Annual soil loss assessment of smallholder rubber growing lands in the Kalutara District, Sri Lanka using the RUSLE model in GIS

L A T S Liyanaarachchi*, J K S Sankalpa*, P G N Ishani*, A M R W S D Rathnayaka*, M W H Gayan*, B W Wijesuriya* and R P Hetiarachchi*

**Rubber Research Institute of Sri Lanka, Dartonfield, Agalawatta, Sri Lanka*

Abstract

Soil loss resulting from various land management practices in traditional rubber-growing areas of Sri Lanka has been a major issue of concern and one of the factors responsible for declining rubber land productivity. There is no or limited information on the spatial variability of soil loss from rubber lands in Sri Lanka's traditional rubber growing areas. This constraint has had a significant impact on the effective management of soil conservation in rubber-growing lands. This study focuses on assessing the soil loss from the smallholder rubber-growing lands in the Kalutara District using remotely sensed satellite image-based Digital Elevation Model (DEM), rainfall grid data, and prepared soil maps with ground-level surveys by Natural Resource Management Centre (NRMC) Sri Lanka. The factors including rainfall, topography, land area and the crop-specific coefficient for the rubber-growing lands in the study area were analyzed using the Revised Universal Soil Loss Equation (RUSLE) and Geographic Information System (GIS). The study revealed that about 30% of smallholder rubber-growing lands fall under the risk to severe risk categories of soil loss while about 60% of rubber lands are under the low-risk category. About 8,500 ha of smallholder rubber lands can be categorized as risk to severe risk for soil loss whilst about 15,000 ha are under the low-risk category for soil loss. The findings of this study are useful in the implementation of an effective soil conservation management plan and has the potential in applying this methodological approach in other areas of Sri Lanka for various crops.

Key words: Geographic Information System, Kalutara District, Revised Universal Soil Loss Equation, smallholder rubber-growing lands

Introduction

Soil erosion is a universal phenomenon that results in the loss of nutrient-rich surface soil, increased run-off from the more impenetrable subsoil, and decreased water availability to plants (Ganasri and Ramesh, 2015). Soil erosion by water has become a global concern in recent decades since the remarkable decline in the natural resources to population ratio (Terranova *et al.,* 2009) and affects global food security (Pimentel *et al*., 1995; Lal, 2001). Many countries around the world

are affected by accelerated soil erosion in varying conditions and developing countries suffer the most because their farming populations are unable to replace lost soils and nutrients (Erenstein, 1999) and the economic impact of the loss of nutrients is significant (Tamene and Vlek, 2006). Furthermore, soils are more vulnerable to erosion due to a variety of factors, including inappropriate agricultural practices, deforestation, overgrazing, forest fires, and construction activities.

The biophysical environment influences soil erosion which includes soil, climate, terrain, ground cover, and interactions between them (Ganasri and Ramesh, 2015). Besides biophysical environment factors, several land use management factors affect soil loss including the type of crop and tillage practices (Panagos *et al.* 2015). Whilst traditional agriculture is widely regarded as one of the primary causes of soil erosion, agroforestry practices are becoming increasingly valued for soil conservation (Béliveau *et al.,* 2017) and Young (1991) reported that tree canopy in agroforestry has the potential to control runoff and soil erosion.

It was reported that the conversion of tropical forest lands to plantations such as rubber (*Hevea brasiliensis* Mull. Arg.) monoculture and rubber-based agroforestry induces run-off and sediment yield Zhu *et al.* (2018). At present, rubber type called "*Amazonian rubber*", is mainly cultivated in South and South-East Asian countries. Smallholder farmers contribute to approximately 80% of global rubber production. In Sri Lanka, for example,

the majority of rubber is grown on smallholders' lands, which account for approximately 71% of the total land extent (89, 588 ha) (MPISL, 2020). More specifically, such farmers seem to have inadequate infrastructure to protect plantation soil from degradation. Rubber can be grown in most parts of Sri Lanka under varying agroecological conditions. The ideal temperature for rubber cultivation is between 25 and 28 degrees Celsius, with an annual rainfall of more than 2000 mm. More rain, on the other hand, may have an adverse impact on tapping days. The optimum sunshine condition is 2100 hours per year and the suitable mean annual relative humidity should be less than 80% (Anon., 2021).

The forest canopy does not always protect the surface soil from rain-splash erosion according to Calder (2001) and this is contrary to the common belief of protecting soil erosion from the forest canopy. Indirect rainfall is reported as having higher kinetic energy than direct rainfall since water intercepted by the canopy flows along leaves and produces larger droplets that eventually strike the ground (Nanko *et al.*, 2008; Geißler *et al*., 2012). Rubber is a tree crop that has vast potential to cultivate in agroforestry and varying geographical regions including hilly areas. Absence or limited studies (Liu *et al*., 2017; Zhu *et al.,* 2018) have focused on analyzing rainfall-induced soil erosion in rubber plantations under different physiographic conditions. Identification of areas with a higher probability of soil loss induced by rainfall and quantification of relevant probable

nutrient loss in such areas is vital in sustainable rubber land management.

The main topographic factors influencing soil erosion are slope, length, aspect, and shape. These factors contribute to rainfall run-off based on their varying degrees (Ganasiri and Ramesh, 2015). Significant efforts have been made to develop models of soil erosion quantification (Nearing *et al.*, 2005). The most widely applied empirical model for soil loss estimation is the Universal Soil Loss Equation (USLE) which is suitable for estimating soil loss in cropland and gently sloping topography. The USLE has been extensively used in studies for the estimation of soil loss with its revised version which is named Revised Universal Soil Loss Equation (RUSLE) (Lee and Lee, 2006; Remortel *et al.*, 2001). RUSLE has more advantages compared to the USLE in estimating the loss of soils (Renard, 1997) and is more flexible to model soil loss compared to USLE (Wischmeier and Smith, 1965). Geographic Information System (GIS) coupled with topographic features provides a user-friendly tool to analyze soil loss using soil loss equations and RUSLE with GIS can provide soil loss on a cell-by-cell basis (Shinde *et al.,* 2010). This approach is more beneficial when attempting to model soil loss over a large space. To address these research gaps, this study, therefore, aims to model the probability of occurrence and the quantity of soil loss in the smallholder rubber lands and subsequent possible nutrient loss.

Methods
Description of the study area and data
The study was conducted in the Kalutara district of Sri Lanka, where traditional rubber-growing lands are located in the Low Country Wet Zone. The study area lies between $79^0\ 88^{'}$ to $80^0\ 38^{'}$ Eastern longitudes and $6^0\ 32^{'}$ to $6^0\ 82^{'}$ Northern latitudes (Fig. 1). Rubber can be found in 26,564 ha of land in the Kalutara District. These lands belong to WL1a and WL1b agroecological regions. The regions of WL1a receive an expected annual rainfall (ERF) of 3200 mm or higher with a 75% probability while WL1b receives 2200 mm or higher. Both groups have major soil groups of Red Yellow Podzolic (RYP) and Low Humic Gley soils, while the terrain condition is undulating, hilly, and rolling. Table 1 gives the types and sources of data for the study.
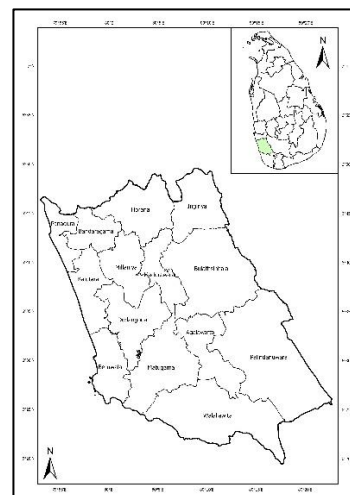

Fig. 1. Map of the study area, Kalutara District, and its Divisional Secretariat Divisions (DSD)

Table 1. *Data description*

Data type	Description	Sources of data collection
Digital Elevation Model (DEM)	100 m resolution grid Data	Genesis (Pvt) Ltd. Sri Lanka
Soil data	The great soil group map	Natural Resource Management Centre of Sri Lanka (Mapa & Somasiri, 1999)
	Soil properties for the Kalutara District	
Rainfall data	2.5m resolution grid data	www.worldclim.com
Rubber land area	Land use classification map of Kalutara District	Land Use Policy Planning Department (LUPPD) Sri Lanka
Crop factor	The effect of crop management practice on the rate of soil erosion	Munasinghe *et al*. (2001), Prasannakumar *et al*. (2012), Senanayake *et al*. (2013)
Soil Erodibility factor	The effect of the specific supporting practices of cultivation for soil erosion from up-slope to down-slope	Munasinghe *et al*. 2001, Prasannakumar *et al*. 2012, Senanayake *et al*. 2013

Model building and conceptualization of variables

The revised universal soil loss model

For this investigation, the revised universal soil loss equation (RUSLE) was used (Renard, 1997). The average annual soil loss was calculated using the RUSLE soil loss equation in the study area and the soil erosion risk map for the study area was mapped using Arc GIS pro version. According to Renard (1997), the RUSLE model simulates the effects of rainfall, topography, soil, and land use on rill and sheet soil erosion induced by rainwater and surface runoff. RUSLE can be mod

eled according to Eq. 1.

$$A = LS * R * K * C * P \qquad \text{(Eq. 1)}$$

Where,

A is the soil loss per unit area per year (t ha^{-1} yr^{-1}), *LS* is the slope length and steepness factor (dimensionless), R is the rainfall erosivity factor (MJ mm h^{-1} ha^{-1} yr^{-1}), *K* is the soil erodibility factor (t ha h MJ^{-1} mm^{-1}, *C* is the cover and management factor (dimensionless and it varies from 0 to 1.5), and *P* is the conservation or control factor (dimensionless and it varies from 0 to 1).

Modelling slope length and steepness factor (LS)

LS is influenced by the combined effect of slope length (*L*), slope steepness (*S*), and slope morphology on rill, inter-rill erosion, and sediment production. As slope length (*L*) increases, so does total soil erosion loss per unit as a result of downslope runoff accumulation. When the slope steepness increases, the velocity and erosivity of runoff increase

(Wischmeier and Smith, 1978). According to Pradhan *et al.* (2012), Inter-rill erosion is caused by raindrop impact on the soil surface and is thought to be uniform along a slope. The (L) parameter expresses the ratio of rill erosion (caused by flow) to inter-rill erosion (caused by raindrop impact) to calculate soil loss concerning a standard plot length of 22.1 m. The slope steepness parameter (S) describes how the slope gradient affects erosion in comparison to the standard plot steepness of 5.16. The effect of slope steepness on soil erosion loss is greater than the effect of slope length. As a result (LS) is the predicted ratio of s Soil loss per unit area from a 22.1 m long 5.16% slope. The digital elevation model (DEM) was used to estimate slope length (*L*) and slope gradient (*S*) for the study area. The DEM was prepared in GIS and derived the slope map for the area of Kalutara District. Then the derived slope map of the area was used to develop the flow direction map and flow accumulation map of the area. The calculation of the slope length factor (*L*) is described in Eq. 2.

$$L = (\frac{\lambda}{22.1})^m \qquad \text{(Eq. 2)}$$

Where *L* is the slope length factor, λ the Horizontal projected slope length (*m*), and *m* is the Slope length exponent. The exponent *m* is affected by the slope steepness in this equation. According to the study by Wischmeier & Smith (1978), the "m" value is equal to 0.5, 0.3, and 0.2 when the slope is ≥ 4.5%, 3-4.5%, and ≤ 1 %, respectively. The

mathematical derivation of slope steepness can be done using the following equations (Eq. 3 and Eq. 4) developed by McCool *et al.* (1987).
If the slope is less than 9%,

$$S = 10 \, \sin\alpha + 0.03 \quad \text{(Eq. 3)}$$
and

If the slope is greater than 9%,

$$S = 16.8 \, \sin\alpha - 0.5 \quad \text{(Eq. 4)}$$

Where *S* is the slope steepness factor and the α is the slope angle in degrees. A raster calculator is available in the ArcGIS ver. 10.2 was employed to generate the *LS* factor using spatial layers of factors, *L* and *S*.

Modelling Rainfall erosivity factor (R)
Rainfall intensity is a primary cause of soil erosion. Factor *R* expresses the possibility of runoff due to the impact of raindrops. To model the *R* factor for the local conditions, it was adopted the modeling approach reported by Premalal (1986) and the equation (Eq. 5) can be expressed as follows.

$$R = (\frac{972.75 + 9.95 * F}{100}) \qquad (5)$$

Where *R* is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1}Year^{-1}) and *F* is the average annual rainfall amount in mm. The same model has been used to estimate the *R* factor by Wijesundara *et al.* (2018) and Fayas *et al.* (2019) to quantify the soil erosion for the Kirindioya River and Kelani River basins in Sri Lanka.

Conceptualising Soil Erodibility Factor (K)

Soil's inherent properties have a direct influence on withstanding soil erosion. Also, the variation of resistance ability to erosion determines by the soil's physical properties such as texture, structure, aggregate stability, and available soil surface material. Brady & Weil (2008) have defined the K factor as the rate of soil loss per unit of erosive energy created by the rainfall calculated under a standard condition by a plot of land consisting of clean bare soil with a slope of 9% and 22.6 m long. The *K* factor for the Sri Lankan soil has been estimated by Wijesekara and Samarakon (2001) based on the estimated values for the great soil groups developed by Joshua (1977). Table 2 gives the *K* factor values for rubber-growing lands in the Kalutara District.

Table 2. *K factor values for different great soil groups in the study area*

Great soil group	Values of K factor
Red Yellow Podsolic	0.22
Sandy Regosols	0.48
Alluvial Soils	0.31

The great soil group map of Sri Lanka was obtained from the Natural Resource Management Centre (NRMC) and a great soil group map for the rubber growing areas in the Kalutara District was developed employing ArcGIS software.

Conceptualisation of Cover Management Factor (C)

The cultivation of crops always contributes to disturbing soils, changing topography, changing flow directions, *etc.* Therefore, cover cropping is practiced in cropland including rubber lands to protect bare land areas from soil erosion. A contrasting effect of crop management practices on soil erosion can be observed and factor *C* has been introduced to show this impact on soil erosion. Renard (1997) has reported the possibility of using the *C* factor for conservation plans. Land use classification maps published by the Survey Department of Sri Lanka were obtained to select the rubber-growing lands in the Kalutara District and the relevant C factor for the rubber-growing lands was estimated. Based on the study of Fayas *et al.* (2019), the *C* factor value for the rubber crop was assigned as 0.44. and spatial variability of the *C* factor was mapped using ArcGIS.

Conceptualisation of Support and Conservation Practice Factor (P)

The soil loss that occurred due to a particular crop-supporting practice in up-slope to down-slope cultivation is defined as the support and conservation practice factor (P). The *P* factor considers the capability of minimizing the eroding potential of rainfall and surface runoff. As the *P* factor values were assigned according to the required management practice for the study area, conservative measures of rubber plantations were considered. The *P* factor values for the different land use practices in Sri Lanka have been

reported in the literature (Munasinghe *et al*., 2001; Prasannakumar *et al.,* 2012; Senanayake *et al*., 2013; Wijesundara *et al*., 2018; Fayas *et al*., 2019). Considering the previous literature on *P* factor values, the *P* factor was assigned as 0.35 for the rubber-growing lands. The spatial variability of the p-factor values for the rubber-growing lands was mapped using ArcGIS.

Development of soil erosion severity map

All the prepared spatial data layers of *LS, R, K, C,* and *P* factors were projected based on the Kandawala Sri Lanka grid system and 100 m spatial resolution in the Kalutara District. The *RUSLE* equation ($A= LS*R*K*C*P$) was estimated using the raster calculator available in Arc GIS and annual soil loss per hectare of land per year on the map was depicted. Derived annual soil loss was categorized as low risk (0-7 t ha^{-1} yr^{-1}), moderate risk (7 -15 t ha^{-1} yr^{-1}), high risk (15 -25 t ha^{-1} yr^{-1}), very high risk (25 - 45 t ha^{-1} yr^{-1}), severe risk (45 - 65 t ha^{-1} yr^{-1}), and very severe risk (more than 65 t ha^{-1} yr^{-1}).

Results and Discussion
Distribution of LS, R, and K factors

Figure 2 shows the spatial variability of the LS, R, and K variables. The LS factors range from zero to 97, and some locations like Bulathsinghala, Walallawita, and Palindanuwara have high LS factor values. Due to the higher likelihood of anticipated rainfall in the aforementioned places, the Rainfall erosivity (R) is similarly high there. The spatial variability of the *K* factor value depends on the variation of soil physical properties in the Kalutara District. The *K* factor value varies from zero to 48 in the District. Since this study is concerned only with rubber plantation there is no spatial variability for C and P factors.

Soil erosion severity map

The annual loss by soil erosion is depicted in Figure 3. While the highest annual soil loss was recorded as 617 t/ha/yr and it was reported close to the Tannahena East Grama Niladhari Division (GND) in Bulatsinghala Divisional Secretariat Division (DSD). The severity of potential risk for soil loss, rubber lands under each category, and percentage contribution to total rubber lands describe in Table 3. Sixty percent of the land area belongs to the "Low Risk" category while around 15% of the land is under the "Very Severe Risk" category of the area.
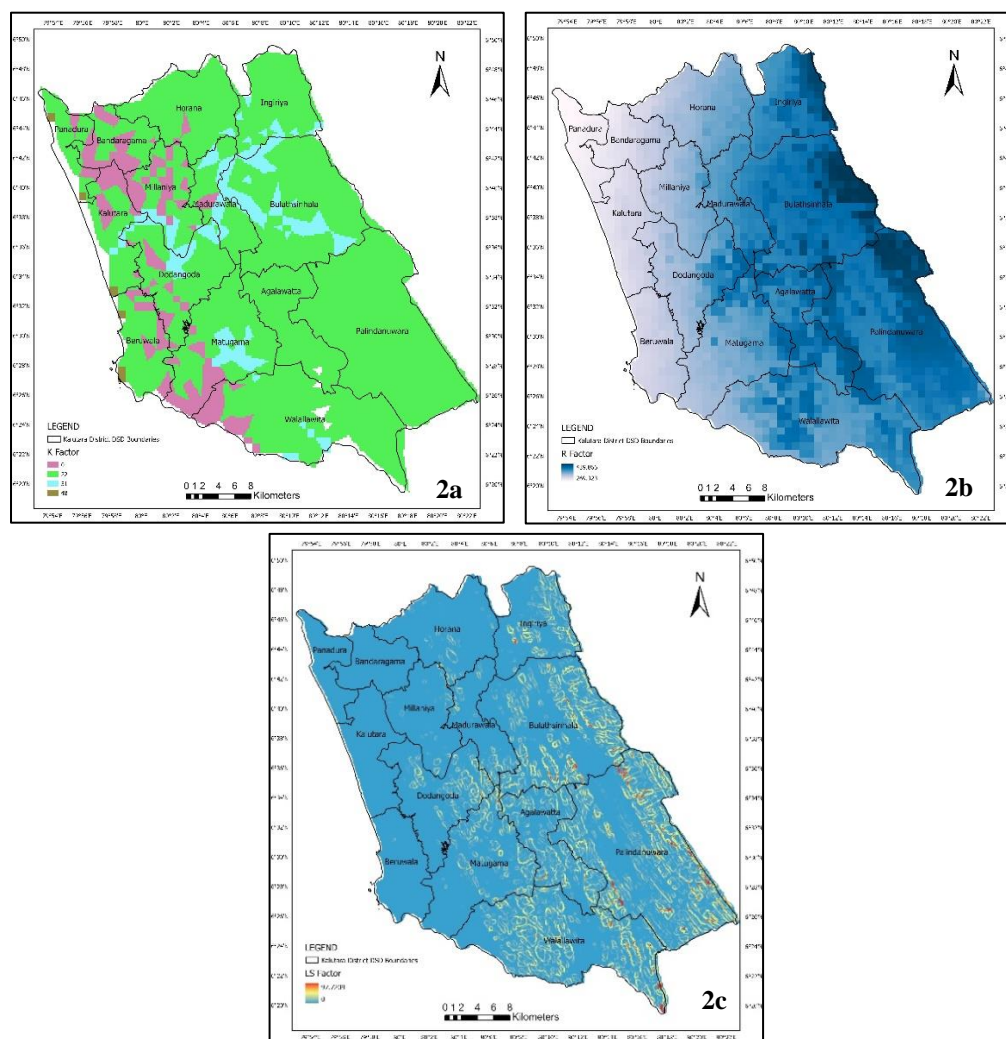
Fig. 2. Spatial variability of the **a.** *LS*, **b.** *R* and **c.** *K* factor

Table 3. *The annual soil loss from the rubber-growing lands in the Kalutara District*

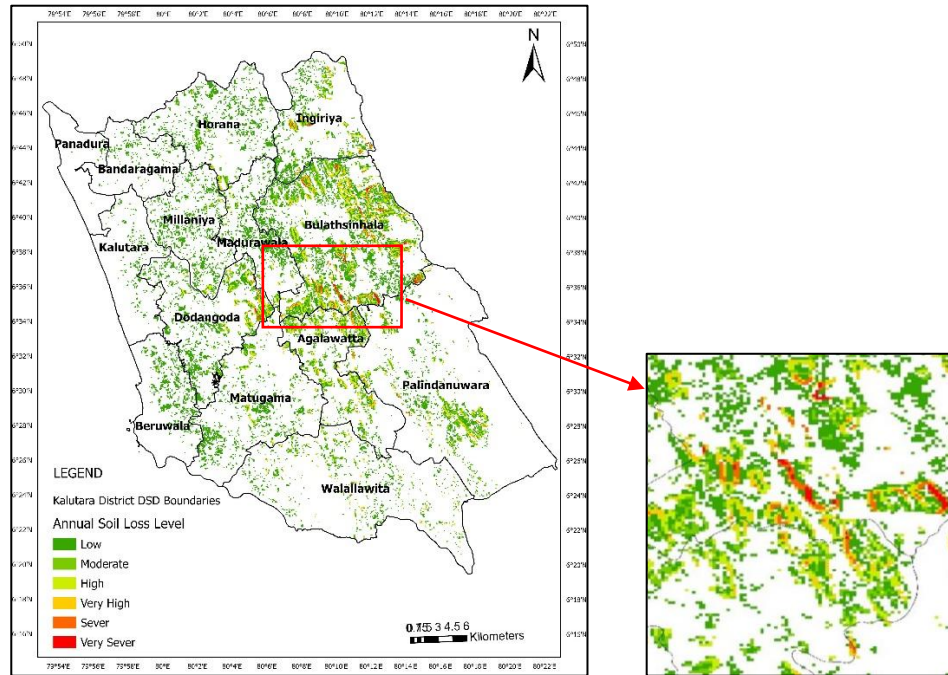| Soil loss risk category	Area of soil loss (ha)	Percentage contribution to total rubber lands (%)
Low risk	15,738	60.0
Moderate risk	1,755	6.6
High risk	1,247	4.7
Very high risk	2,012	7.6
Severe risk	1,492	5.6
Very severe risk	4,064	15.5

Fig. 3. The spatial variation in the annual loss of soil in the Kalutara District

Approximately 8,800 ha of rubber land (high risk to severe risk) requires immediate soil conservation measures. The spatial variability of the distribution of the risk of soil loss can be regarded as an indicator of the priority that soil conservationists and plantation managers must assign. The majority of these high-risk rubber lands are concentrated in specific areas of the Agalawatta and Bulathsinghala Divisional Secretariats within the Kalutara District, primarily due to the elevated rainfall erosivity observed in these regions.

Conclusions

According to the findings of this study, it is evident that approximately 30% of the rubber lands in the Kalutara District are at high to very high risk of soil erosion. The spatial distribution of soil erosion risk highlights the importance of implementing site-specific soil conservation measures that are proportionate to the potential erosion in each area. Additionally, a comprehensive best management plan can be developed to safeguard rubber-growing soils based on the identified risk levels, which can contribute to cost reduction in conservation efforts across farmlands.

Recommendations

To protect against soil loss and ensure sustainable rubber cultivation, it is crucial to consider the potential risk of

51

erosion when expanding rubber into non-growing areas. Non-rubber areas adjacent to high-risk soil loss areas may be particularly susceptible to erosion and require special attention. While approximately 60% of the District's rubber-growing areas are classified as low-risk, conducting site-specific investigations before formulating a conservation management plan is essential.

Moreover, it is important to note that the accuracy of topographic layers used in this study is contingent on the satellite imagery utilized and its spatial resolution. To improve accuracy, it is recommended to employ the appropriate satellite images and analysis methods. Furthermore, the findings of this study can be enhanced with the acquisition of more accurate and timely data in the future.

Acknowledgment

References

Anon. (2021). *Hand Book of Rubber Vol.1: Agronomy.* P.317. (Eds. V H L Rodrigo and P Seneviratne) Rubber Research Institute of Sri Lanka, Dartonfield, Agalawatta, Sri Lanka.

Béliveau, A, Lucotte, M, Davidson, R, Paquet, S, Mertens, F, Passos, C J and Romana, C A (2017). Reduction of soil erosion and mercury losses in agroforestry systems compared to forests and cultivated fields in the Brazilian Amazon. *Journal of Environmental Management* **203(1)**, 522-532. DOI: https://doi.org/10.1016/j.jenvman.2017.07.037.

Brady, N C, Weil, R R and Weil, R R (2008). *The Nature and Properties of Soils*. 13th ed. Prentice Hall, Upper Saddle River. New Jersey.

Calder, I R (2001). Canopy processes: implications for transpiration, interception and splash-induced erosion, ultimately for forest management and water resources. *Plant Ecology* **153,** 203-214. DOI: https://doi.org/10.1023/A:1017580311070.

Erenstein, O C A (1999). The Economics of Soil Conservation in Developing Countries: The Case of Crop Residue Mulching. PhD Thesis, Wageningen University, Wageningen.

Fayas, C M, Abeysingha, N S and Nirmanee, K G S (2018). An Application of RUSLE Model to Prioritize Erosion Control in Kelani River Basin in Sri Lanka.

Ganasri, B P and Ramesh, H (2015). Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin. *Geoscience Frontiers* **7(6)**, 1-9 DOI: http://dx.doi.org/10.1016/j.gsf.2015.10.007.

Geißler, C, Kühn, P, Böhnke, M, Bruelheide, H, Shi, X and Scholten, T (2012). Splash erosion potential under tree canopies in subtropical SE China. *Catena.* **91**, 85-93. DOI: https://doi.org/10.1016/j.catena.2010.10.009.

Joshua, W D (1977). Soil erosive power of rainfall in the different climatic zones of Sri Lanka.

Lal, R A T T A N (2001). Soil degradation by erosion. *Land Degradation & Development* **12(6),** 519-539 DOI: https://doi.org/10.1002/ldr.472.

Lee, G S and Lee, K H (2006). Scaling effect for estimating soil loss in the

RUSLE model using remotely sensed geospatial data in Korea. *Hydrology and Earth System Sciences Discussions* **3(1),** 135-157.

Liu, W, Luo, Q, Lu, H, Wu, J and Duan, W (2017). The effect of litter layer on controlling surface runoff and erosion in rubber plantations on tropical mountain slopes, SW China. *Catena* **149,** 167-175 DOI :10.1016/j.catena.2016.09.013.

Mapa, R B and Somasiri, S (1999). Soils of the Wet Zone of Sri Lanka: Morphology, Characterization and Classification. Soil Science Society of Sri Lanka, Sri Lanka.

McCool, D K, Brown, L C, Foster, G R, Mutchler, C K and Meyer, L D (1987). Revised slope steepness factor for the Universal Soil Loss Equation. *Transactions of the ASAE*, **30**(5), pp.1387-1396.

MPI (2020). Statistical Information on Plantation Crops. Ministry of Plantation Industries Sri Lanka, Sethsiripaya, Battaramulla, Sri Lanka.

Munasinghe, M A K, Pushpakumara, V, Bandara, T M J and Herath, H M B (2001). Use of information systems for soil erosion hazard assessment of the Central Province of Sri Lanka. *Annals of Department of Agriculture* **3**, p.148.

Nanko, K, Onda, Y, Ito, A and Moriwaki, H (2008). Effect of canopy thickness and canopy saturation on the amount and kinetic energy of throughfall: An experimental approach. *Geophysical Research Letters* **35**(5).

Nearing, M A, Jetten, V, Baffaut, C, Cerdan, O, Couturier, A, Hernandez, M, Le Bissonnais, Y, Nichols, M H, Nunes, J P, Renschler, C S and Souchère, V (2005). Modeling response of soil erosion and runoff to changes in precipitation and cover. *Catena* **61(2-3)**, 131-154 DOI: https://doi.org/10.1016/j.catena.2005.03.007.

Panagos P, Borrelli P, Meusburger K, Alewell, C, Lugato, E and Montanarella,

L (2015). Estimating the soil erosion cover-management factor at the European scale. *Land Use Policy* **48,** 38-50.

Pimentel, D, Harvey, C, Resosudarmo, P, Sinclair, K, Kurz, D, McNair, M, Crist, S, Shpritz, L, Fitton, L, Saffouri, R and Blair, R (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science* **267(5201)**, 1117-1123.

Pradhan, B, Chaudhari, A, Adinarayana, J and Buchroithner, M (2012). Soil erosion assessment and its correlation with landslide events using remote sensing data and GIS: a case study at Penang Island, Malaysia. *Environmental Monitoring and Assessment* **184(2),** 715-727.

Prasannakumar, V, Vijith, H, Abinod, S and Geetha, N J G F (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. *Geoscience frontiers* **3**(2), pp.209-215.

Premalal, R (1986). Development of an erosivity map for Sri Lanka. *Department of Agricultural Engineering.* University. Peradeniya, Kandy, Sri Lanka.

Remortel V, Hamilton, M and Hickey, M R (2001). Estimating the LS factor for RUSLE through iterative slope length processing of digital elevation data. *Cartography* **30(1)**. 27-35.

Renard, K G (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE).* United States Government Printing.

Senanayake, S S, Munasinghe, M and Wickramasinghe, W M A D B (2013). Use of erosion hazard assessments for regional scale crop suitability mapping

in the Uva Province. *Ann Sri Lanka Dep Agric.* 15, pp.127-141.

Shinde, V, Tiwari, K N and Manjushree, S (2010). Prioritization of micro watersheds based on soil erosion hazard using remote sensing and geographic information system. *International Journal of Water Resources and Environmental Engineering* **2(3)**, 130-136.

Tamene, L and Vlek, P L G (2006). Analysis of factors determining sediment yield variability in the highlands of Northern Ethiopia. *Geomorphology* **76,** 76-91.

Terranova, O, Antronico, L, Coscarelli, R and Iaquinta, P (2009). Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: An application model for Calabria (southern Italy). *Geomorphology* **112(3-4)** 228-245. DOI: https://doi.org/10.1016/j. geomorph. 2009.06.009.

Wijesekera, S and Samarakoon, L (2001). Extraction of parameters and modeling soilerosion using GIS in a GRID environment (2001). *Retrieved September*, 27.

Wijesundara, N C, Abeysingha, N S and Dissanayake, D M S L B (2018). GIS-based soil loss estimation using RUSLE model: A case of Kirindi Oya river basin, Sri Lanka. *Modeling Earth Systems and Environment* **4**, pp.251-262.

Wischmeier, W H and Smith, D D (1965). *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: Guide for selection of practices for soil and water conservation*. Agricultural Research Service, US Department of Agriculture.

Wischmeier, W H and Smith, D D (1978). *Predicting rainfall erosion losses: a guide to Conservation Planning* (No. 537). Department of Agriculture, Science and Education Administration.

Young, A (1991). Agroforestry for Soil Conservation. CAB International, Wallingford: UK.

Zhu, X, Liu, W, Jiang, X J, Wang, P and Li, W (2018). Effects of land-use changes on runoff and sediment yield: Implications for soil conservation and forest management in Xishuangbanna, Southwest China. *Land Degradation & Development* **29**(9), 2962- 2974. DOI: https://doi.org/10.1002/ldr.3068.

Address for correspondence: Mr L A T S Liyanaarachchi, Research Officer, Soils & Plant Nutrition Dept., Rubber Research Institute of Sri Lanka, Dartonfield, Agalawatta, Sri Lanka,
e-mail: *sangeethliyanaarachchi@gmaill.com*