Sediment and Nutrient Concentration from Different Land Use and Land Cover of Bukit Merah Reservoir (BMR) Catchment, Perak, Malaysia

Kepekatan Sedimen dan Nutrien dari Guna Tanah dan Penutup Tanah yang Berbeza di Kawasan Tadahan Kolam Bukit Merah, Perak, Malaysia

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Abstract

This study was based on plots under various types of land use and covers at North Pool, Bukit Merah Reservoir (BMR) catchment. The rainfall was generated from a rainfall simulator to produce constant intensity of 53 mm/hour. Runoff, sediment and nutrient losses were measured. The results show that sediment concentration was highest from the bare soil plot (429.80 mg/L), and the lowest is from the grass plot (135.80 mg/L). Soil types in the catchment area also influenced the infiltration rate and the amount of surface runoff. The result also shows that the nutrient concentration in the totality of all forms of nitrogen is highest from the bare soil plot. This is due to the highest surface runoff were generated and the top layer soil was exposed to erosion activities of flowing water. The highest implication to the catchment management or soil conservation and nutrient retention has deteriorated water quality supplying to Bukit Merah reservoir. In controlling this problem, best management practice (BMP) should be maintained in the agricultural areas and convert the bare soil areas to at least as a grassy area or back to natural forest.

Keywords

Erosion, Sediment concentration, Nutrient concentration, Runoff, Rainfall simulator

Abstrak

Kajian ini dijalankan berdasarkan plot yang dibina di pelbagai jenis penggunaan tanah dan meliputi kawasan tadahan di Kolam Utara, Bukit Merah Reservoir (BMR). Hujan telah dijana menggunakan pensimulasi hujan untuk menghasilkan intensiti hujan yang tetap iaitu 53 mm/jam. Air larian, kepekatan sedimen dan nutrien telah diukur. Keputusan menunjukkan bahawa kepekatan sedimen adalah paling tinggi daripada plot tanah kosong (429.80 mg/L), dan yang paling rendah adalah daripada plot rumput (135.80 mg/L). Jenis tanih di kawasan tadahan juga akan mempengaruhi kadar penyusupan dan jumlah air larian yang dihasilkan. Hasil kajian juga *menunjukkan bahawa kepekatan nutrien dalam keseluruhan semua bentuk nitrogen adalah tertinggi daripada plot tanah yang terdedah. Ini adalah disebabkan oleh air larian yang paling tinggi telah dihasilkan kerana tanih lapisan atas telah terdedah dengan aktiviti hakisan oleh air yang mengalir. Implikasi yang paling besar dalam konteks pengurusan kawasan tadahan atau pemuliharaan tanah dan pengekalan nutrien ialah menyebabkan kemerosotan kualiti bekalan air yang mengalir masuk ke kolam Takungan Bukit Merah. Untuk mengawal masalah itu, langkah terbaik adalah mengekalkan kawasan pertanian berdasarkan kepada amalan pengurusan terbaik (BMP) dan menukar kawasan tanah terdedah kepada sekurang-kurangnya kawasan berumput atau kembali kepada hutan semula jadi.*

Kata kunci

Hakisan, Kepekatan Sedimen, Kepekatan Nutrien, Hujan Simulasi.

Introduction

Soils of the earth have been continuously changing. Soil erosion is a complex and multifaceted process which involves a host of factors and conditions with combinations, variations and interactions, which substantially affect water pressure, and might also, have apposing effect on the processes of surface sealing, runoff generation and sediment production. Otherwise, a low soil water content, and thus high negative pore water pressure, increases the cohesiveness of the soil, which results in a reduced detachability by runoff shear forces and raindrop impact (Romkens *et al.,* 2001). Based on Morgan (1979), soil erosion is a two phase process consisting of the detachment of individual particles from the soil mass and their transport by erosion agents such as running water and wind. When sufficient energy is no longer available to transport the particles is a third phase, deposition, occurs.

Landscape change produced by human actions can have a strong impact upon water resources both in terms of their quantity and their quality. These hydrological changes may influence overland flow, soil erosion, stream flow and sediment transport. Change in vegetation, a form of desertification, is associated with losses and redistributions of soil nutrient by wind and water (Kaufmann *et al.,* 2014). In a tropical region such as Malaysia, storm events play an important role in determining the amount of sediment transported out of a catchment system (Wan Ruslan, 2000). Tropical rainfall is characterised by heavy and intense storms with large rain drops influencing soil erosion and the removal and transport of sediment. Rainfalls with intensities exceeding 200 mm hr^{-1} have been reported, while those greater than 100 mm hr^{-1} are common (Lal, 1976). In Peninsular Malaysia, about 125 mm h^{-1} is expected in 30-min duration storms occurring approximately once in five years, and 100 mm hr^{-1} intensities occur once in two years (Douglas, 1984). Such storms would definitely create a higher erosion rate, and will produce a high amount of suspended sediment and nutrients transported by river systems.

In the various regions of the world, losses of plant cover are associated with lower rates of soil water infiltration and greater runoff (Castillo *et al.,* 1997). The impact on land use and land cover changes, especially in term of changes from forest cover to other land cover, has been one of the important issues on land use research comparison. Nowadays, the agriculture sector is a second largest industry in Malaysia. The concentration of the most fertile topsoil decreases its ability to sustain crop production. Large amount of agricultural chemicals (fertilizer and pesticides) are applied to farmlands in the Malaysia and elsewhere to increase crop production. Part of these chemicals are adsorbed to soils and sediments, and transported to the river (Nearing, 1995). Soil erosion can be reduced by applying appropriate land management and adapting best management practise (BMP). The development and evaluation of BMP need accurate soil concentration estimation from various land management scenarios. Quantification of soil concentration is one of the greatest challenges in natural resources and environmental planning (Bhuyan *et al.,* 2002). Agriculture has been identified as a major non-point source of water pollution (Myers *et al.*,1985). The fertility of an agricultural soil can be defined simply as 'its capacity to produce the crops desired' with the emphasis that soil fertility "is an outcome of the effects of many kinds of living organisms, and chemical and physical processes acting on the inert parent material from which soil is made". The individual, measurable and soil properties that contribute to soil fertility are rarely agreed upon by different authors (Patzel *et al.*, 2000).

Based on the discharge characteristic in the watershed, water pollution can be divided in to two types: point source (PS) and non point source (NPS). Compared with PS, NPS is more intermittent and complicated and thus more difficult to control (Liu et al. 2014). Due to the large variety of source, NPS pollution accounts for a large proportion of NPS pollution and plays an important role in the water quality problems (Emili & Greene, 2013). Nutrient transported via surface runoff, phosphorus (P) and nitrogen (N) are essential to crop and animal production and are also the major nutrient controlling eutrophication of surface waters (Kleinman *et al.,* 2006). Today, a growing strategy for reduce P and N losses from agriculture lands is to target "critical source areas" based on transportation, where high concentration of P and N are found in areas that are the prone to surface runoff (Sharpley *et al.,* 1994; Heathwaite *et al.,* 2000). P and N mobilization from agriculture nonpoint-source depend on the coincidence of source (Soil, crop and management) and transport (runoff, erosion and processes) factors.

In the natural environment, N and P are essential for plant growth, but their application agricultures areas may result in NPS of both surface and subsurface waters (Casalí *et al.,* 2008 and Kato *et al.,* 2009). Nutrient are transport, generally in solution, but may be linked to particulate matter. At the watershed scale, P and N have different contributing areas where source and transport factors coincide to initiate nutrient mobilization. Transport factors are more limiting for P relative to N, because the high mobility of N as nitrate in leaching water means that virtually all the nitrate created by source factors is translated into N concentration (Heathwaite *et al.,* 2000). Land use activities in headwater catchments may have a cumulative effect, detectable in larger watershed scales. By changing the timing of flood hydrographs, changes in vegetation may desynchronise hydrographs from sub-catchments and can, in some cases reduce peak flows downstream (Harr, 1981).

In a wet tropical scenario, intense rainfall events are significant factors in the Malaysia. Based on agricultural land use dominated with oil palm and sundry trees as well as other vegetative cover such as forest and grass, are usually assumed to absorb the impact of major storm, due to the high infiltration rates of the soils. Conversely, following the storms, some field were observed to have undergone riling and gullying, although this was locally attributed in some cases to the effect of water building up in road drainage ditches, and spilling over into the agricultural areas. However, the nature of the cultivation does leave large areas exposed, and the removal of vegetation between the crops can lead to significant crusting, and overland flow and erosion rates may be significant. In order to the test this hypothesis, it was decided to carry out a series of field experiment to assess the response of the cultivated zones in the study areas to a major rainfall event. This was carried out principally by rainfall simulation generated from a rainfall simulator as described in the next section.

In order to characterise and explain the slope response to rainfall, a number of interrelated factors are required. First, the amount of rainfall lost to infiltration should be quantified to assess the quantities available for runoff. Second, once runoff is generated, all of runoff must to identify soil characteristic and hydrology perspective. As such, the objective of this study is to quantify the runoff, sediment and nutrient erosion based on various land use in the catchment. To this end, we measured runoff, sediment and concentration from the five plots based on catchment land use and relates these data with the site characteristics.

Rainfall Simulator

Rainfall simulator is a common alternative approach to produce rainfall which is controllable in time and space that allows the repetition of many years of rainfall in a very short time period. Scientists are driven to design and to use different types of rainfall simulators in order to accelerate the data collection processes on erosion, infiltration, surface runoff and sediment transport (Erpul *et al.,* 1998). After classical studies of drop velocity (Laws, 1940) and of drop size distribution of natural rainfall (Laws & Parsons, 1943), many attempts were successively made by Meyer and McCune (1958). The advantage and limitations were in detail given by Meyer (1965). Rainfall simulator studies are new approach to determine the soil erosion rate in Malaysia. Rainfall simulator is a valuable research tool used in the study of the hydrologic and erosion responses of the natural environment. The major objection to rainfall simulators is that they do not produce natural rainfall energies or variable intensities. However, the major advantage of simulators is that maximum control can be achieved over where, when, and how data are collected and result can be easily compared among ecosystems. Data from rainfall simulator studies can be use by researcher, land manager, and planner to evaluate management or treatment effect on ecosystem response (Simanton *et al.,* 1985; Foster *et al.,* 2000).

Rainfall simulator is portable, easily maintained, flexible and easily adapted in the area, such as slopes (Navas *et al.,* 1990). A programmable oscillating nozzle rainfall simulator (Foster et al. 1979) was uses to generate desired rainfall patterns for all trials. The use of rainfall simulator in the study will enable data replication to particular rainfall intensity and time, also can be repeated as necessary. However there are still limitations in the use of rainfall simulator, especially in terms of cost and time (take a long time and high cost) (Walsh *et al.,* 1998).

Study Area

Site selection was based on rainfall characteristics, topography, and land use cover. An area in the west coast of peninsular Malaysia was selected because of the high potential for soil erosion, associated with a high annual rainfall and the influence of the South-west monsoon. The annual rainfall is greater than 2500 mm and is strongly seasonal (Figure 1). This study was carried out at the North Pool, Bukit Merah Reservoir, Perak, Malaysia. Vegetation of the study area has been described by Department of Urban and Rural Planning (JPBD) map. The total area in this catchment area and the soil characteristic are shown in Table 1 and Table 2 respectively. The North Pool, BMR has three sub-catchments, namely Merah River, Jelutong River and Selarung River. Based on the three catchment areas, five erosion plots were constructed based on land use and land cover type (oil palm, forest, grass, sundry tree and bare soil) in the study area (Figure 2). The location of the erosion plots was carefully selected to represent different soil type, slope and hydrologic characteristics. The study was carried out in April 2008 to April 2009.

The first plot site representing agricultural land use (oil palm - Elaeis Guineensis) is located at Merah River (Figure 2). The slope gradient of the plot is 4^0 and 50% of the surface cover has climber plants. This agricultural area often uses fertilizer to nourish the fertility of the soil to ensure a good growth and has high productions rates. The forest plot had a natural plant with sandy loam soil and calcareous soil with relatively high percentage of sand. This site covered with 35% of natural vegetation, a slope gradient of 3^0, and this site was selected to represent the natural land cover without human influence. The third plot site representing the grass land cover, located between Selarung dan Jelutong river catchment. It located at a vicinity of Boer goat farming, and the grass (Taiwan Napier Grass -*Pennisetum Purpurium*) was planted to serve as a main grazing area for the goats. The slope gradient is 3^0. The fourth plot consists of sundry tree, and it was based on the plant found in the catchment area such as papaya, banana and others, and also considered as a major contributor of sediment and nutrient to the river and located in the Jelutong River catchment. The final plot is bare soil, which represent the open and exposed soil found in the catchment area. This plot was selected as a comparison to the other plots that have vegetation cover.

Table 1 Distribution of land use by sub-basin catchment area of North Pool, BMR.

Catchment Land Use	Merah River Area (km²)	Jelutong River Area (km²)	Selarung River Area (km²)	Plot Location (GPS)	
				N	E
Oil Palm	4.54	2.25	0.000004	05˚04’54.5”	100˚43’1.2”
Forest	11.75	24.09	4.17	05˚02’1.20”	100˚43’1.8”
Grass	-	0.6	0.2	05˚01’1.20”	100˚43’23.6”
Sundry tree	-	1.50	0.3	05˚07’37.3”	100˚45’8.2”
Bare Soil	-	0.22	-	05˚01’2.20”	100˚1’2.60”
Total	16.29	28.66	4.67	-	-

Table 2 Selected data on physical and chemical analysis (Gee & Bauder, 1986) properties of representative topsoil of five sites on the North Pool, BMR, Perak, Malaysia.

Soil physical and Chemical property	Field site				
	Oil Palm	Forest	Grass	Sundry tree	Bare Soil
Soil Texture	Silt	Sandy loam	Sandy Loam	Silt	Silt Loam
Total Sand (%) 2.000-0.053 x 10^{-3} m	30.12	60.13	49.13	23.38	45.94
Total Silt (%) 0.053-0.002 x 10^{-3} m	60.34	30.14	37.70	68.15	39.74
Total Clay (%) <0.002 x 10^{-3} m	9.54	9.73	13.17	8.47	14.32
pH-H_2O	6.80	6.90	6.70	6.80	6.80
Organic Carbon (%)	0.56	0.69	1.13	0.70	0.33
Bulk Density (kg m^{-3})	1.81	1.45	1.54	1.84	1.68
Cover Plant Density (%)	50	35	100	45	0

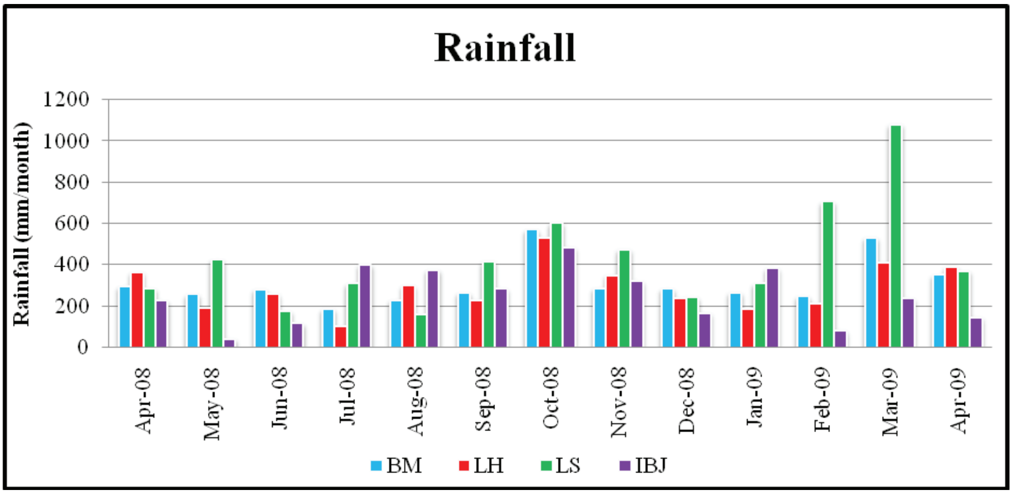

Figure 1 Monthly variation of rainfall at Bukit Merah (BM), Ladang Holyrood (LH), Ladang Stoughton (LS) and Ibu Bekalan Jelai (IBJ) station from April 2008 to April 2009.

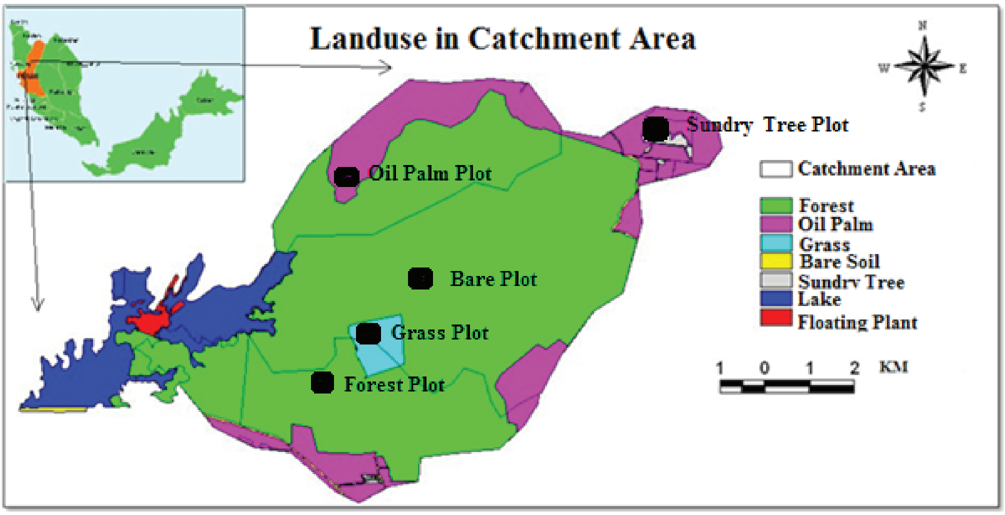

Figure 2 Study plot location based on catchment area and land use (Merah, Jelutong and Selarung Rivers).

Materials and Methods

This study uses a pressurized type rainfall simulator that satisfies specific criteria such as runoff sample collection efficiency, rainfall intensity and event duration for runoff and erosion experiment purposes. Rainfall simulation in the catchment area were performed on five plots (oil palm, grass, forest, bare soil and sundry tree), each with 2.0 m x 1.5 m in dimension were laid out on a 3-5° slope. A field-portable rainfall simulator, developed and describe by Zullyadini *et al.*, (2009), was used to apply water at a nominal rate of 53 mm hr^{-1} to this plot.

The simulator devices for this experiment consist of a triangular frame mast with a height of 3 m, an arm of 3 m length mounted at the top of the mast and 3 nozzles spaced 1.1 m apart are installed at the nozzle boom, such that the nozzles height is 2.4m. According to Duncan 1972, this height is adequate for creating terminal velocities similar to natural rainfall for all drop sizes. Full jet type nozzles with wide-angle square spraying, model 1/2HH-50WSQ (Spraying Systems Co. USA) were chosen for their wide spraying angle, the square wetted zone, and the high uniformity of the spray. Water under an adequate pressure was supplied to the nozzle by a 13 hp water pressure pump. This simulator delivers rainfall with 90% of kinetic energy of similar natural rainfall and a comparable drop-size distribution (Figure 3). Calibration of rainfall simulator is essential in order to produce rainfall simulations that have similar characteristics of natural rainfall. The rainfall simulator have an average Coefficient of Uniformity (CU) of 80% to 95% which exceeded the minimum value of a disperse irrigation system (Christiansen 1942). CU is defined as the deviation of individual observations from mean over the mean value and number of observations. A high CU value indicates small deviation from the mean intensity. The impact of rainfall intensity on CU was found to be negligible. The drop size distribution (DSD) of the simulated rainfall was measured using the flour pellet method described by Hudson (1963). DSD obtained for this rainfall simulator ranging from 0.8 mm to 4.1 mm suitability for tropical rain drop size (Tew Kia Hui, 1999). The median drop size for the simulated rainfall was calculated as 1.3 to 2.0 mm. The kinetic energy was determined to be 0.29 MJ ha^{-1} mm^{-1} based on tropical rain (Hudson, 1965). The runoff water is collected in a trough and is vacuumed continuously into 28L container for runoff volume measurement.

According to Morgan *et al.,* (1997), only two replicate of each density or plots is necessary. During the rainfall simulator experiment, time of runoff initiation, and the end of runoff were recorded. Soil samples were collected at 30 cm depth at respective plots and soil particle analysis were conducted based on the hydrometer method after dispersion with Sodium Hexametaphoshate (Day, 1965). Soil pH was determined by mixing the soil with distilled water (solutions/soil = 1:1) (Peter *et al.*, 2006). Percentage plant covers were measured based on a grid cell of 0.5 m^2. Water samples were collected in polypropylene bottles and filtered through pre-rinsed Whatman (cellulose nitrate) GF/C 0.45 µm diameter 47 mm, and analysed for NH_4, NO_2, NO_3, PO_4, TP, and TN using standard method (APHA, 1995). The difference between the digested and undigested concentration is assumed to represent dissolved organic forms of nitrogen and phosphate.

Result and Discussion

Results indicated that surface runoff was usually attained within 5-10 min after the beginning of simulated rainfall. However, this also depends on the plant cover, soil structure and rainfall intensities. The magnitudes of surface runoff varied according

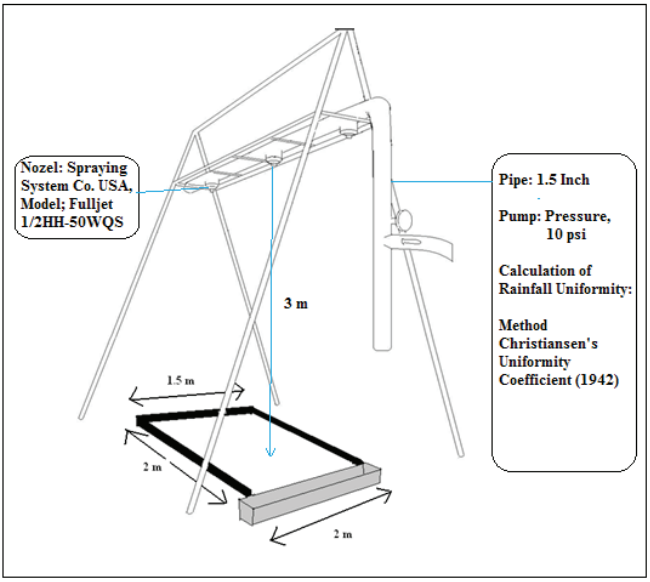

Figure 3 Description of rainfall simulator used in the study.

to the infiltration capacities of each land use type. The North Pool catchment area has five different types of land use and the extent of sediment and nutrient concentration as well as runoff was influenced by many factors. One of the factors was land surface management practice, particularly the one that affects the land cover. Results show that surface water runoff hydrology was greatly influenced by the interactions between the soil moisture condition, soil/landscape location and the rainfall intensity. As expected, the runoff and sediment concentration was highest at the bare soil plot, and the lowest is at the grass plot (Table 3).

Since there is no direct comparison could be made from the result of this study with other study conducted in Malaysia, however the finding conforms to that made by Hofman & Ries (1991), who found that soil compaction and surface roughness had very limited effect on erosion from simulated rainfall on rangeland in North Dakota, USA, and that the major influence was grazing land management practice. In addition, the data obtained can be used to evaluate other studies with different land use and land cover. Data obtained from the rainfall simulator study can be used by other researchers as a reference, as well as farmland management and urban planning to evaluate the effect of environmental response (Simanton *et al.,* 1984). However, according to Heathwaite & Linasita (1996), rainfall plays an important role in the conduct of spark erosion and corrosion in water runoff.

Actually, the purpose of plot study under rainfall simulator was based on the rain factor frequency that is approximately similar to an area. Rainfall simulator study can be used to reflect the hydrology and erosion effects on the natural environment (Neff, 1979). The real objective is not to produce simulated rainfall equal to the kinetic energy of natural rainfall and uniformity, but the advantage of making rainfall simulated is easily applied and replication based on real rainfall (Walsh et al. 1998).

Soil erosion is a complex process and involves several factors, combined; diversity, and relevance, the kinetic energy involving the erosion surface, the occurrence of runoff and sediment transport (Romkens *et al.,* 2001). According to the runoff generated, the highest TSS concentration recorded was bare soil (429.80 mg/L) when compared to the other land use type. This finding is similar to what suggested by Gucinski *et al.,* (2001), stated that the ability of the land area exposed to erosion by rain splash and runoff is low compared with areas of vegetation cover. On the other hand, the lowest TSS concentration was grass, which recorded TSS concentration of 135.80 mg / L. In most countries in the world, the removal of grass will affect the rate of infiltration and increased runoff (Castillo *et al.,* 1997). The study conducted by Bach et al.(1986) in the Chihuahuan desert, New Mexico have found that the rate of infiltration was high for a soil under grass and Abrahams *et al*., (1995) have applied simulated rain to see the erosion in the groove for a little grass compared to the exposed land area.

Soil type will also influence the infiltration rate and the amount of runoff generated. Soil type is also play an important role as the amount of water that is not infiltrated will be generated as runoff. Total runoff is determined based on the saturated water flowing over the land surface area (Lee & Heaney, 2003). Different land cover has a different affects on the soil erosion rate. From the hydrological perspective, the relationship between land use changes that result in changes in vegetation cover will influence increase and accelerate the flow of runoff into the river runoff (Wemple *et al.,* 1996).

Nutrient mobilization from different land cover (agriculture or natural forest) depends on the source (soil, crop and management) and transport (runoff and erosion at hill slope) factors. Source control factors related to the catchment areas that have a high potential to contribute nutrient. For Phosphorus, source areas are often spatially confined and limited in extent, generally reflecting soil phosphorus and phosphorus inputs (Gburek *et al.,* 2000). For nitrogen, amount applied in excess of crop requirements can be leached from the soil profile in percolating water.

Concentration of the soil top layer will reduce the level of soil fertility to sustain crop productivity. Based on modern agricultural systems practiced today, fertilizer and pesticides were applied to increase agricultural productivity. Some of the chemicals used will be absorbed into the plants and soil. This situation will increase the number of nutrients in the river (Bowling & Lettenmaier, 2001). Nutrients stored in soil are only a few centimetres from the surface and decrease based on depth of soil (Woods, 1989).

Runoff that occurred also contained nutrient and transported with the sediments (Stalnacke, 1999). In this study, the nutrients will dissolve in runoff generated that mainly originated from agricultural areas. However, agriculture does not necessarily provide a lot of nutrients in reliance on management practice at agricultural areas. At the bare soil plot, nutrient concentration in the totality of all forms of nitrogen is the highest recorded during the study period. This is because bare soil also produced the highest runoff and the top layer soil was exposed to erosion activities by flowing water. This corresponds with the study by William *et al.*, (1999), states that the more runoff occurs, the more sediment and nutrients will be transported. However, this situation will depend on several instances, such as availability of nutrients within the plot, soil type, rainfall and slope. Soil erosion can be reduced based on the best management practices (Bhuyan *et al.,* 2002).

Table 3 Result of the rainfall simulations sediment and nutrient mobilization in the North Pool, BMR, Perak, Malaysia

Plot	Sediment Concentration (mg/L)	Nutrient Concentration (mg/L)						Runoff (L/m^2)
		NO_2	NO_3	NH_4	TN	PO_4	TP	
Oil Palm	389.07	0.0032	1.0765	0.0393	0.0195	0.0056	2.3456	22.00
Forest	385.07	0.0017	1.3451	0.0461	0.0091	0.0034	0.9423	2.16
Grass	135.80	0.0111	2.0681	0.0465	0.0441	0.0067	2.2587	14.23
Sundry Tree	285.67	0.0025	1.1234	0.0345	0.0342	0.0043	1.1291	8.80
Bare Soil	429.80	0.0107	2.3537	0.0673	0.0486	0.0059	1.4589	44.00

Conclusion

Understanding the interactions of source and transport factors in sediment and nutrient runoff is the key to the improved management of water quality. Many surface runoff study evaluate source factors while controlling transport factors. By conducting rainfall simulations experiments under various hydrologic conditions at a different land use and land cover, this study provides insight into the transport process of nutrient and sediment.

The rainfall simulation method provides limited information because of the size of the plots and design of the simulator. It is difficult to extrapolate data about sediment production to larger scale. Nevertheless, the result of the simulations can be used for comparative purpose. This has been the objective of the study: to determined data of runoff and erosion, especially soil erosion and nutrient transport in five plots based on different plants cover in the catchment area in North Pool, Bukit Merah Reservoir, Perak, Malaysia.

Different soil properties have been cited as responsible factors for sediment concentration variability. Small scale variations caused by the test site itself (soil texture, soil type, slope angle and shape, occurrence of subsurface flow) as well as by plot preparation (surface roughness, plant development, degree of soil cover) always tend to superimpose measurements under regular field conditions. For our experiments, we assume differences of plant cover and soil type to be the most crucial factor for erosion and nutrient concentration. Some of the nutrients concentration in these experiments, especially those in soluble forms, may be associated with the fertilizer used in the agricultural areas.

In general, the rainfall simulation erosion studies are relatively new research area in Malaysia, and the result from our studies has only begun to answer some of the basic question regarding erosion estimating techniques. Additional studies, research approaches, and analysis are still needed to fully understand the hydrological erosion process on runoff.

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