Tropical Agricultural Research Vol. 13: 165-176 (2001)

Key Issues and Recommendations Related to Field Data Collection in Soil Erosion Assessment Using GIS

G.R.N. Karunatilaka and N.T.S. Wijesekera

Department of Civil Engineering
University of Moratuwa
Moratuwa, Sri Lanka

ABSTRACT. Erosion of soil by wind and water has been a problem ever since land was first cultivated, because erosion results in loss of productivity of soils, necessitating the use of fertilizer to maintain yields. Another problem of soil erosion is the increase of sediment in rivers, watercourses and reservoirs creating water quality problems. Due to the critical nature of soil erosion, it is of great importance to identify the critical zones of soil erosion and introduce prevention or management measures. The commonly used equation for soil erosion estimates is the Universal Soil Loss Equation (USLE). However, the factors in this equation require field validation prior to their application for a particular region. Therefore, the estimation of factors of USLE should be based on field assessments, which require systematic approaches. A systematic field survey is used to identify the erosion, soil texture slope and land-use, highlighting the key issues that need to be considered in the process of data collection. The collected field data were plotted using the ARC/INFO software and the statistics pertaining to the spatial distribution of erosion, land cover and slope classes were identified.

INTRODUCTION

Soil erosion has been one of the major problems faced by mankind. Farmers, agriculturists, watershed managers *etc.*, treat soil erosion control or soil conservation as a top priority. This is because soil erosion removes the porous topsoil that is rich in nutrients and capable of storing rainwater. Erosion of soil by wind and water has been a problem ever since land was first cultivated. Soil erosion is extremely important in agricultural land where the reduction of soil within a field, the breakdown of soil structure, and the decline in organic matter and nutrients result in a reduction in the cultivable soil depth and decline in soil fertility. Accordingly, erosion results in loss of productivity of soils, necessitating the use of fertilizer to maintain yields. Another problem of soil erosion is the increase of sediments in rivers, watercourses and reservoirs creating water quality problems. Eroded soil is the largest pollutant of surface waters in most of the countries. The denuded lands in the upper Mahaweli watershed poses a threat to the capacity of the major multipurpose reservoirs in Sri Lanka. The sediment yield at Polgolla in the upper Mahaweli watershed has been estimated between 3.5-4.0 t/ha/year (Peter, 1995). There are many problems associated with sediment deposition. Eroded soils reduce the capacity of rivers and lakes causing flood and also navigation problems. Erosion in irrigation canals leads to reduced canal capacities and command areas, shortened design life of structures and reservoirs *etc.*

Human activities have increased the rate of erosion over the natural rate of soil erosion, which is about 0.1 tons/acre/year (0.224 t/ha/year). Accelerated erosion rates caused by human activities can be more than 100 times in excess of the natural or geologic erosion rate. Erosion rates of over-grazed areas can exceed 5 tons/acre/year (11.2 t/ha/year) and average value of 40-50 tons/acre/year (89-112 t/ha/year) can reasonably be expected during urban development when the soil is not vegetated and constantly reworked (Shen and Julien, 1993).

Due to the serious environmental problems associated with soil erosion, it is very important to identify the critical zones of soil erosion and provide prevention or management measures. The assessment of critical erosion zones requires estimation of parameters such as soil, rain, terrain vegetation *etc.* The commonly used equation for soil erosion estimates is the Universal Soil Loss Equation (USLE). However, the factors in this equation requires field validation prior to their application for a particular region. This study was carried out for a relatively small area and this paper describes the key issues, methodology and recommendations for the process of field data collection.

Parameters

The USLE has been developed to predict long-term average soil losses due to runoff from small fields under specified cropping and management systems. The USLE is based on the findings that soil erosion losses depend on soil erodibility, slope length and degree of slope, maximum 30 min amount of rainfall and land cover factor. Therefore, field data collection requires evaluation of soil type, land cover, terrain slope and the level of erosion in various zones. Studies done for Sri Lankan conditions have shown that the maximum 30 min rainfall can be well approximated by a regression relationship of mean annual rainfall (Gunawardena, 1995).

Field assessment techniques

In general, field assessment techniques of agricultural lands had been based on the land capability classifications. Land capability classification was developed by United States Soil Conservation Service as a method of assessing the extent to which limitations such as erosion risk, soil depth, wetness and climate hinder the agricultural use that can be made of the land. Land capability units are identified and classified in to 8 classes arranged from very slight risk of damage to very rough land unsuitable even for woodlands. Erosion surveys done based on these systems have been reported by Morgan (1995) who conducted soil erosion surveys using a 0.5 × 0.5 km grid-based technique. Morgan (1995) also describes a geomorphologic mapping system to gain an understanding of the dynamics of erosion. He has also identified the distribution and type of erosion, erosivity, runoff, slope-length, slope-steepness, slope-curvature, soil type and land use. The need for soil erosion estimates to be compared with additional field data has been highlighted. A coding system to appraise soil erosion in the field mentioned in the same work (Table 1) considers the exposure of tree roots, surface crusting, splash pedestals, soil moulds, gullies, rills, blow outs and dunes bare soil *etc.*

Stocking and Elwell (1973) used a similar method for rating erosion risk. They have used factorial scoring system for rating erosion risk for Zimbabwe. Taking a 1:1,000.000 base map, the country is divided on a grid system into units of 184 km^2. Each unit is rated on a scale from 1 to 5 in respect of erodibility, erosivity, slope, ground cover and human occupation, the latter taking account of the density and the type of settlement. The scoring is arranged so that 1 is associated with a low risk of erosion and 5 with a high risk. The five factor scores and summed to give a total score, which is compared with an arbitrarily chosen classification system to categorize area of low, moderate and high erosion risk. The scores are mapped and area of similar risks delineated.

Table 1. Coding system for soil erosion appraisal in the field.

Code	Indicators
0	No exposure of tree roots; no surface crusting; no splash pedestals; over 70% plant cover (ground and canopy)
½	Slight exposure of tree roots; slight crusting of the surface; no splash pedestals; soil level slightly higher on upslope or windward sides of plants and boulders; 30-70% plant cover
1	Exposure of tree roots, formation of splash pedestals, soil mounds protected by vegetation, all to depths of 1-10 mm; slight surface crusting; 30-70% plant cover
2	Tree root exposure, splash pedestals and soil mounds to depth of 1-5 cm; crusting of the surface; 30-70% plant cover
3	Tree root exposure, splash pedestals and soil mounds to depth of 5-10 cm; 2-5 mm thickness of surface crust; grass muddied by wash and turned downslope; spays of coarse material due to wash and wind; less than 30% plant cover
4	Tree root exposure, splash pedestals and soil mounds to depths of 5-10 cm; splays of coarse material; rills up to 8 cm deep; bare soil
5	Gullies; rills over 8 cm deep; blowouts and dunes; bare soil.

Other than those methods most common method of field assessment is remote sensing. Example of such studies are Development of Soil Erosion Maps of the Upper Klang Valley, Malaysia (Fook *et al.*, 1992), Erosion Response Model in Bajaj Sagar sub catchment (http://www.gisdevelopment.net/application/water_resources/watershed/watws0002.htm), Micro-Watershed Development plans in Shetrunji River Basin Gujarat, India (http://www.gisdevelopment.net/application/water_resources/watershed/watws0001.htm), Soil Erosion Model in Techi Reservoir, Taiwan (Chao-Hsien and Ju-Hui, 1999), *etc.* Although much information can be obtained from areal photographs, this needs to be verified and supplemented by additional data collection in the field.

Data collection methods

Field data collection for soil erosion assessment needs systematic approaches. Such surveys could be done either grid based, cluster based or based on existing roads or footpaths. The grid-based system divides the entire area into grids and this has been used to assess parameters using areal photos. These photos needs to be verified by additional data collected in the field, using cluster based or footpath methods. The cluster-based method could be to cluster a group region of similar character and then to pick up individual parameters or erosion classes corresponding to each of them. In rough or difficult terrain, instead of the grid-based system, a network of footpaths, roads could be utilized to construct a network covering the entire area to be surveyed. Field surveys could be easily done by the use of precoding for each parameter.

MATERIALS AND METHODS

Study location

Field assessment of physical watershed parameters was done in an area of approximately 25 ha located in Katubedda, Moratuwa (Fig. 1). The difference in elevation in the selected area is about 76 feet (23 m). Slope changes from flat areas to slopes with gradients reaching 40%. When considering last ten years, average annual rainfall in this area is 2485 mm. Land cover changes from built-up areas, playgrounds to reserved forest patches. Soil in the area is basically of one kind. This soil is well-drained, reddish to yellowish in colour, moderately fine textured, strongly acidic and classified as Red Yellow Podzolic according to Moormann and Panabokke (1961).

Pre-coding of parameters

In the present study, field survey was done using cluster based method to identify and verify erosion, soil texture, slope and land-use. Erosion classes used in this survey were chosen similar to that of Morgan (1995) (Table 2). The method of assessment described by Morgon (1995) was difficult without a specific description of erosion levels and hence a coding leading to a quantitative assessment was used. This quantitative scheme was prepared using details about depth of exposure of tree roots, depth of gullies or channels, exposure of sub soil *etc.* This coding is based on pilot studies done to the selected area using personnel who has experience in the above subject and observations and experiences from typical watersheds. Slopes in the area were classified into six classes as practised by Sheng (1972) and recommended in Morgon (1995) for hilly lands in the tropics (Table 3). Soil texture was taken to vary between seven classes as indicated in Table 4. An initial reconnaissance survey was done and six land use classes were identified (Table 5).

Table 2. Erosion classification for field survey.

Codes	Coding by Morgan (1995)	Present study (Field survey)
1	No apparent, or slight erosion	No erosion is visible
2	Moderate erosion: moderate loss of topsoil generally and/or marked dissection by run-off channels or gullies	No gully formation or no exposure of plant roots. Soil loss is less than 5 cm in depth
3	Severe erosion, severe loss of top soil generally and/or marked dissection by run-off channels or gullies	Loss of topsoil is clearly visible and the loss is less than 25 cm, gullies or runoff channels visible
4	Very severe erosion: complete truncation of the soil profile and exposure of the subsoil and/or deep and intricate dissection by run-off channels or gullies	Exposure of subsoil, deep channels or gullies. Loss of soil is greater than 25 cm

Table 3. Slope classification.

Code	Slope type	Description
1	Gentle sloping	< 7°
2	Moderate sloping	7° - 15°
3	Strongly sloping	15° - 20°
4	Very strongly sloping	> 20°

Table 4. Classification of soil.

Code	Texture	Description
1	Sand	More than 85% sand
2	Loamy sand	80-85% sand
3	Sandy loam	Less than 35% clay 50-80% sand
4	Clay loam	Less than 30% clay less than 50% sand.
5	Sandy loam	More than 30% clay 50-70% sand
6	Clay	30-50% clay less than 50% sand
7	Heavy clay	More than 50% clay

Table 5. Land-use classification.

Code	Land-use
1	Buildings
2	Forest
3	Scrub cover
4	Garden
5	Bare space
6	Grass land
7	Paved (roads)

Field data collection

The Performa for recording soil erosion in the field devised by Baker (Morgan 1995) was chosen and modified to suit the needs of the study. The modified Table includes only the land cover, slope, soil type and the level of erosion. Temperature and rainfall were not considered due to the small size of the area, where a considerable change of values were not found compared with that of the region. Erodibility and permeability were also not included in the field sheets since such values could not be collected during the surveys. Modified field sheets were tested on a pilot area using personnel who were experienced and conversant in the coded parameters. Initially, an attempt was made to carry out a grid based system where the selected grid size was 1000×1600 ft. The pilot testing showed that literature values were not directly applicable to this area. The grid based system though applicable to areal photographs posed problems in indicating different land uses, slope classes and erosion zones on ground surveys. The main reason was the use of a field sheet and a map, as two units caused difficulties in cross-referencing. The other reason was the difficulty in moving along the ground on a grid system to collect information.

As a modification a pilot area testing was attempted on a cluster base instead of grids but still the field data sheet proved to be inconvenient, because it is time consuming to mark the exact location in the field sheet and using the map and field sheet together causes difficulties in cross referencing. Field area survey was divided into clusters using footpaths and roads and the recording of physical parameters and descriptions was done on the map of the area. This proved faster and more realistic since the map provided easy readable checking of locations, reliability of some parameters and quick identification of locations. The field survey of study area had a single soil type and the variation over the area was very little. Land cover could be easily identified and the slope could be easily verified using clusters. Four erosion classes were identified according to the extent of erosion. This classification was done using a quantification scheme given in Table 2. The collected data was digitizes using GIS ARC/INFO software. Identified field erosion levels, contours, slope classes and land use maps were produced by exporting this data to ARC/VIEW. Those maps can be used to establish data for erosion level assessment modeling, their calibration and verification.

The contours (Fig. 1), identified field erosion levels (Table 6, Fig. 2) and land-cover (Table 7, Fig. 3) show a clear picture of the present situation of the study area. The erosion map predicts not only the nature of erosion but also the location of erosion. The field survey enabled the rectification of the contour map of the study area, prepared in 1987. Since the available land cover map was, 1:1,200 field data were invaluable to obtain land cover in greater detail. The slope classes based on the field observations are in Fig. 4 and Table 8.

RESULTS AND DISCUSSION

Field identification of parameters for soil erosion assessment needs prior coding of classification groups for easy recording. Absence of such grouping cause difficulties in large area coverage, consumes significant time for recording, and hampers the uniformity in assessments. Though such classification could be guided by the available literature, they need to be verified using pilot tests done prior to use for full-scale surveys.

In rough and undulating or hilly terrain, a cluster-based recording of parameters on a map of the study area was shown to be the best way of recording. Such map-based recording provides better positioning, cross-referencing and also whether identification of some parameters/features was rationally done. Though Tables or data sheets have been customarily used for field data collection, this study showed that a map based data collection system is the best-suited method for identification of spatial variation for mapping.

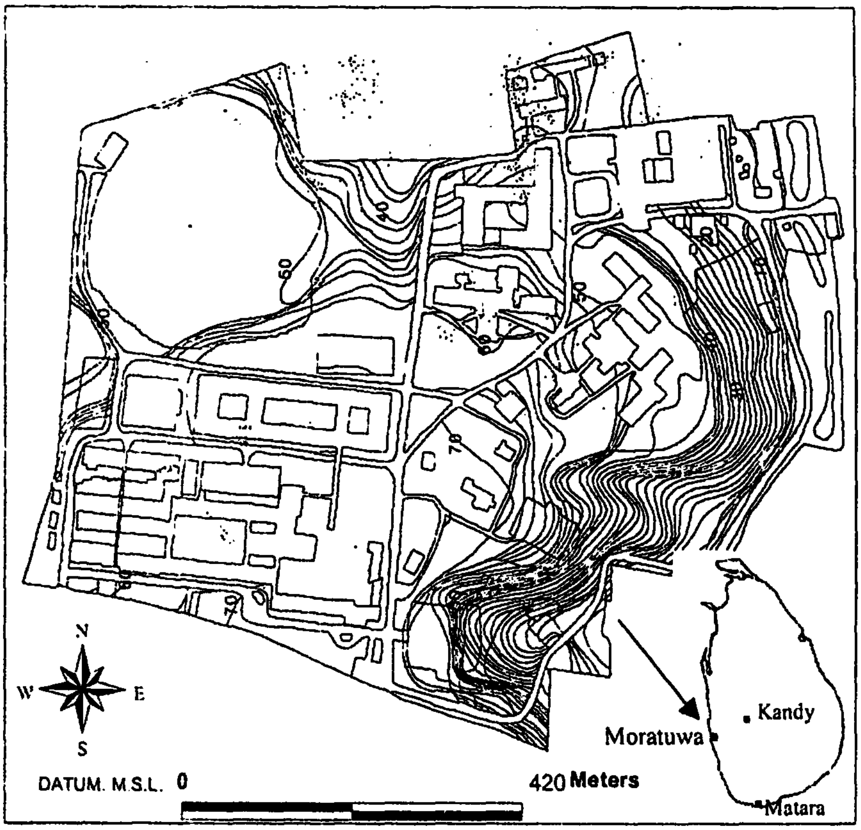

Fig. 1. Study area location and contour map.

Table 6. Statistics of the erosion level of the study area.

Erosion level	% Area	Area (m^2)
1. No apparent erosion	39.15	97875
2. Moderate erosion	58.29	145725
3. Severe erosion	1.70	4250
4. Very severe erosion	0.86	2150

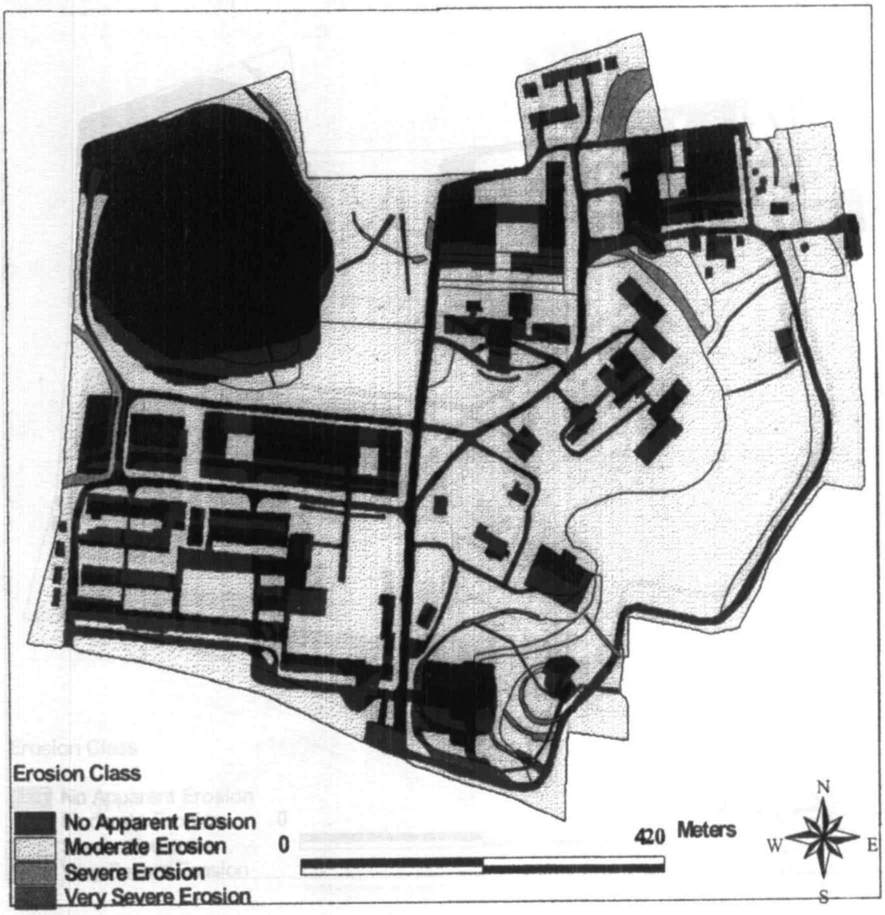

Fig. 2. Field observed erosion levels.

Table 7. Statistics of the land cover of the study area.

Cover type	% Area	Area (m^2)
1. Buildings	17.54	43850
2. Forests	11.73	29325
3. Scrub cover	5.23	13075
4. Garden	42.20	105500
5. Bare space	1.43	3575
6. Grassed	13.36	33400
7. Paved (roads)	8.51	21275

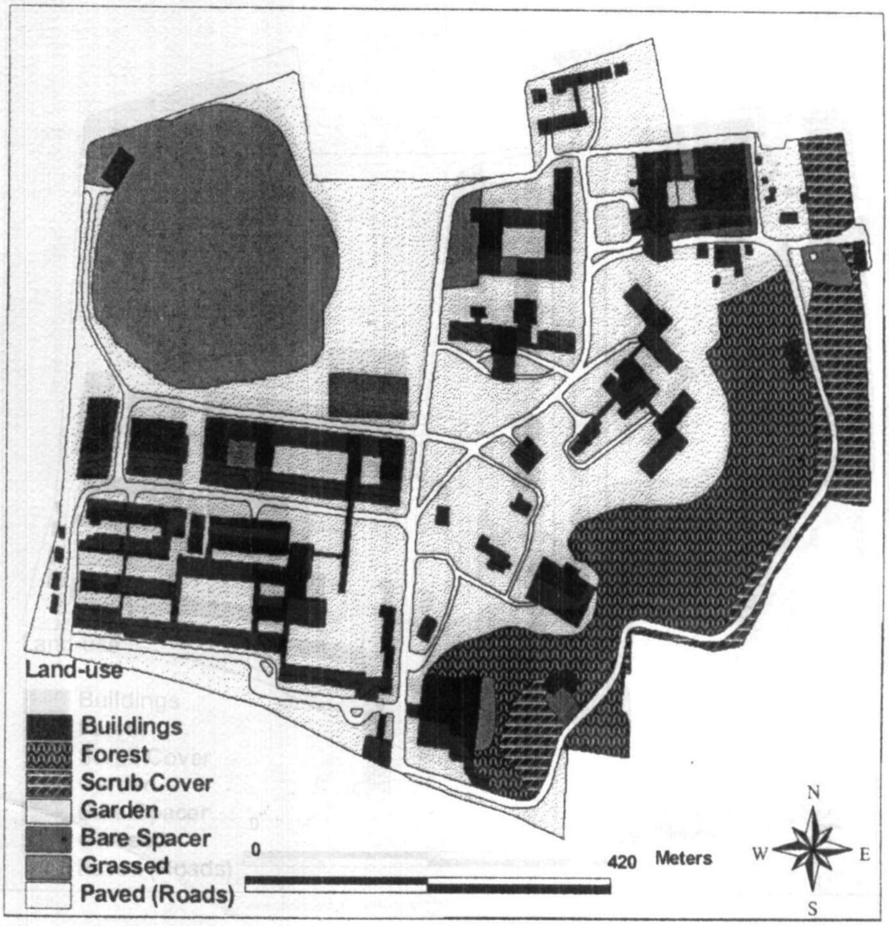

Fig. 3. Land cover classes of the study area.

Soil erosion assessment in field required quantitatively identifying the difference between erosion classes. In this study the following classes were found as adequately representative. A depth of less than 5 cm of soil removal for Class 2, at least 25 cm of earth removed for Class 3 and a loss of soil more than to a depth of 25 cm, roots and gullies clearly formed for Class 4 showed as quite satisfactory. This was different from the literature-identified groups both in the number of groups and in the quantification aspect. The quantification helped averaging of erosion level over spatial extents.

Study area had no apparent erosion in built-up areas where the slopes were mild and drains were provided. The forest and scrub cover areas showed moderate erosion, while a few isolated segments showed to have undergone severe erosion and gully formation. Very severe erosion zone covered approximately 1% of the extent, which was half of the extent with moderate erosion. The map of erosion classes indicated that though the percentage of severe and very severe extents were quite small, those regions were concentrated in the strongly sloping area in the south western region of study area.

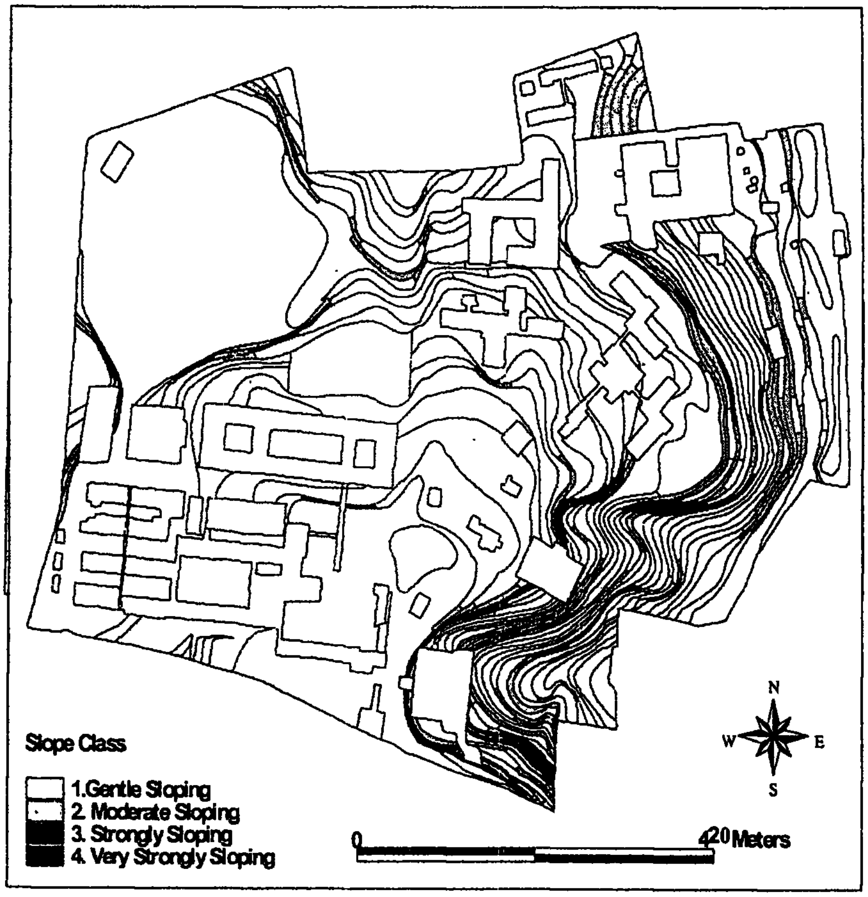

Fig. 4. Slope class classification.

Table 8. Statistics of the slope classes of the study area.

Slope classes	% Area	Area (m^2)
1. Gentle sloping	92.28	230700
2. Moderate sloping	5.13	12825
3. Strongly sloping	2.40	6000
4. Very strongly sloping	0.19	475

Land cover classes, and slope classes are needed for the model calibration and the spatial distribution of erosion levels are required for model verification. The field survey conducted for the purpose of data collection for modeling (Table 7, 8 and 9) enabled identification of spatial distributions. These data can be effectively used to establish a suitable model to predict critical zones for soil conservation.

Published literature does not indicate practical examples of field data collection in small-scale areas except for large plot-based studies. In this context the final coding and the parameters to be identified on a map based field sheets could prove invaluable in ensuring fast and uniform data collection for GIS databases.

CONCLUSIONS

Map based recording of parameters was found as the best identification system for the spatial variation mapping of land cover, soil, landscape and erosion level since the map provided easy readable checking of locations, reliability of some parameters and quick identification of locations. When considering the field sheet it is time consuming marking the exact location of details and using the map and field sheet together causes difficulties in cross-referencing.

The study identified a quantification scheme for precoding of parameters, which is a very important aspect of field data collection. Such a quantification scheme has been used in most of similar researches but preparation of the most suitable quantification scheme relevant to a particular area offers correct and easy recording ability.

Other than the values available in published literature, pilot testing of the study area and representative watersheds is also of great importance for the precoding of parameters. Suitability of these parameters to a particular area cannot be identified if such pilot testing is not carried out.

The maps produced through an efficient and rational field data collection enables the establishment of data for erosion level assessment modeling, their calibration and verification.

ACKNOWLEDGEMENTS

This work was done as part of the work envisaged under a research grant of the University of Moratuwa. The authors are thankful to the Department of Civil Engineering for the support and assistance provided for this work.

REFERENCES

Chao-Hsien, Y. and Ju-Hui, L. (1999). The Study of Integrated Model of GIS and Multiple Criteria Decision Making for Watershed Management, Geoinformatics and Socioinformatics, Proceed. Geomatics '99 Conference, The Association of Chinese Professional in GIS.

Fook, L.K., Bolhassan, J. and Armstrong, C.L. (1992). Soil Erosion Mapping Using Remote Sensing and GIS Techniques for Land-use Planners, Asian Pacific Remote Sensing Journal, Vol. 5.

Gunawardena, E.R.N. (1995). Importance of Natural Forests in Sri Lanka for Soil Conservation and Hydrology, Department of Forestry, Sri Lanka.

Moormann, F.R. and Panabokke, C.R. (1961). Soils of Ceylon, Tropical Agriculturist, Vol. CXVII.

Morgan, R.P.C. (1995). Erosion Hazard Assessment, Soil Erosion and Conservation, Longman Group Limited, United Kingdom.

Peter, B. (1995). Sedimentation Study of Upper Mahaweli Catchment Sri Lanka, Wallingford HR, Report EX 3201.

Shen, H.W. and Julien, P.Y. (1993). Erosion and Sediment Transport, Handbook of Hydrology, Mc. Grow-Hill, Inc., USA.

Sheng, T.C. (1972). A treatment-oriented land capability classification scheme for hilly marginal lands in the humid tropics. J. Scientific Res. Council Jamaica. 3: 93-112.

Stocking, M.A. and Elwell, H.A. (1973). Soil Erosion Hazard in Rhodesia. Rhodesian Agric. J. 70: 26-35.