INFLUENCE OF DROP SIZE DISTRIBUTION AND KINETIC ENERGY IN LABORATORY RAINFALL SIMULATION

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SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2022

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By

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This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF CIVIL ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering
University Sains Malaysia

August 2022

Appendix A8

UNIVERSITI SAINS MALAYSIA

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2021/2022

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: Influence of Drop Size Distribution and Kinetic Energy In Laboratory Rainfall Simulation

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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Date : 9/8/2022

ACKNOWLEDGEMENT

I would like to acknowledge and give my warmest thanks to my supervisor Ts. Dr. Mastura Azmi who made this work possible. Her guidance and advice carried me through all the stages of writing my project. Special thanks also to Dr Siti Aimi Nadia that allow my thesis to go extra mile. I would also like to thank my fellow friend, Zuraini Binti Zulmahdi, Nurain Soleha Binti Kamaruddin and Meow Lian ke for letting my final year project be an enjoyable moment, and for their brilliant comments and suggestions.

I would also like to give special thanks to my parents, Roshar Bin Ismail and Hasmah Binti Saad and my family members for their continuous support and understanding when undertaking my research and writing my project. Your prayer for me was what sustained me this far.

Lastly, I am thankful for the support and help from the lab technician of School of Civil Engineering, USM including Mr. Muhamad Zabidi Yusuff, Mr. Azuan Ali Abdullah and Mr. Dziauddin Zainol Abidin. They consistently provided me a helpful hand for the experiments as well as preparing the tools for my experimental setup. Their useful practical and hands-on experiences helped me to avoid multiple unnecessary mistakes.

ABSTRAK

Pelbagai bukti saintifik telah dikemukakan berkaitan dengan keburukan perubahan iklim terhadap cerun. Pelbagai kaedah pengumpulan data hydrologi telah dibangunkan bagi mereplikasikan hujan semula keatas satu skala makmal walaupun ianya sukar. Matlamat kajian ini adalah untuk menggunakan simulator hujan jenis titisan untuk mereka bentuk, membina, menentukur dan menjalankan simulasi hujan. Keamatan hujan 60 dan 80 mm/j digunakan untuk mewakili kejadian hujan lebat dalam tempoh 1 jam. Kaedah pelet tepung dan analisis ayak digunakan untuk mendapatkan taburan saiz kejatuhan bagi simulasi hujan. Keputusan menunjukkan saiz penurunan purata bagi semua keamatan hujan yang dikaji adalah antara 4 - 5 mm. Nilai median taburan saiz kejatuhan atau dikenali sebagai D_{50} bagi hujan simulasi untuk 60 dan 80 mm/j ialah 4.03 dan 5.12 mm. Disebabkan ketinggian penurunan yang agak rendah iaitu 2.3 m, halaju terminal yang dipantau adalah antara 75% iaitu 8.82 untuk 60 mm/jam dan 9.11 untuk 80 mm/jam, adalah lebih rendah daripada nilai untuk hujan semula jadi dengan lebih daripada 90% untuk terminal. halaju. Keadaan ini juga mengurangkan tenaga kinetik hujan sebanyak 27.42- 28.51 J/m2mm berbanding hujan semula jadi. Ini juga menyumbang kepada pergerakan jisim tanah yang kecil kerana tiada perubahan ketara pada permukaan cerun semasa simulasi. Kebolehubahan hujan semula jadi yang tidak menentu dihapuskan kerana hujan mungkin dikawal. Tumpuan utama adalah pada simulator hujan jenis titisan, yang menghasilkan sifat hujan yang hampir sama dengan hujan sebenar.

ABSTRACT

Numerous scientific evidence has given credence to the true existence and deleterious impacts of climate change on slope. Different means of hydrological data collection have developed and used to replicate the natural rainfall on laboratory scale model even though it is difficult. The aim of this paper was to use a drip-type rainfall simulator to design, build, calibrate, and run a simulated rainfall. Rainfall intensities of 60 and 80 mm/h were used to represent heavy rainfall events of one hour duration. Flour pellet methods and sieve analysis were used to obtain the drop size distribution of the simulated rainfall. The results show that the average drop size for all investigated rainfall intensities ranging from 4 - 5 mm. The median value of the drop size distribution or known as D_{50} of simulated rainfall for 60 and 80 mm/h are 4.03 and 5.12 mm, respectively. Due to the comparatively low drop height of 2.3 m, the terminal velocities monitored were between 75% which is 8.82 for 60 mm/hr and 9.11 for 80 mm/hr, were lower than the value for natural rainfall with more than 90% for terminal velocities. This condition also reduces rainfall kinetic energy of 27.42- 28.51 J/m^{2}mm compared to natural rainfall. This also contribute to small mass movement of soil because there is no significant change in slope surface during simulation. This phenomenon, which represents the best interchange between all pertinent rainfall parameters found with the particular simulator setup, is relatively prevalent in portable rainfall simulators. The unpredictable and erratic changeability of natural rainfall is eliminated because rainfall may be regulated. The main focus is on drip-type rainfall simulators, which produce properties of rainfall that are almost identical to those of actual rainfall.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Malaysia has a humid and hot tropical climate. It is significantly influenced by the rugged terrain and complex land-sea interactions. The effects of climate change have rendered Malaysia a disaster-free zone. However, the increasing use of advanced technology in development has also affecting climate change. In recent years, moderate climate-related disasters have become more frequent. These refer to floods and landslide that had a big impact on socioeconomic of nation. In contrast, landslides in Malaysia mainly triggered by rainfall and resulting in damaging the mountainous and coastal areas. Extreme precipitation events with long duration and high frequency are frequently occurred in Malaysian urban areas, particularly along the West Coast. Convective processes primarily create this phenomenon (Embi & Dom, 2004), followed by monsoon seasons. Although Malaysia is considered less susceptible to natural disasters than other countries, it still exposes to climate change and natural disasters due to the increasing of urbanisation (Suhaila et al., 2010).

Soil erosion is a physically complex process influenced by natural and human factors. The amount of runoff and erosion is affected by two significant factors which is precipitation characteristics and land use management. Since precipitation is the primary cause of soil erosion, directly affecting soil particle separation, decomposition of soil aggregates, and eroded sediment migration, precipitation-induced soil erosion accounts for most of the total erosion, Parsons & Stone. (2006). The intensity of precipitation is an essential factor in determining storm characteristics. The influence of raindrops on the soil surface during high intensity rainfall causes the increasing of soil particle detachment

(Van Dijk, Bruijneel, & Rosewell, 2002) and higher rainfall intensity also results in higher rates of infiltration of runoff and the increasing transport of suspended sediment load (Rose, 1993). Precipitation simulation has become an essential tool for studying hydrological and soil erosion mechanisms. It is used to investigate the rainwater interactions with soils, soil erosion, overland flow generation, and infiltration which are the key research areas (Tossell et al., 1987). The goal of this research is to developing a rainfall simulator in order to imitate the natural rainfall process, and to investigated the effect of a producing raindrop on a slope surface.

1.2 Problem Statement

Rainfall's physical qualities, such as intensity, raindrop characteristics, and effective rain such as the amount of rain that can result in runoff, all have an impact on erosion (Meshesha et al. 2014; Salles et al. 2002; van Dijk et al. 2002). Splashing is the results from the movement of soil particles caused by the impact of the rainfall on the soil surface. The majority of the spilled soil clogs surface pores, reducing water infiltration, increasing water runoff, and accelerating soil erosion.

Moreover, because soil splashing, rainfall's kinetic energy (KE), which is half of the product of raindrop mass and squared velocity, has frequently been utilised as a key sign of how effectively it may separate soil particles. Raindrops' kinetic energy is transferred to soil particles, resulting in splashing and the beginning of soil erosion as a result of the soil particles' disintegration and mobilisation (Wang et al. 2014).

Thus, kinetic energy and drop size need to be use to several rainfall erosivity indicators to forecast rainfall-driven soil loss. For modelling and forecasting soil erosion in rainfall simulator, it is essential to understand and measure kinetic energy and the raindrop droplet size distribution (DSD) (Cevasco et al. 2015).

1.3 Objectives

There are a few objectives needed to achieve in this laboratory work:

1. To determine the parameter of rainfall intensity.
2. To assess the effect of drop size distribution and kinetic energy in laboratory rainfall simulator.
3. To observe the change on slope surface due to heavy rainfall.

1.4 Scope of Work

The scope of work in this research focused on physical modelling and a rainfall simulator. This modelling will be subjected to rainfall intensity. The selected rainfall intensity chosen is 60 mm/hr and 80 mm/hr based on latest major cases that happened in Pulau Pinang, and then if clarify with data from Department Irrigation and Drainage (DID). This study will be revolved around five main parameter of rainfall intensity which is rainfall intensity, drop size distribution, terminal velocity, uniformity of rainfall intensity and kinetic energy. A few measurements instrument will establish the physical modelling to achieve the study's objective.

1.5 Significant of Study

In the field and in the lab, rainfall simulators are tools used in hydro geomorphological or hydrological research (Askoy et al., 2012) to create soil losses related to runoff, infiltration, and sediment loss owing to use, cover, and management in various soil classes (Sarasty et al., 2017).

The data obtain in this study will be able to benefit the future study of rainfall simulation regarding relation of drop size distribution and kinetic on other parameter of rainfall and also effect on soil.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

There has been a significant amount of research done using rainfall simulators to investigate rainfall and the hydrological processes that occur in the soil, such as runoff, erosion, and infiltration. (Abudi et al., 2012). The most essential goal in developing a rainfall simulator is to produce an effect that is identical to that of actual precipitation, which is an immensely complicated phenomenon that has never before been capable of being imitate (Aksoy et al., 2012). Rainfall simulators have been an important tool in the past few decades for studying the erodibility of soil under diverse conditions of slope and rainfall intensity on a wide variety of soil types (Grismer, 2012). Runoff is a significant part of the soil erosion process, and it is dependent on natural rainfall and other elements associated to it, such as variations in intensity, drop size, drop energy, spatial and temporal distribution, and so on. (Perez Latorre et al., 2010). There are two primary types of rainfall simulators, drop-forming or non-pressurized nozzle rainfall simulators, and pressurized nozzle rainfall simulators. There have been many different types of rainfall simulators built, including small portable infiltrometers that feature a circular rainfall region with a diameter of 6 inches, as well as the Kentucky rainfall simulator, which covered a reasonably wide area with dimensions of 4.5 meters by 22 meters (Moore et al., 1983). The design of rainfall simulators is not standardized, and they can vary considerably depending on a number of factors like rainfall intensity, spatial rainfall distribution, target area, drop size, droplet velocity, and kinetic energy (Iserloh et al., 2013).

2.2 Rainfall Simulator Classification

There are two classification of rainfall simulator that widely used for indoor or outdoor investigation drip former and pressurised nozzle (PN) simulator.

A drip simulator, often referred to as a drop former, makes use of hanging yarn or hypodermic needles to produce droplets of the required size with no forward motion. As a result of the fact that its impact velocity is achieved through free fall, others have characterised it as a non-pressurised simulator (Lassu et al.,20150. The diameter of the raindrop and its kinetic energy are both determined by the height of the drop, which is determined by the drilled holes. It is possible to produce droplets with a diameter that ranges from three to six millimetres, depending on the size of the holes. The capability of the drip simulator to create relatively large drips at a modest application rate is the primary benefit that this device offers (Yakubu et al.,2017). It is possible to produce droplets with a diameter that ranges from 3 to 6 millimetres, depending on the size of the holes (Palmer, 1963). The capability of the drip simulator to create relatively large drips at a modest application rate is the primary benefit that this device offers (Morin et al.,1967).

The Pressurized Simulator (PN) creates a drop distribution that has a nonzero beginning velocity and an impact velocity that is comparable to the terminal velocity of raindrops. These drops can be produced in a wide variety of sizes, from very small to very large. Nozzles with a high discharge rate are necessary in order to maintain a high velocity while yet producing drops of the appropriate size (Lassu et al.,2015). By utilising an intermittently moving device that intercepts the raindrops, the application rates can be lowered to a more manageable level. Meyer, in 1958, was the first person to construct an example of this kind of simulator. This simulator makes use of the most effective nozzle, which is referred to as "yet-for-rain simulation" (spraying system 80,100-veejet nozzle).

However, the issue with the 80,100-veejet nozzles was that they did not simulate the energy characteristic of rainfall, despite the fact that they are an improvement over other nozzle. This particular form of rainfall simulator generates around 80% of the necessary kinetic energy per volume of natural rainwater runoff (Wilson et al,2014).

2.3 Rainfall Intensity

Climate change and its effects have been the subject of several studies. Rainfall is expected to become more severe and less frequent as temperatures rise (Strauch et al., 2017). The flux boundary condition across the ground surface will be affected by changes in rainfall patterns. As a result of changes in groundwater hydrology, rainfall-induced slope failures may be reduced (Chen, Lee, & Law, 2004).

Malaysia is located in the tropics. The average temperature in Malaysia is 25.4°C. Average monthly temperatures fluctuate by just one degree Celsius between a low of 24.9°C in January and a high of 25.9°C in May, with little seasonal variation. A year's worth of precipitation falls about between 200 millimetres (mm) in June and July and 350 millimetres (mm) in November and December, on average. there are two types of monsoons which is southwest and north-eastern monsoon seasons

Figure 2.1 shown the monthly climatology of minimum temperature, mean temperature, max temperature and precipitation in Malaysia from 1991 until 2020 (climate Change Knowledge Portal, 2021). Meanwhile figure 2.2 show average rainfall in Penang (weather and climate, 2022).

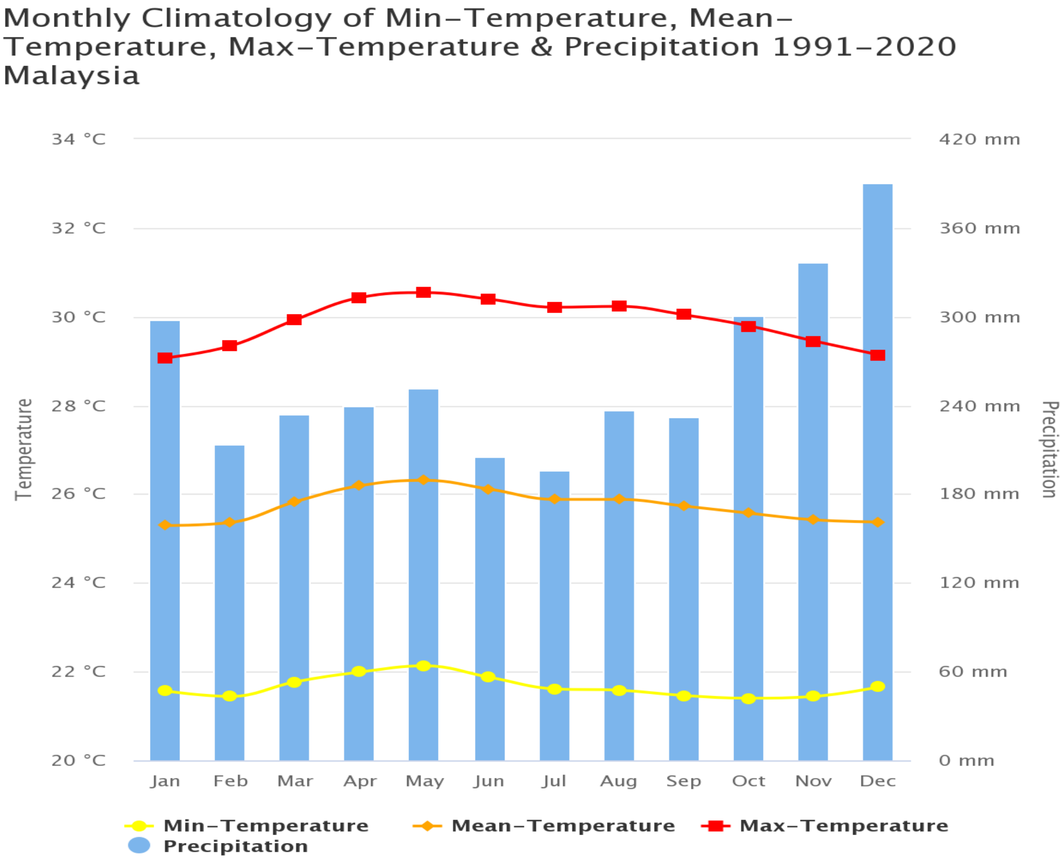

Figure 2.1: Monthly Climatology

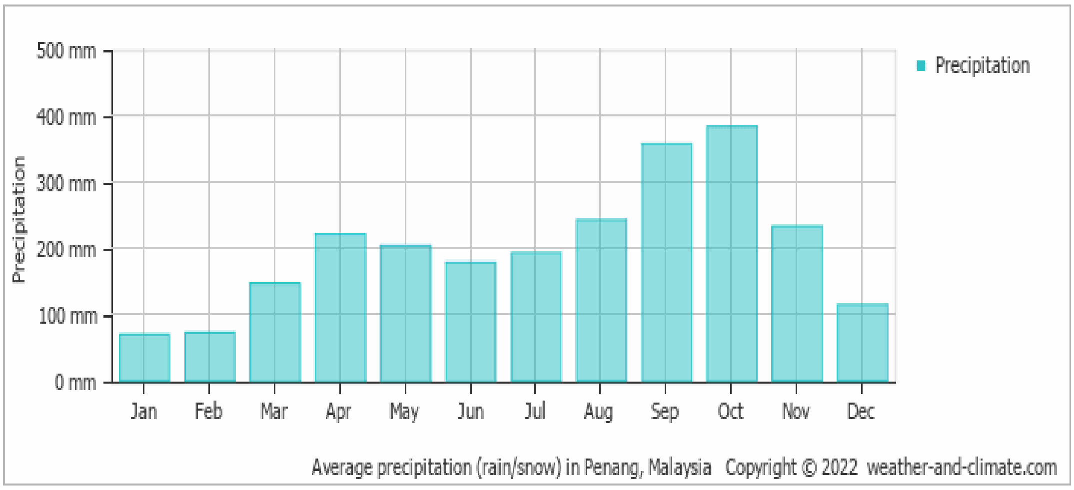

Figure 2.2: Average Rainfall in Penang for Year 2022

2.4 Drop Size Distribution

The drop size control is a key parameter of the rainfall simulator since it provides information regarding the range of droplet diameters for the experiments that are being carried out. The drop size distribution has a role in determining not only the terminal velocity but also the striking velocity of the simulated rainfall. A relatively small change in the median drop size can have a significant impact on the kinetic energy, which in turn influences the soil detachment processes. The drop size distribution has been evaluated using a variety of methods and approaches, such as stain, flour pellet, photographic, and others.

Bently (1904) was the first researcher to utilise the flour pellet method in order to evaluate the size distribution of raindrops. The compaction of the flour and the sample size both have an effect on the drop size distribution (Kohl,1974). For the event after rainfall, an analysis of the pellets using a sieve allowed for the determination of the drop size distribution (Miguntanna,2009). When determining the size of the pellets, Parsakhooet et al. (2012) utilised a ruler. Arnaezet et al. (2007) utilised digital image analysis to obtain more accurate information regarding the pellet size. Clarke and Walsh (2007) classified the sieve-analyzed pellets into a total of seven different size categories. The mean pellet mass of each class was converted to the mean drop mass using a mass ratio that was found by Laws and Parson (1943). The optimal drop size distribution index, according to Hudson (1971), is the mean drop diameter, which is denoted by D50

Figure 2.3, demonstrates how the sample from flour pellet method was process for calibrating the drop diameter was carried out using five different drop diameters (Mhaske et al., 2019).

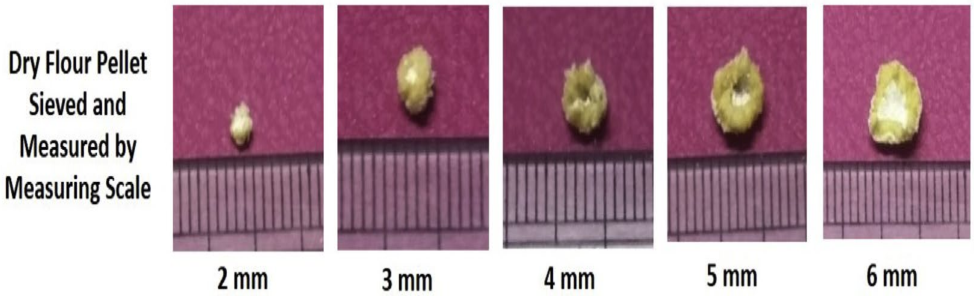

Figure 2.3: Raindrop Calibration

Table 2.1 rainfall simulator that using flour pellet method with difference rainfall intensities (Mhaske et al., 2019).

Table 2.1: Difference Drop Size with Difference Rainfall Intensities

Srl. no.	*D* range (mm)	No. of drops	Accu. drop	Srl. no.	*D* range (mm)	No. of drops	Accu. drop
Rainfall intensity: 65 mm/h				Rainfall intensity: 93 mm/h			
1	0.5–1.5	16	5%	1	0.5–1.5	115	25%
2	1.6–1.9	60	21%	2	1.6–1.9	113	25%
3	2.0–2.9	152	52%	3	2.0–2.9	152	34%
4	3.0–3.9	52	18%	4	3.0–3.9	40	9%
5	4.0–4.9	8	3%	5	4.0–4.9	17	4%
6	5.0–6.5	4	1%	6	5.0–6.5	12	3%
Rainfall intensity: 112 mm/h				Rainfall intensity: 148 mm/h			
1	0.5–1.5	52	12%	1	0.5–1.5	80	19%
2	1.6–1.9	112	27%	2	1.6–1.9	44	10%
3	2.0–2.9	164	39%	3	2.0–2.9	140	33%
4	3.0–3.9	44	10%	4	3.0–3.9	108	26%
5	4.0–4.9	20	5%	5	4.0–4.9	20	5%
6	5.0–6.5	28	7%	6	5.0–6.5	29	7%

2.5 Terminal Velocity

The striking velocity of falling raindrops has a significant impact on the process of soil erosion, which is accordingly connected to the kinetic energy of the drops (Bryan, 1981). If the issue can be made a bit less complicated, one need only take into account the gravitational force and the drag force when calculating the terminal velocity of a rain droplet's travel, and this may be done by assuming that the droplet is moving at a constant speed (Abudi et al., 2012). The droplets' size as well as the speed at which they are travelling at their terminal point both have an effect on their striking velocity and their kinetic energy (Aksoy et al., 2012). If the droplet is larger, both its mass and its kinetic energy will be greater (Kohl, 1974), and the value of its terminal velocity will be greater as well. If the droplet hits the surface of the soil with a larger velocity, then the amount of soil that is eroded will be greater. This means that the amount of soil that is eroded has a direct correlation to the droplet size, which in turn determines the terminal in addition to the striking velocities of the drop itself.

The majority of the cases use laboratory-type simulators, with the exception of those that are positioned in stairwells or specifically built towers (e.g., Cerdà et al., 1997; Clarke et al., 2007). Some of the cases use drip-type field simulators. Epema and Riezebos (1983) presented a mean velocity result of as 4.7 m/s for 4.1 mm diameter raindrops falling from 0.85 m, as compared with findings on terminal velocity by Laws (1941) for the same size of drop at 9 m/s. Epema and Riezebos (1983) also presented a mean velocity result of as 4.7 m/s for 4.1 mm diameter raindrops falling from 0.85 m (Clarke et al., 2007). On-site portable simulators and small-scale laboratory simulators use a greater median drop size to compensate for the velocity reduction when the fall height is constrained. Clarke et al., (2007) found that Hudson's (1963) obtain median drop diameter of natural rainfall at intensities more than 165 mm/hr was 1.5 mm with an average speed of 5.5 m/s (Laws, 1941).

According Van Boxel, J. (1998), only drop with less than 1 mm will achieve 95% of their terminal velocity within 2 meter of height. Figure 2.4 shown terminal velocity of rainfall based on size of raindrop and distance.

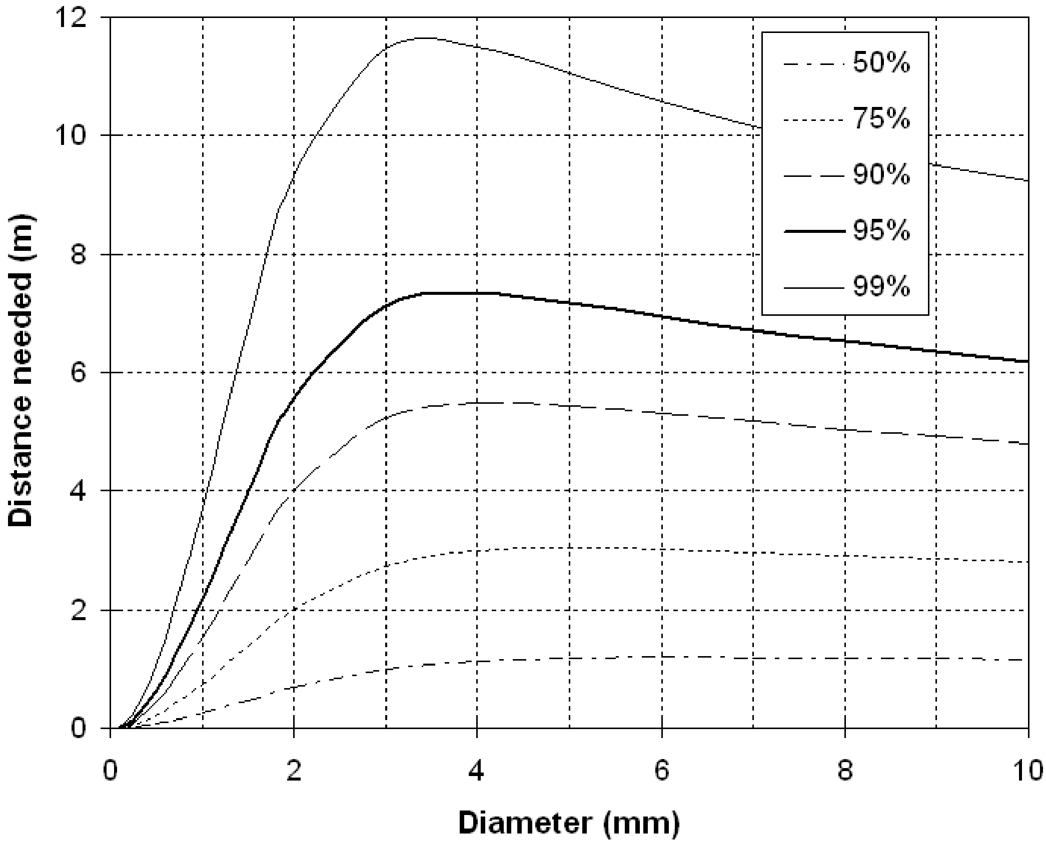

Figure 2.4: Suitable Diameter and Distance for Rainfall to achieve their terminal velocity

2.6 Uniformity of Simulator Rainfall

Uneven rainfall is difficult to generate without careful planning of where the soil surface would be beneath the simulated rain (Agassi and Bradford,1999). Some researchers utilized a single spray nozzle to cover the entire target area (Meyer and Harmon, 1979), while others employed a system with multiple spray nozzles to evenly distribute the water from each nozzle (Aksoy et al., 2012). Analysis of rainfall patterns on the target area was conducted so that researchers could learn more about the uniformity of rainfall produced by the rainfall simulator.

There are few empirical that can be used to determine the uniformity of rainfall simulator. Christiansen Uniformity Coefficient (Cu) was one of it (Clark et al., 2007). The Cu is defined by following equation:

$$\mathrm{Cu} = 1 - \left[\frac{SD}{\mathrm{Mean}}\right] \times 100 \tag{2.1}$$

where, SD is standard deviation.

Table 2.2 below show Uniformity that be carried out by Mhaske et al.,(2018)

Table 2.2: Uniformity Test

Rainfall uniformity test using Christiansen coefficient (*Cu*).

Rainfall intensity (mm/h)	*Cu* (%)
65	81
93	86
112	84
148	88

Meanwhile according to Shoemaker et al., (2012) calculated an average uniformity of rainfall distribution of 83 to 87% on the test plots. The summarized can be seen in Table 2.3

Table 2.3: Summary of rainfall simulators and testing

Study	Drop Size Distribution, mm (in.)	Uniformity	Simulator Height, m (ft)	Rainfall Intensity, mm/hr (in./hr)	Plot Sizes, m^2 (ft^2)	Slopes, %
ASTM [a] D6459-15 [22]	Less than 10% > 6 (0.24) Less than 10% < 1 (0.04)	>80%	4.27 (14)	50.8, 101.6, 152.4 (2, 4, 6)	29.7 (320)	33
Moore et al. [14]	D50 = 2.25 (0.089)	80.2 to 83.7	3 (9.84)	3.5 to 185 (0.138 to 7.28)	4.5 (48.4) or 99 (1065)	
Shoemaker et al. [19]		83 to 87	3.05 (10)	111.8 (4.4)	0.74 (8)	33
Kim et al. [20]			2.44 (8)	71.12 to 83.82 (2.8 to 3.3)	8 (86)	29 to 30
McLauglin and Brown [9], Miller [21]	2.25 to 2.5 (0.089 to 0.098)	85.7 to 93.2	3.96 (13)	33 and 66 (1.3 and 2.6)	2 (21.8)	10 and 20

2.7 Kinetic Energy

As a measure of the potential for rain to dislodge soil aggregates, total kinetic energy of rainfall (KE) is utilised. KE reflects the sum of rain drop kinetic energy (Salles et al., 2002). Depending on the time and volume of rainfall, the kinetic energy can be described in two different ways. Kinetic energy per unit area per unit time is computed by dividing the total kinetic energy by the square of the area. In this study, KE_{Time} (J/m2/h) is presented. The rainfall depth per unit area is expressed as the volume-specific kinetic energy of rain (J/m2/mm) and is denoted by the symbol KE_{mm}.

The kinetic energy of rainfall can be calculated in a few of ways: empirical rules relating drop diameter (D) and terminal fall velocity (vt) or by using measurements of drop size distribution (DSD) and vt. The size of raindrops must be known in order to calculate DSD (D). According to Jan Petru and Jana Kalibova (2018), a total of 90 measurements were made, spanning a speed range of 15.9 mm/h to 172.3 mm/h in intensity and KE = 706.6 J/m2/h, or 58.6 mm/h, was the mean rainfall rate. There was a significant discrepancy between the values reported by Iserloh et al., (2013) and Ries et al., (2013) in terms of the median drop diameter (2009). Table 2.4 shown that difference Kinetic Energy with difference rainfall intensity that be carried out by Mhaske al et., (2018).

Table 2.4: Kinetic Energy for Different Rainfall Intensities

Rainfall intensities and their corresponding kinetic energies.

Nozzle model no.	Rainfall intensity (mm/h)	Kinetic energy (J) in 0.5 m^2 area
DA13250	65	6.064
DA13350	93	7.327
DM14.500	112	9.424
DM24.100	148	11.671

Because the height of the setup cannot be made particularly high in laboratory studies to emulate natural rainfall, the simulated raindrops may hit the soil surface plot before reaching their terminal velocities. The flow pressure at the nozzle, the size of the droplets, and the height of the experimental setup are all factors that affect the droplets' striking velocity.

2.8 Impact of Heavy Rainfall on Slope

It is not uncommon for enormous quantities of dirt to migrate downslope due to gravity in slope failures all around the world. When the shear force on the slope is greater than the slope's shear strength, something happens to the slope. Infiltration and evapotranspiration are two examples of flux boundary conditions that can be affected by changes to rainfall patterns. A rise in the groundwater table will occur as a result of increased soil water content as rainwater permeates through the pores. A drop in effective stress and an increase in pore-water pressure result in a reduction in the soil's shear strength to support loads. Failure of a slope occurs when the shear strength mobilised along a crucial slip surface is no longer sufficient to maintain the shear stress (Chen et al., 2004)

Over the years, a great deal of research has been done to try to figure out just how important rainfall patterns are to slope stability. It has been shown that slope failures are rather stable during the warm-dry season in Umbria in Italy, whereas during the cold-wet season landslide incidents increase significantly when the amount and intensity of rainfall are increased (Ciabatta et al., 2016).

Many research have been done in Singapore on the impact of rainfall on the stability of local slopes. At the end of December 2006 and the beginning of January 2007, Singapore saw above-average monthly rainfall, resulting in eleven landslides in the city (Rahardjo et al., 2011). Slope stability is affected more by precipitation on low-conductivity slopes than high-conductivity slopes, according to Rahimi, Rahardjo, and Leong (2011). Distinct types of slopes are affected by different rainfall patterns. When there is a delayed rainfall pattern, HC slopes are more likely to meet their minimum factor of safety (FS) when the intensity increases with time and reaches a peak near the conclusion of the rainfall event.

The effect of rainfall on slope also can be determined from the splash erosion. According to Morgan (2005), the two phases of soil erosion involve the separation of individual soil particles by raindrops and the transportation of these particles by sheet flow. According to Fernández-Raga et al. (2017), the first stage of interrill erosion by sheet flow is the detachment of soil particles by splash erosion, which is influenced by a number of variables including rainfall intensity (Park et al., 1983), slope gradient (Fan and Wu, 1993), rainfall kinetic energy (Al-Durrah and Bradford, 1981), and flow depth (Morgan et al., 1998). Splash erosion is the first important mechanism of the soil erosion process, hence it follows that the construction of process-based soil erosion models requires an accurate assessment of splash detachment capacity in vulnerable areas.

CHAPTER 3

METHODOLOGY

3.1 Overview

A portable Rainfall Simulator (RS) is developed to investigate the impact of rain drop and kinetic energy on the slope. To conduct this study, the rainfall intensity needed to be selected. Various variable need to closely control to archive the same similarity characteristic with natural rainfall. Two types of analysis will be used to achieve the objective which is physical modelling and mathematical analysis. In physical modelling, rainfall simulator where to setup the necessary parameter and flour pellet method where to determine the size of raindrop will carried out. While for mathematical analysis it will contain fourth different analyses which is drop size distribution, terminal velocity, distribution uniformity and kinetic energy with the purpose to achieve the similarity with natural rainfall. By doing the observation on slope, the impact of raindrop on the slope can be observe within a certain period. The observation will be carried out on the pattern of raindrop on the slope surface. The overall methodology of this study is summarized in figure 3.1.

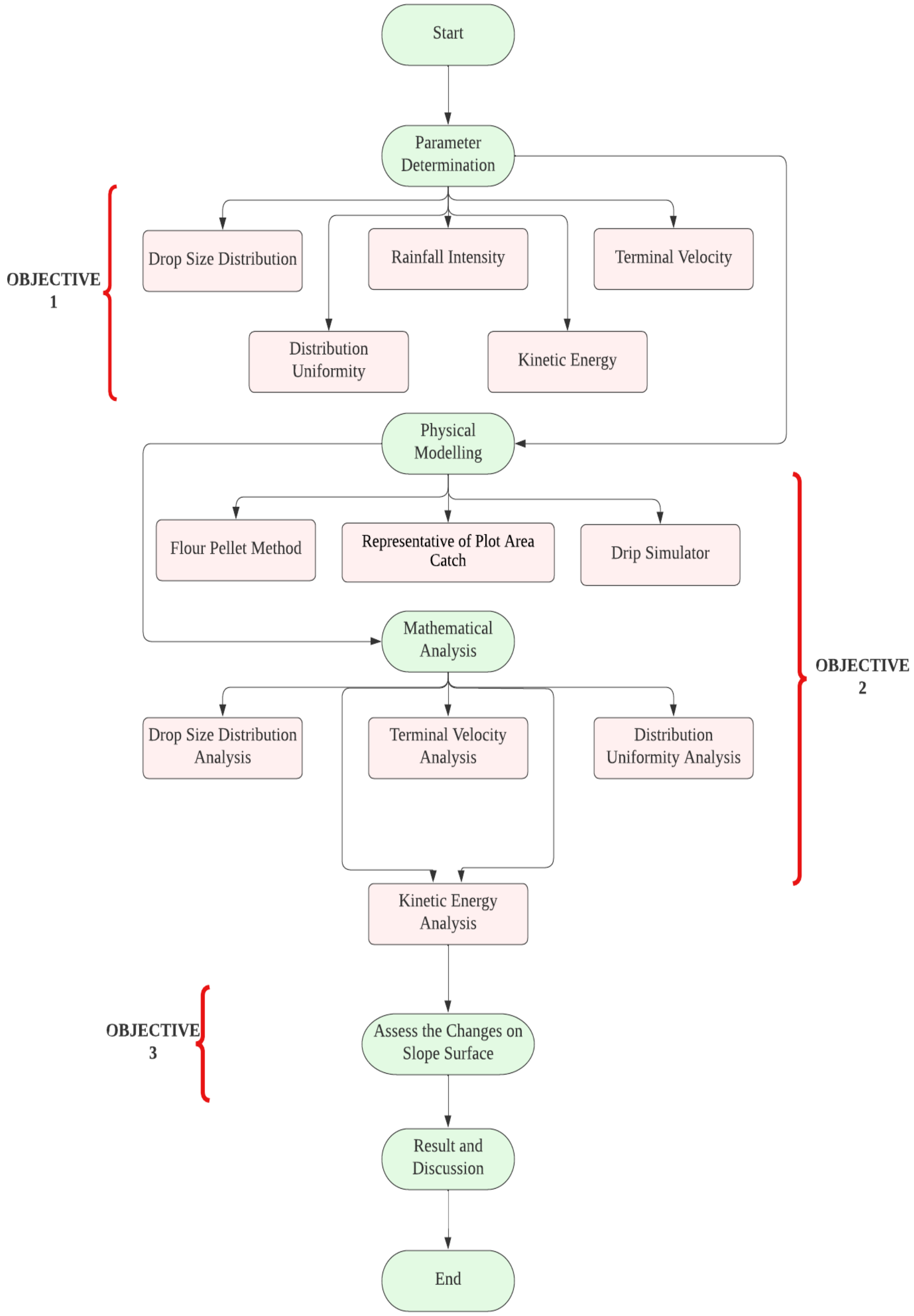

Figure 3.1: Methodology Summary

3.2 Characteristic of Rainfall Simulator

3.2.1 Rainfall Intensity

An excessive rainfall or precipitation event is one in which the overall rainfall and intensity of the rainfall exceeds the previous highest rainfall. The criteria for selecting intense rainfall intensity are to identify the greatest intensity that is noteworthy in terms of the incidence of any natural phenomena such as flood and landslide events in addition to extreme precipitation.

In determine the value of rainfall intensity, the comparison can be made by compare the chosen intensity with the existing classification. The existing classification was taken from Department of Irrigation & Drainage Malaysia, DID (2017) as shown in table 3.1.

Table 3.1: Rainfall Intensity Classification

Department of Irrigation & Drainage, Malaysia, DID	
Rainfall Intensity Classification	Rainfall Intensity (mm/hr)
Light	1 < I < 10
Moderate	10 < I < 30
Heavy	30 < I < 60
Very Heavy/Extreme	>60

3.2.2 Drop Size

One of the most important natural rainfall factors to consider is drop size, which ranges between 0.5 and 5 mm (Yakubu and Yusop. 2017). Raindrop diameter measurement has been explored using numerous methodologies, however there is no set standard for determining raindrop diameter size (Yakubu and Yusop, 2017). In general, two methodologies have been developed to determine drop size: manual and automatic raindrop measurement (Kathiravelu et al., 2016) which flour pellet method for manually and impact disdrometer for automatic measurement.

3.2.3 Terminal Velocity

A natural raindrop falling from a greater height has a higher terminal velocity before contact. This has a number of implications on soil breakdown and infiltration. This is especially significant when studying soil erosion concerns, as drops should achieve their terminal velocity before contact with soil surface (Nassif SH. 1973). This rainfall characteristic is strongly dependent on the simulator's height. The terminal velocity is reached when the downward gravitational forces acting on the rainfall are balanced out by the drag acting on the drop (Yakubu and Yusop, 2017).

3.2.4 Kinetic Energy

The degree to which the energy of rain is quantified is known as its kinetic energy. It is the most important element in the soil detachment process. Rain's energy is proportional to its erosivity and it is express in J/m^{2}mm (Grismer M, 2012). In other word, kinetic energy is used as a measure of rain's capacity to disrupt soil aggregates, and it effectively quantifies the sum of the kinetic energy of rain drops falling on the ground (Salles et al., 2002).

3.2.5 Rainfall Distribution Uniformity

Uniformity is one of the most significant measures of measuring how uniformly distributed the rainfall is on a plot to minimize ponding and over saturation on one other side in simulated rainfall on a plot (Yakubu et al. 2017). There are some factors that may impact the uniformity of rainfall simulator which is wind, slope and altitude (Grismer M, 2012).

3.3 Physical Modelling

3.3.1 Rainfall Simulator

The rainfall simulator's structural structure is composed of Dexion steel, which offers stability for a drip system of 2.3 m in height. The model is supplied with water via a 50 L water tank. The tank is supplied with a pump connected to the main water pipe, and water runs through 10 lateral lines, with 10 drips in each lateral line producing raindrops. On the rainfall simulator system, a flowmeter was attached to measure the discharge; the flow rate of the water. A pressure regulating valve can be used to manually control the discharge, allowing for the appropriate rainfall intensity. The drippers used in the tests were Claber Rainjet types 91217 and 91209. The drippers were chosen because of their ability to produce equally distributed droplets of various diameters. They were linked to the laterals' Dexion steel (Ramli H et al., 2021). The illustration setup as show below while in laboratory setup in appendix:

a) Figure 3.2 shows the setup of rainfall simulator.

b) Figure 3.3 show drip emitter system consists of 10 laterals connected to sub main.

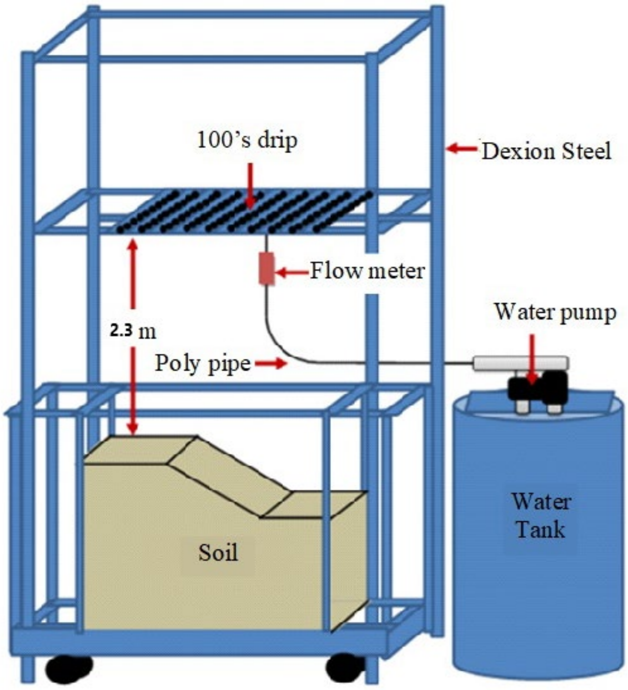

Figure 3.2: Rainfall Simulator Setup

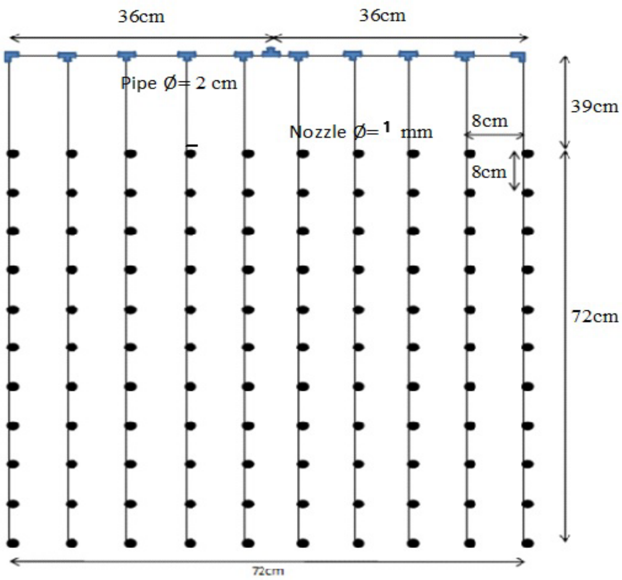

Figure 3.3: Drip Emitter System

For drip emitter system, the system has 100 nozzle drip points spread across a 72 cm 72 cm square area. Ten nozzle drips are evenly distributed at 8 cm along ten lateral lines connected to the mainline. The effective test area of the system is 80 cm x 80 cm. The pipe diameter is 2 cm, and the drip hole for producing rainfall is 1 mm. The water supply system was designed to give sufficient flow to the risers while maintaining an appropriate operating pressure.

3.3.2 Representative of Plot Area Catch

The catchment box was adjusted so that it could measure the depth of water that reached the ground exactly beneath the rain simulator. Most of this water flows into the buffer zone, and only if water falls uniformly from the entire rain simulator base will measurements of the water that really lands on the plot area be correct. In order to test this, a 1 m x 1 m x 1 m empty box was constructed. A drip was then placed in the center of the rain simulator, and the depth that it collected over the course one hour at intensity was measured and linked to a reservoir scale reading.

3.3.3 Flour Pellet Method

This method was chosen because drop that will be produce is around 0.3 mm to 6 mm according Kathiravelu et al., (2016). This method use tray with size of 1.0 m x 1.0 m that consists 1-inch uncompacted fine wheat of flour which will be expose to the rainfall around 1 to 2 second. During the rainfall simulation, the drops did not all fall at the same time and formed in the order of their size on impact. Its purpose was to collect single raindrop. The flour plate was covered and placed 2.3 meters below the drip. The valve will be opened for few minutes so that the raindrop will stable. The cover will be removed for split second. The valve was quickly closed to stop the rainfall. Take note of the raindrop pattern being within the effective test region. Each drop that dropped on the pallet created small flour balls, which were dried at 105 degrees Celsius for 24 hours.