The Effects of Rainfall Patterns on Runoff, Sediment, and Nutrients Under Various Artificial Rainfall Experiments

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Abstract

Assessing the effects of rainfall patterns on runoff, sediment, nutrients under variation of rainfall pattern are significant in the quantification of sediment transported by overland flow. Previous experimental and field works studied that sediment transport is influenced by hydraulic properties of flow, physical properties of soil and surface characteristics. This study aims at determining the effect of rainfall patterns on surface runoff, sediment loss and nutrient loss. Experiments were carried out using four rainfall patterns, namely Pattern A (uniform-type: 8-8-8 l/min), Pattern B (increasing-type: 7-8-9 l/min), Pattern C (increasing-decreasing-type: 7-9-8 l/min) and Pattern D (decreasing-type: 9-8-7 l/min) with the changes of intensity every 30 minutes that gives total rainfall duration of 90 minutes for each pattern. The simulation was performed in three repetitions. The average total runoff produced was 668.65, 701.40, 699.10, and 722.63 liters, for rainfall patterns A, B, C, and D, respectively. The trend of runoff generated was influenced by the rainfall patterns, Pattern D generated the highest amount of runoff meanwhile Pattern A generated the lowest. For total suspended sediment concentrations, the mean value among every three repetitions of rainfall pattern resulted as 14,518.88, 13,732.73, 8,011.71 and 19,918.50 mg/l for patterns A, B, C, and D, respectively Pattern D contributed to the highest amount of sediment accumulated whereby Pattern C generated the lowest sediment despite the trend showed a different approach than the other 3 patterns. In nutrient concentrations, the determined total losses for ammonia nitrogen were 3.986, 2.891, 3.504, and 4.601g; nitrate nitrogen were 3.934, 2.665, 4.008, and 3.259g; phosphorus were 1.346, 0.222, 0.207, and 0.679g, for patterns A, B, C, and D, respectively. In general, rainfall pattern does have a significant impact on the trend of nutrient losses, where the trend shows that higher concentrations at the start and eventually lowered through the end, but Pattern D as compared to other patterns resulted in a more severe nutrient loss. For the affected area of the soil movement process, the calculated means of the affected area are 79.60, 68.70, 72.43, and 64.97% for patterns A, B, C, and D respectively. The lowest mean of the affected area is contributed by Pattern D and the highest by Pattern A.

Introduction

Water erosion gives a severe type of soil erosion as it is susceptible to give more impact on the soil surface compared to wind erosion. This is caused by rainfall that is known as the major factor that contributes to water erosion since it caused the soil particle to lose and detached. The mechanism of rainfall erosion i.e. topography, soil properties, and rainfall characteristics had been investigated whether by simulated or natural rainfall. The rainfall that is saturated enough in the soil becomes surface runoff; known as a partial contributor to soil loss. Meanwhile, the energy of raindrops that detach the soil structure is another partly contributor.

Merritt et al. (2003) stated that three stages describe the water erosion process are detachment, transport, and deposition of soil particles (refers Fig. 1). Detachment is the first process that caused soil clods to break into smaller particles and is considered an independent variable and plays an important role as no erosion must happen unless detachment takes place (Sadeghi et al., 2017). Detachment is usually caused by the locally forceful shear stress to the soil surface by raindrop force called rainfall detachment or may be caused by surface runoff when the shear stress on the soil surface exceeds the critical shear stress of soil. The second process of water erosion is transportation and is considered a dependent variable upon detachment. In shallow water conditions especially, raindrops splash provide temporary disturbances that caused static particles to move eventually transported by overland flow (Hajigholizadeh et al., 2018; Kiani-Harchegani et al., 2018). The deposition is the last stage of water erosion and is also considered a dependent variable upon the earlier two stages. Sediment removed in the detachment process is transported by surface runoff. Once detached, sediment particles are transported in the flow. A deposition may take place when sediment transport capacity is lesser than sediment load in the flow(Aksoy et al., 2020).

There are several factors affecting water erosion that may fall under four categories, namely; rainfall characteristics (rainfall intensity and duration), soil properties (particle size, infiltration, erodibility, specific gravity and bulk density), topography (slope and vegetation cover) and surface runoff. Mohamadi & Kavian (2015) studied that among the important parameters in predicting soil erosion i.e.; raindrop size and amount, storm duration and velocity of raindrops, rainfall intensity were the main rainfall factor as an intense storm produces high kinetic energy because high-intensity storm contains a greater percentage of energy to impact on the soil. An experimental study conducted by Dong et al. (2018) tested the rainfall intensities of 60, 96, and 129 mm/hr under similar conditions and found that the high intensity produces the highest soil content in the runoff. The finding is similarly found in Almeida et al. (2021) where the highest rainfall intensity varied from 75.0 to 44.6 mm h-1 produced a maximum sediment yield (0.138 g m-2 min-1) and runoff rates (0.87 mm min-1). In a particular natural rainfall event, the intensity is rarely constant throughout the event, but it has a significant or a slight change in intensities. Tao et al. (2017) studied the effects of rainfall intensity variation in a rainfall event and found that it impacted the process of runoff generation without a significant effect on the total runoff volume. Furthermore, it is also observed that it gives a significant impact on the process of sediment yield and nutrient loss as well as the total sediment yield and nutrient loss accumulated meanwhile the early high rainfall intensity produced severe erosion and nutrient loss. This is agreeable with study from Alavinia et al. (2019) that applied four simulated rainfall patterns on sandy and sandy loam soil and found that there is no significant difference in the runoff for the two soil types. However, there were major differences in soil losses ranging from 77.6 to 82.8 g/m^2 for sandy soil and 90.1 to 134.0 g/m^2 for sandy loam soil among the different rainfall patterns and stages. B. Wang et al. (2017) studied five rainfall patterns on 10° soil on an experimental plot and found that soil loss is governed most by increasing-rainfall patterns while the lowest is from the constant - rainfall event. The sediment yield produced by constant-rainfall events is at around 61.8% of the average soil loss from the increasing - rainfall event. Ran et al. (2019) conducted experiments using five rainfall patterns in 1 hr duration and had 40 mm rainfall depth on slope gradients ranging from 5° to 40° and found that the rising-falling rainfall produces the largest total runoff and soil erosion amount. They also found that at a same slope gradient, the relative difference between the total runoff and soil erosion amounts of different rainfall patterns was up to 111% and 381% respectively.

In the topography factor, Han et al. (2021) found that vegetation coverage and slope gradient significantly affect runoff and sediment yield, however, the effects of slope gradient on runoff and sediment yield are opposite to those of vegetation coverage. Surface runoff, other than the result of raindrop impact has been recognized as an erosive agent as it causes shear stress to the soil surface, which if it exceeds the cohesive strength of the soil would result in sediment detachment (Merritt et al., 2003). Liang et al. (2020) studied the effects of between three conditions of slope angle, rainfall intensity and vegetation cover on the erosion characteristics using indoor-simulated rainfall tests on Pisha sandstone slopes and found sediment yield is significantly affected by rainfall intensity and least affected by slope angle. To study the effect of runoff flow rate on soil erosion, the present work of Mbiakouo-djomo et al. (2018), aims to simulate the dynamics of soil erosion taking into account the three main parameters influencing the phenomenon; the nature of the soil (compaction), hillslope, and the rainfall intensity. The study was conducted on the samples under the three phases of tests, namely; a phase of rain simulation, a phase of streaming simulation, and a combined phase of rain and streaming. For the phase of rain simulation, the flow rates of 0.10 and 1.20L/s were applied to samples on 0, 2, and 4.37% slopes. The result showed that the larger flow rate gives a maximum mass of soil moves about five times increment compared to the smaller flow rate.

Through water erosion, not only sediments that are transported but various nutrients such as nitrogen and phosphorus, especially from agricultural sites may wash away in the surface runoff that can cause land degradation resulting in eutrophication. This process not only decreases the soil fertility and the ability of crops to survive but also reduces the quality of water resources for human consumption. Rainfall especially with higher intensity increases the risk of soil erosion and eventually nutrient loss. Dong et al. (2018) investigated the solute transport by using Potassium Bromide as a tracer and concluded that solute content in runoff is related to the sediment mass by showing that; a) under initial moisture content of 15% and 25%, the solute content was 1.51 and 2.63 times greater than when the initial moisture content was 5%, respectively, b) the higher the rainfall intensity applied, the higher the amount of runoff solute content and c) under slope gradient of 15° and 25°, the solute content was 1.43 and 3.51 times greater than when slope gradient was 5°, respectively. Dai et al. (2018) have studied the amount of nitrogen (TN) and phosphorus (TP) losses under natural rainfall events and found that sediment yield is the major controller of the TN and TP loss. This is because heavy rainfall produces a higher rate of soil erosion and nutrient loss where 93% of TN and 99% of TP were transported with sediments. Zhang et al. (2010) conducted field experiments to study soil erosion and loss of nitrogen (N) from a 15° hillslope and found soil erosion caused an N loss of about 250 mg/m^2 for the bare soil plot. In general, N concentrations decreased with time and approached a steady value throughout the experiment. Rainfall is the major factor and has been studied frequently, but the effects of rainfall patterns on soil erosion and nutrient loss have rarely been investigated. Due to the reason, Tao et al. (2017) studied three types of nutrient; nitrate nitrogen, ammonia nitrogen and phosphorus losses under four different rainfall patterns and found that decreasing-type, rainfall has the most nutrient loss rate compared to the other patterns, regardless of the nutrient types.

Previous experimental and field works studied that sediment transport is influenced by hydraulic properties of flow, physical properties of soil, and surface characteristics (Aksoy & Kavvas, 2005). Rainfall intensity or flow rate can be considered as the second independent variable in addition to the slope for better performance, flow discharge being more definitive than the rainfall intensity in quantifying the sediment discharge. According to Tao et al. (2017), solute transfer to the soil surface runoff and runoff erosion are influenced by rainfall characteristics. However, the relationship of rainfall patterns on sediment as well as the nutrient loss has been rarely investigated, although both uncontrolled losses will affect the environment and eventually water resources quality. Therefore, the objective of this study was to determine the effect of different rainfall pattern conditions on the surface runoff, sediment yield and nutrient loss.

Materials And Methods

A good plan and management are needed to ensure all the progress goes smoothly so that the objectives of the study can be achieved successfully. There are six major stages involved throughout this study as shown in Fig. 2.

2.1 Advanced hydrology apparatus

Rainfall simulation in this study used an equipment provided at the university, namely H313 Hydrology Apparatus from TecQuipment. The apparatus contains a closed water circuit with a storage tank and pump. The existing runoff plot of the apparatus was 2.0m (length) × 1.0m (width) × 0.19m (depth) which provided a plot area of 2m^2 and a plot volume of 0.38m^3 (refer Fig. 3, Fig.4, and Fig. 5). The apparatus has a jacked mechanism for an adjustable slope and consists of eight nozzles, in two banks of four, with an individual valve that can be turned on or off for the supply of water. The reservoir tank capacity is approximately 220 liters.

However, for this study, some adjustments were made to the equipment to provide a more reliable method for data collection during the running of rainfall simulation. The adjustments mainly focused on the outlet chamber and surface runoff collection system as shown in Fig. 6. The existing 2 adjustable overflow pipes are removed and the whole outlet chamber area is filled with a sloping channel that diverting the runoff from the weir into both holes. The water then runs through the runoff collection drain underneath the plot area to the runoff catchment tank placed at the end of the aluminum drain. Surface runoff was measured from the height of the water collected in the tank at a predefined time and is then converted to the volume. Other than that, to ensure the simulated rainfall mimicking the natural rainfall, the nozzle system is propped using pieces of wood so that it is not slanted following the inclined soil plot as shown in Fig. 7. However, care should be taken to not let the wood not interrupt the nozzle spray angle.

2.2 Soil properties and bed formation

Sample soil was collected from the quarry area in one of the provinces in Selangor, Malaysia. The district has more or less uniform temperature throughout the season (at night 24-27°C and at the day time 33-38 °C) (Al Mamun et al., 2018) and annual precipitation may vary from 1800 to 2600 mm (Al Mamun et al., 2018; Cheah et al., 2019) as the region is affected by heavy and prolonged rainfall during southwest monsoon (June to September) and the northeast monsoon (December to March).

After the soil is delivered to the site, it is first air-dried at room temperature, whilst the big chunks were crushed to the smallest form possible as shown in Fig. 8 (A). The soil also separated from any debris before being sieved through 10 mm diameter to make it easier to work with, the sieving process is shown in Fig. 8 (B). Table 1 shows the physical and chemical properties of the soil samples used, which is classified as sandy loam soil with the percentages of sand (>0.05mm), silt (0.05 – 0.002 mm), and clay (<0.002 mm) were 85.1%, 8.9%, and 6.0%, respectively. From the soil particle size distribution curve, the median diameter of soil particle, D_{50} of 0.36 mm was obtained.

To prevent any technical problem occurs while using the equipment, the plot first was adjusted to 7% with the aid of some wood pieces.7% slope was used because the existing capacity of the equipment along with the additional soil load is taken into consideration. Before soil filling, the plot is layered using pieces of cloth (Fig. 8 (C)) and is filled with sieved soil layer by layer (Fig. 8 (D)) whose soil bulk density is required to be 1.5 g/cm^3, followed by light compaction to get the leveled catchment area in the experiment tank at the marked height. Compaction was done using long sticks as the guide for flatness before compaction using a 3kg brick dropped at around 20cm height several times throughout the plot area following the method of compaction by Khaerudin et al. (2017) shown in Fig. 8 (E). The final prepared soil plot is as shown in Fig. 8 (F).

Table 1 Some physical and chemical properties of the soils

Soil property	Value
Sand (%)	85.1
Silt (%)	8.9
Clay (%)	6.0
Specific gravity	2.558
Particle density, g/cm^3	2.779
pH	4.68
Conductivity, μS/cm	74.6
Mean moisture content (%)	18.862
Bulk density, g/cm^3	1.50
D_{50} (mm)	0.36

2.3 Rainfall simulation

After the catchment area is well prepared, the rainfall simulation was started. Water is allowed to run through the nozzle system by setting the desired flowrate of the flow meter in the duration of 90 minutes of rainfall for each simulation. According to Dai et al. (2018), 30 min was the typical duration for the observation of maximum rainfall intensity of natural rainfall event thus the changes of flowrate were done after every 30 minutes to achieve the target rainfall pattern, namely: A (uniform-type: 8-8-8 l/min), B (increasing-type: 7-8-9 l/min), C (increasing-decreasing-type: 7-9-8 l/min) and D (decreasing-type: 9-8-7 l/min). The four rainfall patterns are shown in Fig. 9. The treatments were done in three repetitions but allowing the soil plot to fully drain for at least 24 hours before the new simulation was applied. Due to the plot is using compacted top soil with no expose to agricultural uses and no plant has been installed, fertilizer was also applied in the compaction process when necessary to ensure there are enough nutrients carried in the runoff until the rainfall simulation ends. From the catalogue, the application rate for the fertilizer is 150g/m^2 (All Cosmos Industries Sdn Bhd (n.d.)) required about 300g per 2 m^2 plot area for each application.

After started, the time of start rainfall and runoff is recorded respectively. Surface runoff is observed by taking water height in the catchment tank using a measuring ruler (refer Fig. 10 (A)) in 3-min intervals to ensure the best and presentable of result data until the runoff ended. After volume reading, 500ml runoff samples each were collected in the sample bottles prepared as shown in Fig. 10 (B) and Fig. 10 (C) for the later sediment and nutrient concentrations evaluation purposes. In total, 30 numbers of samples were taken from each experiment. The runoff samples are kept in the refrigerator for a minimum period of 24 hours before analysis to allow sediment to settle and ensures nutrient composition does not affect. Runoff samples were evaluated for total suspended sediment concentrations (SSC) by using an oven-drying method while nutrient concentrations were evaluated by using Hach spectrophotometer DR2800. The types of nutrients that were analyzed are Ammonia Nitrogen (NH_4-N), Nitrate Nitrogen (NO_3^--N), and Phosphorus (PO_4^{3-}) where the procedure is repeated for every rainfall simulation. NH_4-N and NO_3^--N are chosen since these are the main forms of soluble N (Tao et al. 2017; Zhu et al. 2015) while N and P are chosen because these nutrients are used in monitoring water quality and their inputs is controlling the growth of phytoplankton that eventually influenced the productivity of marine system (Tavakoly Sany et al. 2014).

Results And Discussion

3.1 Surface runoff

Fig. 11 shows the results of runoff measurement for each rainfall pattern respectively. Runoff produced starting to increase significantly and then stabilized during the first 30-min duration of rainfall. After stabilized, the runoff seems to show the same pattern as the intensity in the following duration through the end. This is due to the rainfall volume at the beginning duration fills up the infiltration capacity in the soil plot until it produces runoff. The average total runoff produced was 668.65, 701.40, 699.10, and 722.63 liters, for rainfall patterns A, B, C, and D, respectively. The results show that rainfall patterns do affect the trend of runoff generated during the rainfall event. Pattern D generated the highest amount of runoff meanwhile Pattern A generated the lowest.

Previous studies found that various rainfall patterns have contributed the highest in total runoff. For instance, Mohamadi & Kavian (2015) found that the increasing pattern yielded the highest total runoff with 2.2 times greater than the pattern that produce the lowest; decreasing pattern. Meanwhile, in Tao et al. (2017) and Ran et al. (2019), an increasing-decreasing pattern produces the highest total runoff. However, in general, the total runoff for each pattern does not have a significant difference, although it gives an impact on the runoff production. According to Alavinia et al. (2019), runoff is mainly controlled by soil moisture, the initial soil condition in these studies may be the result of this issue.

3.2 Sediment

Fig. 12 shows the SSC for each rainfall pattern condition. It shows that rainfall pattern does have a significant impact on sediment produced where Pattern C showing trend similar to the particular rainfall pattern, however, patterns A, B, and D are showing a decreasing trend. In contrast, the trend does not have a major impact where the mean value among every three repetitions of rainfall pattern resulted as 14,518.88, 13,732.73, 8,011.71 and 19,918.50 mg/l for patterns A, B, C, and D, respectively. From these results, Pattern D contributed to the highest amount of sediment accumulated whereby pattern C generated the lowest sediment despite the trend showed a different approach than the other 3 patterns.

The findings in this study are consistent with those studies of Mohamadi & Kavian (2015), W. Wang et al. (2016), and B. Wang et al. (2017) found an increasing pattern that contributed the highest amount of soil loss. However, it is in contrast with Tao et al. (2017) that found a decreasing pattern produce the highest that is similar to this study's findings. This is because the higher intensity applied in the first phase of rainfall duration results in a higher capacity of raindrop hits on soil plots that cause splash erosion. The loose particles were carried out with the surface runoff shown by the figure where the early phase has the highest concentrations until it reaches stable mode through the end of the duration.

3.3 Nutrients

The nutrient concentrations namely ammonia nitrogen, nitrate-nitrogen, and phosphorus associated for each rainfall pattern are shown in Fig. 13, Fig. 14, and Fig. 15 respectively. The combination of these three types of nutrients is shown in Fig. 16. For ammonia nitrogen and nitrate nitrogen nutrient, the trends showed that most transport processes happened in the beginning 30-min of rainfall duration and consequently achieve stable mode through the end. The determined total losses for ammonia nitrogen were 3.948, 2.902, 3.536, and 4.081g; nitrate nitrogen was 3.891, 2.677, 4.032, and 3.255g; phosphorus was 1.333, 0.223, 0.2010, and 0.690g, for patterns A, B, C, and D, respectively. In general, rainfall pattern does not have a significant impact on the trend of nutrient losses, where the trend shows that higher concentrations at the start and eventually lowered through the end, but pattern D as compared to other patterns resulted in more severe nutrient losses.

Dai et al. (2018) studied the amount of nitrogen (TN) and phosphorus (TP) losses under natural rainfall events and found that sediment yield is the major controller of the TN and TP loss. This is because heavy rainfall produces a higher rate of soil erosion and nutrient loss where 93% of TN and 99% of TP were transported with sediments. Zhang et al. (2010) conducted field experiments to study soil erosion and loss of nitrogen (N) from a 15° hillslope and found soil erosion caused an N loss of about 250 mg/m^2 for the bare soil plot. In general, N concentrations decreased with time and approached a steady value throughout the experiment regardless of constant or varies-intensity rainfall conditions. Findings from this study are satisfying as the concentrations for ammonia nitrogen and nitrate nitrogen shows the same trend. Though there are not enough previous studies on the relationship of rainfall pattern to nutrient loss, however from the findings, it is generally similarly found by Tao et al. (2017) that decreasing pattern contributes the most severe nutrient loss. The reason is that the higher rainfall intensity of the early phase has produced a higher rate of nutrient loss since the impact from high intensity released solute at the soil surface to the runoff as compared to low intensity.

3.4 Soil profile measurement

The data in Table 2 were derived from the measurement at a distance 15cm × 15cm square grid on the soil plot surface before and after every rainfall simulation done to determine the soil profile in the plot. Meanwhile, Fig. 17 shows the photographs of the soil plot before and after each simulation and the soil profile plot for a respective experiment. The difference was calculated by subtracting the before and after values. This means that the positive difference value shows that the soil is eroded meanwhile the negative value shows raised soil that is carried by runoff. The no difference value shows that there is no difference in height reading before and after the rainfall simulation that can be assumed that a particular soil area maintains the same with no eroded or raised soil involved. From these three values, positive and negative values are then added and divided by the total area of soil plot to determine the affected area in terms of soil movement process during rainfall simulation. The calculated means values of affected areas are 79.60, 68.70, 72.43, and 64.97% for pattern A, B, C and D respectively. The lowest means value of the affected area is contributed by pattern D and highest by pattern A.

Table 2 Summary of measured soil profile before and after rainfall simulation

Rainfall pattern	Experiment No.	Difference in height of soil reading before and after rainfall simulation (%)			Percentage of affected area	Mean
		Positive value (eroded soil)	Negative value (raised soil)	No Difference		
Constant	1	35.7	50	14.3	85.7	79.60
	2	37.8	48	14.3	85.8	
	3	25.5	41.8	32.7	67.3	
Increasing	1	22.4	62.2	15.3	84.6	68.70
	2	20.4	42.9	36.7	63.3	
	3	29.6	28.6	41.8	58.2	
Increasing-decreasing	1	51	27.6	21.4	78.6	72.43
	2	25.5	41.8	32.7	67.3	
	3	24.5	46.9	28.6	71.4	
Decreasing	1	26.5	49	24.5	75.5	64.97
	2	19.4	37.8	42.9	57.2	
	3	26.5	35.7	37.8	62.2	

3.4 Response of total runoff, total SSC, nutrient concentrations, and soil affected area to rainfall patterns

Table 3 presented the summary of experiment variables and their respective mean value. The mean is calculated from the value obtained in the three repetitions of each rainfall pattern. The variables, including runoff, sediment concentrations, and the three nutrient concentrations namely ammonia nitrogen, nitrate-nitrogen, and phosphorus. The mean values are each discussed in subchapters 3.1 to 3.3. By considering the twelve experiments, the mean calculated for runoff is 697.944 liter, for total SSC is 14,045.451mg/l; for ammonia nitrogen concentration is 3.612mg/l; for nitrate-nitrogen concentration is 3.464mg/l and for phosphorus concentration is 0.614mg/l.

Table 3 Summary of experiment results

Rainfall pattern	Experiment No.	Runoff (liter)		Total SSC (mg/l)		Ammonia Nitrogen Concentrations (mg/l)		Nitrate Nitrogen Concentrations (mg/l)		Phosphorus Concentrations (mg/l)	
		Total	Mean	Total	Mean	Total	Mean	Total	Mean	Total	Mean
Constant	1	636.785	668.649	20643.566	14518.879	5.349	3.948	4.585	3.891	2.267	1.333
	2	668.072		11509.419		3.146		4.810		0.140	
	3	701.090		11403.653		3.348		2.279		1.591	
Increasing	1	679.363	701.404	24686.202	13732.733	2.293	2.902	1.902	2.677	0.095	0.223
	2	704.662		9190.308		2.836		2.960		0.402	
	3	720.187		7321.689		3.577		3.169		0.173	
Increasing-decreasing	1	675.538	699.096	9243.128	8011.707	2.440	3.536	2.027	4.032	0.142	0.210
	2	698.813		6371.820		2.638		5.730		0.147	
	3	722.936		8420.173		5.530		4.338		0.340	
Decreasing	1	710.323	722.627	34856.812	19918.495	3.504	4.081	2.770	3.255	0.256	0.690
	2	718.696		12107.835		2.551		4.312		0.151	
	3	738.863		12790.807		6.188		2.682		1.662	
Total			697.944		14045.451		3.612		3.464		0.614

Table 4 and Fig. 18 present the results of ANOVA and the mean plot for the seven particular variables studied. Variable's nutrients are combined in one plot to better observe the trend pattern among the three nutrients. ANOVA was used to evaluate differences in the runoff, sediment concentrations, nutrient concentrations, and total affected soil area between the four rainfall patterns. The outcome of the statistical test is probability named the p-value, which is compared to a threshold called the significance level. The performance result of the system is related if the p-value is lower than that significance level.

According to the results, we can conclude that there is no significant interaction between the seven variables and the rainfall patterns since the p-value is lower than 0.05 in none of the performance metrics. ANOVA assumes that the data come from a normally distributed population with a homogeneous variance and similar covariance and sphericity (differences between all possible pairs of groups are equal).

Table 4 One-way ANOVA's results

	Rainfall pattern	Sample volume	Mean	F value	P value
Total runoff (liter)	Constant	3	668.6490	2.649	0.120
	Increasing	3	701.4040		
	Increasing-decreasing	3	699.0957		
	Decreasing	3	722.6273		
Total SSC (mg/l)	Constant	3	14518.8793	0.987	0.446
	Increasing	3	13732.7330		
	Increasing-decreasing	3	8011.7070		
	Decreasing	3	19918.4847		
Ammonia Nitrogen	Constant	3	3.94767	0.399	0.758
	Increasing	3	2.90200		
	Increasing-decreasing	3	3.53600		
	Decreasing	3	4.08100		
Nitrate Nitrogen	Constant	3	3.89133	0.691	0.583
	Increasing	3	2.67700		
	Increasing-decreasing	3	4.03167		
	Decreasing	3	3.25467		
Phosphorus	Constant	3	1.33267	1.736	0.237
	Increasing	3	0.22333		
	Increasing-decreasing	3	0.20967		
	Decreasing	3	0.68967		
Soil Affected Area	Constant	3	79.6000	1.084	0.410
	Increasing	3	68.7000		
	Increasing-decreasing	3	72.4333		
	Decreasing	3	64.9667		

Conclusions

Rainfall patterns were performed in the experiments to study the effects of rainfall patterns on the sediment and nutrient loss rate. The experiment was done using Hydrology Apparatus with some adjustment on the drain system. The apparatus has a soil plot area of $2m^2$ that is filled with sandy loam soil and compacted layer by layer through the top. Four rainfall patterns are chosen, namely A (uniform-type: 8-8-8 l/min), B (increasing-type: 7-8-9 l/min), C (increasing-decreasing-type: 7-9-8 l/min) and D (decreasing-type: 9-8-7 l/min) with the changes of intensity every 30 minutes that gives total rainfall duration of 90 minutes for each pattern. The simulation was done in three repetitions.

a. The average total runoff produced was 668.65, 701.40, 699.10, and 722.63 liters, for rainfall patterns A, B, C, and D, respectively. The findings show that rainfall patterns do affect the trend of runoff generated by pattern D generated the highest amount of runoff meanwhile pattern A generated the lowest.
b. For sediment concentrations, finding shows that rainfall pattern does have a significant impact on sediment produced where pattern C showing trend similar to the particular rainfall pattern, however, for patterns A, B, and D are showing a decreasing trend. In contrast, the trend does not have a major impact where the mean value among every three repetitions of rainfall pattern resulted as 14,518.88, 13,732.73, 8,011.71 and 19,918.50 mg/l for patterns A, B, C, and D, respectively. Pattern D contributed to the highest amount of sediment accumulated whereby pattern C generated the lowest sediment despite the trend showed a different approach than the other 3 patterns.
c. In nutrient concentrations, the trends of ammonia nitrogen and nitrate-nitrogen concentrations showed that most transport processes happened during the first phase of rainfall duration and consequently achieve stable mode in the preceded phase through the end. The determined total losses for ammonia nitrogen were 3.986, 2.891, 3.504, and 4.601g; nitrate nitrogen was 3.934, 2.665, 4.008, and 3.259g;

phosphorus was 1.346, 0.222, 0.207, and 0.679g, for patterns A, B, C, and D, respectively. In general, rainfall pattern does not have a significant impact on the trend of nutrient losses, where the trend shows that higher concentrations at the start and eventually lowered through the end but pattern D as compared to other patterns resulted in more severe nutrient loss.

d. For the affected area of the soil movement process, the calculated means of the affected area are 79.60, 68.70, 72.43, and 64.97% for patterns A, B, C, and D respectively. The lowest mean of the affected area is contributed by pattern and highest by pattern A.

For recommendation, the simulation has been done on bare land conditions, thus further studies on the vegetation cover may need further investigation. Other than that, variation of slope gradient and different soil types may be suitable for further studies. However, in general, the relationship of rainfall patterns on nutrient loss should be investigated more in the future due it has previously been rarely investigated.

Declarations

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Consent to participate - Not applicable

Consent to Publish - Not applicable

Authors Contributions

Hanna Mariana Henorman: Methodology, Data collection, Writing original draft. **Duratul Ain Tholibon:** Supervision, Writing - review and editing. **Masyitah Md Nujid:** Conceptualization, Investigation. **Hamizah Mokhtar:** Writing - review and editing. **Jamilah Abd Rahim:** Writing - review and editing. **Azlinda Saadon:** Writing - review and editing.

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Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and materials

The authors declare that [the/all other] data supporting the findings of this study are available within the article [and its supplementary information files]

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Figures

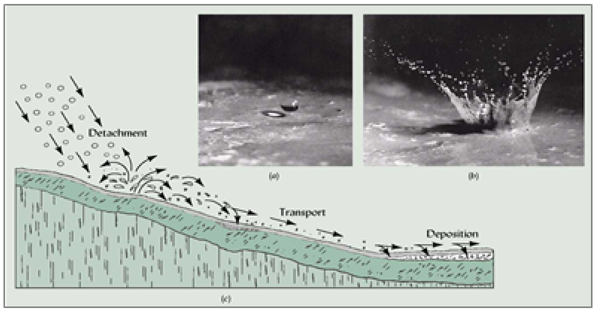

Figure 1

Water erosion stages a) raindrop hits the soil b) splash impact on the soil surface (Trail Grades (and Outslope) - Trailism (n.d.))

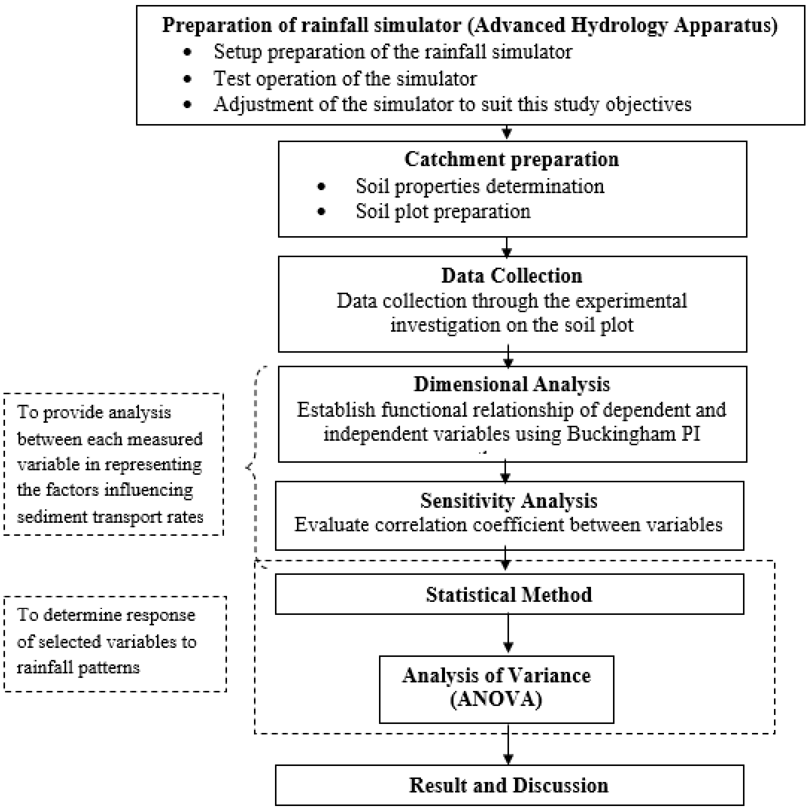

Figure 2

The framework of methodology

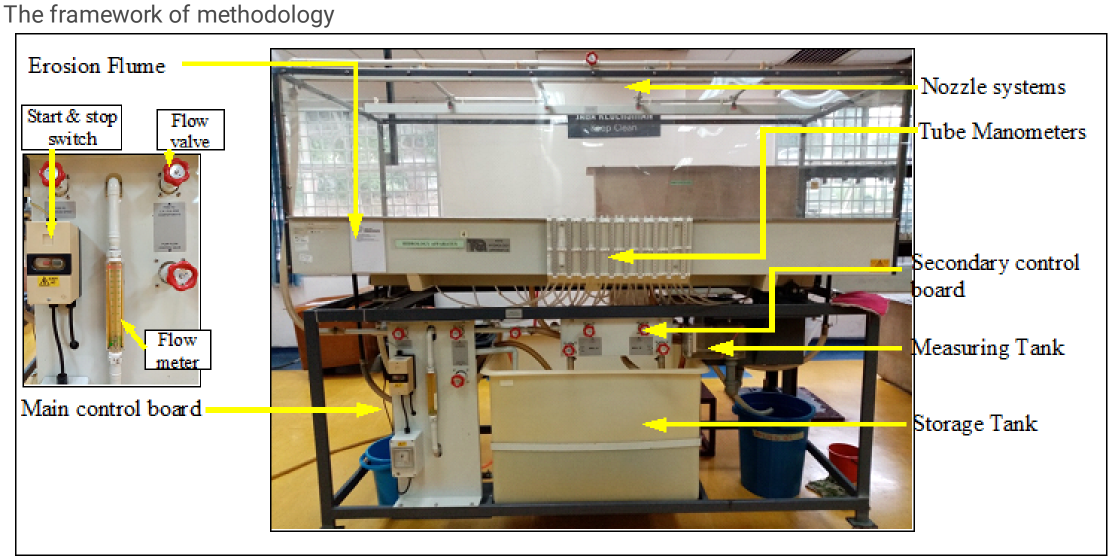

Figure 3

Components of Hydrology and Rainfall Apparatus (Front View)

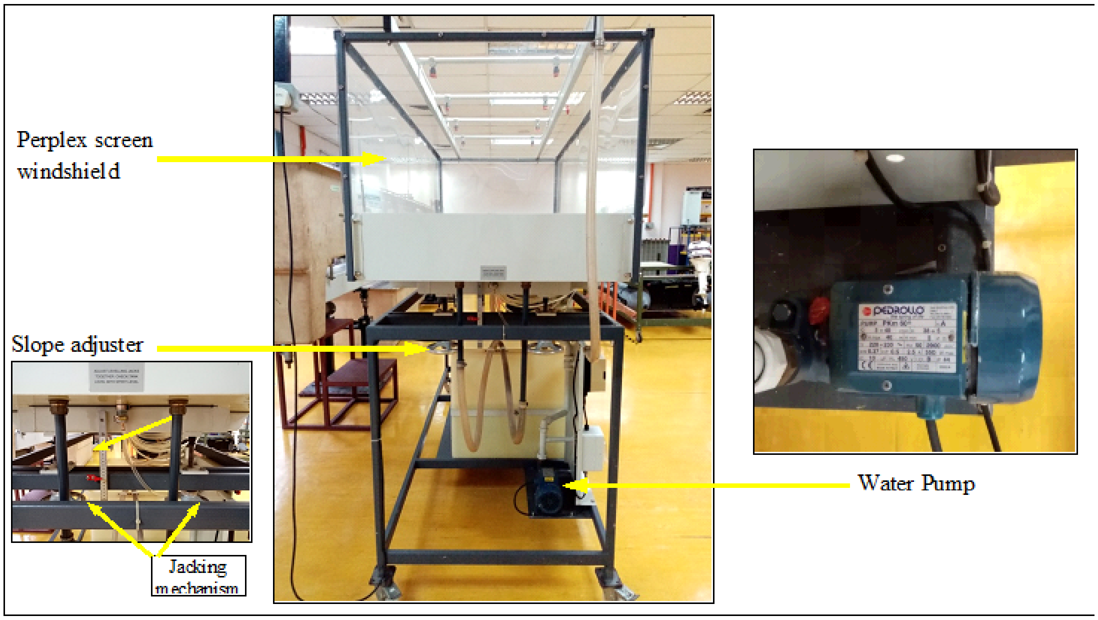

Figure 4

Components of Hydrology and Rainfall Apparatus (Side View)

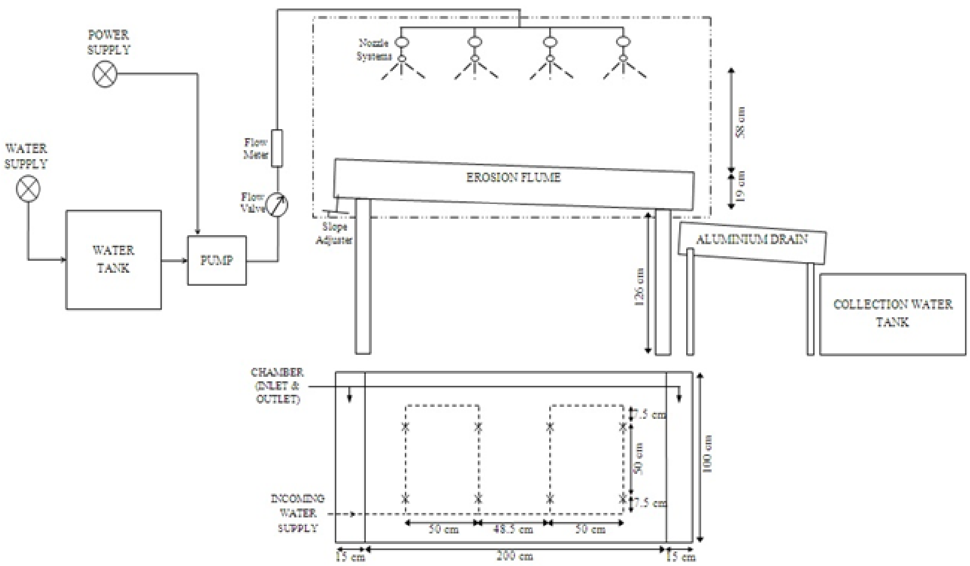

Figure 5

Sketch of rainfall simulator and erosion flume (above) Plan of erosion flume and nozzle systems (below)

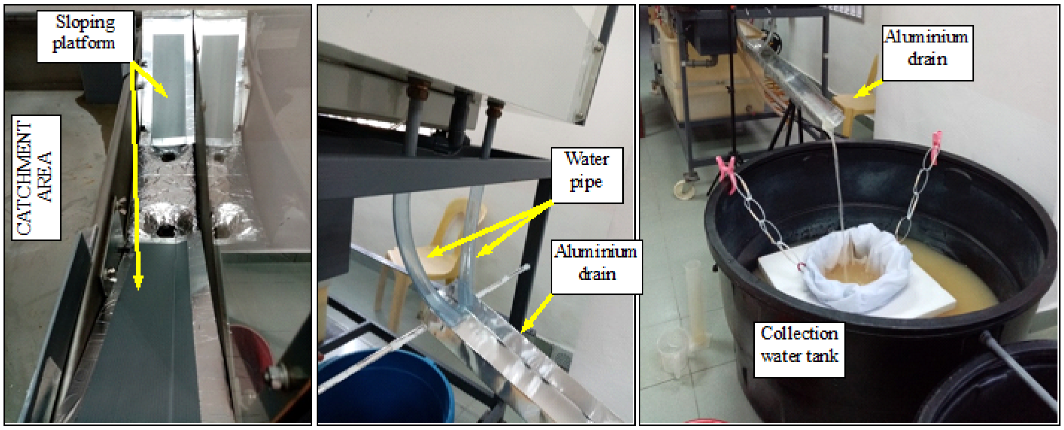

Figure 6

Runoff catchment drainage adjustment

Figure 7

Nozzle system propped

Figure 8

Process of soil management for the erosion flume (A) Soil sorting (B) Soil sieving (C) Layering base of the flume with cloth (D) Filling flume with soil layer-by-layer (E) Compaction using brick (F) Prepared soil plot in flume

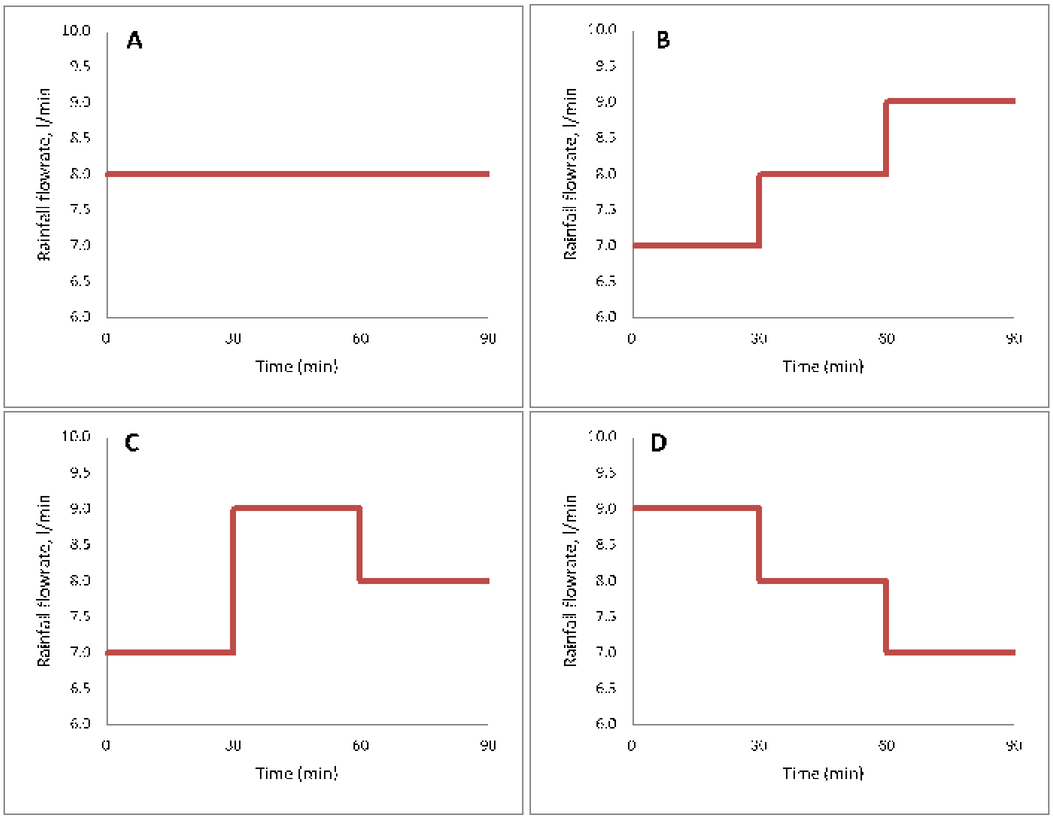

Figure 9

Four different rainfall patterns (A) constant-type, (B) increasing-type, (C) increasing-decreasing-type and (D) decreasing-type

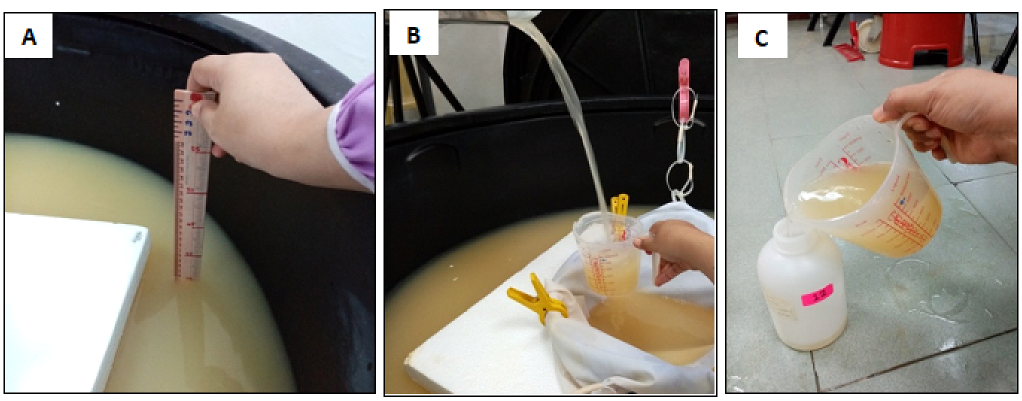

Figure 10

Runoff measuring and sample collection method (A) Runoff volume measurement (B) Runoff sample collection (C) Runoff sample filled into bottles

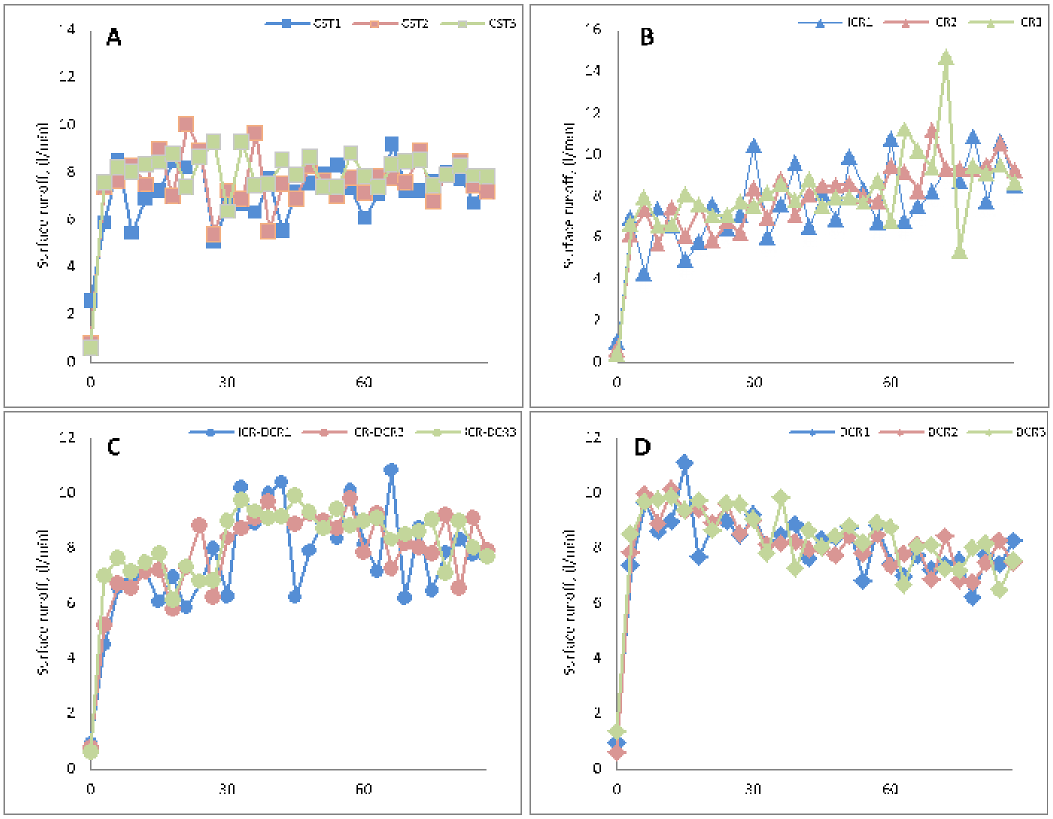

Figure 11

Determined surface runoff for (A) constant-type, (B) increasing-type, (C) increasing-decreasing-type and (D) decreasing-type

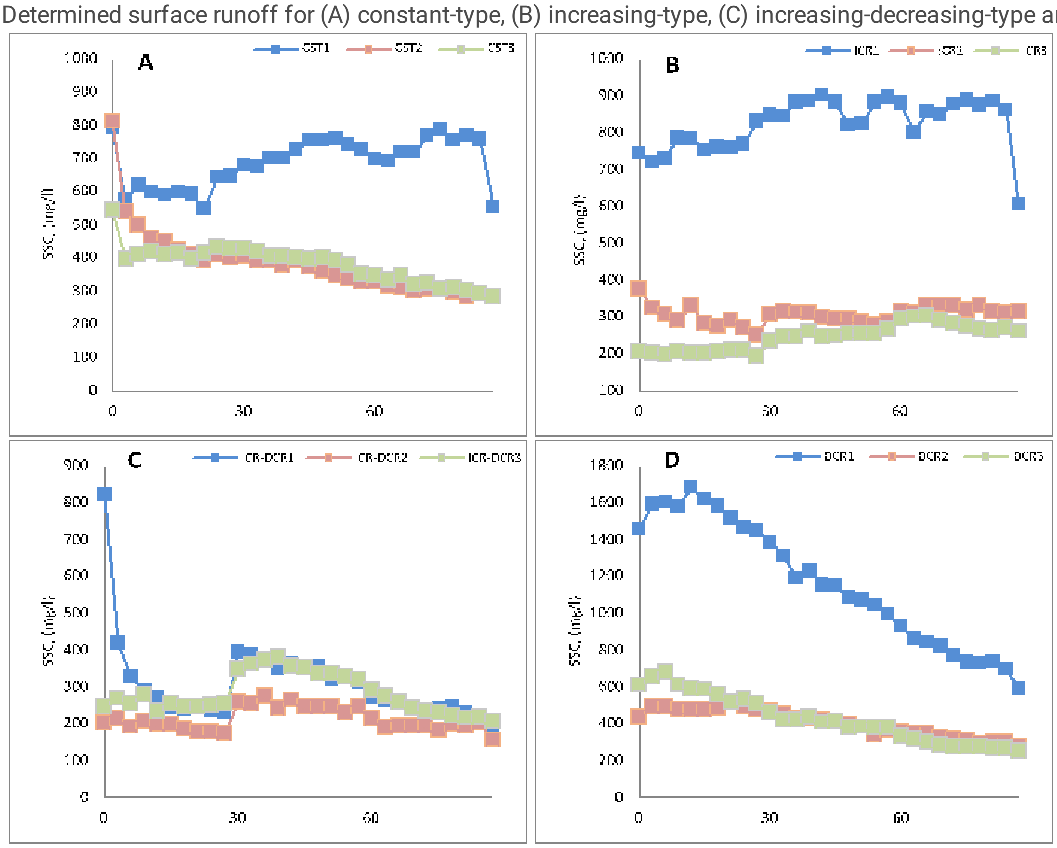

Figure 12

Determined SSC of (A) constant-type, (B) increasing-type, (C) increasing-decreasing-type and (D) decreasing-type

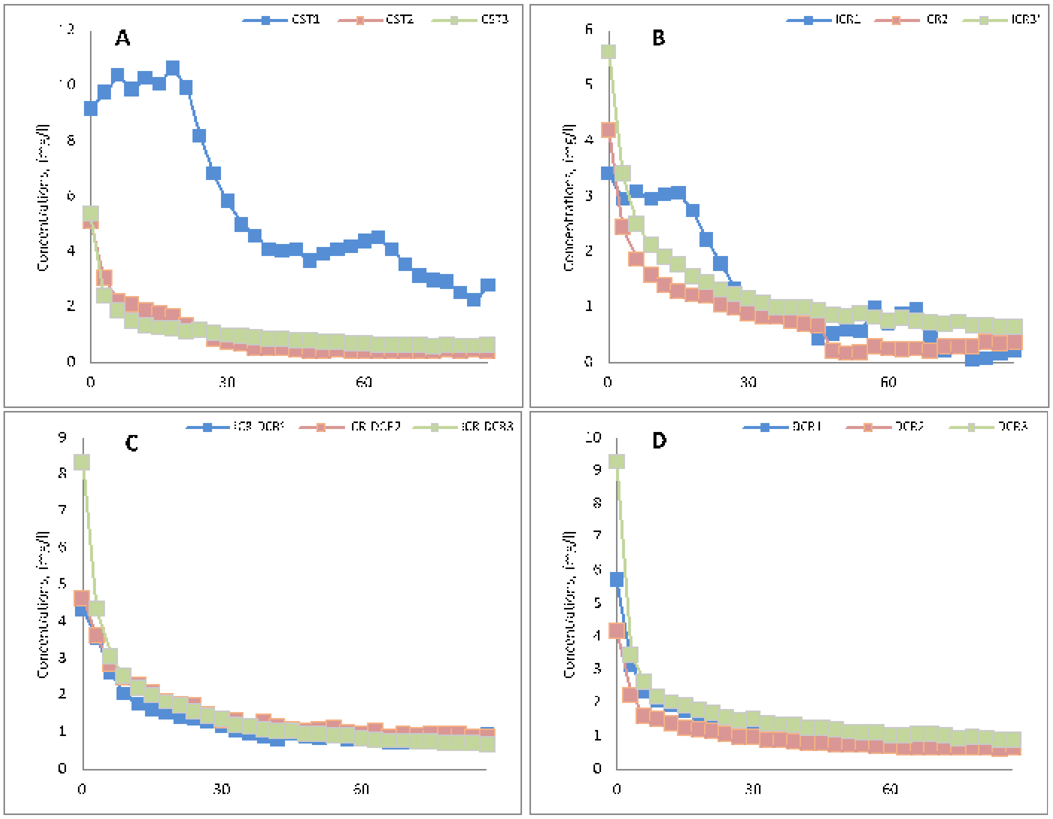

Figure 13

Determined ammonia nitrogen concentrations of (A) constant-type, (B) increasing-type, (C) increasing-decreasing-type and (D) decreasing-type

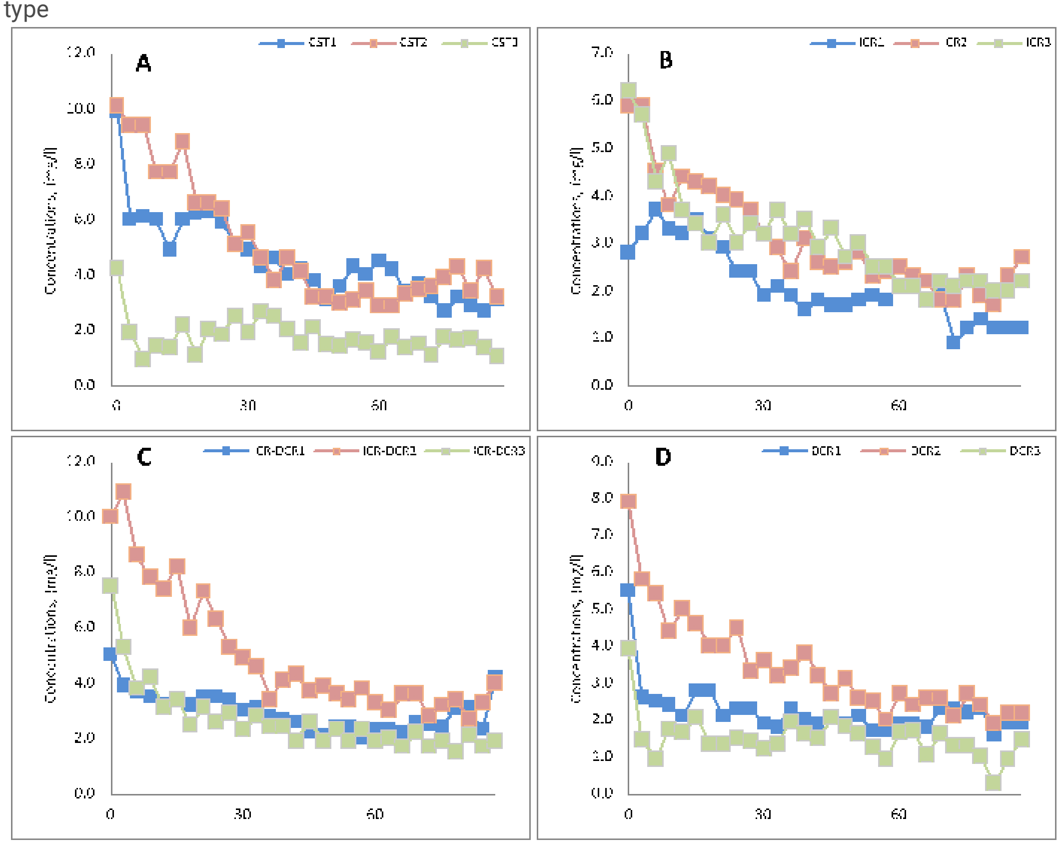

Figure 14

Determined nitrate nitrogen concentrations of (A) constant-type, (B) increasing-type, (C) increasing-decreasing-type and (D) decreasing-type

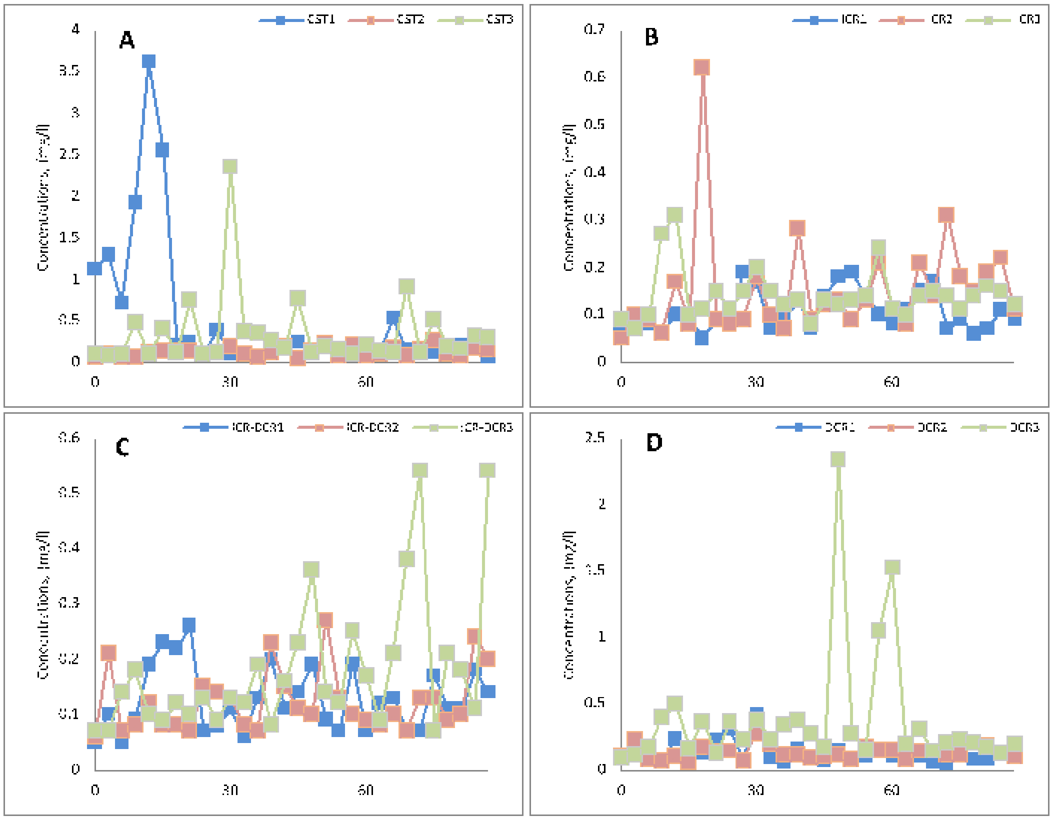

Figure 15

Determined phosphorus concentrations for (A) constant-type, (B) increasing-type, (C) increasing-decreasing-type and (D) decreasing-type

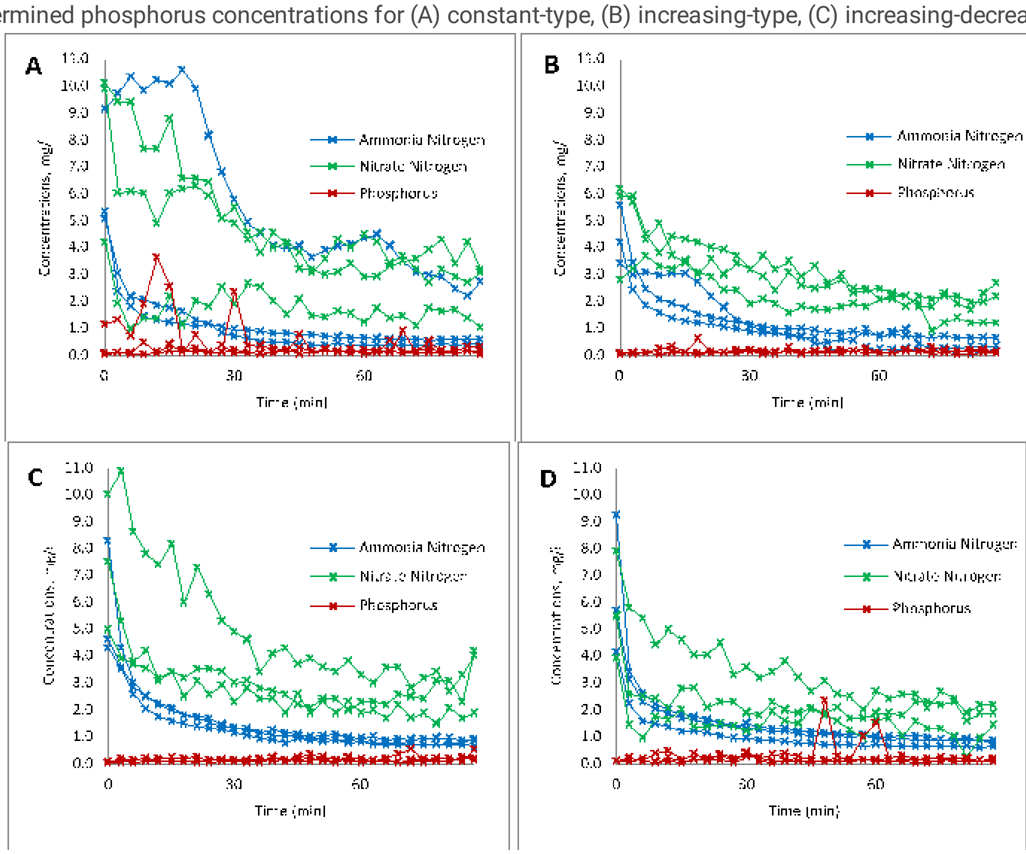

Figure 16

Combination of determined nutrient concentrations for (A) constant-type, (B) increasing-type, (C) increasing-decreasing-type and (D) decreasing-type

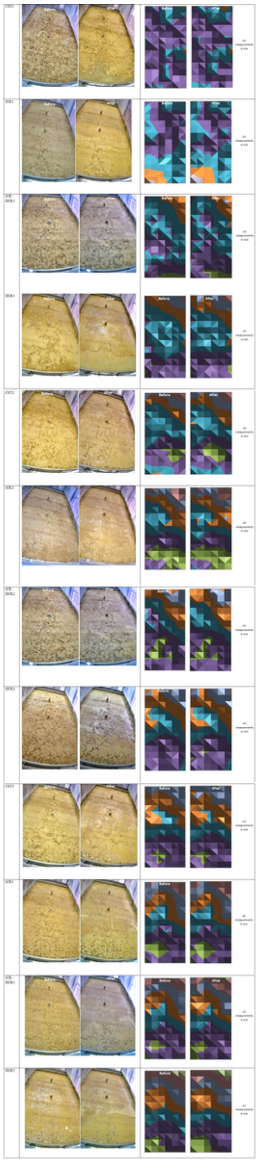

Figure 17

Photograph (left)and soil profile (right) of before and after each experiment

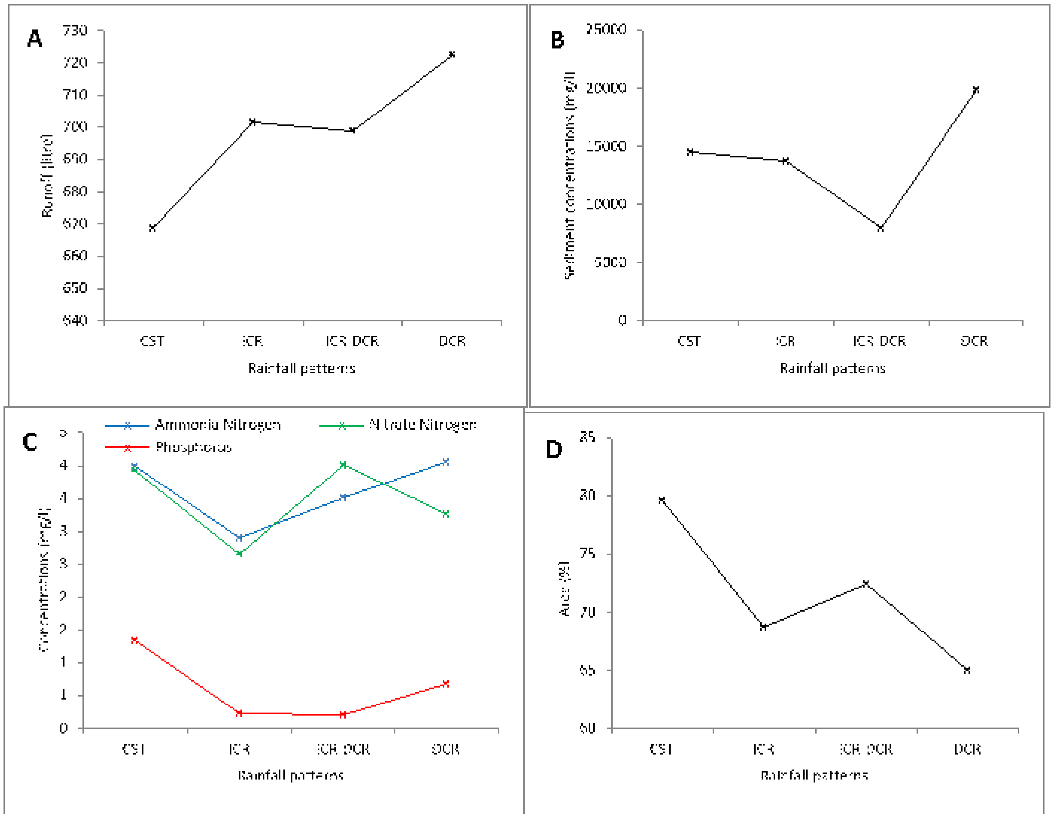

Figure 18

Each rainfall patterns mean plot for (A) Total runoff (B) Total SSC (C) Three types of nutrients (D) Soil affected area