



GIS-based soil loss estimation using RUSLE model: a case of Kirindi Oya river basin, Sri Lanka

N. C. Wijesundara¹ · N. S. Abeysingha¹  · D. M. S. L. B. Dissanayake²

Received: 26 October 2017 / Accepted: 6 January 2018 / Published online: 16 January 2018
© Springer International Publishing AG, part of Springer Nature 2018

Abstract

Soil erosion is one of the main reasons for low crop productivity. Identification of areas vulnerable to soil erosion is crucial in applying soil conservation measures especially in river basin. Kirindi Oya river basin is one of the important river basins that supply irrigation for the downstream dry zone of Sri Lanka. This study assessed the soil erosion and generated soil erosion hazard map for Kirindi Oya basin using revised universal soil loss equation (RUSLE) model in Arc GIS 10.2. Predicted soil erosion rates estimated from RUSLE model ranged from 19 to 184 t ha⁻¹ year⁻¹ with an average 33 t ha⁻¹ year⁻¹ for the entire river basin. The basin was categorized into five different erosion hazard classes, low, moderate, high, very high, and extremely high. The study revealed that majority of extremely vulnerable soil erosion areas (> 60 t ha⁻¹ year⁻¹) belongs to Haldummulla area in Badulla district of the basin. About 47% of the basin area in the dry zone was categorized into low erosion hazard class (< 30 t ha⁻¹ year⁻¹). However, these soil loss rates were above the critical soil loss rates (6.7 t ha⁻¹ year⁻¹) stipulated to dry zone, Sri Lanka. The results of this study may help stakeholders to implement soil conservation measures in the Kirindi Oya basin.

Keywords Kirindi Oya · Revised universal soil loss equation · Soil erosion · Soil erosion hazard map

Introduction

Soil erosion is a natural process of soil material removal and transportation through the action of erosive agents such as water, wind, gravity, and this process is escalated by human disturbance (Gunawan et al. 2013). It is a serious and continuous environmental problem all over the world especially in developing countries (Amsalu and Mengaw 2014). Erosion process occurs globally and causes economic losses, decrease productivity of topsoil and finally arises energy, food, and water security problems. These issues, consequently, lead to loss of water-storage capacity of watersheds, damages to water reservoirs and dams and pollute surface water (Adhami and Sadeghi 2016). The prevention of soil

erosion and sediment deposition are important due to their direct impact on fertility of agricultural land and quality of water. About 85% of land degradation globally is caused by soil erosion which declines in crop yield up to 17% and leads to increases the expenses on fertilizers initially but afterward may lead to land abandonment (Singh and Panda 2017).

Soil erosion in Sri Lanka has become a severe environmental and socio-economic problem. It is initiated by irregular and unsafe human activities, but ultimate results of which are silt depositing in hydropower generating reservoirs, lowering of land productivity and silt depositing in natural water ways and irrigation tanks (Ministry of Agriculture 2012). According to Dharmasena (2014), 44% of Sri Lankan agricultural lands are facing the problem of soil erosion and it is mainly concentrated in hilly country where main watersheds of major rivers are located.

Not only in Sri Lanka, many regions in the world, unchecked soil erosion and associated land degradation caused to vast areas economically unproductive. Often, quantitative assessments are required to infer the extent and magnitude of soil erosion problems in order to get effective management strategies to reclaim the lands (Prasannakumar et al. 2012). The quantitative assessment and prediction of

✉ N. S. Abeysingha
nabeysingha@gmail.com

¹ Department of Agricultural Engineering and Soil Science, Faculty of Agriculture, Rajarata University of Sri Lanka, Puliyankulama, Anuradhapura, Sri Lanka

² Department of Environmental Management, Faculty of Social Science and Humanities, Rajarata University of Sri Lanka, Mihinthale, Anuradhapura, Sri Lanka

soil erosion have been a challenge for a long time, but at present, several soil erosion models have been developed. The Universal Soil Loss Equation (USLE), and the Revised Universal Soil Loss Equation (RUSLE) are the most widely used soil erosion models (Udayakumara et al. 2010).

The application of USLE model (Wischmeier and Smith 1978) was limited to gently sloping cropland situations. Subsequently, USLE was modified to RUSLE model (Renard et al. 1997) which could apply for soil loss estimation of rangeland, forests, disturbed sites, and steep slopes (Remortel et al. 2001). Thereafter, GIS-based RUSLE frequently used specially the soil erosion assessment on a river basin scale (Amsalu and Mengaw 2014; Ganasri and Ramesh 2016; Prasannakumar et al. 2012). These assessments helped to develop management scenarios and provide options to policy makers for managing soil erosion hazards in the most efficient manner for prioritization of different regions of the basin for treatment. In Sri Lankan context, the application of RUSLE with the interface of GIS is comparatively limited for the assessment of soil erosion in river basin scale. According to the published literature, we could not find any soil erosion assessment on river basin scale in Sri Lanka. This may be probably due to non-availability of digital version of soil and land use maps and limited use of remote sensing techniques to develop land use map as the country is always in cloud cover. Therefore, an attempt was taken to simulate the soil erosion in Kirindi Oya river basin which is in the South-Eastern part of the dry zone of Sri Lanka using RUSLE with the limited data availability. The Kirindi Oya is 118 km long and is fed by a catchment area of 1203 km² (Abeysingha et al. 2017). Kirindi Oya river basin is one of

the important river basins in the dry zone of Sri Lanka which supplies water for a number of irrigation reservoirs. This study was mainly carried out to create soil erosion hazard map for Kirindi Oya river basin using RUSLE model to prioritize the areas of the river basin for soil conservation programs.

Study area

The Kirindi Oya river basin flows from the medium range hills of Sri Lanka to the Indian Ocean. However, its downstream area is located in undulating and flat terrain. Main land use of the basin is crop lands. According to our assessments, mean annual rainfall of the upstream and downstream area is about 1984 and 1075 mm respectively while mean annual temperature of the upstream (Bandarawela) is 20.8 °C and downstream (Weerawila) of the basin is 28.1 °C. This results in high evaporation, which exceeds the rainfall during most months of the year. Drying tendency of the basin has become a critical problem and a major deterrent on the farming systems practiced in this region (Abeysingha et al. 2017). Downstream reservoirs of the basin such as Yoda Wewa, Debara Wewa, Badagiriya Tank and Lunugamwehara reservoir are the main source of water for the farming. Soil erosion in the upstream areas of the basin may lead to siltation of these important reservoirs. These reservoirs utilize the upstream stream flow and thus better management of the basin determines the sustainable supply of water from these important reservoirs (Fig. 1).

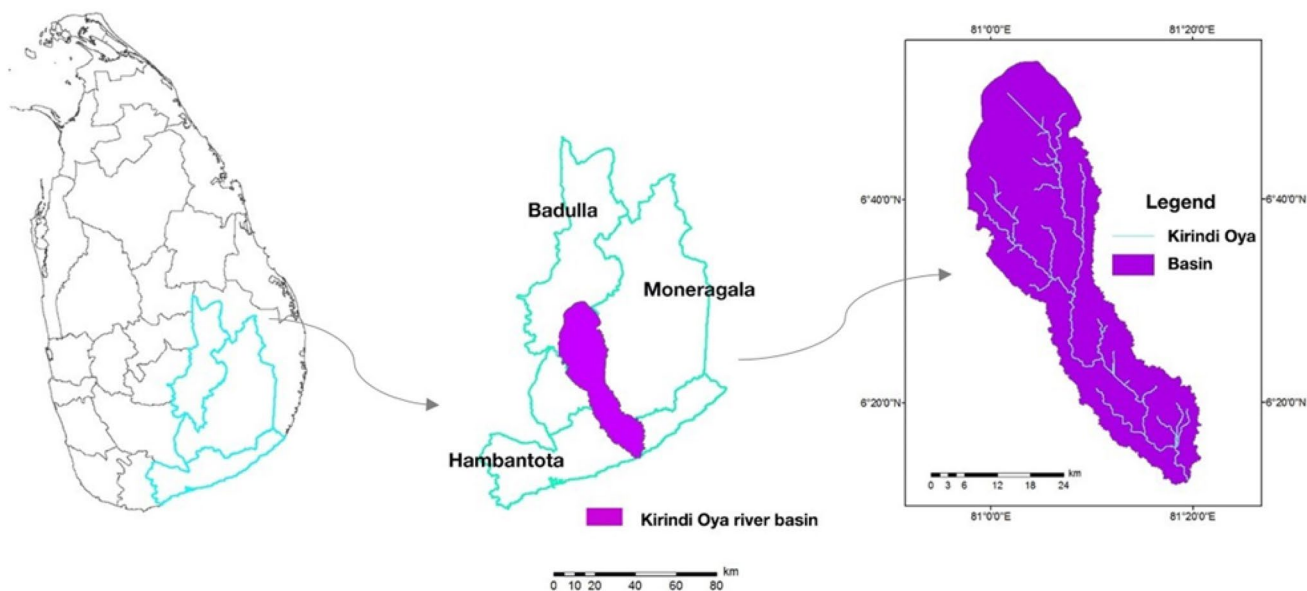


Fig. 1 Location map of Kirindi Oya river basin

Methodology

RUSLE parameter estimation

Numbers of models have been developed for soil erosion assessment. These models are of three main types as empirical, conceptual and physical based models. However, USLE and modified Universal soil loss equation (MUSLE) and RUSLE are the most popular empirically based models used globally for erosion prediction and control and those have been tested in many agricultural watersheds in the world (Praveen and Kumar 2012). In this study, we used RUSLE to assess the annual average soil loss in Kirindi Oya river basin in Sri Lanka. RUSLE (Renard et al. 1997) can be expressed as in Eq. 1:

$$R \times K \times LS \times C \times P \quad (1)$$

where

A computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for *K* and for the period selected for *R*. In practice, these are usually selected so that *A* is expressed in $\text{t ha}^{-1} \text{ year}^{-1}$,

R rainfall–runoff erosivity factor—the rainfall erosion index plus a factor for any significant runoff from snow melt expressed in $\text{MJ mm ha}^{-1} \text{ h}^{-1}$ per year;

K soil erodibility factor—the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow expressed in $\text{t ha}^{-1} \text{ MJ mm}^{-1}$;

L slope length factor—the ratio of soil loss from the field slope length to soil loss from a 72.6-ft length under identical conditions;

S slope steepness factor—the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions;

C cover management factor—the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow;

P support practice factor—the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to soil loss with straight-row farming up and down the slope.

Data used

Rainfall data

Monthly rainfall data at 13 rainfall stations of Kirindi Oya River basin were collected (Bandarawela, Bandaraeliya, Katharagama, Kinigama, Palatupana, Pelwatta, Wallawaya, Weerawila, Tissamaharamaya, Thanamalwila, Uwarakandagolla, Kuda Oya and Koslanda) from Meteorology

Department of Sri Lanka and Natural Resource Management Centre (NRMC) Peradeniya, Sri Lanka (Table 1).

Soil map and soil properties

Soil maps and relevant soil properties for the basin were collected from ‘Soils of the Dry Zone of Sri Lanka book’ (Mapa et al. 2010) and ‘Soils of the Intermediate Zone of Sri Lanka book’ (Mapa et al. 2005). (Fig. 2).

Land use maps

Land use maps of the districts located in Kirindi Oya river basin were collected from IUCN (The International Union for Conservation Nature, country office, Sri Lanka) and those have been originally developed by the Land Use Policy Planning divisions of respective districts (Badulla, Moneragala, Hambantota).

Contour map

Contour map of Sri Lanka was collected from Survey Department of Sri Lanka. This map was used to generate the Digital Elevation Model (DEM) in Arc GIS environment for the basin.

Rainfall erosivity factor (*R*)

Rainfall erosivity factor (*R*) quantify the effect of raindrop impact and also reflect the amount and rate of runoff likely to be associated with the rain (Renard et al. 1997). We

Table 1 Details of the rainfall stations in the Kirindi Oya river basin and the data period and calculated average annual rainfall

Name	Longitude	Latitude	Period	Average annual Rainfall(mm)
Bandaraeliya	81.02201	6.780833	1970–1999	2033.71
Bandarawela	80.962	6.810831	1976–2014	1599.86
Katharagama	81.333928	6.413597	1989–1999	1060.58
Kinigama	81.052011	6.83033	1960–1992	1474.37
Koslanda	81.082011	6.730328	1985–2000	3390.26
Kuda Oya	81.122366	6.534515	1990–2013	1181.06
Palatupana	81.382014	6.25032	1969–1999	910.42
Thanamalwila	81.122011	6.460324	1990–2013	1143.15
Tissamaharama	81.302013	6.280321	2001–2013	1226.19
Weerawila	81.236275	6.256917	1976–2014	870.77
Wellawaya	81.1	6.73	1990–2003	1473.81
Uwa Karandagolla	81.07644	6.831054	1990–2013	1933.37
Angunakolapellessa	81.022325	6.447693	1976–2014	1139.67

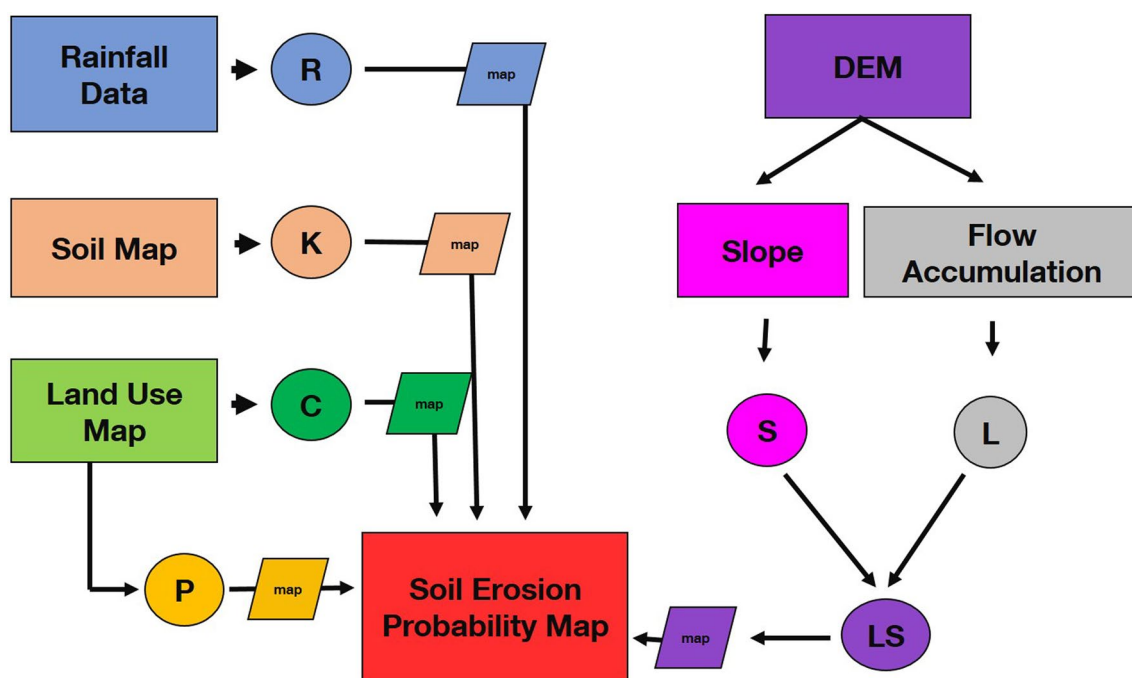


Fig. 2 Overall methodology for creation of soil erosion probability map

used R factor developed for Sri Lanka by Premalal in 1986 (Wijesekara and Samarakoon 2002) (Eq. 2). These kinds of regression equations developed for local conditions are used by scientist (Gelagay and Minale 2016; Zeng et al. 2017) when the watershed has no records of daily rainfall intensity:

$$R = \frac{(972.75 + 9.95 \times \text{Average annual rainfall})}{100}. \quad (2)$$

Monthly rainfall data of 13 rainfall stations (Fig. 3) were used to calculate R factor. First, rainfall data were interpolated to the basin using both IDW and Kriging methods in Arc GIS which are mostly used by the authors who use RUSLE (Biswas and Pani 2015; Gelagay and Minale, 2016 etc.). We tested the suitability of both the methods (IDW and Kriging) for the basin. We removed three locational rainfall data, one station data at a time and did the interpolation using both the methods. Thereafter, we compared the interpolated values for the three locations/stations separately with the observed values of those stations and found using ‘T’ test that IDW method interpolated the data better than the Kriging method for three stations. Therefore, rainfall erosivity factor (R factor) raster map with 30 m resolution was generated by IDW interpolation method in Arc GIS environment to the basin (Fig. 3).

Soil erodibility factor (K)

The soil-erodibility factor (K) represents the effect of soil properties and soil profile characteristics on soil loss. K is

the rate of soil loss per rainfall erosion index unit as measured on a unit plot. The unit plot is 72.6 ft (22.1 m) long, has a 9% slope, and is continuously in a clean-tilled fallow condition with tillage performed upslope and downslope (Renard et al. 1997).

Soil erodibility factor was estimated using soil types data. Collection of data from field is time consuming and expensive method. Therefore, distribution of soils in the river basin area (Fig. 4) was extracted from soil maps (Mapa et al. 2005, 2010), by digitizing the soil maps and clipping with river basin shape file integrating with ArcGIS 10.2. Then, K factor raster map with 30 m resolution was generated using soil maps and soil erodibility (K) values. Assigned K values for different soil types were based on different studies in Sri Lanka as shown in Table 2 (Joshua 1977; Wijesekara and Samarakoon 2002). Soils in which erodibility values were not known, and reasonable approximations were made considering their soil properties such as texture, structure, permeability class, very fine sand, sand, silt, and organic carbon percentages obtained from Mapa et al. (2005, 2010). For this approximation, we used erodibility nomograph made by Wischmeier and Smith (1978) along with those soil properties.

Estimation of slope length and steepness factor (LS)

LS factor accounts for the effect of topography on soil erosion in RUSLE. Erosion increases as slope length increases and is considered by the slope length factor (L). Slope length is

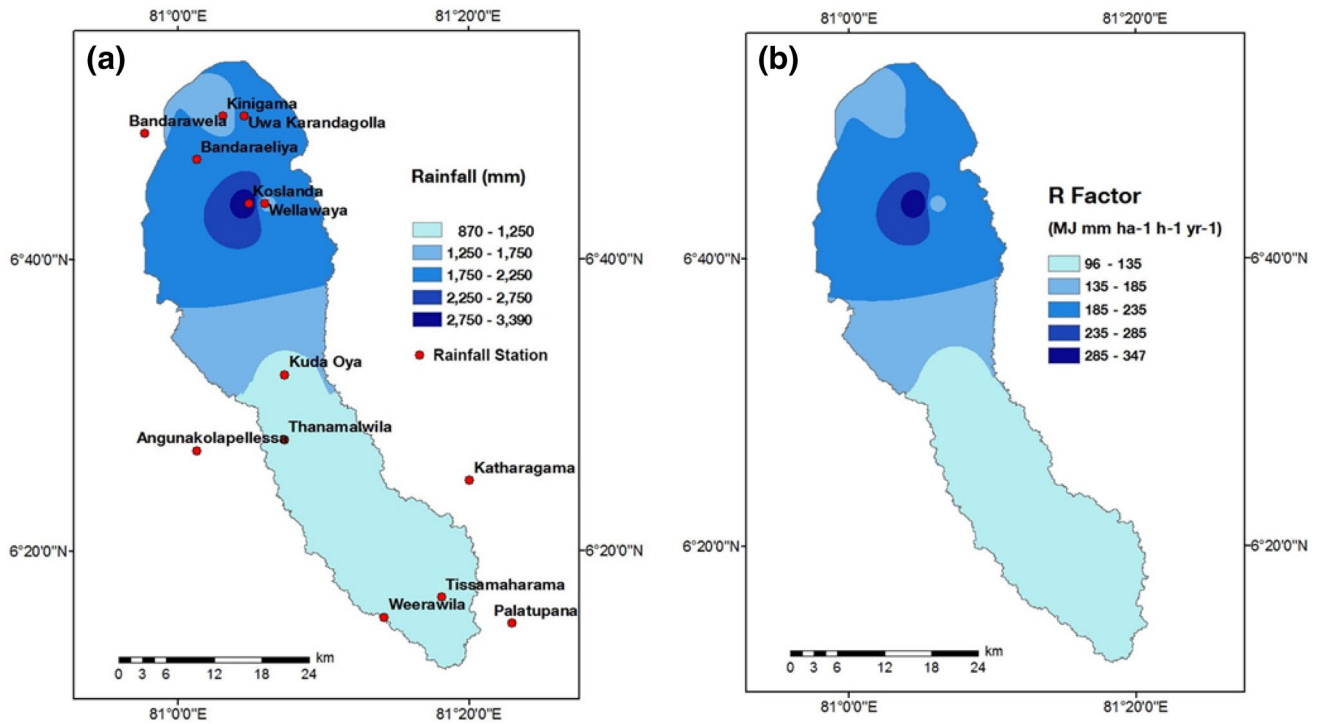


Fig. 3 a Rainfall variability map. b R factor map

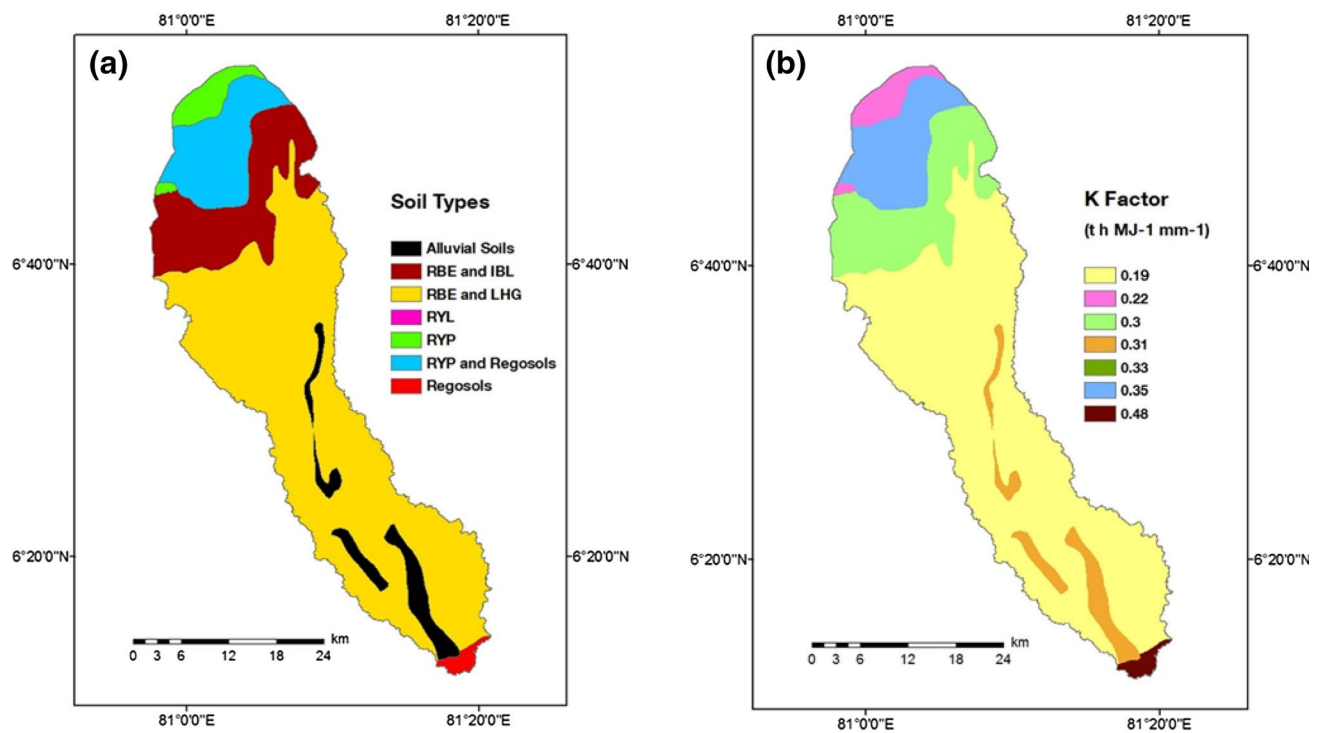


Fig. 4 a Soil types map (RBE—Reddish Brown Earths, LHG—Low Humic Glay Soils, RYL—Red–Yellow Latosol, RYP—Red–Yellow Podzolic, IBL—Immature Brown Loams). b K factor map

Table 2 Soil erodibility values for soil types in Kirindi Oya river basin. *Source* Joshua (1977); Wijesekara and Samarakoon (2002)

Soil type	Erodability (K)
Red–yellow pedsol	0.22
Sandy regosol	0.48
Reddish brown earths	0.27
Red–yellow latosol	0.33
Immature brown loams	0.33
Low humic gley	0.10
Alluvial soils	0.31

defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel. Slope steepness factor (*S*) reflects the influence of slope gradient on erosion (Renard et al. 1997). *LS* factor was generated using DEM (30 m resolution) created by contour maps that has been collected from Survey Department of Sri Lanka. In addition, flow accumulation and slope map were produced using ArcGIS with created DEM. In this study, *L* factor was calculated using Eq. 3:

$$L = \left(\frac{\lambda}{22.1}\right)^m \tag{3}$$

where λ horizontal projected slope length (m), (λ flow accumulation \times cell size); *m* slope length exponent that varies based on slope steepness. *m* equals 0.5 if the percent slope is 4.5 or more, 0.4 on slopes of 3–4.5 percent, 0.3 on slopes of 1–3 percent and 0.2 of uniform gradient of less than 1 percent (Wischmeier and Smith 1978).

S factor was calculated by Eqs. 4 and 5:

$$S = 10.8 \sin\theta + 0.03 \text{ for slope percent } < 9\% \tag{4}$$

$$S = 16.8 \sin\theta - 0.50 \text{ for slope percent } \geq 9 \tag{5}$$

where θ slope angle in degree (Renard et al. 1997; Remortel et al. 2001) that was calculated from slope map. *LS* factor map (Fig. 5) was generated by multiplication *L* and *S* factors in raster calculator tool in ArcGIS.

Estimation of the cover and management factor (C)

The effect of cropping and management practices on erosion rate is expressed by *C* factor, and it is the factor used most often to compare the relative impacts of management options on conservation plans (Renard et al. 1997). *C* factor map is related to Land use map. Land use map for Kirindi Oya river basin was extracted from land use maps of Moneragala, Badulla and Southern province by merging land use maps and clipping with Kirindi Oya

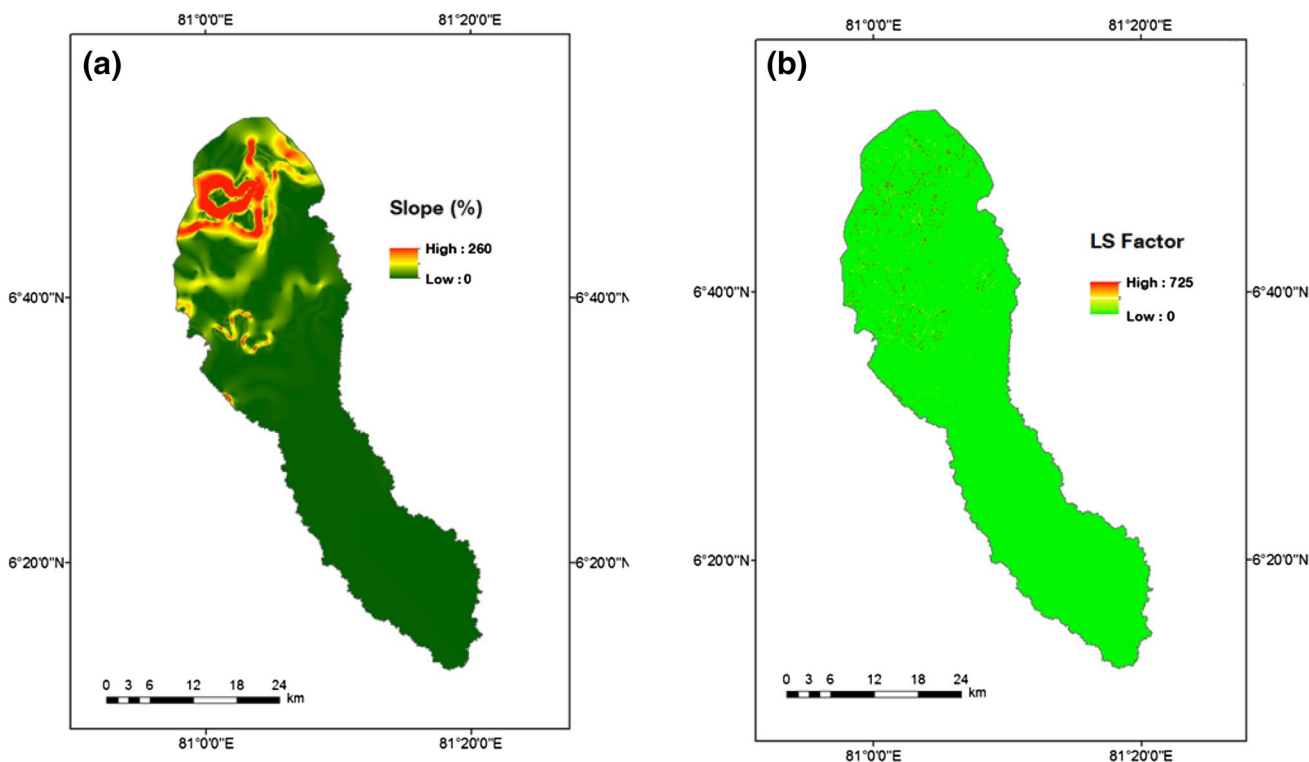


Fig. 5 a Slope map. b LS factor map

river basin shape file. Then, *C* factor raster map (Fig. 6) with 30 m resolution was generated with the developed land use map of Kirindi Oya river basin and *C* factor values were assigned using the look up function in re-class tool in ArcGIS 10.2.1. Assigned *C* factor values (Table 3) for different land use and land cover categories was based on different studies in Sri Lanka (Senanayake et al. 2013; Munasinghe et al. 2001).

Estimation of the support and conservation practices factor (*P*)

Support practices factor (*P*) can be defined as the ratio of soil loss with a specific support practice to the corresponding loss with upslope and down slope tillage (Renard et al. 1997). *P* factor map is also related to land use map. The most of the *P* factor values were taken from Munasinghe et al. (2001) and Prasannakumar et al. (2012) and the rest of *P* values for the land use types such as home garden, chena, open forest, rock and boggy areas were assessed based on different literature (Munasinghe et al. 2001; Prasannakumar et al. 2012). *P* factor raster map with 30 m resolution was generated with the developed land use map of Kirindi Oya river basin and *P* factor values were assigned using the look up function in re-class tool in ArcGIS 10.2.1. (Fig. 6).

Creation of soil erosion hazard map

Erosion hazard map (Fig. 7) was created using raster overlay analysis with rainfall–runoff erosivity factor, soil erodibility factor, slope length and steepness factor, cover and management factor, support and conservation practices factor by assigning equal weights for individual themes.

Results and discussion

Soil loss values in Kirindi oya river basin obtained through RUSLE is depend on the six parameters of RUSLE such as rainfall–runoff erosivity factor, soil erodibility factor, slope length and steepness factor, cover and management factor, support and conservation practices factor. These factors were estimated on 30 m × 30 m grid scale. First, we discuss the spatial distribution of soil erosion factors in the Kirindi Oya River basin and then soil erosion rates predicted from the RUSLE model are discussed.

Spatial distribution of soil erosion factors

Average annual rainfall varied among rainfall measuring stations. The maximum value (3390.24 mm) was recorded in Koslanda which is located in upstream of the river basin and the lowest average annual rainfall (870.79 mm) was observed in the downstream station, Weerawila. Variation

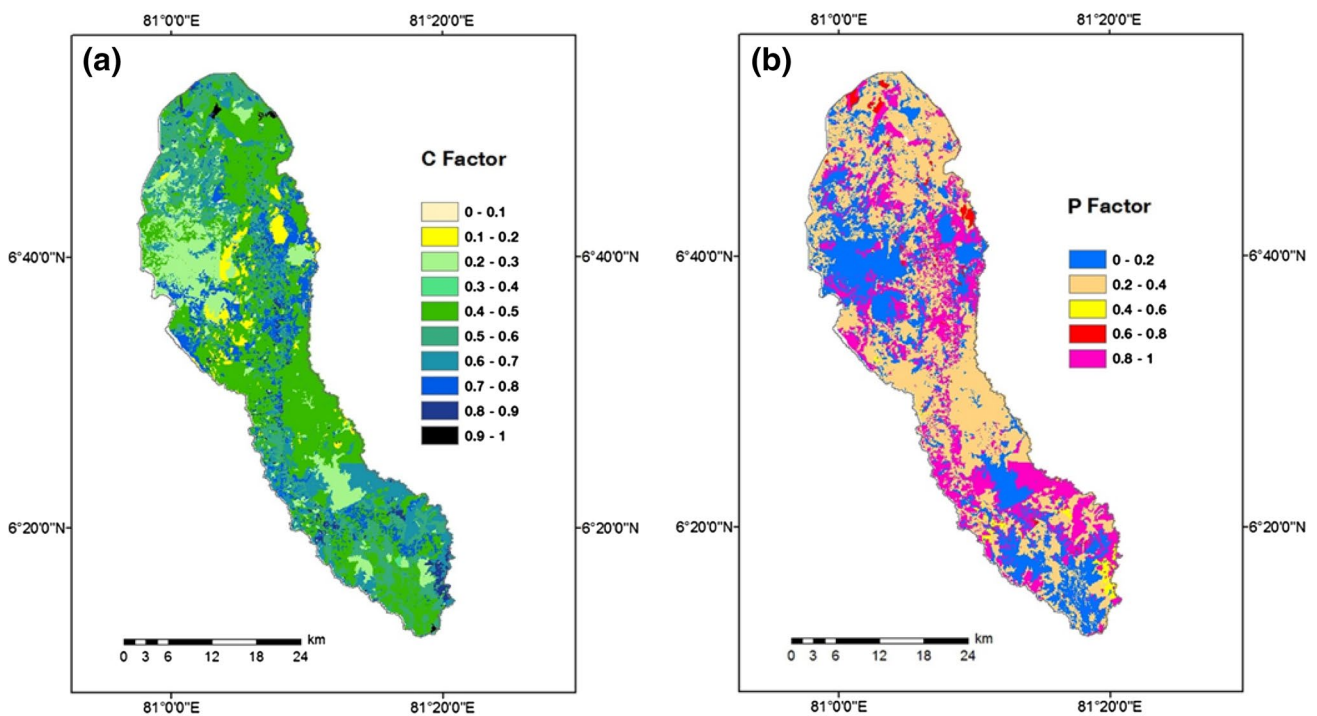


Fig. 6 a *C* factor map. b *P* factor map

Table 3 Area % occupied by different land use types, *C* factor values and *P* factor values for land use types in Kirindi Oya river basin. Source for *C* and *P* factors: Munasinghe et al. (2001); Prasannakumar et al. (2012); Senanayake et al. (2013)

Land use type	Area (%)	<i>C</i> Factor	<i>P</i> Factor
Home garden	12.38	0.51	0.25
Paddy	8.54	0.43	0.15
Chena	1.14	0.8	0.4
Sugarcane	0.83	0.73	1
Banana	0.31	0.73	1
Open forest	27.46	0.5	0.3
Dense forest	11.19	0.2	0.1
Forest plantations	0.77	0.45	0.7
Annual crop	0.81	0.8	1
Boggy area	0.3	0.3	1
Road	0.59	0.7	0
Rock	3.36	0.1	0
River	0.61	0.5	0
Tank	4.47	0.2	0
Streams	0.07	0.2	0
Cannel	0.02	0.4	0
Other crop lands	8.1	0.73	1
Scrubs	11.68	0.6	1
Coconut	0.53	0.54	0.6
Rubber	0.51	0.44	0.35
Tea	3.69	0.57	0.35
Grass lands	1.39	0.51	1
Built-up area	0.61	0.73	0
Bare lands	0.45	1	1

of *R* factor follows the variation of average annual rainfall. Estimated *R* factor values ranged from 96.37 to 347.06 MJ mm ha⁻¹ h⁻¹ year⁻¹. The mean value of *R* for the entire catchment is 164.73 MJ mm ha⁻¹ h⁻¹ year⁻¹. It is clear that *R* factor is greater in upstream than the downstream of the basin which indicates that higher soil erosion is in upstream than the downstream area of the basin.

Soil erodibility factor (*K*) is one of the main factors governing soil erosion. It expresses the susceptibility of soil towards erosion and measures the contribution of soil types (Kumar and Gupta 2016). Therefore, *K* factor was evaluated based on different soil types and their properties found in the Kirindi Oya river basin. Distribution of soil types within the basin is shown in Fig. 4. The results showed that more than 64% of Kirindi Oya river basin is covered by RBE and LHG soils. Reddish brown earths and immature brown loams cover more than 15% of the study area. Remaining lower than 21% of the area is covered by red–yellow podzolic, regosols, red–yellow latosolic, and alluvial soils.

K factor is shown in Fig. 4 and it varied from 0.19 to 0.48 t h MJ⁻¹ mm⁻¹, higher the values indicates more susceptible to soil erosion. In general, clay soils have low *K*

value because these soils are resistant to detachment. Sandy soils also have low *K* values due to high infiltration rates and reduced runoff, and because sediment eroded from these soils is not easily transported. Silt loam soils have moderate to high *K* values as the soil particles are moderate to easily detachable, infiltration is moderate to low producing moderate to high runoff, and the sediment is moderate to easily transport. Silt soils have the highest *K* values as these soils crust readily, producing high runoff rates and quantities (Ganasri and Ramesh 2016). Main soil types RBE and LHG soils in the basin contain high sand content in upper soil horizon which may lead to lower *K* factors. Higher *K* values were recorded in regosols and red–yellow podsoil soils (RYP). The mean soil erodibility factor for Kirindi Oya river basin was 0.23 t h MJ⁻¹ mm⁻¹.

Higher values of *LS* are more vulnerable to erosion. *LS* factor was calculated using slope as an input. As shown in Fig. 5, slope percentage varied from 0 to 260% and average slope percentage is 5.52%. *LS* factor values ranged from 0 to 725 and the mean was 0.61. Most of the upstream area of Kirindi Oya river basin has associated with high slope and high *LS* factor values than downstream area which indicate high erosion is in upstream area than those of downstream areas. However, most of the areas of Kirindi Oya river basin is associated with low slope and consequent low *LS* factor value which causes to lower soil erosion.

According to the land use map created for the basin (Fig. 8), there were 24 land use classes. Considerable land extent of the area covers open forest (27.5%), home garden (12.38%), scrubs (11.68%), and dense forest (11.19%), etc. (Table 3). *C* factor is used to indicate the effect of cropping and management practices on soil erosion rates in agricultural lands and it varied from 0 for well protected land cover to 1 for barren areas in the basin (Ganasri and Ramash 2016). The mean *C* factor value for Kirindi Oya river basin was 0.48. However, a major portion of river basin has a *C* factor in between 0.4 and 0.5 and this area occupies low and moderate erosion categories. Highest *C* factor values are scattered throughout the basin. Crop lands (sugarcane, banana, annual crops, chena, other crop lands), build-up areas, bare lands, and boggy areas have higher *C* factor values contributing to high soil erosion rates. However, these land use types are limited to few areas of the river basin. Most of the area of Kirindi Oya river basin is covered by open forest, home garden, scrubs and dense forest which have comparatively lower *C* values.

The *P* factor accounts for control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration and velocity, and hydraulic forces exerted by runoff on the soil. *P* factor varies from 0 for good conservation practices to 1 for poor conservation practices (Ganasri and Ramesh 2016). According to our assessment, mean *P* factor value for this basin was 0.4.

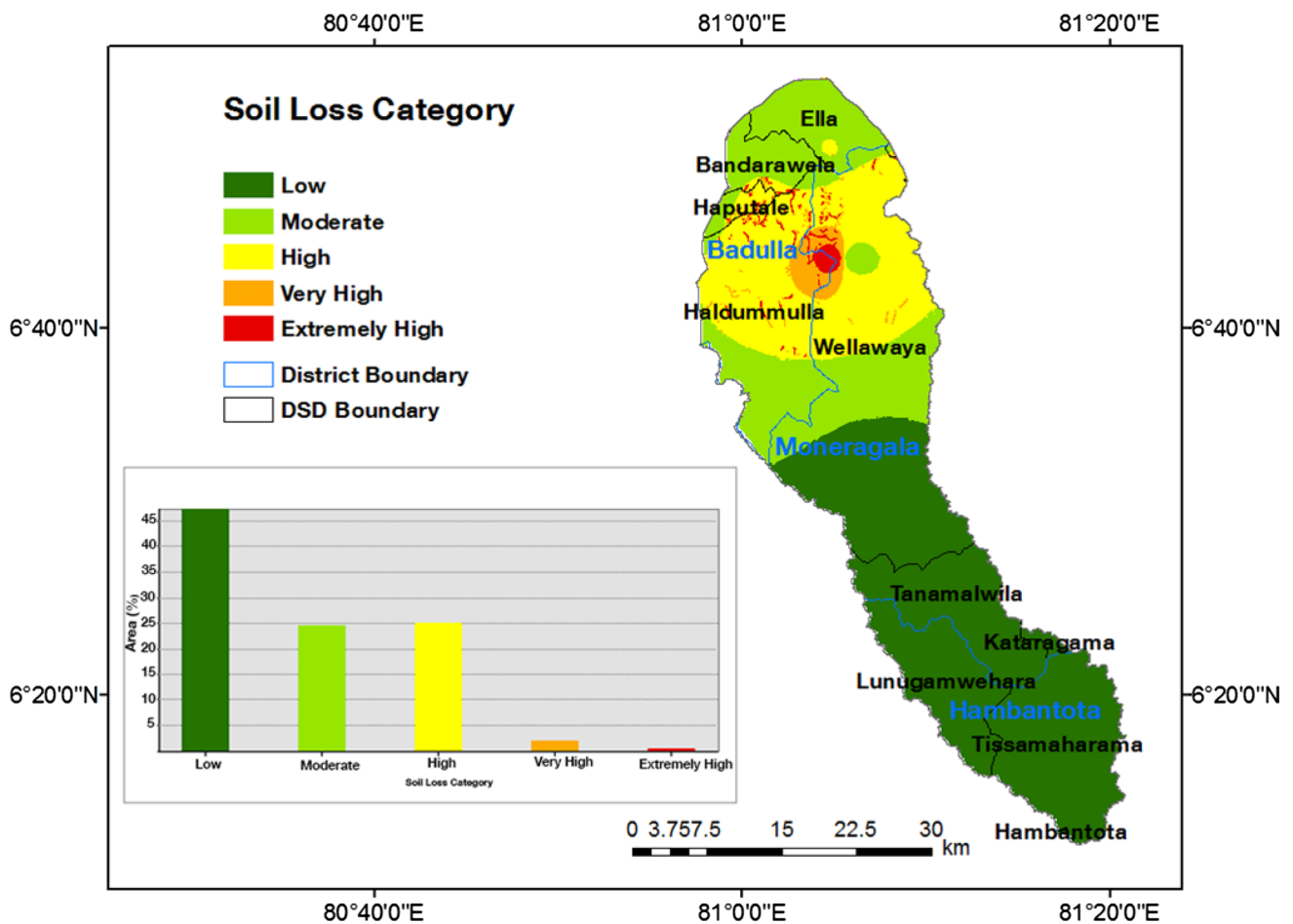


Fig. 7 Soil erosion probability map

However, a major area of the basin has a *P* factor within 0.2–0.4. The highest *P* factor values are also scattered throughout the basin.

Risk assessment of soil erosion

The soil erosion potential map (Fig. 7) was generated by overlaying all the layers of RUSLE. According to the assessment, the lowest soil erosion rate of Kirindi Oya river basin was 19 t ha⁻¹ year⁻¹ and the highest rate was 184 t ha⁻¹ year⁻¹. However, the mean annual soil erosion rate of Kirindi Oya river basin was 33.32 t ha⁻¹ year⁻¹ and it is higher than acceptable soil loss tolerance limit formulated by the Ministry of Environment and Renewable Energy of Sri Lanka (Table 4).

The spatial validation of the erosion assessment result is challenging due to the lack of direct measurement data and lack of appropriate past research on the study area. Food and Agriculture Organization of the United Nations annual report in 2015, showed that erosion rates on hilly croplands in tropical and subtropical areas may reach values up to

Table 4 Estimated rates of tolerable soil loss of Sri Lanka. Source: Ministry of Environment and Renewable Energy in Sri Lanka (2014)

Climatic zone	Tolerable soil loss (t ha ⁻¹ year ⁻¹)
Up country wet zone	13.2
Mid country wet zone	9
Low country dry zone	6.7

50–100 t ha⁻¹ year⁻¹. Pimentel et al., 1995 also showed that soil erosion on crop lands averages about 30 t ha⁻¹ year⁻¹ ranging from 0.5 to 400 t ha⁻¹ year⁻¹. The main land use of Kirindi Oya river basin is agriculture, and therefore, the values reported in the present study is comparable with these studies. Moreover, in the central highland of Sri Lanka, soil erosion rates under shifting cultivation and tobacco was reported as 70 t ha⁻¹ year⁻¹ (Gunatilake and Vieth 2000). Soil erosion rates again in central highland of Sri Lanka under tea cultivation have been reported for three different agro-management practices: (1) seedling plots, without any

soil conservation, soil loss equals $75 \text{ t ha}^{-1} \text{ year}^{-1}$; (2) unprotected seedling tea lands where soil losses range between 46 and $18.5 \text{ t ha}^{-1} \text{ year}^{-1}$; and (3) managed plots, where soil loss is low at $2 \text{ t ha}^{-1} \text{ year}^{-1}$ (El-Swaify and Krishnarajah 1983). Upstream part of *Kirindi Oya* river basin is also located in highlands approximately similar to central highlands and cultivates tea as a crop. This study reported $30\text{--}40 \text{ t ha}^{-1} \text{ year}^{-1}$ values (Fig. 7) in the tea growing area (Fig. 8) is comparable with the findings of El-Swaify and Krishnarajah, (1983).

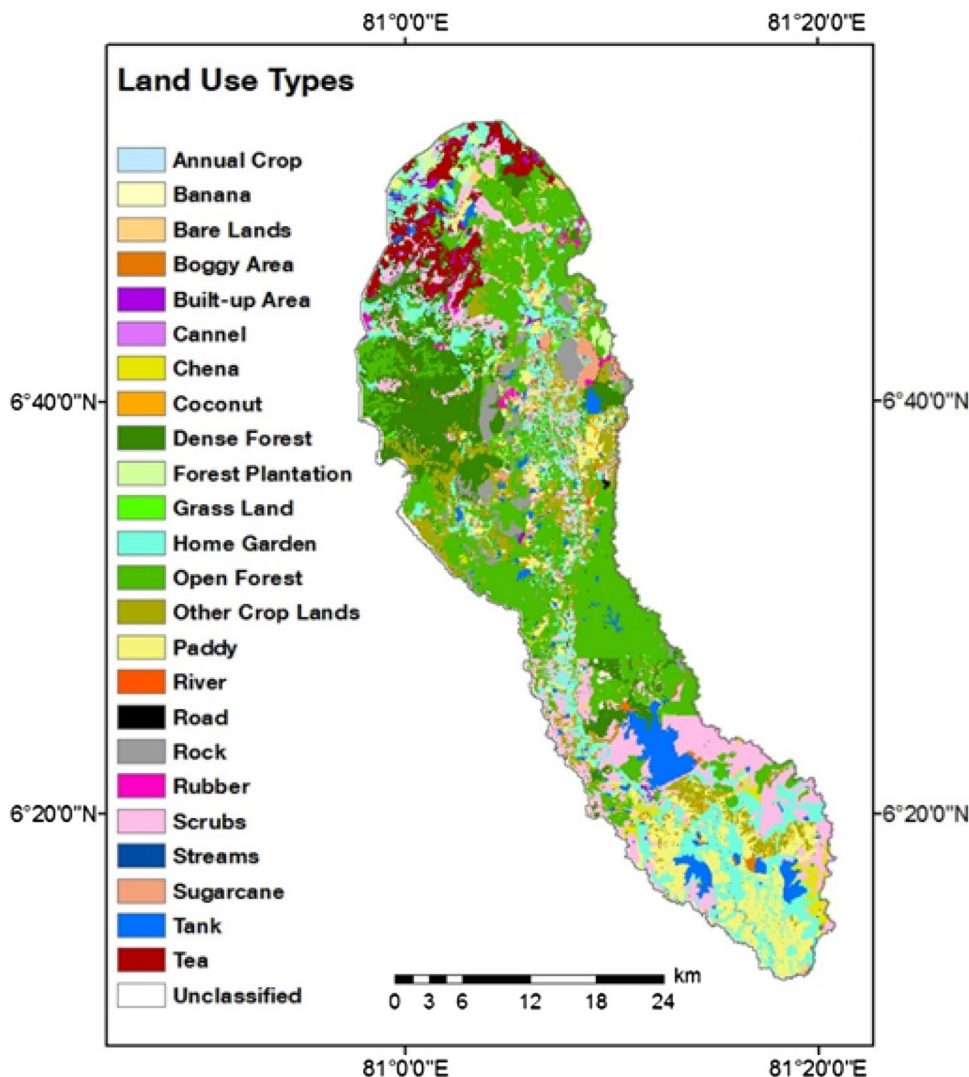
Since mean annual soil erosion rate of Kirindi Oya river basin ($33.32 \text{ t ha}^{-1} \text{ year}^{-1}$) is higher than acceptable soil loss tolerance limit formulated by the Ministry of Environment and Renewable Energy of Sri Lanka, this study suggests that soil erosion of this basin needs to be immediately combated by implementing a proper river basin management plan. In order to support such a programme, we categorized soil erosion rates of the basin into five different

erosion hazard categories, low ($< 30 \text{ t ha}^{-1} \text{ year}^{-1}$), moderate ($30\text{--}40 \text{ t ha}^{-1} \text{ year}^{-1}$), high ($40\text{--}50 \text{ t ha}^{-1} \text{ year}^{-1}$), very high ($50\text{--}60 \text{ t ha}^{-1} \text{ year}^{-1}$), and extremely high ($> 60 \text{ t ha}^{-1} \text{ year}^{-1}$), (Table 5), so that planners or watershed managers can focus more attention to high to extremely high erosion areas of the basin to establish soil conservation measures.

Table 5 Estimated soil loss rate and area distribution

Soil loss rate ($\text{t ha}^{-1} \text{ year}^{-1}$)	Category	Area (km^2)	Area (%)
< 30	Low	590.86	47.35
$30\text{--}40$	Moderate	308.25	24.60
$40\text{--}50$	High	314.77	25.22
$50\text{--}60$	Very High	26.41	2.12
> 60	Extremely High	7.58	0.61

Fig. 8 Land use map of Kirindi Oya river basin



According to this categorization, large portion (47.35%) of the basin area falls under low erosion hazard class ($< 30 \text{ t ha}^{-1} \text{ year}^{-1}$) which is distributed in lower elevated downstream part of the basin located in Hambantota and Moneragala districts (Fig. 7). Furthermore, the area can be characterized by its low rainfall erosivity, low elevation, and low soil erodibility. RBE and LHG Soils are the main soil types found in this area and paddy, chena, scrub lands, open forests and other crop lands are the main lands uses in low erosion hazard area in Kirindi Oya basin. Though we categorized this area to a low ($19\text{--}30 \text{ t ha}^{-1} \text{ year}^{-1}$) erosion class, these erosion rates are above the critical soil loss limits, therefore, at least good agro management practices and proper land use practices are suggested to adopt to the area in order to limit the soil erosion.

24.7% of Kirindi Oya river basin falls under moderate erosion hazard class ($30\text{--}40 \text{ t ha}^{-1} \text{ year}^{-1}$) and is located in Badulla and Moneragala administrative districts. This area is mainly in upstream of the basin where tea is grown. Estimated soil loss of high erosion hazard class is $40\text{--}50 \text{ t ha}^{-1} \text{ year}^{-1}$ and 25.22% of the total area falls under this class. The area is mainly distributed in the upper part of the study area and the area also belongs to Haldummulla, Wellawaya, and Haputhale Divisional Secretariats (DS) divisions in Badulla and Moneragala districts. Moreover, 2.12% of the total area falls under very high erosion hazard class ($50\text{--}60 \text{ t ha}^{-1} \text{ year}^{-1}$). It distributes mainly in Haldummulla and Wellawaya DS divisions in Badulla and Moneragala districts. Scrub lands, home garden, and open forest are the main land uses under very high erosion hazard category. A small portion of the basin (0.61%), can be categorized into an extremely high erosion hazard class ($> 60 \text{ t ha}^{-1} \text{ year}^{-1}$). The area belongs to this erosion category is also distributed mainly in Haldummulla DS division in Badulla district. Moreover, this area lies under RBE and Immature Brown Loam soils. Land uses of this area are home garden and scrub lands. We suggest implementing a watershed development program to conserve the soil in this area specially implementing soil conservation measures to combat the soil erosion.

According to our analysis, upstream part of the Kirindi Oya river basin is more vulnerable to soil erosion than those of downstream part and this may be due to tea cultivations in upstream area. Ministry of Environment and Renewable Energy in Sri Lanka (2014), estimated that loss of top soil by water erosion in the mid and up country tea lands is in the range of 30–50 cm during the period of last 100 years. This amount is equivalent nearly to 40 tons $\text{ha}^{-1} \text{ year}^{-1}$. The present study further corroborates their findings as this study found that the upstream area where tea is cultivated has soil erosion in the range of $30\text{--}50 \text{ t ha}^{-1} \text{ year}^{-1}$. Moreover, Jayarathne et al. (2010), used USLE equation to predict the soil loss at Kandekatiya DS division in Badulla district

and estimated soil loss was in the range of 0 to more than $500 \text{ t ha}^{-1} \text{ year}^{-1}$. Our study estimated values for Badulla area within the basin was $30\text{--}184 \text{ t ha}^{-1} \text{ year}^{-1}$ and the values are lower than those of Jayarathne et al. (2010). Potential soil loss has been estimated in seven places in dry zone of Sri Lanka using USLE and showed that soil loss ranged from 27 to $108 \text{ t ha}^{-1} \text{ year}^{-1}$ (Dharmasena 1992). Present study using RUSLE observed soil loss rate $< 30 \text{ t ha}^{-1} \text{ year}^{-1}$ in dry zone area of Kirindi Oya basin. The difference may be due to the fact that we have used an updated version of USLE. The estimated values of this study specially erosion hazard map can be used with confidence to initiate the soil conservation program for Kirindi Oya river basin. Moreover, the assessment of soil erosion in the field is a time consuming process and also require more resources. Therefore, the ranking of critical soil erosion prone areas for soil erosion conservation programme using RUSLE model at river basin scale is very useful for resource poor country like Sri Lanka.

Conclusion

Spatial amount of soil erosion obtained through the simulation of RUSLE parameters by GIS showed the use of spatially variable information efficiently where ground based observation is difficult. This study could generate soil erosion potential map of $30 \times 30 \text{ m}$ resolution using RUSLE for the Kirindi Oya river basin. The basin was categorized into five different erosion hazard classes namely low ($< 30 \text{ t ha}^{-1} \text{ year}^{-1}$), moderate ($30\text{--}40 \text{ t ha}^{-1} \text{ year}^{-1}$), high ($40\text{--}50 \text{ t ha}^{-1} \text{ year}^{-1}$), very high ($50\text{--}60 \text{ t ha}^{-1} \text{ year}^{-1}$), and extremely high ($> 60 \text{ t ha}^{-1} \text{ year}^{-1}$). Moreover, mean annual soil erosion rate of Kirindi Oya river basin was assessed as $33.32 \text{ t ha}^{-1} \text{ year}^{-1}$. These generated data can be particularly used to conservation prioritization in this basin.

A major portion of the total area of the river basin was classified under low erosion hazard, moderate erosion hazard and high erosion hazard classes (97.27% of total study area). Specially, 2.73% of the basin is under very high to extremely high erosion hazard class. However, all these erosion rates are above the critical soil loss limits. Therefore, large part of this basin could be a threat to agricultural productivity and it may extend its offsite effects to downstream reservoirs such as Yoda Wewa, Debara Wewa, Badagiriya Tank and Lunugamwehera reservoir. The study further revealed that upstream areas of Kirindi Oya river basin located in Haldummulla DS division in Badulla district is fallen on extremely high erosion hazard class and suggests immediate measures to combat soil erosion in the area. Moreover, the results of this study would help in formulating watershed management planning in Kirindi Oya river basin.

Acknowledgements We wish to thank to the Department of Meteorology and Natural Resources Management in Sri Lanka for providing rainfall data used in this study. In addition, we wish to thank staff of the IUCN (International Union for the Conservation of Nature)—country office of Sri Lanka, for providing the land use maps for this study.

References

- Abeyasingha NS, Jayasekara JMNS., Meegastenna TJ (2017) Stream flow trends in up and mid-stream of Kirindi Oya river basin in Sri Lanka and its linkages to rainfall. *MAUSAM* 68(1):99–110
- Adhami M, Sadeghi SH (2016) Sub-watershed prioritization based on sediment yield using game theory. *J Hydrol* 541:977–987
- Amsalu T, Mengaw A (2014) GIS based soil loss estimation using RUSLE model: the case of Jabi Tehinan woreda ANRS, Ethiopia. *Nat Resour* 5:616–626
- Biswas SS, Pani P (2015) Estimation of soil erosion using RUSLE and GIS techniques: a case study of Barakar River basin, Jharkhand, India. *Model Earth Syst Environ* 1:42
- Dharmasena PB (1992) Rainfall erosivity and potential erosion in the central dry zone. *Trop Agric* 148:111–120
- Dharmasena PB (2014) Current status of land degradation in Kandy district. *Academia*. https://www.academia.edu/17509154/Current_Status_of_Land_Degradation_in_Kandy_District. Accessed 13 Aug 2017
- El-Swaify SA, Krishnarajah P (1983) What erosion by water is and what it does. In: Carpenter RA (ed) *Natural systems for development: what planners need to know*. Macmillan, New York, pp 99–161
- Ganasri BP, Ramesh H (2016) Assessment of soil erosion by RUSLE model using remote sensing and GIS—a case study of Nethravathi Basin. *Geosci Front* 7:953–961
- Gelagay HS, Minale AS (2016) Soil loss estimation using GIS and Remote sensing techniques: case of Koga watershed, Northwestern Ethiopia. *Int Soil Water Conserv Res* 4(2):126–136
- Gunatilake HM, Vieth GR (2000) Estimation of on-site cost of soil erosion: a comparison of replacement and productivity change methods. *J Soil Water Conserv* 55:197–204
- Gunawan G, Sutjningsih D, Soeryantono H, Sulistioweni W (2013) Soil erosion estimation based on GIS and remote sensing for supporting integrated water resources conservation management. *Int J Technol* 2:147–156
- Jayarathne KDBL., Dayawansa NDK, De Silva RP (2010) GIS based analysis of biophysical and socio-economic factors for land degradation in Kandeketiya DS division. *Trop Agric Res* 21(4):361–367
- Joshua WD (1977) Soil erosive power of rainfall in the different climatic zones of Sri Lanka. In: *Erosion and Solid Matter Transport in Inland Waters, Proceedings of Symposium Publication, No. 122*. IAHS/IAISH, Paris, pp 51–61
- Kumar S, Gupta S (2016) Geospatial approach in mapping soil erodibility using CartoDEM—a case study in hilly watershed of lower Himalayan range. *J Earth Syst Sci* 125(7):1463–1472
- Mapa RB, Dassanayake AR, Nayakekorale HB (2005) Soils of the intermediate zone of Sri Lanka. In: *Morphology, Characterization and Classification, Special Publication No.4*. Soil science society of Sri Lanka
- Mapa RB, Somasiri S, Dassanayake AR (2010) Soils of the Dry zone of Sri Lanka. In: *Morphology, Characterization and Classification, Special Publication No.7*. Soil science society of Sri Lanka
- Ministry of Agriculture (2012) Soil conservation programme. Ministry of Agriculture Battaramulla Sri Lanka. <http://www.agrimin.gov.lk/web/index.php/our-services/88-soil-conservation>. Accessed 27 June 2017
- Ministry of Environment and Renewable Energy in Sri Lanka (2014) National action programme (NAP) for combating land degradation in Sri Lanka 2015–2024. Natural Resources Management Division, Ministry of Environment and Renewable Energy, Sri Lanka. <http://www.unccd.int/ActionProgrammes/Sri%20Lanka-2015-2024-eng.pdf>. Accessed 12 Aug 2017
- Munasinghe MAK, Pushpakumara V, Bandara TMJ, Herath HMB (2001) Use of information systems for soil erosion hazard assessment of the central province of Sri Lanka. *Ann Dep Agric* 3:148
- Pimentel D, Harvey C, Resosudarmo P et al (1995) Environmental and economic costs of soil erosion and conservation benefits. *Science* 267:1117–1123
- Prasannakumar V, Vijith H, Abinod S, Geetha N (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. *Geosci Front* 3(2):209–215
- Praveen R, Kumar U (2012) Integrated approach of universal soil loss equation (USLE) and geographical information system (GIS) for soil loss risk assessment in upper south Koel basin, Jharkhand. *J Geogr Inf Syst* 4:588–596
- Premalal (1986) Development of an erosivity map for Sri Lanka. A research report submitted for the B.Sc. degree. Department of Agricultural Engineering, University Peradeniya, Sri Lanka
- Remortel V, Hamilton RM, Hickey R (2001) Estimating the LS factor for RUSLE through iterative slope length processing of digital elevation data. *Cartography* 30(1):27–35
- Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1997) Predicting soil erosion by water: a guide to conservation planning with revised universal soil loss equation (RUSLE). United States Department of Agriculture, Washington, D.C. (**Agricultural Handbook No. 703**)
- Senanayake SS, Munasinghe MAK, Wickramasinghe WMADB. (2013) Use of erosion hazard assessments for regional scale crop suitability mapping in the Uva Province. *Ann Sri Lanka Dep Agric* 15:127–141
- Singh G, Panda RK (2017) Grid-cell based assessment of soil erosion potential for identification of critical erosion prone areas using USLE, GIS and remote sensing: a case study in the Kapgari watershed, India. *Int Soil Water Conserv Res* 5(3):202–211
- Udayakumara EPN, Shrestha RP, Samarakoon L, Schmidt-vogt D (2010) People's perception and socioeconomic determinants of soil erosion: a case study of Samanawewa watershed. *Sri Lanka Int J Sediment Res* 25:323–339
- Wijesekara S, Samarakoon L (2002) Application of a soil erosion model in a grid-based GIS environment. *Asian J Geo Inf* 3(1):49–54
- Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses: a guide to conservation planning. *Agricultural hand book No. 537*, United States Department of Agriculture, Washington, D.C.
- Zeng C, Wang S, Bai X, Li Y, Tian Y, Li Y, Wu L, Luo G (2017) Soil erosion evolution and spatial correlation analysis in a typical karst geomorphology using RUSLE with GIS. *Solid Earth* 8:721–736