RELATIONSHIP OF WATER QUALITY WITH SOIL EROSION AND FOREST HEALTHINESS IN SELECTED SUB-CATCHMENTS OF SAMANALAWEWA WATERSHED

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ABSTRACT

Soil erosion and forest healthiness are important parameters which affect the water quality of watersheds. Thus, the prime objective of this study is to evaluate and map the rate of soil erosion and forest quality of the Samanalawewa watershed (SWW) and to establish their relationship with water quality of the watershed. Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) Sediment Delivery Ratio (SDR) model, and Normalized Difference Vegetation Index (NDVI) were mainly used to calculate soil erosion, and forest healthiness of SWW with the support of Remote Sensing and Geographic Information System. Water quality parameters: temperature, pH, electrical conductivity, total dissolved solids, dissolved oxygen, biochemical oxygen demand, alkalinity, total hardness, nitrate, phosphate were analyzed. The study revealed that the present human-induced soil erosion of the catchment varies from 0 to 139.9 t/ ha/ yr with an annual average of 14.5 t/ ha/ yr, which is ~3 times greater than the soil loss tolerance (T) in Sri Lanka. The Average NDVI values/ forest quality varied between-0.329and 0.462 among 12sub- catchments indicating that SWW is having moderate vegetation healthiness. Further, Pearson correlation test was conducted in order to establish a relationship between water quality parameters, soil erosion, and forest healthiness / NDVI of each sub-watershed. However, there was no direct relationship between water quality parameters and soil erosion rates. Nonetheless, a negative correlation between NDVI and nitrate (r^2= 0.521, p=0.008) has been found. The findings of the research suggest that catchment water quality is not significantly affected by soil erosion of the catchment possibly due to the presence of fairly healthy forest cover in the catchment.

Keywords: *InVEST SDR model, soil erosion, water quality*

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. Natural factors which contribute to soil erosion include, topography (slope angle and slope length) and soil properties (texture, structure, moisture, roughness, and organic matter)(Lal, 2001; Udayakumara et al., 2010) Sediments runoff from eroded lands found to have adverse impacts on catchment water quality, aquatic habitats, biota and the carrying capacity of the reservoirs built in the watershed (Woldu, 1998). Moreover, the sediments and attached pollutants such as nutrients, pesticides and toxic materials can also negatively affect water quality (Zhang et al., 2009).Therefore, estimates of soil erosion rates in the catchment and prudent actions on better soil management initiatives are crucial for effective catchment management. Recently numerous models have been developed to estimate the soil erosion rates of catchment (Meijerink & Lieshout, 1996) and among them Integrated Valuation of Ecosystem Services and Trade-offs (INVEST) Sediment Delivery Ratio (SDR)model introduced by the Sanford University-USA is a widely applied in order to map and calculate soil erosion rates because of its properties such as high accuracy in predictions, ability to integrate more input variables for prediction and flexibility of usage (Sharp et al., 2016).

Forest cover of a watershed often contributes to reduce soil loss (DeFries et al., 2002) and improve the soil fertility. Forest healthiness is an important indicator of the forests which often contribute to mitigate the adverse environmental impacts resulting from catchment land use activities and to improve water quality in river catchments (Braatz & Nations, 2001) by serving as natural sponge.

Forest healthiness can be measured using Normalized Difference Vegetation Index (NDVI). It is a simple graphical indicator which use remote sensing technique. NDVI categorize vegetation by measuring the difference between near-infrared and red light. Chlorophyll strongly absorbs visible light and the cellular structure of the leaves strongly reflected near infrared light (Nath, 2014). When the plant becomes sick/ dehydrated or disease infected, the spongy layer deteriorates and plants absorb more near infrared light rather than reflecting it (Keenan et al., 2015). Therefore, higher NDVI values, is an indicator of very healthy vegetation such as tropical or temperate forests. Moderate NDVI values indicate the healthy vegetation and lower NDVI values represent the less or no vegetation such as urban areas or dead forest. Zero and negative values of the NDVI is an indicator of water bodies, bare lands and rocky areas etc. (Griffith & Price, 2012).

The Samanalawewa watershed is an important watershed in Sri Lanka, because it contains one of the most important hydropower generating reservoirs of the country, the Samanalawewa reservoir. This reservoir was constructed during the period of 1988-1992 by damming the Walawe river at the confluence of its tributary, the Belihuloya, at an elevation of 400 m mean sea level (MSL)(Udayakumara et al., 2010). Most of the paddy farmers in the downstream area depend exclusively on this reservoir for their irrigation water (TEAMS 1992).

Soil erosion due to intensive agricultural practices and reduced forest quality in catchments can adversely impact the water quality of catchment. However, no comprehensive study has been carried out recently in the Samanalawewa watershed to find out how soil erosion and existing forest quality impact on the water quality of the catchment. Therefore, this study aims to evaluate and map the rate of soil erosion and forest healthiness of the Samanalawewa watershed (SWW) and to establish their relationship with water quality of the watershed.

2. LITERATURE REVIEW

2.1. Soil Erosion

Soil erosion is a complex process which includes the detachment, movement and deposition of soil particles affected by both wind and water (Lal, 2001; Sui et al., 2009).

Soil erosion can be taken as one form of soil degradation along with soil compaction, loss of soil structure, and low organic matter, poor internal drainage, salinization and soil acidity problems (Diyabalanage et al., 2017).

2.2. Effects of Soil Erosion in Samanalawewa Watershed

One of the growing concerns in most areas of Sri Lanka is "Human-induced soil erosion". According to the perception of farm households in the Samanalawewa area, there are six major causes contributing to soil erosion: improper soil management and crop management practices, deforestation, urbanization, industry and natural causes. Improper soil management practices, cultivation in unsuitable soil, lack of soil conservation measures and inappropriate tillage practices are among the causative factors of soil erosion. Improper crop management practices, such as reduction of plant cover, nutrient mining and shortening of fallow period were perceived as causes of soil erosion and deforestation due to commercial forestry, development of infrastructure, expansion of agriculture, urbanization, industrial activities and natural catastrophes (Udayakumara et al., 2010) are among the other contributing factors.

2.3. Soil Erosion Modeling

The main objective of soil erosion models is either explanatory or predictability (Petter, 1992). Erosion models are usually most feasible access by generating data on erosion hazard (Meijerink & Lieshout, 1996). The most widely used models include Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Coordination of Information on the environment (CORINE), Modular Soil Erosion System (MOSES), Water Erosion Prediction Project Erosion Model (WEPP), Honda model and InVEST Sediment Delivery Ratio (SDR) model etc. (Nakos, 1983).

2.4. Forest Healthiness

Vegetation covers and vegetation healthiness are very essential factors in reducing soil loss (Petter, 1992). In general, as the protective canopy cover enhances, the erosion hazard reduces (Yassoglou & Kollias, 1989). It protects the soil against the action of falling raindrops, maintains the roughness of the soil surface, increases the degree of infiltration of water into the soil, binds the soil mechanically, reduces the speed of the surface runoff, improves the physical, chemical and biological properties of the soil and diminishes micro-climatic fluctuations in the uppermost layers of the soil (Petter, 1992).

2.5. Water Quality in Samanalawewa Watershed

The major rivers of Sri Lanka arise from the central hills and their catchment areas are subjected to various land use changes as a result of intensive agricultural practices and infrastructure development activities (Watawala et al., 2010).

The Walawe river catchment is one of the largest catchments in Sri Lanka, which provides water to Walawe river and the major reservoir; Samanalawewa built along the river. This catchment is considered very significant to the Sri Lanka's economy as it also supplies water needed to generate electricity requirement within the country and to irrigate a large area of paddy and other field crops (TEAMS 1992).

Substantial use of land and land cover changes has been occurred in the catchment during the last few decades. For Evaluation of such land conversion impacts on stream ecological integrity is important for taking decisions on catchment management. Therefore, objective of this study is to measure soil erosion rate, forest healthiness and water quality of the study area.

3. METHODOLOGY

3.1. Study Area

The study area of the Samanalawewa watershed stretches from the north at 80.680972º to 80.925972º longitudes to the east at 6.554583º to 6.783472º latitude, and covers an area of about 302km^2 (Figure 01).

3.2. Assessing Soil Erosion in the Study Area with Integrated Valuation of Ecosystem Services and Trade-offs (InVEST)

This model requires eleven types of input data for the estimation of soil erosion. The project coordinate system was a WGS 1894 UTM zone 44 which was used for all raster inputs. Among those eleven types of input data, eight numbers of input data are required to run this model successfully as shown in Table 1.

3.3. Assessing Forest Healthiness in the Study Area with Normalized Vegetation Index (NDVI)

Earth Resources Data Analysis System (ERDAS) imagine processing and ArcGIS™ 10.5 software were used in order to image classification, image processing, analyzing and generation of NDVI maps.

3.4. Water Sampling & Analysis

Twelve 2nd or 3rdorder tributaries draining through the Samanalawewa watershed from twelve sub watersheds were selected for water sampling (Figure 2). Water samples were collected in duplicates from each sampling location at monthly intervals from selected twelve sampling locations (n=12) of the catchment from March 2019 to May 2019 and the GPS coordinates of each location were taken.

Water quality parameters; temperature, pH, electrical conductivity (EC), total dissolved solids (TDS) measurements were taken on-site by Multi- parameter (Thermo scientific- ORION) at the sampling sites. The flow rates were measured using flow meter (FP 111) in sampling locations. Dissolved oxygen (DO), biochemical oxygen demand (BOD), alkalinity, hardness, nitrate-N, phosphate-P were measured following APHA (2005) (American Public Health Association) procedures.

4. DATA ANALYSIS & RESULTS

4.1. Data Analysis

In order to establish the relationship between soil erosion and forest quality with water quality, Pearson correlation test was used to analyze the data using Minitab 17 and Microsoft Excel 2013.

4.2. Soil Erosion Assessment

The delineated Digital Elevation Model indicated that, the elevation of the study area ranges from 84m to 2141m. The calculated rainfall erosivity (R) of the Samanalawewa watershed ranged from 63.2to 77.3 MJ mm ha^{-1} h^{-1} yr^{-1}.The soil erodibility (K) varied from 0.1 to 0.27 in the area and nine types of soils were identified in the area. Seventeen major land use cover (LULC) classes were also identified in the catchment. The delineated watershed has an area of 302 km^2 and includes twelve main sub watersheds. The biophysical table explains the sediment retention in the watershed due to existing cropping types and soil and water conservation measures.

4.3. Forest Healthiness Assessment

The NDVI is an indicator of the healthiness of land cover area, which measures the quality of vegetation. Average NDVI Values/ forest quality varied from -0.291 to 0.463 (Figure 3) among selected sub-watersheds.

4.4. Water Quality Assessment

All water quality parameters measured were within the standard limits of drinking water (SLS 614:2013).

5. DISCUSSION OF THE FINDINGS

According to the results of InVEST SDR model, the study revealed that the annual total soil erosion rate in the SWW due to current land use and land cover is 139.9 t/ ha/ yr. The calculated sub-watershed level soil erosion (Table 2) revealed, the least soil loss in the sub-watershed 11 (Welioya sampling location) which is 22.4 t/ha/yr. Welioya sampling site is locates in an area where fewer agricultural lands present and with higher forest coverage. Sub watersheds 1 (Balangoda), 8 (Diyawinna) and 12 (Handagiriya) also recorded lower soil erosion rate. While sub-watershed 5 shows high rate of soil erosion possibly due to disturbance of the sub catchment due to cultivation of paddy and vegetables. Sub watersheds 3 (Imbulpe), 7 (Thanjantenna) and 4 (Belihuloya) had relatively high soil loss value comparison to the other location. In 2008, the total soil loss of Samanalawewa watershed ranged from 0 to 289 t/ ha/ yr(Udayakumara et al., 2012). However, when the current soil loss value is compared with the past value, current soil erosion rate has reduced possibly due to water and soil conservation measures adaptation in farm-level, introduction of agroforestry practices, increasing the awareness about soil erosion factors among peoples

The average NDVI values for all the sub watersheds (Table 3) considered were between 0.144 to 0.371, whereas the minimum value was recorded for the sub watershed 2 (Oluganthota) while the maximum value was recorded for Diyawinna. The average NDVI values recorded for some of the sub-watersheds in the study area ranged between 0 to 0.33, representing poor vegetation quality. Apart from the sub-watersheds 8 (Diyawinna), 9 (Kuragala), 10 (Welioya), 12 (Handagiriya) and 11 (Rajawaka), which had relatively higher vegetation quality, all the other sampling sites under consideration had less vegetation representation poor vegetation healthiness.

However, the correlation analysis between water quality parameters and forest quality / NDVI indicated a significant ($p<0.05$) negative correlation between average NDVI values and nitrate-N (r^2= 0.521, p=0.008) levels in the river water.

6. CONCLUSION & CONTRIBUTIONS

Findings of the study suggested that despite the soil erosion taking place in the Samanalawewa watershed, water quality of the catchment is unaffected possibly due to the presence of healthy vegetation cover along the streams as reflected by the NDVI values estimated for each sub-watershed.

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TABLES AND FIGURES

Table 1: Required input data for successfully run InVEST model

No	Data used	Data Type	Source/s
1	Digital Elevation Model (DEM)	Raster	SRTM satellite images (Acquisition date: 26/ 04/ 2019)
2	Rainfall erosivity index (R factor)	Raster	Rainfall data was obtained from Meteorological Department of Sri Lanka
3	Soil erodibility (K factor)	Raster	Soil type map was obtained from Irrigation Department of Sri Lanka
4	Land Use Land Cover (LULC)	Raster	Survey Department of Sri Lanka
5	Watershed	Vector	Demarcation using watershed tool in hydrology tools of ArcGIS 10.5
6	Sub- watersheds	Vector	Demarcation using watershed tool in hydrology tools of ArcGIS 10.5
7	Biophysical table	.CSV	Secondary data
8	Threshold flow accumulation	Subjective value	Secondary data

Table 2: The average NDVI values extracted for the selected sub-watershed within the study area

Watershed ID	Sediment retention t/ha/yr	Sediment export t/ha/yr	Total_soil_loss t/ha/yr
1	427.4	2.0	38.2
2	1077.1	18.0	146.9
3	4859.1	60.7	407.3
4	8637.7	33.4	190.1
5	7276.6	88.2	422.1
6	2812.0	22.4	151.5
7	2053.8	48.2	395.5
8	1839.2	7.7	71.5
9	2505.2	12.7	138.5
10	243.1	1.8	22.4
11	1592.8	15.3	129.8
12	1665.5	7.9	72.7
Watershed	2602.4	20.3	139.9

Table 3: Values of sediment retention, sediment export and total soil loss

No	Sampling locations	Avg. NDVI
1	Balangoda	0.244
2	Oluganthota	0.144
3	Imbulpe	0.2484
4	Belihuloya	0.288
5	Hirikatuoya	0.257
6	Puwakgahawela	0.328
7	Thanjantenna	0.228
8	Diyawinna	0.371
9	Kuragala	0.334
10	Welioya	0.359
11	Rajawaka	0.338
12	Handagiriya	0.340

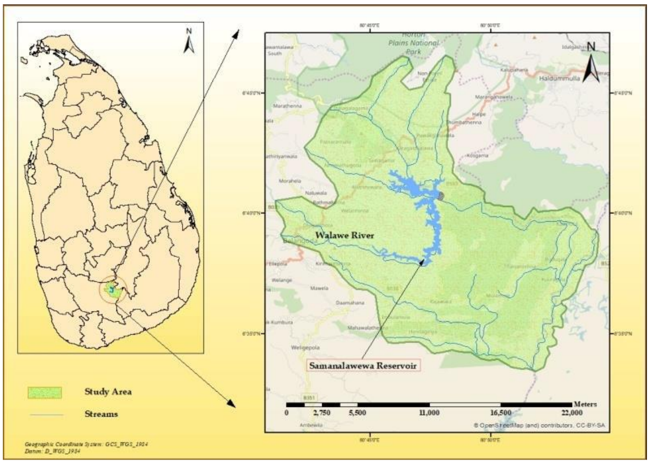

Figure1: Samanalawewa watershed

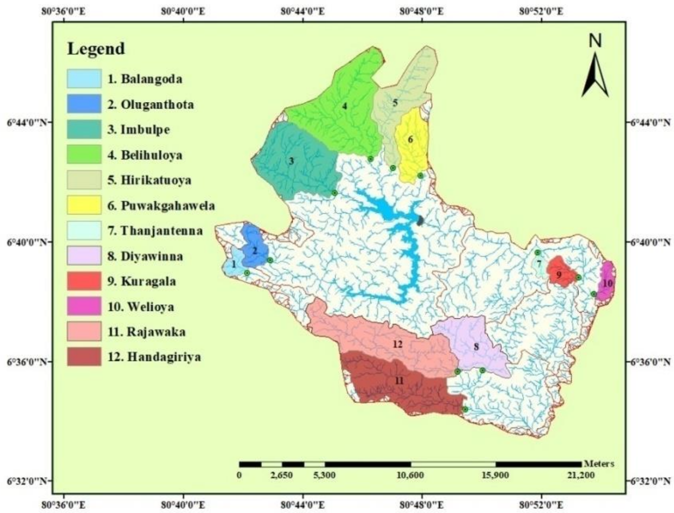

Figure 2: Sample locations of Samanalawewa watershed

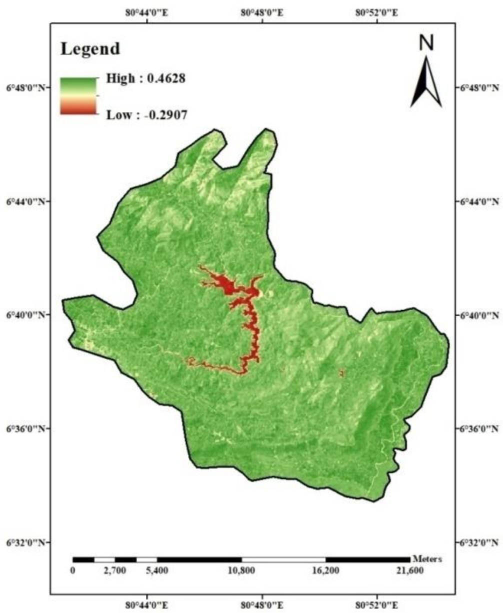

Figure 3: NDVI map of Samanalawewa watershed