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Accessing the soil erosion rate based on RUSLE model for sustainable land use management: a case study of the Kotmale watershed, Sri Lanka

DMSLB Dissanayake[1,2] · Takehiro Morimoto[3] · Manjula Ranagalage[1,2]

Abstract

Water based soil erosion is a serious socio-economic and environmental problem across the world especially in the tropical region. Assessing the soil erosion quantitatively and spatially provides information to prioritize the soil conservation area in sustainable land management view point. Among the other soil erosion approaches, erosion modeling has been playing a significant role and provides an accurate result in a cost-effective manner. In this study, revised universal soil loss equation (RUSLE) was integrated with remote sensing (RS) and geographic information system (GIS) to analyse the quantitative and spatial distribution of soil erosion across the entire Kotmale watershed which is located in the western part of the central mountain region in Sri Lanka. In the methodology, the parameters of the RUSLE model were estimated using pixel overlay method in ArcGIS software, both spatial data and remote sensing data facilitated with appropriate calibration. From the analysis, the annual soil erosion ranges from 0 to 472 t ha^{-1} year^{-1} with the mean and standard deviation 9.8 t ha^{-1} year^{-1} and 15.7 t ha^{-1} year^{-1} respectively. The mean erosion rate of the model was correlated with ground based data. After the final model was established, conservation priority area was identified by using hot and cold spot analysis. Here "hot spots" shows the area with high soil erosion clustering value, while "cold spot" refers to area with low soil erosion clustering. The soil conservation priority map has been produced and the result shows that approximately 25% represents hot sport. The result would be an aid and sources for soil and water conservation in the Kotmale watershed.

Keywords RUSLE · Kotmale watershed · Soil erosion · Erosion prone area · Hot and cold spot · Agriculture land sustainability

1. Introduction

The erosion phenomenon consists in the detachments of individual soil particles from the soil mass which are transported by erosive agents such as water and wind (FAO 2015). It moves the soil particles of the most upper layer of the ground from one plot to another plot. Further, soil erosion is a complex and progressive phenomenon that has been increasing around the twentieth century all over the world (Singh and Panda 2017). It is estimated that 75 billion metric tons of soil is removed by wind and water in annually (Diyabalanage et al. 2017). Moreover, FAO stated that global soil erosion by water is 20–30 Gt (gigatons) year^{-1} (FAO 2015). In addition to that, two billion hectares had been eroded by human intervention in globally. By this, water erosion has contributed to 1100 million hectares (Ganasri and Ramesh 2016). Water erosion in the tropical region is comparatively high due to the annual distributed rainfall coupled with other

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factors which are prevailing to the rill and inter-rill erosion (FAO 2015). Accelerated water erosion has become a leading soil degradation scenario in the tropical region because of the human activities (Diyabalanage et al. 2017).Hence, global soil erosion by water has reached an alarming level and it should be addressed sustainably.

Field survey based conventional soil erosion assessment methods are not cost effective and time-consuming task. Thus, several erosion models have been developed, and they can be categorized into three groups such as empirical, conceptual and physical (Devatha et al. 2015). Each model has its own attributes and application scope with the data that has been used to run the model (Ricker et al. 2008; Rahman et al. 2009; Wijesundara et al. 2018). Universal Soil Loss Equation (USLE) is an empirical soil erosion model which was formulated by the United States Department of Agriculture (USDA) in 1978 to conjecture amount of soil loss in long-term basis (Abdo and Salloum 2017). Furthermore, it focuses on inter-rill and rill erosion from cropland by water with the effects of some attributes of geology, climatology and topographical features. USLE was updated as The Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997). RUSLE was originally developed to assess soil erosion of gently sloping agricultural land (Wischmeier and Smith 1978). Hence, in recent years many researchers across the world adopted RUSLE. Some of them aligned to the watershed to compute the magnitude of the soil erosion associated with agricultural activities (Prasannakumar et al. 2012).

The clustering pattern of soil erosion provide the clear picture to undestand the conservation priority area. The Getis-Ord Gi* statistic is commonly used tool for understand the clustering pattern. The hot and cold spot analysis has been used by several field of studies, including disaster management (Gajovic and Todorovic 2013), urbanization (Rodriguez Lopez et al. 2017), land cover influence (Li et al. 2016), ecology (Wasowicz 2014) and green volume estimation (Handayani et al. 2018). A pixel to become a hot spot, it should have a high value and surrounded by high value recoded pixels (ESRI 2016a). Hot and cold spot analysis can be used to examine the spatial clustering pattern of variable (Ranagalage et al. 2018a). This study used hot and cold spot to identify the conservation priorities of Kotmale watershed.

Four major reservoirs have been constructed along the Upper Mahaweli Catchment Area (UMCA) by the Accelerate Mahaweli Development Program (AMDP). Kotmale is one of them which headwaters of the Mahaweli river (The Mahaweli Authority of Sri Lanka 2012). Moreover, the Kotmale watershed is important in several aspects such as drainage on the dry zone, enhancing the strength of the hydroelectricity and contributing to the inland and outland development. The main objective of this study was to assess the quantitatively and spatially amount of annual soil loss using RUSLE combining with GIS and RS in the Kotmale catchment. In addition to that, secondary objectives are made (1) to compute soil erosion probability zone and priority area, (2) to examine human interference for the soil erosion in the viewpoint of agricultural activities and land use changes, and (3) to identify the conservation priority are using hot and cold spot.

Materials and methods

Study area: Kotmale watershed

The Kotmale is one of the watershed in UMCA covers approximately 572 km^2 of surface from the dam site, feeds the both Kotmale and upper Kotmale reservoirs. The geographic location extends from latitude 7°6′32.80″N to 6°47′33.12″N and from longitude 80°50′21.26″E to 80°34′31.34″E which encompasses in the south-central mountainous and administrative belongs to Nuwara Eliya district in Sri Lanka(Fig. 1). The watershed is very intricate and diverse attributable to the location of the hilliest area. The Digital Elevation Model (DEM) derived from 1:50,000 data (Sources - Department of Survey in Sri Lanka) illustrates an elevation ranges from 681 m to 2505 m above mean sea level and slopes ranging from 0° to 72°. The general slope of the terrain is towards Northeast of the watershed. Regarding hydro–climatological status, the watershed area is located in a tropical climate region, characterized by heavy rainfall and relatively constant, high temperature and humidity. The Kotmale watershed experiences according to the monsoon distribution of the rainfall. The greatest rainfall is reported during the Southwest monsoon (May to September). Annual rainfall over the Kotmale watershed area is approximately 1800–2500 mm but may be fluctuated due to the seasonal variation and climate changes (Johansson 1989). The Kotmale river (Kotmale Oya) is the longest tributary and headwaters of the Mahaweli river which is the fourth longest river in Sri Lanka. The river originates as the *Agra river* (*Agra Oya*) in the Hatten plateau itself, and the total length is approximately 70 km (Johansson 1989). The hydro–climatological features have made the area very liable to heavy soil erosion.

As an ecological perspective, mountain forest distributes upper part of the catchment area, and less dense forest patches are dispersed across the watershed. The watershed contains a rich biodiversity which including several flora and fauna organisms. There have been taken place many biophysical and socio-economical changes in the Kotmale watershed associated with soil erosion (Johansson 1989). Land degradation, siltation, loss of soil fertility and loss of natural habitats are highlighted among them. Despite of several research opportunities which are enabled by RUSLE,
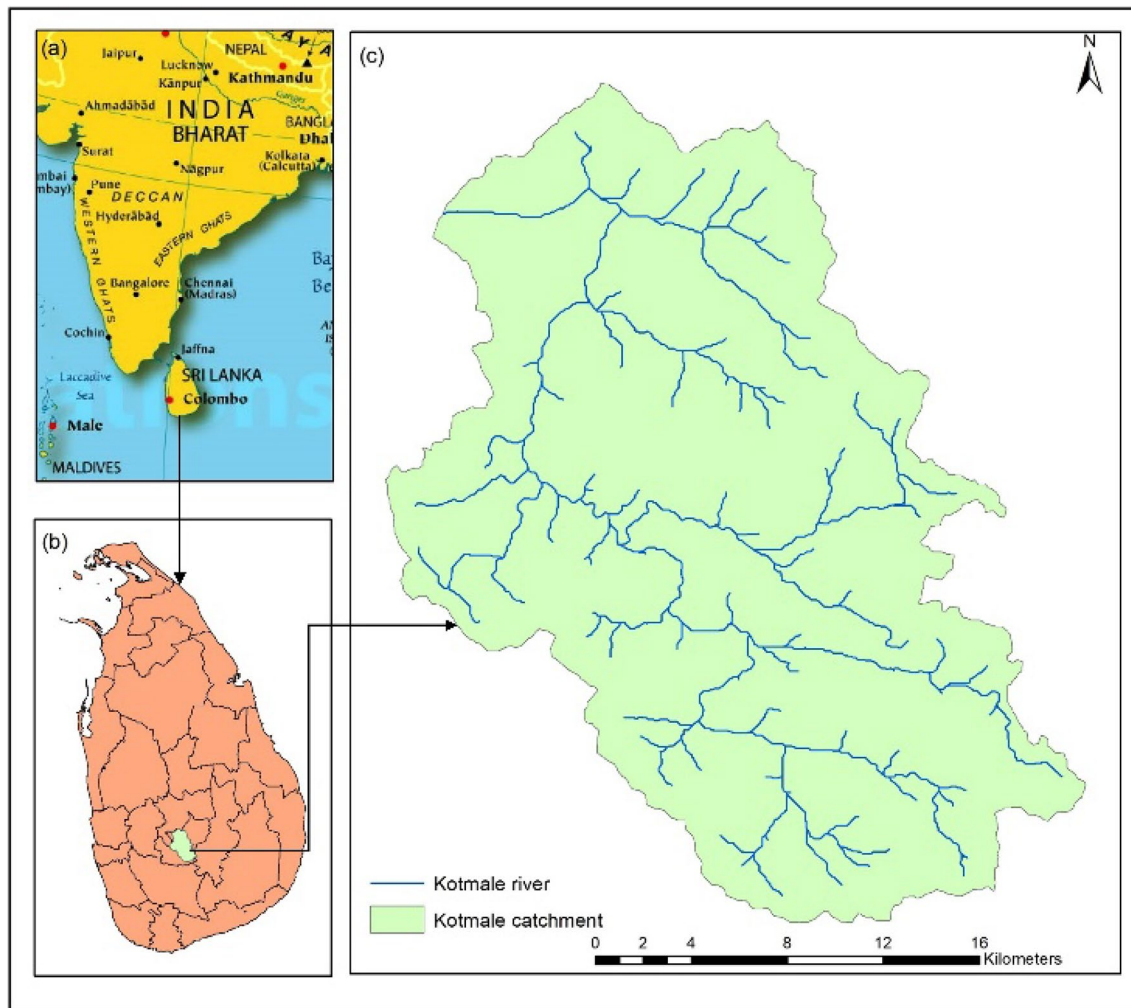
Fig. 1 Location map of the study area: **a** map of South Asia (map source: http://www.nationasonline.org); **b** location of Kotmale watershed; **c** the extent of the study area with Kotmale river (*Kotmale Oya*)

GIS, and RS only few research studies have conducted in watershed level in Sri Lanka but not directly address to the Kotmale watershed (Zubair 2001; De Silva 2002; Weerasinghe 2007). Only some reports illustrate socio-economic and environmental information (The Mahaweli Authority of Sri Lanka 2012; Johansson 1989). By considering the above information, Kotmale watershed was selected as a research area because of soil erosion at an alarming rate that would be needed to address immediately.

RUSLE module structure

The RUSLE represents how both physical and anthropogenic or semi anthropogenic (land use/land cover) affect rill and inter-rill soil erosion caused by raindrop and surface runoff (Renard et al. 1997). In this study, RUSLE

model was used to compute the long term average annual soil loss and five factors were analyzed using the following empirical equation. Eq. 1.

$$A = R \times K \times LS \times C \times p \tag{1}$$

where, A is the estimation of average annual soil loss or gross soil erosion by sheet and rill erosion (t ha^{-1} year^{-1}); R is the rainfall erosivity factor which accounts for the energy and intensity of rainstorms (mm ha^{-1} h^{-1} year^{-1}); K is the soil erodibility factor which is a measure of the susceptibility of soil to detachment under a standard condition ; LS is the combination of the slope steepness and slope length measurements; C is the cover and management factor which accounting for effects of prior land use, canopy, surface cover and surface roughness; P is the support practice factors.

RUSLE model integration with GIS and RS

Recent advances in GIS and RS have been enabling more precise estimation of RUSLE model to make easy laboratory processing. Hence, many scholars have used RUSLE model with GIS and RS for the various kinds of research and decision making purposes (Ozsoy et al. 2012; Balasubramani et al. 2015; Biswas and Pani 2015; Fenta et al. 2016). In the application of RUSLE model on GIS and RS environment, soil loss is estimated by using raster analysis. For the estimation and mapping of the spatial distribution of soil loss in the study area, all parameters (maps) having the same projection system (World Geodetic System 1984/ Universal Transverse Mercator 44N) and spatial resolution of the data was set at 30 m × 30 m cell which is consistent with the Landsat-8 operational land imager/thermal infrared sensor (OLI/TIRS) image and make a uniform spatial analysis environment in the GIS platform.

All water bodies including lakes (tanks) and reservoirs were excluded from the analysis by considering zero contribution to sheet erosion and rill erosion because RUSLE model computes only erosion which caused by sheet, rill, and inter-rill erosion. Some similar studies have adopted this methodology to the computation of the reliable results (Prasannakumar et al. 2012; Thomas et al. 2017). Then, the layers were overlaid and multiplied pixel by pixel with respective attributes which is shown in Eq. 2 (Gelagay and Minale 2016).

$$A = R_i \times K_i \times LS_i \times C_i \times P_i \tag{2}$$

where, the subscript i represents the ith cell.

Derivation of R factor from rainfall data

The rainfall erosivity factor (mm ha^{-1} h^{-1} year^{-1}) reflects the detachment of soil at a location by raindrop splash erosion. The product of rainfall kinetic energy (E) and the maximum 30 min rainfall intensity (I30) continuous precipitation data are required to calculate the R factor (Wischmeier and Smith 1978; Ganasri and Ramesh 2016), but it is very difficult to gather the rain gauging based records of rainfall intensity for long periods in research area due to malfunction of data collection procedure. Hence, many scholars have proposed more mature and simple calculation methods of rainfall erosivity based on monthly and annual rainfall (Marco 2004; Dutta et al. 2015). This calculation method can be effortlessly incorporated with RS and GIS through the interpolation technique. There are several kinds of interpolation technique in GIS environment. Among them, Inverse Distance Weighted (IDW) is widely used computation of spatial data due to simplicity and high accuracy (Ozsoy et al. 2012; Gunaalan et al. 2018). R factor was computed by using

monthly rainfall data which was published by the Department of Meteorology in Sri Lanka in 2016. In this computation process, 26 rain gauging stations which are located not only within the watershed but also 5 km buffer bordering range have been considering for maintaining high accuracy of the result (Ganasri and Ramesh 2016). A number of formulas have been developed to compute the R factor, among them the Eq. 3 was used to compute the R factor which is developed by Premalal 1986 (Wijesekara and Samarakoon 2001), especially for Sri Lanka.

$$R = \frac{972.75 + (9.95 \times P)}{100} \tag{3}$$

where, R is a rainfall erosivity factor, P is the mean annual rainfall in mm.

Derivation of K factor from soil attributes

Soil erodibility (K) factor represents both susceptibility of soil to erosion and the rate of runoff, as measured under the standard unit plot condition (Ganasri and Ramesh 2016). Spatial distribution of the soil types and its categories were identified by using 1:200,000 vector data published by the Department of the survey in Sri Lanka but there were not relevant attributes (texture, organic matter, structure, and permeability) of each soil types with existing data. Hence, each attribute of the soil types are determined by secondary data sources which were published by the Soil Science Society of Sri Lanka in 1999 (Mapa et al. 1999). As a next step, nomography is used to compute the value of K based on its properties such as texture, organic matter, structure and permeability (Wischmeier and Smith 1978; Ganasri and Ramesh 2016).

Derivation of LS factor from topography

The effect of the topography is playing the wider role in the soil erosion process. Thus, RUSLE model accounts it by the LS factors which combine the effect of a slope length factor (L) and slope steepness factor (S). The L factor represents the effect of slope length on erosion and it is defined as the distance from the origin of overland flow along its flow path to the location of either concentrated flow to the channel or deposition. When L factor increases, total soil erosion and soil erosion per unit area is increased by progressive accumulation of runoff in the downslope direction. S factor represents the effect of slope steepness on erosion. Soil loss and its velocity increases more rapidly with slope steepness than it does with slope length (Prasannakumar et al. 2011). The GIS and RS technology have enabled more precise estimation of LS factor through the raster calculation process by using DEM. Equation 4 illustrates LS factor computation method employed in this study. A number of similar studies have adopted this

methodology for calculation of LS factor (Lu et al. 2004; Balasubramani et al. 2015; Ganasri and Ramesh 2016).

$$LS = \left(\frac{Q_a \, M}{22.13} \right)^y \left(0.65 + 0.045 \times S_g + 0.65 \times S_g^2 \right) \quad (4)$$

where, LS is slope length and slope steepness, Q_a is the flow accumulation grid, M is the grid size (30×30), and y is the dimensional exponent that depends on the slope gradient. 0.5 on the slope of 5% or more than, 0.4 on the slope of 3.5–4.5%, 0.3 on slopes of 1–3%, and 0.2 on the uniform gradient of less than 1% (Wischmeier and Smith 1978). In this study, the slope gradient was 3.1%. Hence, 0.3 was taken as a value of y. S_g is the angle of the slope.

30 m spatial resolution DEM was used as a primary data source to compute the LS by using Arc GIS 10.4. After conducting fill and flow direction process, flow accumulation was calculated with Arc hydrology tool in order to formulate the L factor. In the same way, the slope was derived from the DEM with the same resolution. Then, S factor was computed by using the slope data. Finally, LS factor was calculated in Arc GIS raster calculation using the map algebra expression in Eq. 4 (Gelagay and Minale 2016).

Derivation of C factor from vegetation cover

Cover and management factor is the subsequent significant factor next to the topographic factor. It is defined as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith 1978). Detachment of soil is very sensitive to vegetation/land cover with slope steepness and slope length factor. Vegetation cover and canopy behaves as a blanket in order to dissipate the raindrop energy before reaching the bare soil surface (Prasannakumar et al. 2011). Normalized Difference Vegetation Index (NDVI) was used to compute the vegetation cove.

NDVI is a common and productive method of monitoring surface vegetation. Its value is various from -1 to $+1$ range donoting -1 as a non-vegetation and $+1$ as a high-dense vegetation (Ranagalage et al. 2017, 2018b). Similarly, C factor value also ranges between 0 to $+1$. Hence, many researchers use this principle to estimate C factor from NDVI (Alexakis et al. 2013; Dutta 2016; Abdo and Salloum 2017). Landsat Thematic Mapper (TM) images (path: 141, row: 55) acquisition date on 2016.03.15 were exploited to assess the NDVI value. Then, NDVI values were scaled to approximate C values using the following provisional Eq. 5

$$C = exp \left[-\alpha \frac{NDVI}{(\beta - NDVI)} \right] \quad (5)$$

where, $\alpha = 1$ and $\beta = 2$ (Alexakis et al. 2013). In many studies have been used this values to compute C factor and found that this scaling approach gave better result (Prasannakumar et al. 2011; Shit et al. 2015) NDVI is Near Infrared (NIR) $-$ Red (R)/Near Infrared (NIR) $+$ Red (R).

Derivation of P factor from land use/land cover

Erosion control practice factor is the ratio of soil loss with a specific support practice to the corresponding loss with up slope and down slope cultivation (Wischmeier and Smith 1978). By considering lack of updated land use and land cover information in the study area, the current land use digital data layer (Sources: Department of Survey in Sri Lanka, 2011) has been updated by using remote sensing data (reference with google earth image). Using this method ten land use types were updated, and field observation data were used to validate the updated land use types (Ranagalage et al. 2018c). Identification of different agricultural land use pattern was one of the objective of this land use updating process. It was difficult to distinguish between each agricultural land use types by using classification (pixel-based or object-oriented) due to the similar spectral signature. By considering this obstacle manual updating was adapted. Values of the P factor have been assigned for each land use types. Two methods were used to assign the value to the P factor in each land use types as shown in Table 1. (1) Literature information and results of the previous research (Prasannakumar et al. 2012; Singh and Panda 2017; Wijesundara et al. 2018) (2) Knowledge of the expertise in the field of agriculture and soil conservation in Sri Lanka. The value of P factor ranges from 0 to $+1$, the value denoting 0 is sustainable conservation methods (dense forest) and the value approaching $+1$ is poor conservation practices(open land) (Prasannakumar et al. 2012; Singh and Panda 2017).

Hot and cold spots analysis

The ArcGIS optimized hotspot analysis (Getis-Ord Gi*) tool was used for spatial analysis (Ranagalage et al. 2018a; Ord and Getis 1995). This analysis based on the 210×210 m grid. After the set of the grid had been established, the mean soil erosion value of final erosion model was calculated. The grid not fully covered the catchment areas was excluded during the hotspot analysis. Specially the grid where located in the boundary were not considered. The Gi* statistic for each mesh represented the z-score. The higher positive z-values were grouped as a hot spot, and negative z-values were grouped as a cold spot. The z-value characterizes the clustering significance for a specified distance based on the confidence level (ESRI 2016a, b).

Table 1 Land use types in the Kotmale watershed with P value

| No.	Land use types	Area km^2	Percentage	"P" Value	References for "P" value
1	Water	6.8	1.2	0.00	Prasannakumar et al. (2012), Aiello et al. (2015), Wijesundara et al. (2018)
2	Dense forest	174.6	30.5	0.10	Aiello et al. (2015)
3	Less Dense forest	40.4	7.1	0.20	Wijesundara et al. (2018)
4	Grass land	3.4	0.6	0.30	Prasannakumar et al. (2012)
5	Paddy land	3.7	0.7	0.35	Wijesundara et al. (2018)
6	Home garden	60.1	10.5	0.25	Wijesundara et al. (2018)
7	Tea land	223.8	39.1	0.50	Prasannakumar et al. (2012)
8	Scrub land	39.9	7.0	0.58	Wijesundara et al. (2018)
9	Bare land	17.9	3.1	0.70	Prasannakumar et al. (2012)
10	Chena	1.4	0.3	0.75	Wijesundara et al. (2018)

Results

Rainfall erosivity factor

Minimum rainfall 413 mm and maximum 2648 mm is observed in the rain gauging station of *Labukele* (station number 22) and *Delthota Estate* (station number 20) respectively. The value of the mean annual rainfall was 1564 mm, and the standard deviation was 317 mm in the year of 2016. Spatial variation of the rainfall illustrates in (Fig. 2a) with respective rain gauging stations. The Western part of the watershed was obtained higher rainfall than the other area because Southwest monsoon (May to September) is the main rain sources of the Kotmale watershed which was explained in details under the study area.

A continuous surface was developed from the point data of the 26 rain gauging stations. The estimated R factor value ranges from 50 to 244 mm ha^{-1} year^{-1}, and standard deviation was 33.9 mm ha^{-1} year^{-1} and mean was 153.6 mm
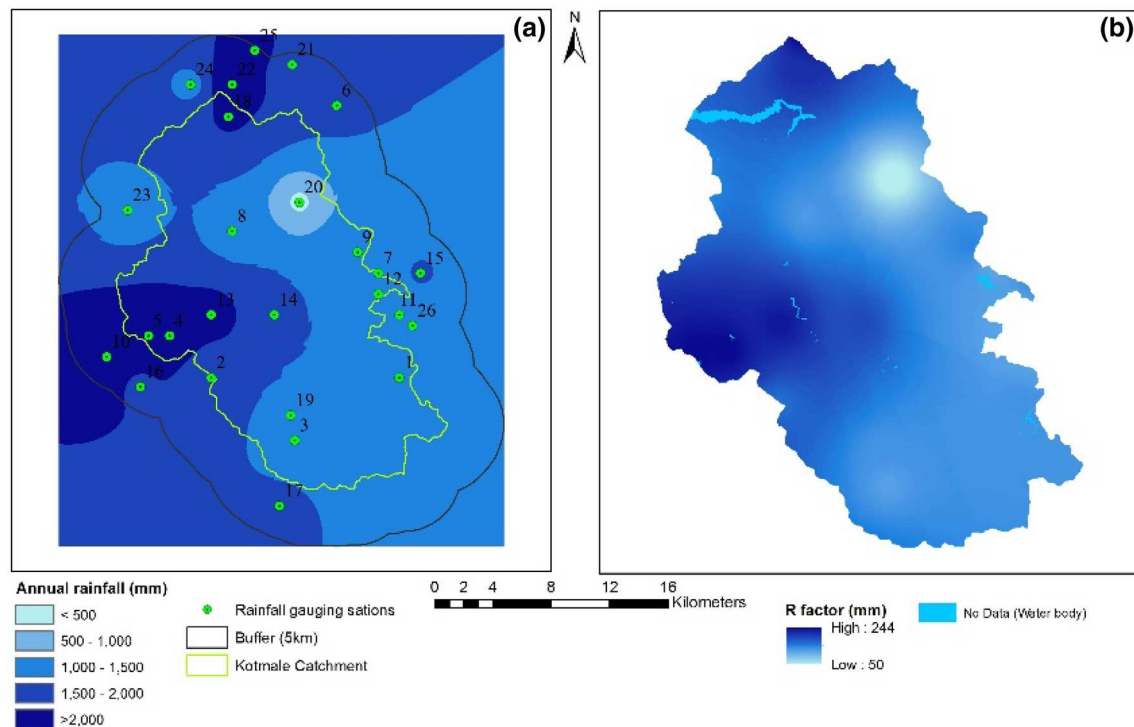
Fig. 2 a Spatial distribution of the rainfall with corresponding rain gauging stations in the Kotmale watershed; **b** R factor of the Kotmale watershed

ha^{-1} year^{-1} within the selected period. High R factor value shows that the area where the highest rainfall was accumulated (Fig. 3b).

Soil erodibility factor

Three dissimilar soil types are comprised in the Kotmale watershed which expressions in (Fig. 3a). Among them, 51% belongs to Red-Yellow Podzolic with hilly and rolling terrain category, and 40% and 9% is denoted by Red-Yellow Podzolic with mountainous terrain and Red-Yellow Podzolic with dark B horizon, respectively. K values are assigned to each soil by considering soil attribute of them. Though there are three soil types, two of them are expressed the most similar classes (Mapa et al. 1999). Hence, these two soil types are denoted with same K value (0.18) and represent the less K value with high permeability rate compared with other soil type. The higher value of K (0.21) belongs to Red-Yellow Podzolic with dark B horizon, and it represents moderate permeability rate which susceptibility to the detachment (Fonseca et al. 2017).
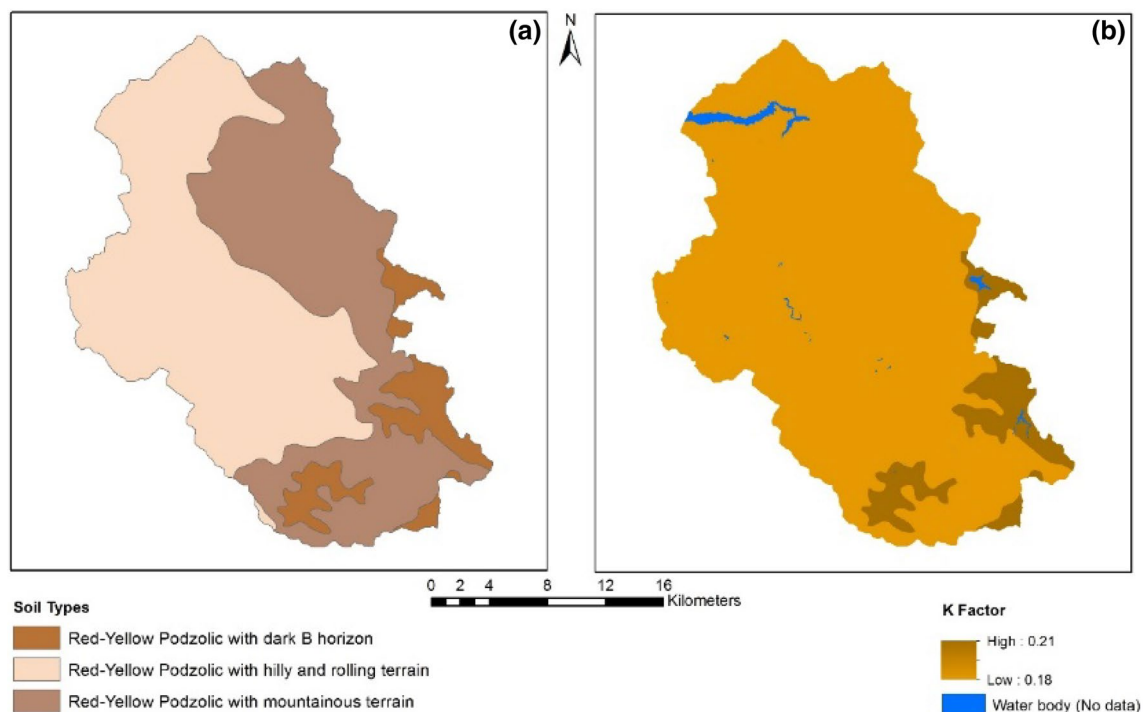
Slope length and steepness factor

The slope of the study area varies from 0° to 72°, with a mean and standard deviation of 13° and 8° correspondingly. The areas where acquired by the water bodies and other few polders denote the 0°, and most of area belongs to high slope

area. As a comparison, most of the hilly areas shows in the northern portion of the watershed than the others, middle and lower slope areas disperse the watershed as shown in (Fig. 4a).

The lower part of the watershed area represents high accumulation (slope length) as a result of the contribution of upstream. The upper part of the watershed area denotes opposite of this principle due to the low contribution of river branches in headwater to the total accumulation (Gelagay and Minale 2016) as shown in (Fig. 4b). Slope steepness (S factor) shown in (Fig. 4c) revealed that the higher value in the high slope area and lower value of the lower elevation area specially polder. With the above explanation, slope length and slope steepness are homogeneously contributed. In addition to that, both (L and S) factors were calculated by considering the slope and flow accumulation which was derived from the same elevation data on DEM. Thus, LS factor was calculated as a combined approach shown in (Fig. 4d). It is observed that the value of LS ranges from 0 to 324.

Cover and management factor

Vegetation cover of the Kotmale watershed was computed by using NDVI. From the analysis, the value of the NDVI ranges from −1 to 0.94, with the mean and standard deviation of 0.77 and 0.12 respectively as shown in the (Fig. 5a).

Fig. 3 **a** Spatial distribution of the soil types in the Kotmale watershed; **b** K factor of the Kotmale watershed
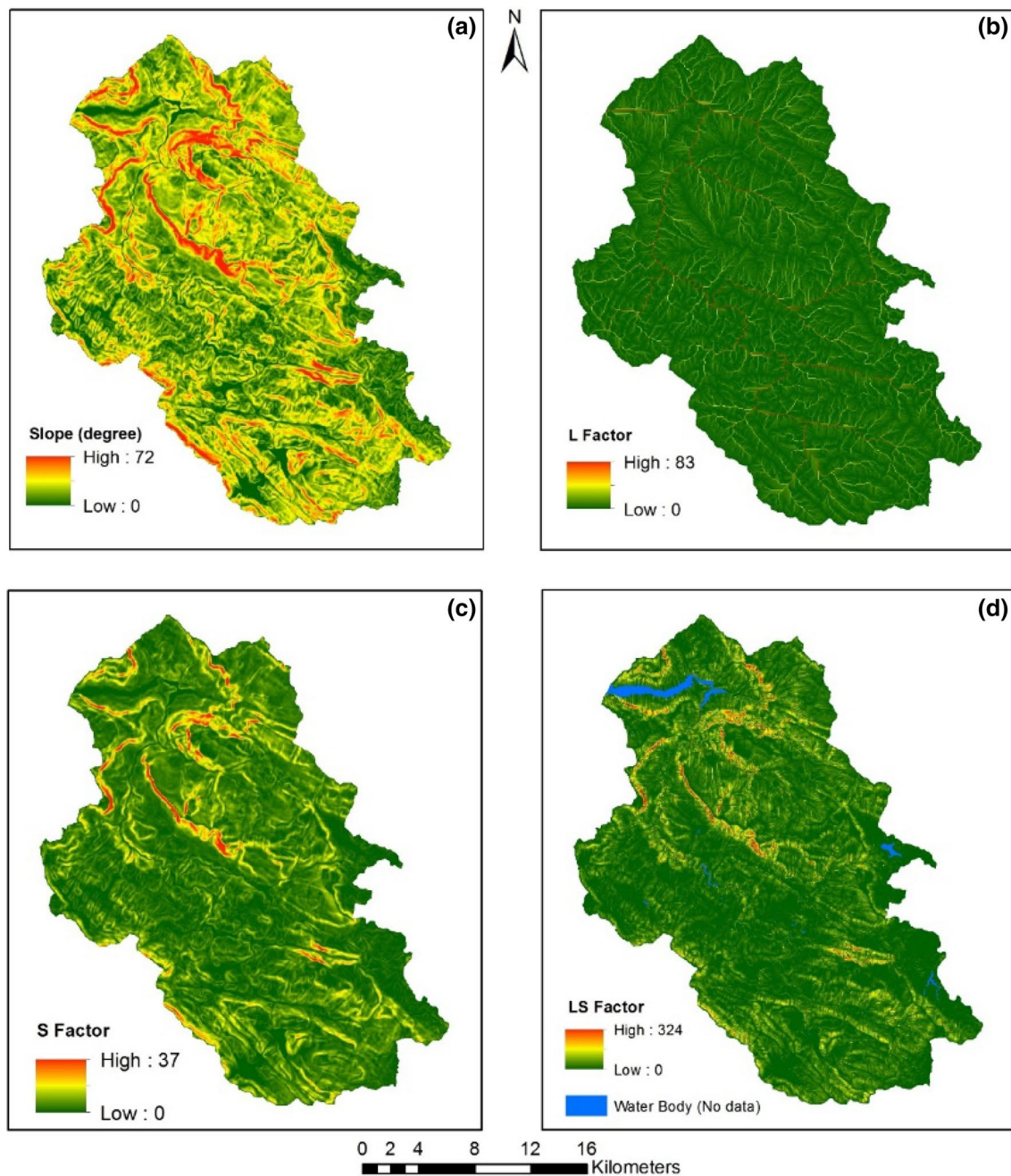
Fig. 4 **a** Spatial distribution of the slope in the Kotmale watershed; **b** slope length; **c** slope steepness; **d** LS factor of the Kotmale watershed

The lowest NDVI values denote the less vegetation cover including water and its gradual increase from non-vegetation to solid vegetation. Values of the C factor were computed by using NDVI and values were ranged from 0 to 1 as shown in (Fig. 5b). Mean value was 0.45, and the standard deviation was 0.17. The lower value of the C factor indicates in the solid vegetation area, and higher value of C factor implies that non-vegetation. Comparatively, the lower value of the C factor disperses through dense forest

area as shown in (Fig. 6b), and other values are taking placed consequently of the portion of vegetation.

Support practice factor

In focusing on the main purpose, spatial distribution of land use types was clustered into the ten classes as shown in (Table 1). Commercial agricultural land (tea cultivation) has spatially distributed over the western part of the watershed
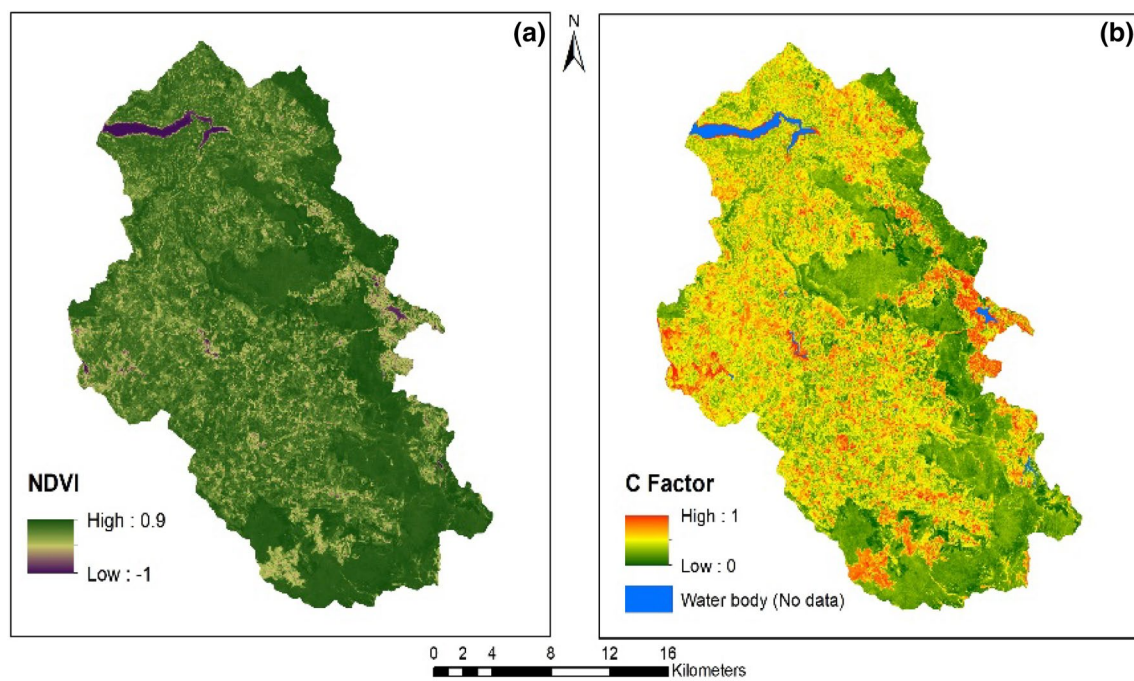
Fig. 5 **a** Spatial distribution of the NDVI in the Kotmale watershed; **b** C factor of the Kotmale watershed
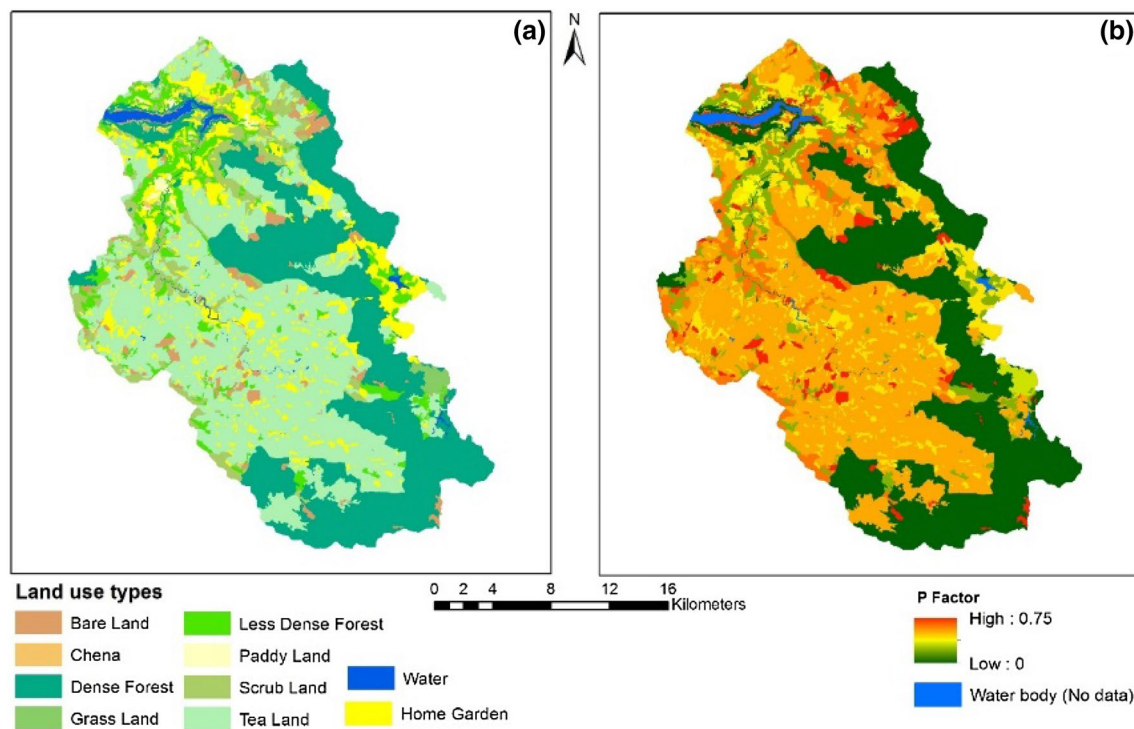
Fig. 6 **a** Spatial distribution of the land use in the Kotmale watershed; **b** P factor of the Kotmale watershed

as shown in (Fig. 6a). The dense forest has distributed along the boundary of South and West part of the watershed as a bounded band and denotes 30.5% out of the total land property.

In this study, the P factor values were computed by evaluating land use information. The value of P factor ranges from 0 to 0.75, highest value observed the area where no conservation methods adopted and lower values observed the area that associated with higher conservation practices as shown in (Fig. 6b).

Spatial distributions of annual soil erosion

The spatial distribution of annual soil erosion was produced by overlaying the five factors of RUSLE using the raster calculator with Eq. 2. According to the result of the analysis, the annual soil erosion ranges from 0 to 472 t ha^{-1} year^{-1} with the mean and standard deviation 9.8 t ha^{-1} year^{-1} and 15.7 t ha^{-1} year^{-1} correspondingly.

For the visual interpretation and easy understanding, the ranges values have been breakdown into the class by using appropriate interval. Earlier similar studies related to the RUSLE and soil erosion based on GIS have been used several approaches to define classes interval for the zone of the potential annual soil erosion to emphasize the real situation (Prasannakumar et al. 2011; Aiello et al. 2015). In this study, classes interval of the severity was defined by using a natural break and examining the past research that has been taken place on similar methodology (Ostovari et al. 2017). This approach have been led to assign five soil erosion severity such as very low (< 10 t ha^{-1} year^{-1}), low (from 10 t ha^{-1} year^{-1} to 30 t ha^{-1} year^{-1}), moderate (from 30 t ha^{-1} year^{-1} to 60 t ha^{-1} year^{-1}), severe (from 60 t ha^{-1} year^{-1} to 100 t ha^{-1} year^{-1}) and very severe (> 100 t ha^{-1} year^{-1}). The created soil erosion probability zone as shown in (Fig. 7) and comprehension summary has been tabulated into the (Table 2).

Fig. 7 Spatial distribution of annual soil erosion (t ha^{-1} year^{-1}) in the Kotmale watershed
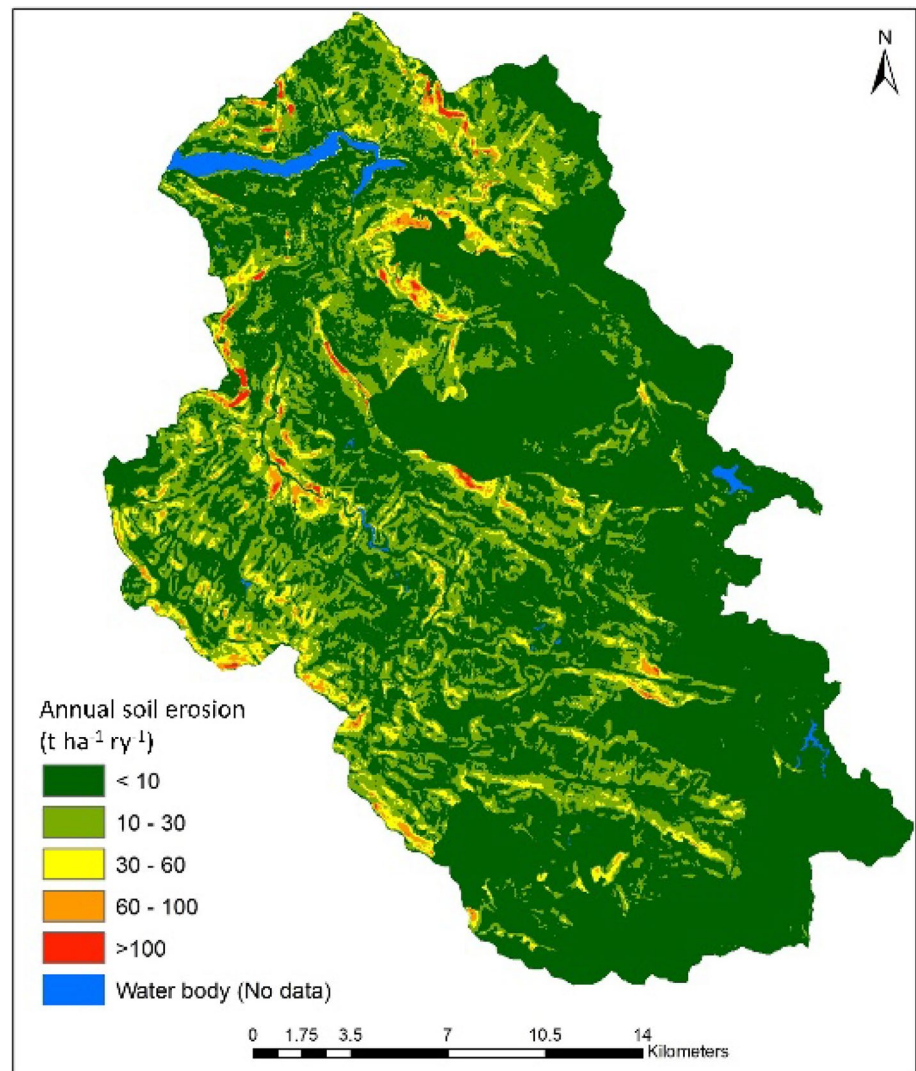
Table 2 Soil erosion severity zones and corresponding area with RUSLE factors

Severity zones (t ha^{-1} year^{-1})	Severity classes	Mean erosion (t ha^{-1} year^{-1})	Area (km^2)	Area percentage	Mean value of the factor				
					R	K	LS	C	P
<10	Very low	2.88	383.2	67.9	151.57	0.18	1.62	0.42	0.25
10–30	Low	16.98	140.4	24.9	172.54	0.18	2.60	0.53	0.48
30–60	Moderate	40.61	31.3	5.5	174.52	0.18	5.07	0.56	0.53
60–100	Severs	73.76	7.6	1.3	174.65	0.18	7.97	0.57	0.57
>100	Very severe	140.39	2.0	0.4	176.52	0.18	13.69	0.58	0.59

Fig. 8 Hot and cold spots of soil erosion
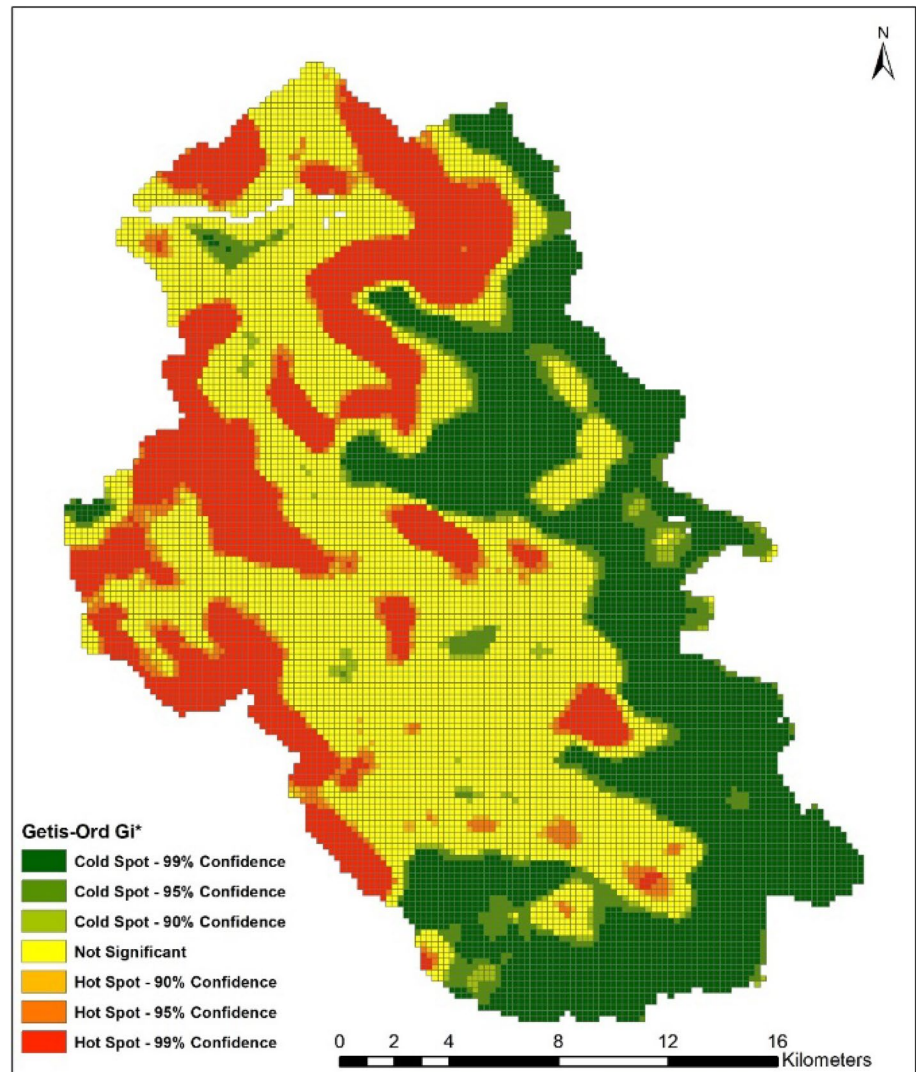
Soil erosion hot spot

Figure 8 shows the spatial clustering pattern of soil erosion in Kotmale catchment area. Most of the hot spot (99% confidence) located in the North, West, Northwestern and Southwestern part of the catchment area. These areas are more vulnerable for occurring more soil erosion than other areas. Most of the cold spot (99% confidence) located in the East and South part of the study area. There cold spot areas consist of more forest area. The cold spot has low soil erosion rate compare with other areas. According to the hot and cold spot analysis, 19.5% of the catchment areas has undergone hot spots, and 28.9% has undergone to cold spots areas. In addition to that 38.2% areas has been grouped as not significant area (Table 3). This area might have more chances to become a hotspot shortly. This result shows that

Table 3 Hot and cold spots of soil erosion in the Kotmale watershed (%)

Spots	Percentage
Cold spot—99% confidence	28.9
Cold spot—95% confidence	5.3
Cold spot—90% confidence	2.2
Not significant	38.2
Hot spot—90% confidence	2.1
Hot spot—95% confidence	3.8
Hot spot—99% confidence	19.5
Total	100

more soil erosion can be predicated in Western side of the Kotmale catchment than the Eastern side of the catchment.

Justification of the model

Validating of the model is most important to trust the result but it was challenging obstacles due to the absence of ground level data and lack appropriate past research(Fu et al. 2006; Ganasri and Ramesh 2016). However, two methods have been adopted based on secondary data sources to validate the results of the current study. (1) First method is cross-check with similar catchment which is available ground level data and, (2) Second method is to validate with the literature information and result of the past research.

"*Uma Oya*" catchment is one of the sub catchment located in UMCA and bio-physical characteristics are most similar to the Kotmale catchment (Diyabalanage et al. 2017).

Annual sediment yield of the *Uma Oya* has been measured by the Mahaweli Authority of Sri Lanka from 1992 to 2012 (Environment and forest conservation division 2017) and result has been plotted into (Fig. 9) but 2005–2008 data was not recoded. Further, Average sediment yield of the whole period (from 1992 to 2012) was 10.45 t ha^{-1} year^{-1}. The result of the RUSLE was 9.8 t ha^{-1} year^{-1} which was applied to the Kotmale catchment. Difference between these two is 0.65 t ha^{-1} year^{-1}. With this result it can be realized that, there isn't significant different between observed and predicated value.

Many researchers were used literature information and result of the past research for validating the soil erosion model. By experience with them, the mean erosion rate of the present study has been correlated with the result of Food and Agriculture Organization of the United Nations annual report in 2015 (FAO 2015). Moreover, it's stated that average soil erosion by water in the tropical area is often < 10 t ha^{-1} year^{-1}. In this study, the average soil erosion is observed as 9.8 t ha^{-1} year^{-1}. In addition to that, Result of the National Action Program (NAP) for combating land degradation in Sri Lanka 2015–2024 is most similar with the result of this analysis (Lanka 2015). NAP reveled that mean soil erosion of the upcountry wet zone approximately 10–13 t ha^{-1} year^{-1} in this study it was 9.8 t ha^{-1} year^{-1}. Moreover, the suspended load in the Mahaweli River was first measured near the Botanic Gardens, Peradeniya in Kandy and result shows that annual maximum rate of sediment yield of 11.5 t ha^{-1} year^{-1} (Hewawasam 2010). Further, (Table 4) shows the summary of the past research which are used literature information to validate the result of the soil erosion model.

Fig. 9 Annual Sediment yield and whole years average sediment yield of the Uma oya catchment in UMCA
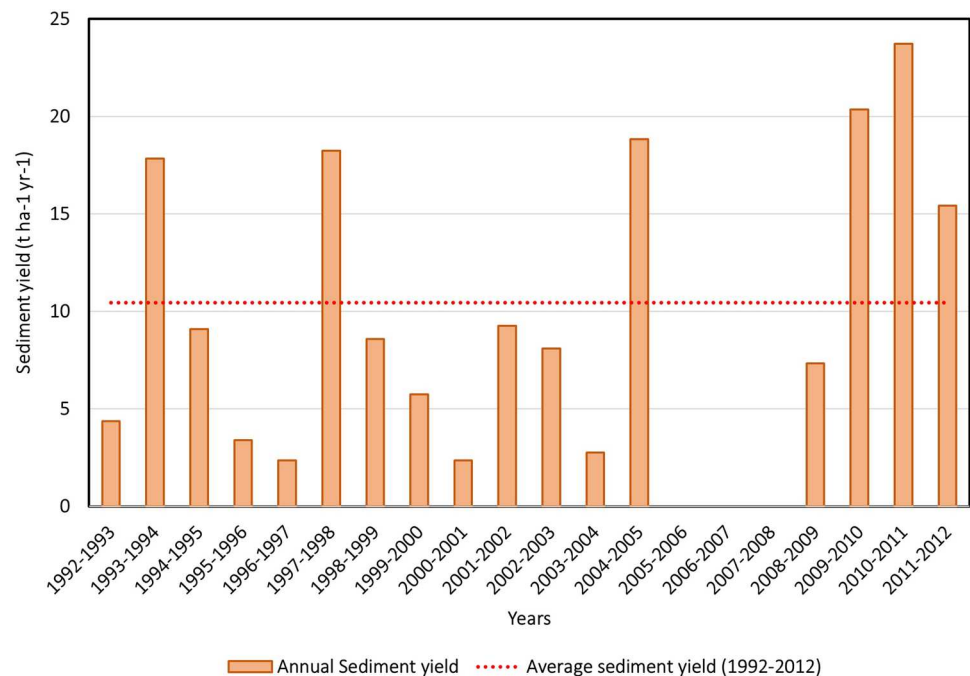
Table 4 Summary of the past research which are used literature information to validate the soil erosion model

No.	Area/Country	Year	Model/method	Validation method	References
1	Brazilian Amazonia—Brazil	2004	RUSLE	Literature information	Lu et al. (2004)
2	Danjiangkou County—Hubei province of China	2009	RUSLE	Literature information and result of the past research	Rahman et al. (2009)
3	"Uva" province—Sri Lanka	2013	USLE	Literature information and result of the past research	Senanayake et al. (2013)
4	Southern Italy	2015	Revised Universal Soil Loss Equation for Complex Terrain (RUSLE3D), Unit Stream Power-based Erosion Deposition (USPED)	Previous studies and on-going research	Aiello et al. (2015)
5	Upper Grande river basin—Brazil	2017	RUSLE	Literature information and result of the past research	Batista et al. (2017)
6	Kirindi Oya river basin, Sri Lanka	2018	RUSLE	Literature information and result of the past research	Wijesundara et al. (2018)

Above all information are summarized that validation of the model is difficult task. However, result of the past research and literature information are facilitated to rectify the above issue. By the way, the study proves that RUSLE model in combination with GIS is an efficient tool to handle large volume data needed for watershed soil loss studies.

Discussion

Soil erosion probability zone and hot spot

According to the result of the annual soil erosion, severe erosion zones (severe and very severe) jointly cover only 1.7% of the total area but this is not an ignorable factor due to the several reasons. (1) The highest value of the soil erosion (472 t ha^{-1} year^{-1}) is observed in severe soil erosion category and, (2) Mean erosion rate is 140.39 t ha^{-1} year^{-1} in this region. In addition to that, the high mean value of the LS factor in (Table 2) provides evidence that the severe erosion zones are spatially distributed across narrow, steep slope part of the watershed. Further, highest values of C factor indicate that less vegetation cover which would be cause for the poor resistant to erosion. High values of the P factor designate that there is lack of conservation practices and high R factor also indicates that probability to high erosion. It is an obvious fact that this zone (severs and very severs) less impervious to the rill and inter-rill erosion. The Gi* value of the hot spot analysis is actually a Z score; the largest Z scores computed that clustering of high values which are generated by the RUSLE. It can be grouping the value of the severe and very severe areas in order to spatially visualize of soil erosion. This scenario can be clearly observed with Fig. 8 than the Fig. 7. Soil as spatially distributed components, identification of its erosion in spatially is more useful for decision making process. Furthermore, hot and cold spot analysis also provides the detailed information related to finding the conservation priority areas, planners need to consider the hot spot area to introduce soil conservation method. Nearly 20% of the watershed has under to hot spot. Hence, key conservation practices and appropriate management strategies are required for this region to conserve the soil sustainably as a priority area.

The moderate class represents 5.5% out of the total area and spatially disperses along the moderate slope area excepting dense forest area. Mean value of the C and P factor of this regain denotes naturally vulnerability to the soil erosion. As a result of these factors, mean erosion rate of the moderate class is observed as 40.61 t ha^{-1} year^{-1}. Attention should be paid to non-significant area to prevent them from becoming hotspot near future. Past research have revealed that non-significant spots have more chance to convert to hot spots than cold shots (Ranagalage et al. 2018a).Thus, it is needed to make an erosion conservation practices for this region as a second priority task.

More than 90% of the area represents the low erosion zones (low and very low) and spatially dispersed most the area in the watershed. This region represents high resistant to the rill and inter-rill erosion because of high vegetation cover (low C factor) and appropriate conservation practices also admitted in this zone (less P factor). As same, other three factors cooperatively lead to the less erosion in this zone. Hence, this zone is under the tolerable soil erosion level and will require erosion control only if the level increases as a consequence of changes in the attributes of anthropogenic or bio-physical factors.

Agricultural land vulnerability and human intervention

In a broad perspective, the factors of the RUSLE model can be categorized into two parts such as physical and

anthropogenic. R factor denotes the rainfall, LS is often representing the topographical variation, and K factor is the natural soil. With these information, it is emphasized that nature (natural environment) is the driving forces of the R, K and LS factors not in a human being. Hence, these factors can be categorized as physical factors. C factor is the cover and management factor, and P factor is the support practice factor that have been taken place by nature or human being to preserve the soil erosion. Thus, C and P factor are the most important to discuss the human intervention to the soil erosion in the perspective of agricultural land vulnerability because of these two factors can increase or decrease as a result of the anthropogenic activities, especially agricultural activities, and other unplanned land use practices.

Land use map (Fig. 6a) has been overlaid with the soil erosion zone map (Fig. 7) by using zonal statistic methods in Arc GIS and values were extracted. Then, the extracted values have been statistically potted into the (Table 5) to access the human intervention to the soil erosion. It shows the mean soil erosion with corresponding land use and contribution of each land use types as a percentage of each soil erosion severity zone.

According to the statistical information of the annual report of the Sri Lanka labor force survey in 2016 (Department of Census and Statistics 2016), 66.1% labor force has contributed to the commercial or non-commercial agricultural activities in the research area. Hence, pressure and competition to the land resources is high. Tea cultivation has been established as main commercial agricultural activity in the watershed with occupying 39.1% from the total area (Table 5). Mean erosion rate of the tea land is observed as 11.9 t ha^{-1} year^{-1}. This information indicates that contribution of the human intervention to the soil erosion because tea is not a natural vegetation and belongs to unnatural vegetation grown by people. By the information of the annual report of the Sri Lanka labor force survey in 2016 (Department of Census and Statistics 2016) and other information gathered through the field survey, vegetable cultivation is important agricultural activity next to the tea

cultivation. There is high demand for the upland (upcountry) vegetable in Sri Lanka (The Mahaweli Authority of Sri Lanka 2012; Jayasooriya and Aheeyar 2016) and it is primary income source for the farmers who are not engaging in tea cultivation and secondary income source of the farmers who have to engage in tea cultivation. Mainly, scrub land, and chena land have been occupied as a vegetable cropland due to the insufficient land resources for the cultivation and high demand for the upcountry vegetable (Johansson 1989). Table 5 shows that, highest mean soil erosion rate (35.9 t ha^{-1} year^{-1}) is denoted by scrub land and more than 44% of the scrub lands are categorized into above the moderate soil erosion zone. Similarly, more than 42% of the chena land also represents the same soil erosion classes and the second highest mean soil erosion 27.4 t ha^{-1} year^{-1} is observed by the chena land. Thus, usage of these land for further agricultural activities without applying appropriate remedial and conservation methods will cause the vulnerable agricultural land and food security due to soil erosion.

Conclusions

This study impels that, GIS and RS have certain capability to integrate RUSLE empirical soil erosion models to predict soil loss quantitatively and spatially and compute the soil probability zone with erosion priority area where alarming indicates to expose the high soil erosion. Moreover, the study reveals that while the estimated highest annual soil loss rate was 472 t ha^{-1} year^{-1}, the mean and standard deviation was 9.8 t ha^{-1} year^{-1} and 15.7 t ha^{-1} year^{-1} respectively in the Kotmale watershed area.

Erosion probability map shows that severe zones were exposed mainly in high slope area and the agricultural area including chena lands and scrub land where located in the moderate slope area. Soil erosion of the agricultural area (commercial and non-commercial) is relatively higher than the natural vegetation, which implies the role of various anthropogenic attributes on simulated soil erosion. The

Table 5 The contribution of each land use types as a percentage for each probability zone

Land use types	Mean erosion (t ha-1 year-1)	Soil erosion probability zone				
		Very low	Low	Moderate	Severs	Very severe
Dense forest	0.3	99.66	0.29	0.06	0.00	0.00
Grass land	2.3	100.00	0.00	0.00	0.00	0.00
Paddy land	8.7	72.97	24.32	2.70	0.00	0.00
Less dense forest	9.6	65.84	29.95	3.71	0.50	0.00
Home garden	9.8	63.33	33.50	3.00	0.17	0.00
Tea land	11.9	56.28	37.06	6.08	0.54	0.04
Bare land	22.0	33.71	44.38	16.29	3.93	1.69
Chena	27.4	21.43	35.71	35.71	7.14	0.00
Scrub land	35.9	16.62	39.04	26.95	13.35	4.03

analysis and results conclude that the RUSLE model can easily integrate with geospatial analysis to compute the rate of annual soil loss and benefit of the prioritization to implement different combinations conservation practices. Overall, the hot and cold spot can be used as a proxy indicator to identify the conservation priorities of the watershed.

Manipulated data can be used as sources for the other studies. The model would be able to apply to the similar studies by following necessary adjustment. In a broad perspective, the mean value of each factor has been increased proportionally with soil erosion, it's denoting that the factors are correlated with the soil erosion. In addition to that, the results of the study is correlated with ground level data and literature information.

Compliance with ethical standards

Conflict of interest The author declares no conflicts of interest.

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