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Developing a GIS based Model to Identify Soil Erosion Prone Areas in the Uma Oya watershed of Sri Lanka; An application of Geographic information system (GIS)

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ජනගහනයේ ශීඝ්‍ර වර්ධනයත්, මානවයාගේ බහුවිධ අවශ්‍යතාවන් සංතෘප්ත කරගැනීමට යාමත් නිසා, මිනිසා පරිසරය මත එල්ල කර ඇති අධික පීඩනය දිනෙන් දිනම වර්ධනය වීම හේතුවෙන් වර්තමානය වන විට ශ්‍රී ලංකාව මුහුණපා ඇති පාරිසරික ප්‍රශ්න අතුරින් පාංශු ඛාදනයට හිමිවන්නේ ප්‍රමුඛස්ථානයකි. පාංශු ඛාදනය යනු මඩි පස පිහිටි ස්ථානයෙන් වෙනත් ස්ථානයකට ගමන් කිරීම ලෙස සරලව අර්ථකතනය කළ හැකිය. මෙය ස්වභාවික ක්‍රියාවලියක් වන අතර එය වැළැක්වීමට නොහැකි වන්නාසේම ස්වභාවිකව සිදුවන පාංශු ඛාදන ක්‍රියාවලිය එතරම් හානිදායක ද නොවේ. එහෙත් මිනිසාගේ විවිධ ක්‍රියාකාරකම් නිසා මෙම පාංශු ඛාදන ක්‍රියාවලිය වේගවත් වීම හේතුකොටගෙන පාංශු ඛාදනය වර්තමානය වන විට විශාල ප්‍රශ්නයක් බවට පත්වී තිබේ. භූගෝලීය තොරතුරු පද්ධතිය යනු මෙවන් පරිසර ප්‍රශ්න අධ්‍යනයට යොදාගත හැකි ඉතා වටිනා මෘදුකාංගයකි. උමා ඔය ප්‍රදේශයට ලැබෙන වර්ෂාපතනයත්, බෑවුම්සහිත භූමියත්, උමා ඔය ඉහළ ජල පෝෂක ප්‍රදේශයේ සිදුවන හේන් වගාව, තේ වගාව වැනි මිනිස් ක්‍රියාකාරකම් ද පාංශු ඛාදනයට හේතුවී ඇති බව පර්යේෂණ ප්‍රතිඵල අනුව සනාථ විය.

වර්ග කිලෝමීටර් 768.07 ක විහිදුනු උමා ඔය ප්‍රදේශයේ ප්‍රාදේශිය ලේකම් කොට්ඨාස 11ක් අධ්‍යනයට ලක් කළ අතර බණ්ඩාරවෙල, ඇල්ල, හපුතලේ යන ප්‍රා.ලේ. කොට්ඨාස එනම් වර්ග කිලෝමීටර් 233.73 ක භූමි භාගය අඩු පාංශු ඛාදනයට ලක්වන ප්‍රදේශ ලෙසත්, වලපනේ වැලිමඩ ප්‍රා.ලේ. කොට්ඨාස එනම් මුළු භූමි ප්‍රදේශයෙන් 24.87%ක ප්‍රතිශතයක් අධික ලෙස පාංශු ඛාදනයට ලක්වන ඒවා බවත්, මුළු භූමි ප්‍රමාණයෙන් ඉතිරි ප්‍රදේශ මධ්‍යස්ථ පාංශු ඛාදනයට ලක්වන ප්‍රදේශ බවත්, මෙම අධ්‍යයනයෙන් හෙළිවිය.

කෙසේ වෙතත්, උමා ඔය ඉහළ ජල පෝෂක ප්‍රදේශයේ සිදු කරනු ලබන මානව ක්‍රියාකාරකම් නිසි ක්‍රමවේදයකට අනුව එනම් පාංශු ඛාදනය වැලැක්වීමේ සහ

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සංරක්ෂණය කිරීමේ නිසි ක්‍රමෝපායන් භාවිතා කරමින් සිදුකරන්නේ නම් පහළ ජලාශවල රොන් මඩ තැන්පත් වීම (උදා:රන්ටැඹේ ජලාශයේ) වැනි අහිතකර පරිසර බලපෑම් අවමකර ගත හැකි බව මෙම පර්යේෂණයෙන් නිගමනයකර ඇති අතර භූ ගෝලීය තොරතුරු පද්ධතිය භාවිතා කිරීම ඒ සඳහා මහඟු පිටිවහලක් විය.

Introduction

At present, people in the world are suffering from various kinds of environmental problems such as global warming, desertification, deforestation, water pollution, air pollution, land degradation, soil erosion, shortage of energy...etc. As a result of these environmental problems, countless economic, environmental and social crisis those are directly generated the third world or the developing countries like Sri Lanka than the developed countries of the world due to the rapid growth of population and mismanagement of the environment.

As a developing country Sri Lanka is suffering from a variety of environmental, economic and social problems therefore, most of them can be considered as man accelerated problems like soil erosion, deforestation...etc, due to a combination of human activities such as agriculture, implementing new development projects, establishing human settlements in most vulnerable areas and the poor management of the environment.

Sri Lanka is a country with the rich water resources and a very supportive topographic structure for hydro power generation. There are 103 rivers in the country and these originate in the hilly areas in Sri Lanka . Increasing demand for power for industrial and development needs as well as for households activities can be easily be satisfied, if the available water resources are utilized properly. The upper watershed of all major rivers of Sri Lanka originate from the central highlands. These areas were covered with dense tropical forests and formed the source of the water springs of the country. Scientists believe that the forest cover plays a vital role in protecting and improving soils and water springs in the catchments areas. Due to improper management of the lands of the country, most of the tropical forests of the hilly area are being cleared.

Soil erosion is a major environmental issue posing a serious threat to sustainable agriculture, and the water storage capacity of the reservoirs due to sedimentation. For effective erosion control, it is needed to estimate the soil loss and identify the key factors using an effective and accurate method. This study is aimed at assessing the range of soil loss values for a typical watershed on mountainous area in Sri Lanka on the basis of Universal Soil Loss Equation

(USLE) with the application of Geographic Information Systems (GIS). Geo-referenced information is a prerequisite for land use management and Geographic Information System can provide means to inventorize resource data and model processes from the local to global scales. The raster and vector based GIS can be utilized for the spatial and temporal analysis of land use and soil erosion.

The study concludes that high rate of soil erosion is mainly because of annual crop cultivation on steep slope lands. It can be seen as a relationship between the changes of population density and that of land uses, which are more related to erosion and an appropriate methodology should be developed to correct these imbalances. It is also concluded that the ARC view spatial analysis for the estimation of soil erosion seems to be very useful using of high resolution grid cell data along with the other factors in order to identify soil loss. The use of GIS has been found to be very effective in analyzing soil erosion spatially by overlaying various maps related to factors affecting soil erosion. This implies for more research on developing an appropriate approach for correctly recognizing soil erosion rates in the Uma Oya watershed in Sri Lanka.

Watershed of Uma Oya is an area where severe high soil erosion is taking place. Due to the loss of soil for cultivation of vegetables in areas such as Nuwara Eliya and welimada, erosion accelerates results during the rainy season. In such a situation the small reservoirs built in Uma Oya under the Uma Oya project will get filled with silt in a very short period of time so that the project is not capable of achieving its expected outcomes. Building reservoirs in the Uma Oya basin without conserving the upper watershed area of the Uma Oya, is a futile exercise.

Study Area

The Uma Oya watershed was selected as the research area, because soil erosion is caused due to both natural and human activities. Agricultural activities on steep slopes in the hilly area of the Uma Oya watershed are mostly responsible for soil erosion. The watershed is situated in two provinces of Central and Uva. Moreover, this watershed that covers within the Nuwara Eliya and Badulla districts encompasses 768.07 square kilometers and covers eleven DS Divions namely, Bandarawela, Ella, Hali Ela, Haguranketha, Haputale, Kandekatiya, Nuwaraeliya, Soranathota, Uva Paranagama, Walapane, and Welimada.

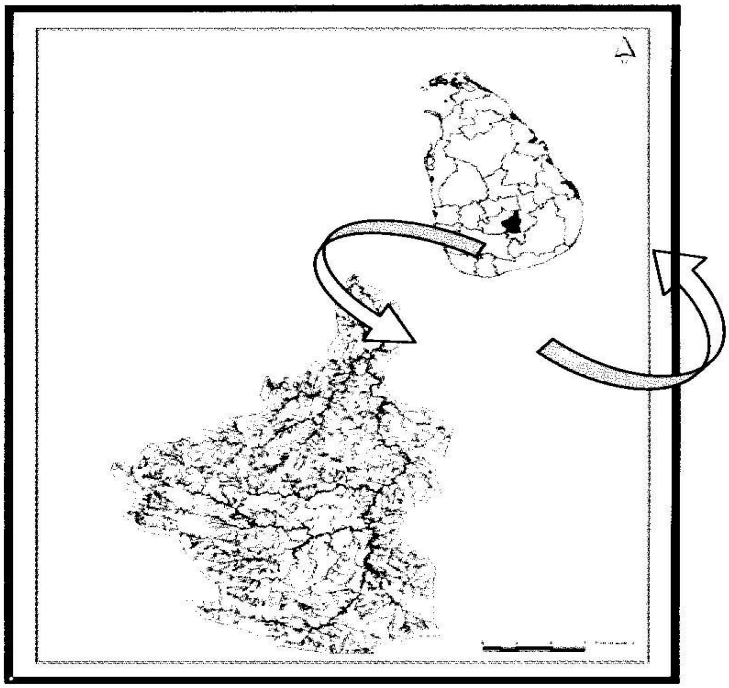

Figure 01.Study area

Objectives

The general objective of this research is to develop a GIS based model to identify soil erosion prone areas in the Uma Oya watershed. There were several specific objectives.

(i). Develop a GIS based model to identify soil erosion prone areas in Uma Oya watershed and mapping.

(ii). Identify the ability of geographic information system (GIS) to analyze and identify soil erosion areas in Uma Oya watershed.

Methodology

The methodology contained three steps of data collection, data analysis, and data presentation as bellow.

Data collection

Secondary data were collected from various Government agencies such as Survey Department, Department of Meteorology, and Census and Statistics. 1:50000 scale maps data were used to derive primary data including soils, land use and land cover, rainfall and slopes.

This study was carried out using secondary data available in different Government agencies in Sri Lanka and relevant research reports conducted by various researchers. 1:50000 Map Sheets 68, 69 have to be used more frequently to derive a lot of data for this research. Having collected the necessary data, the researcher recognized the data according to the purpose of the study i.e. to develop GIS based model to identify soil erosion prone areas. Table 01 shows the summary of the information on the data sources used in the study.

Table 01. Summary of Information on the Data Sources Used in the Study

Data	Scale/Resolution	Year	Source
Contour data	1:50,000	1989,1995,1996	Survey Department ,Sri Lanka
Heights data	1:50,000	1989,1995,1996	Survey Department, Sri Lanka
Watershed data	1:50,000	1989,1995,1996	Survey Department ,Sri Lanka
Land use data	1:50,000	1989,1995,1996	Survey Department ,Sri Lanka
Soil data	1:250000	1992	Survey Department, Sri Lanka
Rainfall data	Monthly/Annual	2003,2006	Dept..of Meteorology, Sri Lanka
DS Divisional data	1:50,000	2001	Dept..of Census and statistics
ArcView3.2.a	Software	1995,2004	Environmental system research institute, Redland USA

Data preparation and analysis

Here the researcher used arc View GIS (software) and Microsoft Excel (software) for data analyzing and identifying soil erosion prone areas which are critically vulnerable to potential soil erosion in the Uma Oya watershed. Having collected land use, rainfall, contour and soil data, they were organized to the needs (Creating, thiessen polygon and 3D maps and using arc View GIS technique) soil erosion causative factors classified as weighted factors as Low, Moderate, High, and Very High Where 40% was given to the rainfall factors weighted as 30%, 20% and 10% were given to Land use, slope, and soil respectively. Then using rater overlay technique, create the final soil erosion distribution map and other maps, where both raster and vector data were used to do calculations and analysis.

Data presentation

Basically, the way of presenting data is the Maps. In addition to that, texts charts, graphs, tables were also be used in data presentation.

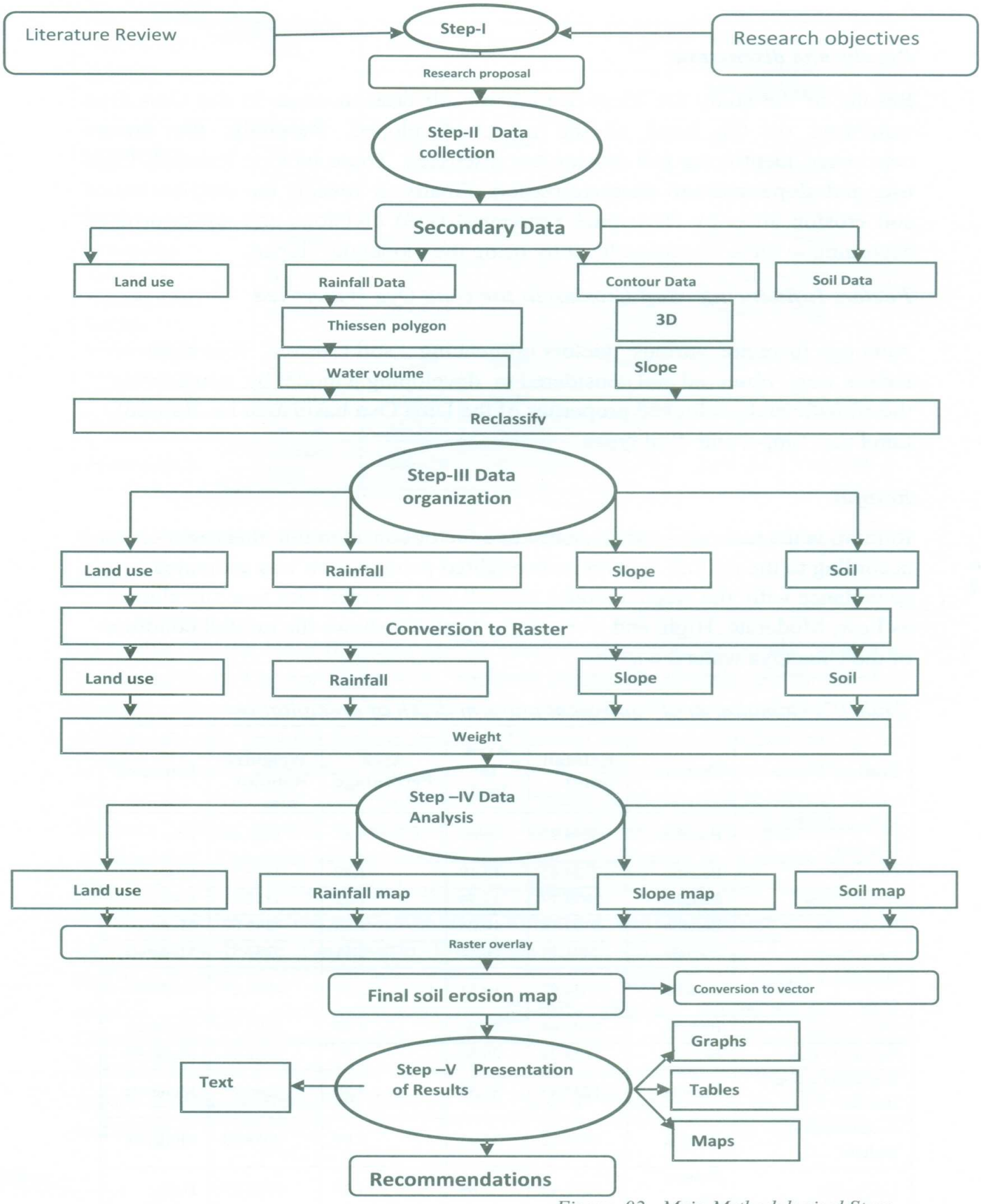

Figure 02. Main Methodological Steps

Results and discussion

Results of the study are identification of soil erosion areas in the Uma Oya watershed on the basis of the model developed. Secondly, the factors considered identifying soil erosion are discussed. These include Rainfall, Land use, and slope and soil characterization. Finally, it reveals the distribution of soil erosion areas by Divisional Secretariat (DS) divisions and are prioritized according to the soil erosion level by using the model developed.

Factors Influencing Soil Erosion in the Uma Oya Watershed

Although there are various factors influencing soil erosion , four main factors were observed and considered in developing a model by considering the climatic and geological properties of the Uma Oya basin area i.e. Rainfall, Land use, Slope, and Soil types.

Rainfal

Rainfall is the main soil erosion causative factor considered in this research, so according to the rainfall data annual weighted precipitation was estimated in accordance with the created model, rainfall was grouped into four sub classes as Low, Moderate, High, and Very High. Table 02 shows the rainfall condition of the Uma Oya watershed.

Table 02. Calculation of equivalent uniform depth of precipitation

Station Name	District	Rainfall (mm)	Area in km2	Area Percentage	Weighted Rainfall mm	Category
Kelliebedda Estate - Haputale	Badulla	2264.90	6.69	0.87	1970.46	Low
Glenore	Badulla	2124.61	12.19	1.59	3378.13	Low
Idalgashinna	Badulla	2055.77	12.54	1.63	3350.91	Low
Nayabedda	Badulla	3169.16	10.26	1.34	4246.67	Moderate
Ledgerwatta	Badulla	2491.71	16.18	2.11	5257.51	Moderate
Diyatalawa survey camp	Badulla	1624.81	19.31	2.51	4078.27	Moderate
Ohiya forest	Badulla	2101.64	25.96	3.38	7103.54	Moderate
Downside Estate	Badulla	1535.24	29.84	3.89	5972.08	Moderate
Welimada group - Badulla	Badulla	1237.45	32.55	4.24	5246.79	Moderate
Bandarawela - Badulla	Badulla	1531.32	35.43	4.61	7059.39	Moderate
Liddesdale	Nuwara Eliya	2229.48	32.68	4.25	9475.29	High

Hakgala Bot. Gard.	Nuwara Eliya	2238.36	33.42	4.35	9736.87	High
Sita Eliya - Nuwara Eliya	Nuwara Eliya	2007.18	33.46	4.36	8751.30	High
Warwick estate - Ambewela	Nuwara Eliya	2308.89	34.08	4.44	10251.47	High
Nuwara Eliya	Nuwara Eliya	2187.95	34.77	4.53	9911.41	High
Attampitiya Estate - Attampitiya	Badulla	1834.77	39.78	5.18	9504.11	High
Rahangala	Badulla	1435.34	46.37	6.04	8669.45	High
Dyraaba Estate-Badulla	Badulla	1662.70	53.74	7.00	11638.90	High
Delmar - Halgra oya	Nuwara Eliya	2522.82	50.60	6.59	16625.38	Very High
Kirklees Estate	Badulla	2351.37	55.80	7.26	17070.95	Very High
Narangalla	Badulla	2579.12	62.05	8.08	20839.29	Very High
Nildandahinna	Nuwara Eliya	2331.70	90.49	11.78	27467.43	Very High

Source: Department of Meteorology, Sri Lanka 2003, 2006, and data calculated in 2009.

According to the table 02 there are 22 rainfall stations in the study area, and Nildandahinna, Delmar-Halga oya, Kirklees Estate, Clydesdale are the rainfall stations situated in Nuwara Eliya and Badulla Districts. Among them, Nildandahinna gets the largest amount of annual weighted precipitation equals to 90.44 square kilometers representing 768.07 square kilometers of the total area of the Uma Oya watershed. Also normally high rainfall received in the Nuwara Eliya district receives high rainfall except the station like Attampitiya, Dyraaba –state , and Rahangala all situated in Badulla District. The high rain fall Category belongs to the Nuwara Eliya District. At the same time, Annual Weighted precipitation of Moderate rainfall belongs to Badulla i.e. Downsite Estate. Legerwatta, Welimada group, Bandarawela, Ohiya forest, and Nayabedda stations all are situated in Badulla District. As well as all low rainfall category also belong to the Badulla District where Idagashinna, Glenore, and Kelliebedda Estate are the low category rainfall station situated in Badulla District.Kelliebedda Estate Haputale is the lowest rain fall station where it was estimated at 2264.90 mm and it extends over in 6.69 square kilometers .

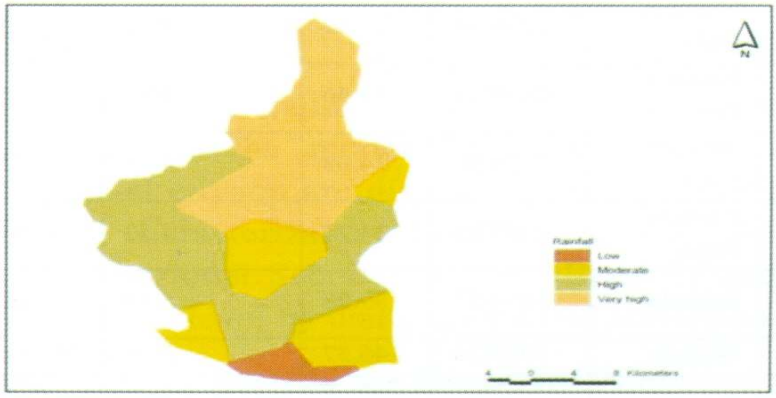

Figure 03. Distribution of rainfall in Uma Oya Basin

Land use

Land use and land cover are the main factors considered as soil erosion causative factors because they are the main sources that influence soil erosion in the Uma Oya watershed. According to the model, land use is categorized mainly into four classes in order of prioritizing considering influence on soil erosion namely Low, Moderate, High, and Very high. Table.4.3 shows different land uses with their assessments.

Table 03. Land use types and their assessments

Name	Area in km2	Percentage	Category
Water holes	0.11	0.01	Low
Tank	0.30	0.04	Low
Playground	0.31	0.04	Low
Marsh	0.34	0.04	Moderate
Reservoir	0.45	0.06	Low
Rock	2.73	0.36	Low
Stream	8.24	1.07	Moderate
Chena	12.99	1.69	Very High
Other cultivation	48.14	6.27	High
Paddy	61.08	7.95	High
Forest	97.12	12.64	Low
Scrub land	113.49	14.77	Moderate
Tea	196.91	25.63	Very High
Homesteads	225.95	29.41	Moderate
Total	768.16	100.00	

Source: Survey Department, Sri Lanka .1989, 1995, 1996.

Chena and tea are the very high soil erosion land use category and Chena extends over 12.99 and tea 196 square kilometers representing (table 03). Here, tea is the main land use largely responsible for soil erosion because at the stage of preparing tea lands, it is exposured to high rain fall and as a result of it tea lands without adequate soil conservation methods are directly subjected to high soil erosion in the Uma Oya area. Chena also largely responsible for soil erosion but in the Uma Oya watershed Chena extends only over 12.99 square kilometers therefore, it belongs to the category of very high soil erosion according to the model developed. Vast portion of the watershed is also used for homesteads and an area of 225.95 square kilometers is the homesteads lands use type. It is also considered as a high soil erosion land use according to the model. Other cultivations paddy, are some other land use types that belongs to the high soil erosion category. A marsh is considered as of moderate soil erosion while forest, playground, reservoir, rock, scrubland, stream, tank, and water holes are considered as Low soil erosion.

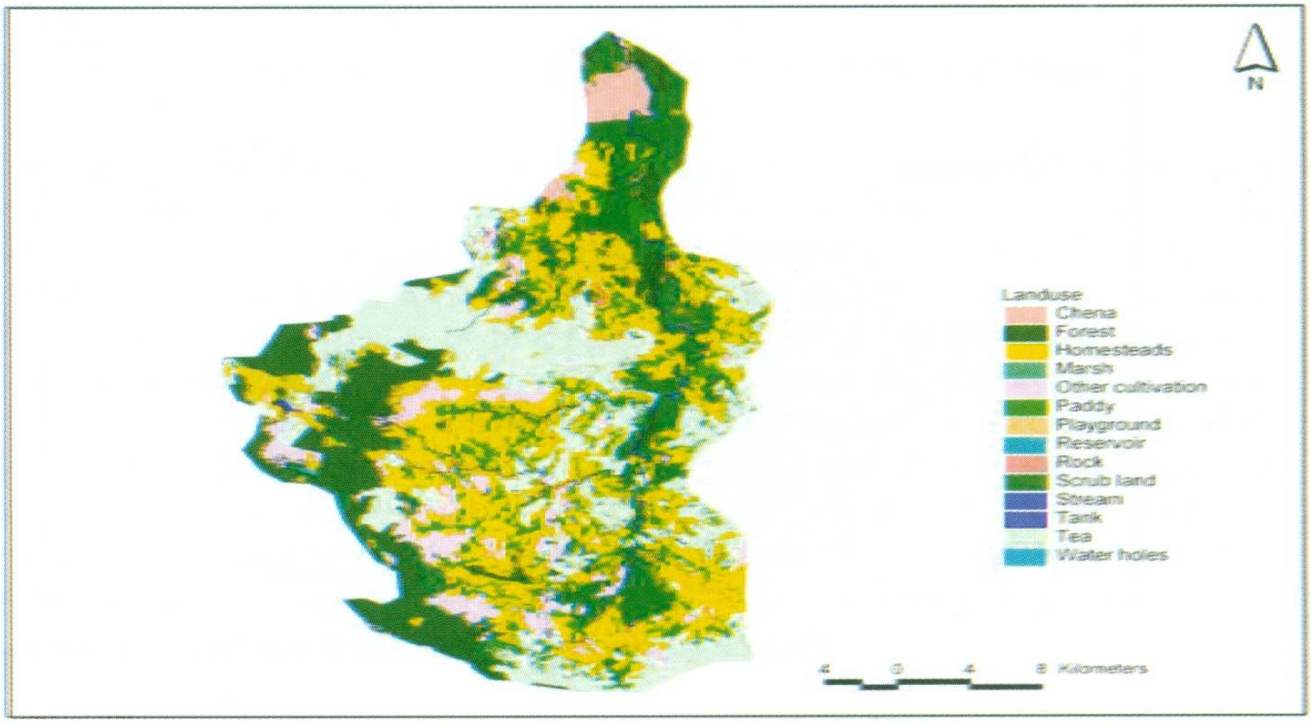

Figure 04.Land use of the Uma Oya watershed

Slope

Slope is also a main soil erosion causative factor considered in the soil erosion model in Uma Oya watershed. Here, slope is categorized into four types according to the slope as 0-8, 8-16,16-24,and 24< in degrees in order to identify the slope condition of the study area, and slope level classes belonging to the

Low, Moderate, High, and Very High respectively. Category of low slope extends over 253.54 square kilometers and moderate slope extends in 278.40 square kilometers. The largest portion of the watershed covering 36.25% of total area. Some 157.43 square kilometers are considered as high slope areas while 78.60 square kilometers is considered as under very high soil erosion. Table 04 as well as Figure 05 shows further more details as follows.

Table 04. Slope Category

Slope (in degrees)	Area in km^2	Percentage of total area
0-8	253.54	33.01
8-16	278.40	36.25
16-24	157.43	20.50
24<	78.60	10.23
Total	767.97	100.00

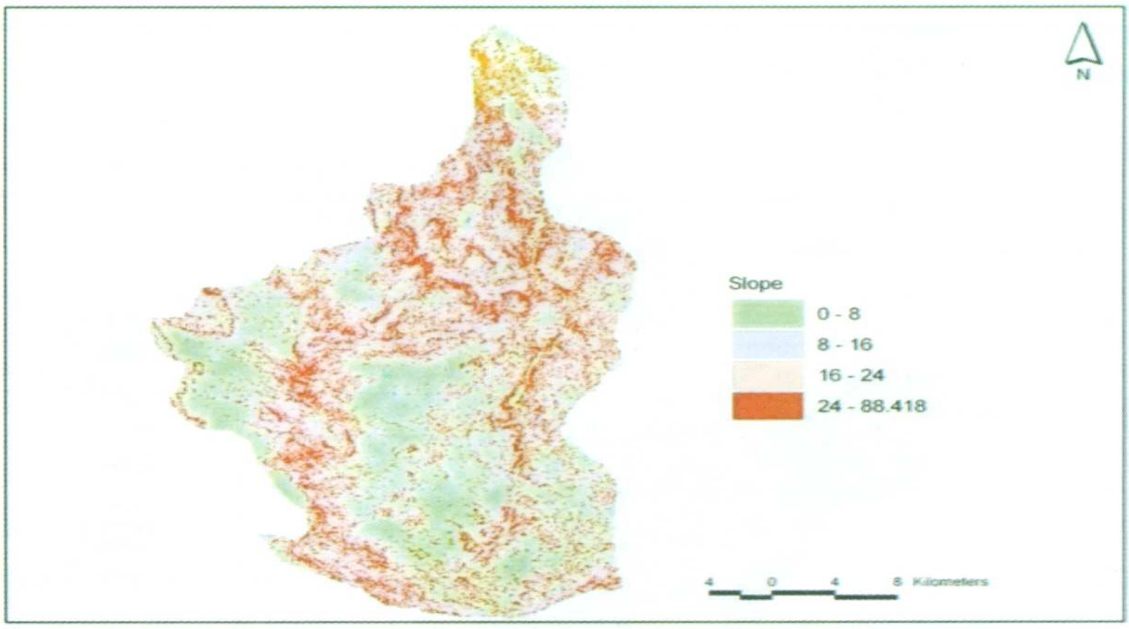

Figure 05.Slope levels of the Uma Oya watershed

Soil type

Soil erosion model developed for Uma Oya watershed shows that soil type is another soil erosion causative factor. Soil types were grouped into four soil erosion classes as Low, Moderate, High, and Very High. Table 05 shows type of soils with area and percentage.

Table 05. Soil types in the Uma Oya watershed

Soil Type	Area in km^2	Percentage	Category
Redish Brown Earths and Low Humic Gley Soils	0.88	0.11	Low
Reddish brown latosolic soils, dissected, hilly and rolling terrain	1.51	0.20	Low
Reddish Brown Earths and Immature Brown Loams; rolling and hilly	56.31	7.33	Moderate
Red-Yellow podzolic soils and mountain regosols	278.42	36.25	Very High
Red-Yellow podzolic soils, steeply dissected, hilly and rolling te	431.05	56.11	High
Total	768.16	100.00	

Source: Survey Department, Sri Lanka.1989, 1995, 1996-Soil Maps

Accordingly, Red-yellow podozolic soils and mountain regosoils are the most responsible soil types for soil erosion in36.25 of the area. It equals to 278.42 square kilometers. Red yellow podozolic soil steeply dissected and rolling is the most predominant soil type covering 56.31% of the total basin area with 431.05 square kilometers. It belongs to the 'High'soil erosion category. Reddish Brown earths and immature Brown Loams and rolling and hilly soils is a moderate soil erosion type extending over 56.31 square kilometers. Reddish brown leptosomic soils, dissected, hilly and rolling terrain and Reddish Brown earths and Low Humic Gley soils belong to the low soil erosion category covering only a portion of the watershed and Figure 06 depicts more information.

Figure 06.Extents of soil type in Uma Oya

Influence of other factors

Here, the soil erosion model was developed by considering the main soil erosion causative factors relevant to the Uma Oya watershed by giving priority to factors. Some soil erosion factors were used for the model in order to create a final soil erosion model of the Uma Oya watershed. Table 06. Depicts the influence level as a percentage.

Table 06. Factor weighting

Factor	Percentage of weight
Rainfall	40
Land use	30
Slope	20
Soil type	10
Total	100

According to rainfall intensity and land use factors were predominant than the others in the watershed area. Therefore 40 percent and 30 percent weightages were allocated for each of these factors respectively. A 20 percent weightage was given for the slope factor and 10 percent weightage for the soil type factor.

Identification of Soil Erosion Areas in Uma Oya Watershed

The model was grouped into four soil erosion classes as Low, Moderate, High, and Very High for soil erosion according to the Weighted Overlay analysis . Extent of soil erosion in Uma Oya watershed is shown in Figure 07 and Figure 08. It was estimated that 8% of the watershed experiences 'very hig0h' soil erosion whereas 23% and 38%, respectively encompass areas affected by "High" and "Moderate" soil erosion and 31% is considered to be affected by "Low" soil erosion of the watershed.

Table 07. Extent of soil erosion

Soil erosion	Area in km^2	Percentage
Low	233.83	31
Moderate	291.97	38
High	179.01	23
Very High	61.40	8
Total	766.20	100

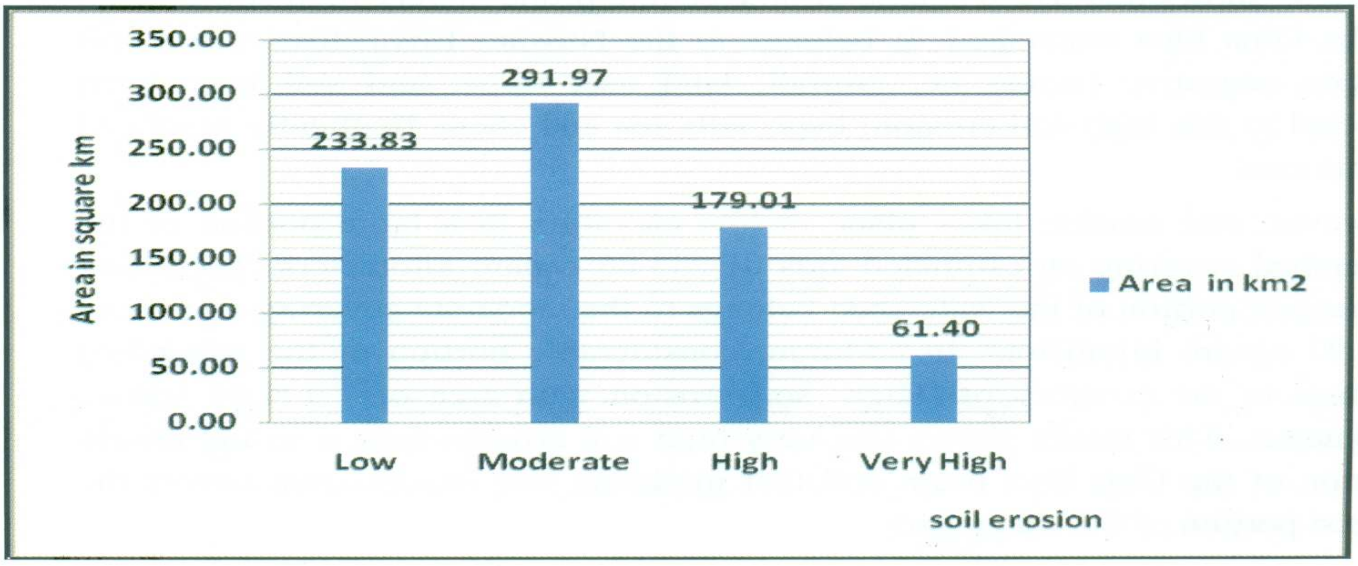

Figure 08. Extent of soil erosion

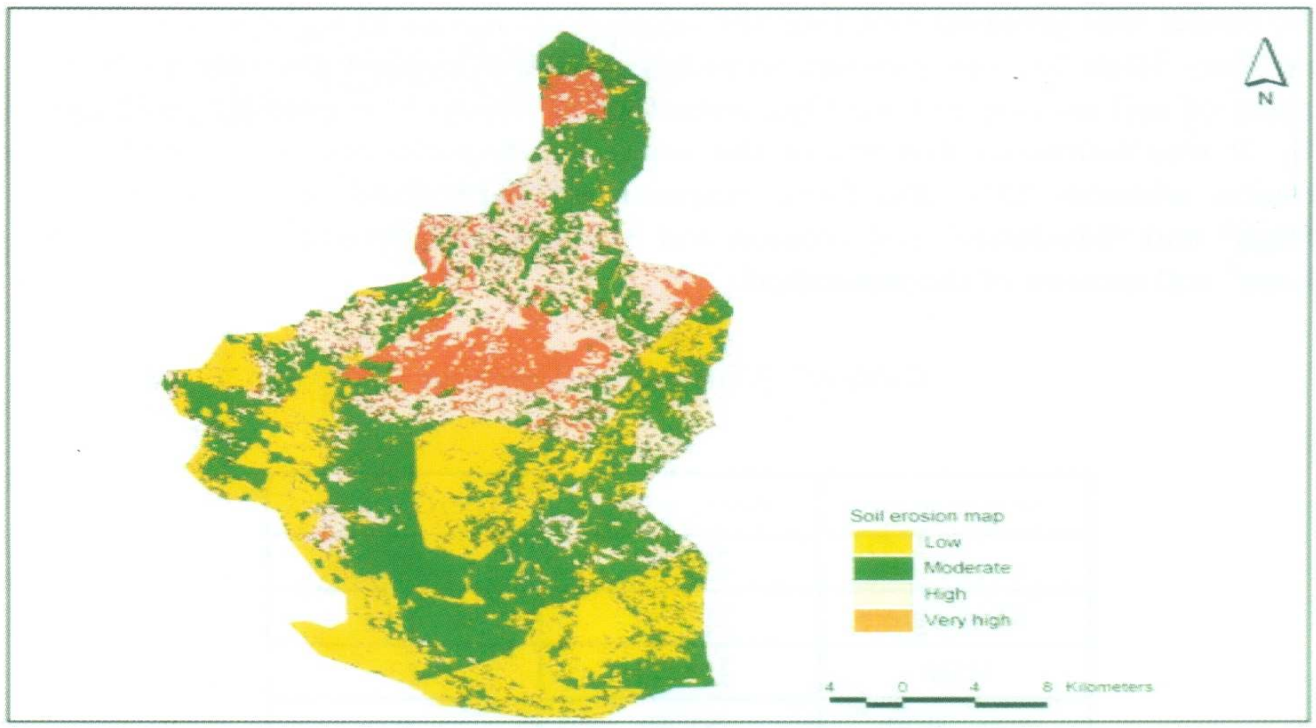

Figure 09.Extent of soil erosion in the Uma Oya watershed

Table:07 shows that 61.40 square kilometers are prone to very high soil erosion in the Uma Oya watershed. It belongs to the Nuwara Eliya district and soil erosion causative factors i.e. rainfall, land use, slope, and soil have been affected to this high soil erosion. Especially tea and chena frequently practiced in this area.

However, soil erosion takes place in low elevation in a large portion of the watershed covering an estimated area of 233.83 square kilometers. Therefore, the largest portion of the watershed belongs to the moderate covering an area of 291.97 square kilometers. In addition, considerable portion of the watershed belongs to the category of 'High' soil erosion with area of 179.01 square kilometers. This model shows that very high soil erosion area is in the lowest portion of the Uma Oya basin and that moderate soil erosion area covers the largest portion of the watershed.

Conclusions and Recommendations

Modeling of soil erosion in Uma Oya watershed area may help to apply proper conservation measures to overcome soil erosion problems. This study used

main soil erosion causative factors i.e. rainfall.landuse, slope, and soil types to model soil erosion prone area identification in GIS environment. According to the developed model, the study area was categorized into four soil erosion levels, as Low, Moderate, High and Very High, the study reveals that 179.03 square kilometers are subjected to high soil erosion and about 7.99 percent of the whole watershed of the Uma Oya. The distribution of soil erosion by DS division level shows that Walapane DS division is the most vulnerable for high soil erosion at the other end as demonstrated by the model, Bandarawela, and Ella DS divisions are the lowest soil erosion prone areas.

Further this study reveals that chena cultivation and tea cultivations are major land use practices in the area. Chena cultivation done with the activation of the South-West Monsoon. Most of the areas are on steep slopes. Cultivated river reservation areas are also observed. Therefore, the consequences of these human activities on land are most vulnerable. It is indicated that the areas of high soil erosion can be accounted for in terms of steep unstable terrain, and the occurrence of high rainfall and low vegetation cover.

The study revealed that the Uma Oya watershed can be classified into four major conservation zones at the macro scale according to the soil erosion areas. It is possible that this GIS based soil erosion identification model can be applied to Sri Lanka at both macro and micro level with necessary data bases.

Although at first research assumed that there is very high soil erosion in the Uma Oya watershed, the results of the study reveals that Moderate soil erosion is the frequent soil erosion type in the basin as shown by the model.

Identification of soil erosion prone areas by using GIS was based on the secondary data collected from the different government agencies. Using only secondary data, it is not possible to go for more intensive analysis. Hence, having collected primary data and adequate secondary data this model could further be developed or improved more effectively.

The extent of the study area is nearly 768.068 square kilometers, practically gathering data for a large area it takes more time and generates a lack precise data. Therefore, micro level analyzing is suitable. The lack of GIS based catchment related soil erosion studies in Sri Lanka compels the researcher to use 1:50000 scale data. Therefore the study only leads to identification of soil erosion prone areas.

Reforestation progarmmes may have to be undertaken while the forest cover of the area must be protected by using both command and control approaches and

economic instruments. Under the command and control approach, laws must be implemented practically in the DS divisions Walapane, and Uva paranagama Chena cultivation and even tea without proper management of lands must be limited. Especially, both side of the Uma Oya must be protected by using the concept of strict nature reserves so at least one kilometer from the bank of the Oya should be permanently conserved towards the both left and right hand from the Uma Oya. It may be more useful growing selected grasses `near the bank side of the Oya and it will help the control the soil erosion on the other hand taking adequate water for the reservoirs . at the same time , a long term plan to control soil erosion and protect the watershed the very high soil erosion areas (Walapane, Uva paranagama). Especially Walapane is not suitable for humans settlements because of the risk of landslides and high soil erosion accelerated by the human activities.

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