Assessing the Influence of Land Use Change Pattern and Soil Erosion on Sediment Delivery Ratio in the Upper Mahaweli River Catchment of Sri Lanka

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Abstract: The Mahaweli River takes in the largest volume of water amounting to one seventh of Sri Lanka's total runoff and has a catchment area that covers 15 % of the land in the country. A number of multipurpose reservoirs have been stored in the Upper Mahaweli River Catchment (UMRC) mainly to generate hydropower, which contributes to about 40-50% of the total hydropower production in the country. This study investigates the impacts of land use change patterns and soil erosion on the sediment delivery ratio (SDR) within the UMRC in Sri Lanka. Utilizing Geographic Information Systems (GIS) and Remote Sensing (RS) tools, the land use and land cover (LULC) changes were analyzed over a period from 2007 to 2023, focusing on soil erosion's contribution to sediment dynamics in the basin. By employing the Universal Soil Loss Equation (USLE) model, factors such as rainfall erosivity, soil erodibility, slope characteristics, crop cover, and land management practices were assessed to estimate soil loss and map erosion hotspots. The InVEST SDR model was then applied to quantify sediment transport and deposition patterns, helping to identify priority areas for soil conservation. Results revealed an average annual soil loss ranging from 0 to 95.015 t ha^{-1} yr^{-1} in the catchment and a mean annual sediment export of 5.56 t ha^{-1} yr^{-1}. It shows mean sediment deposition rate as 2.4 t ha^{-1} yr^{-1}. Erosion severity was classified into five hazard classes, very low (0 - 5 t ha^{-1} yr^{-1}), low (5 - 10 t ha^{-1} yr^{-1}), moderate (10 - 20 t ha^{-1} yr^{-1}), high (20 - 50 t ha^{-1} yr^{-1}) and very high (>50 t ha^{-1} yr^{-1}). A critical 1.5% area was identified as a considerable soil erosion hazard area, necessitating urgent measures for erosion control. Findings indicate significant LULC changes, driven primarily by deforestation, agricultural expansion, and urbanization, which have intensified mean soil erosion rate from 2.39 t ha^{-1} $yr^{-1}$to 11.22 t ha^{-1} yr^{-1}, highest mean sediment export rate as 2.29 t ha^{-1} yr^{-1} and highest mean sediment deposition rate as 5.36 t ha^{-1} yr^{-1} in different watersheds. Importantly, the identified erosion hotspots and sediment export zones indicate a substantial risk of accelerated sedimentation in downstream reservoirs, potentially reducing storage capacity and affecting hydropower efficiency in the Upper Mahaweli system. These findings support targeted watershed management interventions to mitigate long-term sedimentation impacts.

Keywords: InVEST SDR model; Land use land cover change; Soil erosion; Upper Mahaweli River Catchment; Universal Soil Loss Equation.

1. Introduction

Soil degradation and deterioration of soil health affect crop production, economic status, and finally food and nutritional security and sustainability. Soil degradation in terms of various modes including erosion obstructs the achievement of the United Nations (UN) Sustainable Development Goals (SDGs) mainly; no poverty (SDG1), zero hunger (SDG2), good health and well-being (SDG3), clean water and sanitation (SDG6), climate action (SDG13) and life below land (SDG15) which is a serious threat to the overall sustainability. Therefore, proper assessment and prevention of soil degradation are important (Karunaratne, 2022). In recent time, the United Nations Convention to Combat Desertification (UNCCD) recognizes land degradation as one of the most noticeable environmental concerns. Land degradation can be occurred by anthropogenic activities. Most forms of land degradation are man-made problems. Soil degradation, particularly erosion, is a major environmental challenge impacting agricultural productivity, water quality, and ecosystem stability globally (Lal et al., 2021). In Sri Lanka's Upper Mahaweli River Catchment (UMRC), extensive deforestation, agricultural expansion, and urbanization have accelerated soil erosion, increasing sediment transport and deposition in rivers and reservoirs (Somasiri et al., 2021). This sedimentation not only reduces reservoir capacities critical for hydropower generation contributing to 40–50% of the country's electricity supply but also impairs aquatic ecosystems and water quality (Ekanayake et al., 2024).

Despite numerous studies on soil erosion in Sri Lanka, significant gaps remain. In particular, there is a lack of calibrated sediment delivery ratio (SDR) assessments due to limited sediment monitoring data, sparse rainfall station networks in mountainous regions, and insufficient integration of land use change dynamics with sediment connectivity modeling. This study addresses these gaps by integrating USLE-based erosion estimation with the InVEST SDR model to evaluate the combined effects of LULC change and sediment transport processes in the Upper Mahaweli River Catchment.

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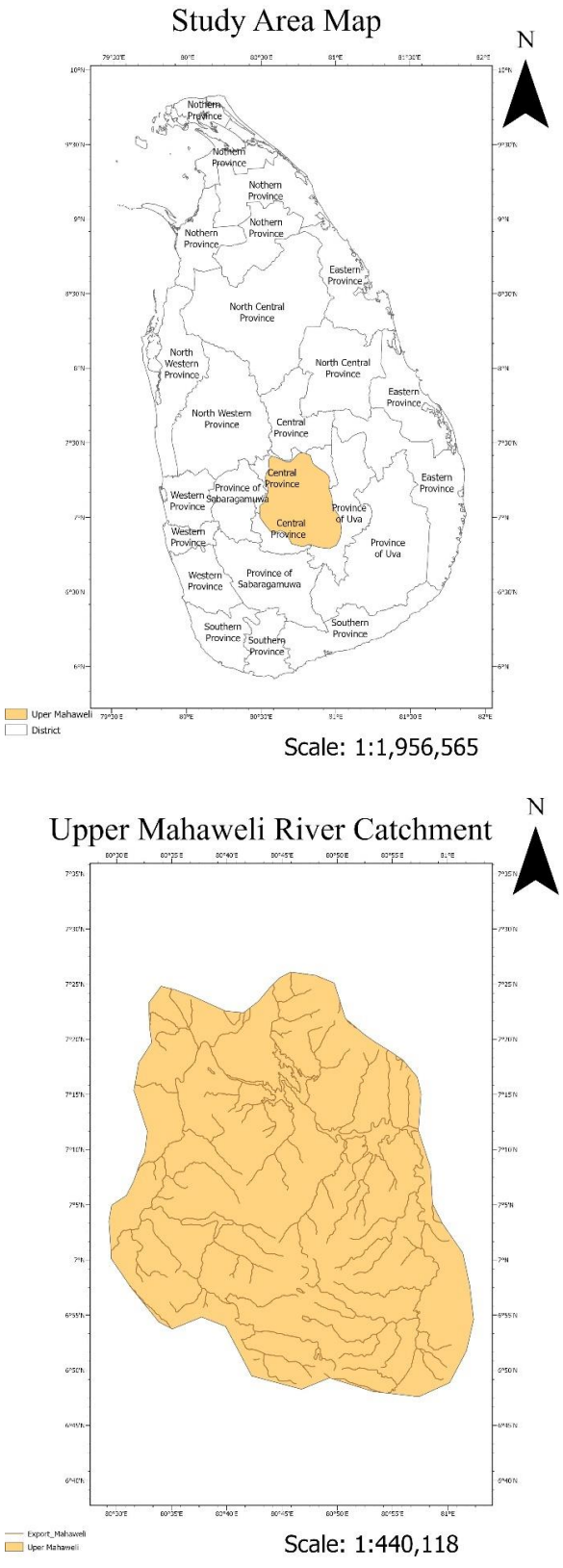


Figure 1: Study area of the research

Understanding the relationship between land use changes, soil erosion, and sediment delivery is essential for sustainable land and water management. Geographic Information Systems (GIS) and Remote Sensing (RS) techniques have proven effective in analyzing land use changes and quantifying erosion patterns over time (Wijesinghe and Withanage, 2021). By incorporating the Universal Soil Loss Equation (USLE) and the InVEST Sediment Delivery Ratio (SDR) model, this study examines land use changes from 2001 to 2023 and assesses their influence on soil erosion and sediment delivery rates within the UMRC (Panditharathne et al., 2019). The study aims to identify erosion-prone areas, evaluate sediment deposition patterns, and provide data-driven insights to support targeted soil conservation efforts. These findings contribute to improving watershed management practices, ensuring long-term water resource sustainability, and safeguarding the UMRC's vital role in Sri Lanka's hydropower and agricultural sectors.

2. Materials and Methods

2.1 Study area identification

The UMRC is a large watershed situated between the elevations 500 m and 2510 m and covers about 3120 km^2 of land in the Central Highlands of Sri Lanka. Geologically, UMRC is underlain by high-grade metamorphic rocks that contain tightly interlocked mineral grains leading to slow weathering (Hewawasam et al., 2013; Behrens et al., 2015). Pedologically, the area is characterized by Red Yellow Podzolic soil (72%), Reddish Brown Earths (6%), Immature Brown Loams (10%), Reddish Brown Latosolic (8%), and Steep Rockland and Lithosols (4%; Mapa et al., 1999). The natural vegetation in UMRC consists of Tropical Lower Montane (900–1500 m) and Tropical Upper Montane (> 1500 m) (Wickramagamages, 1998). The UMRC includes both wet (76%) and intermediate (24%) agroclimatic zones of Sri Lanka. The mean annual rainfall is approximately 2650 mm with a standard deviation of 1060 mm. Figure 5 depicts the average annual rainfall distribution in and around UMRC (Somasiri et al., 2021). Study area of the research shows by the Figure 1.

2.2 Data Sources

SRTM 30 m x 30 m resolution digital elevation model (DEM) collected from USGS Earth Explore (https://earthexplorer.usgs.gov/) Landsat images from USGS Earth Explore landsat collection 2 level 2 landsat 8 – 9 create land use land cover map. The soil map of the study area was extracted from the soil map produced by the NRMC, Peradeniya, Sri Lanka. Rainfall data from 2001 to 2023 was collected from Natural Resource management Centre, Peradeniya. InVEST 3.14.2. Workbench, Arc GIS, MS office package were required software for the different functions.

Additional information has been included to explicitly describe spatial data processing steps. All datasets were standardized to a common spatial framework to ensure consistency in analysis. Specifically, all raster and vector layers were projected to the WGS 1984 UTM Zone 44N coordinate system, and raster datasets were resampled to a uniform spatial resolution of 30 m. Slope and flow accumulation were derived from the DEM using standard hydrological tools in ArcGIS.

2.3 Identification of Land Use Land Cover Changes

2.3.1 Data acquisition and image processing

Landsat images about the study area were gathered through the United States Geological Survey (USGS) Earth Explore website (https://earthexplorer.usgs.gov/).

Table 1: Details of the Landsat images

Year	Types of Data	Cloud Cover (%)	Acquisition Date
2007	Landsat 4-5 TM C_2L_2	3	2007.03.23
2016	Landsat 8-9 OLI/TIRS C_2L_2	5	2016.01.27
2023	Landsat 8-9 OLI/TIRS C_2L_2	9.24	2023.03.05

Landsat 5 images were composed of 1, 2, 3, 4, 5 and 7 bands and Landsat 9 images were composed of 1, 2, 3, 4, 5, 6 and 7 bands. Composite images were merged and clipped to get the study area using ArcGIS 10.7.1 software. Table 1 shows the details of the Landsat images.

2.3.2 Image classification

The pre-processed Landsat images 2007, 2016 and 2023 were classified using the ArcGIS Interactive supervised classification method and, based on the results training samples were created for the maximum likelihood supervised classification and random trees classifier. The study has chosen the False color composite (FCC) RGB bands 4, 3, 2 and 5, 4, 3. This combination normally makes vegetation red, water bodies from dark blue to black and urban areas blue.

2.4 Watershed Delineation

Sub-catchments were delineated using hydrological and topographic data of UMRC available as 30 m resolution digital elevation model from USGS. The sub-catchments were outlined in the ArcGIS environment following the delineation method of the watershed tool in hydrology under the spatial analyst category.

2.5 The description of the model used Soil Erosion Assessment

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Sediment Delivery Ratio (SDR) model was used to assess soil erosion. Specifically, the InVEST SDR model is utilized to map sediment generation and its delivery to streams over land (Dias et al., 2019) and used it nationally and internationally (Marques et al., 2021; Qiao et al., 2024; Dias et al., 2019; Abeysingha et al., 2023). Universal Soil Loss Equation is the basic equation used in the InVEST SDR model and can be expressed as,

$$\mathbf{A = R \times K \times LS \times C \times P} \qquad \text{Eq: 1}$$

Where,
A -Average annual soil loss, $t.ha^{-1}.yr^{-1}$,
R - Rainfall erosivity factor, $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$,
K - Soil erodibility factor, $t.h.MJ^{-1}.mm^{-1}$,
LS - Slope length and gradient factor (dimensionless)
C - Cover and management factor(dimensionless)
P - Conservation and support practice factor (dimensionless)

Table 2: Details of Rain gauge stations

Rainfall station	Latitude	Longitude	Mean annual rainfall (mm)	R factor (MJ mm ha^{-1} h^{-1} yr^{-1})
Peradeniya	7.25	80.56	2086.83	217.36
Kundasale	7.309624	80.710353	1543.18	163.27
Seetha Eliya	6.933036	80.810243	1920.10	200.7

2.5.1 Estimation of Rainfall Erosivity Factor (R)

The rainfall erosivity factor R, which considers the impact of raindrops, serves to estimate the effect of rainfall intensity on soil erosion. Monthly rainfall data from 03 rainfall gauging stations near the study area (Table 2) for 22 years (2001 – 2023) duration were used in calculating the average R factor using the rainfall erosivity factor equation developed for Sri Lankan conditions by Premalal (1986). This equation has been widely used in Sri Lanka (Fayas et al., 2019; Panditharathne et al., 2019;) and can be expressed as,

$$\mathbf{R = (972.75 + 9.95 \times P)/100} \qquad \text{Eq: 2}$$

Where,
R – annual rainfall erosivity (MJ mm ha^{-1} h^{-1} yr^{-1})
P – mean annual precipitation (mm) (Somasiri et al., 2021).

As per the requirement of the model, points were interpolated both point rainfall data and respective R point values to the entire catchment. For this purpose, Inverse Distance Weighted (IDW) was tested to interpolate using ArcGIS (10.7.1.). Due to limited availability of long-term continuous rainfall data within the UMRC, only three stations were used. Although this may not fully capture micro-climatic variability in mountainous terrain, these stations represent key agro-climatic zones (wet and intermediate). IDW interpolation was selected due to its simplicity and suitability for sparse datasets. However, it assumes distance-based decay and does not account for elevation-driven rainfall variability, which may introduce spatial uncertainty.

2.5.2 Estimation of Soil Erodibility Factor (K)

Soil erodibility, as employed in the USLE, is determined by factors such as soil texture, soil structure, and the organic matter content of the soil (Wischmeier and Smith, 1978; Renard et al., 1997). Soil map of the study area was obtained from the NRMC. A new field was created in the attribute table of the digitized soil map shape file, named K factor, and the mean K values of each soil series were entered. Table 3 shows the soil erodibility value for each soil category. Then K factor raster map was generated from a vector soil map with 30 m × 30 m resolution using the Feature to Raster tool in ArcGIS 10.7.1.

Table 3: Soil Erodibility Value for each Soil Type

Soil Type	% In UMRC	Soil Erodibility Factor
Reddish Brown Latosolic	8	0.17
Reddish Brown Earth	6	0.27
Immature Brown Loam	10	0.33
Steep Rockland and Lithosols	4	0.35
Red Yellow Podzolic	72	0.22

2.5.3 Slope length and steepness factor (LS)

The LS factors that represent topographic factors length (L) and steepness (S) of a slope provide the terrain characteristics of a given site. The digital elevation model (DEM), which can be used to identify the terrain characteristics, was generated using the digital elevation model from USGS.

$$\mathbf{LS} = (\mathbf{Flow\ accumulation} \times \mathbf{cell\ size} / \mathbf{22.13})\mathbf{0.4} \times \mathbf{Sin}\ (\mathbf{Slope\ angel\ in\ Degree} / \mathbf{0.0896})\mathbf{1.3}$$

Eq: 3 (Patel et al., 2024).

The LS factor was derived using a DEM-based flow accumulation approach, which is widely used in GIS-based erosion modeling. However, in steep and highly dissected terrains such as the Sri Lankan Central Highlands, DEM resolution (30 m) may introduce uncertainties in representing micro-topographic variations. Despite this, the method is considered appropriate for basin-scale analysis.

2.5.4 Land Use Land Cover map preparation

Land Use Land Cover maps were prepared using Landsat images from USGS using supervised classification This land use and land cover map was employed to develop crop management (C) and erosion control practice (P) factors.

2.5.5 Cover Management Factor (C)

The vegetation cover and management factor (C) is the ratio of the total soil loss from land with vegetation cover

Table 5: Cover management value

Classes	Cover management value
Water bodies	0
Forest	0.2
Vegetation	0.8
Build up area	0.73

Table 4: Biophysical Table

Land Use Code	P Values	C Values
1	0	0.73
2	0.5	0.80
3	0	0
4	0.1	0.2

or field management to the total soil loss from continuous fallow land with clear tillage. It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The C factor is a ratio comparing the soil loss from land under a given crop and management system to the corresponding loss from a standard condition. Table 4 shows the C values for different land use.

2.5.6 Support and Conservation Practices Factor (P)

The P factor, representing land cover and management practices in RUSLE and USLE, is acknowledged as the most uncertain factor. It varied from 0 to 1 and a P value of 0 indicates an area with very good land management practices, while a P value of 1 indicates an area without conservation practices as Table 5 The data of P factors were then added to a CSV file and developed the biophysical table required for the model, corresponding to the Land Use/Land Cover (LULC) code.

2.6 Soil Erosion Hazard Map Preparation

R, K, LS, C and P factors maps were computed using the ArcGIS 10.7.1 software. The spatial analyst extension and the raster calculator in ArcGIS software was employed to estimate soil erosion loss (ton ha^{-1} yr^{-1}) by using the USLE model and generated the soil erosion hazard map.

2.7 InVEST Sediment Delivery Ratio Model

Inputs of the InVEST model were digital elevation model, rainfall erosivity factor raster file, soil erodibility raster file, land use land cover map, watershed vector file, biophysical table, threshold flow accumulation value, Borselli K parameter, maximum SDR value, Borselli IC_0 parameter and maximum L value. Biophysical table contain information on each land-use (LULC) class was included in the model related to crop (C-factor), management factor (P-factor) as the Table 5. The C-factor of land depends on crop type and the tillage method used. A .csv (Comma Separated Value) table containing model information corresponding to each of the land uses (Sandamali et al., 2023).

Threshold flow accumulation: The number of upstream cells that must flow into a cell before it is considered part of a stream, which was used to classify streams from the DEM. This threshold directly affects the expression of hydrologic connectivity and the sediment export. A threshold flow accumulation value of 1000 was selected based on the InVEST user guide and preliminary testing to approximate observed stream networks. This parameter strongly influences hydrological connectivity and sediment routing. Although the selected value produced a

Table 6: Details of the land use change

LULC Class	2007 Area (km^2)	2007 (%)	2016 Area (km^2)	2016 (%)	2023 Area (km^2)	2023 (%)
Build up Area	647.16	21.20	700.12	22.93	751.09	24.6
Vegetation	1622.94	53.17	1713.17	56.12	1935.42	63.4
Water Bodies	37.45	1.23	40.43	1.32	48.16	1.57
Forest	744.80	24.4	598.66	19.61	317.67	10.4
Total	3052.37	100	3052.39	100	3052.35	100

realistic drainage pattern, sensitivity to this parameter was not explicitly quantified and remains a source of uncertainty. Future work should include sensitivity analysis to evaluate its impact on sediment export estimates. when a flow path reaches the stream, sediment deposition stops and the sediment exported is assumed to reach the catchment outlet. It is important to choose this value carefully, so modeled streams come as close to reality as possible (Udayakumara and Gunawardana, 2021).

The SDR module of InVest model first calculates the sediment delivery ratio (SDR) value, which is the ratio of the sediment amount reaching the outlet section of the catchment to the total amount of upstream soil loss, and then predicts the actual amount of sediment reaching the through the streams.

$$SE = RUSLE \times SD \quad \text{Eq: 4}$$

$$SDR = \frac{\text{SDRmax}}{1+\exp(c\,0-\frac{\text{Ic}}{\text{kb}})} \quad \text{Eq: 5}$$

Where RUSLE is Revised Universal Soil Loss Equation, SE is the sediment export; SDR is the sediment delivery ratio SDR_{max} is the maximum sediment delivery ratio, which is determined to be 0.8 by sampling and experimental analysis; IC is the connectivity index; Borrelli IC0 and kb are the calibration parameters and their default values are 0.5 and 2. Threshold flow accumulation was 1000. This study used default values for these parameters as no observed sediment data was available for calibration and validation of the model (Ekanayake et al., 2024).

2.8 Field Validation through collected images

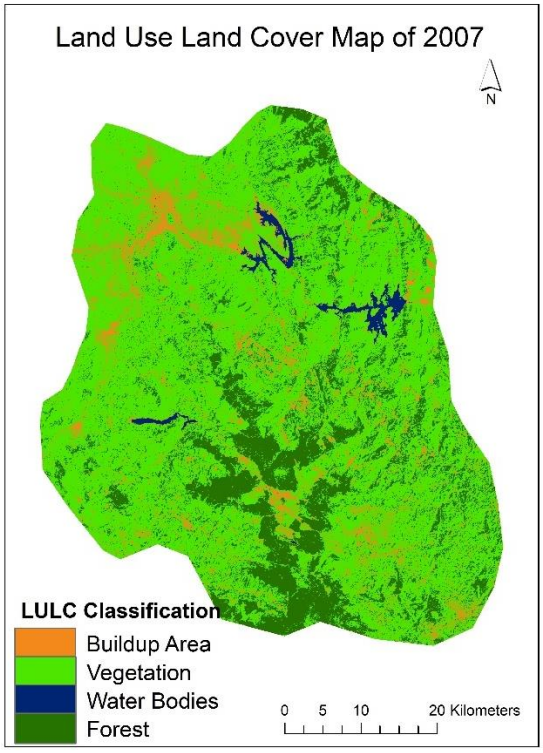
Validation was done using field verifications. Ground points were obtained and compared with prepared ground truth actual images were collected to validate crated soil erosion map.

2.9 Model Assumptions and Uncertainty Analysis

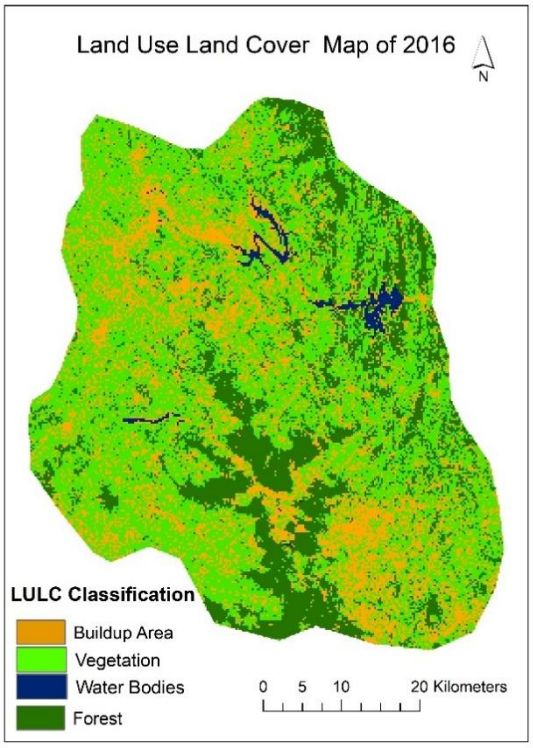
The USLE model assumes sheet and rill erosion processes and does not account for gully or mass erosion. The InVEST SDR model further assumes uniform sediment transport processes and requires calibration parameters (k, IC0), which were adopted as default values due to lack of observed sediment data. Among the parameters, the P-factor introduces the highest uncertainty due to generalized assignment based on literature values rather than field-measured conservation practices. Additionally, DEM-derived LS factor and rainfall interpolation using limited stations contribute to spatial uncertainty.

Table 7: Accuracy Assessment data

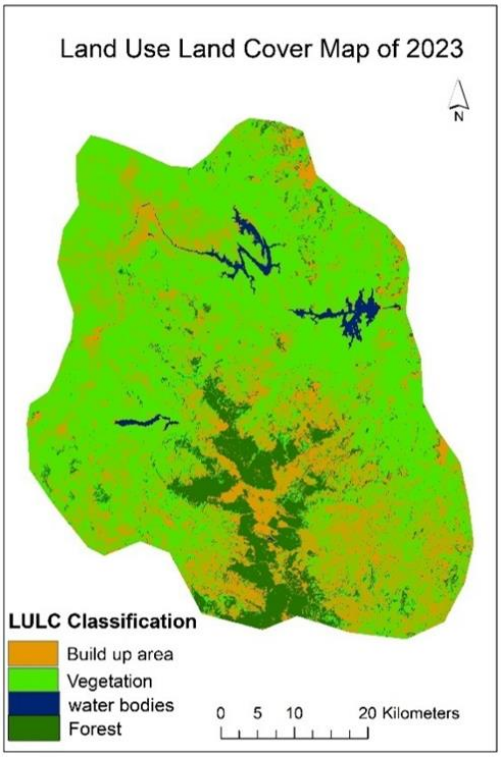
	Year	Buildup Area	Vegetation	Water Bodies	Forest
Producer's Accuracy (%)	2007	100	95	100	93
	2016	83	100	0	83
	2023	100	92	0	82
User's Accuracy (%)	2007	85	100	100	100
	2016	100	91	0	100
	2023	73	98	0	93
Overall Accuracy %	2007		96		
	2016		94		
	2023		92		
Kappa Coefficient	2007		94		
	2016		87		
	2023		84		



a)



b)



c)

Figure 2: (a, b, c) presents the supervised classified LULC maps for the years 2007, 2016, and 2023 using ArcGIS.

3. Result and Discussion

3.1 Land use land cover changes

The study examined land use and land cover (LULC) changes in the Upper Mahaweli River Catchment, Sri Lanka, using Landsat 5 and Landsat 9 satellite imagery processed in ArcGIS. LULC was categorized into four classes: built-up area, vegetation, water bodies, and forest, using the interactive supervised classification method. LULC maps were produced for the years 2007, 2016, and 2023 Figure 2 (a, b, c).

According to Table 6, from 2007 to 2023, the built-up area increased from 647.16 km² to 751.09 km², vegetation expanded from 1622.94 km² to 1935.42 km², and water bodies grew from 37.45 km² to 48.16 km². In contrast, forest cover significantly declined from 744.80 km² to 317.67 km². These changes over the period 2007–2023 are illustrated in Figure 3.

The LULC classification was aggregated into four generalized classes to ensure consistency with available datasets and model requirements. However, this simplification may mask important heterogeneity within land use types such as tea plantations, home gardens, and chena cultivation, which exhibit distinct erosion characteristics.

The classification accuracy assessment results are presented in Table 7. Then the percentage changes in individual LULC classes between the study years are presented in Table 8.

The LULC classification was aggregated into four generalized classes to ensure consistency with available datasets and model requirements. However, this simplification may mask important heterogeneity within land use types such as tea plantations, home gardens, and chena cultivation, which exhibit distinct erosion characteristics.

3.2 Sub-Watershed Delineation

There were 18 micro and macro watersheds by determination of watershed delineation method in spatial analyst tool in Arc GIS as Figure 4.

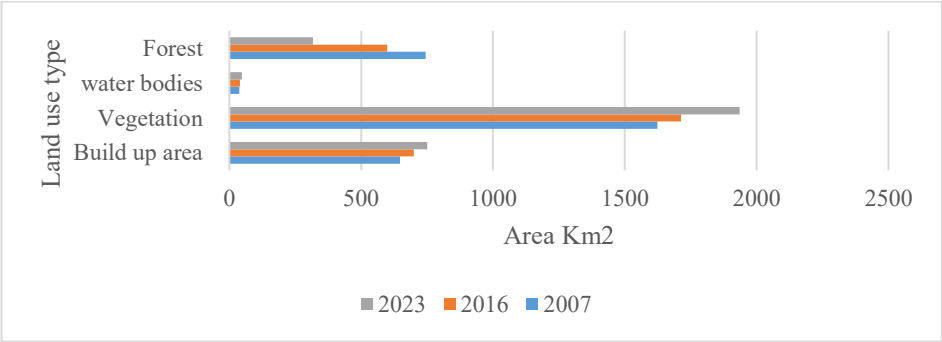


Figure 3: Graphical representation of land use change

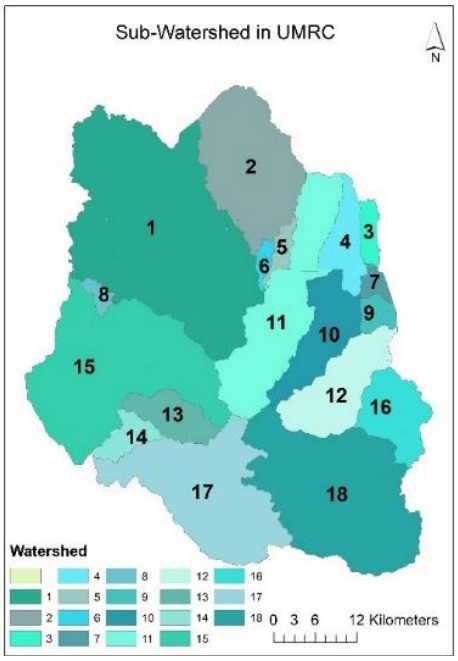


Figure 4: Sub-Watershed Map of UMRC

3.3 Soil erosion assessment

Soil erosion severity map and the sediment delivery to UMRC were calculated using the USLE parameters embedded in InVEST SDR model.

3.3.1 Rainfall Erosivity factor (R)

Rainfall is one of the most sensitive factors for soil erosion assessment (Ganasri and Ramesh, 2016). Mean annual rainfall over the area varied from 1543 to 2087 mm. The following Figure 5 shows the rainfall distribution in study area. The maximum value was recorded in Peradeniya rain gauge station in wet zone of the country as 2087 mm and the lowest average annual rainfall was observed in Kundasale rain gauge station in intermediate zone of the country as 1543 mm. Seetha Eliya rain gauge station is located in intermediate zone of Sri Lanka had 1920 mm mean annual rainfall. R factor map dictates that the R factor ranges from 163.27 to 217.36 MJ mm ha^{-1} h^{-1} yr^{-1} in the upper Mahaweli area. 163.27, 200.77 and 217.36 were R factor value for Kundasale, Seetha Eliya and Peradeniya respectively. R factor follows the variation of mean annual rainfall. The same InVEST-SDR model was used by (Abeysingha et al.,2023) for Deduru Oya basin, and the R factor values were shown to range from 311.25 to 609.58 MJ.mm.ha^{-1}.$h^{-1}$$yr^{-1}$. Whereas, most part of Deduru Oya river basin is located in the Intermediate zone and the resultant R factor values are higher and equal for the studied area. Management practices to reduce the impact of rainfall and sediment control measures can be adopted based on the R values. Following Figure 5 shows the R factor map.

Uncertainty in the rainfall erosivity (R-factor) is primarily linked to the limited density of rainfall stations (n = 3) used for interpolation across a highly heterogeneous mountainous basin. The application of the Inverse Distance Weighted (IDW) method assumes isotropic spatial variability and does not explicitly account for orographic effects, which are known to significantly influence rainfall distribution in the Central Highlands of Sri Lanka. Consequently, localized extremes in rainfall and thus erosivity may not be fully captured.

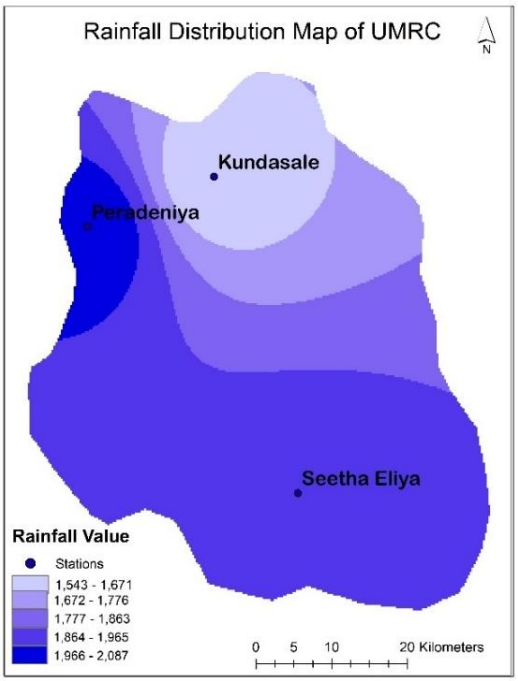
3.3.2 Soil erodibility factor (K)

The study area comprised of red yellow podzolic, reddish brown earth, reddish brown latosolic, immature brown loams and steep rockland. Each of these soil types has a soil erodibility factor assigned to them in previous studies of Sri Lanka. The major soil type of the study area was Red Yellow Podzolic soil type (70%), which has an erodibility of 0.22 (Table 3). Therefore, the soil erodibility factor in UMRC varied between 0.17 and 0.35 t ha MJ^{-1} mm^{-1}. Jayasinghe et al., (2017) reported that landslides frequently occur in cultivated agricultural lands with Red-Yellow Podzolic soil types and steeply dissected, hilly, and rolling terrains. Figure 6 shows soil erodibility map.

3.3.3 Slope length and steepness factor (LS)

The UMRC area slope varied from 0 to 74.68 % and LS values ranged from 0 to 81.05 (Figure 7). Higher values of LS are more vulnerable to erosion. Slope as an input for calculation of LS factor.

The derivation of the LS factor from a 30 m resolution DEM introduces additional uncertainty, particularly in steep and highly dissected terrains where fine-scale topographic variability governs flow concentration and slope processes. DEM resolution limitations may result in smoothing of terrain features, potentially affecting flow accumulation patterns and leading to either overestimation or underestimation of erosion in critical areas.



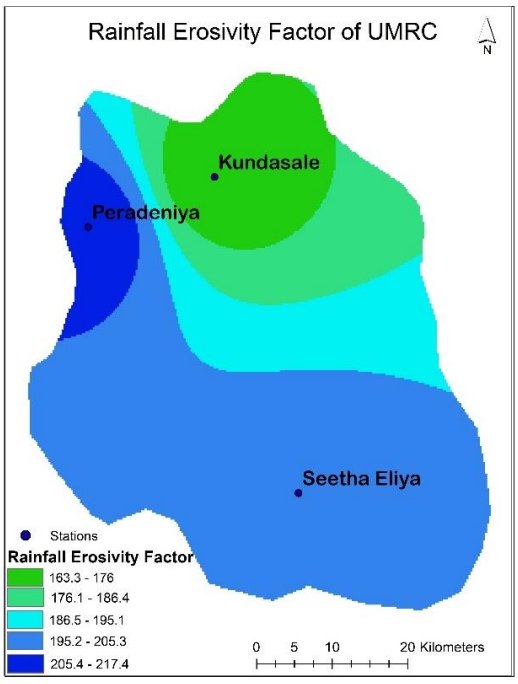


Figure 5: Rainfall distribution map and rainfall erosivity factor map

3.3.4 Cover and management factor (C)

The cover-management factor (C-factor) of both the Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1978), and the revised version, RUSLE (Renard et al., 1997), express the protective effect of soil cover against the erosive action of rainfall. C value of the study area were in the range of 0 to 0.8. Figure 8 shows the C factor map for this study area. Land use land cover map of 2023 used to create cover and management factor.

3.3.5 Support and conservation practice factor (P)

P factor is ranging from zero for good conservation practices to one for poor conservation practices. LULC map of 2023 (Figure 9) indicates that upper Mahaweli area

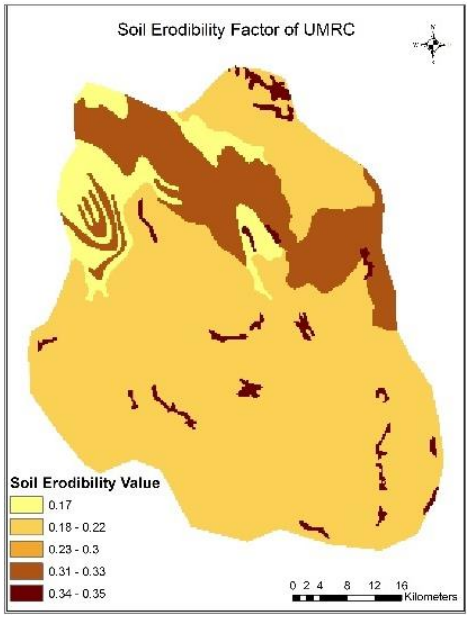


Figure 6: Soil erodibility map of UMRC

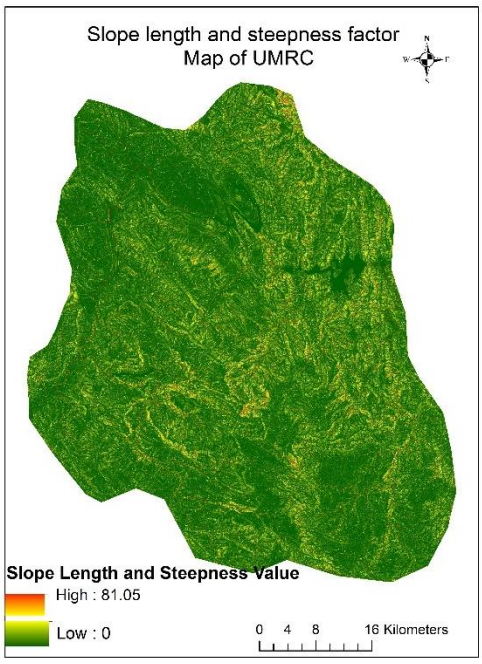


Figure 7: Slope length and steepness factor map

consists of different LULC classes. Table 5 shows the P factor values for relevant LULC class. P factor assigned for the areas in the UMRC ranged from 0 to 1.

3.4 Soil Erosion Hazard map generation

Whereas, tssshe total soil loss map, derived using the Universal Soil Loss Equation (USLE), provides a comprehensive assessment of soil erosion within the catchment. The mean annual soil loss was estimated at 5.56 t ha^{-1} yr^{-1}, with USLE values ranging from 0 to 95.01 t ha^{-1} yr^{-1}. According to the (Ekanayake et al., 2024) the mean annual, minimum and maximum soil loss of Lower Malwathu Oya reservoir was estimated at 0.21 t ha^{-1} yr^{-1}, with USLE values ranging from 0 to 15.55 t ha^{-1} yr^{-1} with low erosion rate. According to the (Somasiri et al., 2021) mean soil erosion rates of different area in UMRC were

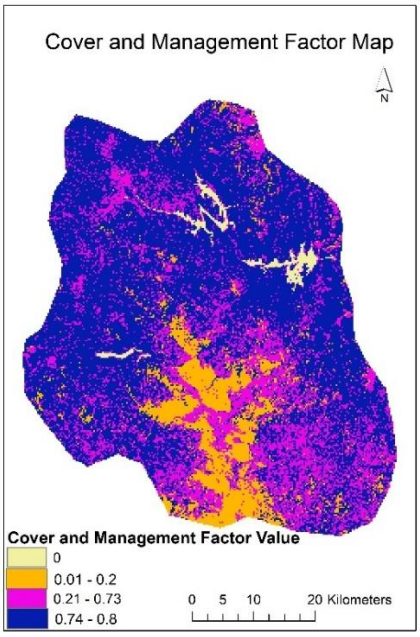


Figure 8: Cover and management factor map of UMRC

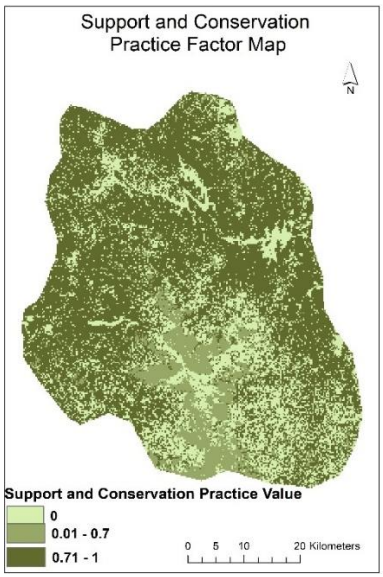


Figure 9: Support and conservation practice factor (P) Map of UMRC

3.46 t ha^{-1} yr^{-1} in Maha Oya, 5.15 t ha^{-1} yr^{-1} in Belihul Oya, 2.09 t ha^{-1} yr^{-1} in Hulu Ganga and 3.27 t ha^{-1} yr^{-1} in Atambage Oya. Comparing those with this research, soil erosion rate of the studied area was very high soil loss rates in studied area compared to others due to high rainfall, slope of the land, agricultural activities in the area.

In soil erosion modeling of Kotmale Oya, Dissanayake et al., (2018) used three tolerable soil loss rates of 13.2, 9.0, and 6.7 t ha−1 y−1 for Upcountry Wet zone, Mid Country Wet Zone and Low Country Dry Zone regions of Sri Lanka, respectively. Udayakumara and Gunawardena, (2016) and Dias et al., (2019) considered 5 t ha−1 y−1 as the soil loss tolerance in Sri Lanka (Somasiri et al., 2021). In another Sri Lankan study, the average rate of soil erosion of tropical countries was considered as 10 t ha−1 y−1 and it was used as a threshold value in the prioritization of sub-catchments for the recommendation of conservation (Senanayake et al., 2020). However, these levels of erosion appear to be too large to be considered as a permissible level or tolerance level when they are compared with the natural soil production rates in the central highlands of Sri Lanka (Hewawasam et al., 2013; Hewawasam, 2019; Blanckenburg et al., 2004). Moreover, modeled soil erosion was categorized as very low, low, moderate, high, and very high referring to arbitrary threshold values (Senanayake et al., 2013).

Table 8: Percentage of land use change

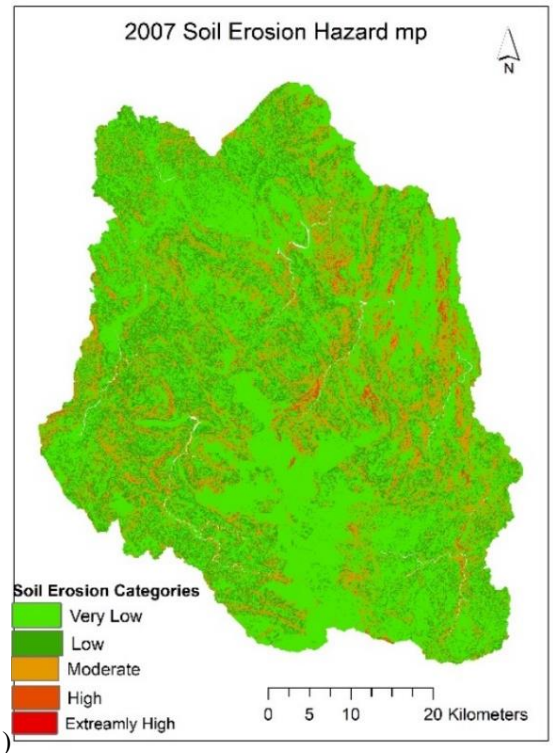
LULC Class	Change 2007 - 2016 (%)	Change 2016 - 2023 (%)
Build up Area	1.73	1.67
Vegetation	2.95	7.28
Water Bodies	0.1	0.26
Forest	-4.78	-9.21

The average annual soil erosion rates were classified into the five priority classes, namely very low (0-5), low (5-10), moderate (10-20), high (20-50) and very high (>50) t ha-1 yr-1 to develop soil erosion severity map. Figure 10: a, b, c shows soil erosion hazard map of 2007, 2016 and 2023. Similar erosion severity classes were observed in (Senanayake et al., 2020).

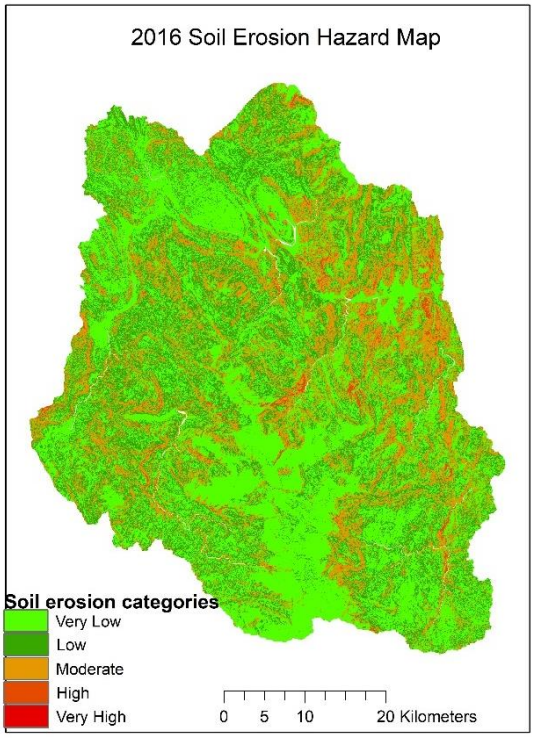
The results presented in Table 9 show that in 2007, approximately 1.12% of the total land area falls within the high erosion class (>20 t ha^{-1} yr^{-1}), exceeding national tolerance thresholds and indicating priority areas for intervention and around 16.43 % of the total land area was within the moderate erosion class (10–20 t ha^{-1} yr^{-1}), approaching or exceeding sustainable soil loss limits depending on local conditions. Approximately 22.47 % of the study area was in low category and 59.95 % of the area was in very low soil erosion category. Outcomes expose that in 2016, nearly 1.51 % of the total land area of the study area was highly vulnerable to soil erosion and around 22.15 % of the total land area was moderately vulnerable to soil erosion. Approximately 46.58% of the study area was in very low category and 29.74 % of the area was in low soil erosion category. Also results reveal that in 2023, nearly 1.49 % of the total land area of the study area was highly vulnerable to soil erosion and around 21.92% of the total land area was moderately vulnerable to soil erosion. Approximately 50.88% of the study area was in very low category and 25.7 % of the area was in low soil erosion category.

3.5 Soil Erosion Estimation of Sub –Watershed

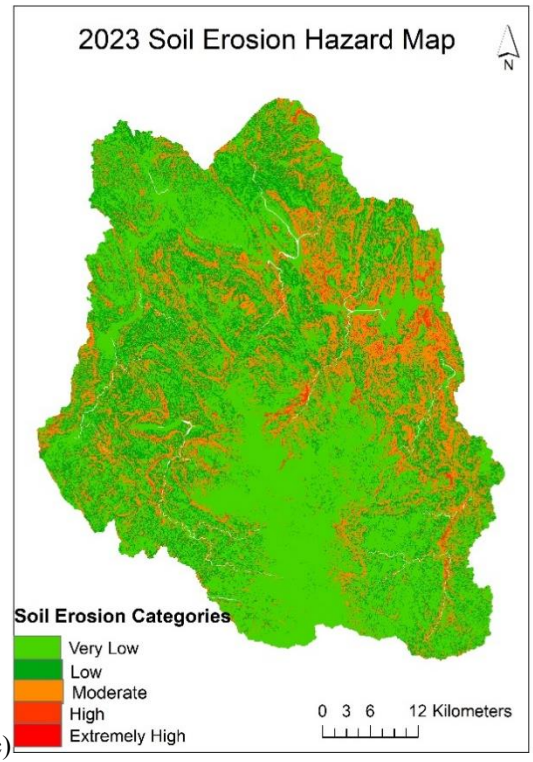
In the UMRC shows variation of soil erosion according to the Sub-watershed. Some watersheds are in the upper level of soil erosion tolerance level in Sri Lanka. Figure 11 a) shows soil erosion hazard map with sub-watershed. Based on the Figure 11 b) mean soil erosion rate in watersheds, the watersheds were ranked according to their values. The highest rates of the soil erosion were 11.22 (t ha^{-1} yr^{-1}), 11.19 (t ha^{-1} yr^{-1}), 9.58 (t ha^{-1} yr^{-1}), 9.16 (t ha^{-1} yr^{-1}), 8.68 (t



a)



b)



c)

Figure 10: a) 2007, b) 2016, c) 2023 soil erosion hazard map

ha^{-1} yr^{-1}) and 8.58 (t ha^{-1} yr^{-1}) in watershed no 9, 7, 5, 6, 3 and 4 respectively. Because, Udayakumara and Gunawardena (2016) and Dias et al., (2019) considered 5 t ha^{-1} y^{-1} as the soil loss tolerance in Sri Lanka (Somasiri et al., 2021). The lowest soil erosion rates were in the watershed no 12, 8, 1, 13 and 18. And also others were in moderate level from 6 (t ha^{-1} yr^{-1}) to 8 (t ha^{-1} yr^{-1}) rates. Table 10 describe how was the soil erosion in all watershed in the study area.

The maximum estimated soil loss reflects localized conditions characterized by steep slopes, high rainfall intensity, and reduced vegetation cover. These values substantially exceed natural soil formation rates, indicating net soil depletion and highlighting the requiring urgent conservation intervention. The mean annual soil loss of 5.56 t ha^{-1} yr^{-1} is broadly consistent with soil loss tolerance thresholds reported for Sri Lanka (~5 t ha^{-1} yr^{-1}), suggesting moderate overall erosion at the basin scale. However, this average mask significant spatial variability, with localized experiencing substantially higher erosion rates.

Watershed number 1 was located in Thalathuoya, Galaha, Gannoruwa, Haguranketha, Katugasthota, Akurana area with highly urbanized and slope. It had agricultural activities and industrial zone. The mean soil rate was 5.56 (t ha^{-1} yr^{-1}). It was highly urbanized area. Mean soil rate was. It was moderate soil erosion in this area. Watershed number 2 was covered Theldeniya, Nilgala, Hunnasgiriya, Madamahanuwara, etc. It was highly urbanized area with Mahaweli river. And also, it had mean soil erosion rate as 7.01 (t ha^{-1} yr^{-1}). It was high value of soil erosion due to high slope of the land, agricultural activities, development activities, etc. Watershed number 3 was situated in highly slope area. And it had bare soil and agricultural activities. And also, it had mean soil erosion rate as 8.68 (t ha^{-1} yr^{-1}). It was high value of soil erosion. The watershed number 4 was ranked in the 5th priority in the study area. watershed was situated in highly slope area. The location of entering Uma Oya to Rantambe tank was situated in this watershed. Also, Rantambe dam and power station were there. It was highly slope area with 8.58 (t ha^{-1} yr^{-1}) mean soil erosion rate. It had bare soil and agricultural activities in Hapukanda area with high slope. Land use change like Rantambe power station, Rantambe dam, urbanization were some reasons for high soil erosion rate. The watershed number 5 had high mean soil erosion rate as

Table 9: Soil erosion estimation value

Category	Erosion Rate ((t ha^{-1} yr^{-1})	Area 2007 (Km^2)	Area 2007 (%)	Area 2016 (Km^2)	Area 2016 (%)	Area (Km^2)	Area %
Very Low	0 - 5	1671.49	59.95	1298.59	46.58	1416.51	50.88
Low	5 _10	626.67	22.47	829.25	29.74	715.56	25.7
Moderate	10_20	458.1	16.43	617.59	22.15	610.29	21.92
High	20_ 50	31.43	1.12	42.15	1.51	41.59	1.49
Extremely High	50 <	0.062	0.002	0.11	0.003	0.08	0.01

9.58 (t ha^{-1} yr^{-1}). It was ranked in 3rd place in study area. Agricultural activities in slopy area like Wedaruwa, land use change, urbanization and some development project like solar project were some reasons for high soil erosion rate. The watershed number 6 had high mean soil erosion rate as 9.16 (t ha^{-1} yr^{-1}). It was ranked in 4th place in study area. Agricultural activities in slopy area and upper land like Hakuruthale, land use change like Victoria power station, urbanization were some reasons for high soil erosion rate. Uma Oya was flowed through this watershed number 7 with 11.19 (t ha^{-1} yr^{-1}) mean soil erosion rate due to high slope. It was the 2nd rank soil erosion watershed in Rantambe area. Agricultural activities in slopy area and upper land, land use change like Rantambe power station, Rantambe dam, urbanization were some reasons for high soil erosion rate. Watershed 8 was located in Gampola, Unabuwa area with highly urbanized and slope. The mean soil rate was 5.67 (t ha^{-1} yr^{-1}). Watershed number 9 was located in Rantambe area with high slope. It had agricultural activities in slope land, part of watershed urbanized and Uma Oya had huge sediment transport. The mean soil rate was 11.22 (t ha^{-1} yr^{-1}). It was the highest sediment risk watershed in the study area. The watershed number 10 was located in Walapane, Arukwatta, Teripaha area with highly urbanized and slope. It had agricultural activities and bare soil. The mean soil rate was 7.11 (t ha^{-1} yr^{-1}).

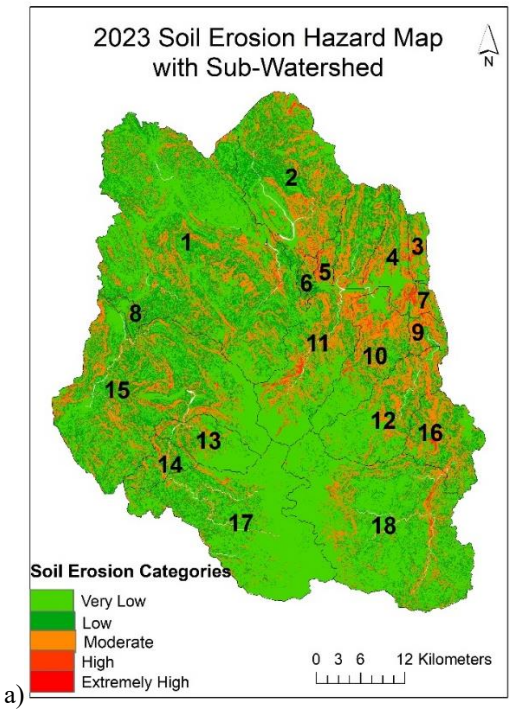
Watershed number 11 was located in Padiyapelella, Mathurata, Rikillagaskada area with highly urbanized and slope. It had agricultural activities like coconut and paddy and bare soil. The mean soil rate was 6.90 (t ha^{-1} yr^{-1}). The watershed 12 was located in Ragala area with highly urbanized and slope. It had agricultural activities and bare soil. It had large forest cover. The mean soil rate was 5.99 (t ha^{-1} yr^{-1}). The watershed 13 was located in Pudalu Oya area with highly urbanized and slope. It had agricultural activities and bare soil. Pudalu Oya was flowed through watershed. The mean soil rate was 4.45 (t ha^{-1} yr^{-1}). The watershed 14 was located in Kothmale area with high slope. Kothmale diary factory, Dimbulla estate were there. The mean soil rate was 7.03 (t ha^{-1} yr^{-1}). Watershed 15 was located in Nawalapitiya, Ulapane area with highly urbanized and slope. It had agricultural activities like tea and bare soil. It had large forest cover. The mean soil rate was 6.05 (t ha^{-1} yr^{-1}). Uma Oya was flowed through watershed 16 with 7.71 (t ha^{-1} yr^{-1}) mean soil erosion rate due to high slope. It was the 7th rank soil erosion watershed in study area. It was situated in Nikagolla, Ketawala area. The watershed 17 was located in Nanuoya, Thalawakele, Dayagama area with highly urbanized and slope. It had agricultural activities like tea, coconut, paddy. The mean soil rate was 2.39 (t ha^{-1} yr^{-1}). The watershed 18 was located in welimada, Bandarawela, Diyathalawa area with highly urbanized and slope. It had agricultural activities like tea, vegetables, paddy. The mean soil rate was 3.55 (t ha^{-1} yr^{-1}).

3.6 Sediment Export

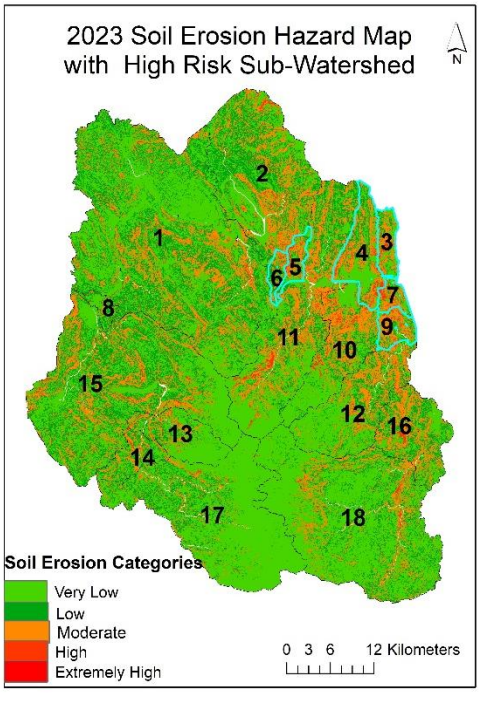
The sediment export map provides a complete visualization of sediment movement from each pixel, ultimately contributing to stream networks (Figure 12). As per the sediment export map, the minimum sediment export, maximum sediment export and mean annual soil export within the upper Mahaweli river catchment was calculated 0 t ha^{-1} yr^{-1}, 43.67 t ha^{-1} yr^{-1} and 0.764 t ha^{-1} yr^{-1}.

According to the (Ekanayake et al., 2024) the mean annual soil export within the closer catchment of the proposed lower Malwathu Oya reservoir is calculated at 0.016 t ha^{-1} yr^{-1}. However, the study reveals a noteworthy range in sediment export values across the sub-basin, from 0 to 2.60 t ha^{-1} yr^{-1}. It was low value compared to the UMRC sediment export value as Figure 12. The observed spatial variability in sediment export aligns with the understanding that land use practices, such as agriculture, can significantly influence soil transport dynamics. The potential for increased soil erosion and subsequent sediment export is considerable in areas such as Bandarawela, Victoria, Randenigala area where agricultural activities are prominent.

The observed spatial variability in sediment export aligns with the understanding that land use practices, such as agriculture, can significantly influence soil transport dynamics. The potential for increased soil erosion and subsequent sediment export is considerable in watershed such as watershed no 9, 14, 11, 16, 12 and 13 where agricultural activities are prominent. According to the Table 11 the mean sediment export values were 2.29 (t ha^{-1} yr^{-1}), 1.61 (t ha^{-1} yr^{-1}), 1.42 (t ha^{-1} yr^{-1}), 1.33 (t ha^{-1} yr^{-1}), 1.27 (t ha^{-1} yr^{-1}) and 1.01 (t ha^{-1} yr^{-1}) respectively. The watershed 9 was located in Rantambe area with high slope. It had agricultural activities in slope land, part of watershed urbanized and Uma Oya had huge sediment transport. The mean soil rate was 11.22 (t ha-1 yr-1). It was the watershed exhibiting the highest mean sediment export (2.29 t ha^{-1} yr^{-1}), corresponding to areas with strong



a)



b)

Figure 11: a) Soil Erosion Map with Sub-watershed b) High-Risk Sub-watersheds

hydrological connectivity and elevated erosion rates in the study area. The watershed no 14 was located in Kothmale area with high slope. Kothmale diary factory, Dimbulla estate were there. The mean soil rate was 7.03 (t ha-1 yr-1). The watershed no 11 was located in Padiyapelella, Mathurata, Rikillagaskada area with highly urbanized and slope. It had agricultural activities like coconut and paddy and bare soil. The mean soil rate was 6.90 (t ha-1 yr-1). Uma Oya was flowed through the watershed no 16 with 7.71 (t ha-1 yr-1) mean soil erosion rate due to high slope. It was the 7th rank soil erosion watershed in study area. It was situated in Nikagolla, Ketawala area. The watershed 12 was located in Ragala area with highly urbanized and

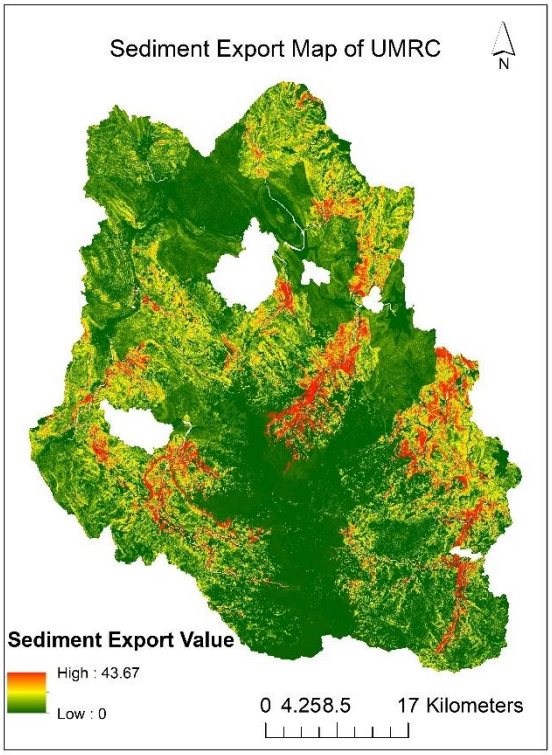


Figure 12: Sediment Export Map

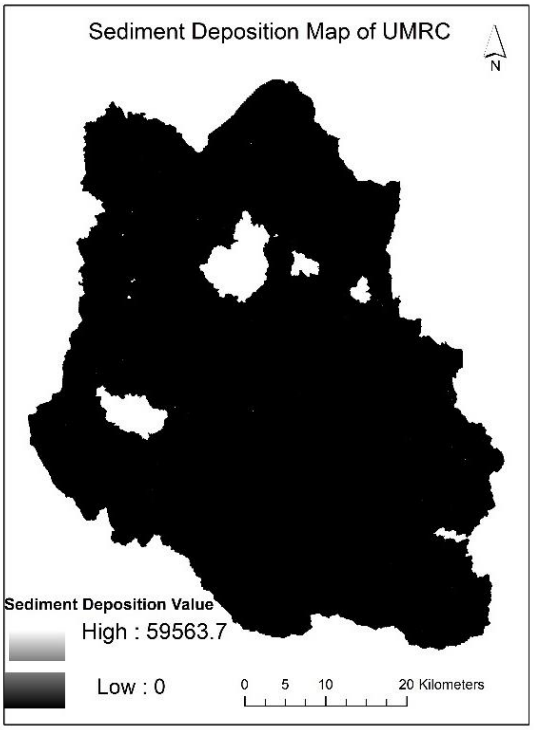


Figure 13: Sediment Deposition Map

slope. It had agricultural activities and bare soil. It had large forest cover. The mean soil rate was 5.99 (t ha-1 yr-1). The watershed 13 was located in Pudalu Oya area with highly urbanized and slope. It had agricultural activities and bare soil. Pudalu Oya was flowed through watershed. The mean soil rate was 4.45 (t ha-1 yr-1).

Furthermore, the correlation between high sediment export values and elevated areas emphasizes the role of topography in influencing erosion patterns. Identifying



Figure 14: Soil Erosion Images from Katugasthota area and Walimada Area



Figure 15: Soil Erosion in Udunuwara Area and Haguranketha Area

specific locations with elevated sediment export values, especially those associated with agriculture and high elevation, is critical for targeted conservation efforts. Implementing soil conservation practices in these hotspots can mitigate the impact of sedimentation on downstream water bodies. The sediment export map serves as a valuable tool in identifying the high sediment export areas and providing actionable insights for tailored watershed management strategies, emphasizing the need for targeted interventions in agriculturally active and elevated regions within the entire catchment. Spatial patterns of sediment delivery are controlled not only by erosion magnitude but also by the connectivity index (IC), which governs the efficiency of sediment transfer from hillslopes to the stream network. with high IC values exhibited elevated SDR, even under moderate erosion conditions, emphasizing the importance of connectivity in sediment transport processes.

3.7 Sediment Deposition

Sediment deposition minimum, maximum and mean values were 0 t ha^{-1} yr^{-1}, 83814.3 t ha^{-1} yr^{-1} ,2.4 t ha^{-1} yr^{-1}. In the Figure 13 high values represented the surrounding area of water bodies. Table 11 shows the mean sediment deposition value of watershed. The highest sediment deposition observed from watershed no 9, 10, 11, 2 and 14 as 5.36 t ha^{-1} yr^{-1}, 4.26 t ha^{-1} yr^{-1}, 4.19 t ha^{-1} yr^{-1}, 4.03 t ha^{-1} yr^{-1}, and 3.89 t ha^{-1} yr^{-1} respectively. Figure 13 shows sediment deposition map of the study area. The watershed no 4 was situated in highly slope area. The location of entering Uma Oya to Rantambe tank was situated in this watershed. And also, Rantambe dam and power station were there. It was highly slope area with 4.299 (t ha^{-1} yr^{-1}) mean soil erosion rate. Randenigala reservoir, Victoria power station and dam, Rantambe dam and power station were high sediment deposited area. Sedimentation studies done in upper catchments in Mahaweli development project (Wallingford, 1995), found that Polgolla barrage has reduced its storage capacity to 56 % over 17 years while Rantembe reservoir has reduced its storage capacity to 72 % during a three-year period after impoundment as there was no soil conservation measures. Therefore, soil conservation measures are suggested to combat siltation of the study area.

Elevated sediment yield from erosion-prone sub-watersheds poses significant risks to downstream hydropower infrastructure. Sedimentation reduces reservoir storage capacity, shortens operational lifespan, and increases turbine abrasion, leading to higher maintenance costs. Previous studies in the Upper

Table 10: Soil Erosion Prioritization

Sub-Watershed Number	Area (km^2)	Total soil loss t/watershed/year	Max Value (t ha^{-1} yr^{-1})	Mean Value (t ha^{-1} yr^{-1})	Rank
9	22.89	268993.58	31.16	11.22	1
7	6.91	180472.43	41.34	11.19	2
5	18.02	184008.42	52.95	9.58	3
6	11.97	116492.60	30.85	9.16	4
3	23.66	218656.53	46.53	8.68	5
4	0.50	577417.29	67.72	8.58	6
16	93.93	774035.61	65.06	7.71	7
10	111.02	849240.79	94.48	7.11	8
14	36.11	269083.74	42.97	7.03	9
2	240.63	1787075.78	56.43	7.01	10
11	242.18	1778473.49	66.31	6.90	11
15	400.54	2601785.14	86.48	6.05	12
12	132.68	846816.33	69.20	5.99	13
8	12.85	77637.55	27.35	5.67	14
1	0.36	3745034.72	82.39	5.56	15
13	63.34	303183.56	62.82	4.45	16
18	392.29	1510432.79	95.01	3.55	17
17	294.93	763658.34	62.13	2.39	18

Mahaweli system have documented substantial storage losses due to sediment accumulation, underscoring the importance of upstream soil conservation to sustain hydropower efficiency and water resource management.

3.8 Field Validation

The ground truth data from images compared to validate soil erosion modelling. Field validation was conducted using a set of georeferenced observation points collected across the Upper Mahaweli River Catchment to assess the spatial reliability of model outputs. At each location, field observations including visible signs of erosion such as rill formation, exposed soil surfaces, slope conditions, and vegetation cover were documented using geotagged photographs. These observations were compared with corresponding model outputs to evaluate the spatial agreement between predicted and observed erosion patterns.

Due to the lack of measured sediment yield or plot-scale erosion data, validation was limited to qualitative assessment rather than statistical accuracy evaluation. While this approach does not allow for quantitative error estimation, it provides a reasonable basis for assessing model performance in data-scarce environments.

4. Conclusion

Scientific management of soil and water is very important to assess erosion and enhancing the agricultural production. Soil erosion is the major cause of the loss of fertility, diminishing crop production and land degradation. Deterioration of soil in the study area can be controlled effectively by adopting watershed treatment measures if spatial distribution of soil erosion is known. Various thematic layers representing different factor of USLE were generated and overlaid to compute spatially distributed gross soil erosion maps for the Upper Mahaweli River Catchment. This study revealed that the present mean annual soil loss
was estimated at 5.569 t ha^{-1} yr^{-1}, with USLE values ranging from 0 to 95.015 t ha^{-1} yr^{-1}. However, the part of the land areas had exceeded the natural rate of soil generation (~5 t/ha/yr) in Sri Lanka. The highest erosion rates (up to 11.22 t ha^{-1} yr^{-1} at sub-watershed scale) exceed national soil loss tolerance thresholds, indicating of critical land degradation requiring prioritized management were 11.221 (t ha^{-1} yr^{-1}), 11.198 (t ha^{-1} yr^{-1}), 9.587 (t ha^{-1} yr^{-1}), 9.166 (t ha^{-1} yr^{-1}), 8.683 (t ha^{-1} yr^{-1}) and 8.584 (t ha^{-1} yr^{-1}) in sub-watershed no 9, 7, 5, 6, 3 and 4 respectively. The potential for increased soil
erosion and subsequent sediment export is considerable in watershed such as sub-watershed no 9, 14, 11, 16, 12 and 13 where agricultural activities are prominent. The mean sediment export values were 2.29 (t ha^{-1} yr^{-1}), 1.61 (t ha^{-1} yr^{-1}), 1.42 (t ha^{-1} yr^{-1}), 1.33 (t ha^{-1} yr^{-1}), 1.27 (t ha^{-1} yr^{-1}) and 1.01 (t ha^{-1} yr^{-1}) respectively. Sediment deposition minimum, maximum and mean values were 0 t ha^{-1} yr^{-1}, 83814.3 t ha^{-1} yr^{-1} ,2.4 t ha^{-1} yr^{-1}. This sub-watershed was located in Rantambe area with high slope. It had agricultural activities in slope land, deforestation, etc. The InVEST SDR model is completely dependent on the USLE while USLE only represents the rill and inter-rill soil erosion process excluding mass erosion and gully erosion processes. Further, the impact of current soil conservation

Table 11: Sediment export and deposition quantification

Sub-Watershed Number	Area (km^2)	Mean Sediment Export ($t\ ha^{-1}\ yr^{-1}$).	Sediment Export t/watershed/year	Mean Sediment Deposition ($t\ ha^{-1}\ yr^{-1}$).	Sediment Deposition t/watershed/year
1	0.36	0.61	405046.32	2.73	2940837.31
2	240.63	0.85	222308.24	4.03	1485362.59
3	23.66	0	0	0	0
4	0.50	0.34	4356.23	0.67	9502.15
5	18.02	0.34	6751.54	1.24	26230.46
6	11.97	0.26	2438.89	0.36	3901.42
7	6.91	0.12	16.22	0.0028	0.37
8	12.85	0.41	5749.46	1.22	19704.61
9	22.89	2.29	31532.08	5.36	92886.29
10	111.02	0.23	27956.27	4.26	666640.3
11	242.18	1.42	362863.04	4.19	1787005.77
12	132.68	1.27	181999.80	3.59	759451.49
13	63.34	1.01	70557.83	2.18	230176.81
14	36.11	1.61	62331.74	3.89	208374.92
15	400.54	0.83	337122.66	2.79	1902788.88
16	93.93	1.33	134798.76	2.97	526348.62
17	294.93	0.42	140093.09	1.17	622981.050
18	392.29	0.59	259185.63	1.94	1208717.81

measures viz contour planting, stone terracing, and drainage systems are not accounted for in the model to reduce soil erosion. The outcomes of this study can be used in formulating agricultural making and soil conservation measures planning in the agriculture sector in vulnerable area such as soil netting and geo textile, bio engineering techniques, slope stabilization techniques, hydroseeding. To prioritize the vulnerable lands to ensure proper land management practices in the agricultural sector on the country's way to meet the SDG. Future research should focus on model calibration using observed sediment data, improved land use classification, and incorporation of climate change projections to enhance predictive reliability and support evidence-based decision-making.

References

Amarathunga, A. A. D., and F. Kazama. 2017. "Impact of Farmer Perceptions and Land Use Pattern on Pesticide Loading into Upper Kotmale Sub-watershed of Mahaweli River Basin in Sri Lanka." *Asian Journal of Water, Environment and Pollution* 14(4):43–59. https://doi.org/10.3233/ajw-170036

Babarande Guruge, T. L., B. Palugaswewa, and S. Egashira. 2024. "Controlling Sedimentation through Regulating the River by Thalpitigala Reservoir Project." *Proceedings of IAHS* 386:1–6. https://doi.org/10.5194/piahs-386-1-2024

Beskow, S., C. R. Mello, L. D. Norton, N. Curi, M. R. Viola, and J. C. Avanzi. 2009. "Soil Erosion Prediction in the Grande River Basin, Brazil Using Distributed Modeling." *Catena* 79(1):49–59. https://doi.org/10.1016/j.catena.2009.06.006

Bhattacharya, R. K., N. Das Chatterjee, and K. Das. 2024. "Modelling of Soil Erosion Susceptibility Incorporating Sediment Connectivity and Export at Landscape Scale Using Integrated Machine Learning, InVEST-SDR and Fragstats." *Journal of Environmental Management* 353:120164. https://doi.org/10.1016/j.jenvman.2024.120164

Borrelli, P., D. A. Robinson, L. R. Fleischer, E. Lugato, C. Ballabio, C. Alewell, ... and P. Panagos. 2017. "An Assessment of the Global Impact of 21st Century Land Use Change on Soil Erosion." *Nature Communications* 8:2013. https://doi.org/10.1038/s41467-017-02142-7

Borselli, L., P. Cassi, and D. Torri. 2008. "Prolegomena to Sediment and Flow Connectivity in the Landscape: A GIS and Field Numerical Assessment." *Catena* 75(3):268–277. https://doi.org/10.1016/j.catena.2008.07.006

De Silva, S. S., N. S. Abeysingha, K. G. S. Nirmanee, P. D. S. Sandamali Pathirage, and A. Mallawatantri. 2022. "Effect of Land Use–Land Cover and Projected Rainfall on Soil Erosion Intensities of a Tropical Catchment in Sri Lanka." *International Journal of Environmental Science and Technology* 20(8):9173–9188. https://doi.org/10.1007/s13762-022-04606-w

Dhakal, B. N. 2022. "Use of Spatial Technology for Land Cover Change Assessment in Protected Area Management." *The Third Pole: Journal of Geography Education*:29–40. https://doi.org/10.3126/ttp.v22i01.52554

Dias, B. A. R. H., E. P. N. Udayakumara, J. M. C. K. Jayawardana, S. Malavipathirana, and D. A. T. W. K. Dissanayake. 2019. "Assessment of Soil Erosion in Uma Oya Catchment, Sri Lanka." *Journal of Environmental Professionals Sri Lanka* 8(1):39. https://doi.org/10.4038/jepsl.v8i1.7875

Dissanayake, D., T. Morimoto, and M. Ranagalage. 2018. "Accessing the Soil Erosion Rate Based on RUSLE Model for Sustainable Land Use Management: A Case Study of the Kotmale Watershed, Sri Lanka." *Modeling Earth Systems and Environment* 5(1):291–306. https://doi.org/10.1007/s40808-018-0534-x

Durigon, V. L., D. F. Carvalho, M. A. H. Antunes, P. T. S. Oliveira, and M. M. Fernandes. 2014. "NDVI Time Series for Monitoring RUSLE Cover Management Factor in a Tropical Watershed." *International Journal of Remote Sensing* 35(2):441–453. https://doi.org/10.1080/01431161.2013.871081

Ekanayake, H. B. G. D. M. P., N. S. Abeysinghe, M. G. T. S. Amarasekara, R. L. Ray, and D. Samarathunga. 2024. "The Use of InVEST SDR Model to Evaluate Soil Erosion in the Closer Catchment of the Proposed Lower Malwathu Oya Reservoir, Sri Lanka." *SSRN*:1–36.

Fayas, C. M., N. S. Abeysingha, K. G. S. Nirmanee, D. Samaratunga, and A. Mallawatantri. 2019. "Soil Loss Estimation Using RUSLE Model to Prioritize Erosion Control in Kelani River Basin in Sri Lanka." *International Soil and Water Conservation Research* 7(2):130–137.

Ferro, V., and M. Minacapilli. 1995. "Sediment Delivery Processes at Basin Scale." *Hydrological Sciences Journal* 40(6):703–717. https://doi.org/10.1080/02626669509491463

Fu, B., J. Wang, L. Chen, and Y. Qiu. 2003. "The Effects of Land Use on Soil Erosion and Water Quality in the Upper Han River Basin, China." *Catena* 55(1):33–46. https://doi.org/10.1016/S0341-8162(03)00064-5

Guo, Z., Z. Yan, R. He, H. Yang, R. Wang, and H. Ci. 2023. "Assessment of Soil Erosion and Its Driving Factors in the Huaihe Region Using the InVEST-SDR Model." *Geocarto International* 38(1). https://doi.org/10.1080/10106049.2023.2213208

Hewawasam, T. 2010. "Effect of Land Use in the Upper Mahaweli Catchment Area on Erosion, Landslides and Siltation in Hydropower Reservoirs of Sri Lanka." *Natural Science Foundation* 38(1):3–14.

Jain, S. K., S. Kumar, and J. Varghese. 2001. "Estimation of Soil Erosion for a Himalayan Watershed Using GIS Technique." *Water Resources Management* 15(1):41–54. https://doi.org/10.1023/A:1012214504033

Jayasekara, M. J. P. T. M., H. K. Kadupitiya, and U. W. A. Vitharana. 2018. "Mapping of Soil Erosion Hazard Zones of Sri Lanka." *Tropical Agricultural Research* 29(2):135. https://doi.org/10.4038/tar.v29i2.8284

Karunarathna, A. S., E. M. Wimalasiri, U. Piyathilake, S. K. Gunathilake, N. Muttil, and U. Rathnayake. 2022. "Modelling Potential Soil Erosion and Sediment Delivery Risk in Plantations of Sri Lanka." *Soil Systems* 6:97. https://doi.org/10.3390/soilsystems604009

Lu, H., J. C. Gallant, I. P. Prosser, C. J. Moran, and G. Priestley. 2001. "Prediction of Sheet and Rill Erosion over the Australian Continent, Incorporating Monthly Soil Loss Distribution." *CSIRO Land and Water Technical Report* 13/01. https://publications.csiro.au/rpr/pub?pid=procite:5ddace39-0e9c-4225-a56e-abc1e2011cf9

Senanayake, S. S. 2023. *Modelling Soil Erosion Hazards and Crop Diversity Changes Due to Climate Variation in Farming Systems at Central Highlands in Sri Lanka Using Geo-informatics Technologies*. Doctoral dissertation, University of Technology Sydney, Australia, 1–264.

Senanayake, S. S., M. A. K. Munasinghe, and W. M. A. D. B. Wickramasinghe. 2013. "Use of Erosion Hazard Assessments for Regional Scale Crop Suitability Mapping in the Uva Province." *Annals of Sri Lanka Department of Agriculture* 15:127–141.

Senanayake, S., B. Pradhan, A. Huete, and J. Brennan. 2020. "Assessing Soil Erosion Hazards Using Land-Use Change and Landslide Frequency Ratio Method: A Case Study of Sabaragamuwa Province, Sri Lanka." *Remote Sensing* 12(9):1483. https://doi.org/10.3390/rs12091483

Sheldrick, B. H., C. Wang, and M. R. Carter. 1993. "Soil Sampling and Methods of Analysis: Particle Size Distribution." Pp. 499–511 in *Soil Sampling and Methods of Analysis*, edited by M. R. Carter. Lewis Publishers/Canadian Society of Soil Science.

Somasiri, I. S., T. Hewawasam, and M. P. Rambukkange. 2021. "Adaptation of the Revised Universal Soil Loss Equation to Map Spatial Distribution of Soil Erosion in Tropical Watersheds: A GIS/RS-Based Study of the Upper Mahaweli River Catchment of Sri Lanka." *Modeling Earth Systems and Environment* 8(2):2627–2645. https://doi.org/10.1007/s40808-021-01245-x

Starks, P. J., D. N. Moriasi, and A. Fortuna. 2023. "GIS-Based RUSLE Reservoir Sedimentation Estimates: Temporally Variable C-Factors, Sediment Delivery Ratio, and Adjustment for Stream Channel and Bank Sediment Sources." *Land* 12(10):1913. https://doi.org/10.3390/land12101913

Van Oost, K., G. Govers, S. De Alba, and T. A. Quine. 2006. "Tillage Erosion: A Review of Controlling Factors and Implications for Soil Quality." *Progress in Physical Geography* 30(4):443–466. https://doi.org/10.1191/0309133306pp487ra

Verstraeten, G., and J. Poesen. 2001. "Factors Controlling Sediment Yield from Small Intensively Cultivated Catchments in a Temperate Humid Climate." *Geomorphology* 40(1–2):123–144. https://doi.org/10.1016/S0169-555X(01)00042-7

Vigiak, O., A. Srivastava, A. Mishra, V. Garg, and E. Bui. 2017. "Improving the USLE-M by Adding a Sediment Delivery Ratio Model." *Environmental Modelling & Software* 90:188–196. https://doi.org/10.1016/j.envsoft.2017.01.002

Walling, D. E. 2006. "Human Impact on Land–Ocean Sediment Transfer by the World's Rivers." *Geomorphology* 79(3–4):192–216. https://doi.org/10.1016/j.geomorph.2006.06.019