Quantitative Assessment of Soil Erosion and its Association with River Health of Uma Oya Watershed, Sri Lanka

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Abstract
Soil erosion in river catchments increases sediment deliver to streams causing water quality deterioration. This study was aimed to determine the relationship between soil erosion and water quality of intensively cultivated Uma Oya watershed and to assess human-induced factors contributing to soil erosion in the watershed. The soil erosion rates of ten selected micro-catchments were evaluated using Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Sediment Retention Model. The overall ecological health of the streams associated with micro-catchments was calculated by assessing physiochemical parameters and benthic macro-invertebrate indices in monthly intervals. A comprehensive questionnaire survey was conducted to obtain information on farmers' land use practices and their level of adoption of water and soil conservation practices (n=83). Person's correlation test and multiple regression analysis were used to estimate association of water quality and soil erosion, and to identify human-induced factors that contribute to soil erosion. The estimated average soil loss of selected micro-catchments varied between 36.4 t/ha/yr to 222.4 t/ha/yr. Correlation analysis indicated average soil loss of the catchment is having significant ($p<0.05$) positive relationships with phosphate, Biological Oxygen Demand (BOD_5), Total Dissolved Solids (TDS), alkalinity, %Chrinomidae and a negative correlation with Percentage Ephemeroptera: Plecoptera: Trichoptera (EPT) taxa in study streams. Results of the questionnaire survey indicated that the farm-level soil loss was attributed to family size, farmer's education and their soil conservation adoptions ($p<0.05$). The findings of the present study suggested close relations among the stream health and soil erosion, and need for human interventions in catchment management.

Keywords: Human intervention, InVEST Sediment Retention Model, Soil erosion, Water quality
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Introduction
Soil erosion is a main form of land degradation in river catchments caused by the interacting effects of factors, such as biophysical characteristics and socio-economic aspects (Mengstie, 2009). Fresh water availability in the Earth is limited and human mediated modifications of natural landscapes of river catchments can significantly affect the water quality of the rivers. Sediments and attached pollutants such as nutrients, pesticides and toxic materials resulting from eroded soils from adjacent catchments can negatively affect river water quality, aquatic habitats and hydrological systems (Udayakumara *et al.*, 2012).

Upper Mahaweli Catchment (UMC) is an intensively cultivated landscape with high levels of human activities. Estimates of the rate of soil loss on hill slopes and sediment yields in the fluvial system of UMC indicate that the human induced activities have increased rates of on-going erosion by more than 100 times over the background rates of natural erosion (Hewawasam, 2010). Uma Oya (UO) watershed is a major sub-catchment of UMC and increased population, intensification of landscape, growing demand on water for agriculture have strained water resources in the catchment. In addition, intensively cultivated lands are highly vulnerable to soil erosion and reduces productivity of croplands (Amarasekara *et al.*, 2009). However, the empirical evidence on quantitative assessment of soil erosion in catchments and their association with surface water quality is lacking in the context of river catchments in Sri Lanka. Erosion control requires a quantitative and qualitative evaluation of potential soil erosion, cropping systems and identification of human interventions. Therefore, identification of the constraints to the adoption of soil and water conservation measures are important for catchment management. The present study aimed to estimate the human-induced soil erosion in UO watershed and its' relationship with water quality.

Materials and Methods
Ten sub-catchments within UO watershed with 2nd or 3rd order tributaries draining into UO

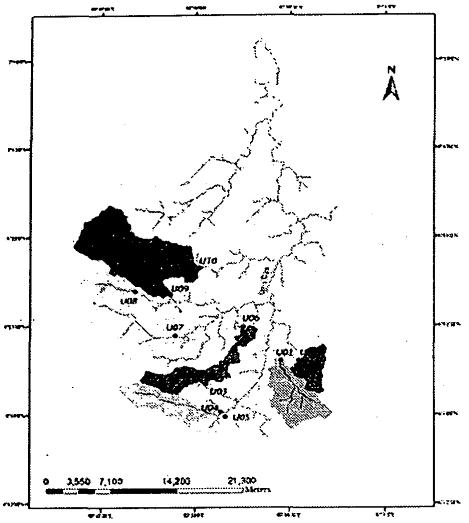

Figure1: Micro-catchments and Sampling Points of UO watershed

were selected as sampling locations for the study (Figure 1).

InVEST Sediment Retention model was used to estimate annual soil loss of UO watershed. Input files of the model were prepared using ArcGIS™10.1 version. Digital Elevation Model of UO watershed was prepared using a STRM™ satellite image of 30mx30m resolution.

The data gathered from Meteorological Department and Irrigation Department were used for the preparation of Erosivity (R) and Erodibility (K) rasters. Annual rainfall data in 2014 and Roose (1996) equation were used for the preparation of R-factor. Land use practices were categorized into five land-use types (Tropical montane forests, Tropical sub-montane forests, Tea, Paddy and Crops) using supervised classification of Landsat™ satellite image of 30mx30m resolution. Crop factor (C), management practice factor (P) and sediment retention values for land use types were obtained from previous studies.

Water samples were collected monthly from 10 sampling locations covering 10 sub-catchments from December 2014 to May 2015. Electrical conductivity (EC), pH, temperature, Biochemical Oxygen Demand (BOD_5), Total Dissolved Solids (TDS), Total Solids (TS), Total Suspended Solids (TSS) , NO_2^--N, NO_3^--N, NH_3-N, PO_4^{3-}-P, SO_4^{3-}, F^- Fe, Mg^{2+} and Na^+ were measured following APHA (2005) procedures. Macro-invertebrate samples were collected from the study stream reaches using a Surber sampler. The macro-invertebrate families were identified and biotic indices (%EPT taxa and % Chironomids) were calculated.

A household questionnaire survey was conducted to obtain information from farming community (n=83) on socio-economic aspects and land use practices on soil and water quality of the catchment.

Pearson's correlation test was conducted to evaluate the association between water quality, benthic macro-invertebrate indices and soil loss data. Multiple regression analysis was carried out to identify the significant factors of farming community contributing to soil erosion. SPSS™21 software was used to analyze the data.

Results and Discussion

Results of the present study indicated that the annual soil loss of sub-catchments range from 36.4 t/ha/yr to 222.4 t/ha/yr. 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 (Udayakumara *et al.*, 2012) and denotes the amount of soil loss that is less than or equal to the rate of soil formation. The current rate of soil erosion in the study area is about 7 to 44 times faster than the soil loss tolerance in Sri Lanka. Many reasons such as wanton destruction of forests and by replacing paddy crop with soil erosion inducing cash crops viz. tomato, cabbage and bean can be attributing to this rate.

Results of the Pearson's Correlation test (Figure 2), indicated a positive significant ($p<0.05$) correlation between soil loss of each sub-catchment and water quality parameters such as phosphate, BOD, TDS, hardness, alkalinity, sulphate and %Chrinomidae. The positive relationship between these water quality parameters and soil erosion in the catchment may be due to many reasons. Phosphorous mostly moves to streams with runoff of soil particles. Applications of phosphate bearing fertilizers are common in the catchment and this may have contributed to higher input of phosphates to the streams in highly eroded sub-catchments.

Moderate positive significant ($p<0.05$) correlations were detected among soil erosion rates in sub-catchments and water quality parameters such as BOD, TDS, hardness, alkalinity and sulphate concentrations. The increased levels of BOD may have attributed to

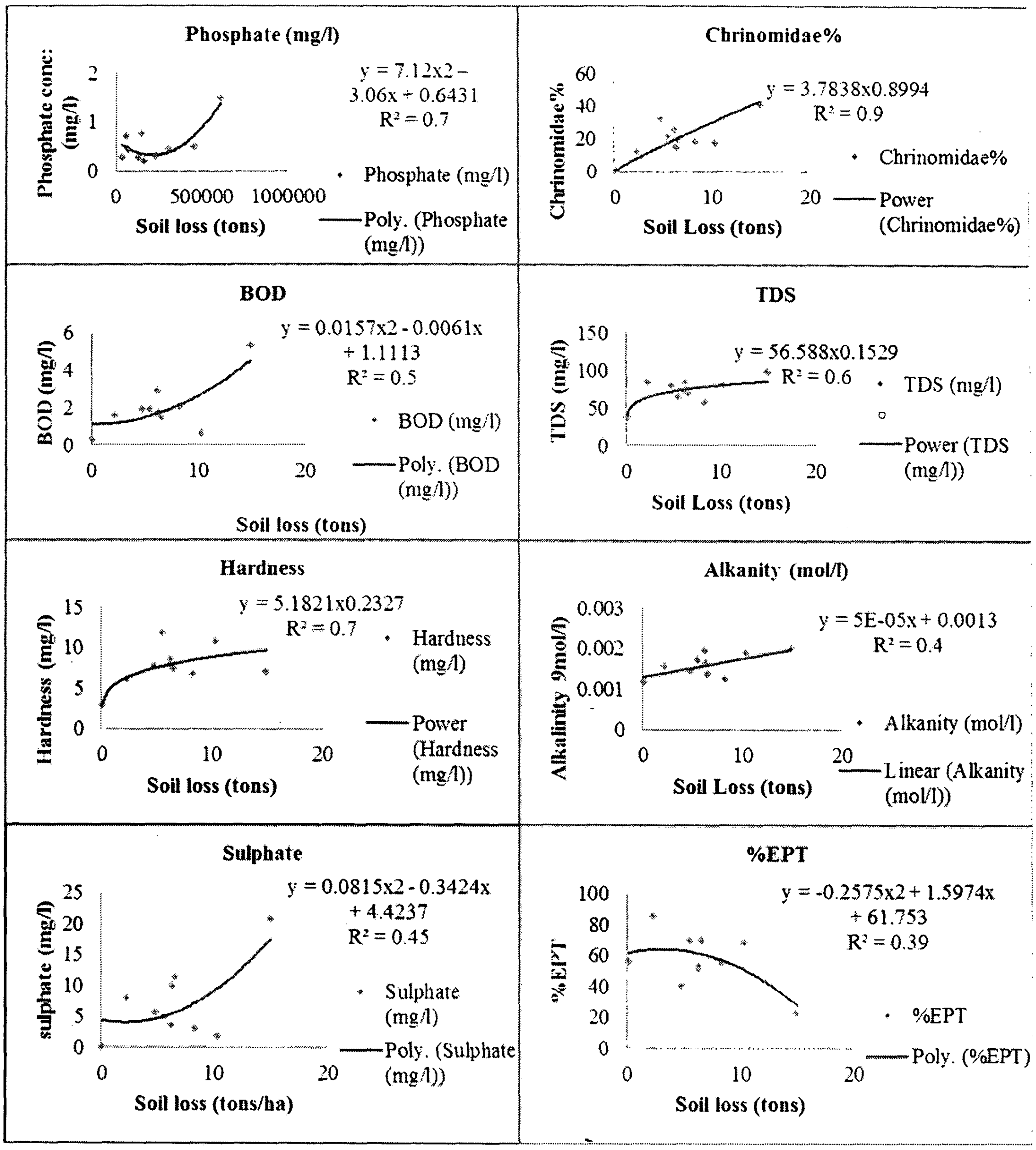

Figure 2: Relationship between average soil losses and average water quality parameters of sub-catchments

excess amount of organic matter discharge into streams through runoff from disturbed landscapes.

Livestock waste, which is widely used as a fertilizer in vegetable cultivation in the catchment, may have contributed to high BOD levels. Alkalinity and hardness in stream water mainly occur due to leaching of limestone rocks. It has been observed during the present study that Dolomite is widely applied to the fields before the initiation of vegetable cultivation. Calcium and Magnesium present in the dolomite may have contributed to the increased hardness of river water associated with eroded landscape. Similarly, the disturbed soils due to crop cultivation, development activities and forest logging have attributed to the input of high levels of dissolved and suspended particles to river water with runoff. Furthermore, results of the present study indicated non-linear significant associations between some water quality parameters and soil erosion. Confounding impacts such as protection provided by buffer zones to streams may have contributed to such relationships.

In the present study, catchment soil erosion is significantly correlated with % Chironomidae as they are more tolerant or better adapted to increase in sedimentation. Moderate negative significant ($p<0.05$) correlation were shown by

%EPT. EPT taxa are sensitive to pollution; a few survive in polluted streams with excessive sedimentation. This suggests that biotic compositions of the investigated streams are also affected by soil erosion.

Results of multiple regression analysis indicated that family size (p=0.039) significantly influenced the farm-level soil loss because soil conservation activities are more labour intensive and 81.9% of farming families within the area consists of 4-5 members. Furthermore, farmer's education level (p=0.043) and adoption of conservation measures (p=0.01) significantly influenced the farm-level soil loss within the catchment. The study showed 83% of interviewed farmers were educated up to Ordinary-Level and 81% of farmers adopted at least one type of soil conservation measures. Although many soil conservation methods had been already introduced to up-country, only primary methods are commonly practiced in UO watershed.

Findings of the present study indicated that the stream ecological health of UO watershed is closely related with sediments deliver to streams at micro-catchment level. Intensive farming systems and land use patterns have significant affects on the soil loss within the watershed. Further, the study highlights the human factors contributing to soil erosion.

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