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ESTIMATION OF THE SEDIMENTATION IN KALU RIVER BASIN WITHIN RATNAPURA DISTRICT USING INVEST SDR MODEL

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ABSTRACT

Soil erosion and sedimentation are the major threats which affect the capacity and water quality in river catchments. The reducing capacity of rivers will contribute a lot for flooding, which is a severe disaster in Ratnapura district. It directly harms the biodiversity of the river. The main aim of the study is to obtain the sediment yield, sediment retention and soil loss potential maps using InVEST SDR model and GIS to identify the soil erosion prone areas in Kalu Ganga river basin. Analysis results show that these maps resulted from both methods are almost same. Digital Elevation Model, Land use land cover, rainfall erosivity index, soil erodibility data, vegetation cover factor (C) and soil conservation factor (P) were the inputs for InVEST SDR model. Universal Soil Loss Equation (USLE) and Sediment Delivery Ratio (SDR) integrated with GIS have been used to estimate Annual Soil Loss and Sedimentation respectively in a GIS model. Soil erosion susceptibility (RKLS), which was an intermediate output of InVEST SDR model, was validated using the GIS model. It was found that the current soil erosion rates in the watersheds varied between 32.444 & 71.409 t/ha/yr and the soil loss was 6-12 times larger than the tolerance (5 t/ha/yr). Current sediment retention and sediment export rates in the watersheds vary between 188.766 & 687.415 t/ha/yr and 3.191 & 9.837 t/ha/yr respectively. In Kalu Ganga river basin current Soil Loss, Sediment Export and sediment retention rates were 65.818, 7.040, 615.171 tons/ha/yr respectively.

Keywords: InVEST SDR, Sedimentation, Soil Erosion, GIS

INTRODUCTION

Background of the study

Soil erosion is the process of removing the soil surface material carried out by wind or water. Water is the major factor for soil erosion process. That process includes detachment, transportation and deposition of individual soil particles (sediment) by raindrop effect and flowing water (Foster and Meyer 1977; Wischmeier and Smith 1978; Julien 2002). Erosion mainly effects on agriculture and natural resources management. It reduces soil productivity, pollutes the streams and fills the reservoirs (Fangmeier et al. 2006). Usually the process of erosion, transportation, and sedimentation is accelerated by Human activities such as construction of roads, highways, and dams, control works on streams and rivers, mining, and urbanization (Julien 2010).

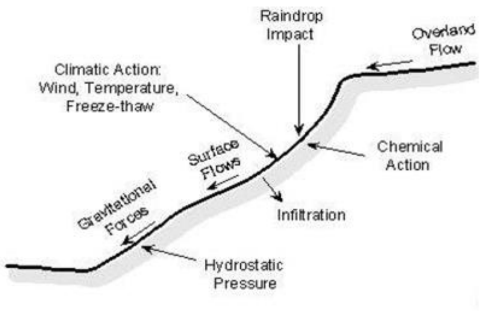


Figure 1 - Process of disintegration and sedimentation

When the raindrops hit the ground surface and remove upper soil particles by sprinkle, the disintegration begins. Sheet disintegration (inter-rill disintegration) and rill disintegration are the main types of disintegration. The process of removed soil particles are along the side, transported to the rills by a slight overland stream is called sheet disintegration. When water from sheet disintegration joins to shape through little channels is called rill disintegration. Disintegration process may cause dregs and also effect to transport the sediments. The transportable sum of disconnected soil (dregs) or sediments will be conveyed down-slope and the rest will be stored on the portion. This process is the fact that causes the sedimentation of the river basin.

Sediments are the unconsolidated rock particles that have been transported by wind or water or shifted under the influence of gravity. The sedimentation process includes weathering, transportation, disposition and diagnosis of sediments (Foster and Meyer 1977; Wischmeier and Smith 1978; Julien 2002). Rocks are disintegrated by the action of physical and chemical process and it is called weathering. Disintegrated rock fragments are transported by the action of water, wind and ice. Transportation distance is determined by the energy of the agent. The transported sediments are deposited when the energy of the agent is lost. They are deposited in various sedimentary environments (disposition). Diagnosis is the change that sediments undergo between deposition and lithification under the normal pressure and temperature conditions. The sedimentation process and yield is changed by some present construction works.

Study area

The study area is the Kalu-Ganga River basin within Ratnapura district in Sri Lanka. This river receives most of the south-west monsoon rainfall and vulnerable for frequent floods. The area of Kalu-Ganga River watershed is about 2,658 km2. Forest, residential and agricultural cropland are the major land-use covers within the river basin. The basin geographically lies within 6.32° and 6.90°N, and 79.90° and 80.75°E as per WGS84 coordinate system and flows from a height of about 2,250 m above MSL.

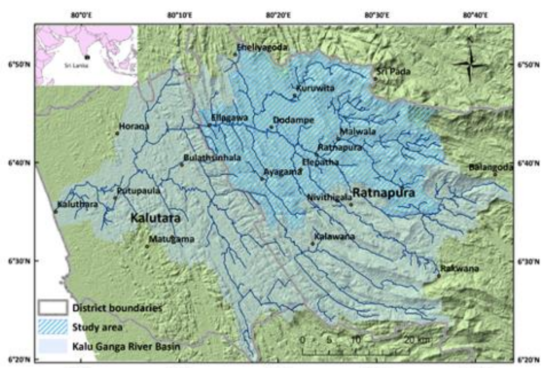


Figure 1 - Study area

Kalu River is affected by the sedimentation due to the soil erosion of its catchment area. It has happened due to various human activities such as building construction and sand dredging. This research will be conducted to determine the soil erosion and sedimentation status of Kalu River reservoir.

Objectives

Primary Objective

- Obtaining the sediment yield map, sediment retention map and soil loss potential map using the InVEST SDR model.

Sub Objectives

- Obtaining the total potential soil loss per pixel in the original land cover calculated from soil erosion susceptibility (A=RKLS) equation.
- Obtaining the total potential soil loss per pixel in the original land cover calculated from the Universal Soil Loss Equation (USLE).

LITERATURE REVIEW

Many scientists have come out with procedures and methods of generating the sediment loss zone maps by identifying remote sensing based spatial layers of sediment yield controlling parameters using GIS.

With the progress of the Geographic Information System (GIS) and the availability of data layers for environmental controllers of soil erosion have opened up new possibilities to model soil erosion. Erosion hazard zones mapping using GIS has been conducted in many countries (Kothyari and Jain, 1997; Priya and Shibasaki, 1998) including Sri Lanka using universal soil loss equation (USLE) (Brieby, 2001). However, Borselli (2008) showed that USLE predictions can overestimate sediment loss if the eroded soil amount that actually reaches the drainage basin outlet is not taken into account. According to that, combination of USLE predictions and sediment delivery ratio (SDR) at pixel level can result more realistic estimations.

InVEST (Integrated Valuation of Environmental Services and Trade-offs) Sediment Delivery Ratio model (Sharp et al., 2015) is a biophysical model that is able to be applied for the findings of Borselli (2008) for more precise estimation of soil erosion and which has been broadly used in many countries (Bahattarai and Dutta, 2006; Cavalli et al., 2013). This model calculates the amount of eroded sediment for each cell first using the Revised Universal Soil Loss Equation (RUSLE) and then the sediment delivery ratio which is the proportion of soil loss actually reaches to the catchment. At present, this new model has been used in Sri Lanka to assess soil erosion and sediment yield. Therefore, the current study was conducted to estimate the sedimentation in Kalu river basin within Ratnapura district using InVEST sediment delivery ratio model.

METHODOLOGY

The study was carried out to assets sedimentation in Ratnapura District using InVEST Model and ARCGIS Software. In this study sediment yield was estimated in two ways; using InVEST Sediment delivery ratio model and by modeling the data in GIS environment. InVEST consists of a collection of free and open-source software models. They are used to map and value the services and things from nature. The proper management of the ecosystem leads to obtain valuable services from the nature which are essential for the existence of the human beings. Such services include food production, life support processes such as water purification, life fulfilling conditions such as beauty and recreation opportunities and the genetic diversity for future use. If they are not properly monitored, the wastage and degradation of natural resources will be higher. Therefore, the governments and other organizations tend to manage the natural resources. InVEST which has a multi service and modular design, plays an important role in this resource management process. It becomes an effective tool in decision making to balance the economic and environmental goals. Also it helps to distinguish the areas for the investment in natural resources which enhances both the resource conservation and human development. The InVEST toolset consists of distinct ecosystem service models and helper tools. Service models were designed for marine, terrestrial, coastal and freshwater ecosystems while helper tools were designed for locating and processing of input data and also to understand and visualize output data.

InVEST models use maps as both inputs and outputs. These models are spatially-explicit and the results are given in either economic or biophysical terms. As an example, InVEST returns results as a net percent value as well as in tons. The spatial resolution of the results is also allows the users to find solutions at local, regional and global scales. These models are independent of GIS software since they function as standalone applications. However, to view the resulting maps, mapping software is needed. The knowledge of Python programming is not mandatory to run InVEST models, only the basic and intermediate GIS software skills are required. Figure 3 shows flow chart of InVEST model Methodology followed to run the InVEST model.

The second method of the study was a manual GIS workflow. Unlike InVEST SDR model, this method required the users to have intermediate or advanced GIS knowledge.

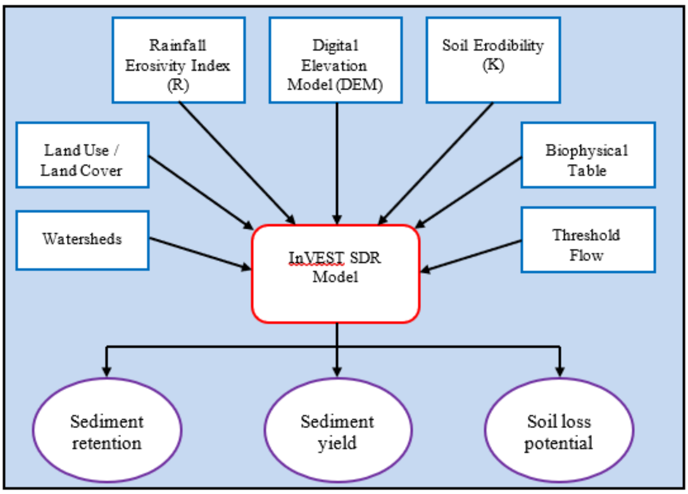


Figure 3 - Flowchart of InVEST Model Methodology

Data sources and preparation

The SDR model requires seven types of data inputs for the estimation of soil erosion. Table 01 shows these data. All the raster and vector input variables were prepared by using ArcMap TM 10.7.

Table 1 Required Data to InVEST Model.

No.	Input data	Sources
1	Digital Elevation Model (DEM)	SRTM Satellite images
2	Rainfall Erosivity Index (R factor)	Roose equation was used with rainfall data from 38 rainfall gauging stations in study area
3	Soil Erodibility (K factor)	Department of Irrigation, Sri Lanka
4	Land Use Land Cover (LULC)	Land Use Policy Planning, Sri Lanka
5	Watersheds	Demarcation based on Hydrology tool in the ArcMap$_{TM}$ 10.7
6	Biophysical Table	From existing data (C and P factors)
7	Threshold Flow Accumulation	From available global data

InVEST model based sediment yield Estimation

InVEST Sediment delivery ratio model estimates the sediment yield in watersheds wise. In this study model was used to estimate sediment yield in Ratnapura District. The model requires eleven types of data inputs to estimate how much sediment yield contributes annually from the each part of watersheds. The same projection system was defined for all raster inputs and also vector inputs and project linear unit was assigned as meter. Those input files for the model are,

Digital elevation model (DEM) (Raster)

Digital Elevation model is a spatial data layer that stores the elevation of a land area. This raster model provides necessary information to calculate sediment transport at pixels basis. The DEM of Ratnapura district was obtained using Shuttle Radar Topography Mission (SRTM) satellite images (30 m resolution).

Rainfall erosivity index (R) (Raster)

Annual rainfall data of 38 rainfall gauge stations surrounding the study area were obtained from the Meteorological Department of Sri Lanka. Rain gauge point shape file was created with attributes. Then the annual average rainfall at each rain gauge stations was determined. Based on these data and below equation the rainfall erosivity amount of each station were determined. The rainfall erosivity map for Ratnapura District was generated by using Inverse Distance Weighted (IDW) interpolation technique.

$$R = \frac{(972.75 + 9.95 * Average\ annual\ rainfall)}{100}$$

Rainfall erosivity map was validated by using 5 separate rain gauge stations which were not used to interpolate the map. The lowest deviation was shown in the map which was interpolated by using IDW method.

Soil erodibility (K) (Raster)

Soil erodibility factor compute the susceptibility of soil particles to detach by rainfall and transported by runoff (Wischmeier and Smith, 1978). Then, raster data layer (30 m resolution) of erodibility factor was prepared. Joshua, (1997) computed K values for major great soil groups and for rock knob planes and erosional remnants (Table 2). Soil map of Sri Lanka was digitized using this information (Alwis and Panabokke, 1972). Then it was transformed to the map of K as an input for InVEST model.

Table 2 - Soil Erodibility Values

Soil erodibility factor values of great soil groups of Ratnapura Soil type	**Value**
Reddish Brown Earth	0.27
Steep Rock Land & Lithosols	0.25
Erosional Remnants (Inselbergs)	0.10
Rock Knob Plains	0.10
Alluvial	0.15
Red Yellow Podzolic	0.22
Reddish Brown Lithosols	0.17
Bog & Half-Bog	0.05

Land use/land cover (LULC) (Raster)

LULC is a raster data set with an integer cell value, representing LULC code. The digital data on LULC for the Ratnapura area were obtained from the Land Use Policy Planning Department of Sri Lanka. Specific codes were assigned for each type of the LULC, corresponding to the data used in the biophysical table.

Watersheds (Vector)

The DEM of Ratnapura was obtained using Shuttle Radar Topography Mission (SRTM) satellite images (30 m resolution). Then the Fill tool was used because Sinks should be filled to ensure proper delineation of basins and streams. If the sinks are not filled, a derived drainage network may be discontinuous. After that flow direction and Flow Accumulation maps were prepared. Then the pour points were selected considering flow accumulation. Pour points were converted to raster mode (Snap pour point). Then the watersheds were prepared according to the snap pour points. After that raster watersheds converted to the vector using raster to polygon tool.

Biophysical table (CSV)

Biophysical table is a .csv table which included the model information corresponding to each of the land use classes such as land use code, land use description, USLE P and USLE C factor. This table is required as an input to the InVEST Model.

Table 3 - C and P factor Values

LU Code	LULC Description	C factor	P factor
1	Forest	0.001	0.1
2	Scrub land	0.7	0.1
3	Marsh	0.001	0.1
4	Rock	0.001	0.1
5	Water area	0.001	0.001
6	Paddy	0.2	0.15
7	Tea	0.2	0.5
8	Chena	0.1	0.25
9	Other cultivation	0.1	0.25
10	Homesteads	0.05	0.25

Threshold for flow accumulation

Threshold directly affects the hydrologic connectivity experience and sediment export. The value is defined as the number of upstream cells that must flow into a cell before it is considered as a part of a stream. By considering the stream network of the study area, thousand was determined as the value for the threshold flow accumulation.

kb and $IC0$

Two calibration parameters, that determines the shape of the relationship between hydrologic connectivity (the degree of connection from patches of land to the stream) and the sediment delivery ratio (percentage of soil loss that actually reaches the stream). The default values are $kb = 2$ and $IC0 = 0.5$.

SDRmax

The maximum SDR that a pixel can reach is a function of the soil texture. More specifically, it is defined as the fraction of topsoil particles finer than coarse s and (1000 μm; Vigiak et al. 2012). This parameter can be used for calibration in advanced studies. Its default value is 0.8.

Drainage layer (optional) (Raster)

A raster with 0s and 1s, where 1s correspond to pixels artificially connected to the stream (by roads, storm water pipes, etc.) and 0s are assigned to all other pixels. The flow routing will stop at these "artificially connected" pixels, before reaching the stream network, and the corresponding sediment exported is assumed to reach the catchment outlet.

GIS based sediment Yield Estimation

The methodology used in this analysis shown in figure 4 involves the use of the USLE in a GIS environment. For each USLE factor, individual raster layers were calculated and processed in a GIS. The product of those factors has given the annual loss of soil in the entire watershed.

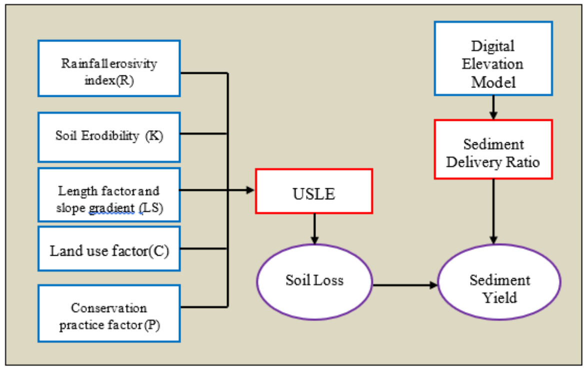


Figure 4 - Flowchart of GIS Based Analysis

Figure 4 summarizes the step by step methodology of the erosion modeling process. Raster maps of the R, K, LS, C and P were overlayed using the ArcGIS Rater calculator tool to create the model USLE. Output of this model is estimated erosion loss within the basin. The resultant soil loss map is shown in Figure 18. Then the Sediment Delivery Ratio (SDR) and model output were integrated by using ArcGIS Raster calculator tool to obtain Sediment Yield of relevant area.

The proposed method is based on the USLE (universal soil loss equation) (Wischmeier and Smith, 1978). This equation provides the average annual erosion for a long period of time based on the slope of a field, data of rainfall, cropping system and management practice. Five key factors are used to calculate soil loss at a given location. Each factor is a numerical estimate of a particular component which affects the severity of soil erosion at that location.

$$A = R * K * LS * C * P$$

A - The potential average annual soil loss in (Ton/ ha / y)

R - Rainfall erosivity factor

K - Soil erodibility factor

LS - Length factor and slope gradient

C - Land use factor

P - Conservation practice factor

Topographic Factor (LS)

The LS factor was obtained by using the equation 1(Stone and Hilborn, 2012):

$$LS = [0.065 + 0.0456(Slope) + 0.0065(Slope)^2](\frac{Slope\ length}{22.1})^{0.5}$$

Slope = slope steepness in %.

Slope length = (flow accumulation * cell resolution) in m (Van Remortel et al., 2004 ; Suhua et al., 2013).

The slope was obtained from SRTM with 30 m resolution (see Figure 3) using arc hydro extension. SRTM DEM was filled by using the Spatial Analyst Extension in ArcGIS software. The filled DEM was used as the input to determine the flow direction. Flow direction was used as input gird to derive the flow accumulation. LS factor was derived from flow accumulation and slope steepness using raster calculator in ArcGIS.

Vegetation Cover Factor (C) and Soil Conservation Factor (P)

The soil loss ratio of bare soil under a given crop is defined as the crop factor. It indicates the impact of soil cover, plants and soil disturbed activities on soil loss. The crop type and used tillage practices impact for C factor of land. Crop factor values related to land cover and land use types of Sri Lanka were obtained from the literature (Kuok et al., 2013) (Table 3). These data have been applied for previous erosion studies in Sri Lanka (Udayakumara and Gunawardena, 2016)

The P factor accounts for the impact of management practices on the amount and rate of runoff. Therefore, soil erosion and P factor depend on support practice methods (Stone and Hilborn, 2000). The P factor values were also obtained from the literature (Kuok et al., 2013) (Table 3). These P factor data has also been applied for Sri Lanka in previous erosion studies (Thuraisingham and Weerasinghe 2009; Udayakumara and Gunawardena, 2016).

SDR Module

The sediment delivery ratio is concerned by many physical characteristics of a watershed. It changes with the drainage area, runoff-rainfall factors, slope, relief-length ratio, land use/land cover and sediment particle size, etc. The empirical equations based on one or more factors are still useful tools to estimate the SDR (Zhou and Wu, 2009).

The slope of the mainstream channel was used to predict the sediment delivery ratio (Muhammad Mukhlisin and Sukoco, 2011). The model was written as follows:

$$SDR= 0.627*SLP^{0.403}$$

Where, the SLP is the slope of drainage line in degree. In the first step, the drainage line was generated from the DEM using Arc Hydro Tools. Afterwards the SDR for each cell in the flow path was computed in ArcGIS using map algebra extension using the Eq. (Hui et al., 2010).

Each cell in the drainage line path can be viewed as the outlet of its upstream catchment. The net annual soil loss at each cell can be obtained by multiplying the cell SDR value and the amount of annual soil loss upstream from that cell (Hui et al., 2010).

RESULTS AND DISCUSSION

Digital Elavation Model (DEM)

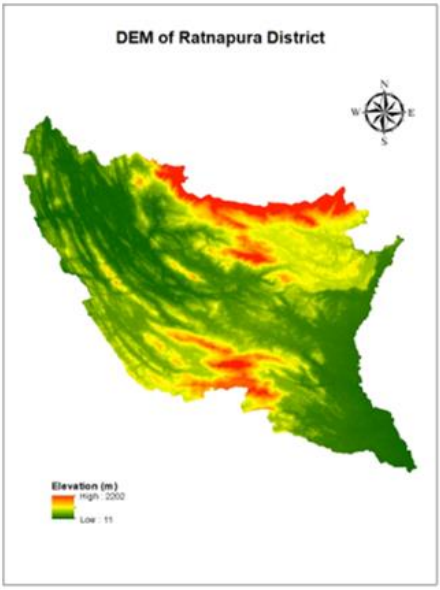


Figure 5 - Digital Elevation Model of the Ratnapura District

Digital Elevation model is a spatial data layer that stores the elevation of a land area. The DEM of Ratnapura district was obtained using Shuttle Radar Topography Mission (SRTM) satellite images (30 m resolution). DEM was corrected by using Fill tool. After filling, the maximum and minimum values were appeared as 11m, 2202m respectively. The accuracy of DEM was checked by comparing with separate 210 observations which were taken from survey department as spreading whole study area. "Extract value to point" tool was used to extract values of corresponding location in the DEM. The difference of the two observations was calculated. Mean and Standard deviation were obtained by using "statistics" operation. The values of mean and the standard deviation were calculated as 5.839925m and 16.85616m respectively. The mean of the point which were taken by the survey department was 467.958728m. The average error percentage of SRTM DEM was 1.248%. Therefore, DEM was 98.752% accurate according to this validation.

Rainfall Erosivity Index (R)

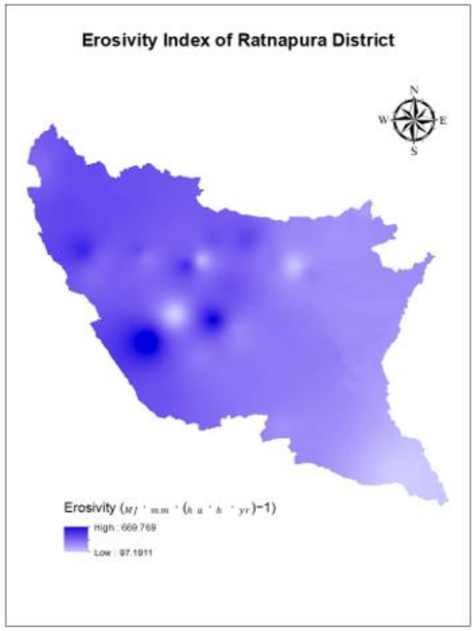


Figure 6 - Rainfall erosivity Index (R) of the Ratnapura District

The rainfall erosivity factor was obtained by the average annual rainfall. Annual rainfall data of 38 rainfall gauge stations surrounding the study area were obtained from the Meteorological Department of Sri Lanka. Then the annual average rainfall at each rain gauge stations was determined by using the existing data. After the rainfall erosivity index was calculated by using Roose equation and also the regression model of Wickramasinghe and Premalal, (1989). Differentiations of the rainfall erosivity index values which were taken by two methods were obtained. Mean and Standard deviation were obtained by using statistics operation. The values of mean and the standard deviation were calculated as 8.155338 and 0.643904 respectively. The calculated rainfall erosivity index values are almost same according to this validation. After the validation, rainfall erosivity map for Ratnapura District was generated by using Inverse Distance Weighted (IDW) interpolation technique.

Soil Erodibility

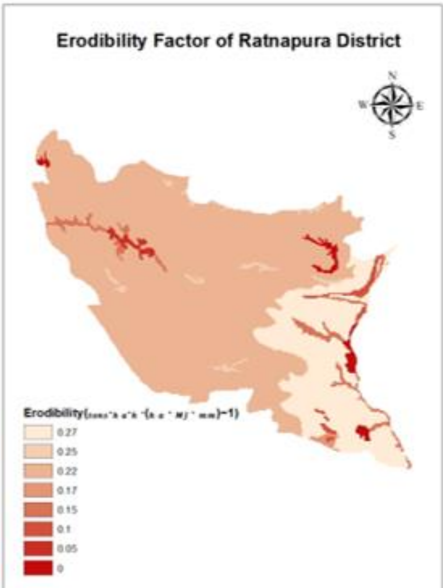


Figure 7- Soil Erodibility of the Ratnapura District

The soil map (Alwis and Panabokke, 1972) of Sri Lanka was digitized using ArcMAP10.7. Then K values were assigned to the each soil type by using the computed K values for major great soil groups by Joshua, (1997). Zero values represent the water areas in this region. The area of the digitized map was 3211.468197 km2 and the original map area was 3290.186546 km2. The error percentage of the digitized map was 2.39252%. According to that, the digitized map was 97.60748% accurate when comparing with the original map.

Land Use/Land Cover

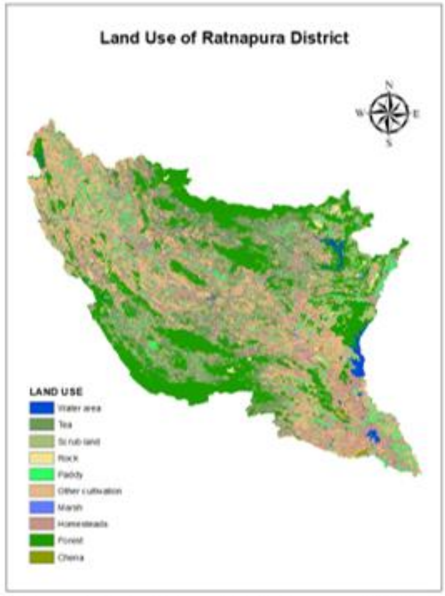


Figure 8 - Land Use of the Ratnapura District

The vector data on LULC for the Ratnapura area, which were created in 2016, were obtained from the Land Use Policy Planning Department of Sri Lanka. There, land use was categorized in to 8 main categories and 63 sub-categories. According to the requirement it was reclassified in to 10 main categories which were represented in figure 8.

Watershed

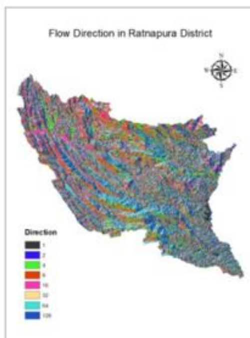


Figure 9 Land Use of the Rathnapura District

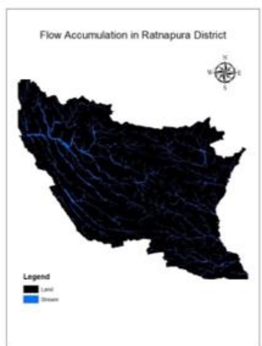


Figure 10 Flow Accumulation of the Rathnapura District

The DEM (Figure 5) was used to obtain Flow direction raster and Flow accumulation raster. The flow accumulation raster was classified into two main classes by using properties of raster. The break value (1000) was assigned for the classification. By that classification, the stream network was obtained and it was used to demarcate the pour points. Flow direction raster and pour points were used to obtain watersheds in Ratnapura district though "watershed" spatial analysis tool.

Figure 11 Watersheds in Rathnapura District

Soil Erosion Susceptibility obtained By InVEST Model

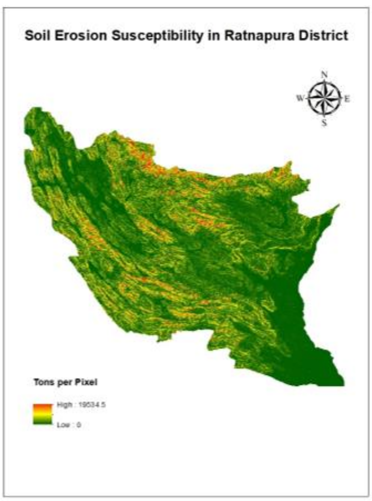


Figure 12 Soil erosion susceptibility of the Rathnapura District

Figure 12 represent the intermediate output of the InVEST SDR Model. Output was obtained by the multiplication of three factors which were named as rainfall erosivity, soil erodibility and LS factor. Total potential soil loss per pixel in the original land cover without the C or P factors applied from the Soil erosion susceptibility (RKLS) equation. That was equivalent to the soil loss for bare soil. The values of soil erosion susceptibility lie between 0 and 19534.5.

Annual Soil Loss Obtained By InVEST Model

Figure 13 represent the intermediate output of the InVEST SDR Model. That was the total potential soil loss per pixel in the original land cover calculated from the USLE equation. Output was obtained by the multiplication of five factors which were named as rainfall erosivity, soil erodibility, LS factor, C factor and P factor. The values of annual soil loss lie between 0 and 1275.88 tons per pixel.

Figure 13 Annual Soil Loss of the Rathnapura District

Sediment Retention Index Obtained By InVEST Model

Figure 14 represent the main output of the InVEST SDR Model. Index of sediment retention used to identify areas contributing more to retention with reference to a watershed where all LULC types are converted to bare ground. This is not the sediment retained on each pixel. It should be interpreted as relative values not absolute. The values of sediment retention index lie between 0 and 7932.31 tons per pixel.

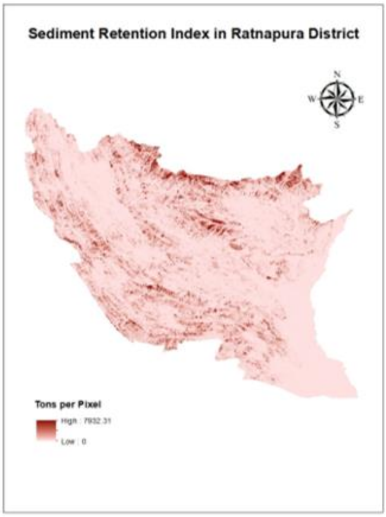


Figure 14 Sediment Retention Index of the Rathnapura District

Sediment Retention Obtained by InVEST Model

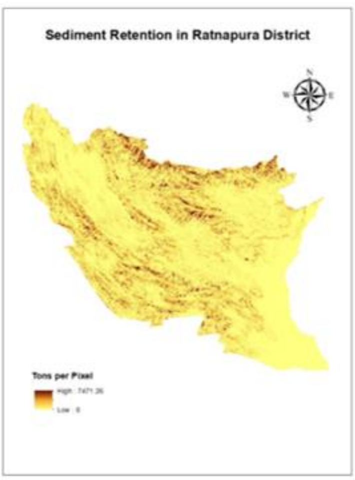


Figure 15 Sediment Retention of the Rathnapura District

Figure 15 represents the main output of the InVEST SDR Model. That was a Map of sediment retention with reference to a watershed where all LULC types are converted to bare ground. The values of sediment retention lie between 0 and 7471.26 tons per pixel. The values obtained from the analysis for different watersheds were included in table 5.

Sediment Export Obtained By InVEST Model

Figure 16 represents the main output of the InVEST SDR Model. That was represented the total amount of sediment exported from each pixel that reaches the stream. The values of sediment export lie between 0 and 477.645 tons per pixel. The values obtained from the analysis for different watersheds were included in table 5.

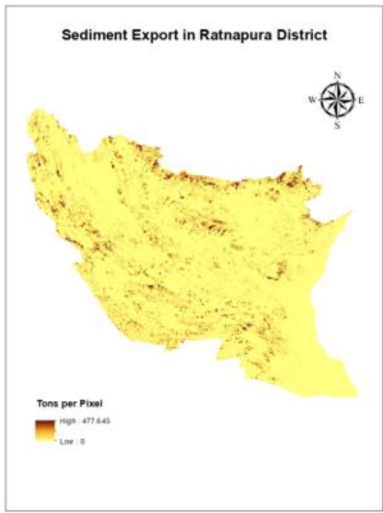


Figure 16 Sediment Export of the Rathnapura District

Output Result of InVEST Model

Table 5 - Soil erosion susceptibility of the Ratnapura District

Watershed	Sediment Retention (tons·ha^{-1}yr^{-1})	Sediment Export (tons·ha^{-1}yr^{-1})	Soil Loss (tons·ha^{-1}yr^{-1})
Kalu Ganga	615.171277	7.03953919	65.81766472
Kukule Ganga	669.8938234	6.764323993	71.40883272
Samanalawewa Reservoir	687.4150268	9.836810865	61.5547265
Udawalawe Reservior	246.4632447	4.458194038	39.23241297
Walawe Ganga	321.8324804	4.618737269	41.09153628
Weli Oya	188.7657151	3.191113143	32.44371871

Soil erosion susceptibility Estimated Using GIS Analysis

Figure 17 indicates the intermediate output of the GIS analysis. Output was obtained by the multiplication of three factors which were named as rainfall erosivity, soil erodibility and LS factor. The values of soil erosion susceptibility lie between 0 and 19403.7 ton per pixel.

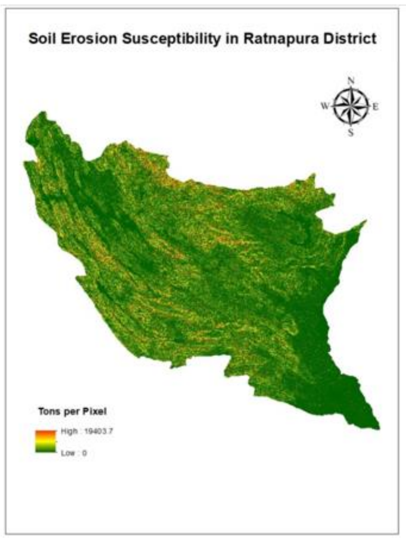


Figure 17 Soil erosion susceptibility of the Rathnapura District

Annual Soil Loss by Using GIS Analysis

Figure 18 represents the main output of the USLE equation in GIS analysis. Output was obtained by the multiplication of five factors which were named as rainfall erosivity, soil erodibility, LS factor, C factor and P factor. The values of annual soil loss lie between 0 and 1266.95 tons per pixel.

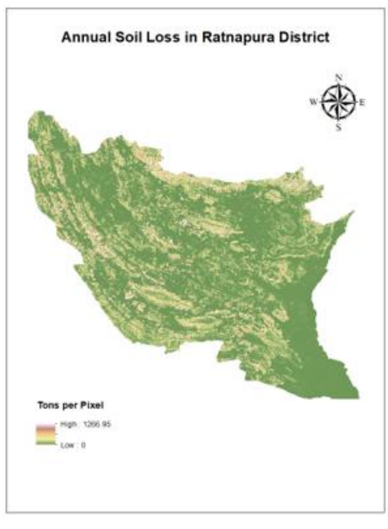


Figure 18 - Annual Soil Loss of the Rathnapura District

Sediment Export by the GIS Analysis

Figure 19 represents the final output of the GIS analysis. That was represented the total amount of sediment exported from each pixel that reaches the stream. Output was obtained by the multiplication of two factors which were named as annual soil loss and SDR .The values of sediment export lie between 0 and 462.055 tons per pixel.

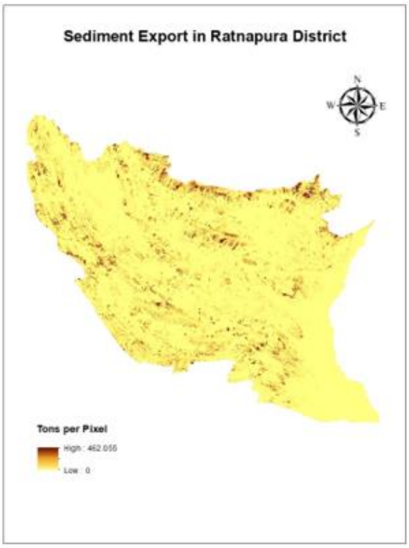
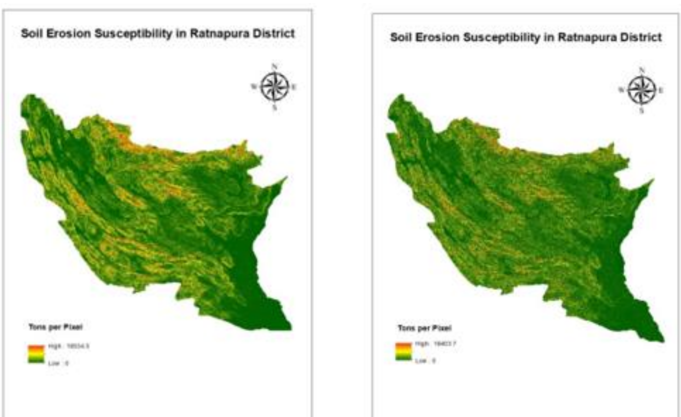


Figure 19 - Sediment Export of the Rathnapura District

Comparison between Soil Erosion Susceptibility obtained by Invest Model and GIS Analysis



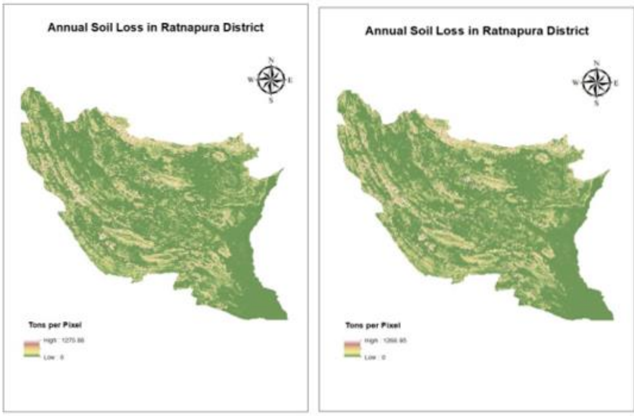
InVEST Model

GIS Analysis

Figure 20 - Soil Erosion Susceptibility of the Ratnapura District by Different method

The soil erosion susceptibility obtained in InVEST model and GIS analysis was approximately same. Figure 20 shows the outputs of two methods which were used to analysis. The difference of values were obtained from the analysis was 130.8 ton per pixel. It was small deviation comparing to those values. Therefore the intermediate output (Soil Erosion Susceptibility) of InVEST model was validated by the GIS analysis.

Comparison between Invest Model USLE estimation and GIS USLE estimation



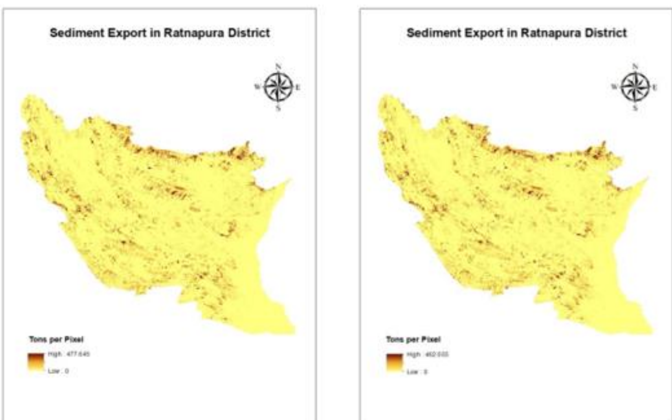
InVEST Model GIS Analysis

Figure 21 - Annual Soil Loss of the Rathnapura District by Different method

The annual soil loss obtained in InVEST model and GIS analysis was approximately same. Figure 21 shows the outputs of two methods which were used to analysis. The difference of values were obtained from the analysis was 8.93 ton per pixel. It was small deviation comparing to those values. Therefore the intermediate output (Annual Soil Loss) of InVEST model was validated by the GIS analysis.

Comparison between Invest Model Sediment Yield Estimation and GIS Sediment Yield Estimation

The annual sediment export obtained in InVEST model and GIS analysis was approximately same. Figure 22 shows the outputs of two methods which were used to analysis. The difference of values were obtained from the analysis was 15.590 ton per pixel. It was small deviation comparing to those values. Therefore the main output (sediment yield) of InVEST model was validated by the GIS analysis.



InVEST Model GIS Analysis

Figure 22 - Sediment Export of the Rathnapura District by Different method

CONCLUSION

This study revealed that the estimation of the sediment yield using GIS techniques along with InVEST model provides a great advantage when generating spatial information on estimating annual soil loss and the sediment yield over large areas. Rural and urban areas in Ratnapura district are subjected to the severe flood. Erosion of soil from the catchments involves the process of detachment of soil from the soil surface and it is transported by rainfall and runoff. Detachment of soil and its transportation by the rainfall runoff is the process of the soil erosion. The detached material was deposited when the amount of sediment was greater than the carrying capacity in the water. Reservoir sedimentation and flood may occur due to soil erosion. Deforestation, soil characteristic of the area, improper usage of catchment and anthropogenic activities were the main causes for the erosion. Identification of the erosion prone areas was essential and that areas are needed to provide a higher attention to reduce soil erosion and sedimentation. Here, both high and low prone areas should be considered therefore, the cost can be reduced when it applies at early stage. By considering the outputs of this study, the erosion prone areas could be identified. The erosion controlling measures can be applied for such areas in order to maintain water quality and the capacity of the water features.

In the current study, InVEST SDR model was used which is one of the best methods for determining the annual soil erosion and sedimentation amounts. In addition, Esri ArcMap 10.7 software was also used to determine above factors. Finally, a comparison of those two methods was taken into account. The results say that both outputs are nearly equal. Therefore, it can be concluded that, the model performance is fair. According to the InVEST model results, Kalu Ganga watershed has the greatest sediment retention, sediment export and the soil loss among the major six watersheds located within Ratnapura district. The minimum amount of those three has resulted in Weli Oya watershed. The amount of the sediment retention ranges from 188.766 to 687.415 (tons·ha−1yr−1). The range of sediment export varies from 3.191 to 9.837 (tons·ha−1yr−1). The range soil loss was also calculated and it varies from 32.444 to 71.409 (tons·ha−1yr−1). It can be concluded that, all the soil loss amounts lie within the tolerance value. However the results of the current study will be important for the future practices to reduce the soil erosion and sedimentation by implementing the required practices.

Future Work

The current study was conducted to ensure the accuracy of InVEST model by comparing the outputs taken from two different methods. It is recommended to conduct the process by changing the DEM resolution simultaneously for both methods and evaluate the variations. Further studies can be conducted to determine the soil conservation methods by using the results of this study. As another path for future work, water quality can be evaluated with the amount of sediment exported.

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