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People's perception and socioeconomic determinants of soil erosion: A case study of Samanalawewa watershed, Sri Lanka

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Abstract

Though soil erosion is an important concern in Sri Lanka, there is a dearth of baseline information on soil erosion in many of its watersheds, which obstructs monitoring of soil erosion and mitigating its effects. In order to assess soil erosion in a critical watershed and to identify its determinants, the Samanalawewa watershed, which contains one of the main hydropower generating reservoirs in Sri Lanka, was selected for this study. Remote-sensing (RS) and geographic information system (GIS) based modeling as well as field experiments were employed to assess and map soil erosion rates. Results indicated that the current rate of soil erosion ranges from 0 to 289 t/ha/yr, and that the average rate of soil erosion has been declining from 20 to 4 t/ha/yr over a period from 1986 to 2008. The current rate of soil erosion is, however, still about 14 to 33 times greater than the natural soil generation rate. Socioeconomic factors and peoples' perception of soil erosion and soil conservation measures were examined using data collected through a household survey. Multiple regression analysis with eighteen covariates of socioeconomic characteristics yielded eleven socioeconomic variables, viz. household size, farm labor, education, land tenure, conservation cost, training, committee membership, professional competencies, income, distance, and financial capital as the predictor variables of soil erosion. Farmers identified improper soil and crop management practices as the major causes of erosion. The adoption of conservation measures, their effectiveness, and their impact on ecosystem services were also examined.

Key Words: Soil erosion, People perception, Determinants of soil erosion, Conservation measures, Sri Lanka

1 Introduction

Soil erosion is a complex process that involves the detachment, movement and deposition of soil particles mainly by wind and water. It can be accelerated by human activities such as removal of vegetation, rangeland grazing, urbanization, and forest fires, but also by natural conditions, viz. topography (slope angle and slope length) and soil properties (texture, structure, moisture, roughness, and organic matter) (Lal, 2001; Sui et al., 2009). Soil erosion in watershed areas and the subsequent deposition of sediment in the water bodies are of great concern mainly because of the loss of rich fertile soil from watershed areas, the reduction in reservoir capacity, the deterioration of downstream water

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quality (European Environment Agency, 1995) as well as the eutrophication of surface water bodies, and the loss of aquatic biodiversity (Onyando et al., 2005).

Land is the most vital and heavily threatened natural resource in Sri Lanka. Land degradation due to soil erosion is of concern mainly because of its consequences for agriculture (MoFE, 2001). Continued soil erosion seriously affects peoples' livelihood in most watersheds of the country.

The assessment and prediction of soil erosion has been a challenge for a long time, and several soil erosion models have been developed since the 1930s (Lal, 2001). These models can be categorized as empirical, semi-empirical and physical processed-based models. Presently, the Universal Soil Loss Equation (USLE) by Wischmeier and Smith (1965), and the Revised Universal Soil Loss Equation (RUSLE) by Renard et al. (1991) are the most widely used soil erosion models.

The study area, Samanalawewa watershed, can be considered as a particularly significant watershed in Sri Lanka because it contains one of the most important hydropower generating reservoirs of the country, the Samanalawewa reservoir. This reservoir has been created by damming the Walawe river at a confluence with its tributary, the Belihul Oya, at an elevation of 400 m mean sea level (MSL). Most of the paddy farmers in the downstream area depend exclusively on this reservoir for their irrigation water. However, despite the fact that substantial land use change has occurred in this watershed as in many others, no soil erosion related study has been carried out in this area since 1986. Lack of recent data limits the application of some empirical and process-based models. Another limitation is that most soil erosion studies do not take into account socioeconomic factors of soil erosion. Hence, this study aims to assess both the status and people's perception of soil erosion, and to identify socioeconomic determinants of soil erosion.

2 Samanalawewa watershed

The study area, Samanalawewa watershed, is situated in the Ratnapura District of Sri Lanka between 80.58^o to 80.92^o east longitudes and 6.56^o to 6.80^o north latitudes and covers an area of about 536 km^2 (Fig. 1). The upper part of the Samanalawewa watershed is situated on the south-facing slope of the rise towards Horton Plains and Peak Wilderness in the Nuwara-Eliya Divisional Secretariat Division (DSD)[1] of the Nuwara-Eliya District. The lower part, which includes the Samanalawewa Hydroelectric Reservoir, covers 897 ha within the DSD of Imbulpe and Balangoda. The Hydro Power Station is situated in the Weligepola DSD and produces 60 to 120 MW, which is about 10 percent of country's total hydroelectricity generation (TEAMS, 1992; CEB, 2006). The watershed is inhabited by about 86,954 people (Dept. of Census and Statistics, 2008). However, due to varying terrain and soil conditions, the population is not distributed evenly within the watershed.

The mean annual rainfall in the study area varies from 900 to 3,175 mm, thus making this watershed extending in seven agro-ecological regions, viz. WU_1,WU_2, WU_3, IU_2, IU_3,WM_3 and IM_2 (W-Wet, I-Intermediate, U-Upcountry, M-Mid country; $_1$, $_2$ and $_3$ are ranking orders determined by the amount of rainfall) (TEAMS, 1992). Different soil groups are found in the different agro-ecological zones. Red Yellow Podzolic soils and Mountain Regosols are the dominant soil groups in WU_1, WU_2, WU_3, IU_2 and $IU_{3,}$ Brown Latosols, Red Yellow Podzols, and immature Brown loams dominate in WM_3, Reddish Brown earth and immature loams are dominant in $IM_{2.}$

The land use data of the study area has not been updated since 1992. According to the past land use classification, land uses have been grouped into six major categories viz. Intensive agriculture (28.3%), forest plantations (5.3%), natural forests (26%), grass lands (29.9%), built-up areas (7.8%) and water bodies (2.7%).

3 Materials and methods

Data were collected from a variety of sources in both digital and analog formats as well as from field experiments, and from a household questionnaire survey. The basic data used were:

- Two ALOS Remotes sensing images (sensor: AVNIR-2, resolution: 12 m spatial; acquisition date: 25 February, 2008).
- Digital elevation data (1:10,000).

[1] DSDs are administrative subdivision of a District.

• Data obtained from field experiments to detect minimum and maximum soil erosion rates (mm/yr) at 30° slopes.

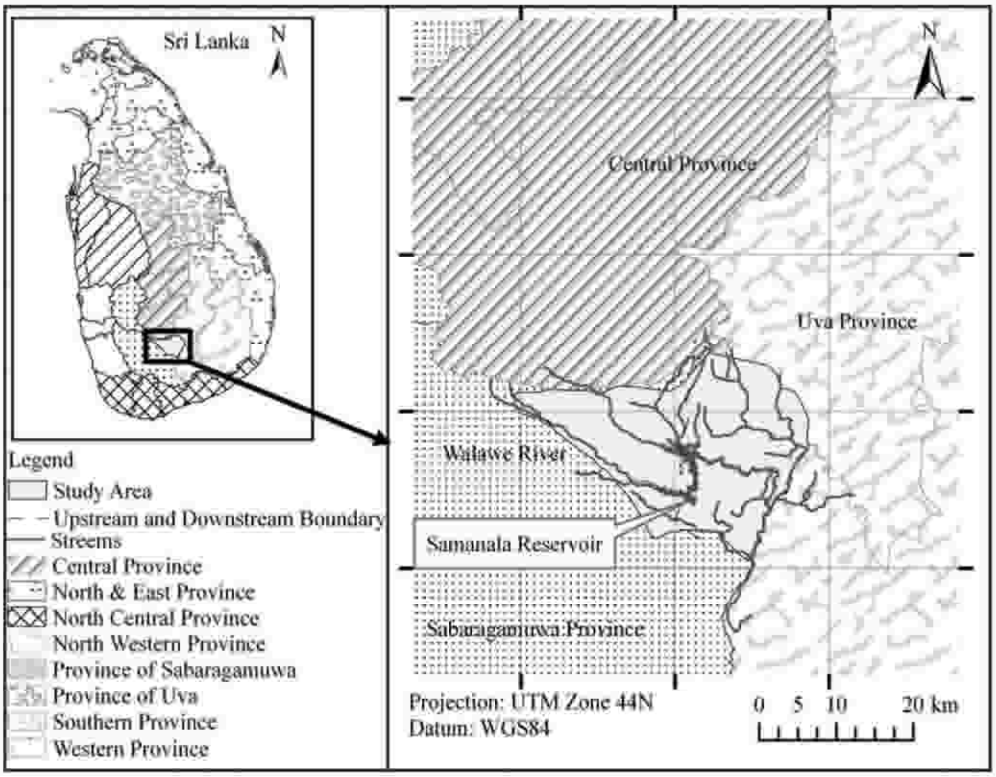

Fig. 1 Map of the study area

• Information from the household questionnaire survey.

• Tabular data taken from the Divisional Secretariat Divisions, the Department of Census and Statistics, Sri Lanka, and from various reference materials.

3.1 Assessment of soil erosion

Due to limited availability of data, the empirical soil erosion model in Eq. 1 (Honda, 1993) was employed to assess the annual rate of soil erosion in the study area. The model has been applied before with satisfactory results in regions with climatic and/or geomorphological conditions that are very roughly similar to the study area such as the Ashio region of Japan (Honda, 1993), the Siwaliks in Nepal (Honda et al., 1996), and mountainous Northern Thailand (Hazarika and Honda, 2001). The strength of the model is that it is not data intensive and thus very useful in an area like the Samanalawewa watershed, where data is scarce. In terms of model performance, Honda et al. (1996) reported that this model has produced results similar in quality to those produced by extensive field work.

The model is mainly governed by slope gradient, vegetation index, and maximum and minimum rates of soil erosion at 30° slopes. The annual rate of soil erosion (E) is given by:

$$E = E_{30}(S/S_{30})^{0.9} \tag{1}$$

where: E = annual rate of soil erosion (mm/yr), E_{30} = rate of soil erosion at 30° slope (defined as below), S =gradient of the point under consideration and S_{30} = tan (30°).

$$E_{30} = Exp\left[\left(\frac{Log(\text{min soil loss}) - Log(\text{max soil loss})}{NDVI_{\max} - NDVI_{\min}}\right)\times\left(NDVI - NDVI_{\min}\right) + Log(\text{max soil loss})\right] \tag{2}$$

where: $NDVI$ = Normalized Difference Vegetation Index of the point under consideration, $NDVI_{max}$ and $NDVI_{min}$ = maximum and minimum $NDVI$ values of the study area. Min. and Max. soil loss = maximum and minimum soil erosion rates (mm/yr) at 30^o slopes of the study area.

In order to implement the above model in Eq. 2, field methods for assessing land degradation (Stocking and Murnaghan, 2001) were applied to estimate minimum and maximum soil erosion rates required to input in the model. 12 experimental plots with drains were established in the study area in the year 2008 to measure maximum and minimum soil erosion rates (mm/yr) on 30^o slopes. The plot sites were selected so as to represent the major soil types as well as to include land cover types where minimum and maximum erosion occurs. In the study area, forest cover is associated with minimum and bare land with maximum erosion. Consequently, six drains were established on bare lands for maximum erosion measurements, and six drains under dense forest cover for minimum erosion measurements. The length, width, and depth of each drain and the commanding catchment area of the experimental plots were 30 m, 0.45 m, 0.75 m, and 300 (30×10) m^2, respectively. The average bulk density of soils in the study area was 1.31 g/cm^3. After one year, the amount of deposited sediments was measured in each drain. No specific properties of sediments, such as particle size, were measured. The deposited sediments indicate the amount of material that has been eroded from the experimental plots above each drain. Erosion was determined by assessing the difference in surface level of the drain before and after deposition. Sediment depth was measured at different points along each drain to obtain the average depth of sediment deposited and thereby to determine the volume of eroded soil. The volume of deposited soil was then divided by the size of the commanding catchment area in order to estimate the depth of eroded soil per year.

Because of its protective function, vegetation cover is an important indicator of land degradation by soil erosion (Rubio and Bochet, 1998). Besides protecting the soil surface, vegetation is also an important factor influencing the physical condition of soils (Shrestha and Kingshuk, 2008). The Normalized Difference Vegetation Index (*NDVI*) obtained through remote sensing data is widely used as an indicator of vegetation cover. The *NDVI* of the study area was computed using ALOS data as shown in Eq. 3. The *NDVI* equation produces values in the range of -1.0 to 1.0, where vegetated areas will typically have values greater than zero, and where negative values indicate non-vegetated surfaces such as water, barren land, ice, snow, or clouds.

$$NDVI = \left(\frac{NIR - R}{NIR + R} \right) \tag{3}$$

where: *R* and *NIR* = Red and Near-infrared bands of the electromagnetic spectrum of the solar radiation respectively.

At first, E_{30} erosion values of each pixel were calculated using Eq. 2 as described above. Soil erosion was then calculated from pixels with different slopes, using Eq. 1. A raster map of slope gradients was prepared with a pixel size of 12m to match the ALOS pixel resolution, using a Digital Elevation Model (DEM) to provide the slope information for Eq. 1. *NDVI* values were calculated using ERDAS^{TM} 9.1 software, and all overlay analyses were carried out in geographic information system (GIS) environment using ArcGIS^{TM} 9.2 software. Thus, annual soil erosion rates were computed and a soil erosion map was created for the study area.

The accuracy of the erosion model was assessed by comparing measured soil erosion values with modeled values. Comparison was also made between the measured values of experimental sites with the modeled values of sampled non-experimental sites having similar slope and *NDVI* values within the study area.

3.2 People's perception and socioeconomic determinants of soil erosion

A household survey was conducted to gather information regarding peoples' perception of soil erosion, and to analyze the socioeconomic determinants of soil erosion. Sampling procedure and survey methodologies are explained below.

3.2.1 Sampling procedure and questionnaire survey

The study area consists of 23,304 households (HHs) in 67 upstream villages and of 4,638 HHs in 9 downstream villages (Dept. of Census and Statistics, 2007). Due to limited resources, 15 villages were selected randomly from upstream and 6 villages from downstream. The total number of HHs in the 21 selected villages was 7,269. Using Eq. 4 for sample size determination given by Yamane (1967), a sample size of 199 HH was obtained with a sample fraction (*k*) of 0.027 at 7 % significance level.

$$n = \frac{N}{(1 + N \times e^2)} \tag{4}$$

where: n is sample size, N is total Households and e is the significance level.

The sampled HHs from both downstream and upstream areas of the watershed were interviewed from February to June 2009. A structured questionnaire was used to collect information on socioeconomic condition, soil erosion status, and soil and water conservation. The questionnaire was designed to document the socioeconomic status of the HHs, to record peoples' perception of the soil erosion status on their farmland, and to document the adopted soil and water conservation strategies. Questions were asked on household characteristics, land ownership, income and expenditure, perception on soil erosion extent, causes and impacts as well as on conservation awareness and practices. Interviews were conducted by the researcher with the help of assistants, who had been trained by the researcher. The collected HH data were analyzed using the Statistical Package for Social Sciences (SPSS^{TM}) 16.0 software.

3.2.2 People's perception on soil erosion

It has been argued that common resources, such as forests and open lands are best managed by the people who use them rather than by governments (Ostrom, 1990). Consideration of peoples' perception is thus an essential factor when making decisions on soil and water conservation. Based on the results of the questionnaire survey, this study assessed the direct and indirect causes of various soil erosion types, the impacts of soil erosion on ecosystem services, the effectiveness of adopted soil conservation measures, and the cost of soil conservation measures.

3.2.3 Socioeconomic determinants of soil erosion

Socioeconomic variables are important determinants of soil erosion (Shahriar et al., 2008). Decisions on soil and water conservation should therefore be made on the basis of socioeconomic considerations and assessments. In order to understand the major socioeconomic factors contributing to soil erosion in the study area, multiple regression analysis technique was employed. Multiple regression analysis is one of the multivariate statistical analysis techniques, which can predict changes in the dependent variable in response to several independent variables (Hair et al., 1992). The average rate of soil erosion was identified at each sampling locality from the generated soil erosion map with support of average GPS readings taken at each surveyed location. The reading was considered as the dependant variable (Y). Eighteen socioeconomic covariates or independent variables were used in this study to present the full spectrum of conditions for soil erosion in the watershed as described below.

X_1. Household size: As soil conservation activities are labor intensive, large households are capable of investing more in conservation than small households. Moreover, the larger the family, the higher the probability that future generation will farm the land and reap the benefits of conservation investments (Featherstone and Goodwin, 1993).

X_2. Farm labor: In Sri Lanka, people between 15 and 64 years of age are considered as economically active family members while children below 15 years of age and disabled members and elders (65 years or above) are considered as dependent family members. A higher dependency ratio in a family reduces its ability to meet subsistence needs. Availability of family labor can also affect soil and water conservation activities.

X_3. Education: Education influences the level of awareness. Increasing education level increases farmers' ability to obtain and utilize information related to soil conservation measures (Pender and Kerr, 1998).

X_4. Security of tenure: Security of tenure will have a positive effect on farmers' decision to invest in soil conservation measures. Conversely, when a system of property rights fails to provide individual users with sufficient security to reap future benefits from their investments, they may decide not to undertake such investments (Asrat et al., 2004).

X_5. Land conversion: Agriculture has been the greatest force of land transformation on this planet including the study area. Nearly a third of the Earth's land surface is currently being used for growing crops or grazing cattle (FAO, 2004). Areas under agriculture are in general subject to more intensive erosion than natural landscapes, such as forest. Land conversion for agriculture is thus associated with increased soil erosion.

X_6. Conservation cost: Any conservation requires investment. Willingness to invest in soil conservation results in less erosion and vice versa (Illukpitiya and Gopalakrishanan, 2004).

X_7. Training: Farmers with proper training in soil and water conservation are able to better manage soil erosion problems than farmers who do not have proper training.

X_8. Indigenous knowledge: Farmers develop indigenous knowledge through practical experience or through learning from the elders who already possess such knowledge. Indigenous knowledge may include knowledge about the cropping systems or activities that lead to increased or decreased erosion.

X_9. Memberships in organizations and committees: Knowledge gained through membership in soil and water conservation committees can help to deal with soil erosion (Shahriar et al., 2008).

X_{10}. Professional competencies: Professional experience can be different at different levels of soil and water conservation committees, and can also differ in terms of its effect on reducing soil erosion. More experienced and high level office bearers at local level committees can have much impact on soil erosion reduction than less experienced ordinary members (Shahriar et al., 2008).

X_{11}. Access to extension officers: Farmers with access to extension officers can obtain support to better take care of their farm lands and to preserve them from further soil degradation (Shahriar et al., 2008).

X_{12}. Transportation potential: Improved access to farmlands through better transportation networks can induce farmers to adopt soil conservation practices.

X_{13}. Distance: Distance is also an important factor of access. Soils and water can be managed more easily when farmland is located at close proximity to the household.

X_{14}. Awareness of policies: Awareness of policies on land, water and forests may induce farmers to decide on actions that are in line with these policies and that may lead to better land use practices supported by such policies.

X_{15}-X_{18}. Financial capital, Farm income, Total household income and Farm expenditure: These four variables can be considered as economic factors affecting farm production or soil conservation. Wealthy farmers are less likely to make risk-averse decisions. Further, when a farmer has sources of income other than farming, he/she can be expected to invest more in soil conservation practices (Ervin and Ervin, 1982).

First, the eighteen covariates were used for the bivariate correlation analysis. Following that, the correlated variables were used for the stepwise multiple regression analysis to eliminate the insignificant ($p<0.05$) variables and to select the most important variables determining soil erosion in a behavior model. Table 1 presents the variables with their scaling and indexing characteristics used in multiple regression analysis. The stepwise research procedure is presented in Fig. 2.

Note: Index a, b and b $= \sum X_i W_i / N$ (5)

where; X_i =Individual level, W_i = Respective weights, and N = Number of responses relating in each group Respective weights of indexes: a, b and c are given in Table 1, Colum 3

4 Results and discussion

4.1 Soil erosion rates from field drains

As mentioned above, 12 drains were constructed on forest land and bare land to trap sediments for an assessment of soil erosion. The estimated mass and volume of sediments deposited in these drains during 2008 are presented in Table 2. Figure 3 shows one of the twelve drains laid out in the study area. The average maximum and minimum rates of soil erosion at 30^{o} slopes, calculated on the basis of measurements at field plots in the study area were 21.50 mm/yr and 0.10 mm/yr.

4.2 Soil erosion in study area

The DEM presented in Fig. 4a shows that the elevation in the area ranges from 100 m to 2,160 m MSL. DEM was used to prepare the slope gradient map as one of the inputs for soil erosion estimation. Figure 4b presents the *NDVI* map of the study area, which was prepared on the basis of the ALOS images, and shows a *NDVI* range of +0.600 to –0.633.The maximum *NDVI* value of +0.6 indicates that the vegetation component in the area is not at its optimum as the value can go up to +1 when the vegetation condition is at its best.

Table 1 Description of socioeconomic variables used in multiple regression analysis

Variable name	Value label	Value	Measurement level
Dependant			
Y. Soil erosion rate		t/ha/yr	Continuous
Covariates			
X_1. Household size		Number	Discrete
X_2. Farm labor	15-64 years	Number	Discrete
X_3. Education	≥ grade 6	Number	Discrete
X_4. Security of tenure		Hectare	Continuous
X_5. Land conversion	Forest-agriculture	1	Dummy
	Agriculture-forest	0	
X_6. Soil conservation cost	Yes	1	Dummy
	No	0	
X_7.Training on soil conservation		Frequency/year	Discrete
X_8. Indigenous knowledge on soil conservation (index)[a]	No	0	Continuous
	Very low	0.25	
	Low	0.5	
	Moderate	0.75	
	High	1	
X_9. Memberships in soil conservation related organizations and committees		Frequency/year	Discrete
X_{10}. Professional competencies/positions related to soil conservation organization committees		Frequency/year	Discrete
X_{11}. Access to extension officers (index)[b]	No access	0	Continuous
	< Once/week	0.25	
	Once/week	0.5	
	2-4 Days/week	0.75	
	> 4 Days/week	1	
X_{12}. Transportation potential to farm land (index)[c]	Very difficult to access	0	Continuous
	Difficult to access	0.33	
	Sometimes difficult to access	0.66	
	Easy to access	1	
X_{13}. Distance to farm land		km	Continuous
X_{14}. Awareness of policies (land/ /water/forest)	Yes	1	Dummy
	No	0	
X_{15}. Financial capital		Farm income/total household income	Continuous
X_{16}. Farm income		Rs.	Continuous
X_{17}. Total household income		Rs.	Continuous
X_{18}. Farm expenditure		Rs.	Continuous

Soil erosion was calculated at the pixel level with 12 m resolution. Maximum, minimum and mean annual soil erosion rates were 22.1 mm/yr, 0.0 mm/yr and 0.33 mm/yr (S.D.=0.31), respectively. Based on soil erosion calculated at each pixel, six preliminary categories of soil erosion ranging from very low to extremely high were identified (Table 3). The study area's gross rate of soil erosion ranged from 0.0 to 289.0 t/ha/yr with an average rate of 4.3 t/ha/ya (S.D. = 4.1) (Fig. 4c).

Figure 5 presents the locations of twelve experimental plots (1B to 6B at bare lands and 1D to 6D at dense forests) and eight test sites outside the experimental plots (7B to 10B at bare lands and 7D to 10D at dense forests) for verifying modeled results.

In relation to suitability of the model for the study area, the average measured and computed soil erosion values for the bare lands were 21.5 and 20.2 mm/yr, respectively, while it was 0.10 and 0.08 in mm/yr, respectively for dense forests (Table 4). The table further presents a comparison between measured and modeled soil erosion values at non-experimental sites of the study area. The average modeled value for bare lands in non-experimental sites was 19.1 mm/yr, about 10% lower, than the measured average of

21.5 mm/yr. In case of dense forests, the average modeled value outside the experimental plots was 0.09 which was also 10% lower, compared to the measured average value of 0.10 mm/yr. Both comparisons at experimental and non-experimental sites indicate relatively satisfactory ability of the model to estimate erosion rates.

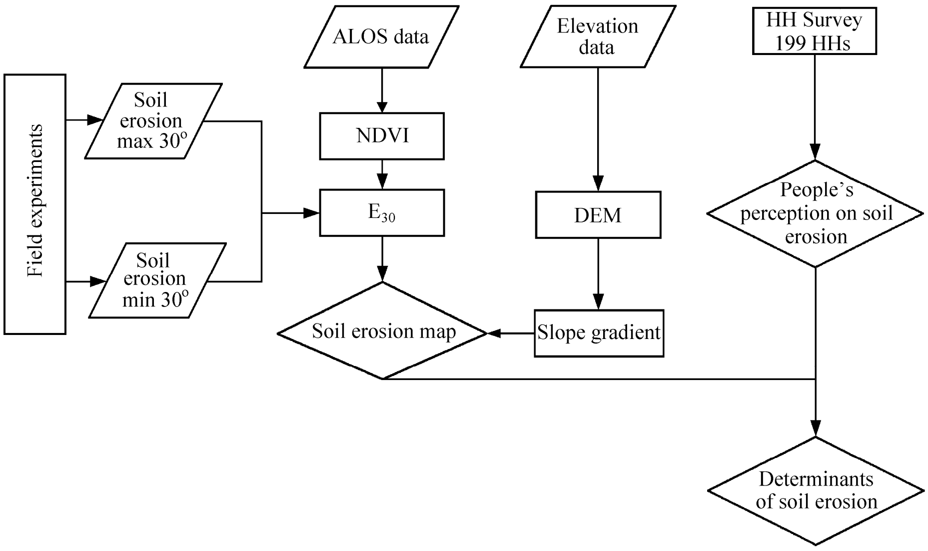

Fig. 2 Research procedure

Table 2 Mass and volume of deposited sediments in twelve drains

Drain No.	Bare land		Dense forest	
	Mass (kg)	Volume (m^3)	Mass (kg)	Volume (m^3)
1	4863.375	3.713	44.213	0.034
2	9903.600	7.560	53.055	0.041
3	6101.325	4.658	35.370	0.027
4	7958.250	6.075	44.213	0.034
5	12114.225	9.248	35.370	0.027
6	9638.325	7.358	17.685	0.014

Fig. 3 Sediments trapped in a drain laid on bare land

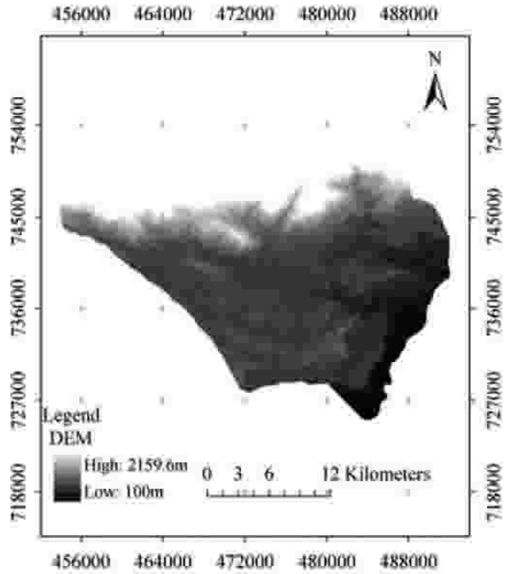

Fig. 4a Digital elevation model (DEM)

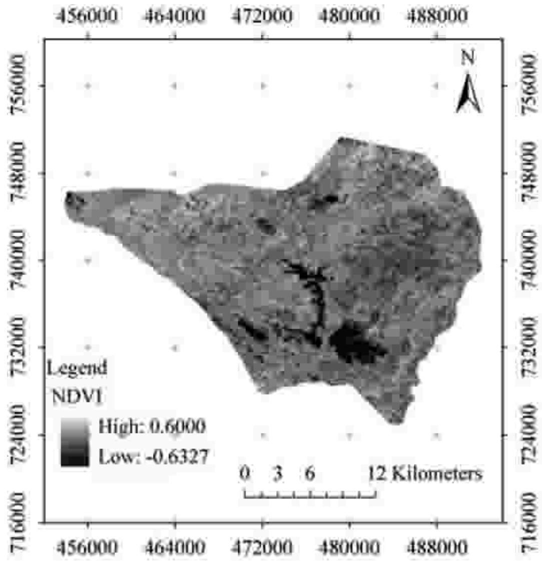

Fig. 4b *NDVI* map of study area

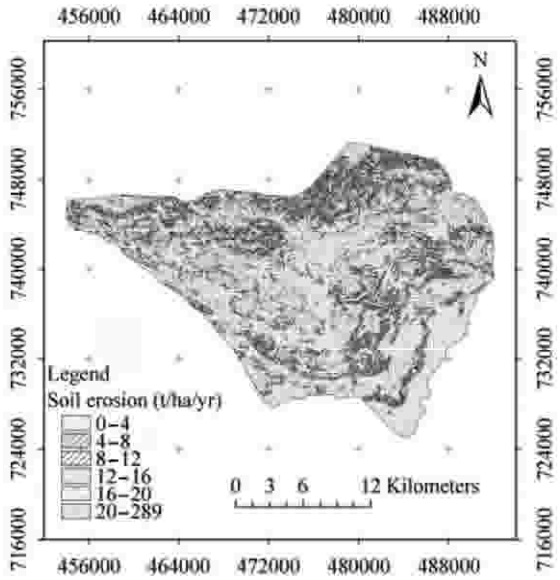

Fig. 4c Soil erosion map of study area

Table 3 Status of soil erosion in study area, 2008

Soil erosion status	Range (t/ha/yr)	Area (%)
Very low	0-4	55.3
Low	4-8	30.2
Moderately high	8-12	10.1
High	12-16	2.9
Very high	16-20	0.9
Extremely high	20-289	0.6

Note: Total area (536 km^2)

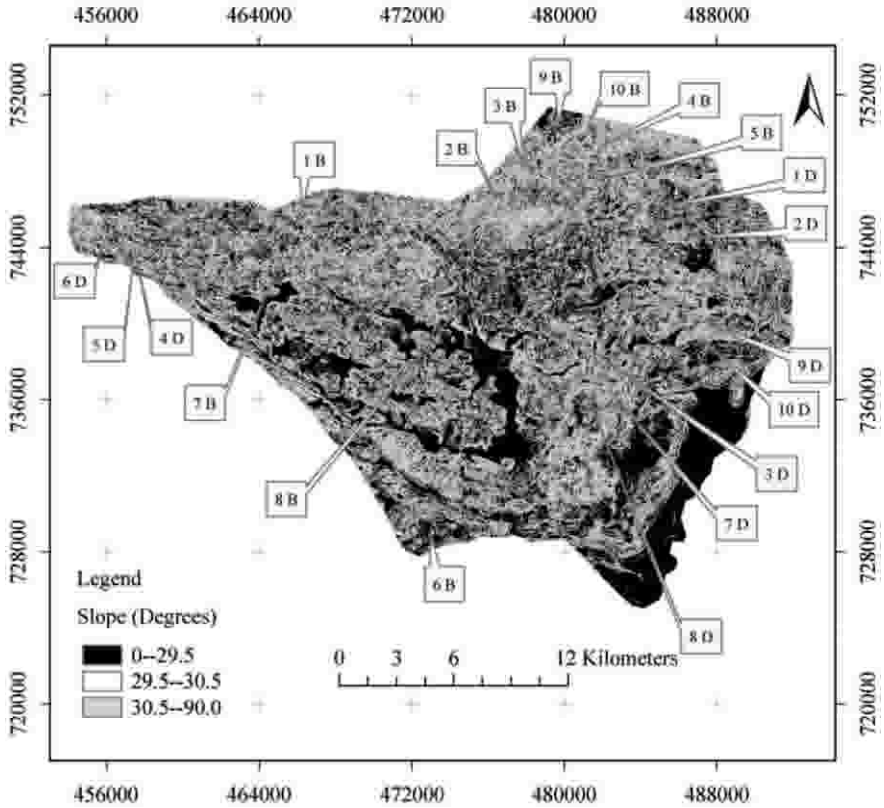

Fig. 5 Spatial distribution of twelve experimental plots and eight test sites

Table 4 Comparison between measured soil erosion values with modeled values

Experimental area slopes (30^o)							
Plot No.	Bare land			Plot No.	Dense forest		
	Measured values (mm/yr)	Computed outputs (mm/yr)	*NDVI* values		Measured values (mm/yr)	Computed outputs (mm/yr)	*NDVI* values
1B	12.4	15.5	-0.553	1D	0.11	0.11	0.519
2B	25.2	22.3	-0.601	2D	0.14	0.02	0.600
3B	15.5	17.7	-0.562	3D	0.09	0.12	0.503
4B	20.3	18.8	-0.568	4D	0.11	0.03	0.590
5B	30.8	26.5	-0.633	5D	0.09	0.09	0.537
6B	24.5	20.4	-0.593	6D	0.05	0.13	0.501
Average	21.5	20.2	-0.585	Average	0.10	0.08	0.542

Non experimental area (30^o) slopes					
Test sites	Bare land		Test sites	Dense forest	
	NDVI values	Computed outputs (mm/yr)		*NDVI* values	Computed outputs (mm/yr)
7 B	-0.570	19.5	7D	0.580	0.09
8 B	-0.550	18.9	8D	0.598	0.08
9 B	-0.562	18.7	9D	0.593	0.08
10 B	-0.568	19.1	10D	0.523	0.12
Average	-0.563	19.1	Average	0.574	0.09

According to TEAMS (1992), the Department of Irrigation of Sri Lanka carried out a sediment sampling study in the study area during October 1985 to September 1986, and reported that the average rate of erosion was 19.8 t/ha/yr. A comparison of this figure with the average rate of 4.3 t/ha/yr established by our study shows that the average soil loss rate has declined from 1986 to 2008. This is most likely due to the fact that people living in hilly areas of the watershed practice tea cultivation using vegetative propagation on bare lands as a major source of their livelihood since the late 1980s due to a price hike of tea. They are compelled by the government to manage their tea lands for increased tea production by applying adequate soil conservation measures and fertilizer provided to them at a concession rate.

Soil loss is a natural process that can be tolerated within certain limits. The acceptable rate of erosion is known as soil loss tolerance (“T” value) (Wischmeier and Smith, 1978) or permissible soil loss (Kok et al., 1995), and denotes the amount of soil loss that is less than or equal to the rate of soil formation. However, the limit may differ from place to place (Li et al., 2009). Research that was recently conducted in India established permissible rates of soil erosion, or “T” values, for soils of hilly terrain, dissected hills, pediment and piedmont plains ranging from 5 to 10 t/ha/yr (Jha et al., 2008). The Water Conservancy Department of China in 1997 identified “T” values of 11 t/ha/yr for the Loess Plateau, 2 t/ha/yr for the Northern Blackland, and 5 t/ha/yr for rocky and hilly regions (Li et al., 2009).

By using cosmogenic nuclides ^{10}B, Hewawasam et al. (2003) estimated that the natural rate of soil generation in the Upper Mahaweli Watershed in Sri Lanka, which ranged from 0.13 to 0.30 t/ha/yr. The current rate of soil erosion in the study area is therefore about 14 to 33 times faster than the natural rate of soil formation. While the current net rate of erosion in the watershed is 4.0 to 4.17 t/ha/yr, the rate of soil erosion can in some areas be as high as 289 t/ha/yr mainly due to frequent forest fires, wanton destruction of forests, and by replacing paddy crop with soil erosion inducing cash crops, viz. tomato, cabbage and bean. From an environmental conservation point of view, these results can be taken as baseline information in order to formulate soil conservation programs and policies.

Soil erosion estimation studies were carried out in the past in other watersheds or regions of Sri Lanka, using an array of different soil erosion estimation techniques. The average rate of soil erosion value obtained for the study area can, within limits, be compared with the rates of soil erosion in other areas under tea (Camellia sinensis). Tea cultivation is widely practiced in Sri Lanka and is one of the country's main sources of foreign exchange. Table 5 shows that tea lands, where mulching is practiced, have the lowest rate of soil erosion i.e. 0.7 t/ha/yr. With proper management, the rate of soil erosion in tea lands can be brought down to 0.33 t/ha/yr or less. Soils are exposed at the time of tea planting, and a high rate of soil erosion (up to 250 t/ha/yr) can be observed at this stage. This highlights the importance of applying soil conservation measures at the right time.

Table 5 Soil erosion estimates in tea lands of Sri Lanka

Status of tea land	Soil erosion (t/ha/yr)	References
During replanting	250.0	Hasselo and Sikurajapathi, 1985
Weeded	51.9	Manipura, 1972
Mulched (during monsoon)	0.7	Ministry of Forestry and Environment, 2001
Un-mulched (during monsoon)	40.0	
Well managed	0.33	Krishnarajah, 1982
Poorly managed	20.0	Krishnarajah, 1983

4.3 Peoples' perception of soil erosion

According to the perception of farm households participating in our survey, there are six major direct causes of soil erosion: improper soil management and crop management practices, deforestation, urbanization, industry, and natural causes (Fig. 6). As discussed above, the rate of soil erosion is very low to moderately high in most areas of the watershed, whereas in other places soil erosion rates can be as high as 289 t/ha/yr. These very high soil erosion rates are mainly due to improper soil management practices, like cultivation of unsuitable soils, lack of conservation measures and inappropriate tillage practices according to 37.9% of the respondents. Improper crop management practices, like reduction of plant cover, nutrient mining and shortening of fallow period were perceived by 33% of respondents as causes of soil erosion, and deforestation due to commercial forestry, development of infrastructure, and expansion of agriculture by 11.9% of the respondents, and urbanization, industrial activities and natural catastrophes by 17.2%. In 2002, a massive earth-slip in the Puwakgahawela area had resulted in numerous environmental and socioeconomic problems (Udayakumara et al., 2003). No other significant earth-slip has occurred thereafter.

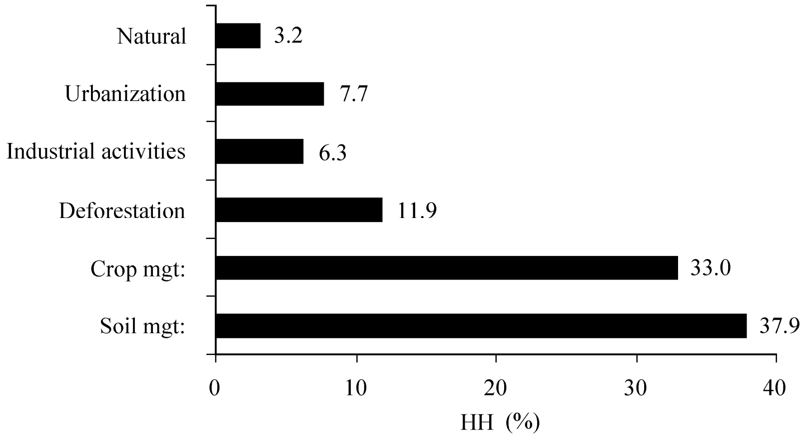

Fig. 6 Direct causes of soil erosion

Indirect causes of soil erosion are equally important as these tremendously affect soil erosion through direct causes. Population pressure, poverty, labor availability, land tenure, people's education, agricultural inputs and governance issues, such as introduction of unsuitable alien trees species to the hill slopes areas and providing license for the gem miners were perceived as major indirect causes (Fig. 7). About 60 % respondents perceived population pressure and poverty as major indirect causes of soil erosion, whereas labor availability and land tenure were perceived as major indirect causes by nearly 30% respondents. According to 10% of respondents, education, agricultural inputs and governance were also indirect causes of soil erosion.

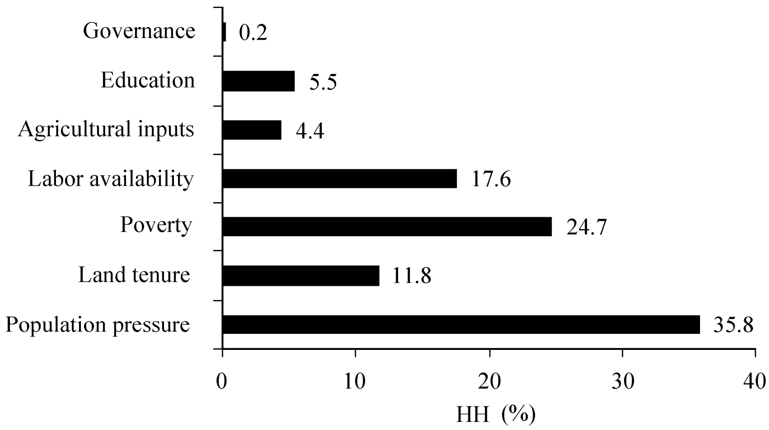

Fig. 7 Indirect causes of soil erosion

Figure 8 presents how soil erosion affects ecosystem and sociocultural services in the study area. 82% of respondents perceived that productivity and ecological services are severely affected while 18% of the respondents perceived that sociocultural services were less affected. Agricultural production and water quantity were seen to have declined drastically, whereas water quality was reported to have deteriorated more gradually. Natural cycles (carbon, nitrogen, phosphate, and water cycles) and biodiversity were also perceived to be severely affected.

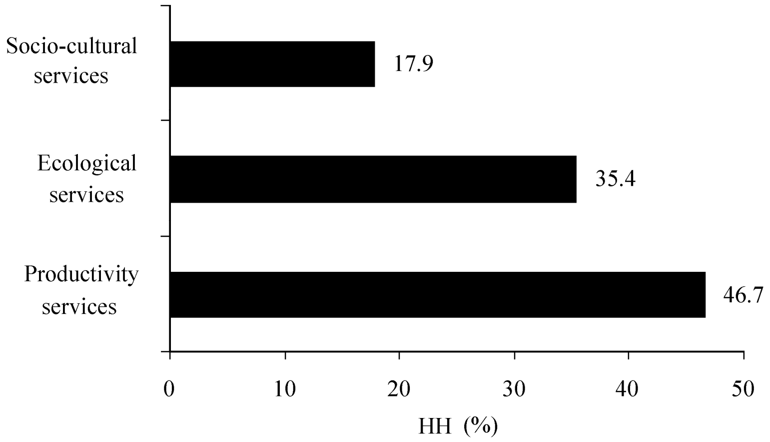

Fig. 8 Soil erosion impact on ecosystem services

Soil and water conservation measures have been practiced in the study area since the late 1980s. Conservation measures fall into four major categories, namely agronomic (e.g. mulch, organic manure, soil surface/subsurface treatments), vegetative (e.g. tree, shrub and grass cover and Sloping Agriculture Land Technology or SALT), structural (e.g. terraces, bunds and ditches) and management (e.g. changing species composition of crops, controlling cropping intensity and fallow period). Based on the respondents' perception, each of these measures can be applied for specific erosion types.

According to Table 6 and as shown by 328 responses, structural measures are the most popular conservation measures adopted to deal with soil erosion, followed by agronomic, and vegetative measures. The least widely used measures are management measures as indicated by only five responses. Agronomic conservation measures were found to be applied almost equally to all erosion types: there were 34% responses for splash erosion, 35.3% for rill erosions, and 30.7% for gullies. Vegetative measures, on the other hand, were used mainly for rills (51.2%) and splash erosion (48.1%), and almost none for gullies. Structural measures were mostly used in case of rills (by 36.6% respondents) and gullies (35.7%).

Table 6 Adopted conservation measures for soil erosion control

Conservation measure	Major erosion types		
	Splash	Rills	Gullies
	HH (%)		
Agronomic (n = 215)	34	35.3	30.7
Vegetative (n =133)	48.1	51.2	0.7
Structural (n = 328)	27.7	36.6	35.7
Management (n = 5)	40.0	40.0	20.0

Note: n is frequency of responses (multiple) for each measure.

The respondents were asked to give their opinion on the effectiveness of each measure for controlling soil erosion. The computation of the effective index in Table 7 shows that agronomic measures ranked highest with an index value of 0.722, followed by structural (0.686) and vegetative (0.686) as the second best effective measures, and management (0.333) as the least effective measure. Structural soil conservation measure, which has been the most widely used measure in the past, was however, not perceived as the most effective one of the adopted measures.

$$\text{Effectiveness of method, } Index = \sum X_i W_i / N \qquad (6)$$

where; X_i =Individual level, W_i = Respective weights, and N = Number of responses in each group (Low= 0.25, Moderate= 0.5, High= 0.75, Very high=1)

The impact of conservation measures on ecosystem services as well as on ecological, and sociocultural services was also assessed. As shown in Table 8, agronomic, vegetative and structural conservation measures are more or less similar in terms of effectiveness and have also a positive impact on all ecosystem services. Impact on productivity was comparatively higher than impact on ecological and sociocultural services. Management measures, however, were not perceived to have an impact on ecological and sociocultural services.

Table 7 Effectiveness of each conservation measure for erosion control

Conservation measure	Effectiveness of each measure				Index value	Rank
	Low	Moderate	High	Very high		
	HH (%)					
Agronomic (*n* = 99)	1.0	30.3	47.5	21.2	0.722	I
Vegetative (*n* = 78)	0	37.2	51.3	11.5	0.686	II
Structural (*n* =145)	0.7	39.3	44.8	15.2	0.686	II
Management (*n* =3)	66.7	33.3	0	0	0.333	III

Note: *n* is frequency of responses (multiple) for each measure.

Table 8 Impact of conservation measure on ecosystem services

Conservation measure	Impact on ecosystem services		
	Productivity services	Ecological services	Sociocultural services
	HH (%)		
Agronomic (*n* =174)	54.0	35.6	10.4
Vegetative (*n* =160)	45.0	38.1	16.9
Structural (*n* =268)	49.3	37.3	13.4
Management (*n* =100)	100	0	0

Note: *n* is frequency of responses (multiple) for each measure.

The purpose of adopting soil and water conservation measures is prevention and mitigation of soil erosion. In some places, people practice these measures to rehabilitate their lands, as for instance in the case of Mana (Cymbopogon confertiflorus) or Guatemala (Tripsacum laxum), i.e. grasses that are planted on bare land for eighteen to twenty-four months before planting tea in order to rehabilitate soils. People have been provided by the Tea Small Holding Development Authority of Sri Lanka (TSHDASL) with incentives to rehabilitate their tea lands with agronomic, vegetative and structural measures since fifteen years or more. Conservation measures, particularly vegetative and agronomic measures, have been practiced in the area for more than two decades (Table 9). Structural and management measures have been practiced for more than 15 and 5 years, respectively. Adoption of these practices may have contributed to the decline in soil erosion discussed above.

Table 9 Duration of adopted soil and water conservation measures

Item	Year (Average ±S.D)
Agronomic (*n* = 105)	20.5±12.9
Vegetative (*n* =125)	23.2±12.7
Structural (*n* = 99)	15.7±13.7
Management (*n* = 75)	5.3±4.6

Note: *n*=sample size

Literature on the estimates of soil erosion related costs in Sri Lanka is meager. What exists was upon close examination found to be based on questionable data and methodologies (Bandara et al., 2001). Annual on-site gross losses ranging between 0.5 and 1.5% of GDP have been reported for tropical developing countries such as Costa Rica, Malawi, Mali and Mexico (World Bank, 1992). Hazarika et al (2001) estimated that by applying soil conservation measures in the Mae Ao watershed in Thailand, the annual erosion rate has decreased from 16.1 t/ha/yr in 1992 to 11.8 t/ha/yr t in 1996, which has also lowered the external cost of soil erosion by US$ 6.2 ha/yr. The first careful estimates of on-site and off-site costs of soil erosion in Sri Lanka have become available from a study by Somaratne (1998). He estimated annual soil erosion-induced costs at about 90-125 US$/ha, which puts the annual cost of soil erosion in Sri Lanka at about 1% of its GDP. According to the questionnaire survey, people in the study area incur costs of about 60 US$ ha/yr in order to curb soil erosion.

4.4 Socioeconomic determinants of soil erosion

Examining the relation between socioeconomic variables and soil erosion, it was found that all 18 covariates presented in Table 1 but four (X_5, X_{12}, X_{18} and X_{14}) had a significant correlation with soil erosion. The significance was at 0.01 confidence levels for all variables, except for one (X_{15}), which was at 0.05 confidence level. Employing the stepwise multiple regression technique, 11 out of 14 covariates were included as predictor variables of soil erosion in the final regression model given in the following equation.

$$Y = 11.11 - 0.209X_1 - 0.162X_2 - 0.196X_3 - 0.152X_4 - 0.126X_6 - 0.264X_7 - 0.203X_9 - 0.228X_{10} + 0.166X_{13} - 0.169X_{15} - 2.472E\text{-}7X_{16} \quad (7)$$

where, Y= Soil erosion rate, X_1 = Household size, X_2 = Farm labor, X_3 = Education, X_4 = Security of tenure, X_6 = Conservation cost, X_7 = Training, X_9 = Membership of organization committees, X_{10} = Professional competencies, X_{13} = Distance, X_{15} = Financial capital, X_{16} = Farm income.

In the above model, all variables were significant at 0.01 confidence level except two variables (X_6, X_{15}) at 0.05 confidence level. The obtained multiple correlation coefficient (R^2) of 0.923 indicated a strong association between predictor variables in the model and soil erosion. Below is a brief account of the significant variables as socioeconomic determinants of soil erosion.

The variables, household size and farm labor have a negative effect on soil erosion in the model. A higher number of family members that can provide more farm labor is very important for farming activities as well as for soil conservation activities. Young farmers may be more educated and more knowledgeable about innovative farming practices and thus more aware of soil problems and available solutions (Illukpitiya and Gopalakrishnan, 2004). As farmers get older, it is reasonable to assume that they pay less attention to long-term investments but may still be interested in agricultural activities which do not harm the environment. As shown by the model, education and training have a negative effect on soil erosion. Education, which includes gaining knowledge on consequences of soil erosion and on soil conservation measures, is an important variable governing the decision-making processes in soil conservation (McDowell and Sparts, 1989). Security of tenure also showed a negative effect on soil erosion in the model. In the study area, most farmers own their land. With 88% of respondents owning their lands, security of tenure is very high. Security of land tenure is an important variable determining investment decisions on soil conservation. Lack of security over land tenure can encourage shortsighted decisions and irresponsible use of land resources (Hu, 1997). Farmers who cultivate land owned by others may be less likely to invest in soil conservation. Tenants lose part of their income as rent for the land, which acts as a financial obstacle to soil conservation. On the other hand, landowners may not be willing to pay for soil conservation on the lands rented out because they feel that part of the on-farm benefits of conservation would go to the tenants (Ervin, 1986; Illukpitiya and Gopalakrishnan, 2004).

Two variables, namely membership in organizations and committees, and professional competencies, have a negative effect on soil erosion. These variables explain the level of cooperation and social coherence, which reflects farmers' ability to organize themselves into groups, influence development planning and budgeting activities, or obtain formal credit or market access that is conducive to soil conservation (Shahriar, 2008). The cost of conservation was found to have a negative relation with soil erosion. 64.7% of respondents reported yearly expenses for soil conservation and gaining a higher productivity of their land. On the other hand, distance was positively related with soil erosion in the model. Farmers close to their land have better opportunities to implement conservation activities than farmers far away from their land. Financial capital and farm income have a negative effect on soil erosion. These variables indicate credit availability for farming activities, i.e. if credit availability is high, farmers can invest more in soil conservation (Illukpitiya and Gopalakrishnan, 2004).

5 Conclusions

Soil erosion is a serious concern in most parts of Sri Lanka. In Samanalawewa watershed, the rate of soil erosion ranges from 0 to 289 t/ha/yr with a watershed level average of 4.3 t/ha/yr. Household survey recognize inappropriate soil and crop management practices as the major direct cause, and increased demand due to population growth, poverty and inadequate labor as the major indirect causes of soil erosion. Peoples' perceptions are supported and further elaborated by the derived soil erosion regression model. The model shows that eleven socioeconomic factors, viz. farm labor, household size, education, security of tenure, conservation cost, training, memberships of organization committees, professional competencies, financial capital, distance to farmland, and farm income, are significant determinants of soil erosion in the study area. The current soil erosion rate seems to be lower when compared to the situation of some two decades ago, but is still about 14 to 33 times faster than the natural soil generation rate. There is thus clearly a need of reducing soil erosion.

Farmers in the area have been practicing soil conservation measures for more than two decades and have realized by now the positive effects of these measures on ecosystem services, particularly through maintaining the productive function and reducing soil erosion. This explains also the declining trend of soil erosion and will eventually reduce the externality cost of soil erosion. According to farmers' perceptions, agronomic measure is the most effective soil conservation measure, followed by structural and vegetative measures. Structural measures, which have been used by many for a relatively long time, are considered as comparatively less effective. This is in concurrence with findings elsewhere that structural measures by themselves are not an efficient way of practicing soil conservation. Addressing the issues related to determinants of soil erosion may further help in reducing soil erosion and enhancing soil conservation.

The soil erosion estimates in this study are based on a simple technique employing only a few important variables. Use of more sophisticated techniques with a larger number of variables might help generate more precise information and lead to better soil and water conservation decision making. In addition, there should be regular monitoring of soil erosion as in the case of this study, which has built up on a soil erosion study that was done some two decades ago.

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