

INTEGRATION OF RESOURCES DATA FOR SOIL EROSION HAZARD ASSESSMENT AND MAPPING IN NUWARA ELIYA AND KANDY DISTRICTS

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ABSTRACT

The object of the study was to classify soil erosion hazard, based on rainfall erosivity, soil erodibility and steepness of slope. The available information on rainfall erosivity, soils and topographical maps was assembled. The data were encoded on a scale of 1 to 4, where 1 and 4 are given to lowest and highest ratings of potential erosion hazard respectively. In order to integrate the three different parameters to determine their combined effect on soil erosion, a grid cell overlay (100 ha) 1 km × 1 km was prepared. The grid was overlaid and the information on rainfall, soil erodibility and slope steepness was manually integrated in each cell. The resultant classes were regrouped to provide five different erosion hazard classes. A map showing the distribution of the erosion hazard classes was prepared and presented. The area under each erosion hazard class was computed. General recommendations for land use and land management are given.

KEY WORDS: Erodibility, Erosion hazard, Erosivity, Geographic information system, Land use

INTRODUCTION

A major challenge in agriculture is to ensure a high level of food production, without irreparably damaging the soil on which this production depends. Soil erosion, a naturally occurring process when accelerated by human activities, causes direct loss of soil and plant nutrients from the eroded areas and damages downstream locations through the deposition of eroded materials. In Sri Lanka, soil erosion has been a major problem for the maintenance of land productivity and it has now attained national importance as a problem affecting the present and future generations.

There are several reports of early studies on erosion hazard assessments for upcountry districts in Sri Lanka (Zijlstra, 1989; T. Senanayake, P. S. Wijesooriya and S. T. D. Turner, 1990, Unpubl.).

These workers have applied computer-aided Geographic Information Systems (GIS) to map erosion classes, but, not all factors contributing to accelerated soil erosion have been integrated in defining the erosion hazard classes. The above studies heavily depend on land classification and land use, but erosivity of rainfall, a key factor has not been taken into account.

Highly erosive rainfall, high runoff, steepness of slopes, adverse soil physical conditions and clearing of natural vegetation for agriculture and other development activities are the main contributing factors for erosion hazards.

Erosion control programmes are implemented at least to maintain soil erosion rates within tolerable limits. To plan and implement such programmes the location, extent and estimates of the rate of soil erosion must be known. Thus, it is necessary to classify erosion hazards possibly on a numerical scale and prepare maps showing the distribution of different classes of erosion hazards in order to suggest suitable management practices.

Land form, soil, climate and agricultural uses in the mid- and up-country districts of Sri Lanka are such that soil erosion is the greatest threat to the sustenance of crop production. The cropping intensities in Kandy and Nuwara Eliya districts are high and therefore, soil erosion problems are highly critical and implementation of measures to arrest damage to croplands is urgent.

In the present study, GIS technology was applied to map the potential soil erosion hazard in the two districts, Kandy (mid-country) and Nuwara Eliya (up-country) using existing information on important factors such as relief, soil, rainfall and land use.

MATERIALS AND METHODS

Manual GIS

The primary method for storing, manipulating and presenting data is the use of a base map. Hence, to develop an information base for data analysis, the following source maps were used.

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<i>Type of information required</i>	<i>Source maps</i>
Slope class map	1:63,360 scale topographical map
Erodibility map	Reconnaissance soil maps compiled on 1:63,360 scale topographical maps
Land use map	1:100,000 scale land use maps
Erosivity map	Iso-erodent map of Sri Lanka on the scale of 1:500,000

The information available in maps shown above for compilation of a base map was found not to be compatible, because they were of different scales. Therefore, these maps were converted to a common scale (1:100000) by redrafting and/or through photographic scale adjustments.

Data model for GIS

There are two major choices of data models for GIS, namely, Vector data model and Raster data model. In the Vector model, objects or conditions in the real world are represented by points and lines that define their boundaries, much as if they were drawn on a map. While the system is accurate in defining the shapes of areas, it is expensive due to the complexity of data encoding and search procedures when two or more data sets are compared.

In the Raster model, the space is regularly subdivided into cells (usually square in shape). The location of geographic objects or conditions is defined by the row and column position of the cell they occupy. The Raster system works particularly well for integration of resource data that occur continuously over large areas such as soil types, land uses etc.,

Because of the simplicity of the data structure of the Raster model and the difficulties encountered in implementing overlay operations in the Vector data, the Raster model was chosen for the study.

Data merging procedure

The information merging procedure was performed by a map overlay method. First, each data set was prepared on a transparent map sheet. These maps (same scale) were then assigned with numbers according to the degree of severity of the conditions being depicted. For example, the slopes were grouped into 4 ranges, 0—20%, 21—39%, 40—60% and more than 60%, and graded 1 to 4; the steeper the slope in an area, higher the value given on the slope overlay. A similar rating system was adopted for overlays depicting other information as well; higher value "4" being assigned to represent high potential for soil erosion, while lower value "1" indicates the areas least susceptible to erosion; values in between "2 and 3" represent an intermediate degree of soil erosion.

Fig. 1 is a conceptual model illustrating the methodology adopted using geo-referenced data in a manually analyzed GIS for the study of soil erosion potential. In this illustration, the data maps are manually coded with respect to a grid. Usually, the data maps are encoded by recording the information category most dominant in each cell in the grid. That is, each cell is assigned a single soil type in the soil data map, a single erosivity value in the iso-erodent map and a single slope class in the topographic data map. However, in this study, data encoding procedure did not strictly conform to cell dominant approach. In order to be more realistic with the existing field conditions, in the event of several data types occurring in a given grid cell, depending on the extent of distribution, a weighted average value was assigned for each grid cell.

In the assessment of soil erosion hazards, the rainfall erosivity class value, soil erodibility class value and slope class value are multiplied to arrive at the net potential erosion class, because each of these factors enhances the erosion in a geometrical progression. Manual superimposition of the three single-parameter maps, thus yielded an analytical erosion susceptibility map with a very large number of susceptibility classes. Theoretically a cell with slope class 1, rainfall erosivity class 1 and soil erodibility class 1 has the least potential for erosion. The multiplication of the above three factor

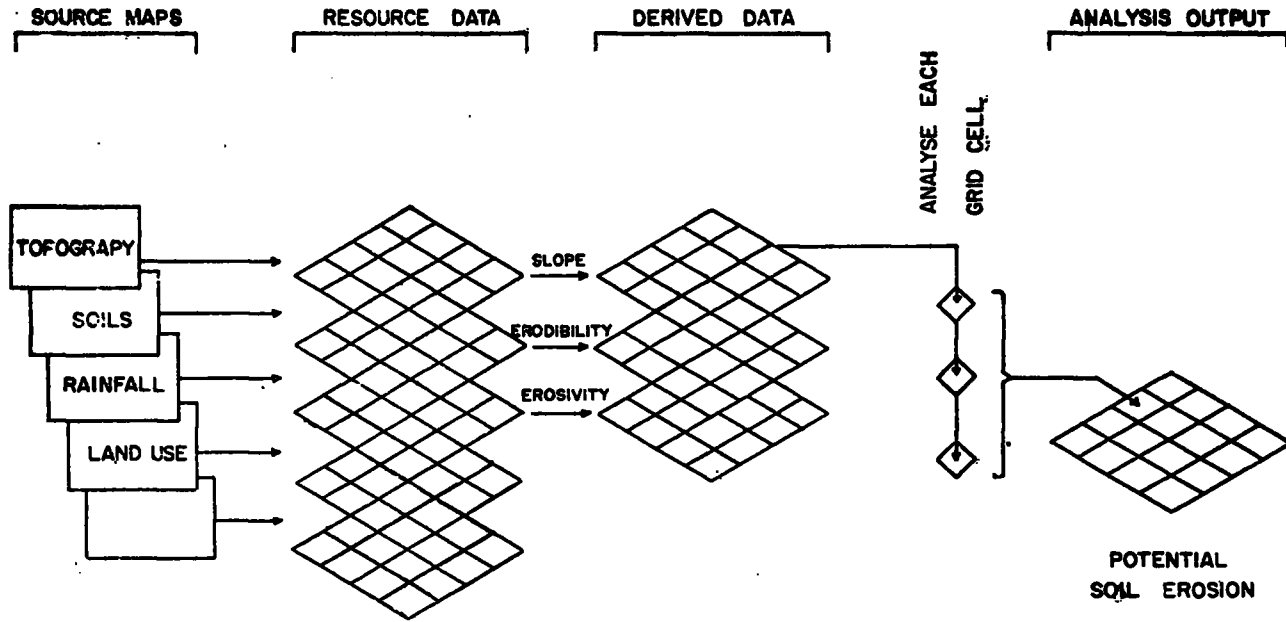


Fig. 1. Analysis procedure using geo-coded data

values ($1 \times 1 \times 1$) yields 1. Therefore the least erosion hazard class has a value of 1. Similarly a cell with highest slope class 4, rainfall erosivity class 4 and soil susceptibility class 4 has the highest potential for erosion and the multiple of the three parameters gives a value of 64. Thus the highest potential erosion hazard class has a theoretical value of 64 and it is also possible to have a maximum of 64 different erosion hazard classes. A cell with any other combination will be between these two extremes. In order to make the information more realistic and of practical value the erosion hazard classes were grouped into a smaller number of five. By a system of allocating a larger number of possible classes at the higher erosion hazard end, the class limits were set as follows:

<i>Erosion hazard class</i>	<i>Susceptibility range</i>
Low erosion	1 — 4
Moderate erosion	5 — 8
High erosion	9 — 16
Very high erosion	17 — 32
Extremely high erosion	33 — 64

Land use as an input to GIS

Three factors considered in the study namely, slope, rainfall and soil erodibility are governed by natural processes. As a consequence, change in their values for a specific geographic area occurs very slowly over time. Hence, GIS data base stored with such information can be considered somewhat static and, therefore, does not require periodical updating. In contrast, land use factor can change significantly over a relatively short span of time because this factor is a function of human choice between alternative land use practices. Therefore, if the land use factor is incorporated in the GIS data base it has to be updated on a regular basis. Any attempt to study potential erosion hazard based on land use information obtained in the past (in the absence of most recent land use information), may not yield the desired results because, for a given area, the present land use conditions may not be exactly the same as what existed at the time

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of the initial land use survey. The rigorous data encoding procedure involved in non-automated GIS however provides little or no flexibility in the data base for updating changes, once it has been established.

Repetitive coverage afforded by satellite data provides greater potential for timely updating of land use/land cover information. An automated GIS has the advantage of using remote sensing data for land use/land cover mapping. However, because of the complexities involved in data processing and analysis procedures, manually compiled data base such as the one established for the purpose of this study is not compatible to accept large volume of remotely sensed data obtained on a variable time frame.

In view of the above, the available information on land use, compiled using 1985 air photographs is not included in the data base for the assessment of erosion hazard. On the other hand, soil erosion hazard is an intrinsic property determined by slope, rainfall and soil erodibility and hence these factors have been included. The ratings adopted for different land uses according to the degree of severity of erosion are given in Table 1. These ratings could be incorporated with the combined results of the other three factors shown in the erosion hazard map to assess the potential soil erosion hazard in a given area under any land use that may be established in the future.

RESULTS AND DISCUSSION

The soil erosion hazard map obtained by combining the values of three data types, soil, slope and rainfall on a cell by cell basis is shown in Fig. 2. The extents classified according to different degrees of erosion are as follows:

Extremely high erosion hazard	6000 ha
Very high erosion hazard	62900 ha
High erosion hazard	180800 ha
Moderate erosion hazard	103500 ha
Low erosion hazard	9500 ha

Table 1. Land use ratings

Land use	Rating			
	Low-1	Moderate-2	High-3	Very High-4
Built up lands			x	
Non Agri lands				+
Homesteads		x		
Tca (up country)	x			
Well managed				
Tca (up country)				
Poorly managed			x	
Tca (mid country)			x	
Paddy	x			
Sparsely used crop land				x
Other crop lands				x
Dense forest	x			
Open forest	x			
Forest plantation		x		
Scrub land		x		
Grass land		x		
Barren land				x
Rubber	x			
Coconut		x		

With the changes in land use and management practices soil loss in a given location, however can vary considerably from year to year. On the other hand, when same land use and management practices are applied on two areas with one having intrinsically very high rating and other having a low or very low erosion hazard rating, the former will have a very high erosion damage whereas the latter will have the least erosion damage. Thus, this kind of a map will serve as a good guide to identify areas that may be affected by high soil erosion risk. Therefore, it will serve to select the more suitable land uses and management practices for a given area of land.

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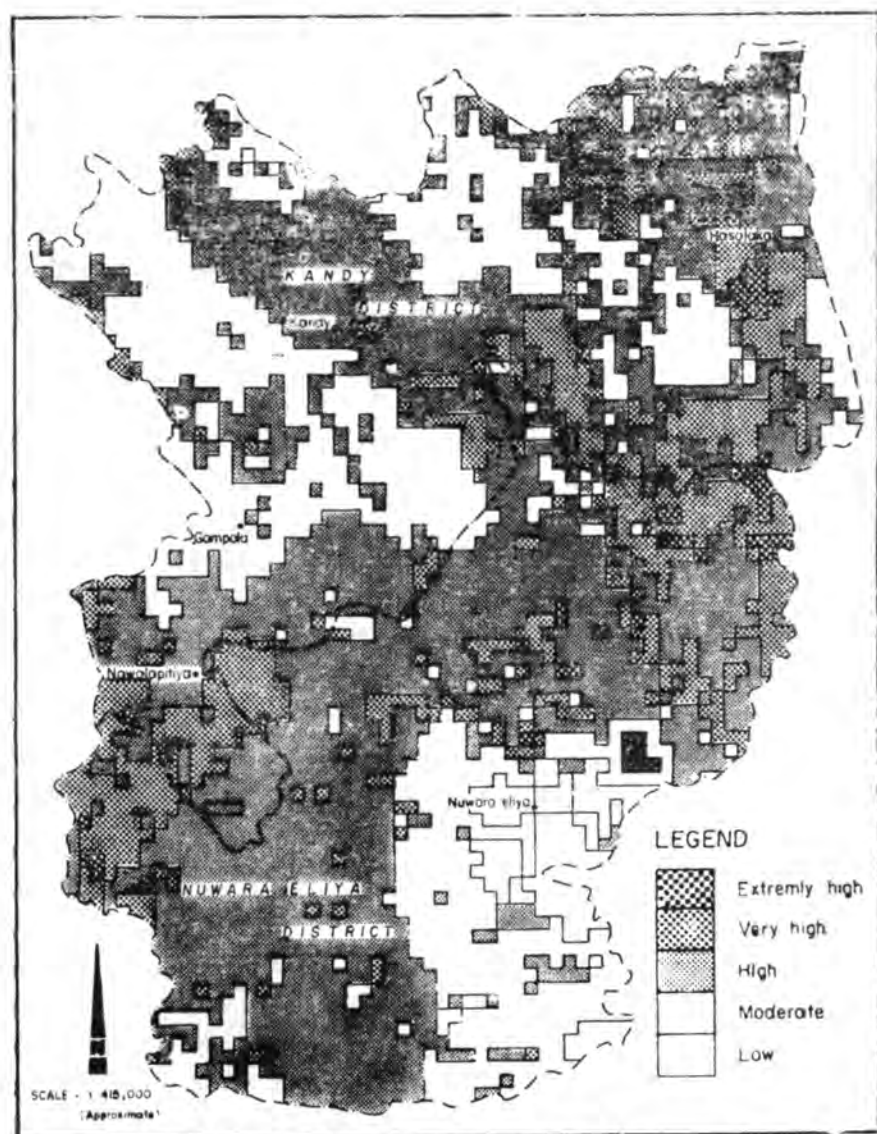


Fig. 2. Erosion hazard map of Kandy and Nuwara-Eliya districts.

The two districts under study receive high rainfall during both North-east and South-west monsoons. The lands consist of very steep slopes, and soils of moderate to high erodibility. Nearly 69% of the area is rated to have a hazard greater than or equal to high erosion hazard category. Protection of these areas from soil erosion has become even more important because of the hydropower reservoirs in the region. In spite of this there is extensive and intensive agriculture being practised without adequate conservation measures.

The soil erosion data above clearly highlight the severity of erosion hazard in the two districts resulting from the combined effects of the three factors, soil, slope and rainfall.

Extremely high erosion hazard areas

The total land area covering the two districts is approximately 370,000 ha, out of which about 6000 ha (1.6%) have been estimated to have extremely high erosion hazards. These lands are currently not suitable for any agriculture. Any attempt to change the natural cover may aggravate the erosion hazard in the area and as such these lands should be left under natural vegetation. If any part of this area is presently being used for agriculture, it is very important to return that part of the area to regenerate the natural vegetation.

Very high erosion hazard areas

The extent of the area susceptible to very high erosion is about 62,900 ha (17.3%) and mainly concentrated around Randenigala, Hasalaka and Nawalapitiya. Although it is the forest which is best suited for this particular erosion class, there are number of other land uses. As evident from the land use maps compiled by the Survey Department (using 1985 air-photographs), Randenigala and Hasalaka areas are dominantly under forest, with several other land uses scattered over the area. These other land uses include, sparsely used crop lands and scrub lands. The soil erosion hazard under sparsely used crop land is very high, thus reforestation or forest/tree-based production system is recommended for these lands. The vulnerability of scrub lands to soil erosion is considerably low. Nevertheless, it is recommended to reforest these lands to improve

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the productivity. In Nawalapitiya area tea and homestead gardens are the most commonly found land uses. A large extent of tea lands are found to be in a highly degraded condition while limited extent is still used to produce marginal yields. In order to improve the existing conditions of degraded tea lands, rehabilitation or replanting with complete soil conservation measures or reforestation is recommended. With the application of appropriate conservation measures, productivity of marginal tea lands could be improved to satisfactory levels. The homesteads in Nawalapitiya area are mainly concentrated in this very high erosion hazard region and hence need considerable protective measures. However, the conversion of this land use to a more fitting one is socially and economically not feasible. Therefore, these lands should be protected with adequate conservation measures.

High erosion hazard areas

About 180,800 ha (49.8%) of lands are in the category of high erosion hazard. This is the largest and the most widespread area under a single erosion class in the two districts. A number of land uses such as vegetables, potato and sparsely used crop lands which induce high soil erosion are found in this area although tree crops appear to be the best suited land use. Depending on the agroecological and socioeconomic conditions well-managed tea, coffee, cloves, and other tree crops such as fruits are recommended for the area. However adoption of mechanical and biological conservation measures is of utmost importance to prevent any further degradation of these lands.

Moderate erosion hazard areas

About 103,500 ha (28.5%) of lands classified under moderate erosion hazard are mainly confined to Ragalla and Diyagama areas in the Nuwara Eliya district and Gampola, Kadugannawa, Madulkele and Panwila areas in the Kandy district. The lands belonging to this erosion category in the Nuwara Eliya district is exclusively used for tea and growing of annual crops such as vegetables, potato etc. The current land uses appear to be highly suited for this particular land class. However, to sustain the productivity of these lands, strict conservation measures are required.

The land uses most common to moderate erosion class in the Kandy district include tea and homestead gardens. Most of the tea lands are highly degraded and produce very low yields. Continued land use and current management practices will lead to further destruction of the lands and thus it is best that tree crops such as cloves and fruit trees are introduced on these lands. In order to improve and sustain the productivity of limited extent of currently marginal tea lands, mechanical and vegetative conservation measures such as stone terraces, lock and spill drains and hedges of live plants such as gliricidia (*Gliricidia maculata*) and vetiver (*Vetiveria zizanioides*) are recommended.

The conversion of homestead gardens to other forms of land uses may not be socially acceptable. Therefore, these homesteads should be managed on the model of Kandyan homestead gardens or with intensive conservation measures.

Low erosion hazard areas

About 9500 ha (2.6%) of lands are classified under low erosion hazard class. The lands belonging to this particular erosion class are found only in the Nuwara Eliya district. These lands are highly suitable for growing of annual crops, especially exotic vegetables, potato etc. However, annual cropping can increase the erosion damage in the area and therefore adequate conservation measures are required. The degree of soil erosion in narrow valleys in the Kandy district is also considerably low and can be classified under the category of low erosion. However, the extent of individual valleys are much smaller compared to the size of the grid (100 ha) which was used. Therefore, when average ratings are assigned for each parameter, the ratings applied on valley slopes and soils within a given grid cell can get masked because of the intrinsically higher ratings associated with soils and slopes of the adjacent highland. As a result, the erosion class to which these valleys belong cannot be shown in a distinct manner on the erosion hazard map.

Irrespective of the nature of the GIS, whether it is automated or manual, both systems have their own limitations. The computer based GIS requires specialized equipments and as such may not

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always be economically feasible. On the other hand, rigorous and time consuming data encoding procedure, and the inflexibility of the data base for accommodating regular changes make the manual GIS somewhat disadvantageous over the corresponding computer-based GIS. In both systems, an accuracy of the final product will mainly depend upon the size of the grid being used. Coarser grids provide less accurate geographic descriptions of data while the finer grids define the geographic specificity of data more accurately.

This explains the inherent limitation of the erosion hazard map to show up the small areas of interest, like narrow valleys in the Kandy district. With the use of smaller grids, finer details of the areas can be located and so it can improve the accuracy of the map. However, if the grid size is made half the size (0.5×0.5 sq.cm) of the present grid (1.0×1.0 sq.cm), there will be a four-fold increase in the number of grids (Number of grids will increase from 3627 to 14508) resulting in more tedious and time consuming data encoding and analysis.

CONCLUSIONS

Soil erosion is mainly dependent upon the combined effect of soil erodibility, rainfall erosivity and steepness of slope. Hence, integration of above parameters to study the degree of spatial correlation between them is necessary in soil erosion studies. GIS is one of the best methodologies that can be adopted for integration of these variables into an assessment process.

The main output of the study is a map showing different classes of erosion hazard, and their geographical distribution. This kind of information is very useful for selection of land uses in the future so that the environmental quality could be improved and maintained.

In spite of some of the limitations mentioned, GIS can inventory large areas for prediction of soil erosion which can save time and money over conventional ground sampling. It is best applied as a pre-screening mechanism to identify areas of major soil erosion hazards, in which a user is concerned with respect to relative amounts and the spatial extent of soil erosion.

This study clearly shows the distribution of erosion hazard areas in the Kandy and Nuwara Eliya districts where about 249,700 ha (69.0%) of lands are estimated vulnerable to high erosion hazard. However, as reforestration is not an acceptable land use alternative to agricultural uses in such a large proportion of land area of these two districts, it emphasises the importance of adopting conservation measures to save our soils.

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