Identification of Erodible Hotspots for Soil and Water Conservation Using Terrain Modeling to Enhance Food Security in Sri Lanka

SS Senanayake* and MAK Munasinghe
Natural Resources Management Center, Department of Agriculture, Peradeniya, Sri Lanka

Abstract
Soil erosion by water is the most prevalent environmental problem in the central highlands of Sri Lanka. On the above context, the soil conservation is critically required in these areas. Uma Oya watershed in central highland is one of the most important sensitive areas with regard to soil erosion. Digital terrain modeling in Geo-informatics is a useful tool for identifying and prioritizing areas for soil and water conservation which are critical to restoring and protecting for crop production. This paper is focused on the use of Geo-informatics techniques to identifying and prioritizing vulnerable places for soil conservation in Uma Oya watershed and visualizing, to better planning and identifying erodible hotspots for soil and water conservation. An integrated soil erosion hazard map of Uma Oya watershed was generated by using Geographic Information Systems (GIS) and existing land use pattern and landslide incident layers in the GIS environment. Data analysis was performed using 3D analysis tool in the spatial analysis. The soil erosion hazard map clearly shows that nearly 63% of total area of the watershed is highly vulnerable for soil erosion. Eleven micro-watersheds were delineated based on drainage systems. 5 out of 11 micro-water sheds fell under severer soil erosion categories of the soil loss severity classes, of which two of them are in the extremely high erosion categories. These identified erodible hotspots can be assessed for further evaluation to install on farm and off farm conservation structures in a sustainable manner.

Keywords: Terrain analysis, Soil conservation
Corresponding author: sumudusenanayake@yahoo.com

Introduction

Uma Oya is a major tributary of Mahaweli River, originates in the central highlands approximately at an elevation of 2500 mMSL and flows eastwards initially and changes its course northwards beyond Welimada plateau and joins Mahaweli River discharging into Rantambe reservoir at an elevation of 152m. The Uma Oya basin is located between 06°45′23″N, 81°03′08″E and 06°59′29″N, 81°00′58″E, covering an area of approximately 720 km^2. Most of lands have been used for commercial scale farming of potato, vegetables, maize as well as export agriculture crops like tea, cardamom, paper, ornamental flowers etc.

This agriculturally active land is exposed to severe soil erosion and landslides, in parallel with the rapid rate of deforestation since recent past. About 50% of lands in Uva province are highly vulnerable and fragile for soil erosion (Senanayake *et al.*, 2013). The forest cover in central highland has been reduced further to a few isolated patches. Earlier work of Hewawasam in 2010 found that vegetables are grown extensively on the steep slopes of the Uma Oya watershed (one of Upper Mahaweli watersheds) without proper land management practices. Soil is almost a non-renewable natural resource over the human time-scale making soil erosion a critical problem. Other than that soil erosion greatly effects on natural water storage capacity of watersheds, quality of surface water sources, aesthetic landscape beauty and ecological balance, storage capacity of manmade structures such as reservoirs and damps. Soil erosion thus largely remains a problem to be tackled as part of the government's efforts at ensuring food security, poverty reduction and environmental sustainability. Hence, a detailed understanding of the extent, risk and spatial distribution of the problem is important to planning and implementation of effective soil and water conservation measures where necessary. GIS based evaluation of micro watershed and prioritization for treatment at watershed level has been used in different countries for soil and water conservation (Binay and Uday, 2011).

The objective of this study was to assess soil erosion hazard and prioritizing vulnerable places for soil conservation in Uma Oya watershed and to prioritize identified erodible hotspots for soil and water conservation.

Materials and methods

A common method to estimate soil erosion is the Universal Soil Loss Equation (USLE). The USLE is an empirical equation, originally developed by Wischmeier and Smith (1978) based on erosion measurements at standardized slopes. The USLE estimates average soil loss for a given site as a product of six major factors (Equation 1), whose values can be expressed numerically. The soil erosion depends on the erosivity of rainfall (R), erodibility of soil (K), slope length and slope steepness (LS), land cover(C) and crop management practices (P) factors.

$$A = RKLSCP \quad (1)$$

It was used in a GIS environment to estimate average annual soil loss (t ha^{-1} y^{-1}) and the spatial distribution of erosion hazard in the watershed studied. Rainfall erosivity map compiled by Wickramasinghe and Premalal (1998) were considered as the base map for rainfall erosivity. The erodibility values for soil were gathered from available literature (Senanayake *et al.*, 2013). The elevation data were obtained by the 20m digital contour map of the Survey Department of Sri Lanka. The C and P factor values were generated based on the land use information obtained from Department of Land Use Policy Planning (2012). The terrain analysis was performed by using 3D analysis tools in Arc GIS 10.1 software to generate Digital Elevation Map (DEM) and Slope map. R, K, LS, C and P factors were integrated to generate a map of soil erosion hazard. The final soil erosion hazard map was produced applying simple arithmetic calculations and Weighted Sum algorithm in ArcGIS. The output was classified to show five classes of soil erosion hazard namely low, moderate, high, very high and extremely high.

Hydrological tool in special analysis was used to identify the micro watersheds within the Uma Oya watershed. Furthermore, soil erosion hazard map, vector special layer of incidences of landslides occurred and map of micro watersheds were overlaid to produce an integrated soil erosion hazard map of the Uma Oya watershed. Soil erosion hazard classes, type of land use, incidents of landslide and expert judgments were used to priorities the micro watersheds for soil and water conservation. Thereafter, erodible hotspots within the micro watersheds were verified by overlaying into Google map and field verification through observations of random field visits.

Results and discussion

Soil erosion hazard indicates the susceptibility of a particular area for soil erosion. The soil erosion hazard map clearly shows that nearly 63% of total area of the watershed is highly vulnerable for soil erosion and requires implementation of different types of soil and water conservation measures for a sustainable land use. Integration of the soil erosion hazard map, vector special layer of incidences of landslides occurred and map of micro watersheds together are important to generate integrated soil erosion hazard map for identification and prioritization of micro watersheds. An integrated soil erosion hazard map of Uma Oya watershed is given in figure 1.

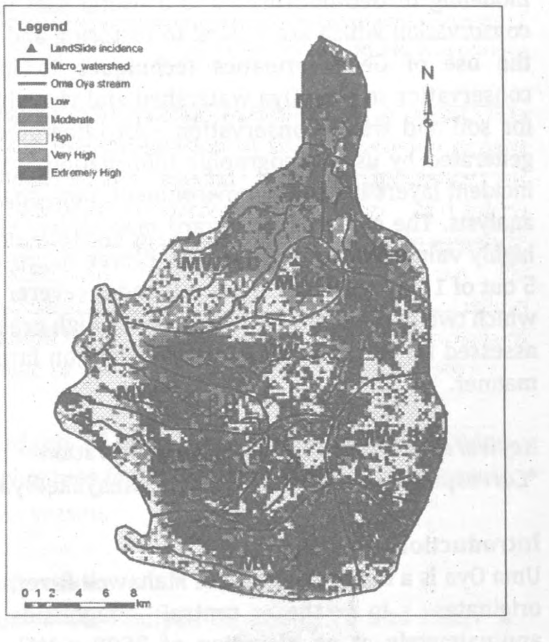

Figure 1: Integrated soil erosion hazard map of Uma Oya watershed.

The integrated soil erosion hazard map of the study area indicates five distinct susceptibility classes namely; low, moderate, high, very high and extremely high are given in Table 1.

Table 1: Extent of erosion hazard categories

Erosion Hazard Category	Area (km^2)	Percentage	Micro watershed	Conservation Priority
Low	42.0	6	MW_11	5
Moderate	112.1	16	MW_3, MW_10, MW_1	4
High	111.8	16	MW_4, MW_9	3
Very High	182.7	25	MW_2, MW_5, MW_6	2
Extremely high	271.8	38	MW_7, MW_8	1
Total	720.3	100		

A total of 11 micro-watersheds were delineated based on drainage systems and coded as MW_1 to MW_11. Five categories of micro watersheds were identified from the integrated map of Uma Oya watershed and ranked for soil and water conservation priority. Based on the spatial distribution of the erosion hazard, 5 out of 11 micro-watersheds fell under severer soil erosion categories of the soil loss severity classes, of which MW_7 and MW_8 are in the extremely high erosion categories respectively. Observations were made at the field verification revealed that most of these lands (MW_7 and MW_8) sloppy were which lands which were abundant lands due to less productivity after cultivating tobacco.

The result also revealed that there is an affiliation between land use category and landslide occurrence according to the special analysis of the overlaying soil erosion hazard map, occurrence of land slide incidence and land use map. In addition, work of Hewawasam in 2010 indicated that most of the causative factors for landslide are anthropogenic activities such as ad hoc cut slopes during construction of slopes building and roads, blocking drainage, mini hydropower projects, deforestation, neglect of lands, reservoir construction, aggregate quarry, land blocking in resettlement without consideration natural drainage systems and upland intensive cultivation in continuous.

The land use map shows most of the extremely hazard category land use type is intensive cultivations such as market garden. This indicates seasonal vegetable cultivation is critically inducing the soil loss in the Uma Oya watershed. Badulla district is contributing about 67% of total potato cultivation in the country. Also 64% of national potato production comes from Badulla District. Welimada is the main area for potato production in Badulla District. Potato cultivation in vegetable gardens has been increasing between 2009 and 2014 from 4100 ha to 5400 ha (Department of Censors and Statistic, 2015). Other dominant land uses in Uma Oya watershed are natural forest, mixed home gardens and tea. The land use types and estimated soil erosion rates in the Upper Mahaweli Catchment; dense forest (soil loss 100 t $km^{-2}y^{-1}$), degraded forest and scrubs (soil loss 2500 t$km^{-2}y^{-1}$) home garden (soil loss 100 t $km^{-2}y^{-1}$), market garden (soil loss 2500 t $km^{-2}y^{-1}$), shifting cultivation and tobacco (soil loss 2500 t $km^{-2}y^{-1}$) (Hewawasam 2010).

In addition, Bandara and Thiruchelvam (2008) pointed out that good level of soil conservation practices increased the farmers' potato yield and income.

Implementing conservation measures even with limited resources in identified11 micro-watersheds can significantly reduce total sediment yield from soil erosion. Thus, it is strategically necessary to use appropriate soil and water conservation measures for identified micro-watersheds that come under extremely high erosion categories. Hence, participatory watershed management and development practices can be applied with community. Furthermore, terrain analysis and other spatial analyses in GIS do not eliminate the need for field assessments. However, they can reduce the amount of time spent in the field and enhance data collection efforts by enabling technicians to select potentially sensitive sites for soil and water conservation. In addition, the qualitative assessment of physical parameters gives an indication of the limitation of the land to watershed development and thus in turn, can be used as a "qualitative measure" of the natural aspect of development (Binay and Uday, 2011).

Therefore, it is a high priority to implement conservation interventions at identified most vulnerable landscapes (erodible hotspots) in micro watersheds. Thus, it is important to setting of priorities in planning, resource allocation and decision making. The results of this study indicate micro watershed MW_7and MW_ 8 are the immediate priority areas for soil conservation. The methodology used in this study can be used in other watersheds to prepare master plans for conservation purpose and for efficient use of limited resources at the implementation.

References

Bandara DGVL and Thiruchalvam S 2008 Factors affecting choice of soil conservation practices adopted by potato farmers in NuwaraEliya district Sri Lanka. Tropical Agriculture Research and Extension.11-2008: 49-54

Binay Kumar and Uday Kumar2011 Micro watershed characterization and prioritization using Geomatics technology for natural resources management. International Journal of Geomatics and Geosciences, 1(4)2011:789-802

Hewawasam T 2010 Effect of landuse in upper Mahawelicatchment area on soil erosion, landslides and siltation in hydropower reservoirs of Sri Lanka. National Science Foundation, Sri Lanka, **38** (1): 3-14.

Senanayake SS, Munasinghe MAK and Wickramasinghe WMADB 2013 Use of erosion hazardassessments for mapping land use options for the Uva province. Annals of Sri Lanka Department of Agriculture, 15: 127-141.

Wickramasinghe, LA and Premalal R 1998 Development of rainstorm erosivity map for Sri Lanka. Proc. of the 5th International Soil Conservation Conference, Eds. SanamRimwanich. Bangkok,Thailand. 1:441-450.

Wischmeier WH & Smith DD 1978 Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. USDA Agriculture Handbook No 537. U.S. Department of Agriculture, Washington D.C.