



# Assessment of rainfall-induced soil erosion on hillslope: a case study at the Guthrie Corridor Expressway, Malaysia

Wan Zurina Wan Jaafar<sup>1</sup> · Md. Rabiul Islam<sup>1</sup> · Lai Sai Hin<sup>1</sup> · Normaniza Osman<sup>2</sup> · Faridah Binti Othman<sup>1</sup> · Mokhtar Azizi Mohd Din<sup>1</sup> · Razaul Karim<sup>1</sup>

Received: 21 September 2018 / Accepted: 13 February 2020 / Published online: 25 February 2020  
© Springer Nature Switzerland AG 2020

## Abstract

The effect of northeast monsoon rainfall to soil erosion on hillslope adjacent the Guthrie Corridor Expressway, Malaysia, is investigated by examining a relationship between vegetation covers and slope steepness. Five plot-scale study areas [i.e., NBNM, PDM, PDNM, NBM and natural dense microbe (NDM)] are marked on the hillslope with different percentage and type of vegetation densities. Experimental equipment is set up at those plots to collect rainwater and soil loss starting from November 2014 until March 2015 with twice collection per month. Based on the data collected, the effect of different vegetation densities associated to soil loss is examined. These are the conclusions that can be made based on this investigation: (1) the observed rainfall pattern shows that mostly the recorded rainfall depth is about 5 mm with 20 min duration of rainfall; (2) plot without vegetation cover (i.e., NBNM) yields greater soil loss with the maximum runoff, whereas the least is exhibited by the plot having NDM. Meanwhile, the rate of soil loss is found greater for the planted vegetation compared to the natural plant; (3) a positive relationship is found between runoff and slope steepness regardless of the vegetation cover types.

**Keywords** Rainfall erosion · Hillslope · Vegetation cover · Monsoon seasons

## Introduction

Soil erosion is one of the top-most environmental and ecological concerns in Peninsular Malaysia especially during the northeast monsoon. It causes loss of nutrient-rich topsoil and increases sedimentation, turbidity and level of pollutants in adjacent water bodies (Goodwin and Sin 2014; Martínez-Casasnovas et al. 2016; Vietz et al. 2017). Construction activities and road systems account for the soil erosion and cause impact to the streams adjoining highways (Gernaey et al. 2004; Maier et al. 2004). About 19% of the total land area is eroded due to the construction of public roadway system (Rezaeianzadeh et al. 2014). Some researchers reported that most of the erosion occurred during the rainy season after a disturbance, and half of the erosions were caused by logging operation in road construction. Even during low

rainfall events, stream sedimentation is caused by a large volume of overland flow over linearly connected road systems through hydraulic erosion processes. Construction of roads with concrete and bituminous materials changes the dynamics of plant and animal populations. It also alters the flow of materials in the landscape, due to the involvement of exotic materials and changes levels of available resources such as water, light and nutrients (Caraman et al. 2007). Hence, the disturbance of soil during construction activity is considered as a major nonpoint source (NPS) of water pollution by sedimentation (Othman et al. 2015; Van der Helm and Rietveld 2002; Yu et al. 2000). Thus, construction activity is ultimately liable for the exclusion of topsoil, destruction of vegetation, surface runoff and soil erosion (Islam et al. 2018; Lai et al. 2008; Ozsoy et al. 2012; Wilson et al. 2018; Zeng et al. 2003). In comparison with natural areas, the construction sites increases the erosion by about 500 times in USA (Azamathulla and Ghani 2010).

However, since erosion as a natural process cannot be eliminated completely, control and managing of sediment loading through best management practices (BMPs) might reduce its impact (Azamathulla and Ghani 2010; Maerker et al. 2017). Numerous BMPs like porous pavement

✉ Wan Zurina Wan Jaafar  
wzurina@um.edu.my

<sup>1</sup> Department of Civil Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia

<sup>2</sup> Institute of Biological Sciences, Faculty of Science, University of Malaya, Kuala Lumpur, Malaysia

materials, vegetated buffers and mulches, retention or detention basins and ponds, silt fences, hydro seeding and the placement of natural fiber mats have been proposed and implemented along highways (Dastorani et al. 2010; Kim et al. 2013; Kumar et al. 2012). Bare soil covering by grass or mulch was proposed by Zhang and Stanley (1999) to control soil erosion. The intensity of surface erosion is related to the land use and soil cover (Boix-Fayos et al. 2009; Firat and Güngör 2007; Gautam and Holz 2001; Hamilton et al. 2017; Zhang et al. 2016). The soil coverage reduces the erosive power of raindrops and increases the volume of water infiltration to the soil surface (Panagos et al. 2015; Piacentini et al. 2018; Talei et al. 2010).

An abundant use of BMPs has been proposed worldwide through different research locations; however, the efficiency of some BMPs is still lacking detailed investigation (Akrami et al. 2014; Zhang and Stanley 1999). Considerable literature exists related to erosion control in a humid environment, but only a few studies evaluated the effect of planted and natural vegetation on sediment loss rate in active and established construction areas of hilly topography nearby highway. An evaluation of various vegetation densities that consist of planted and natural vegetation in relation to surface runoff and soil loss based on plot-scale sites on roadside slope adjacent to a highway is presented in this study. The significance of vegetation cover and the mutual interaction of vegetation cover and slope steepness on soil loss are also investigated.

## Study area

Hillslope adjacent of the Guthrie Corridor Expressway (GCE), Malaysia, is chosen as a study area. The annual average precipitation is about 1570 mm with an average minimum and maximum temperatures of 26 °C and 36 °C, respectively. A location map of study area along with five study plots is shown in Fig. 1a, b, and characteristics about each plot area is shown in Table 1. A total five numbers of plots were established at two different locations with vegetation densities varies between 5 and 95%. Out of the five plots, four were of size 8 m × 8 m and one of size 5 m × 5 m. The plots are situated in an elevation range between 45 and 75 m, whereas the slope percentage ranges from 50 to 80%. On the basis of the slope values, the study area can be characterized as prone to soil erosion (Dunne 1977). The soil group classified under the group B implies water infiltration rate is ranging from 3.81 to 7.62 mm h<sup>-1</sup>. As for the soil texture, it falls under the categories of 2 and 3, i.e., fine and coarse granular.

## Methods

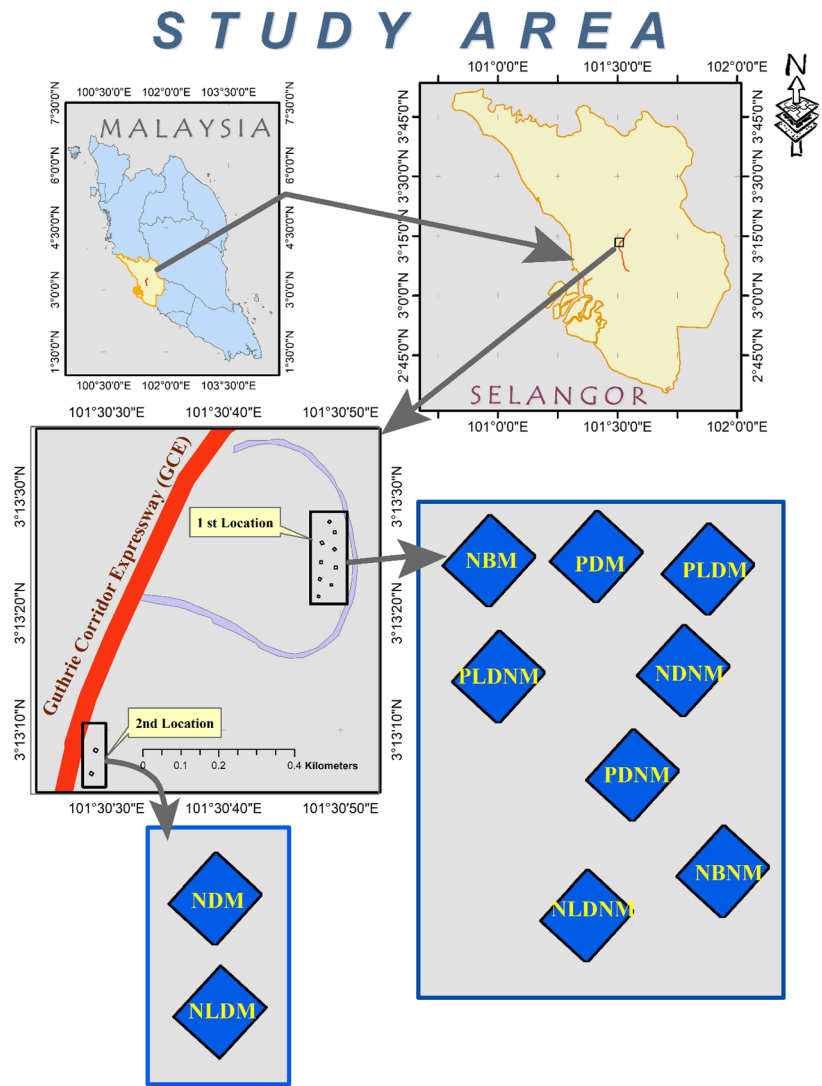
### Plot characterization and plant transplantation

In this study, some of the vegetation cover is seeded with microbes. The seeds of *Melastoma malabathricum* L and *Lantana camara* L are germinated with a surrounding temperature of 30 °C. About three weeks later, they are placed in a PVC pipe filled with sandy loam soil and placed in a greenhouse at the Institute of Biological Sciences, Faculty of Science, University of Malaya. When the seedlings reached about 1.0 m height, they are then transplanted to the site and a 50 g of commercialized bio-fertilizer is applied a week after transplantation. Bio-fertilizer is buried at 10 cm of soil depth adjacent to the transplanted plants in the microbe treated planted plot (PDM). A plot that received the transplantation but did not use the bio-fertilizer is named as the non-microbe planted plot (PDNM). At some plots, although the transplantation of *Melastoma malabathricum* L is not applied, this species is still available naturally. By applying bio-fertilizer to the naturally grown plants, the plot is characterized as natural plants with microbes (NDM). A plot that has a few naturally grown plants of similar species but without bio-fertilizer is known as a natural bare non-microbe plot (NBNM). Similarly, a plot with few naturally grown plants and with bio-fertilizer is known as a natural bare microbe plot (NBM). The name assigned on each plot (i.e., PDM, PDNM, NDM, NBNM, NBM) depending on either natural or planted vegetation cover, density of vegetation and also the inclusion of bio-fertilizer which indicates the presence of microbes or not.

### Field settings

A tipping bucket rain gauge is installed near to the experimental plots for measuring precipitation accurately. Therefore, a site reconnaissance survey is the first thing to do to identify the most suitable location for the rain gauge installation. As the experimental plots are located on hillslope, the crown of the small territory was considered as a suitable position for the rain gauge installation (Shih 1982). A data logger is attached to the rain gauge to facilitate collection of the precipitation data. For isolating the runoff from different plots, these are enclosed with 25-cm-high wooden barriers. The sketch diagram of the barrier setup and the layout plan of experimental plot along with sediment collector, pipes, barrier, etc., are depicted (Figs. 2, 3, 4). The size designed of sediment collectors to be used for all plots is same. Normally, the volume of sediment collector depends on how much water

**Fig. 1** Location (a) and aerial view (b) of the study area



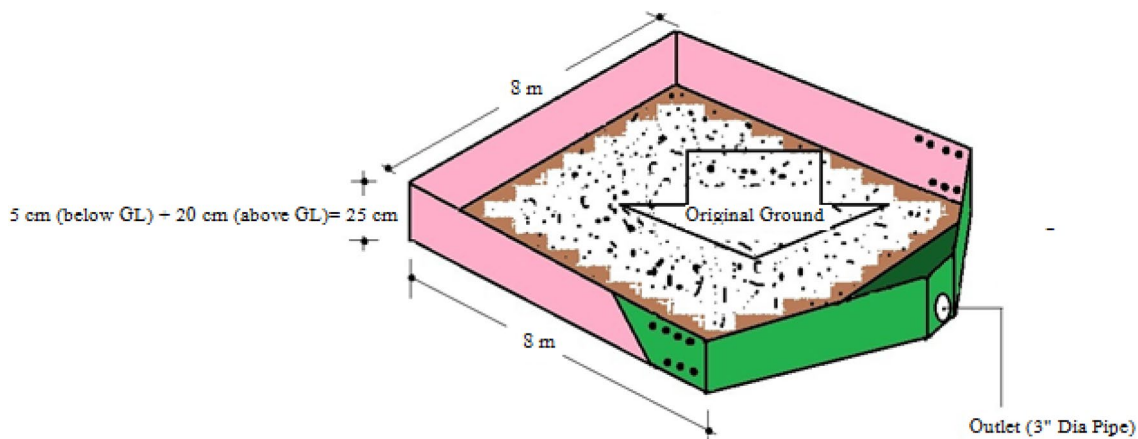
(a)



(b)

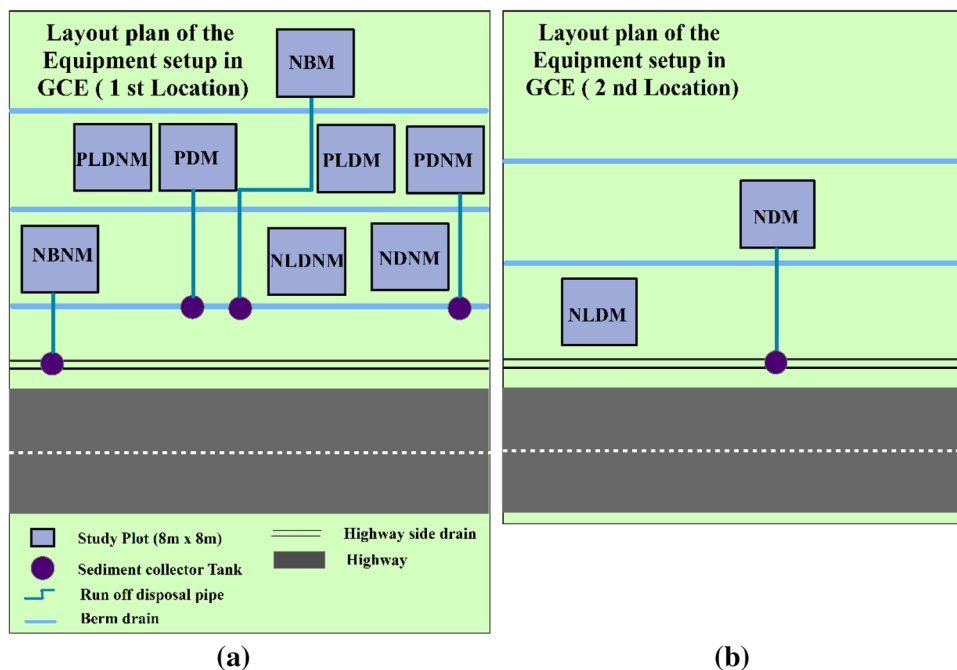
**Table 1** Characteristic of the plots

Plots	NBM	NBNM	PDM	PDNM	NDM
Description	Natural bare microbes	Natural bare non-microbes	Planted dense microbes	Planted dense non-microbes	Natural dense microbes
Plot size (m×m)	8×8	5×5	8×8	8×8	8×8
Hydrologic soil group	B	B	B	B	B
Avg. elevation (m)	74.39	75	76	76	44.96
Slope (%)	56	77	78	68	76
Permeability (category)	2	2	2	2	2
Vegetation cover (%)	25	5	60	70	96
Soil texture	2 (fine granular) and 3 (medium or coarse granular)				

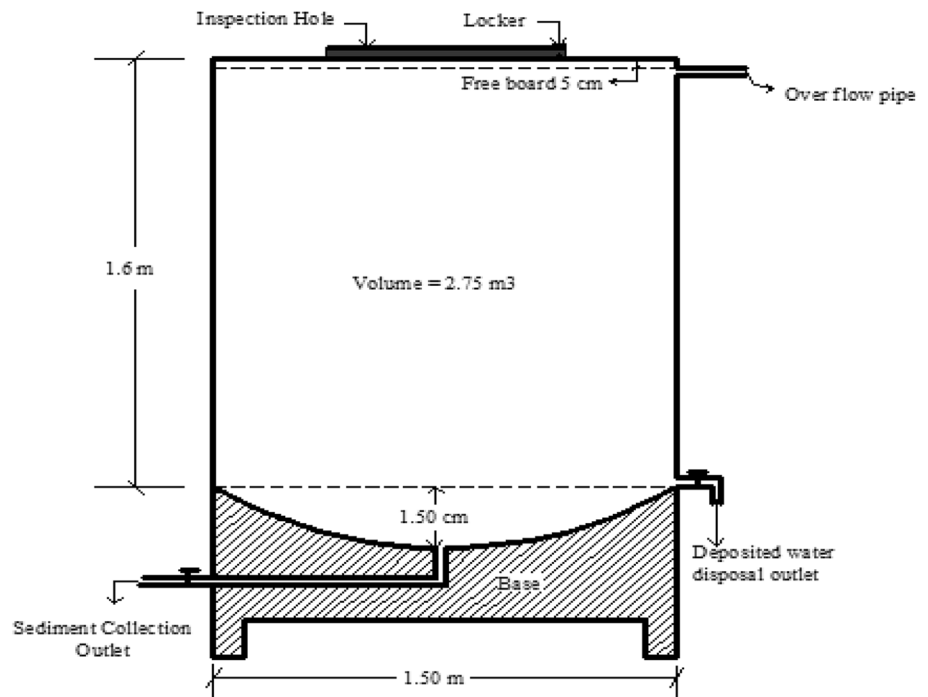


**Fig. 2** Sketch of the barrier

**Fig. 3** Layout plan of the experimental plot a location 1, b location 2



**Fig. 4** A sketch of sediment collector



would be accumulated to it as runoff. And the total volume of runoff water depends upon characteristics of the areas which receive the rainfalls and generate runoff for the given rainfall events. In this research, the volume of sediment collector is taken as  $2.75 \text{ m}^3$ . It is considered to be sufficient in accumulating the runoff and eroded soil for the semi-monthly retention period because the effective areas receiving rainfall events are actually less than the actual plot area since all study plots are situated in slope landscape. In addition, in the study area the frequency of intensive rainfalls that are capable of generating runoff is found very low (Fig. 5).

### Rainfall, surface runoff and sediment

As the experiment is performed during the monsoon season, the data for rainfall, runoff and sediment were collected on fortnightly basis. In each observation, the accumulated runoff is measured by volume and the sediment yield is determined by weight. Other than the settled sediments, suspended load in the sedimentation tank is also evaluated using the TSS analyzer for achieving accurate results. The wet eroded soil deposited at the bottom of the tank (after removing the water) is taken out and weighed in the laboratory after drying it at  $105 \pm 5 \text{ }^\circ\text{C}$  for 24 h. Rainfall is observed for the monsoon period, which is started from November 2014 to March 2015. The observed rainfall events with intensities that exceed  $2.75 \text{ mm h}^{-1}$  are considered as erosive and therefore are used for runoff and erosion computation. In this study, the observed rainfall

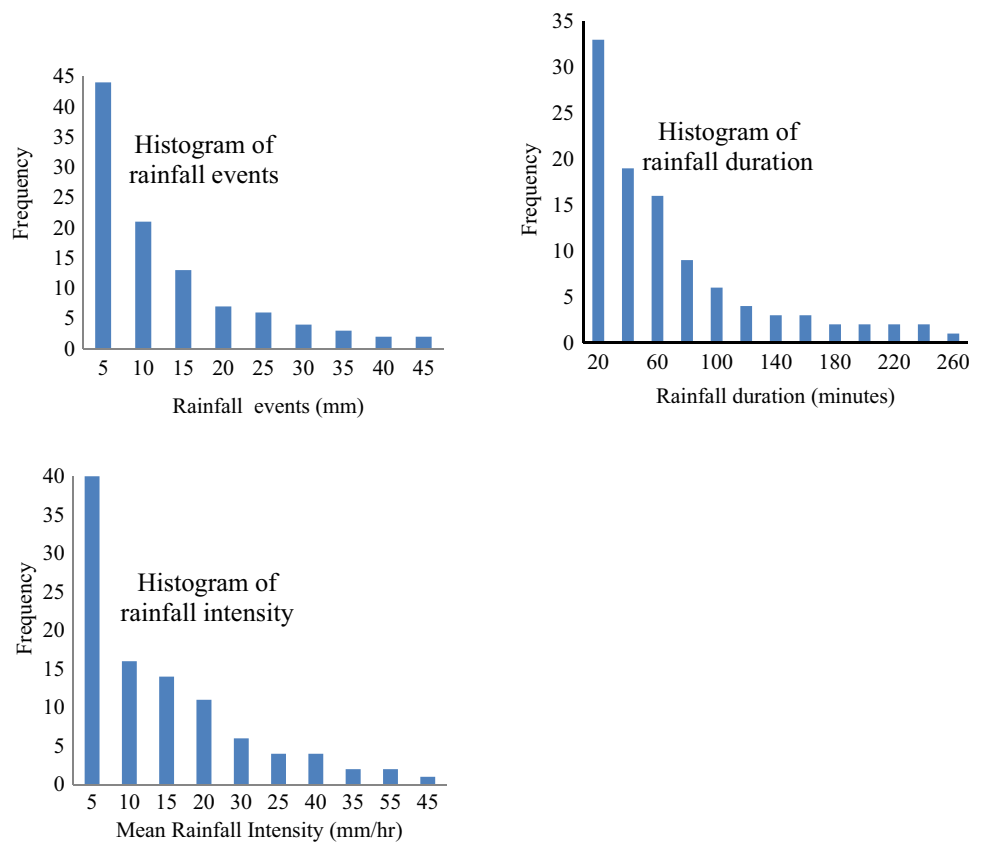
and soil loss are measured at plots, whereas for the runoff, the SCS method is used to derive this parameter. The SCS runoff curve number method had been used to predict the potential runoff in Alor Gajah and the Jasin basin (Adham et al. 2014). The collected rainfall and sediment data at plot areas are collected every 15th day of the month.

### Vegetation cover and topography

A digital camera is used to capture the actual density of vegetation. Using a portable camera, a ground image of the plot is captured vertically from 2.0 m above the ground to examine the distribution of vegetation cover based on the plot basis. Once the image is captured, it is then processed using the maximum likelihood algorithm in the ArcGIS10.1. In each image, a few representative pixels of the two classes namely bare soil and vegetation cover are selected as a reference for the algorithm classification. However, as the different images contain different pixel counts, a weightage area for the two classes is applied in the computation. The percentage of vegetation ground cover is computed by taking a ratio between the area of vegetation cover and the total area (i.e., vegetation cover and bare surface). Despite the fact that photograph images might not have been captured with a particular scale, the results obtained are normalized as all images are acquired in the same manner. Slope steepness is measured based on the digital elevation model (DEM) of the study plot.



**Fig. 5** Frequency distribution of rainfall events, duration and intensity



## Results

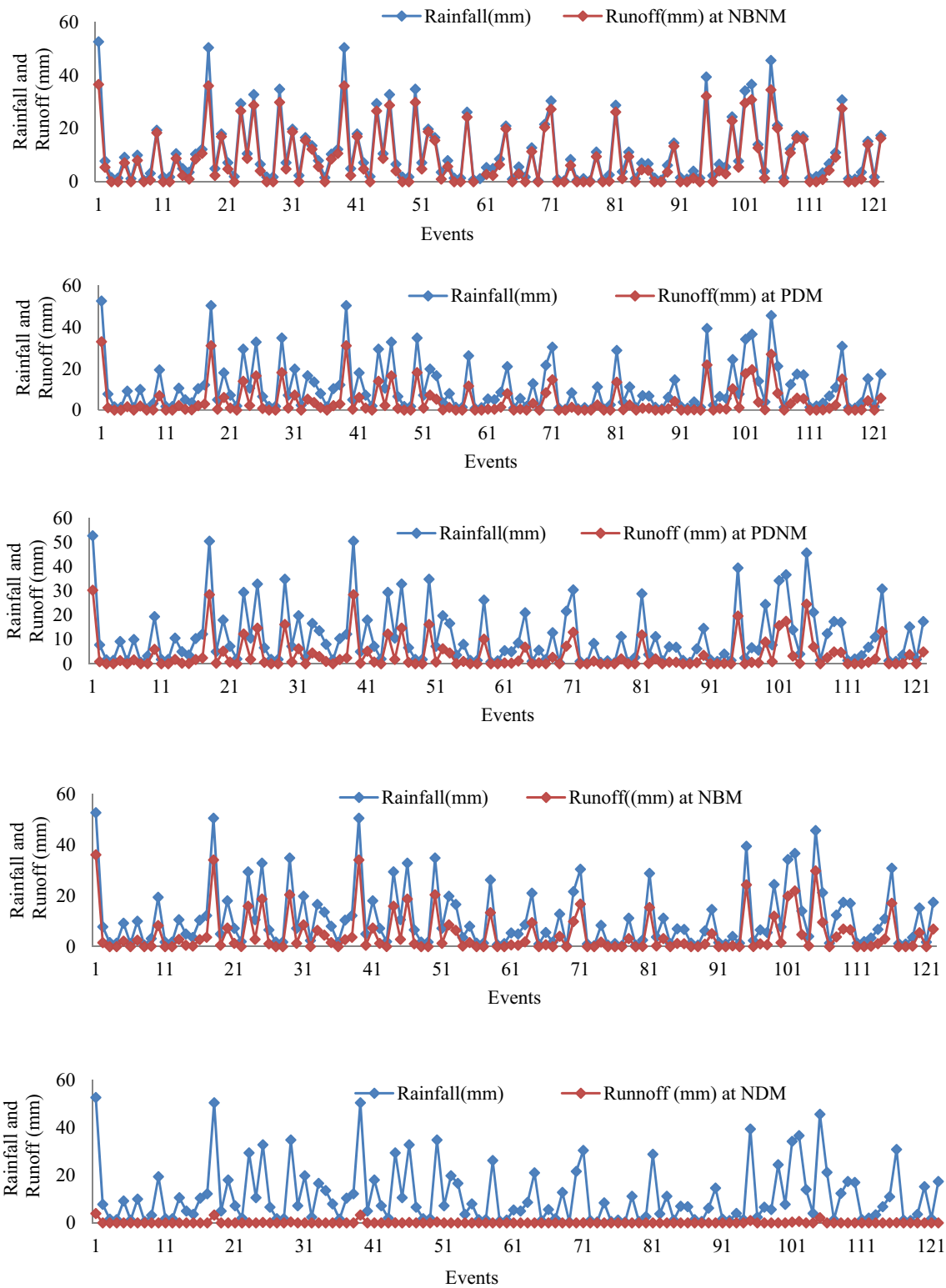
### Rainfall and runoff patterns

This section presents observation result of recorded rainfall at those five plots. Based on the data collected starting from November 2014 until March 2015, the recorded observed mean monthly rainfall was 310, 273, 220, 77 and 240 mm, respectively. In addition to this, magnitude, duration and intensities of rainfall pattern are also analyzed of which their values are found to vary between 3.6 to 52.6 mm, 15 to 396 min and 1.03 to 49.37 mm h<sup>-1</sup>, respectively. The rainfall frequency, duration and intensity graphs are depicted (Fig. 5) whereby it can be seen that in most rainfall events the highest recorded rainfall depth was about 5 mm with 20 min duration of rainfall and intensity of 5 mm h<sup>-1</sup>. The effect of vegetation cover on the surface runoff of hillslope area is investigated as the vegetation cover, and slope steepness have contributed to the amount of runoff directly. In this study, the amount of runoff yielded in relation to the number of rainfall events for all plots is depicted (Fig. 6). Out of five plots, the NBNM plot has yielded the largest amount of runoff followed by the NBM, PDM and PDNM. The amount of surface runoff in plots NBM, PDM and PDNM is almost similar. For the surface runoff at the NBNM plot, the amount is about equal to the event rainfall. This might be due to

minimal vegetal cover and therefore less infiltration process into the subsurface to occur. Conversely, only a few events of runoff are observed at the NDM plot. Correlation between rainfall and surface runoff is also shown (Fig. 7), and result shows that most of the R<sup>2</sup> values are well correlated with values are nearly 0.99.

### Factors affecting surface runoff and soil loss

This section investigates on the slope steepness and vegetation cover that affect the surface runoff and soil loss. First, in terms of slope steepness, it is found that the slope values of the study plots are varied within considerable range as they are located in hillslope (i.e., 77%, 78%, 68%, 56% and 76% for NBNM, PDM, PDNM, NBM and NDM plots, respectively). Second, the amount of surface runoff for the corresponding sequence plots of slope steepness is found to be 1058.77, 502.42, 438.92, 580.19 and 16.02 mm, respectively. The surface runoff of the respective plots is significantly varied due to difference in their slope steepness and infiltration rate. Infiltration rate is increased simultaneously with the increase in vegetation cover in a particular plot. That's why the runoff is resulted from the NDM plot which occupied by the vegetation cover of 96% is minimum. Whereas the maximum runoff is obtained from the NBNM plot whose vegetation cover is of only 5% (Table 1). Here,

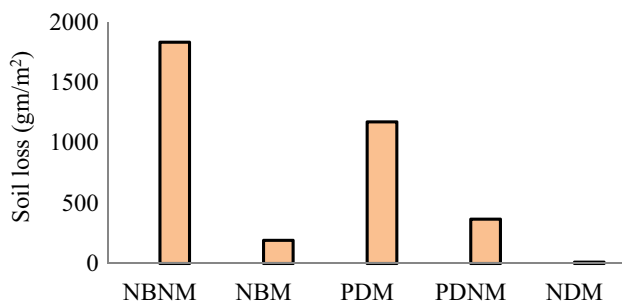
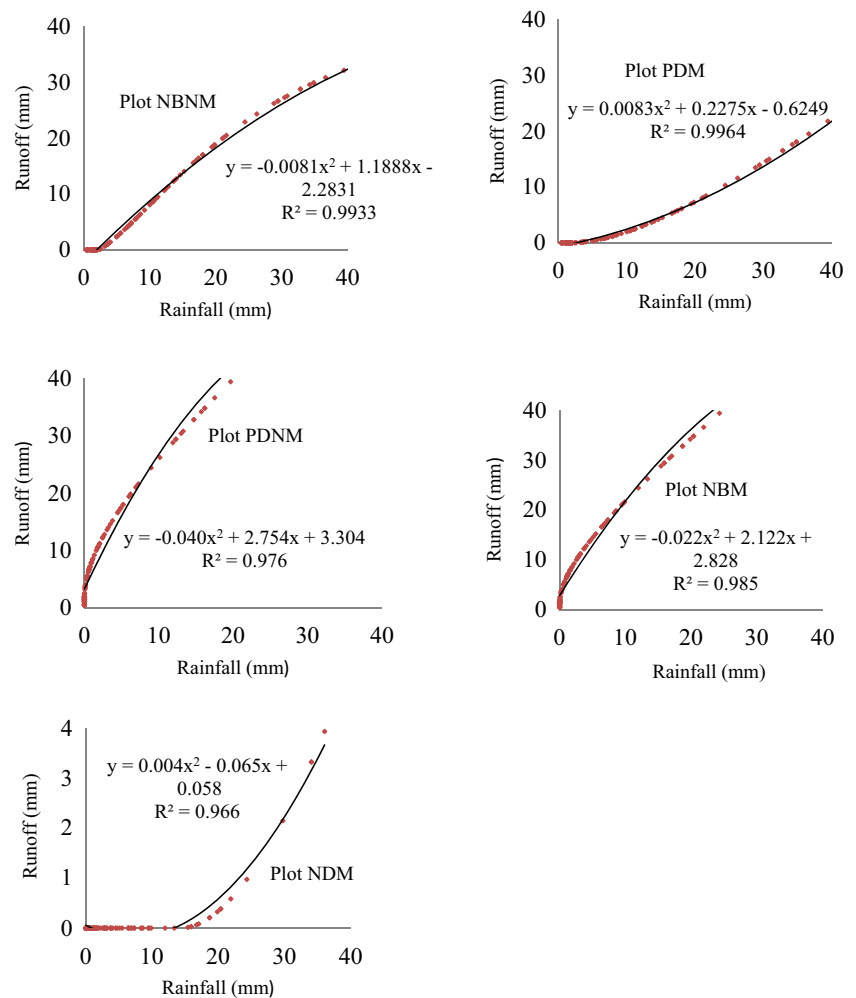


**Fig. 6** Surface runoff and rainfall events of all plots

the maximum runoff that resulted from the NBNM plot is found about 9 times higher than that of the NDM plot despite the slope steepness of those plot is nearly equal. Hence, the

role of the vegetation cover in reducing runoff is clearly depicted. The rest of plots have demonstrated a positive relationship between runoff and slope steepness regardless of the

**Fig. 7** Relationships between rainfall and surface runoff



**Fig. 8** Mean soil loss

vegetation cover type. The relationship between runoff and slope steepness with the presence of a vegetation fraction is almost consistent among all plots.

Usually, plots with steeper slope had greater soil loss than those with the lower values of slope steepness. The mean soil loss obtained was about 1833.4, 1173.32, 367.08, 192.42 and 11.92 g m<sup>-2</sup> for the NBNM, PDM, PDNM, NBM and NDM, respectively, as depicted (Fig. 8). Erosion occurred

at the NBNM was about 1.5, 5 and 9 times more than that of the PDM, PDNM and NBM, respectively. On the contrary, the erosion rate was found to be lowest for the NDM plot owing to high dense developed shrubs. The shrubs make the top soil stable enough for protection against heavy rainfall and any detachment hazards (Greacen and Sands 1980; Khaki et al. 2015). The rate of soil loss increases with slope steepness and vice versa with the existence of vegetal coverage (Chang et al. 2014). Hence, the erosion rate has individually demonstrated a negative and positive relationship with vegetation cover and slope steepness, respectively (Wang et al. 2014; Zhang et al. 2011). In the steepest slope topography, the availability of vegetation cover serves as the best criterion in controlling soil erosion.

## Conclusions

In this study, rainfall-induced soil erosion is assessed based on the observation of soil loss and rainfall data from study plots located on hillslope adjacent to the GCE with the



main focus on examining the effect of various vegetation density on the five experimental plots with either natural or planted vegetation and either with or without microbes. As the experiment incorporates natural and planted vegetation and microbes at those plots, the effect is somehow complicated. However, the concern of this study is to investigate various density of vegetation at those plots in relation to the soil loss that occurs during the monsoon season. In terms of vegetation, we can conclude that the naturally developed vegetation types especially fern and sod grass that grows on hillslope can contribute well in reducing the potential erosion. Based on the counted rainfall events data, the general pattern observed about the depth and duration is in most events, and the frequent rainfall depth occurs is about 5 mm with 20 min rainfall duration. As for plots, plot without vegetation cover (i.e., NBNM) yields greater soil loss and with maximum runoff whereas the least is exhibited by the plot having natural dense microbe (NDM). Meanwhile, the planted vegetation is found to be somehow effective in reducing the rate of soil loss. A positive relationship is found between runoff and slope steepness regardless of the vegetation cover type.

**Acknowledgements** The authors would like to acknowledge the University of Malaya for overall financial support and the PROLINTAS Expressway Sdn. Bhd., Malaysia, for using their Guthrie Corridor Expressway (GCE) slopes as experimental sites. This research was carried out by University of Malaya Research Grant (UMRG) under the project “Investigate Soil Hydrological Aspects and Vegetation Cover for Slope Erosion” Project No. PR005B-13SUS.

## References

- Adham M, Shirazi S, Othman F, Rahman S, Yusop Z, Ismail Z (2014) Runoff potentiality of a watershed through SCS and functional data analysis technique. *Sci World J*. <https://doi.org/10.1155/2014/379763>
- Akrami SA, Nourani V, Hakim S (2014) Development of nonlinear model based on wavelet-ANFIS for rainfall forecasting at Klang Gates Dam. *Water Resour Res* 28(10):2999–3018
- Azamathulla HM, Ghani AA (2010) ANFIS-based approach for predicting the scour depth at culvert outlets. *Water Resour Res* 2(1):35–40
- Boix-Fayos C, Martínez-Mena M, de Vente J, Albaladejo J (2009) Influence of land use changes on soil carbon stock and soil carbon erosion in a Mediterranean catchment. Paper presented at the Congreso Internacional sobre Desertificación
- Caraman S, Sbarciog M, Barbu M (2007) Predictive control of a wastewater treatment process. *Int J Comput Commun Control* 2(2):132–142
- Chang FJ, Chang LC, Wang YC (2014) Artificial intelligent techniques for optimizing water allocation in a reservoir watershed. Paper presented at the EGU General Assembly Conference Abstracts
- Dastorani MT, Moghadamnia A, Piri J, Rico-Ramirez M (2010) Application of ANN and ANFIS models for reconstructing missing flow data. *Environ Monit Assess* 166(1–4):421–434
- Dunne T (1977) Evaluation of erosion conditions and trends. In: Kunkle SH, Thames JL (eds) *Guidelines for watershed management*. FAO conservation guide 1, UN Food and Agriculture Organization, Rome, pp 53–83
- Firat M, Güngör M (2007) River flow estimation using adaptive neuro fuzzy inference system. *Math Comput Simul* 75(3):87–96
- Gautam D, Holz K-P (2001) Rainfall-runoff modelling using adaptive neuro-fuzzy systems. *J Hydroinf* 3(1):3–10
- Gernaey KV, van Loosdrecht MC, Henze M, Lind M, Jørgensen SB (2004) Activated sludge wastewater treatment plant modelling and simulation: state of the art. *Environ Model Softw* 19(9):763–783
- Goodwin GC, Sin KS (2014) *Adaptive filtering prediction and control*. Courier Corporation, North Chelmsford
- Greacen EL, Sands R (1980) Compaction of forest soils. A review. *Soil Research* 18(2):163–189
- Hamilton SK, Hussain MZ, Lowrie C, Basso B, Robertson GP (2017) Evapotranspiration is resilient in the face of land cover and climate change in a humid temperate catchment. *Hydrol Process* 32(5):655–663
- Islam MR, Jaafar WZW, Hin LS, Osman N, Hossain A, Mohd NS (2018) Development of an intelligent system based on ANFIS model for predicting soil erosion. *Environ Earth Sci* 77(5):186
- Khaki M, Yusoff I, Islami N (2015) Simulation of groundwater level through artificial intelligence system. *Environ Earth Sci* 73(12):8357–8367
- Kim S, Shiri J, Kisi O, Singh VP (2013) Estimating daily pan evaporation using different data-driven methods and lag-time patterns. *Water Resour Manag* 27(7):2267–2286
- Kumar P, Kumar D, Jaipaul A (2012) Evaporation estimation using artificial neural networks and adaptive neuro-fuzzy inference system techniques. *Pak J Meteorol* 8(16):81–88
- Lai SH, Soom M, Amin M, Law PL, Mah DYS (2008) Applications of GIS and remote sensing in the hydrological study of the Upper Bernam River Basin, Malaysia. *J Inst Eng, Malays* 69(1):13–18
- Maerker M, Sommer C, Zakerinejad R, Cama E (2017) An integrated assessment of soil erosion dynamics with special emphasis on gully erosion: case studies from South Africa and Iran. Paper presented at the EGU General Assembly Conference Abstracts
- Maier HR, Morgan N, Chow CW (2004) Use of artificial neural networks for predicting optimal alum doses and treated water quality parameters. *Environ Model Softw* 19(5):485–494
- Martínez-Casasnovas JA, Ramos MC, Benites G (2000s) Soil and water assessment tool soil loss simulation at the sub-basin scale in the alt Penedès–Anoia Vineyard Region (Ne Spain) in the 2000s. *Land Degrad Dev* 27(2):160–170
- Othman F, Muhammad S, Azahar S, Alaa Eldin M, Mahazar A, Othman M (2015) Impairment of the water quality status in a tropical urban river. *Desalin Water Treat* (ahead-of-print). <https://doi.org/10.1080/19443994.2015.1012331>
- Ozsoy G, Aksoy E, Dirim MS, Tumsavas Z (2012) Determination of soil erosion risk in the Mustafakemalpaşa River Basin, Turkey, using the revised universal soil loss equation, geographic information system, and remote sensing. *Environ Manag* 50(4):679–694
- Panagos P, Borrelli P, Meusburger K, Alewell C, Lugato E, Montanarella L (2015) Estimating the soil erosion cover-management factor at the European scale. *Land Policy* 48:38–50
- Piacentini T, Galli A, Marsala V, Miccadei E (2018) Analysis of soil erosion induced by heavy rainfall: a case study from the NE Abruzzo Hills Area in Central Italy. *Water* 10(10):1314
- Rezaeianzadeh M, Tabari H, Yazdi AA, Isik S, Kalin L (2014) Flood flow forecasting using ANN, ANFIS and regression models. *Neural Comput Appl* 25(1):25–37
- Shih S (1982) Rainfall variation analysis and optimization of gaging systems. *Water Resour Res* 18(4):1269–1277. <https://doi.org/10.1029/WR018i004p01269>
- Talei A, Chua LHC, Wong TS (2010) Evaluation of rainfall and discharge inputs used by adaptive network-based fuzzy

- inference systems (ANFIS) in rainfall–runoff modeling. *J Hydrol* 391(3):248–262
- Van der Helm A, Rietveld L (2002) Modelling of drinking water treatment processes within the Stimela environment. *Water Sci Technol Water Supply* 2(1):87–93
- Vietz GJ, Lintern A, Webb JA, Straccione D (2017) River bank erosion and the influence of environmental flow management. *Environ Manag* 61(3):454–468
- Wang J, Sun G, Shi F, Lu T, Wang Q, Wu Y, Oli K (2014) Runoff and soil loss in a typical subtropical evergreen forest stricken by the Wenchuan earthquake: their relationships with rainfall, slope inclination, and vegetation cover. *J Soil Water Conserv* 69(1):65–74. <https://doi.org/10.2489/jswc.69.1.65>
- Wilson GV, Wells R, Kuhnle R, Fox G, Nieber J (2018) Sediment detachment and transport processes associated with internal erosion of soil pipes. *Earth Surf Process Landforms* 43(1):45–63
- Yu RF, Kang SF, Liaw SL, Chen MC (2000) Application of artificial neural network to control the coagulant dosing in water treatment plant. *Water Sci Technol* 42(3–4):403–408
- Zeng G, Qin X, He L, Huang G, Liu H, Lin Y (2003) A neural network predictive control system for paper mill wastewater treatment. *Eng Appl Artif Intell* 16(2):121–129
- Zhang Q, Stanley SJ (1999) Real-time water treatment process control with artificial neural networks. *J Environ Eng* 125(2):153–160
- Zhang GH, Liu GB, Wang GL, Wang YX (2011) Effects of vegetation cover and rainfall intensity on sediment-associated nitrogen and phosphorus losses and particle size composition on the Loess Plateau. *J Soil Water Conserv* 66(3):192–200. <https://doi.org/10.2489/jswc.66.3.192>
- Zhang QG, Huang RQ, Liu Y-X, Su X-P, Li G-Q, Nie W (2016) A physically based geometry model for transport distance estimation of rainfall-eroded soil sediment. *Appl Sci* 6(2):34
- Zhang X, Lin P, Chen H, Yan R, Zhang J, Yu Y, Lv D (2018) Understanding land use and cover change impacts on runoff and sediment load at flood events on the Loess Plateau, China. *Hydrol Process*. <https://doi.org/10.1002/hyp.11444>

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.