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Development of Rainfall Erosivity (R) In Revised Universal Soil Loss Equation (RUSLE) For An Equatorial Region Of Sarawak.

Johari, A.H., Law, P.L., Taib, S.N.L., Darrien, M.Y.S., Yong, L.K. (2018)
Corresponding Author: Johari, A.H.

--***ABSTRACT***--

The Revised Universal Soil Loss Equation (RUSLE) was developed for the Department of Agriculture of USA for predicting top soil erosion rate and sediment yield from agricultural areas or plantations located in temperate region, with extremely low annual rainfall (1,000 mm/year), as compared to equatorial region of more than 4,000 mm/year such as Sarawak whereby a great portion (>25%) of land area covered with peat. The primary objective of this research was to develop the factors of Rainfall Erosivity (R) for an equatorial region of Sarawak. In order to achieve the objective of this study, soil samples were collected from Sri Aman, Sarawak. The soil samples were tested for physical properties. A rainfall simulator was constructed to conduct six simulated rainfalls on three types of hill slopes; a cone, a pyramid, and a plateau. Photos of raindrops were taken with a high speed camera during simulated rainfalls to determine raindrop sizesand consequently to determine kinetic energy of the raindrops. Runoff samples were taken to determine sediment concentration. From the experimental results, it was observed that the median drop diameter for simulated rainfalls on the plateau-shape hill slope and cone-shaped hill slope was 2.0 mm. For simulated rainfall on pyramid-shaped hill slope, the median drop diameter was 2.5 mm. Values of total kinetic energy of raindrops on plateau-shaped hill slope, cone-shaped hill slope, and pyramid-shaped hill slope were 0.287 MJ/ha.mm, 0.332 MJ/ha.mm and 0.317 MJ/ha.mm, respectively. The rainfall intensities for simulated rainfalls on plateau-shaped hill slope, cone-shaped hill slope and pyramid-shaped hill slope were 142.96 mm/h, 142.78 mm/h, and 151.17 mm/h, respectively. An equation of Total Kinetic Energy of rainfall for an equatorial region of Sarawak (E_{eqt}) was derived from correlations of kinetic energy of rainfall and rainfall intensity. The values of Equatorial Rainfall Erosvity (ER) were determined from multiplication of 30-minute rainfall intensity and Equatorial Kinetic Energy of Rainfall (E_{eqt}). Results of Equatorial Rainfall Erosivity (ER) and Rainfall Erosivity (R) were compared for the rainfall station of Kuching in the year 2014.

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I. INTRODUCTION

Rainfall is one of many factors that cause soil erosion, where raindrops and runoff break the bonds among soil particles (Elbasit et al., 2010,; Baharudin, 2007; Dijk et al., 2002; Ali and Tew, 2006; Wischmeier and Smith, 1978). Rainfall erosivity was defined as the ability of rainfall to cause soil erosion (Goh and Tew, 2006). Rainfall intensity and rainfall drop size distribution (DSD) have unique correlation that determines rainfall characteristics including rainfall erosivity (Elbasit et al., 2010; Best, 1949; Baharudin, 2007).

Rainfall Erosivity factor (R) is one of the factors embedded in the Revised Universal Soil Loss Equation (RUSLE) (Wischmeier and Smith, 1978).An R-factor for a given rainfall period is a number, which indicates the erosivity of the rain expressed as the index of EI_{30}. The factor of E is the total energy for a rainfall and I_{30} is the rainfall's maximum 30-minute intensity. According to Wischmeier and Smith(1978b), rainfall with depthof less than 13mm and separated from the other rain periods by more than 6 hours are not included in the computation of R-factor, except for 6mm of rain falls in 15 minutes. The index of EI_{30} is the product of the total energy for a rain and the rainfall's maximum 30-minute intensity (Wischmeier and Smith, 1978; Tew, 1999).

The Revised Universal Soil Loss Equation (RUSLE) has been used to predict an annual erosion rate of a field slope that based on rainfall pattern, soil type, topographical factor, crop system and management practices(Renard et al., 1997). The equation applied to calculate soil loss in Equation 1.

$$A=R \times K \times L \times S \times C \times P \qquad (1)$$

The equation includes Soil Loss (A), Rainfall Erosivity (R), Soil Erodibility (K), Slope Length (L), Slope Steepness (S), Cover Management factor (C), and Erosion Control Practice factor (P). Since the publication of the Universal Soil Loss Equation (USLE) in 1959 by Wischmeier and Smith and the Revised Universal Soil Loss Equation (RUSLE) by Renard et al.(1997), the equations have been widely used worldwide and are the onlytools applied in Malaysia to predict soil loss from landscape sites with moderate slopes, normally less than 50% (Tew, 1999).

The RUSLE was developed in the United States of America for the Department of Agriculture for predicting top soilerosion rate from agricultural areas or plantations located in temperate region, with extremely low annual rainfall (1,000 mm/year)(Renard et al., 1997). Whereas in an equatorial region, rainfall can be more than 4,000 mm/yearsuch as in Sarawak, whereby the state has a great portion (>25%) of land area covered with peat(Malaysian Meteorological Department, 2016; Mohamed et al., 2002; Peter, 2006). The application of RUSLE to predict peat or mineral soil erosion rate and sediment yields for equatorial regions may have significant deviations. The objective of this study was to derive an equation to estimate kinetic energy of rainfall in an equatorial region of Sarawak.

II. METHODOLOGY

To achieve the objectives of this study, an organized approach is shown in Figure 3.1.The physical properties of soil conducted on the samples were moisture content, organic content, field density, permeability, and particle size distribution. The procedures carried out to determine the physical properties were according to the British Standard (BS1377-Part 2:1990).

2.1 Rainfall simulator

This section describes the design, construction, calibration and operation of a drip-type simulator and the soil plot for erosion study on a slope. The frame of rainfall simulator was constructed in steel with dimensions of 0.64 m x 1.38 m at the base, 0.64 m x 1.38 m at the top with a protruding triangle as a support for the sprinkler, and 1.0 m in height. The structure was built up with an adjustable steel angle of 30 mm x 30 mm x 5 mm in dimension. The water tank, pumping unit, and sprinkler were temporarily placed at a height of approximately 10.36 m on the 2nd floor of chemical engineering laboratory building in Universiti Malaysia Sarawak, Kota Samarahan (Figure 1 and Figure 2).

The top of the main frame consisted of a triangular structure attached to support the connecting hose and as a device to hold the sprinkler. Horizontally, the sprinkler remained to be at 1.5 m in height from its base. The surrounding from the sprinkler to the receiving erosion plot where the water drops are falling, was left opened and exposed to wind to imitate a natural rainfall. The sprinkler system adapted for this project was a drip-type sprinkler since the sprinkler is easily available in the local market. A water pump was applied to deliver water to the sprinkler, and the tank was utilised for storage of water.

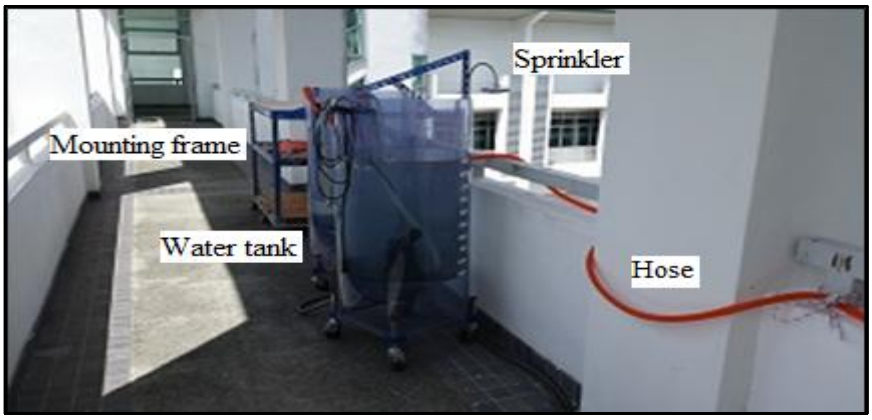


Figure 1: Sprinkler is attached to a steel frame to stabilize flow of water.

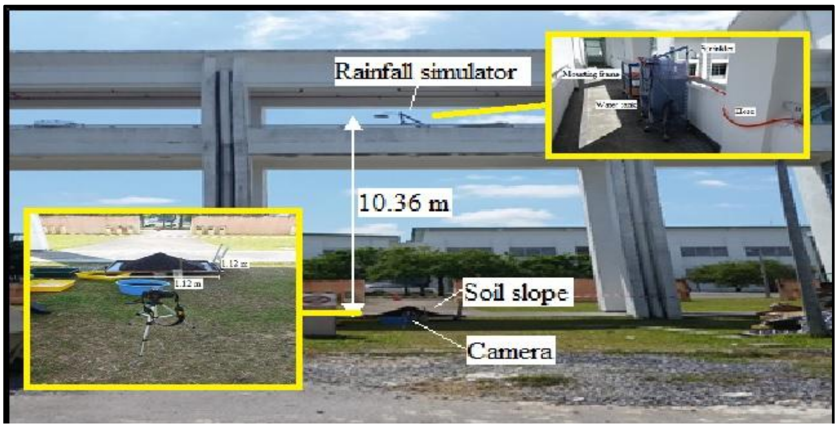


Figure 2: Location of rainfall simulator.

2.2 Experimental erosion plots

The soil used for this study was taken from the location of Sri Aman, Sarawak (location: $1^0 12'13''$ N, $111^0 32'15''$ E), where the soil was visually classified as peat. The soil sample weighed approximately 200 kg and the sample was a disturbed sample. The soil was analysed for its physical properties.

There were three separate slopes with different shapes and measurements; cone, pyramid, and plateau. However, all of the shapes had a similar slope of 45^0. As shown in Figure 3, the soil slope was built with loosely packed organic soil with the shape of a cone. The dimensions were 1 m in diameter and 0.5 in height. In Figure 4, the soil slope is a loosely-packed pyramid with dimensions of 1 m by 1 m for the base and 0.5 m of its height. The third soil slope used for rainfall in this study was a plateau (Figure 5), with its dimensions of 1 m by 1 m at the base and 0.5 m in height. At the top, the dimensions were 1 m in length and 60 mm in width.

Figure 0:Cone-shaped soil slope.

Figure 4:Pyramid-shaped soil slope.

Figure 5: Plateau shaped soil slope.

2.3Simulated Rainfall

Two simulated rainfalls were conducted on one type of the hill slopes, with total of six simulated rainfalls on the three types of hill slopes; plateau-shaped hill slope, pyramid-shaped hill slope, and cone-shaped hill slope. The period of simulated rainfall was selected as 30 minutes. An exact rainfall intensity was determined from the volume of collected runoff per simulated rainfall event.

2.4Photos of Raindrops

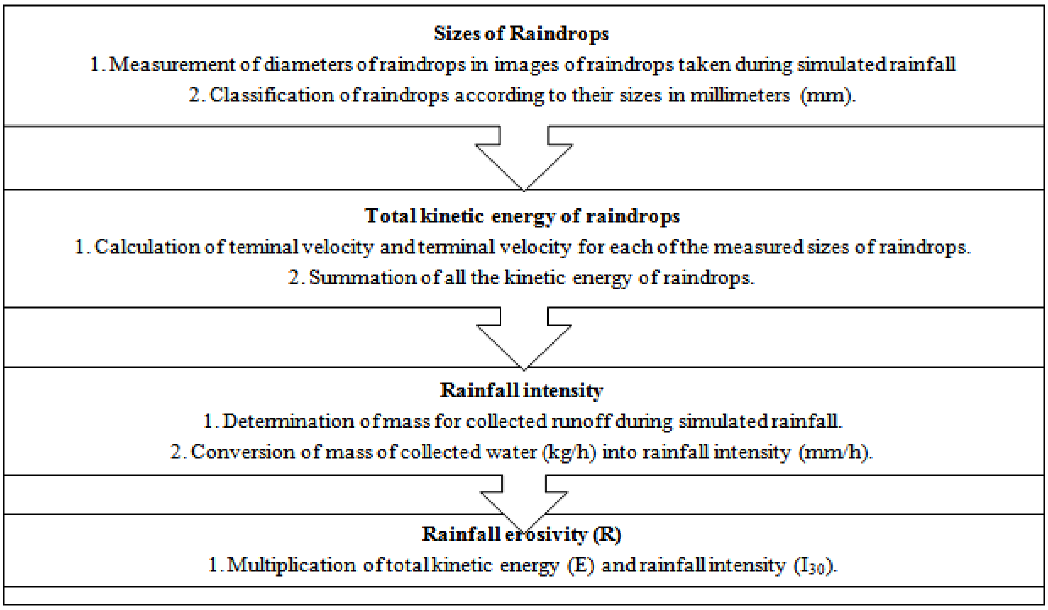
Photos of raindrops from simulated rainfalls are required because the photos would be analysed in the computer to measure the diameter of clear and visible raindrops. Subsequently, the diameters of raindrops would be used in estimating the amount of raindrops, kinetic energy, and rainfall erosivity of the simulated rainfalls. The high-speed camera used in this study was a Nikon D3100. The camera is located several meters from the slopes and on an even ground.

2.5 Collection of Soil Samples

For each of the soil slopes, soil samples were taken at five selected points, beginning at the toe of slope and upwards the slope. One sample was collected for each of the five points. The soil samples were collected after running the rainfall simulation for 30 minutes. Another five samples were collected after the second 30 minutes of rainfall simulation.

2.6 Determination of Rainfall Erosivity factor (R) for Equatorial Organic Soil

For simulated rainfall, the factor of rainfall erosivity was determined by first measuring the rain drop size in diameter and calculating the numbers of rain drop that have similar sizes.The classified raindrops were then calculated for their kinetic energy and terminal velocity such as described in the following sections. The R-factor can be determined by multiplying kinetic energy (E) with rainfall intensity in 30 minutes of rainfall simulation (I_{30}). For rainfall data, the factor of rainfall erosivity was determined by multiplying rainfall intensity from each rainfall event and its total kinetic energy. The flow process in determining the Equatorial Rainfall Erosivity factor (ER) for simulated rainfall is described in Figure 6.



Sizes of Raindrops

1. Measurement of diameters of raindrops in images of raindrops taken during simulated rainfall
2. Classification of raindrops according to their sizes in millimeters (mm).

Total kinetic energy of raindrops

1. Calculation of teminal velocity and teminal velocity for each of the measured sizes of raindrops.
2. Summation of all the kinetic energy of raindrops.

Rainfall intensity

1. Determination of mass for collected runoff during simulated rainfall.
2. Conversion of mass of collected water (kg/h) into rainfall intensity (mm/h).

Rainfall erosivity (R)

1. Multiplication of total kinetic energy (E) and rainfall intensity (I_{30}).

Figure 6: The flow process to develop the factor of Equatorial Rainfall Erosivity (ER) using simulated rainfall data.

2.7 Measurement of Raindrop Size

2.7.1 Terminal velocity of raindrops

The terminal settling velocity of the raindrops can be calculated once the diameter, mass, density of raindrop and density of air are known from rainfall simulation. The formulas applied to determine terminal velocity of raindrop can be referred to in the following Table 1. The unit for terminal velocity of raindrop is in meter per second (m/s).

Table 1: Summary of sizes of raindrops, Reynolds number, drag coefficient and terminal velocity.

Region of flow	Sizes of raindrops, d (mm)	Reynolds number (Re)	Drag coefficient (C_D)	Terminal velocity, v_{TS} (m/s)
Laminar (Stoke's Law)	0.001 – 0.1	0.001 - 1	$C_D = \frac{24}{Re}$	$v_{TS} = \frac{\rho_0 d_a^2 g}{18\eta}$
Transition	0.1 – 2	1 – 1000	$C_D = \frac{24}{Re}(1 + 0.15Re^{0.687})$	$v_{ts} = \sqrt{\frac{4d\rho_{drop}\,g}{3C_D\rho_{air}}}$
Turbulent (Newton's Law)	2.1 – 5.8	More than 1000	$C_D = 0.44$	$v_{ts} = \sqrt{\frac{4d\rho_{drop}\,g}{3C_D\rho_{air}}}$

2.7.2 Kinetic energy of raindrops

For simulated rainfall, the kinetic energy of a raindrop can be determined using the formula of:

$$E_{kinetic} = \frac{1}{2}mv^2 \qquad (2)$$

Where

$E_{kinetic}$ = kinetic energy (Joule),
m = mass of raindrop (kg),
v = terminal velocity (m/s).

The mass of a raindrop can be estimated from multiplication of density of water and volume of the raindrop. The volume of raindrop is determined from the sizes of the raindrop. Terminal velocity of the raindrop was determined from the formulas described in Table 1. Total kinetic energy of raindrops was determined from summation of kinetic energy contained by the raindrops.

For rainfall data, , the kinetic energy of a rainfall is determined by firstly derived from an equation that correlates rainfall intensity from rainfall data and total kinetic energy (Brown and Foster, 1987). The correlation of rainfall intensity and total kinetic energy is mathematically expressed as follows:

$$E = a + b\log_{10} I_{30} \qquad (3)$$

Since the hill slope of a plateau follows the characteristics of gently sloped land such as studied in RUSLE, the correlation of total kinetic energy for plateau-shaped hill slope was compared to either the similar correlation for cone-shaped hill slope or the pyramid-shaped hill slope. An example of a comparison between the two equations can be seen as in the following (Figure 7).

$E = a + b\log_{10} I_{30}$ …. (1) for plateau-shaped hill slope
$E = a + b\log_{10} I_{30}$ …. (2) for pyramid-shaped hill slope

Figure 7: An example of two equations solved simultaneously to find the constants of *a* and*b*.

The equations were mathematically solved to obtain the constants of a and b. The resulting equation is a new equation to determine total kinetic energy of a rainfall for an equatorial region of Sarawak.

2.7.3 Rainfall Erosivity (R)

For simulated rainfall, the factor of Rainfall Erosivity was determined by multiplying the calculated total kinetic energy raindrops (E) and rainfall intensity (I_{30}) (Renard et al., 1996). For rainfall data, the factor of R was determined by multiplying the rainfall intensity (I_{30}) and total kinetic energy (E)of the rainfall event. The equation applied to calculate rainfall erosivity is described as follows (Wischmeier and Smith, 1978a):

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(I_{30})_k\right]_j \qquad (4)$$

Where *k* is the number of the individual storm up to *m*, the total number of storms in a year, and *j* is the number of year up to *n*, the total number of years over which data was collected.

III. RESULTS AND DISCUSSION

3.1 Kinetic Energy of Simulated Rainfalls

The drop size distributions for the simulated rainfalls are graphically presented in Figure 8, Figure 9, and Figure 10. The raindrop sizes at 25%, 50% and 75% of total volume can be determined from the cumulative frequency distribution of the raindrop size. Figure 8 shows the raindrop size distribution of a simulated rainfall on a plateau-shaped hill slope and its cumulative distribution of raindrop size. From Figure 8, 25% of the total raindrops contains raindrops with sizes of up to 1.0 mm. The median raindrop diameter was 2.0 mm. The upper 25% of the raindrop size distribution consists of at least the raindrops with a size of 2.0 mm. Raindrops with sizes of 4.5 mm and 6.0 mm has the lowest count with 2 drops per size. Whereas raindrops with size of 2.0 mm has the highest count with a volume of 1.22×10^{-9} litres or 33% of total raindrops.

From Figure 9, it is known that 25% of the total raindrops of simulated rainfall on cone-shaped hill slope contains raindrops with sizes of up to 2.0 mm. The median raindrop diameter was observed to be 2.0 mm. The upper 25% of the raindrop size distribution consists of at least the raindrops with a size of 3.5 mm. Raindrops with sizes of 5.5 mm has the lowest count with 1 drop. Whereas raindrops with size of 2.0 mm has the highest count with a volume of 124 drops or 26.6% of total raindrops.From Figure 10, it is known that 25% of the total raindrops of simulated rainfall on pyramid-shaped hill slope contains raindrops with sizes of up to 2.5 mm. The median raindrop diameter was observed as 2.5 mm. The upper 25% of the raindrop size distribution consists of at least the raindrops with a size of 3.0 mm. Raindrops with sizes of 6.0 mm has the lowest count with 1 drop. Whereas raindrops with size of 3.0 mm has the highest count with a volume of 4.02×10^{-9} litres or 32.8% of total raindrops.

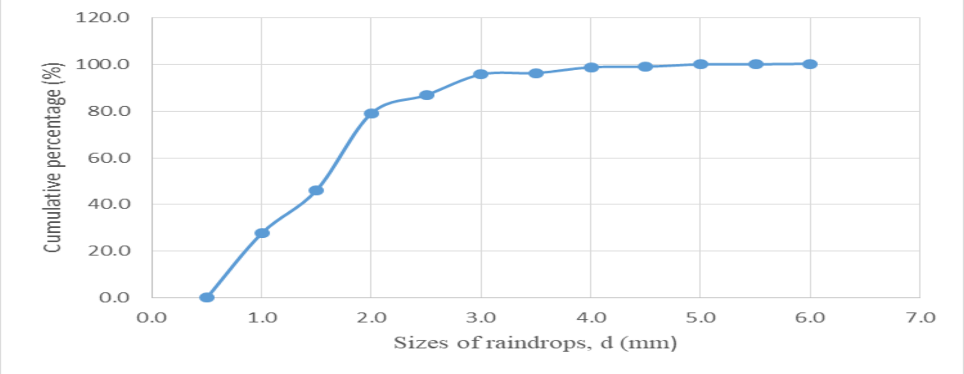


Figure 8: The cumulative drop size distribution of simulated rainfall on plateau-shaped hill slope.

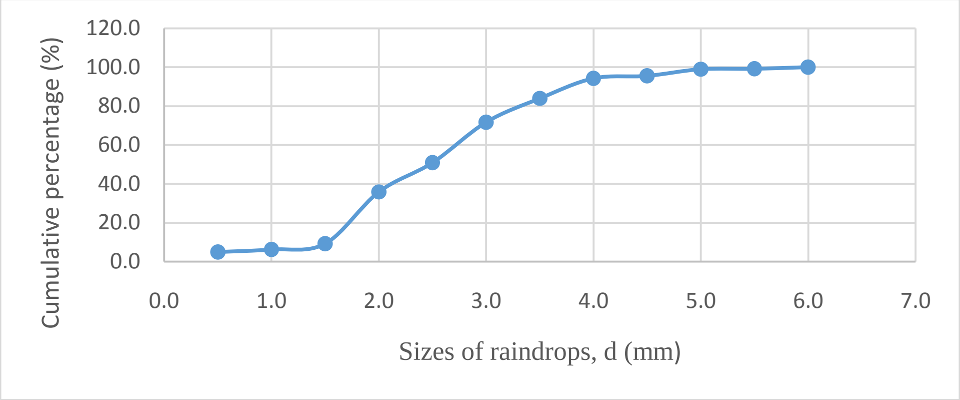


Figure 9: The cumulative drop size distribution of simulated rainfall on cone-shaped hill slope.

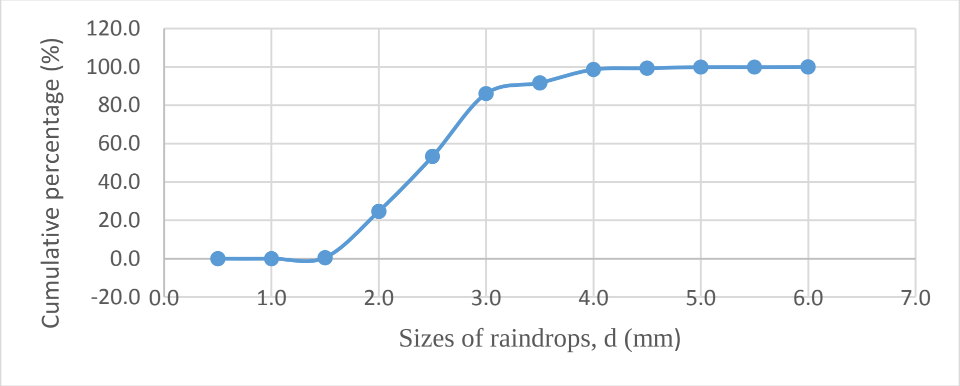
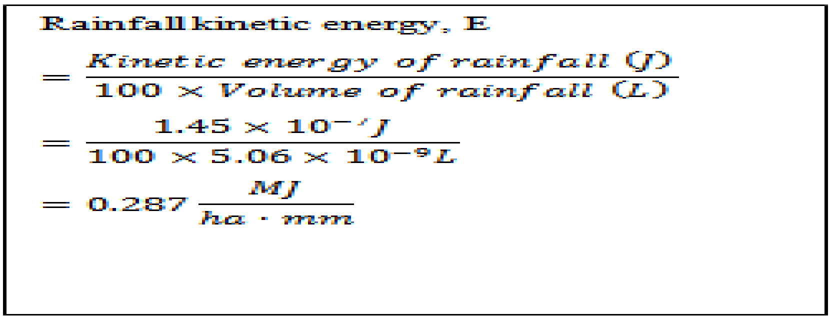


Figure 10: The cumulative drop size distribution of simulated rainfall o pyramid-shaped hill slope.

The average counts of raindrops and their distributions were described in the following Tables (Table 2, Table 3, Table 4). The total counts of raindrops were obtained from measurements of raindrops in the raindrops images. From Table 2, total volume of raindrops is 5.06 x 10^{-9} litres and total kinetic energy of raindrops is 1.45 x 10^{-7} Joules. The division of kinetic energy of raindrops by the calculated volume for plateau-shaped hill slope resulted in total kinetic energy of raindrops of 0.287 MJ/ha.mm. The calculations of total kinetic energy of raindrops for simulated rainfalls on plateau-shaped hill slope is shown in Figure 11. From Table 3, total volume of raindrops is 7.25 x 10^{-9} litres and total kinetic energy of raindrops is 2.41 x 10^{-7} Joules. The division of kinetic energy of raindrops by the calculated volume for cone-shaped hill slope resulted in total kinetic energy of raindrops of 0.332 MJ/ha.mm. The calculations of total kinetic energy of raindrops for simulated rainfalls on cone-shaped hill slope is shown in Figure 12**.** From Table 4, total volume of raindrops is 1.08 x 10^{-8} litres and total kinetic energy of raindrops is 3.41 x 10^{-7} Joules. The division of kinetic energy of raindrops by the calculated volume for pyramid-shaped hill slope resulted in total kinetic energy of raindrops of 0.317 MJ/ha.mm. The calculations of total kinetic energy of raindrops for simulated rainfalls on pyramid-shaped hill slope is shown in Figure 13.

Table 2: The values of kinetic energy of raindrops on plateau-shaped hill slope.

Sizes of raindrops (mm)	Drop counts	Distribution (%)	Terminal velocity of raindrops (m/s)	Volume (L)	Kinetic energy of raindrops (J)
0.5	0	0	2.04	0	0
1.0	243	27.6	3.91	1.27×10^{-10}	9.75×10^{-10}
1.5	163	18.5	5.41	2.88×10^{-10}	4.22×10^{-9}
2.0	290	33.0	6.57	1.21×10^{-9}	2.62×10^{-8}
2.5	69	7.8	7.42	5.65×10^{-10}	1.55×10^{-8}
3.0	78	8.9	8.00	1.10×10^{-9}	3.53×10^{-8}
3.5	5	0.6	8.36	1.12×10^{-10}	3.93×10^{-9}
4.0	22	2.5	8.54	7.37×10^{-10}	2.69×10^{-8}
4.5	2	0.2	8.56	9.54×10^{-11}	3.5×10^{-9}
5.0	9	1.0	8.47	5.89×10^{-10}	2.11×10^{-8}
5.5	0	0.0	8.31	0	0
6.0	2	0.2	8.11	2.26×10^{-10}	7.44×10^{-9}
Total	883			5.06×10^{-9}	1.45×10^{-7}

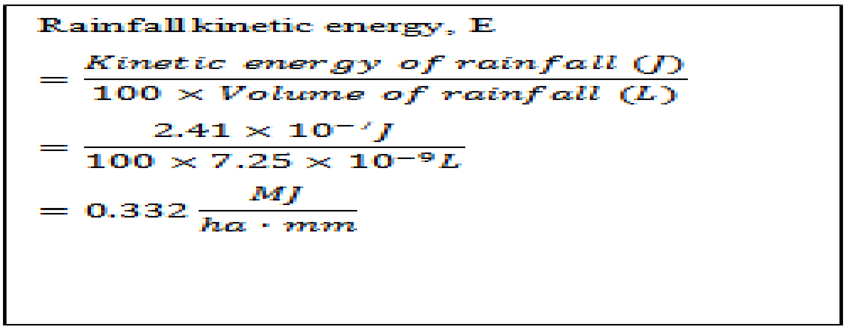


$$\text{Rainfall kinetic energy, E} = \frac{Kinetic\ energy\ of\ rainfall\ (J)}{100 \times Volume\ of\ rainfall\ (L)} = \frac{1.45 \times 10^{-7} J}{100 \times 5.06 \times 10^{-9} L} = 0.287\ \frac{MJ}{ha \cdot mm}$$

Figure 11: The calculation of total rainfall kinetic energy on plateau-shaped hill slope.

Table 3: The values of kinetic energy of raindrops on cone-shaped hill slope.

Sizes of raindrops (mm)	Drop counts	Distribution (%)	Terminal velocity of raindrops, v_{ts} (m/s)	Volume, V (L)	Kinetic energy of raindrops (J)
0.5	23	2.6	2.04	1.50×10^{-12}	3.13×10^{-12}
1.0	6	0.7	3.91	3.14×10^{-12}	2.41×10^{-11}
1.5	14	1.6	5.41	2.47×10^{-11}	3.62×10^{-10}
2.0	124	14.1	6.57	5.19×10^{-10}	1.12×10^{-8}
2.5	70	8.0	7.42	5.73×10^{-10}	1.58×10^{-8}
3.0	97	11.0	8.00	1.37×10^{-9}	4.39×10^{-8}
3.5	57	6.5	8.36	1.28×10^{-9}	4.48×10^{-8}
4.0	48	5.5	8.54	1.61×10^{-9}	5.86×10^{-8}
4.5	6	0.7	8.56	2.86×10^{-10}	1.05×10^{-8}
5.0	16	1.8	8.47	1.05×10^{-9}	3.76×10^{-8}
5.5	1	0.1	8.31	8.71×10^{-11}	3.01×10^{-9}
6.0	4	0.5	8.11	4.52×10^{-10}	1.49×10^{-8}
Total	466			7.25×10^{-9}	2.41×10^{-7}



$$\text{Rainfall kinetic energy, E} = \frac{Kinetic\ energy\ of\ rainfall\ (J)}{100 \times Volume\ of\ rainfall\ (L)} = \frac{2.41 \times 10^{-7} J}{100 \times 7.25 \times 10^{-9} L} = 0.332\ \frac{MJ}{ha \cdot mm}$$

Figure 12: The calculation of total kinetic energy of raindrops on cone-shaped hill slope.

Table 0: The values of kinetic energy of raindrops on pyramid-shaped hill slope.

Sizes of raindrops (mm)	Drop counts	Distribution (%)	Terminal velocity of raindrops, v_{ts} (m/s)	Volume, V (L)	Kinetic energy of raindrops, E (J)
0.5	0	0	2.04	0	0
1.0	0	0	3.91	0	0
1.5	5	0.6	5.41	8.84×10^{-12}	1.29×10^{-10}
2.0	209	23.8	6.57	8.76×10^{-10}	1.89×10^{-8}
2.5	248	28.2	7.42	2.03×10^{-9}	5.58×10^{-8}
3.0	284	32.3	8.00	4.02×10^{-9}	1.29×10^{-7}
3.5	49	5.6	8.36	1.10×10^{-9}	3.85×10^{-8}
4.0	60	6.8	8.54	2.01×10^{-9}	7.33×10^{-8}
4.5	6	0.7	8.56	2.86×10^{-10}	1.05×10^{-8}
5.0	5	0.6	8.47	3.27×10^{-10}	1.17×10^{-8}
5.5	0	0.0	8.31	0	0
6.0	1	0.1	8.11	$1.13 \times 10_{-10}$	3.72×10^{-9}
Total	867			1.08×10^{-8}	3.41×10^{-7}

$$\begin{aligned}\text{Rainfall kinetic energy, E} \\ &= \frac{Kinetic\ energy\ of\ rainfall\ (J)}{100 \times Volume\ of\ rainfall\ (L)} \\ &= \frac{3.41 \times 10^{-7} J}{100 \times 1.08 \times 10^{-8} L} \\ &= 0.317\ \frac{MJ}{ha \cdot mm}\end{aligned}$$

Figure 13: The calculation of total kinetic energy of raindrops on pyramid-shaped hill slope.

3.2 Rainfall Intensity of Simulated Rainfall (I_{30})

During the event of simulated rainfalls, surface runoffs carrying suspended sediment were discharged at one point at the edge of tray and collected in a small basin. These runoffs were weighed in order to estimate the rainfall intensity for a duration of 30 minutes. The mass of runoff were converted into rainfall intensity on the basis of 1 kg equals 1 mm of rainfall (FAO, n.d.). The following table (Table 5) describes the total mass of collected runoff and conversion of mass of runoff (kg) into rainfall intensity in mm/h. The results of rainfall intensity in Table 5 indicates that the average rainfall intensity for simulated rainfalls on an erosion plot of pyramid-shaped hill slope was 8.39 mm/h and 8.21 mm/h higher than an average rainfall intensity for simulated rainfalls on erosion plots of cone-shaped hill slope and plateau-shaped hill slope respectively. On the other hand, the rainfall intensities of simulated rainfalls on plateau-shaped hill slope and cone-shaped hill slope were slightly different.

Table 5: The calculation of rainfall intensity from collected runoff.

Type of erosion plot	Plateau		Cone		Pyramid	
Sample	1	2	1	2	1	2
Amount of surface runoff (L/m^2)	70.91	72.05	72.85	69.93	76.85	74.31
Mass of soil (kg/m^2)	175	170	20	18	80	76
Total mass of collected runoff (kg)	70.91	72.05	72.85	69.93	76.85	74.31
Rainfall intensity (mm/h)	141.83	144.1	145.7	139.86	153.71	148.63
Average rainfall intensity (mm/h)	142.96		142.78		151.17	

3.3 Derivation of Equatorial Rainfall Erosivity (ER)

The derivation of an Equatorial Rainfall Erosivity (ER) requires a formula to determine the total kinetic energy, which was derived based on a logarithmic equation by Brown and Foster(1987), where two equations that correlated total kinetic energy (E) and rainfall intensity (I_{30}) were solved. By solving simultaneous equations, the following equation (Equation 5) was derived.

$$E_{eqt} = 1.263 - 0.433 \log_{10} I_{30} \qquad (5)$$

The derived equation to determine E_{eqt} was embedded into the equation of Rainfall Erosivity factor (R) to determine the factor of an Equatorial Rainfall Erosivity (ER) for Sarawak based on Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). The Equation 6 shows the formula to determine an Equatorial Rainfall Erosivity (ER) in Sarawak per storm event.

$$ER = E_{eqt} I_{30} \qquad (6)$$

Where,
ER = Equatorial Rainfall Erosivity for Sarawak (MJ.mm/(ha.h).
E_{eqt} = Equatorial Total Kinetic energy (MJ/ha.mm).
I_{30} = Rainfall intensity (mm/h).

A comparison between the values of Equatorial Rainfall Erosivity (ER) for Sarawak and Rainfall Erosivity (R) from the Revised Universal Soil Loss Equation (RUSLE) was carried out to observe the differences in the severity of rainfall in Sarawak and the rainfall in the United States. Figure 14 presents the calculated values of ER and R based on the hourly rainfall data obtained from The Meteorological Department of Malaysia for the rainfall station of Kuching, Sarawak in the year 2014. From Figure 14, it is known that the Equatorial Rainfall Erosivity (ER) was 71.62% more than the value of Rainfall Erosivity (R) in RUSLE. This indicates that the erosivity of rainfall in the equatorial region of Sarawak is more severe by more than half of the severity of rainfall located in the temperate region of the United States.

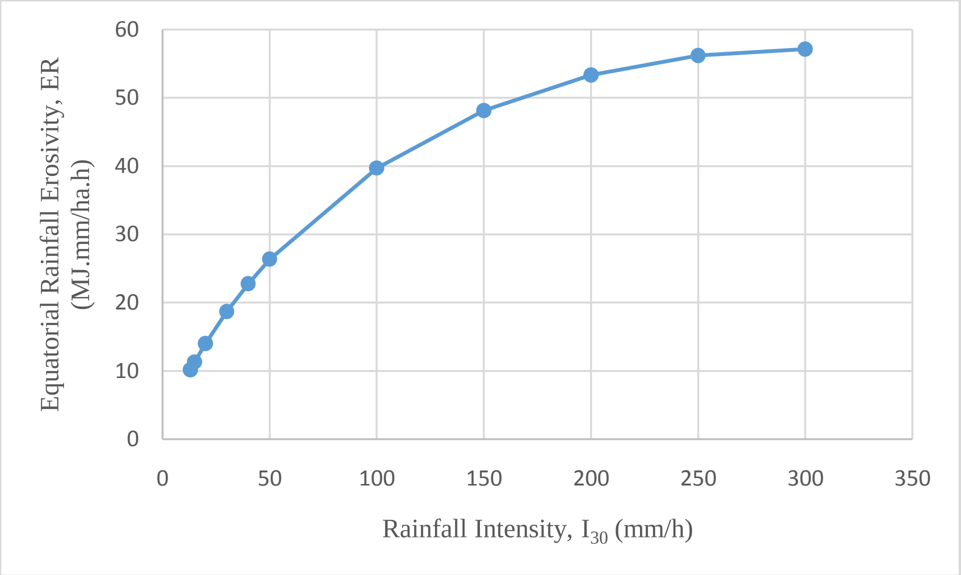


Figure 14: The comparison of values of Equatorial Rainfall Erosivity (ER) with Rainfall Erosivity (R).

3.4 Sensitivity Analysis of Equatorial Rainfall Erosivity (ER)

The development of ER was sourced from a record of hourly rainfall data in Kuching, Sarawak, where high rainfall depth can be observed. A sensitivity analysis on the newly developed formula to observe how the results increase with the increment of maximum rainfall intensity (I_{30}). Figure 15 presents the sensitivity of the formula of ER towards the maximum rainfall intensity (I_{30}). From Figure 15, it is known that the sensitivity of ER increased from the maximum rainfall intensity (I_{30}) from 13 mm/h to 30 mm/h. The results of ER decreased from the I_{30} of 30 mm/h to 50 mm/h. There was an abrupt increase of ER by 50% when the I_{30} was at 100 mm/h. The results of ER significantly decreased when the maximum rainfall intensity (I_{30}) increased from 100 mm/h to 300 mm/h.

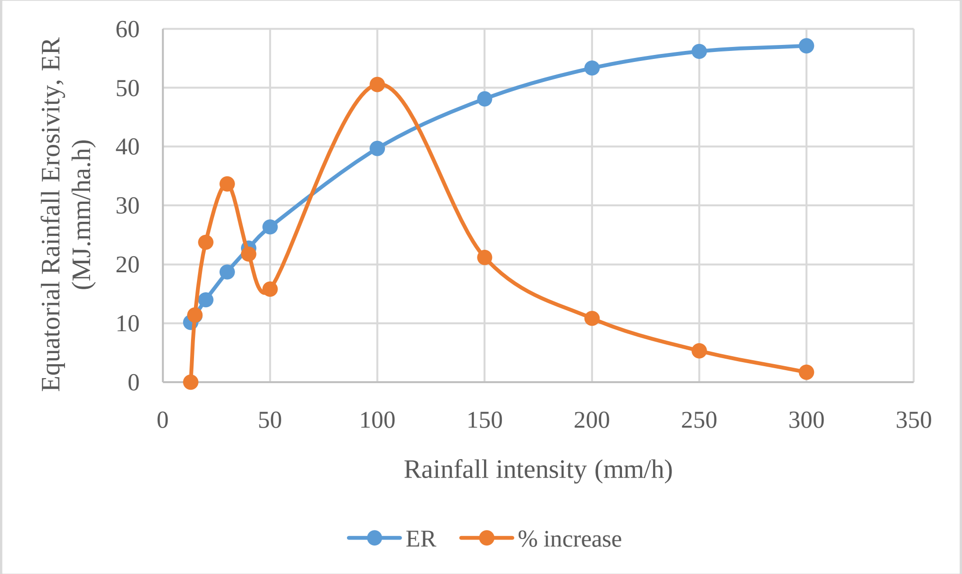


Figure 15: The sensitivity analysis of Equatorial Rainfall Erosivity (ER) for Sarawak.

IV. CONCLUSIONS

The formula of an Equatorial Kinetic Energy (E_{eqt}) for Sarawak region was developed from the rainfall intensities in the simulated rainfalls. Equation 7 shows the Equatorial Kinetic energy (E_{eqt}).

$$E_{eqt} = 1.263 - 0.433 \log_{10} I_{30} \qquad (7)$$

The formula of an Equatorial Rainfall Erosivity (ER) for Sarawak region had been developed by replacing the Rainfall Kinetic Energy (E) with an Equatorial Rainfall Erosivity (ER) for Sarawak region (Equation 8). A comparison between the results of an Equatorial Rainfall Erosivity (ER) and Rainfall Erosivity (R) from RUSLE was carried out. The value of ER was 71.26% higher than the value of R, based on actual rainfall data of Kuching, Sarawak.

$$ER = E_{eqt} I_{30} \qquad (8)$$

REFERENCES

[1]. Abd Elbasit, M. A. M., Yasuda, H., Salmi, A., & Anyoji, H. (2010). Characterization of rainfall generated by dripper-type rainfall simulator using piezoelectric transducers and its impact on splash soil erosion. *Earth Surface Processes and Landforms*, *35*(4), 466–475. https://doi.org/10.1002/esp.1935

[2]. Baharudin, F. Bin. (2007). *A Study on Rainfall-Runoff Characteristics of Urban Catchment of Sungai Kerayong*. Universiti Sains Malaysia. Retrieved from http://eprints.usm.my/7772/1/A_STUDY_ON_RAINFALL-RUNOFF_CHARACTERISTICS_OF_URBAN_CATCHMENT_OF_SUNGAI_KERAYONG.pdf

[3]. Best, A. C. (1949). The size distribution of raindrops. *Q. J. Roy. Meteorol. Soc*, *76*(July), 16–36. https://doi.org/10.1002/qj.49707632704

[4]. Brown L.C. & Foster G. R. (1987). Storm Erosivity Using Idealized Intensity Distributions. *American Society of Agricultural and Biological Engineers*, *30*(2), 0379–0386. https://doi.org/10.13031/2013.31957

[5]. Dijk, A. I. J. M. Van, Bruijnzeel, L. A., & Rosewell, C. J. (2002). Rainfall intensity and kinetic energy relationships : a critical literature appraisal. *Journal of Hydrology*, *261*, 1–23.

[6]. FAO. (n.d.). Chapter 4: Rainfall and Evapotranspiration. Retrieved March 13, 2017, from http://www.fao.org/docrep/r4082e/r4082e05.htm

[7]. Goh, E., & Tew, K. H. (2006). *Soil Erosion Engineering: Reliability-based Engineering Design, Soil Erosion Assessment and Best Practices*. Universiti Sains Malaysia.

[8]. Haji Ali, F., & Tew, K. H. (2006). A Near Real-time Early Warning System on Erosion Hazards. *American Journal of Environmental Sciences*, *2*(4), 146–153.

[9]. Malaysian Meteorological Department. (2016). General Climate of Malaysia. Retrieved from www.met.gov.my

[10]. Mohamed, M., Padmanabhan, E., Mei, B. L. H., & Siong, W. B. (2002). *The Peat Soils of Sarawak. Strapeat - Status Report*.

[11]. Park, S. W., Mitchell, J. K., & Bubenzer, G. D. (1980). An analysis of splash erosion mechanics. In *Proceedings of the ASAE 1980 winter meeting* (p. 27). Chicago, USA.

[12]. Peter, C. L. Sen. (2006). *Road Construction over Peat in Sarawak*. Universiti Teknologi Malaysia. Retrieved from http://www.efka.utm.my/thesis/IMAGES/3PSM/2006/3JGP/GEO/PARTS3/peterchangleongsenaa010417d06ttp.pdf

[13]. Renard, K., Foster, G., Weesies, G., McCool, D., & Yoder, D. (1997). Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). *Agricultural Handbook No. 703*. https://doi.org/DC0-16-048938-5 65–100.

[14]. Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1997). Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE). Agriculture Handbook No. 703.

[15]. Renard KG, Foster GR, Weesies GA, McCool DK, Y. D. (1996). *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation*. https://doi.org/DC0-16-048938-5 65–100.

[16]. Tew, K. H. (1999). *Production of Malaysian soil erodibility nomograph in relation to soil erosion issues*. Subang Jaya, Selangor: VT Soil Erosion Research and Consultancy.

[17]. Wischmeier, W. H., & Smith, D. (1978a). Predicting rainfall-erosion losses. In *A guide to conservation planning. Agricultural Handbook No. 537* (p. 58). Washington D.C., USA.

[18]. Wischmeier, W. H., & Smith, D. D. (1978b). *Predicting rainfall erosion losses - A Guide to Conservation Planning*. *Agriculture handbook no. 537*. https://doi.org/10.1029/TR039i002p00285

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