.2 which is 04° 48'N (latitude) and 100° 54'E (longitude) with the height above MSL of 77.5 m .

The highest rainfall amount in millimeters recorded for Sitiawan station has been shown in APPENDIX A, Table A.3 which is 04° 13'N (latitude) and 100° 42'E (longitude) with height above MSL of 7.0 m.

The highest rainfall amount in millimeters recorded for Ipoh station has been shown in APPENDIX A, Table A.4 which is 04° 34'N (latitude) and 101° 06'E (longitude) with height above MSL of 40.1 m.

From Table A.2 it has been observed that some of the rainfall data for Lubuk Merbau station from the period of 1998 to 2004 is missing which shows that there were days that do not rain at all. The similar situation is observed for the Sitiawan station as shown in Table A.3 and Ipoh Station as shown in Table A.4.

However, it was decided to work with the rainfall data from the year 2005 to 2011 as the data for this duration was the most recent and complete.

3.5.1.1 The rainfall intensity in millimeters per hour from the period of 2005 to 2011 for Lubok Merbau, Sitiawan, and Ipoh station

Table 3.1 The rainfall intensity (mm/hour) from the period of 2005 to 2011 for Lubok Merbau station

Year	1/4*	1/2*	3/4*	1#	2#	3#	4#
2005	210.4	110.4	77.06	60.2	31.8	21.33	16
2006	141.6	111.2	84.2	66.4	34.3	23.33	17.5
2007	112	86	76.8	65.8	37.8	28.6	22.45
2008	155.2	116.8	87.46	68	36.1	25.06	18.85
2009	105.6	79.2	58.13	53	39.8	26.8	20.7
2010	96	87.2	83.2	71.4	39.1	26.33	19.75
2011	136	120.8	90.93	70	38.6	26	19.75
Total Avg.	136.68	101.65	79.68	64.97	36.78	25.35	19.28
Avg. High	210.4	120.8	90.93	71.4	39.8	28.6	22.45
Avg. Low	96	79.2	58.13	53	31.8	21.33	16

Cont.

Year	5#	6#	12#	24#	48#	72#	96#	
2005	12.84	10.73	5.36	2.69	1.48	1.41	1.24	
2006	14	11.7	5.85	3.07	1.70	1.43	1.42	
2007	18.28	15.3	7.75	3.94	2.21	1.81	1.43	
2008	15.12	12.63	6.75	3.38	1.94	1.42	1.40	
2009	16.6	13.9	6.96	3.62	2.03	1.40	1.27	
2010	15.8	13.16	6.58	3.29	2.31	1.92	1.79	
2011	16.12	13.9	7.35	4.5	3.31	2.60	2.05	
Total Avg.	15.53	13.04	6.65	3.49	2.14	1.71	1.51	**36.31**
Avg. High	18.28	15.3	7.75	4.5	3.31	2.60	2.05	**45.58**
Avg. Low	12.84	10.73	5.36	2.69	1.48	1.40	1.24	**27.94**

The average rainfall intensity (mm/hr) for Lubuk Merbau station from the period of 2005 to 2011 was found to be 36.31mm/hr, whereas; the high average rainfall intensity calculated was 45.58 mm/hr, and the low rainfall intensity calculated was 27.94 mm/hr. Figure 3.45 shows the graph of total average rainfall, average high rainfall, and average low rainfall for Lubok Merbau station.

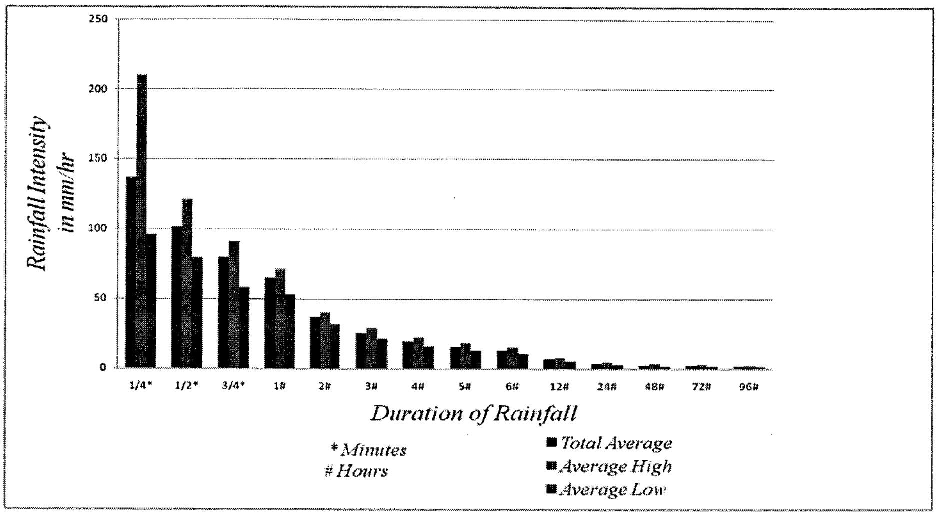


Figure 3.45 The rainfall intensity in millimeters per hour from the year 2005 to 2011for Lubuk Merbau, Perak Malaysia

Table 3.2 The rainfall intensity (mm/hour) from the period of 2005 to 2011 for Sitiawan station

Year	1/4*	1/2*	3/4*	1#	2#	3#	4#
2005	137.6	122	113.6	107.6	78.1	52.66	40
2006	153.6	112.4	85.6	80.2	48.6	42.93	34.7
2007	94.4	70.4	56.26	45.4	27.1	18.2	13.65
2008	167.2	150.8	135.2	113	78	56.46	42.75
2009	141.6	119.2	93.06	74.4	40.5	27.93	21.2
2010	112.8	84	70.66	65.8	44.6	32.13	24.85
2011	168	125.2	89.06	67	33.8	22.53	17.5

Total Avg.	139.31	112	91.91	79.05	50.1	36.11	27.8
Avg. High	168	150.8	135.2	113	78.1	56.46	42.75
Avg. Low	94.4	70.4	56.26	45.4	27.1	18.2	13.65

Cont.

Year	5#	6#	12#	24#	48#	72#	96#	
2005	32.12	26.76	13.38	6.7	3.75	2.50	1.87	
2006	27.92	23.3	11.66	6	3.17	2.11	1.81	
2007	10.92	9.2	6.11	3.2	1.90	1.29	0.98	
2008	34.36	29.03	14.61	9.35	5.0	3.35	2.79	
2009	17.08	14.26	7.33	4.07	2.15	1.44	1.09	
2010	20	17.16	8.61	4.44	2.22	1.68	1.27	
2011	14.72	12.26	8.05	4.26	3.22	2.76	2.23	
Total Avg.	22.44	18.85	9.96	5.43	3.05	2.16	1.72	**42.84**
Avg. High	34.36	29.03	14.61	9.35	3.75	3.35	2.79	**60.11**
Avg. Low	10.92	9.2	6.11	3.2	1.90	1.29	0.98	**25.64**

The average rainfall intensity (mm/hr) for Sitiawan station from the period of 2005 to 2011 calculated was 42.84 mm/hr, whereas; the high average rainfall intensity calculated was 60.11 mm/hr, and the low rainfall intensity calculated was 25.64

mm/hr. Figure 3.46 shows the graph of total average rainfall, average high rainfall, and average low rainfall for Sitiawan station.

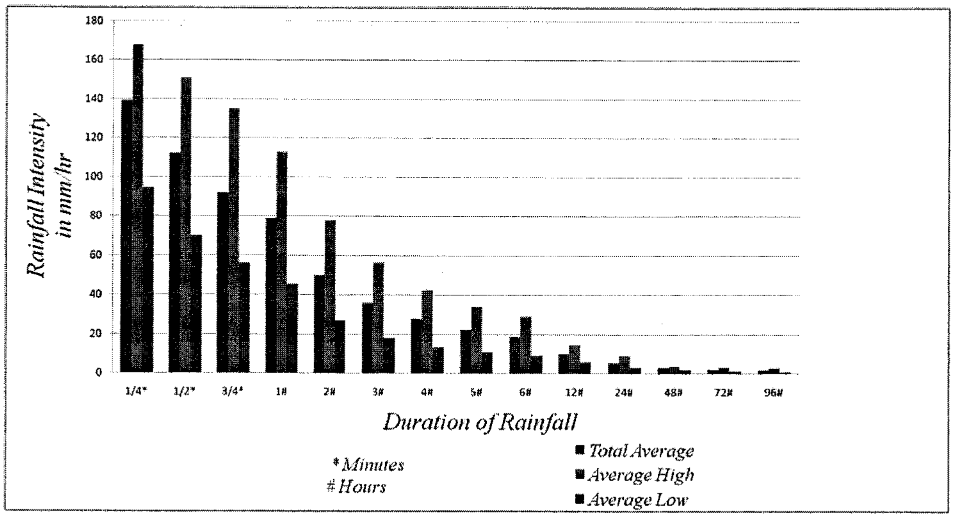


Figure 3.46 The rainfall intensity in millimeters per hour from the year 2005 to 2011for Sitiawan, Perak Malaysia

Table 3.3 The rainfall intensity (mm/hour) from the period of 2005 to 2011 for Ipoh station

Year	1/4*	1/2*	3/4*	1#	2#	3#	4#
2005	113.6	86.4	74.4	63.6	45.1	30.13	22.6
2006	167.2	136.4	119.7	101.6	60.2	40.13	30.1
2007	124	97.2	72.8	61.6	34.6	23.06	17.3
2008	141.6	128.8	105.3	84.6	44.7	30.53	25.6
2009	138.4	104	85.06	79.2	49.1	35.86	27.7
2010	144	124	105.06	83.8	51.5	34.73	26.05

2011	139.2	117.6	89.06	67.4	37.5	25	18.75
Total Avg.	138.28	113.4	93.05	77.4	46.1	31.34	24.01
Avg. High	167.2	136.4	119.7	101.6	60.2	40.13	30.1
Avg. Low	113.6	86.4	72.8	61.6	34.6	23.06	17.3

Cont.

Year	**5#**	**6#**	**12#**	**24#**	**48#**	**72#**	**96#**	
2005	18.12	15.1	8.9	4.53	2.28	1.72	1.35	
2006	24.08	20.06	10.03	5.56	3.31	2.33	1.95	
2007	13.84	11.63	6.51	3.97	2.19	2.23	1.69	
2008	20.48	17.06	8.53	4.74	2.98	2.23	1.78	
2009	22.56	18.8	9.41	4.70	2.95	1.99	1.60	
2010	20.84	17.36	8.7	4.8	3.66	2.53	1.92	
2011	15	12.5	6.25	4.11	2.07	1.39	1.14	
Total Avg.	19.27	16.07	8.33	4.63	2.77	2.06	1.63	**41.31**
Avg. High	24.08	20.06	10.03	5.56	3.66	2.53	1.95	**51.65**
Avg. Low	13.84	11.63	6.25	3.97	2.07	1.39	1.14	**32.11**

The average rainfall intensity (mm/hr) for Ipoh station from the period of 2005 to 2011 was found to be 41.31 mm/hr, whereas; the high average rainfall intensity calculated was 51.65 mm/hr, and the low rainfall intensity calculated was 32.11 mm/hr. Figure 3.47 shows the graph of total average rainfall, average high rainfall, and average low rainfall for Ipoh station.

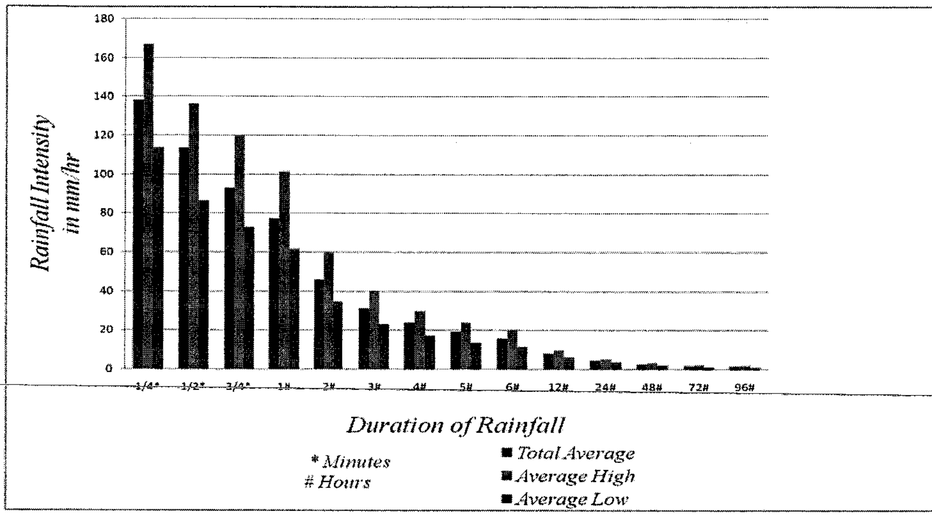


Figure 3.47 The rainfall intensity in millimeters per hour from the year 2005 to 2011for Ipoh, Perak Malaysia

3.5.2 Selection of the Rainfall Intensities and Determination of the Kinetic Energy

The total average rainfall intensities from the Table 3.1, Table 3.2, and Table 3.3 were observed to be 36.31 mm/hr, 42.84 mm/hr, and 41.31 mm/hr. These intensities were further averaged to get a single rainfall intensity that can be used for the experimental runs. The total averaged rainfall intensity from these three stations was observed to be **40.15 mm/hr.**

The average high rainfall intensities were observed to be 45.58 mm/hr, 60.11 mm/hr, and 51.65 mm/hr which were further averaged to get a single rainfall intensity that can be used for the experimental runs. The averaged high rainfall intensity from these three stations was calculated to be **52.44 mm/hr**.

Similarly, the average low rainfall intensities were found to be 27.94 mm/hr, 25.64 mm/hr, and 32.11 mm/hr which were further averaged to get a particular intensity to b used for the experimental runs. The averaged low rainfall intensity from these three stations was found to be **28.56 mm/ hr**.

The *total average, average high, and average low* rainfall intensities calculated from the three stations gave an average of *40.15 mm/hr, 52.44 mm/hr, and 28.56 mm/hr* respectively. The average values were quite close; however it was decided to disregard the *average low rainfall intensity* and to work with the *total average* and *average high* intensities on the experimental plots to study the behavior of an individual plot against soil loss, water discharge, turbidity, and the total suspended particles. Based on the rainfall intensity classification, the rainfall intensities opted for the experimental runs are classified as shown in Table 3.4 (Zainal Abidin and Arbai, 1998).

Table 3.4 Classification of rainfall intensity

Rainfall Intensity (mm hr^{-1})	**Remarks**
< 6.5	Low
6.5 – 13	Medium
13 – 50	High
> 50	Severe

The rainfall data analyzed for Perak, Malaysia shows that the rainfall intensities selected for conducting the experiments that is 40 mm hr^{-1} and 52 mm hr^{-1} lies nearly under the high rainfall events.

3.6 Framework of the Chapter

The methodology section of the thesis is framed in Figure 3.48 which indicates that the information on the previous work was gathered to conceive the creative approach and to find out the most appropriate way of dealing with the concerned issue. Once the concept was developed the next step was to ensure its feasibility, followed by experimental phase which then ended the project.

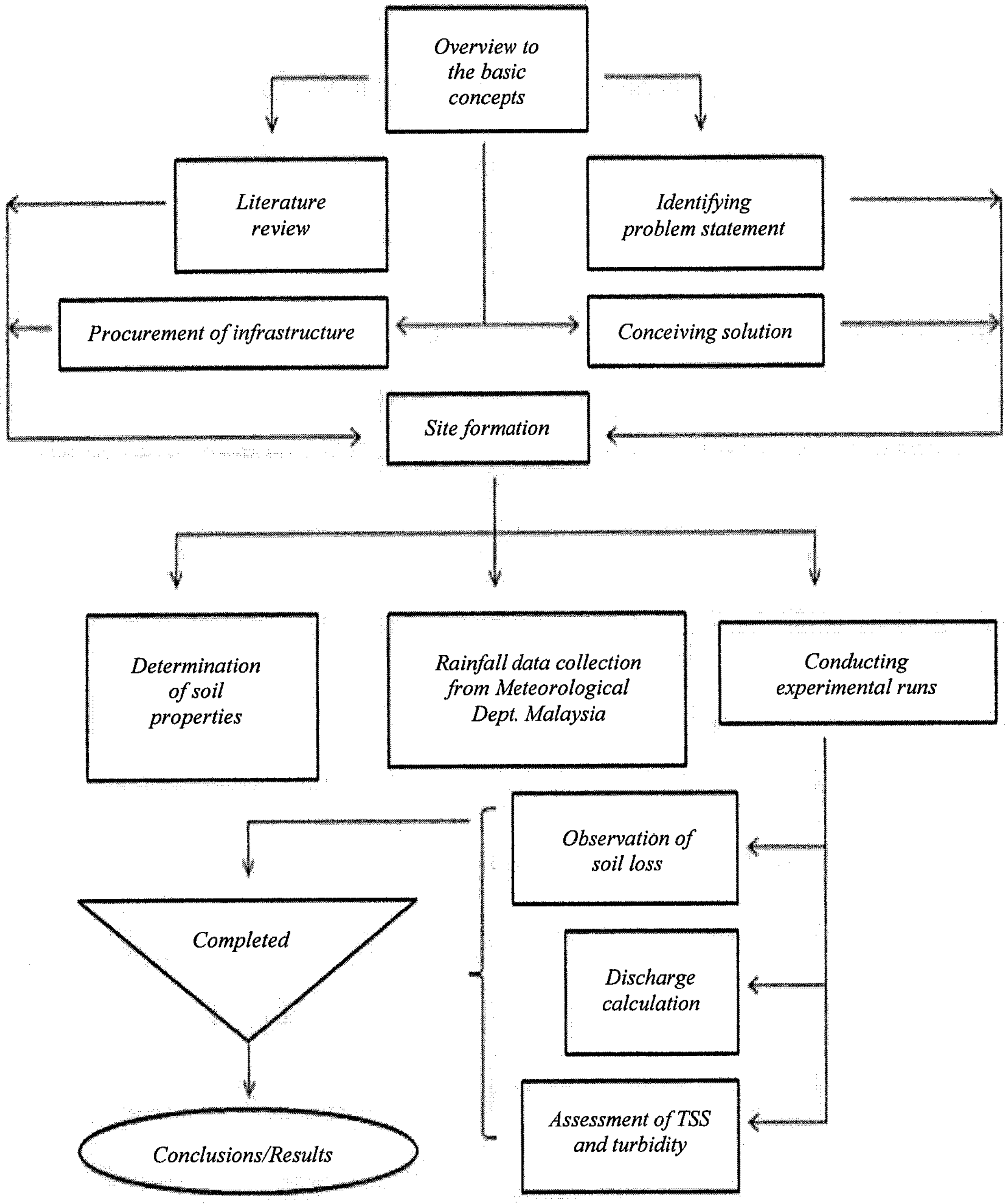


Figure 3.48 Framework of the chapter

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter comprises of the research findings which were analyzed while conducting the experiments. The results attained were adequately discussed to understand the significance of the outcomes. The behavior of all the plots, namely plot A (complete grass covered surface), plot B (0% of grass covered surface, bare surface), plot C (50% of grass covered surface), and plot D (30% of grass covered surface) under simulated rainfall conditions were observed. Note that the rainfall data for the Perak, Malaysia was analyzed to make it more realistic to the natural rainfall conditions through artificial rainfall simulators, as discussed in chapter 3. The rainfall intensities opted for the runs were 40 mm hr^{-1} and 52 mm hr^{-1}. The experimental site was constructed in such a way that it should meet all the requirements of the real field condition which was built in compliance with the studies mentioned in the literatures. For an individual rainfall event, each plot was observed for four factors including eroded soil, water discharge, turbidity and suspended particles which were monitored at different time intervals during the study phase and are further discussed in this chapter. Together for the four plots there were observed a total of 32 readings which concludes the findings of this thesis.

This chapter is sub-divided into three parts. The first part comprises "plot-to-plot" discussions along with the graphical representation of all the results obtained from the findings of the research under the rainfall events of 40 mm hr^{-1} and 52 mm hr^{-1} separately. The second part comprises the total average soil loss, water discharge, turbidity, and TSS values together for both the rainfall events and the third part presents overall discussion based on what was observed while conducting the runs for each phase which clarifies the findings of the study. The results attained from the study area were higher as the samples were directly collected from the known source whereas; in the real conditions the samples are obtained from the different sources which are influenced by the effluents and the runoff from the surrounding areas through several polluting agents.

The procedure of conducting experiments, collecting samples, and the lab works have already been discussed in detail in Chapter 3. However, this chapter slightly recalls that the eroded soil samples were collected at the intervals of 15 minutes for the period of 2 hours in the labeled plastic bags. To study the turbidity and the amount of total suspended solids present in the water, water samples were collected after every 15 minutes in the labeled plastic bottles. The water discharge was observed for a period of 2 hours and 40 minutes. For the first 2 hours the discharge was observed at the intervals of 15 minutes during the occurrence of the artificial rainfall while the remaining 40 minutes were kept at smaller frequent intervals of 5 minutes, once the rainfall was stopped. The purpose was to observe the influence of surface runoff in the absence of rainfall. The soil loss was measured in gram per meter square (g m^{-2}), the water discharge was observed in meter cube per second (m^3 sec^{-1}), the water turbidity was measured in nephelometric turbidity units (NTU), and the total suspended solids were measured in milligram per liter (mg L^{-1}).

4.2 Plot-to-Plot Comparison

The bare soil surface was served as a **control plot** to equate the soil loss results followed by the water discharge, turbidity and TSS obtained from all the other plots so that the efficiency of the cover percentage can be justified. The plot-to-plot comparisons were observed for two rainfall events that is the average total rainfall event (40 mm hr^{-1}) and the average high rainfall event (52 mm hr^{-1}) so that the proficiency of each plot can be determined for that particular rainfall intensity.

4.2.1 Simulated Rainfall Event of 40 mm hr^{-1} (Average Total Rainfall Event)

The results for all the plots were successively discussed under the rainfall event of 40 mm hr^{-1}. The tables and figures obtained from all the results were assembled so that it assures ease while comparing the results between the same variables.

4.2.1.1 Estimation of soil erosion from all plots under rainfall event of 40 mm hr^{-1}

For the rainfall event of 40 mm hr^{-1}, the erosion rates observed from the fully grass covered surface "plot A" were almost negligible for which the reason is suggested to be the dense grass covered surface which hindered the impact of falling water and sheltered the soil which did not allow the particles to scatter.

The erosion rates observed from the exposed soil surface "plot B" were drastic. It initiated with the soil loss of 64 g m^{-2} at the time interval of 15 minutes which varied up to 500.9 g m^{-2} at the time interval of 120 minutes.

50% of grass covered surface "plot C" performed well in reducing the soil detachment. The soil loss occurred, but the closely spaced grass patches did not allow the soil particles to flow away with the generated runoff. The soil loss observed at the time interval of 15 minutes was nearly around 1 g m^{-2} only. The maximum soil loss obtained was 11.94 g m^{-2} at the time interval of 120 minutes which was almost negligible when compared with the maximum soil loss attained from the bare soil surface.

The results attained from 50% of the grass covered surface showed decrement in the soil loss when compared with the control plot. However, for the sake of an economical approach the percentage of grass cover was further reduced up to 30% "plot D". The maximum soil loss observed from this plot was noticed to be 89.19 g m^{-2} at the time interval of 120 minutes which was intolerable. The reason for the excessive soil loss occurrence was due to the reduced percentage of grass cover which increased the distance between the grass patches and allowed the detached soil particles to run away with the generated runoff. Although the soil loss observed from this plot was high but it was comparatively low when compared with the control plot.

The soil loss occurred at different rates at different time intervals. However, the graph attained for the soil loss demonstrates accumulated soil loss at each interval. Due to the negligible soil loss, the slope of the line observed for 100% of the grass covered surface was found unvarying. For the remaining three plots namely, 0% of the grass covered surface, 30% of the grass covered surface, and 50% of the grass covered surface, positive slopes were observed as the accumulated soil loss varied with the passage of time.

The erosion rates obtained from all the plots for the rainfall intensity of 40 mm hr^{-1} are shown in APPENDIX B, Table B.1. All the plots were observed under the same conditions so that the study output can be precisely compared. However, the collected soil samples were dried and the accumulated erosion rates were attained.

To visualize the results more clearly Figure 4.1 shows the graph which gives a clear perspective of the soil loss that occurred while running the experiments under the rainfall event of 40 mm hr^{-1}.

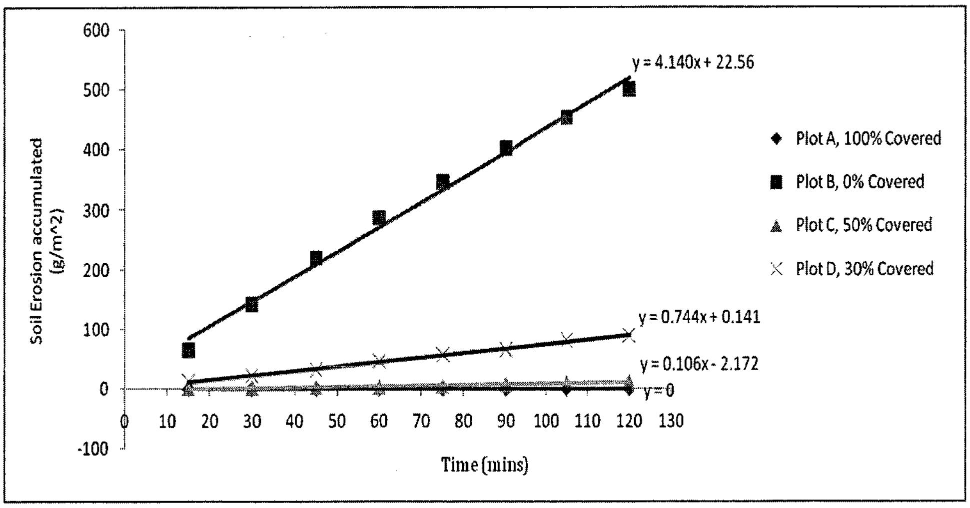


Figure 4.1 Observation of soil loss from all the plots at different time intervals under the rainfall intensity of 40 mm hr^{-1}

4.2.1.2 Assessment of water discharge from all plots under rainfall event of 40 mm hr⁻¹

A V-notch weir was designed to study the discharge pattern from all the plots affected by the modeled rainfall event of 40 mm hr^{-1}, the description of which has been discussed in Chapter 3. The water head was noted in the bottom container after every 15 minutes for 2 hours (occurrence of artificial rainfall) and after every 5 minutes for the next 40 minutes (no rainfall, only surface runoff) which helped knowing the response of the water flow affected by the rain drop impact along with the surface runoff and by the surface runoff only for all the plots.

From "plot A", a little variance in the water discharge was observed. The maximum discharge was observed to be $1.1x10^{-5}$ m^3 sec^{-1} during the occurrence of artificial rainfall. However, there was noticed a sudden decrement in the discharge values for the remaining 40 minutes when there was no rainfall and the minimum discharge value observed was found to be $4.46x10^{-7}$ m^3 sec^{-1}.

The bare soil surface "plot B" offered the maximum discharge values under the rainfall intensity of 40 mm hr^{-1}. A gradual increase in the water discharge was observed from the exposed soil surface during the occurrence of artificial rainfall. At the time interval of 105 minutes and 120 minutes, the water discharge was found constant that is $5.78x10^{-5}$ m^3 sec^{-1}. The reason for the constant discharge flow is suggested that the soil pores got saturated which did not allow further water penetration into the soil. A rapid decline in the flow rate was observed for the next 40 minutes when there was no rainfall. However, the minimum flow rate observed from the bare soil surface was found to be $4.40x10^{-6}$ m^3 sec^{-1}.

For "plot C", the water discharge was to be observed in the similar way as observed for "plot A", and "plot B". However, while running the experiments it was noticed that the presence of closely spaced grass patches and the soil pore capacity restricted the water flow. Although, it was hypothesized that the discharge values from "plot C" would be in between the discharge values observed for "plot A" and "plot B" but the water collected at the catchment outlet was lower than that of "plot A" and "plot B". The maximum discharge observed from "plot C" was found to be

$6.8x10^{-6}$ m^3 sec^{-1} at the time interval of 120 minutes during the occurrence of artificial rainfall. However, the water collected in the designed container did not flow out of the container (the water height did not reach the crest elevation) which hindered the discharge calculation for the remaining 40 minutes.

For the initial first hour, the water discharge was observed to be slightly varying from "plot D". Later, there was observed a sudden increase which remained constant at the time interval of 75 minutes, 90 minutes, 105 minutes, and 120 minutes. The reason is suggested that the soil pores got occupied by the water which did not allow further saturation of the soil. Moreover, the reduced percentage of cover increased the gap between the grass patches. However, the maximum water discharge observed from "plot D" was found to be $3.9x10^{-5}$ m^3 sec^{-1} which was higher than the maximum water discharge observed from plot C whereas; when the simulators were kept off the discharge was reduced up to $2.52x10^{-6}$ m^3 sec^{-1} due to no increment in the surface runoff.

The discharge rates (flow rate per unit time) observed for the period of 2 hours (during the occurrence of rainfall) and 40 minutes (when there was no rainfall) under the rainfall intensity of 40 mm hr^{-1} are shown in APPENDIX B, Table B.2.

The relationship among different discharge values have been summarized in the form of hydrograph as stated in Figure 4.2 for all the plots under the rainfall intensity of 40 mm hr^{-1}.

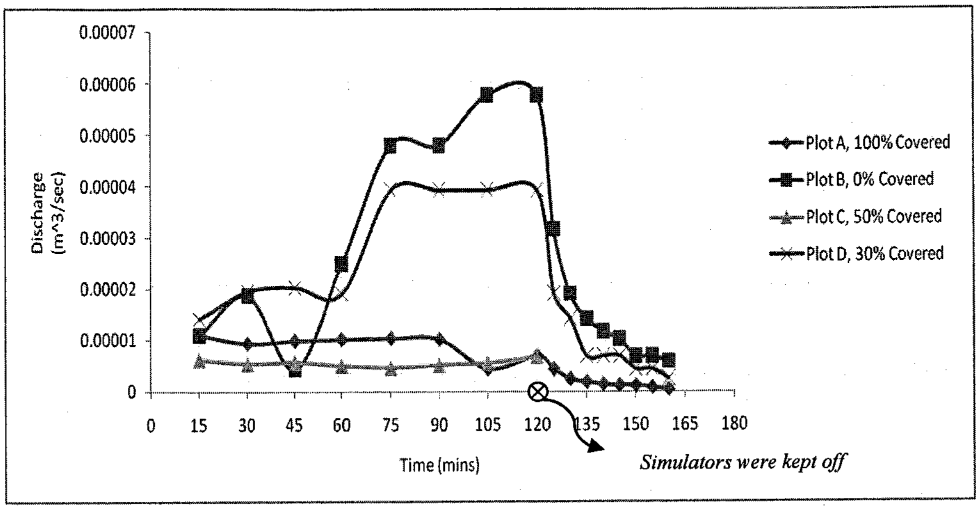


Figure 4.2 Observation of the water discharge from all the plots at different time intervals under the rainfall intensity of 40 mm hr^{-1}

4.2.1.3 Observation of water turbidity from all plots under rainfall event of 40 mm hr^{-1}

For determining the water turbidity, water samples were collected after every 15 minutes in the labeled plastic bottles of known volume while conducting the runs. The way how the turbidity was determined has been discussed in Chapter 3.

Due to negligible soil loss the maximum and minimum turbidity values obtained from the fully grass covered surface "plot A" were found to be 75 NTU and 31.66 NTU respectively which were 21.75 times and 31.63 times lower than the maximum and minimum turbidity values obtained from the bare soil surface "plot B".

Without any protection cover there was observed a major soil loss from the bare soil surface "plot B" which not only influenced the water discharge but also affected the water turbidity and the presence of suspended particles in the water. However, the maximum turbidity value obtained from "plot B" was found to be 1631.5 NTU and the minimum turbidity value was observed to be 1001.5 NTU.

Being partially covered the maximum and minimum turbidity values obtained from "plot C" were found to be 490 NTU and 233 NTU respectively which were 3.32 times and 4.29 times lower than the maximum and minimum turbidity values obtained from the bare soil surface "plot B". The maximum turbidity value observed from "plot C" was only 30% of the maximum turbidity value observed from the bare soil surface "plot B". Similarly, the minimum turbidity value observed from "plot C" was only 23.26% of the minimum turbidity value observed from the exposed soil surface "plot B".

The maximum turbidity value observed from "plot D" was found to be 1472.5 NTU which was only 1.10 times lower than the maximum turbidity value obtained from the bare soil surface. The water samples collected from the slightly grass covered area were found very muddy. The higher turbidity rates could have been due to the cloudiness of the water which could have reflected the light waves resulting in the increased turbidity values. However, the results obtained from 30% of the grass covered surface were quite close to the results obtained from bare soil surface. The maximum turbidity value observed from "plot D" was 90.25% of the maximum turbidity value obtained from "plot B". The minimum turbidity value observed from "plot D" was 1120 NTU which was higher than the minimum turbidity value observed from "plot B".

The turbidity values attained from all the plots formed positive slopes with the passage of time under the rainfall intensity of 40 mm hr^{-1}. The equation of the straight line showed that the tangent of the inclination was steeper for the bare soil surface, followed by 30% of the grass covered surface, 50% of the grass covered surface, and 100% of the grass covered surface.

The turbidity values obtained from all the plots under the rainfall intensity of 40 mm hr^{-1} are shown in APPENDIX B, Table B.3.

Figure 4.3 shows the turbidity values obtained at different time interval from all the plots under the rainfall intensity of 40 mm hr^{-1}.

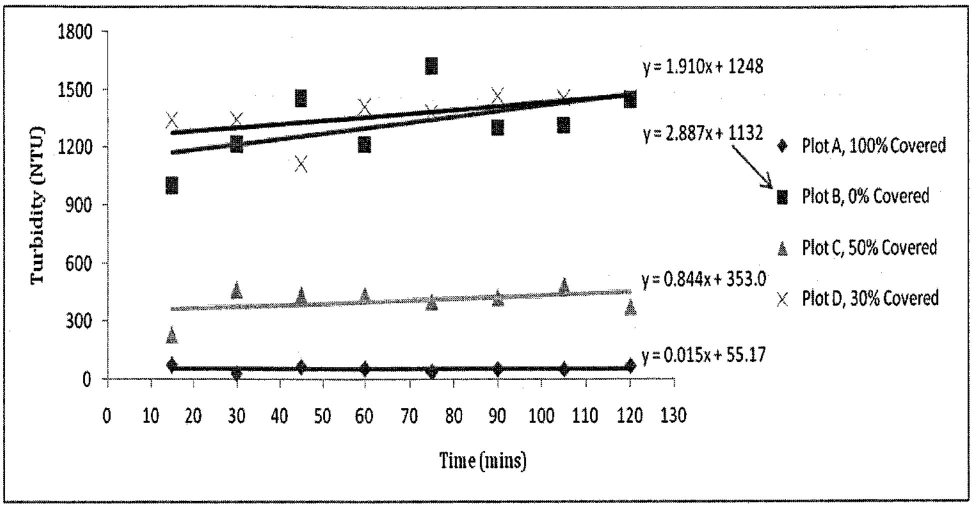


Figure 4.3 Turbidity values obtained at different time intervals from all the plots under the rainfall intensity of 40 mm hr^{-1}

4.2.1.4 Determination of total suspended solids (TSS) from all plots under rainfall event of 40 mm hr^{-1}

The water samples collected during the experimental runs were used both for determining the water turbidity and total suspended solids for all the plots. The way how total suspended solids (TSS) were determined has been discussed in Chapter 3.

The water samples collected from "plot A" were used to determine the concentration of total suspended solids which retained on the filter paper. The maximum and minimum TSS values observed from "plot A" were found to be 11.3 mg L^{-1} and 5.3 mg L^{-1} respectively which were only 16.37% and 16.40% of the maximum and minimum TSS values observed from the bare soil surface "plot B". The reason for the minimal TSS values was the presence of fully covered grass surface which nullified the impact of the rain drops on the soil particles and restricted the detachment process.

The TSS values observed from the bare soil surface "plot B" were quite high due to no surface cover. The soil surface being exposed, allowed rain water to detach the soil particles which were carried away by the generated runoff. Due to the excessive soil loss the maximum TSS value obtained for "plot B" was 69 mg L^{-1} and the minimum TSS value obtained for "plot B" was noted to be 32.3 mg L^{-1}.

The maximum and minimum TSS values obtained from 50% of the grass covered surface were found to be 24.3 mg L^{-1} and 7.0 mg L^{-1} respectively which were 2.83 times and 4.61 times lower than the maximum and minimum TSS values observed from the control plot "plot B". The maximum TSS value observed from "plot C" was only 35.21% of the maximum TSS value observed from the bare soil surface "plot B". Similarly, the minimum TSS value observed from "plot C" was only 21.67% of the minimum TSS value observed from the exposed soil surface "plot B". The reason for the reduced TSS values is suggested that the closely spaced grass patches scattered the flow direction and reduced the flow velocity which restricted the sediments transport.

The percentage of grass cover was further reduced to observe the concentration of total suspended solids attained from "Plot D". Although the TSS values were observed to be low compared to "plot B" but there was not found any marginal difference. The maximum and minimum TSS values observed from "plot D" were found to be 44 mg L^{-1} and 15 mg L^{-1} which were only 1.56 times and 2.15 times lower than the maximum and minimum TSS values observed from the exposed soil surface. The maximum TSS value observed from "plot D" was 63.7% of the maximum TSS value observed from the bare soil surface "plot B". Similarly, the minimum TSS value observed from "plot D" was 46.43% of the minimum TSS value observed from the bare soil surface.

It was observed that the corresponding increase in the turbidity can not necessarily produce higher values of TSS. The correlation of the suspended particles with the turbidity can be inconsistent as the degree of opaqueness of water is influenced by the variety of components other than the suspended particles like air bubbles, floating debris, water discoloration, and the presence of organic compounds (Bin Omar and Bin MatJafri, 2009; Riley, 1998; Clifford et al., 1995; ISBD, 2011). The correlation between TSS concentration and turbidity is not universal (Ahmedi, 2013). Turbidity is purely an optical property which varies with the size and shape of the suspended particles together with the substance of which they are made. It measures the refractory features of an object in the water which is not always directly related to the TSS concentration (Bash et al., 2001; Carlson, 2005).

The TSS values obtained from each plot at different time intervals under the rainfall intensity of 40 mm hr^{-1} are shown in APPENDIX B, Table B.4.

Figure 4.4 shows the graphical representation of the TSS values obtained from all the plots under the rainfall intensity of 40 mm hr^{-1}. The graph clarifies that how the TSS values varied among different plots with the passage of time under the same rainfall event.

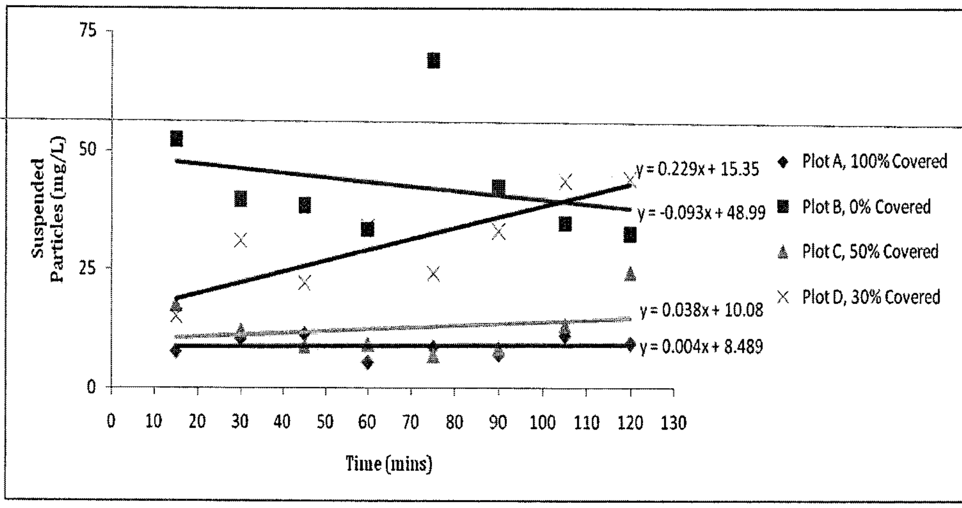


Figure 4.4 TSS values obtained at different time intervals from all the plots under the rainfall intensity of 40 mm hr^{-1}

4.2.2 Simulated Rainfall Event of 52 mm hr^{-1} (Average High Rainfall Event)

The results obtained for the soil loss, water discharge, turbidity, and suspended solids were discussed successively from all the plots under the rainfall event of 52 mm hr^{-1}. The plot to plot comparisons assisted in knowing the impact of similar rainfall events on the different percentage of grass covered soil surfaces. The outcomes attained were compared with the control plot that is "plot B" so that the efficiency of each plot can be justified. The tables and figures obtained from all the results were gathered so that it ensures ease while comparing the results between the same variables.

4.2.2.1 Estimation of soil erosion from all plots under rainfall event of 52 mm hr^{-1}

For the fully grass covered surface "plot A", the soil loss was trifling under the rainfall intensity of 52 mm hr^{-1} due to the presence of dense grass cover which minified the rain drop impact and sheltered the soil particles. The presence of cover nullified the falling force of the rain water which could not strike the soil surface.

The results obtained from the bare soil surface "plot B" initiated with the soil loss of 64.52 g m^{-2} at the time interval of 15 minutes. A gradual increase was observed afterwards with the passage of time which then reached the maximum soil loss of 578.73 g m^{-2} at the time interval of 120 minutes.

In mitigating the soil loss, 50 % of the grass covered surface showed salient results. The grass patches worked as a filter which trapped the detached sediments and minimized the surface water flow. The minimum soil loss observed from "plot C" was found to be 2.09 g m^{-2} at the time interval of 15 minutes and the maximum soil loss was observed to be 17.39 g m^{-2} at the time interval of 120 minutes. Even though the soil loss was there but the grass patches restricted the movement of soil particles and dribbled the detached sediments. The maximum soil loss observed from "plot C" was only 3.0% of the maximum soil loss observed from the bare soil surface and the minimal soil loss obtained from "plot C" was only 3.23% of the minimum soil loss observed from the bare soil surface.

The soil loss observed from 30% of the grass covered surface "plot D" was comparatively higher than "plot C" due to the reduced surface cover. The maximum and minimum soil loss observed from "plot D" were found to be 102.4 g m^{-2} and 11.42 g m^{-2} respectively. The maximum soil loss observed from "plot D" was 17.69% of the maximum soil observed from the bare soil surface and the minimum soil loss observed from "plot D" was also 17.69% of the minimum soil loss observed from the bare soil surface.

The soil loss observations were nearly same for both the rainfall events. For 100% of the grass covered surface, the line of the best fit was found unvarying which made the slope of the straight line zero. It was due to the negligible soil loss. However, the other three plots, namely 0% of the grass covered surface, 30% of the grass covered surface, and 50% of the grass covered surface formed positive slopes due to accumulated increment in the soil loss.

The soil loss observed from all the plots under the rainfall intensity of 52 mm hr^{-1} has been shown in APPENDIX B, Table B.5.

Figure 4.5 shows the graphical representation of the soil loss which was observed under the rainfall intensity of 52 mm hr^{-1}. The graph obtained, demonstrates the variation observed at different time intervals which helps understanding the situation occurred while conducting the experiments.

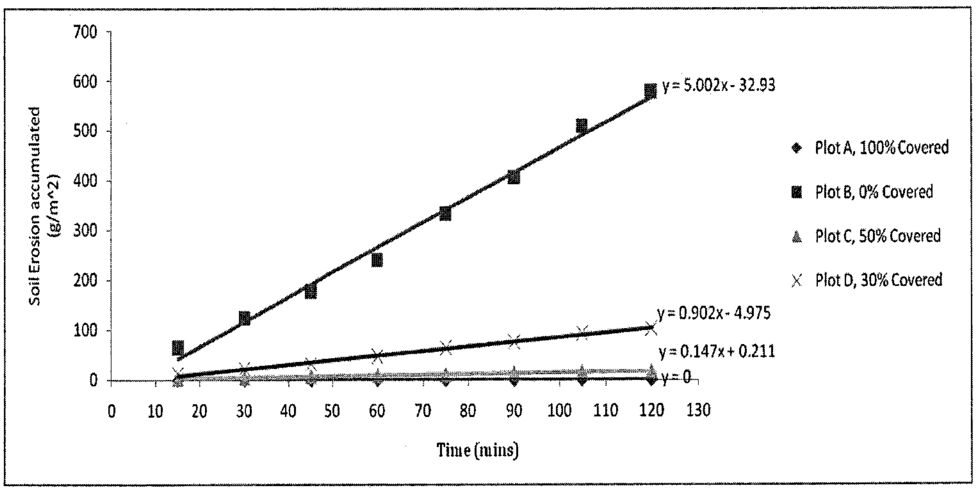


Figure 4.5 Observation of soil loss from all the plots at different time intervals under the rainfall intensity of 52 mm hr^{-1}

4.2.2.2 Assessment of water discharge from all plots under rainfall event of 52 mm hr^{-1}

The water discharge observed from the fully grass covered surface "plot A" was found nearly constant for the initial two hours. The maximum discharge was found to be 2.49×10^{-5} m^3 sec^{-1} during the occurrence of artificial rainfall whereas; when there was no rainfall the minimal water discharge was observed to be 1.03×10^{-6} m^3 sec^{-1}.

For the bare soil surface "plot B", the water discharge was observed to be very high. The maximum discharge observed from the exposed soil surface was found to be 9.39×10^{-5} m^3 sec^{-1} which was 3.7 times the maximum water discharge observed for the fully grass covered surface. However, when there was no rainfall the minimum water discharge was observed to be 4.86×10^{-6} m^3 sec^{-1} which was 4.7 times the minimum water discharge observed for the fully grass covered surface. Due to no surface cover, the velocity of the generated runoff from the loosely structured soil surface was raised.

The discharge was observed to be very low from 50 % of the grass covered surface "plot C" when compared with the discharge values obtained from "plot A" and "plot B". In reducing the water discharge "plot C" performed very well which shows that 50 % of the grass covered surface was adequate enough in controlling the water discharge for the modeled rainfall event. The maximum water discharge observed from this plot during the occurrence of artificial rainfall was found to be 9.73×10^{-6} m^3 sec^{-1} which was 10.36% of the maximum water discharge observed from the bare soil surface whereas; when there was no rainfall the minimum water discharge observed from "plot C" was found to be 7.88×10^{-8} m^3 sec^{-1} which was 1.62% of the minimum water discharge observed from the bare soil surface. This happened due to the presence of closely spaced grass patches which hindered the runoff flow and scattered the flow direction.

30% of the grass covered surface "plot D" allowed the surface runoff to flow more quickly as compared to "plot C". The discharge gradually started increasing when the rainfall simulators were kept on. Later, a constant flow was observed. The lack of cover provided passage to the generated runoff due to which the water discharge was observed high. The maximum water discharge observed from "plot D" was found to be 4.80×10^{-5} m^3 sec^{-1} which was 51.11% of the maximum water discharge observed from the bare soil surface. However, when the simulators were kept off, the minimum water discharge was found to be 4.46×10^{-7} m^3 sec^{-1} which was 9.17% of the minimum water discharge observed from the bare soil surface.

The discharge values observed from all the plots under the rainfall event of 52 mm hr^{-1} are shown in APPENDIX B, Table B.6.

Figure 4.6 shows the graph obtained for the water discharge under the rainfall event of 52 mm hr^{-1}. The fluctuations in the discharge values can easily be understood from all the plots under the same rainfall event through the graphical representation. The graph more likely represents the hydrograph which rose gradually during the occurrence of artificial rainfall for the first two hours. Later, a gradual fall was observed when there was no rainfall and the flow was assisted by the surface runoff only for the remaining 40 minutes.

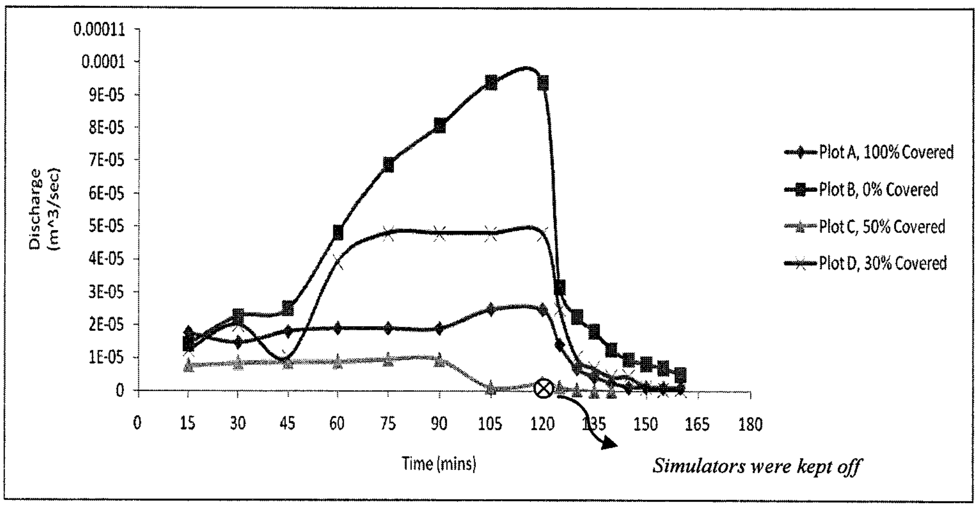


Figure 4.6 Observation of the water discharge from all the plots at different time intervals under the rainfall intensity of 52 mm hr^{-1}

4.2.2.3 Observation of water turbidity from all plots under rainfall event of 52 mm hr⁻¹

The maximum turbidity value obtained from the fully grass covered surface "plot A" was found to be 135 NTU and the minimum turbidity value was observed to be 93.33 NTU. Compared to the bare soil surface the maximum turbidity value obtained from "plot A" was only 5.2% of the maximum turbidity value obtained from "plot B". Similarly, the minimum turbidity value obtained from "plot A" was only 9.8% of the minimal turbidity value obtained from "plot B".

The turbidity values obtained from the exposed soil surface "plot B" were severe. The maximum turbidity value obtained from "plot B" was found to be 2585 NTU which was 19.14 times the maximum turbidity value obtained from the fully grass covered surface. However, the minimum turbidity value obtained from "plot B" was noticed to be 951.5 NTU which was 10.19 times the minimum turbidity value obtained from the fully grass covered surface.

The maximum turbidity value obtained from the partially grass covered surface "plot C" was found to be 678 NTU which was 26.2% of the maximum turbidity value obtained from the bare soil surface "plot B". The minimum turbidity value obtained from "plot C" was found to be 328 NTU which was 34.47% of the minimal turbidity value obtained from the bare soil surface "plot B". The maximum turbidity value observed from 50% of the grass covered surface was 3.81 times lower than the maximum turbidity value observed from the bare soil surface. Similarly, the minimum turbidity value obtained from 50% of the grass covered surface was 2.9 times lower than the minimum turbidity value observed from the bare soil surface.

A marginal difference between the turbidity values was observed when the maximum and minimum turbidity values obtained from "plot C" were compared with the maximum and minimum turbidity values obtained from "plot D". The maximum turbidity value observed from 30% of the grass covered surface was only 1.5 times lower than the maximum turbidity value observed from the bare soil surface. Similarly, the minimum turbidity value observed from "plot D" was 1.04 times lower than the minimum turbidity value observed from the bare soil surface. In percent, the maximum turbidity value observed from 30% of the grass covered was 66.53% of the maximum turbidity value observed from the bare soil surface and the minimum turbidity value observed from the 30% of the grass covered surface was 95.46% of the minimum turbidity value observed from the bare soil surface.

The turbidity values observed from an individual plot showed variations at different time intervals. The line obtained predicted the best fit of the scattered data. The slope of the line observed from 0% of the grass covered surface, 30% of the grass covered surface, and 100% of the grass covered surface formed positive slant. For 50% of the grass covered surface the line of the best fit formed a negative slope.

The turbidity values attained from all the plots under the rainfall intensity of 52 mm hr^{-1} are shown in APPENDIX B, Table B.7.

Figure 4.7 shows the graphical representation of the turbidity values obtained from all the plots under the rainfall intensity of 52 mm hr^{-1}.

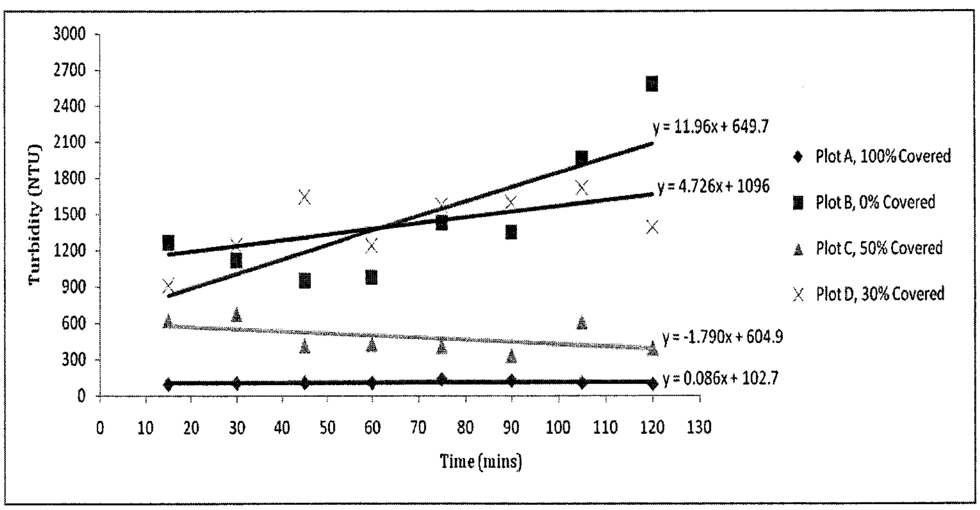


Figure 4.7 Turbidity values obtained at different time intervals from all the plots under the rainfall intensity of 52 mm hr^{-1}

4.2.2.4 *Determination of total suspended solids (TSS) from all plots under the rainfall event of 52 mm hr^{-1}*

The maximum and minimum TSS values obtained from the fully grass covered surface "plot A" were found to be 13 mg L^{-1} and 2.3 mg L^{-1} respectively. However, the maximum TSS value obtained from "plot A" was only 22.29% of the maximum TSS value obtained from the bare soil surface "plot B" whereas; the minimum TSS value obtained from "plot A" was only 26.74% of the minimum TSS value attained from the exposed soil surface "plot B".

The maximum TSS value obtained from the exposed soil surface "plot B" was found to be 58.3 mg L^{-1} which was 4.48 times the maximum TSS value obtained from "plot A". Similarly, the minimum TSS value obtained from the exposed soil surface "plot B" was found to be 8.6 mg L^{-1} which was 3.73 times the minimum TSS value obtained from "plot A".

The maximum and minimum TSS values obtained from the partially grass covered surface "plot C" were found to be 26.6 mg L^{-1} and 10.65 mg L^{-1} respectively. The maximum TSS value obtained from "plot C" was 45.62% of the maximum TSS value obtained from "plot B" and the minimum TSS value obtained from "plot C" was 1.23 times the minimum TSS value obtained from "plot B".

The maximum and minimum TSS values obtained from 30% of the grass covered surface "plot D" were found to be 46 mg L^{-1} and 20 mg L^{-1} respectively. The maximum TSS value obtained from "plot D" was 78.90% of the maximum TSS value obtained from "plot B" and the minimum TSS value obtained from "plot D" was 2.32 times the minimum TSS value obtained from "plot B".

The maximum TSS value was observed from the bare soil surface, followed by 30% of the grass covered surface, 50% of the grass covered surface and 100% of the grass covered surface. However, positive slopes were formed for 0% of the grass covered surface, 30% of the grass covered surface, and 100% of the grass covered surface whereas; for 50% of the grass covered surface a negative tilt was observed forming a decreasing trend. In general, variations in the TSS values were observed from all the plots at different time intervals. The line attained for 50% of the grass covered surface shows only the best fit for the scattered data.

The TSS values obtained from each plot at different time intervals under the rainfall intensity of 52 mm hr^{-1} are shown in APPENDIX B, Table B.8.

Figure 4.8 shows the graphical representation of the TSS values obtained from all the plots under the rainfall intensity of 52 mm hr^{-1}. The graph clarifies that how the TSS values varied among different plots with the passage of time under the same rainfall event.

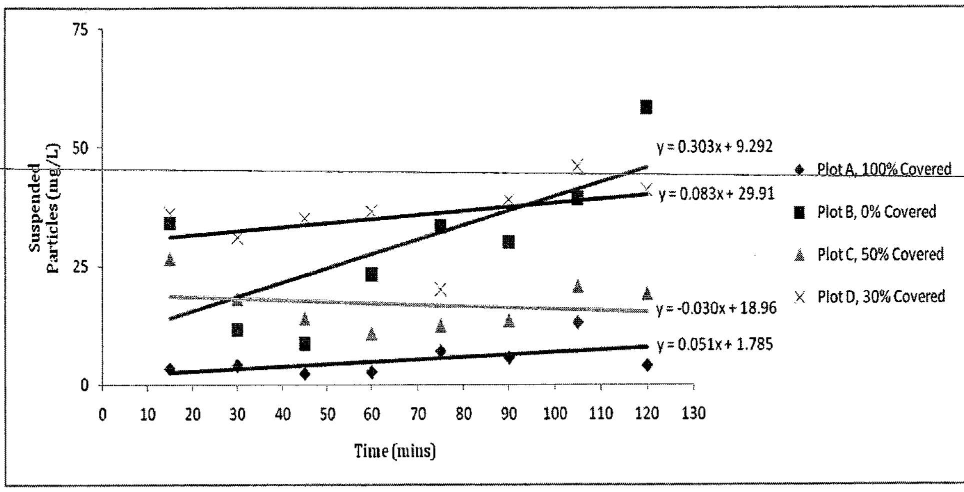


Figure 4.8 TSS values obtained at different time intervals from all the plots under the rainfall intensity of 52 mm hr^{-1}

4.3 Total Average Soil Loss, Water Discharge, Turbidity, and Total Suspended Solids for Each Plot

The rainfall intensities analyzed for Perak, were quite close that is 40 mm hr^{-1} and 52 mm hr^{-1}. However, it was decided to observe the behavior of an individual variable together for both the rainfall intensities on each plot. The results observed for the total average soil loss, water discharge, turbidity, and total suspended solids for both the rainfall intensities are further discussed under this heading.

4.3.1 Total Average Soil Loss for Each Plot

The total average soil loss observed for both the rainfall intensities was noted for the fully grass covered surface, bare soil surface, 50% of the grass covered surface, and 30% of the grass covered surface. From the fully grass covered surface the total average soil loss was found to be negligible whereas; from the exposed soil surface it was observed to be marginally higher and drastic. However, from 50% of the grass covered surface the total average soil loss declined sharply compared to the bare soil surface and from 30% of the grass covered surface it was observed to be considerably higher as shown in Figure 4.9.

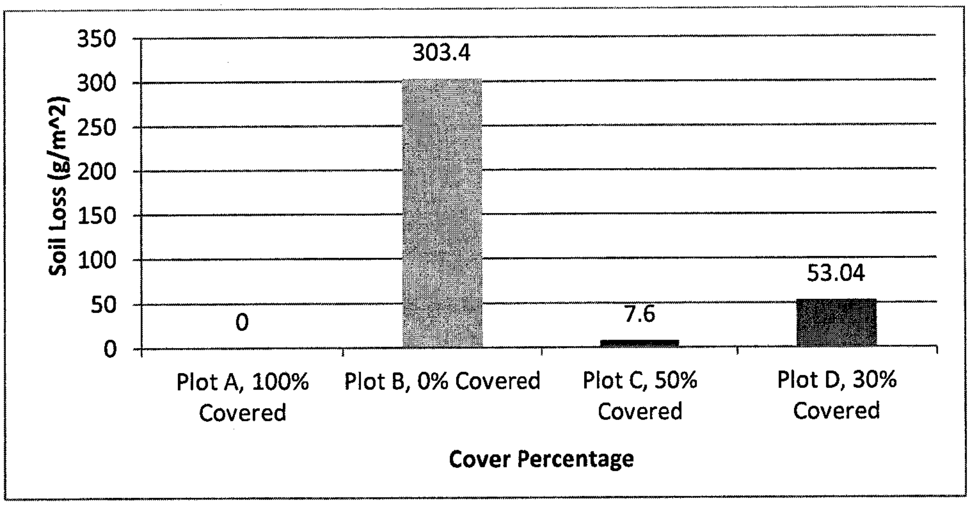


Figure 4.9 Total average soil loss for each plot for both the rainfall intensities

4.3.2 Total Average Water Discharge for Each Plot

Same like the total average soil loss observed for both the rainfall intensities the total average water discharge was also observed for each plot. The total average water discharge observed for "plot B" rose sharply when compared with the fully grass covered surface. A decline was observed in the total average water discharge attained from 50% of the grass covered surface compared to rest of all the plots. Although, it was hypothesized that the water discharge observed from the fully grass covered surface would be minimal but the results obtained showed a dip in the water discharge observed from "plot C". The reason for this was suggested to be the grass patches which were placed closely and did not allow the generated runoff to move firmly to the catchment zone. The results obtained from all the plots are further shown in Figure 4.10.

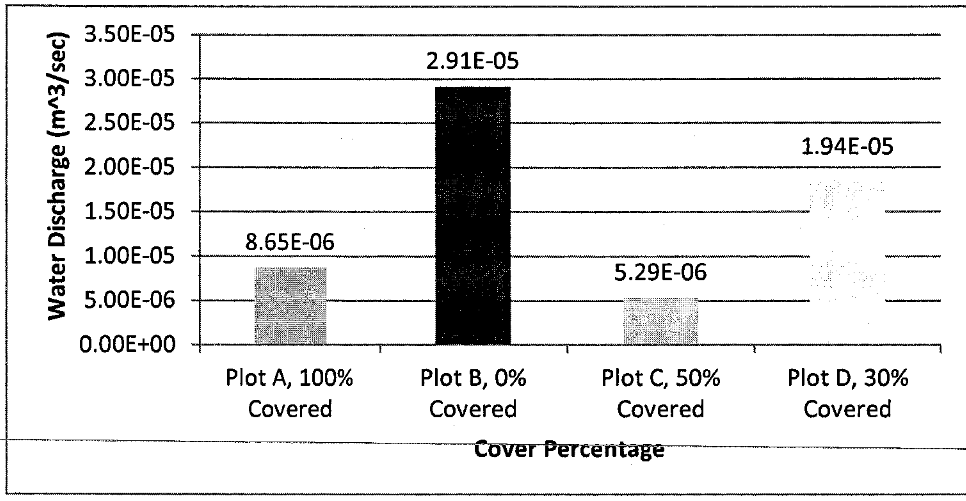


Figure 4.10 Total average water discharge for each plot for both the rainfall intensities

4.3.3 Total Average Turbidity for Each Plot

The total average turbidity values obtained from all the plots were also observed together for both the rainfall events. The average turbidity values obtained from the fully grass covered surface were low compared to all the other plots whereas; the average turbidity values obtained from the bare soil surface were marginally higher followed by 30% of the grass covered surface and 50% of the grass covered surface as shown in Figure 4.11.

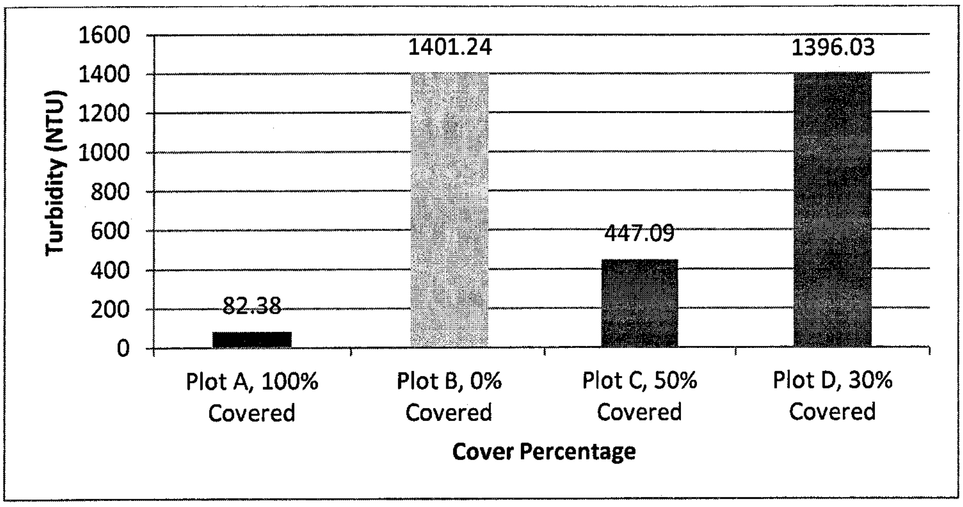


Figure 4.11 Total average turbidity for each plot for both the rainfall intensities

4.3.4 Total Average Total Suspended Solids (TSS) for Each Plot

The total average TSS values were also determined from the samples collected while conducting the runs together for both the rainfall intensities. The graph observed for the total TSS values follows nearly the same way to the graph obtained for the total average turbidity values. The presence of total suspended solids observed in the samples collected from the fully grass covered surface were low compared to the other three plots as shown in Figure 4.12.

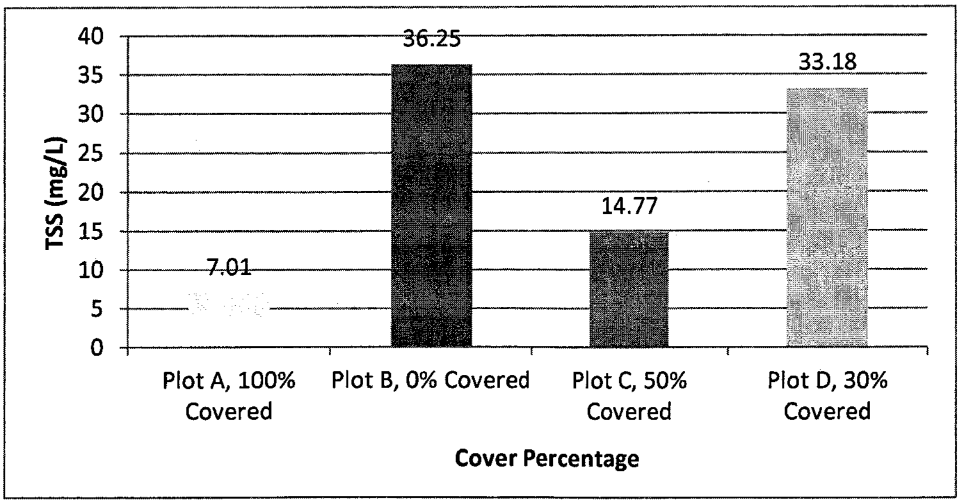


Figure 4.12 Total average TSS values for each plot for both the rainfall intensities

4.4 Validations

To determine the credibility of the information which was discovered, several researches were compared as stated in Table 4.1. The results attained were linked with the other studies so that the study validates that the outcomes achieved are acceptable. The results did not exactly match with the previous studies but it nearly agreed with the other studies which were conducted with the different methodology, parameters and conditions.

Table 4.1 Comparison of the study with the other researches

Authors/ Year	Papers	Remarks	Our Study
(Salim and Tajuddin, 2011)	Effectiveness of local plants on sediment control for sustainable river management.	In an experimental study, the soil loss observed from the bare soil surface and cow grass covered surface for the slope angle of 27° was found to be **493 g and 0.04 g** respectively under the high rainfall event.	The maximum average soil loss observed from the bare soil surface and cow grass surface (fully covered) was found to be **539.8 g and ~ 0 g** respectively for the rainfall intensity of 40 mm hr^{-1} and 52 mm hr^{-1}.
(Xiao et al., 2011)	Effects of grass and shrub cover on critical unit stream power in overland flow.	Under the rainfall intensity of 45 mm hr^{-1}, there was **not observed any rill development** on the grass covered plots.	There was **no indication of rill development** on the grass covered surface for both the rainfall events.
(Murphy, 2011)	Evaluation of turbidity in highway construction runoff in Texas.	From a highway construction site, the turbidity range may vary up to several thousand NTU containing a minimum of **15 NTU, an average of 701 NTU, and a maximum of 16000 NTU**.	The maximum turbidity value observed from the bare soil surface under the rainfall intensity of 40 mm hr^{-1} and 52 mm hr^{-1} were found to be **1631.5 NTU and 2585 NTU** respectively.

(Li et al., 2011)	Effects of bahia grass cover and mulch on runoff and sediment yield of sloping red soil in Southern China.	**Severe soil loss was observed from the bare soil surface** when compared with the grass covered surface and mulch covered surface under the middle and heavy rainstorm events.	**Drastic soil loss was observed from the bare soil surface** when compared with the other plots for both the rainfall events.
(Hallock et al., 2008)	Water quality relative to groundcover treatments under simulated rainfall.	The maximum turbidity value observed from the vegetation covered surface under the rainfall intensity of 38 mm hr^{-1} for a period of 1.5 hours and the slope gradient of 26.56° was found to be **138.3 NTU.**	The maximum turbidity value observed from the fully grass covered surface under the rainfall intensity of 52 mm hr^{-1} for a period of 2 hours and the slope gradient of 30° was found to be **135 NTU.**
(Edwards and Withers, 2008)	Transport and delivery of suspended solids, nitrogen and phosphorus from various sources to freshwaters in the UK.	Among the various sources the concentration of the suspended solids (mg L^{-1}) towards the fresh water from the road runoff lies between **55 to 149 mg L^{-1}.**	The average maximum suspended solids concentration observed from the bare soil surface was found to be **63.7 mg L^{-1}**, for both the rainfall events.
(Barbosa and Hvitved-Jacobsen, 1999)	Highway runoff and potential for removal of heavy metals in an infiltration pond in Portugal.	The total suspended solids (TSS) concentration range in the highway runoff water for a total of 73 samples was found to be in between **<8 to 147 mg L^{-1}.**	The range of suspended solids concentration observed from all the plots lies in between **2.3 to 69 mg L^{-1}.**

4.5 Discussions

Under this heading all the findings were gathered and generally discussed. The results obtained are compiled in a broader way so that the discussions can be elaborated. Although, both the rainfall intensities were very close to each other but it was noticed that all the independent variables arose gradually for the higher rainfall intensity that is 52 mm hr^{-1}.

4.5.1 Discussions Based on the Observations Attained from the Fully Grass Covered Surface "plot A"

Both the rainfall events were found ineffective in eroding the soil from the fully grass covered surface. The erosion rates were negligible while running the experiments on "plot A". Due to the minimal soil detachment the suspended particles were also found to be insignificant. It has been noticed that the grass covered surface enhanced the slope equilibrium which increased the shear strength of the soil particles. Equated to the bare soil surface the water discharge was found to be low under the same simulated rainfall conditions which allowed the artificial rain water to retain in between the dense grass cover and penetrate the soil. However, when there was no rainfall the discharge was aided up by the runoff flow only. The visual observation of the water color was fairly clean which assured that there have been received negligible amount of detached soil sediments at the catchment outlet. Undoubtedly, 100% of the grass covered surface is the best solution to restrain the soil loss.

4.5.2 Discussions Based on the Observations Attained from the Bare Soil Surface "plot B"

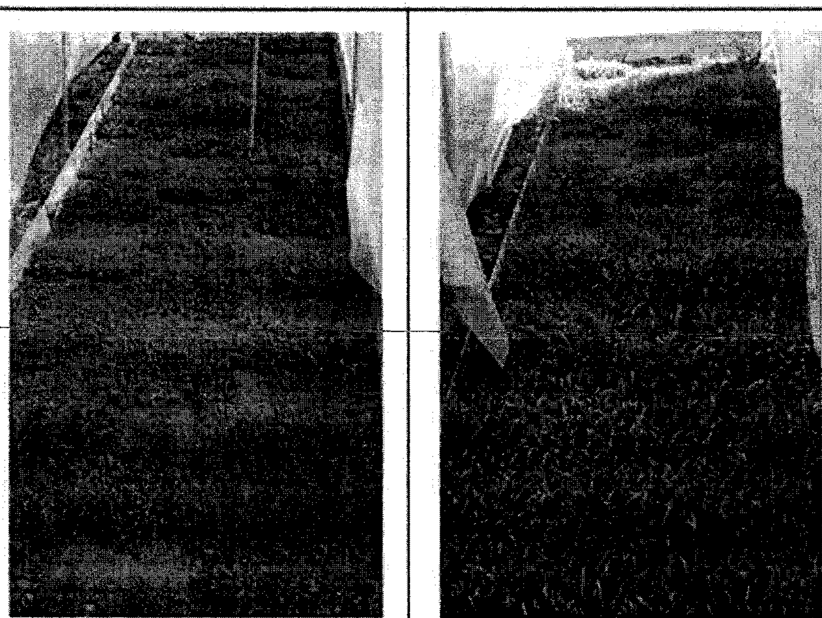
The bare soil surface was observed as a **control plot** to compare the soil loss results followed by the water discharge, turbidity and TSS obtained from all the plots so that the efficiency of the cover percentage can be justified. The results obtained from the bare soil surface were drastic when compared with the other plots conditions for both the rainfall events. The experiments carried out on the bare soil demonstrated that higher the rainfall intensity higher would be the soil loss. The soil eroded at different rates and at different intervals of time. However, the results obtained show the accumulated soil loss at each interval. The striking impact of raindrops permitted soil detachment which was apparently noticed throughout the experiments. Initially, the soil particles were scattered which then flowed with generated runoff that not only caused a marginal increment in the soil detachment but also caused a gradual increase in the water discharge with the passage of time that affected the cloudiness of water and raised the concentration of suspended solids in the water. At different time intervals, the water discharge was observed to be constant for which the reason is suggested to be the soil pore capacity which did not allow further penetration of the rain water into the soil and the water collected at the catchment remained constant. The water samples collected for determining the turbidity and TSS were very muddy which was clearly visible to the naked eye, containing high concentration of suspended and settled soil particles. The experimental conditions outlined the similar problem faced by the newly built road embankments which usually remain bare during the construction phase.

4.5.3 Discussions Based on the Observations Attained from 50% of the Grass Covered Surface "plot C"

After observing the fully grass covered surface and the bare soil surface it was decided to observe the behavior and study the response of the partially covered soil surface for the immediate soil protection against soil loss, water discharge, turbidity, and suspended solids under the rainfall event of 40mm hr^{-1} and 52mm hr^{-1}. Based on the same procedures followed for "plot A" and "plot B" the eroded soil was determined, the discharge was noticed, water turbidity was evaluated and the suspended particles were assessed. However, the results obtained are further discussed below under this heading.

A marginal decrement in the soil loss was observed when compared with the soil loss occurred from the bare soil surface. Although the soil loss was there, but the grass patches worked well in restricting the soil particles from flowing away. The grass patches worked as a filter for an individual soil particle which trapped it from flowing away. A decline in the water discharge was also observed when compared with the bare soil scenario and fully grass covered pattern. This could have happened due to the presence of grass patches which were closely spaced that influenced the water flow and allowed the water to penetrate the soil. Together with the soil pore capacity, the water holding capacity of the grass worked remarkably well. Due to the reasonable soil loss compared to the bare soil surface, the turbidity and TSS values dropped steeply.

The efficiency of 50% of the grass covered surface was already noticed by conducting the experimental runs. However, the next observation was to notice the grass growth rate with the passage of time. Figure 4.13 shows the grass growth rate for plot C which was naturally grown and nurtured rapidly. The observation made showed that the plot area was covered up to 80% within a period of two months only after conducting the experiments.



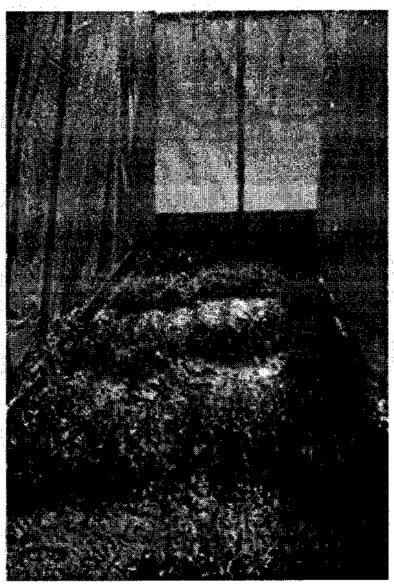
50% of the grass covered surface	*After two months 80% of the area was covered*

Figure 4.13 Grass growth observation for "plot C"

4.5.4 Discussions Based on the Observations Attained from 30% of the Grass Covered Surface "plot D"

Keeping in view the efficiency of 50% of the grass covered surface it was decided to reduce the percentage of cover so that an efficient and immediate approach can be recommended for the embankments protection. However, it was decided to reduce the cover percentage up to 30% "plot D". Compared to 50% of the grass covered surface the soil loss observed from 30% of the grass covered surface was drastic. Although, the grass patches worked as a filter but due to the large distance among the grass patches the soil particles were easily carried away by the generated runoff. The increased runoff raised the water discharge, observed in the bottom container. The turbidity values abruptly changed for the water samples collected at the different time intervals. This happened due to the density of the soil particles which have remained either in suspension or settled in the water while collecting the samples. Similarly, the graph obtained for the suspended particles showed fluctuations for which the same reason is suggested.

The grass growth rate for 30% of the grass covered surface was also observed for a period of two months. No immediate improvement in the growth rate was observed. Moreover, majority of the grass was observed to be dying which hardly grown up to 40% as shown in Figure 4.14. The grass did not firmly grasp the soil which could have restricted the interconnection of the roots link due to which no quick germination was observed.



30% of the grass covered surface

After two months 40% of the area was covered only

Figure 4.14 Grass growth observation for "plot D"

4.6 Framework of the Chapter

After attaining all the results based on the experiments, Figure 4.15 compiles all the work so that the findings of the thesis can easily be understood.

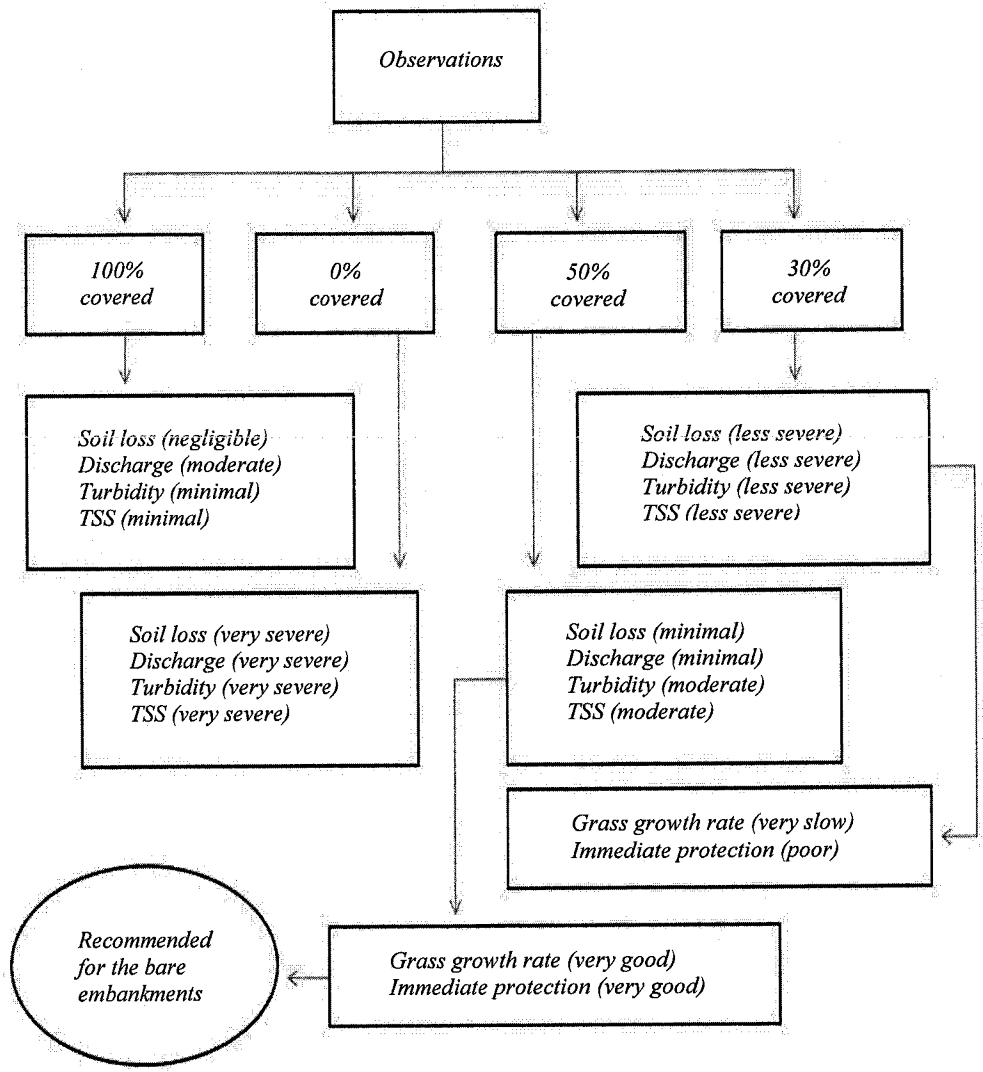


Figure 4.15 Frame work of the chapter

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 Introduction

This chapter is based on the discussions which were observed while conducting the experimental runs and relies on the reasoning, observed during the study phase. It ties together all the issues and come out with the final judgment in the form of conclusions. Based on the findings, some study outcomes were prepared which may benefit the end user. Lastly, there have been made some necessary recommendations together with the future works which will explore the research area in several other ways.

5.2 Findings

Based on the consequences observed from the experimental phase, following findings were revealed:

- It was explored that if the percentage of grass cover provided to shelter the exposed soil surface is not adequate then the soil loss would nearly be the same as for the bare soil areas which leads to the intolerable rates of total suspended solids and the turbidity to the receiving water ways.
- A very small amount of soil loss was observed from 100% of the grass covered surface. Moreover, the turbidity and TSS values attained were comparatively lower than the values obtained from the bare soil surface,

50% of the grass covered surface, and 30% of the grass covered surface. Undoubtedly, this is the best solution.

- Excessive soil detachment was noted on the bare soil surface (0% of the grass covered surface). The direct impact of rain drops and generated runoff led to the higher erosion, water discharge, turbidity, and TSS values.

- Due to the insignificant amount of surface cover, 30% of the grass covered area emulated almost the same results for the turbidity and TSS values as observed from the bare soil surface. Moreover, the largely spaced grass patches caused an increment in the water discharge which raised the delivery ratio of the detached particles to the water body.

- The closely spaced grass patches, 50% of the grass covered area grasped the roots beneath the soil and allowed the grass to germinate naturally which covered the nearby area up to 80% in a period of two months. Reduced soil loss, turbidity and TSS values were also observed when equated with the bare soil scenario and 30% of the covered surface. Particularly, the volume rate of water flow was significantly reduced which was a salient observation when compared with all the other plots.

5.3 Study Outcomes

Based on the observations and the findings extracted from the experimental phase few study outcomes were prepared which are illustrated in Table 5.1. The outcomes obtained from the study will assist an engineer to select the optimum grass percentage necessary for the immediate soil protection under the given circumstances. It further allows them to make a rough interpolation that a particular percentage of grass cover would have that much of impact on the water pollution towards the environment. Specifically, the study seems meaningful when the cost of grass to cover an area becomes important.

Table 5.1 Study outcomes based on the environmental impact for planting grass on a bed slope of 30° under the moderate rainfall events

Grass Cover	Erosion	Turbidity	TSS	Remarks
0%	100%	100%	100%	Not recommended as the soil remains exposed and available for detachment.
30%	17.48%	99.62%	91.53%	Although economical, but provides no immediate protection to the exposed soil surface. The turbidity and TSS values nearly equated with the values obtained from the bare soil plot. Moreover, the grass growth rate was very slow.
50%	2.50%	31.90%	40.74%	Fairly economical, recommended as an optimum percentage of cover to provide immediate shelter. It further moderated the generated runoff, and even the grass growth rate was good.
100%	~ 0%	5.87%	19.33%	Undoubtedly, the best solution. Recommended for the areas where the rainfall is extremely severe and intermittent.

5.4 Conclusions

Based on the thesis title "Efficiency of grass patterns on slope erosion controls due to runoff", three specific objectives were established which are recalled in this section.

The first specific objective was "to compare the behavior of detached soil particles at different percentages of grass cover". Usually, the increase in the percentage of grass cover reduces the soil detachment. However, the study disclosed that a particular percentage of grass cover is sufficient enough to produce nearly the same results as for the fully grass covered area for the specific rainfall intensities.

The second significant objective was "to estimate the presence of turbidity and total suspended solids caused by soil loss". The concentration of the total suspended solids (TSS) and the turbidity values obtained from the bare soil and 30% of the grass covered surfaces were extremely high. The TSS concentration observed from 50% of the grass covered surface was nearly twice compared to the fully covered grass whereas; the turbidity values observed were almost 5.5 times the turbidity value observed from the fully covered grass. Based on the grass growth observation for a period of 2 months, it is suggested that concentration of TSS and turbidity values will certainly reduce as the grass grown at a very fast pace.

The third main objective was "to propose the optimum percentage of cover suitable for the immediate soil protection". Based on the specific rainfall conditions, soil type, and the slope gradient, 50% of the native grass cover surface was recommended as an economical approach for the immediate shelter of the exposed soil surface on the bare highway embankments.

In general, the soil loss from a known source, in particular, bare embankments to the receiving water ways can be possibly controlled by understanding the soil properties, climatic conditions, runoff characteristics, slope factors, the type of land cover suitable for the soil shelter, and the **percentage of cover**.

5.5 Recommendations and Future Work

The newly built road embankments without any vegetation cover are inclined to severe soil loss. To mitigate this phenomenon which is the major source of siltation, immediate vegetation recovery is suggested. The results attained recommends that planting the vegetation cover by at least 50% on the highway embankments will significantly reduce the hazards originated from soil loss as an immediate soil conservation approach. Furthermore, it will fully cover the gradient with in a period of 3 to 4 months which will shelter the entire area from the impact of upcoming rainfall events.

The study can be extended to observe the response of other water quality parameters that is the amount of dissolved oxygen in the water, pH of the collected water samples, and etc. Based on the rainfall data attained for a particular area, different percentage of grass cover can also be examined with different pattern designs and simulated rainfall intensities. Soil type varies from place to place; therefore the study can also be monitored for the different soil types. Various species of native grass matures at slightly different times, however the study can also be observed for the soil shelter based on the quick germination rate of different grass species. Lastly, the study was noticed for a particular slope angle; however the study may also be performed for the slopes slightly steeper than 30°.

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APPENDIX A

Table A.1 Particles size distribution test

Test sizes	Wire mesh (g)	Soil + Wire mesh (g)	Mass retained (g)		Percentage retained
			actual	corrected (m)	$(m/m_1) \times 100$
2mm	473.1	484.1	11	501.2	100 %
1.18mm	434.7	453.6	18.9	501.2 - 18.9 = 482.3	96.22 %
600μm	403.2	450.5	47.3	482.3 - 47.3 = 435	86.79 %
425μm	366.7	413.2	46.5	435 - 46.5 = 388.5	77.51 %
300μm	358.1	437.1	79	388.5 - 79 = 309.5	61.75 %
212μm	346.0	430.5	84.5	309.5 - 84.5 = 225	44.89 %
150μm	333.5	402.6	69.4	225 - 69.4 = 155.6	31.04 %
63μm	322.9	427.3	104.4	155.6 - 104.4 = 51.2	10.21 %
passing 63μm	393.2	433.4	40.2	51.2 - 40.2 = 11	2.19 %

Table A.2 The highest rainfall amount in millimeters recorded for Lubok Merbau station

Year	1/4*	1/2*	3/4*	1#	2#	3#	4#
1994	25.2	38.1	42.7	45.6	60.2	61.7	65.7
1995	27.7	47.9	53.7	56.2	57.1	62.9	63.0
1996	28.0	49.0	66.7	75.0	88.4	92.6	93.5
1997	26.2	49.7	69.1	74.8	77.9	77.9	77.9
1998	34.2	67.4	-	81.1	84.5	85.7	-
1999	22.4	36.0	-	61.8	80.7	82.9	-
2000	27.0	47.5	-	-	-	-	-
2001	31.0	48.1	-	-	-	-	-
2002	27.0	37.0	-	-	-	-	-
2003	29.9	39.9	-	-	-	-	-
2004	36.5	50.0	-	-	-	-	-
2005	52.6	55.2	57.8	60.2	63.6	64.0	64.0
2006	35.4	55.6	63.2	66.4	68.6	70.0	70.0
2007	28.0	43.0	57.6	65.8	75.6	85.8	89.8

2008	38.8	58.4	65.6	68.0	72.2	75.2	75.4
2009	26.4	39.6	43.6	53.0	79.6	80.4	82.8
2010	24.0	43.6	62.4	71.4	78.2	79.0	79.0
2011	34.0	60.4	68.2	70.0	77.2	78.0	79.0

Cont.

Year	**5#**	**6#**	**12#**	**24#**	**48#**	**72#**	**96#**
1994	67.6	68.0	88.4	89.5	112.8	123.5	158.5
1995	63.0	66.5	72.7	85.0	97.0	139.0	142.0
1996	93.6	93.6	93.6	93.6	165.6	165.9	168.6
1997	77.9	77.9	77.9	77.9	109.7	131.4	161.0
1998	-	88.2	88.2	-	-	-	-
1999	-	85.7	85.7	-	-	-	-
2000	-	-	-	-	-	-	-
2001	-	-	-	-	-	-	-
2002	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-

2005	64.2	64.4	64.4	64.6	71.4	102.2	119.6
2006	70.0	70.2	70.2	73.8	81.8	103.4	136.8
2007	91.4	91.8	93.0	94.6	106.2	130.6	138.2
2008	75.6	75.8	81.0	81.2	93.4	102.8	134.4
2009	83.0	83.4	83.6	87.0	97.8	100.8	122.2
2010	79.0	79.0	79.0	79.0	111.0	138.4	172.6
2011	80.6	83.4	88.2	108.4	159.0	187.4	197.4

Table A.3 The highest rainfall amount in millimeters recorded for Sitiawan station

Year	**1/4***	**1/2***	**3/4***	**1#**	**2#**	**3#**	**4#**
1951	25.4	40.9	49.8	61.7	76.7	78.7	78.7
1952	33.0	48.3	61.5	68.6	74.7	74.9	75.2
1953	29.2	50.5	68.1	74.9	84.1	85.3	86.9
1954	30.5	51.6	66.5	74.7	119.4	142.5	151.1
1955	33.0	43.4	44.7	45.0	46.7	48.3	49.0
1956	31.5	37.3	46.7	49.0	49.5	49.8	50.0
1957	29.2	50.8	61.0	68.1	80.3	81.0	82.3

1958	29.2	53.1	63.8	67.3	71.9	72.4	72.4
1959	35.8	63.5	70.6	76.7	78.7	78.7	78.7
1960	30.5	40.6	46.2	55.9	88.4	108.5	109.2
1961	25.4	43.2	55.6	58.4	70.6	74.4	74.7
1962	34.8	47.2	49.5	49.8	60.7	61.2	61.2
1963	50.8	67.1	77.7	79.5	93.7	94.0	94.0
1964	27.9	40.1	56.4	67.3	83.6	94.7	119.6
1965	38.4	53.8	69.3	75.4	79.8	80.3	80.3
1966	37.1	54.9	64.0	65.0	66.0	66.0	66.8
1967	34.3	61.2	75.2	87.4	122.9	133.9	134.9
1968	39.9	44.2	44.2	44.2	44.2	49.0	54.6
1969	34.8	52.3	58.4	62.2	70.4	74.4	75.7
1970	27.9	53.3	60.5	75.4	110.7	112.3	112.3
1971	30.2	51.8	52.1	52.1	54.1	87.4	94.5
1972	26.2	49.8	57.4	65.0	89.2	109.2	109.2
1973	48.3	61.0	68.6	71.6	77.5	80.5	80.8
1974	33.5	45.0	50.3	54.4	74.7	74.7	74.7

1975	33.7	52.0	65.6	74.8	104.1	108.9	109.6
1976	35.0	60.2	81.0	92.5	118.0	143.7	169.4
1977	24.0	32.8	37.0	38.6	47.6	52.7	56.5
1978	34.8	51.2	68.3	76.0	83.5	88.3	91.1
1979	35.1	65.2	86.3	96.3	115.9	124.5	129.3
1980	29.0	39.6	50.2	67.3	99.6	100.9	100.9
1981	46.0	69.1	79.8	83.9	86.8	90.3	91.7
1982	32.0	50.7	65.3	73.8	87.3	87.3	97.9
1983	33.7	54.9	60.3	66.5	77.5	77.8	78.0
1984	29.5	49.1	57.0	60.3	68.4	68.7	69.1
1985	38.1	51.2	56.6	60.1	70.9	74.8	75.1
1986	35.6	63.7	76.1	76.3	76.5	76.5	76.5
1987	32.4	40.1	54.2	70.3	103.5	103.9	104.0
1988	35.1	58.2	76.0	84.4	93.6	93.6	93.6
1989	41.1	59.0	65.2	67.4	70.3	72.6	72.9
1990	33.3	53.4	65.5	75.2	90.3	100.3	112.7
1991	34.5	45.1	49.3	51.5	59.1	64.4	67.6

1992	29.4	46.9	62.2	66.7	75.9	77.7	85.0
1993	37.4	53.3	62.4	65.4	75.1	77.3	83.7
1994	35.8	54.9	61.1	63.5	69.8	70.4	71.0
1995	33.2	54.5	67.0	73.6	82.3	85.1	88.9
1996	36.4	55.3	66.6	79.7	103.5	105.7	107.1
1997	38.6	60.9	82.3	87.1	88.8	90.2	90.9
1998	24.8	42.7	-	57.6	71.0	73.4	-
1999	31.5	55.0	-	81.8	102.0	106.7	-
2000	34.0	51.2	-	-	-	-	-
2001	25.1	43.1	-	-	-	-	-
2002	30.8	49.5	-	-	-	-	-
2003	33.2	59.8	-	-	-	-	-
2004	24.4	34.1	-	-	-	-	-
2005	34.4	61.0	85.2	107.6	156.2	158.0	160.0
2006	38.4	56.2	64.2	80.2	97.2	128.8	138.8
2007	23.6	35.2	42.2	45.4	54.2	54.6	54.6
2008	41.8	75.4	101.4	113.0	156.0	169.4	171.0

2009	35.4	59.6	69.8	74.4	81.0	83.8	84.8
2010	28.2	42.0	53.0	65.8	89.2	96.4	99.4
2011	42.0	62.6	66.8	67.0	67.6	67.6	70.0

Cont.

Year	5#	6#	12#	24#	48#	72#	96#
1951	78.7	78.7	78.7	102.9	133.4	167.1	215.4
1952	75.2	75.2	75.2	87.6	87.6	91.4	101.9
1953	87.4	87.6	96.5	96.5	96.8	108.5	116.6
1954	155.2	156.2	156.5	156.5	188.7	188.7	204.0
1955	49.0	52.6	59.7	62.2	79.2	111.8	123.7
1956	50.0	50.0	50.3	78.7	88.9	101.6	124.7
1957	82.5	82.5	82.5	82.5	103.1	128.5	135.1
1958	72.4	72.4	80.0	80.0	87.4	95.0	118.6
1959	78.7	78.7	97.8	98.0	105.9	139.2	156.2
1960	109.2	109.2	109.2	109.5	145.5	152.1	160.3
1961	74.7	74.9	74.9	84.1	89.2	100.3	101.6
1962	61.2	61.2	72.6	72.9	75.7	93.2	100.3

1963	94.0	109.7	110.5	119.9	125.0	151.1	164.8
1964	122.2	125.5	126.2	126.2	126.2	131.8	145.0
1965	80.3	80.3	80.3	80.3	86.6	123.4	141.2
1966	70.4	93.0	105.7	133.4	148.1	159.5	180.6
1967	134.9	135.1	135.1	194.3	200.2	203.5	203.7
1968	57.4	58.4	58.7	58.7	87.1	103.9	104.4
1969	76.2	76.5	76.5	76.5	87.4	102.9	117.1
1970	112.3	112.3	112.3	114.3	152.4	152.9	179.8
1971	95.5	96.5	98.8	99.3	130.8	152.1	184.7
1972	109.2	109.2	109.2	111.8	111.8	133.1	135.1
1973	86.1	93.2	101.9	112.8	144.0	150.1	169.7
1974	76.2	76.2	76.2	79.5	91.7	108.5	108.5
1975	113.9	114.7	115.6	116.0	122.7	163.2	163.3
1976	177.6	178.7	190.7	191.5	204.5	269.7	271.2
1977	57.2	57.3	63.4	100.2	122.6	136.3	153.1
1978	93.4	94.1	95.1	106.3	109.6	123.9	138.4
1979	131.2	133.3	137.1	138.6	145.3	157.3	180.0

1980	100.9	101.3	101.3	101.3	109.2	111.9	111.9
1981	92.3	92.4	92.4	92.4	107.1	152.3	193.1
1982	103.0	103.0	103.0	124.3	125.5	157.8	158.2
1983	78.7	78.9	82.2	90.8	90.8	144.6	144.6
1984	74.1	74.4	74.4	108.5	147.0	167.1	171.1
1985	75.1	75.2	75.2	75.2	75.4	102.5	119.0
1986	76.5	76.5	100.9	102.6	103.9	125.9	146.2
1987	104.0	104.0	104.3	145.8	146.2	146.5	168.8
1988	93.6	94.7	94.7	94.7	140.4	141.2	142.6
1989	73.0	73.0	73.0	73.0	125.1	131.2	131.6
1990	115.0	115.4	115.9	115.9	118.9	137.9	144.0
1991	68.9	69.8	69.9	84.3	102.2	126.7	129.2
1992	88.4	89.3	95.6	96.5	102.8	105.5	108.4
1993	89.0	96.0	120.9	121.0	180.9	189.0	209.1
1994	72.4	72.7	72.7	72.7	136.5	138.4	138.5
1995	89.6	89.6	89.8	90.4	118.7	122.3	134.3
1996	107.1	107.1	107.1	118.1	127.8	127.8	156.3

1997	91.8	91.8	92.3	98.7	104.9	123.6	131.4
1998	-	77.9	77.9	-	-	-	-
1999	-	110.9	110.9	-	-	-	-
2000	-	-	-	-	-	-	-
2001	-	-	-	-	-	-	-
2002	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-
2005	160.6	160.6	160.6	160.8	180.4	180.4	180.4
2006	139.6	139.8	140.0	144.0	152.6	152.6	174.2
2007	54.6	55.2	73.4	76.8	91.6	93.4	94.8
2008	171.8	174.2	175.4	224.4	240.2	241.2	268.0
2009	85.4	85.6	88.0	97.8	103.4	104.2	105.4
2010	100.0	103.0	103.4	106.6	106.6	121.0	122.0
2011	73.6	73.6	96.6	102.4	154.6	199.4	214.2

Table A.4 The highest rainfall amount in millimeters recorded for Ipoh station

Year	**1/4***	**1/2***	**3/4***	**1#**	**2#**	**3#**	**4#**
1951	43.2	75.7	92.5	99.1	102.1	102.1	102.1
1952	36.1	47.2	54.4	73.7	83.6	84.3	84.3
1953	35.3	50.5	70.9	85.9	89.4	91.4	91.4
1954	30.7	45.5	63.0	69.1	88.9	107.2	113.5
1955	39.1	48.0	48.5	50.3	55.1	83.8	83.8
1956	27.9	47.2	62.7	71.6	83.8	94.7	94.7
1957	32.5	41.4	43.9	48.3	55.9	74.9	91.2
1958	44.7	59.9	64.8	77.7	90.4	116.3	120.1
1959	29.7	47.5	58.4	72.6	87.4	87.4	88.6
1960	27.9	40.9	48.3	50.3	52.3	59.7	67.1
1961	30.5	50.8	66.0	74.4	89.4	97.0	100.3
1962	41.7	54.6	62.7	64.3	66.8	70.6	71.1
1963	39.4	51.1	62.2	67.6	80.5	80.5	80.5
1964	30.2	46.2	52.3	54.4	72.6	74.4	74.4
1965	38.1	57.9	70.9	97.3	144.0	144.0	144.0

1966	28.4	51.6	68.3	74.9	78.2	81.0	88.9
1967	51.8	75.2	83.3	87.6	89.4	89.9	89.9
1968	32.0	43.4	45.7	48.3	64.0	67.8	71.1
1969	48.8	60.2	69.8	80.0	85.3	85.3	91.9
1970	42.2	62.5	69.8	75.4	75.4	84.8	104.4
1971	38.9	48.5	50.3	50.3	61.2	63.5	63.5
1972	35.1	46.7	51.1	54.1	64.5	70.1	73.4
1973	47.0	53.3	61.5	62.2	70.6	76.2	76.2
1974	37.6	50.3	58.7	65.0	86.9	87.4	87.4
1975	30.6	42.7	55.6	61.9	77.4	81.0	83.4
1976	34.5	48.7	63.4	68.8	72.3	78.9	81.9
1977	32.4	52.8	63.9	68.0	72.2	81.7	86.1
1978	44.2	74.0	74.7	74.7	74.7	74.7	74.7
1979	34.1	54.0	60.2	69.6	99.1	99.4	99.4
1980	34.4	45.1	59.7	73.1	79.7	79.7	79.7
1981	29.4	44.2	54.7	62.6	76.0	77.0	82.1
1982	42.7	65.8	77.4	81.2	83.2	83.9	85.3

1983	42.2	56.0	71.9	80.3	85.3	88.2	88.9
1984	45.1	75.8	88.1	88.5	106.9	110.0	129.1
1985	37.3	51.2	52.1	54.3	71.6	71.7	75.6
1986	52.6	78.9	105.2	113.1	115.3	115.3	115.3
1987	35.6	52.2	62.0	69.8	89.3	90.2	90.2
1988	35.7	53.1	64.2	78.1	92.5	92.7	92.7
1989	37.5	53.2	61.5	68.9	70.0	72.1	78.6
1990	40.9	64.5	74.7	81.1	85.7	87.5	87.6
1991	37.1	57.2	63.8	66.7	75.9	76.7	77.3
1992	41.1	63.2	73.2	78.6	80.5	80.5	80.8
1993	37.6	50.4	55.6	58.2	87.8	91.5	93.1
1994	33.1	50.5	58.4	59.4	59.7	60.4	60.6
1995	35.1	53.3	78.3	84.3	88.1	89.1	89.1
1996	39.1	60.3	77.3	102.2	116.6	116.7	116.7
1997	28.5	49.1	63.3	60.7	62.0	62.2	62.2
1998	29.9	44.8	-	59.7	70.2	73.7	-
1999	35.2	64.2	-	91.6	97.1	98.9	-

2000	40.0	51.2	-	-	-	-	-
2001	34.0	63.0	-	-	-	-	-
2002	31.8	58.2	-	-	-	-	-
2003	35.2	55.6	-	-	-	-	-
2004	29.2	50.6	-	-	-	-	-
2005	28.4	43.2	55.8	63.6	90.2	90.4	90.4
2006	41.8	68.2	89.8	101.6	120.4	120.4	120.4
2007	31.0	48.6	54.6	61.6	69.2	69.2	69.2
2008	35.4	64.4	79.0	84.6	89.4	91.6	102.4
2009	34.6	52.0	63.8	79.2	98.2	107.6	110.8
2010	36.0	62.0	78.8	83.8	103.0	104.2	104.2
2011	34.8	58.8	66.8	67.4	75.0	75.0	75.0

Cont.

Year	**5#**	**6#**	**12#**	**24#**	**48#**	**72#**	**96#**
1951	102.1	102.1	102.1	110.0	132.8	155.2	206.5
1952	85.6	85.9	103.1	104.1	126.7	144.0	149.1
1953	91.4	91.4	97.0	131.1	162.6	183.1	224.0

1954	113.8	113.8	113.8	113.8	145.3	145.8	147.3
1955	83.8	83.8	94.0	96.5	123.4	135.4	137.4
1956	95.0	95.2	98.8	99.8	114.8	143.5	185.2
1957	96.5	98.6	98.6	101.6	132.1	179.8	183.9
1958	120.7	120.7	120.7	121.2	173.2	187.2	199.1
1959	89.4	89.4	89.4	121.2	134.1	135.6	141.0
1960	71.9	73.9	90.9	100.3	130.3	130.3	130.3
1961	101.6	104.9	106.4	109.5	109.5	133.4	135.4
1962	71.1	71.9	71.9	100.1	113.5	116.8	155.2
1963	80.5	80.5	81.0	81.0	97.5	116.3	154.9
1964	74.4	74.4	74.4	76.7	101.9	105.7	118.6
1965	144.0	144.0	144.0	152.1	167.4	167.4	174.0
1966	88.9	88.9	88.9	94.0	124.2	143.5	193.0
1967	89.9	90.2	90.9	108.7	111.3	140.0	140.0
1968	73.9	75.2	75.2	75.2	104.1	111.5	113.0
1969	92.2	92.2	92.2	92.2	106.7	122.9	138.2
1970	139.7	150.9	150.9	186.7	216.4	218.9	271.3

1971	63.5	63.5	67.6	68.8	82.5	105.4	106.7
1972	73.7	74.4	74.4	75.7	121.4	121.4	125.2
1973	76.2	76.2	81.5	82.3	145.3	147.6	210.6
1974	87.9	87.9	89.7	130.8	138.2	184.7	188.0
1975	83.5	83.7	84.3	88.6	133.4	175.1	240.1
1976	82.0	82.2	82.2	113.1	129.7	156.6	159.5
1977	86.1	86.1	87.4	128.8	168.7	169.3	181.0
1978	74.7	74.7	74.7	80.2	94.0	106.3	111.7
1979	99.4	99.4	99.4	101.7	121.0	188.6	202.4
1980	82.3	83.7	90.6	102.4	139.3	145.5	155.4
1981	90.0	92.5	94.7	115.3	115.4	118.6	169.9
1982	85.5	85.6	85.6	118.1	126.4	156.3	171.8
1983	89.0	89.0	89.0	105.5	135.0	156.3	167.7
1984	134.4	135.4	135.4	135.4	139.4	152.9	156.1
1985	82.7	84.9	84.9	100.6	114.2	136.2	155.6
1986	115.3	115.3	115.3	134.4	134.4	134.4	146.4
1987	90.2	90.2	95.2	95.6	149.9	190.8	197.6

1988	92.7	92.7	99.0	99.0	153.7	160.0	160.1
1989	82.2	88.1	90.0	102.7	116.4	144.2	166.1
1990	87.6	87.6	87.6	89.4	105.6	143.7	154.0
1991	77.5	77.5	77.5	87.1	123.2	125.9	156.7
1992	81.0	81.2	81.2	81.2	96.9	97.4	174.7
1993	93.1	93.1	109.5	111.5	112.2	112.2	112.2
1994	60.6	60.6	79.8	81.4	114.5	182.2	158.9
1995	89.1	89.1	91.3	119.8	146.8	164.5	212.0
1996	116.7	116.7	116.7	119.2	145.8	145.8	145.8
1997	62.2	62.2	62.2	82.8	83.8	109.9	109.9
1998	-	75.6	76.4	-	-	-	-
1999	-	101.4	101.8	-	-	-	-
2000	-	-	-	-	-	-	-
2001	-	-	-	-	-	-	-
2002	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-

2005	90.6	90.6	106.8	108.8	109.8	124.2	130.2
2006	120.4	120.4	120.4	133.6	159.2	168.2	187.2
2007	69.2	69.8	78.2	95.4	105.2	160.8	162.6
2008	102.4	102.4	102.4	113.8	143.2	161.2	171.4
2009	112.8	112.8	113.0	113.0	142.0	143.6	154.2
2010	104.2	104.2	104.4	115.2	176.0	182.8	185.0
2011	75.0	75.0	75.0	98.8	99.4	100.4	110.2

APPENDIX B

Table B.1 Soil loss from all the plots under the rainfall intensity of 40 mm hr^{-1}

Time interval (min)	Soil detachment (g m^{-2}) from all the plots at different intervals of time under the rainfall intensity of 40 mm hr^{-1}			
-	Plot A (100% covered)	Plot B (0% covered)	Plot C (50% covered)	Plot D (30% covered)
15	-	64.75	0.9	12.41
30	-	142.1	1.49	22.56
45	-	219.8	2.16	31.47
60	-	286.9	3.04	45.69
75	-	346.4	3.81	56.31
90	-	401.9	6.85	64.87
105	-	453.8	9.87	80.39
120	-	500.9	11.94	89.19

Table B.2 The water discharge observed for the period of 2 hours and 40 minutes under the rainfall intensity of 40 mm hr^{-1}

Time interval (min)	Observation of water discharge (m^3 sec^{-1}) from all the plots at different intervals of time under the rainfall intensity of 40 mm hr^{-1}			
	During the occurrence of rainfall			
-	Plot A (100% covered)	Plot B (0% covered)	Plot C (50% covered)	Plot D (30% covered)
15	0.000011005	1.09929E-05	6.28E-06	1.413E-05
30	9.3978E-06	0.000018845	5.50E-06	1.963E-05
45	9.93367E-06	4.40899E-06	5.76E-06	2.041E-05
60	1.02015E-05	2.4941E-05	5.10E-06	1.916E-05
75	1.03623E-05	4.80588E-05	4.71E-06	3.934E-05
90	1.02015E-05	4.80588E-05	5.23E-06	3.934E-05
105	4.40899E-06	5.78408E-05	5.61E-06	3.934E-05
120	6.95493E-06	5.78408E-05	6.87E-06	3.934E-05
	During no rainfall			
125	4.40899E-06	3.16516E-05	-	1.916E-05
130	2.52385E-06	1.91655E-05	-	1.427E-05
135	1.93941E-06	1.42771E-05	-	6.954E-06

140	1.44474E-06	1.17488E-05	-	6.954E-06
145	1.22947E-06	1.02249E-05	-	6.954E-06
150	1.22947E-06	6.95493E-06	-	4.408E-06
155	8.59702E-07	6.95493E-06	-	4.408E-06
160	4.46159E-07	5.85308E-06	-	2.523E-06

Table B.3 The turbidity values obtained from all the plots at different time intervals under the rainfall intensity of 40 mm hr^{-1}

Time interval (min)	Turbidity values (NTU) from all the plots at different intervals of time under the rainfall intensity of 40 mm hr^{-1}			
-	Plot A (100% covered)	Plot B (0% covered)	Plot C (50% covered)	Plot D (30% covered)
15	75	1001.5	233	1345
30	31.66	1218	465	1348.33
45	66.66	1460	441.5	1120
60	58.33	1221.5	440	1418.33
75	40	1631.5	405	1388.33
90	55	1308	428	1472.5
105	53.33	1320	490	1463.33

120	70	1455	378	1460

Table B.4 The presence of suspended particles in the water samples observed for a period of 2 hours under the rainfall intensity of 40 mm hr^{-1}

Time interval (min)	Total suspended solids (mg L^{-1}) from all the plots at different intervals of time under the rainfall intensity of 40 mm hr^{-1}			
-	Plot A (100% covered)	Plot B (0% covered)	Plot C (50% covered)	Plot D (30% covered)
15	7.6	52.3	17.6	15
30	10.3	39.6	12.3	31
45	11.3	38.3	9	22
60	5.3	33.3	9.3	34
75	8.6	69	7	24
90	7	42.3	8.5	33
105	11	34.6	13.3	43.5
120	9.3	32.3	24.3	44

Table B.5 Soil loss from all the plots under the rainfall intensity of 52 mm hr^{-1}

Time interval (min)	Soil detachment (g m^{-2}) from all the plots at different intervals of time under the rainfall intensity of 52 mm hr^{-1}			
-	Plot A (100% covered)	Plot B (0% covered)	Plot C (50% covered)	Plot D (30% covered)
15	-	64.52	2.09	11.42
30	-	124.62	4.73	22.21
45	-	177.95	7.29	31.65
60	-	241.59	8.9	47.09
75	-	333.9	10.91	64.81
90	-	407.33	14.25	75.56
105	-	509.29	16.01	92.35
120	-	578.73	17.39	102.4

Table B.6 The water discharge observed for the period of 2 hours and 40 minutes under the rainfall intensity of 52 mm hr^{-1}

Time interval (min)	Observation of water discharge (m^3 sec^{-1}) from all the plots at different intervals of time under the rainfall intensity of 52 mm hr^{-1}			
	During the occurrence of rainfall			
-	Plot A (100% covered)	Plot B (0% covered)	Plot C (50% covered)	Plot D (30% covered)
15	1.78064E-05	1.41338E-05	7.85213E-06	1.256E-05
30	1.49005E-05	2.27E-05	8.6373E-06	2.041E-05
45	0.0000183	2.4941E-05	8.89909E-06	1.022E-05
60	1.91655E-05	4.80588E-05	9.0299E-06	3.934E-05
75	1.91655E-05	6.87294E-05	9.73664E-06	4.805E-05
90	1.91655E-05	8.07634E-05	9.6842E-06	4.805E-05
105	2.4941E-05	9.39803E-05	1.22947E-06	4.805E-05
120	2.4941E-05	9.39803E-05	2.52385E-06	4.805E-05
	During no rainfall			
125	1.42771E-05	3.16516E-05	1.22947E-06	2.494E-05
130	6.95493E-06	2.25212E-05	4.46159E-07	1.022E-05
135	4.40899E-06	1.81185E-05	7.88705E-08	6.954E-06

140	2.52385E-06	1.25588E-05	7.88705E-08	4.409E-06
145	1.22947E-06	9.51013E-06	-	4.409E-06
150	1.22947E-06	8.17268E-06	-	1.229E-06
155	1.03469E-06	6.95493E-06	-	4.461E-07
160	1.03469E-06	4.86321E-06	-	4.461E-07

Table B.7 The turbidity values obtained from all the plots at different time intervals under the rainfall intensity of 52 mm hr^{-1}

Time interval (min)	Turbidity values (NTU) from all the plots at different intervals of time under the rainfall intensity of 52 mm hr^{-1}			
-	Plot A (100% covered)	Plot B (0% covered)	Plot C (50% covered)	Plot D (30% covered)
15	93.33	1268	623	908.33
30	103.33	1125	678	1243.33
45	106.66	951.5	413	1645
60	105	981.5	426.5	1242.5
75	135	1430	406.5	1571.66
90	123.33	1353	328	1598.33
105	106.66	1966.5	608	1720

120	95	2585	390	1391.66

Table B.8 The presence of suspended particles in the water samples observed for a period of 2 hours under the rainfall intensity of 52 mm hr^{-1}

Time interval (min)	Total suspended solids (mg L^{-1}) from all the plots at different intervals of time under the rainfall intensity of 52 mm hr^{-1}			
-	Plot A (100% covered)	Plot B (0% covered)	Plot C (50% covered)	Plot D (30% covered)
15	3.3	34	26.6	36
30	4	11.6	18.1	31
45	2.3	8.6	13.95	35
60	2.6	23.3	10.65	36.5
75	7	33.3	12.45	20
90	5.6	30	13.5	39
105	13	39.3	20.65	46
120	4	58.3	19.15	41