

USE OF GEOGRAPHICAL INFORMATION SYSTEMS FOR SOIL EROSION HAZARD ASSESSMENT OF THE CENTRAL PROVINCE OF SRI LANKA

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ABSTRACT

Over the past two decades it has become increasingly evident that land and water resources are scarce, the effects of human induced activities are more visible and identification and prediction of causes are more complex. In the light of the above situation, better methods for land and water resources management and planning is crucial. Geo-referenced information is a prerequisite for land and resource management and tools such as Geographical Information Systems (GIS) can provide means to inventorize resource data and model processes from the local to global scales. A study was carried out using GIS technology with the overall objective of generating information that are required for optimum utilization of land and water resources. The specific objectives of the study were to assess relative potential and the hazard of soil erosion within the Central Province and to prioritize the areas for soil conservation planning. The slope percentage of the terrain, erodibility of the soils, erosivity of the rainfall and the present land use were considered as inputs to the model. These input data layers were spatially analyzed and the products were subjected to field validation. Once the necessary corrections were accommodated, outputs depicting relative potential soil erosion and the soil erosion hazard were prepared. Based on these outputs, a set of recommendations was formulated which can be implemented at provincial level land use planning and management.

KEYWORDS: Erosion Hazard, Erosion Potential, GIS, Land use

INTRODUCTION

Over the past two decades it has become increasingly evident that land and water resources are becoming scarce, the effects of human induced activities are more visible and identification and prediction of causes and effects are more complex. In the light of the above situation, better land and water resource management and planning yield direct benefits in improved resource management and ultimately in improved quality of life. Geo-referenced information is a prerequisite for land and water resource management and tools such as Geographical Information System (GIS) can provide means to inventories resource data and model processors from the local to global scales.

A study was carried out using GIS technology with the objective of generating information required for optimum utilization of land and water resources. The specific objectives of the study were to assess the relative soil erosion potential and hazard within the Central Province and to prioritize the areas for soil conservation planning.

MATERIALS AND METHODS

Many models have been developed for soil erosion modeling and estimation. The complexity of these models can be varied from screening and planning models such as USLE (Wischmeier and Smith, 1978) to complex hydrological assessments models, such as CREAMS (Knisel, 1980), and ANSWERS (Beasley *et al.*, 1980). However, the main inputs for the above models to assess the soil erosion are, erosivity of rainfall (R), erodibility of soil (K), slope length factor (L), percent slope (S), cover and management factor (C), and support practice factor (P). The inherent soil erosion potential of a particular geographical area depends on R, K, L and S, while the soil erosion hazard can be assessed if C and P factors are incorporated as well.

Assessment of relative soil erosion potential

The soil erosion potential depends on R, K, L and S. Although the slope length factor L, influences the inherent soil erosion potential of an area, it was ignored for the present study on the basis that L factor is highly localized and it can be accounted only in very detail level planning such as individual farm planning. In a study of this nature, which is aimed at provincial scale planning, incorporation of L factor into the modeling procedure will tend to overestimate the erosion potential. Therefore, only R, K and S factors were considered for the assessment of relative soil erosion potential. The input data that were used to estimate soil erosion potential are as follows.

Rainfall erosivity (R) (J/Sq.m)

Rainfall erosivity map compiled by Wickramasinghe and Premalal (1988) was considered as the base map for rainfall erosivity. The erosivity isohyets and point data of the above map were interpolated using Geographic Information System (GIS) software Arcview, version 3.1, and converted into a grid (cell) database with 250m resolution. Thereafter, the area falling within the Central Province was extracted for the analysis. Figure 1 depicts the distribution of rainfall erosivity within the province.

Erodibility (K)

The erodibility values for soils occurring in the Central Province were gathered from available literature (Bandara, 1991; Zijlstra, 1989). However, for soils of which the erodibility values are not known, reasonable approximations were made considering their relative susceptibility or resistance to soil erosion. The distribution of soils in the Central Province were extracted from the Generalized Soil Map of Sri Lanka (1975) which is shown in figure 2.

Slope percentage (S)

The elevation data for the Central Province were digitized from contour maps published by the Survey Department. Although, the initial contour map was prepared with 100m contour intervals, later it was improved with 20m interval contours, especially in the areas where landscape is relatively subdued. Subsequently, the contour information was interpolated and slope percentages were calculated with 250m resolution, using Arcview GIS software.

Spatial analysis to assess the relative soil erosion potential

Since all the input databases were in the same geographic coordinate system, the grid databases containing rainfall erosivity (R), erodibility (K), and slope percentage (S) were also in the same geographic coordinates. Moreover, the cell size or the resolution was 250m in all three datasets. Hence, the capabilities of ArcView GIS software were utilized to multiply the above three grid databases to generate an intermediate output, which represents the relative potential of soil erosion. However, this intermediate output may not represent the real world situation, hence it was subjected to a field validation. The above intermediate output was then reclassified to show five qualitative classes of potential soil erosion, namely low, moderate, high, very high and extremely high. This model was field checked at number of sample sites. Depending on the field observations, necessary corrections were accommodated and the output depicting soil erosion potential classes was derived (figure 3).

Assessment of soil erosion hazard

In addition to the factors considered for the assessment of soil erosion potential, cover and management factor C, and practice factor P, also play a role in hazard assessment. However, for the present study only C was taken into consideration.

Input data for soil erosion hazard assessment

Soil erosion potential

The generated soil erosion potential map was an input to the hazard assessment.

Land use

The C factor was generated based on the present land use information. Land use maps published by the Survey Department were digitized and updated through field observations. The estimation of C factor was carried out by employing the equation, $C = 0.04 * e^{0.01 * \text{percentage bare soil}}$, a method suggested by Kooiman (1978) for similar climatic situations. The percentage of bare soil under each land use was obtained through visual observation and the values are given in table 1. The figure 4 shows the map of the present land use.

Table 1. Land uses and C-factors

| <i>Land use</i> | <i>% Bare Soil</i> | <i>C_factor</i> | |
|--------------------------------------|----------------------------|-----------------|------|
| Built-up land | 60 | 0.73 | |
| Associated non agricultural land | 75 | 0.85 | |
| Homestead | 15 | 0.46 | |
| Tea | Well managed tea | 20 | 0.49 |
| | Moderately managed tea | 35 | 0.57 |
| | Poorly managed tea | 60 | 0.73 |
| Rubber | 10 | 0.44 | |
| Coconut | 30 | 0.54 | |
| Mixed tree and other perennial crops | Paddy (dry , mid) | 30 | 0.54 |
| | paddy (wet zone) | 40 | 0.60 |
| | Paddy (intermediate zone) | 50 | 0.66 |
| Sparsely used crop land | 60 | 0.73 | |
| Other croplands | 60 | 0.73 | |
| Dense forest | 5 | 0.42 | |
| Open forest | 10 | 0.44 | |
| Forest plantations | 55 | 0.69 | |
| Scrub lands | 40 | 0.60 | |
| Grasslands | 25 | 0.51 | |
| Bare lands | 100 | 1.00 | |

Spatial analysis to assess the relative soil erosion hazard.

Arc View GIS capabilities were utilized to analyze the above two input databases and the product was reclassified into five soil erosion hazard classes, namely low, moderate, high, very high and extremely high. This intermediate product was field checked at number of sample sites and final output depicting soil erosion hazard classes was derived (figure 5), once the necessary corrections were accommodated after field observations.

RESULTS AND DISCUSSION

The potential soil erosion map (figure 3) indicates five potential soil erosion categories, namely low, moderate, high, very high and extremely high. Extents of each category falling under different administrative districts are given in table 2.

All five potential erosion classes occur in Nuwara Eliya district. However, in extents very high and high erosion potential classes dominate over the other three classes. The areas towards the southwestern border of Nuwara Eliya district falls into extremely high soil erosion potential class. Although the area consists of comparatively less erodible Red Yellow Podzolic (RYP) soils, the combination of steep slopes associated with mountainous landscape and erosive rains make this area highly vulnerable to soil erosion. Therefore, any conservation measures adopted should not only be focused towards the reduction of slope gradient or the slope length but also be aimed at maintaining good vegetative cover in order to reduce the impact of rain drops. In contrast, the area surrounding Nuwara Eliya, and Sita Eliya falling into low soil erosion potential class, exhibits low erosion risk. The relatively subdued landscape, very low erosive rains and soils with low erodibility (RYP), accounts for the above. The area between the two extreme levels of potential soil erosion classes (extremely high and low classes which are located towards the south-western border and the south-eastern boarder respectively), shows a gradual gradation in soil erosion risk. Since the soil of the area is predominantly RYP, the gradual change of erosion risk is basically due to the change in rainfall erosivity and the slope of the terrain. Therefore, in soil conservation point of view, need for maintaining a permanent vegetative cover as of natural forest is much more pronounced in the areas towards the southwestern part of the Nuwara Eliya district compared to that of the south-eastern part. In addition, the areas surrounding Haguranketha and Rikillagaskada also fall into the extremely high soil erosion potential class and these areas too demand conservation under a permanent vegetative cover coupled with intensive soil conservation measures.

Table 2. Extents under each potential soil erosion class for each district

| <i>Potential soil erosion</i> | <i>Nuwara Eliya</i> | | <i>Kandy</i> | | <i>Matale</i> | |
|-------------------------------|---------------------|----------|--------------------|----------|--------------------|----------|
| | <i>Extent (ha)</i> | <i>%</i> | <i>Extent (ha)</i> | <i>%</i> | <i>Extent (ha)</i> | <i>%</i> |
| Low | 20,443 | 12 | 29,968 | 16 | 53,148 | 26 |
| Moderate | 35,638 | 21 | 19,127 | 10 | 77,567 | 38 |
| High | 50,513 | 30 | 69,036 | 37 | 57,751 | 29 |
| Very high | 45,470 | 26 | 58,932 | 31 | 13,472 | 7 |
| Extremely high | 18,511 | 11 | 12,097 | 6 | 0 | 0 |
| Total | 170,575 | 100 | 189,160 | 100 | 201938 | 100 |

The areas identified to be under extremely high potential soil erosion class bordering Nuwara Eliya district, extends even up to Kandy district and spreads towards the east of Delthota and Pupuressa. This area predominantly consists of highly erodible Immature Brown Loam (IBL) soils occurring on steeply dissected, hilly and rolling landscape. Moreover, these area experiences very high erosive rains compared to the other areas of the district. Therefore, the combined effects of all the factors affecting the soil erosion potential being ranked very high, this areas becomes highly vulnerable to soil erosion. On the other hand, nearly 16% of land under low erosion potential class in Kandy district is located around Peradeniya, Kadugannawa, Katugastota and surrounds. However, the extents of lands falling into high to extremely high potential erosion classes are more in Kandy district compared to that of Nuwara Eliya district (table 2).

In Matale district, except the extremely high erosion potential class, all the other four erosion classes are found. The mountainous landscape, highly erodible IBL soils and relatively high rainfall erosivity place the Knuckles range in the very high erosion potential class. Although the landscape of Matale district is relatively subdued compared to the other two districts, the lands falling into high to very high potential classes are around 35% of the district total. This indicates that among the three factors considered for the assessment of soil erosion potential, the rainfall erosivity and erodibility of soils play a dominant role over the other factor, land slope, when moving towards the northern part of the province. This observation stresses the need to adopt vegetative/ agronomic soil conservation measures, which would reduce the erosion caused by raindrop impact more than the mechanical measures designed to reduce the slope gradient of the landscape.

The soil erosion potential map represents the risk of erosion or the potential irrespective of the land use. Therefore, this type of information can be utilized for soil conservation policy planning at provincial level. However, soil erosion potential of a particular area can be changed considerably through

changing its land use. Therefore, the usefulness of the soil erosion potential map is limited, as it does not indicate the areas where land use changes are required. Once the erosion potential of a particular area is studied with its present land use, more realistic and more useful soil erosion hazard map can be derived.

Figure 5 depicts the relative soil erosion hazard for the Central Province and it highlights the key areas for implementation of soil conservation programs and also the areas that can be considered for land use changes. The table 2 indicates the extents of lands falling under each soil erosion hazard class in each district. The table indicates that, under the existing land use, lands falling into high to extremely high classes are more in Kandy district compared to the other two. Extents of lands under above classes in Kandy district are 87,750 while in Nuwara Eliya and Matale it is 67,350 ha. and 32,475 ha respectively. This indicates that if land use changes as a measure of conservation are contemplated Kandy district should receive the highest priority over the other two districts.

Extremely high erosion hazard areas

Most of the areas with extremely high soil erosion hazard are around Hanguranketha, and Rikillagaskada as shown in the figure 5. The areas are dominantly under sparsely used annual croplands. Therefore, in terms of soil erosion control, this area should be given the highest priority. Although natural vegetation or an agroforestry system would be the best-suited land use for this area, it is not possible to completely rule out the vegetable cultivation, since it forms the main livelihood of the majority of people. Therefore, vigorous soil conservation measures, both mechanical and agronomic, are necessary for these areas, until such time annual crops are replaced by a land use with permanent vegetative cover. In addition, such areas are scattered around Dolosbage and also towards its south as shown in the figure 5. These areas fall into the extremely high erosion potential class (figure 3). The major land uses in the area include marginal to moderate tea or plantation forest such as pinus. Marginal tea lands should be either diversified or replanted with tea after rehabilitation while pinus plantations should be replaced with a more environmental friendly ecosystem like natural forest.

Very high erosion hazard areas

Most commonly found land uses in this category are moderate to marginal tea, plantation forest (mostly pinus) sparsely used croplands, other croplands or scrubs. In case of marginal tea lands, improvement with vegetatively propagated tea (VP), filling of vacancies, reforestation or diversification with minor export

crops depending on the climatic suitability would significantly minimize the risk of erosion. The lands under sparsely used croplands are mostly grown with annuals and it is advisable to motivate farmers to replace annual crops with permanent type of land uses. The other croplands and scrubs could be left out for reforestation or agroforestry.

High erosion hazard areas

Perennial cropping is the best-suited land use for this class. Since this erosion hazard class is mostly occurring in Nuwara Eliya and Kandy districts, the risk of erosion can be minimized by establishment of well managed tea, export crops or fruit trees, depending on the agro-ecology of the area concerned. However, annual cropping should be practiced only on bench terraces along with other conservation measures.

Moderate soil erosion hazard areas

The areas falling into this class are scattered in all three districts. The area in Nuwara Eliya district is dominantly under well-managed tea, and it can be considered as a suitable land use for the situation. However, instances where vegetables are grown, strict conservation measures would be highly beneficial. In Kandy district, most of the lands under this class are under homesteads or under moderate to marginal tea. The risk of erosion under homesteads can be minimized through improvement of canopy cover with suitable tree crops, along with other soil conservation measures. Marginal tea lands could be rehabilitated and replanted or diversified with agroforestry systems or with minor export crops. If suitable land use changes can be introduced, these lands can be brought under the class of low erosion hazard. In Matale district these lands are mostly under scrub or sparsely used croplands. Conversion of scrub into forest / agro-forestry systems would not only minimize the erosion risk, but also would be more economically viable.

Low erosion hazard areas

Highest extents falling into this class are found to be in Matale district while in Kandy and Nuwarawliya districts such extents are comparable (table 3). In Matale district, the dominant land uses under this class are homesteads, paddy, minor export crops and rubber. Since these land uses impose less soil erosion risk, continuation of such land uses along with soil conservation measures would be the best choice. In Kandy district these lands are predominantly under homesteads and introduction of horticultural crops such as Durian, Avacado and Rambutan

would be highly beneficial. In Nuwara Eliya district, areas falling into this class are predominantly under well-managed tea or forest. Therefore, land use changes are not required. Since the potential erosion is also low in this area (figure 3), annual cropping such as exotic vegetables, potato, floriculture etc. can be grown. Nonetheless, the importance of soil conservation practices should not be undervalued.

Table 3. Extents under each soil erosion hazard class for each district

| <i>Soil erosion hazard</i> | <i>Nuwara Eliya</i> | | <i>Kandy</i> | | <i>Matale</i> | |
|----------------------------|---------------------|------------|--------------------|------------|--------------------|------------|
| | <i>Extent (ha)</i> | <i>%</i> | <i>Extent (ha)</i> | <i>%</i> | <i>Extent (ha)</i> | <i>%</i> |
| Low | 49,610 | 29 | 46,792 | 25 | 94,500 | 47 |
| Moderate | 53,635 | 31 | 54,618 | 29 | 75,929 | 37.4 |
| High | 28,185 | 17 | 36,171 | 19 | 12,450 | 6.2 |
| Very high | 32,890 | 19 | 47,790 | 25 | 18,900 | 9.3 |
| Extremely high | 6,255 | 4 | 3,790 | 2 | 160 | 0.1 |
| Total | 170,575 | 100 | 189,161 | 100 | 201,939 | 100 |

CONCLUSION

Interpretation of available basic geographical data and generation of information, conversion of them into unique geographical units or classes can be performed with the GIS technology, in relatively shorter time periods than of conventional manual methods. Identification of such spatial units with unique characteristics would be highly useful for agricultural planning and development activities.

The soil erosion potential map indicates the spatial distribution of relative and inherent potential of land for soil erosion within the Central Province. This map can be used for regional scale agricultural planning but its use in detail level planning is limited. The information provided therein can be utilized for prioritization of conservation efforts within the province, and would be helpful for agricultural policy planning purposes.

The soil erosion hazard indicates the effect of present land use on soil erosion potential. This highlights the areas to be prioritized in the conservation efforts under the present land use and the areas that land use changes or improvements are required. It appears that the present land uses in Nuwara Eliya and Matale districts are more stable compared to that of Kandy district. Therefore, in any interventions on land use changes, Kandy district should receive very high priority.

With the view to combat soil erosion in areas with extremely high and very high potential classes, it very important to do away with annual cropping. However, this will become a Herculean task unless and until more economically viable, socially acceptable perennial crop based land use systems are introduced for these areas. Therefore, research into developing and testing of suitable crop and land management technologies for above critical areas is a high priority.

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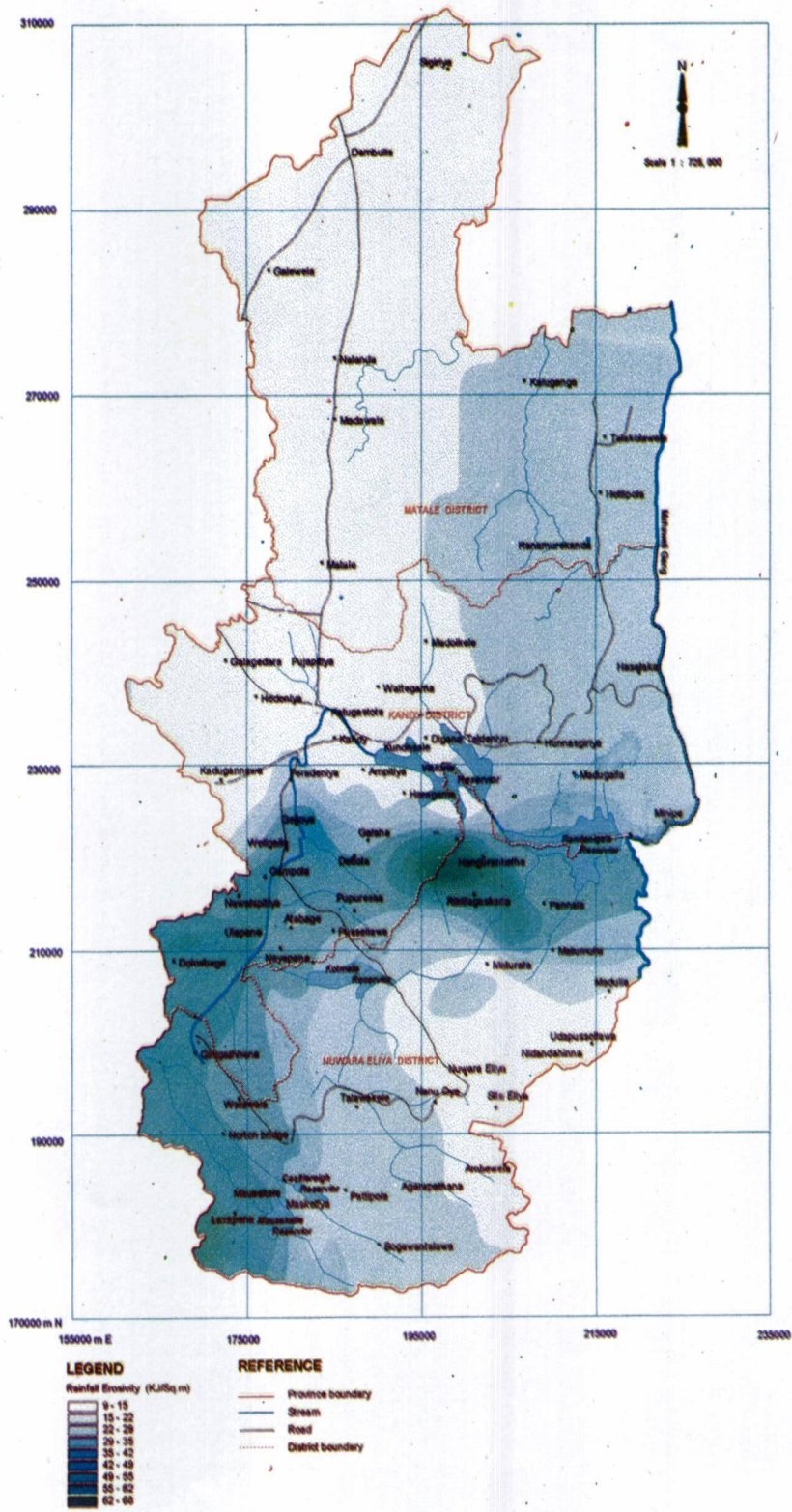


Figure 1. Rainfall Erosivity - Central Province

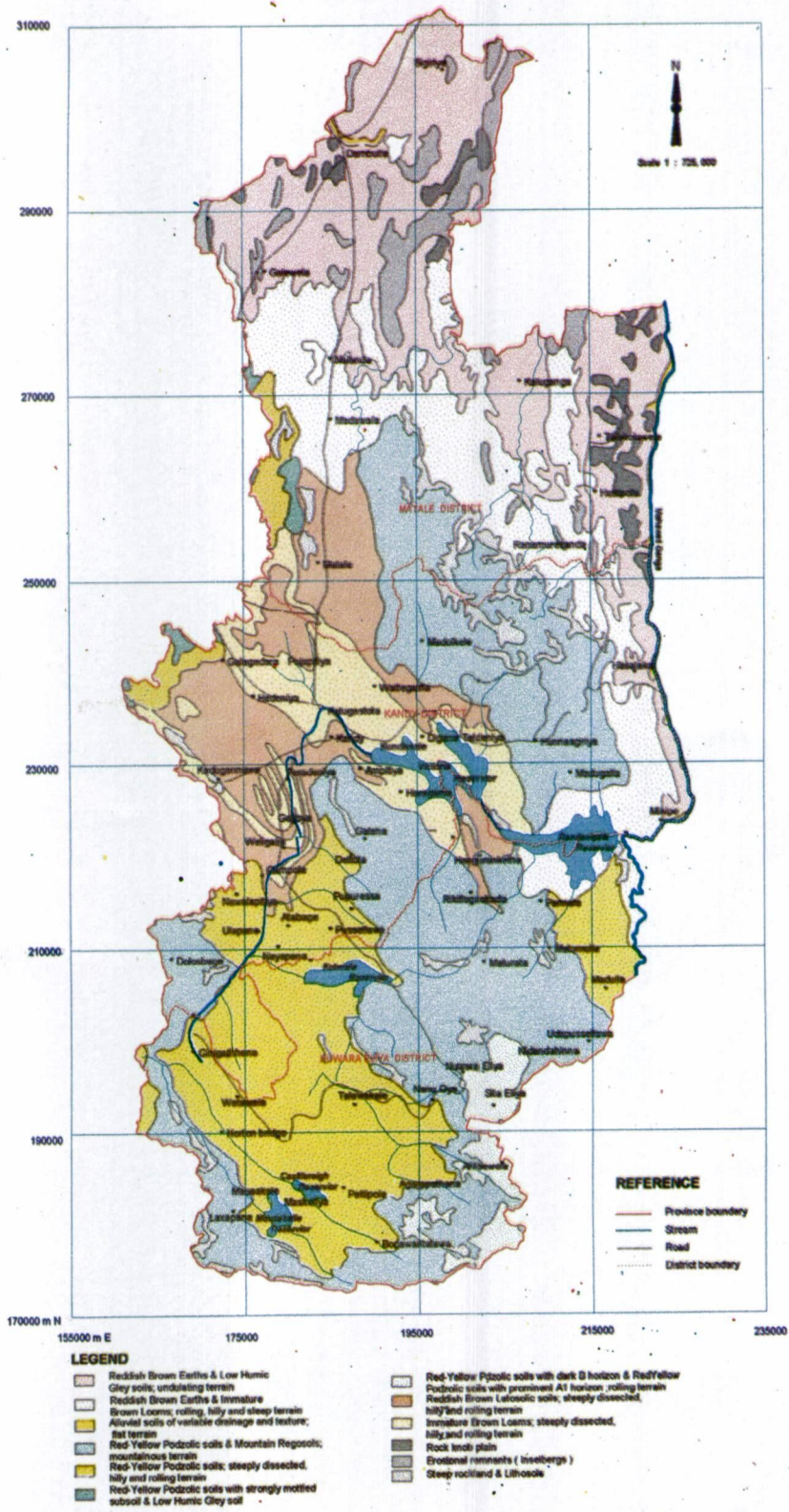


Figure 2. Distribution of soils - Central Province

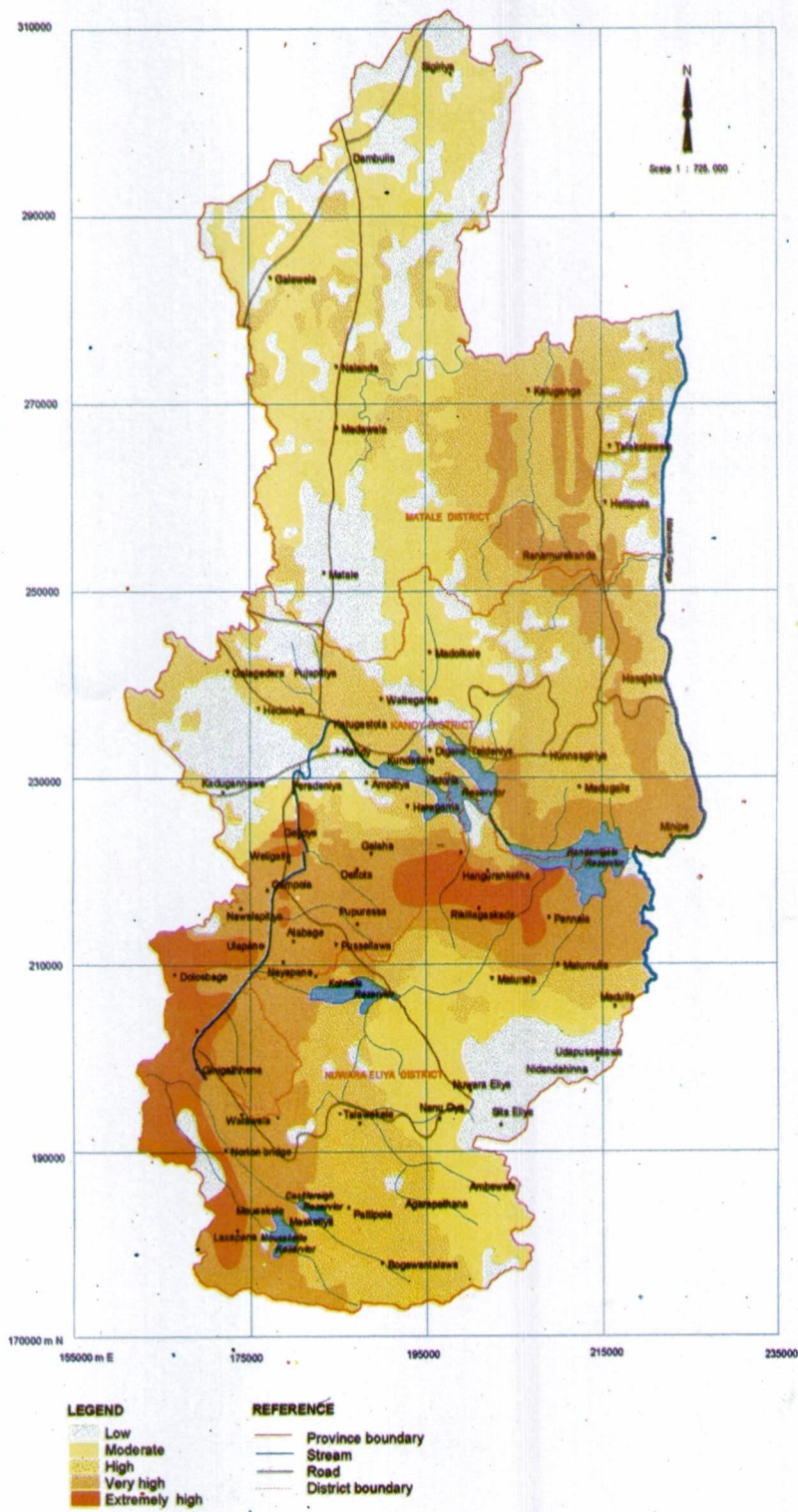


Figure 3. Soil erosion potential - Central Province

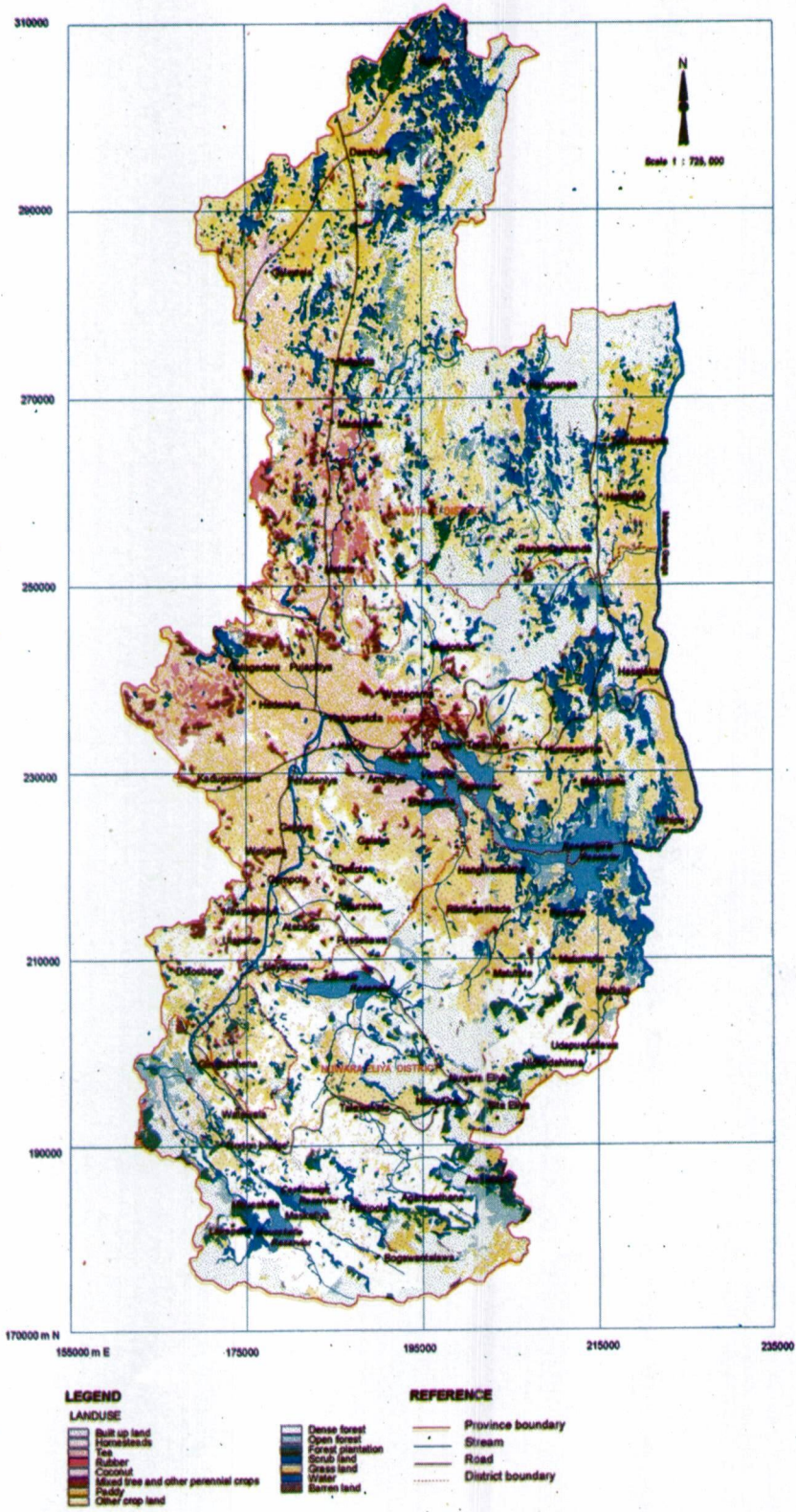


Figure 4. Present land use - Central Province

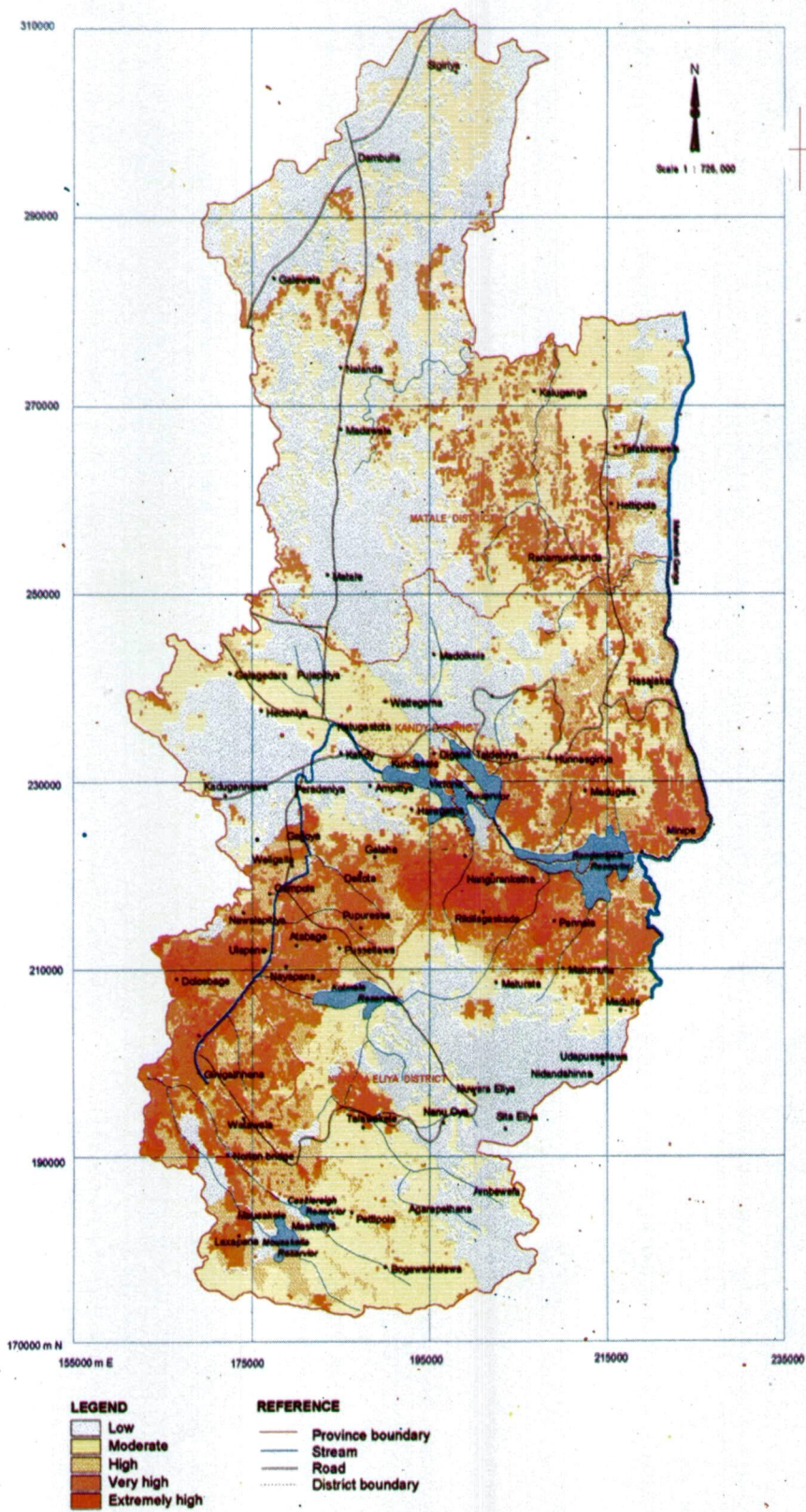


Figure 5. Soil erosion hazard - Central Province