Modeling the Influence of Land Use/Land Cover Changes on Sediment Yield and Hydrology in Thika River Catchment Kenya, Using Swat Model

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Abstract
The Thika River catchment has undergone tremendous changes in land use and land cover in the recent past. These changes are suspected to have impacted negatively on the hydrology and soil conservation of the catchment. In order to make recommendation for the management of the Catchment, a study was undertaken to assess the impact of the changes in land use and land cover on water and sediment yield on Thika River Catchment, whereby land cover changes from the satellite images of 1987 and 2000 were analysed. Weather and stream flow data for the years 1979-1984 was used to simulate streamflow and sediment yield using Soil and Water Assessment Tool (SWAT) model. Remote sensing and GIS techniques using Idrisi Kilimanjaro software were used in evaluating land use and cover changes. The results revealed that the forest cover in the Thika River catchment decreased by 36%, the area under horticultural crops increased by 32% while the built up area expanded by a whopping 141%. Deforestation is mostly occurring on the highlands forests whereas opening of land for agriculture is in the upper midland and along the river channels. The calibrated SWAT model accurately predicted the streamflow in the Thika River under different land use and land cover scenarios with an R^2 of 82%. The scenario studies indicated that increasing forest cover would substantially reduce sediment yield and modulate stream flow. A 100% forest cover would decrease the current sediment yield by 30%, while a decrease in forest cover of 20% would increase sediment yield by 40%. It is therefore recommended that planting of trees and agroforestry should be undertaken to increase the forest cover of the catchment and consequently reduce sediment yield.

Key words: SWAT, Modeling, Land Use/Land cover Changes, Influence, catchment Sediment yield.

1. INTRODUCTION

Soil erosion is a worldwide environmental problem that degrades soil productivity and water quality, causes sedimentation of reservoirs and increases the probability of floods (D.Oyung & J. Bartholic,2001). Most of the countries in the tropics have no appropriate and accurate soil erosion prediction model although the Soil Loss Estimation Model for Southern Africa (SLEMSA) and the Universal Soil Loss Equation (USLE) are used in different tropical countries (M.K. Mulengera, 1999).

Thika River contributes substantially to the sedimentation of the dams situated along River Tana (D.B Thomas, 1992). The report (D.B. Thomas, 1992) showed that River Thika contributes a total of about 75,188 tonnes of suspended sediment per year. It is estimated that the annual loss in storage capacity of the world's reservoirs due to sedimentation is around 0.5-1.0%. For many reservoirs, however, annual depletion rates are much higher and can go up to 4% or 5% such that they lose the majority of their capacity after only 25-30 years. The Masinga reservoir located in the catchment provides a substantial proportion of power and water consumed in Kenya.

The reservoir which was designed for hydropower generation, public water supply and irrigation is faced with severe sedimentation. The designed sediment load into the reservoir in 1981 was estimated to be 3.0×10^6 m^3 per year, about 1% per annum reservoir reduction (B.M. Mutua et al,. (2000). By the year 2000, annual sediment loading had increased to over 11.0×10^6 m^3, nearly four times more, reducing the design capacity by more than 15% (B.M. Mutua et al,. (2000).

As land degradation has become more evident with numerous land uses e.g. the stone quarries within upper Tana Catchment over the years, the operation and life span of reservoirs is therefore under imminent danger from erosion and sedimentation. Deforestation on the upper zones of the catchment and neglect of steep lands previously used in growing of coffee, has also contributed to soil erosion that eventually leads to a very high sediment yield. In the middle zone of the catchment, the Thika River passes through intensively cultivated steep slopes devoid of proper soil conservation practices around Gatunyu market. This zone has widespread riverbank cultivation for horticultural crops, which has exposed the banks to severe soil erosion. In the lower areas and plains overgrazing and felling of trees for charcoal burning has caused widespread soil erosion (C.C.K. Gachene (1995). In order to come up with plausible recommendations to reverse the soil erosion and curb dams sedimentation, there was need to conduct a study to evaluate and document the effect of the changes of the land use and land cover over the years on soil erosion and siltation of the reservoirs in the catchment.

2. METHODOLOGY

The required input data for this study were Digital Elevation Model (DEM), landuse/landcover map, soil map and soil data, weather data, Landsat images, sediment and stream flow data. This data was available from various sources, which includes Internet, Ministry of Water and Irrigation (MWI), Kenya Meteorological Department (KMD), Kenya Soil Survey (KSS) and Regional Centre for Mapping of Resources for Development (RCMRD). Land use/land cover map was obtained from the International Livestock Research Institute (ILRI). GIS database were found at www.ilri.cgiar.org/gis and Kenya Soil Survey.

A Digital Elevation Model (DEM) gives the elevation, slope and defines the location of the streams network in the catchment. A Thika catchment DEM with a spatial resolution of 90 x 90 m was used in this study. The DEM was in Lambert Equal Area Azimuthal projection (LEAA). The terrain data at a resolution of 90 x 90 m was obtained from the Shuttle Radar Topography Mission (SRTM) data (FAO, 2004), which in turn had been acquired from USGS EROS data archives. The DEM was clipped using GIS techniques. Land use/land cover data combined with soil data was used to give hydrologic characteristic of the catchment, which was used to determine the amount of excess precipitation, recharge to the ground water system and storage in the soil layer. Land use/land cover map for the year 2000 was used.

The soil data required for SWAT to predict stream flow are those that describe the hydraulic properties of the soil. The stream flow data were available for two gauging stations in the Catchment: 4CB04, and 4CB05. The 4CB05 station had data ranging from 1995-2000 but there was a lot of missing data and only station 4CB04 had all the required data. Table 3.2 gives a summary of the stream flow data. The sediment data were available for the year 1984 for gauging station 4CB04. More sediment load data was collected between April and June 2006. Water samples from the Thika River for sediment analysis were collected at various locations in the catchment. The data from these samples was to be used in comparing sediment concentration from different land uses and land covers. Rainfall data were available for thirteen rainfall-recording stations in and around the catchment. These data were maximum and minimum temperature, solar radiation, relative humidity and wind speed. Other data was obtained from Kenya Meteorological Department (KMD).

Landsat images bands 1 to 4 for MSS and bands 1 to 5 and 7 for TM and ETM + images of 1987 and 2000 which completely cover the catchment were used in this study.

SWAT

Soil and Water Assessment Tool (SWAT) is a process based continuous daily time-step model. It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time S.L.Neitsch (2000a). Figure 1 show the process and display of the SWAT model.

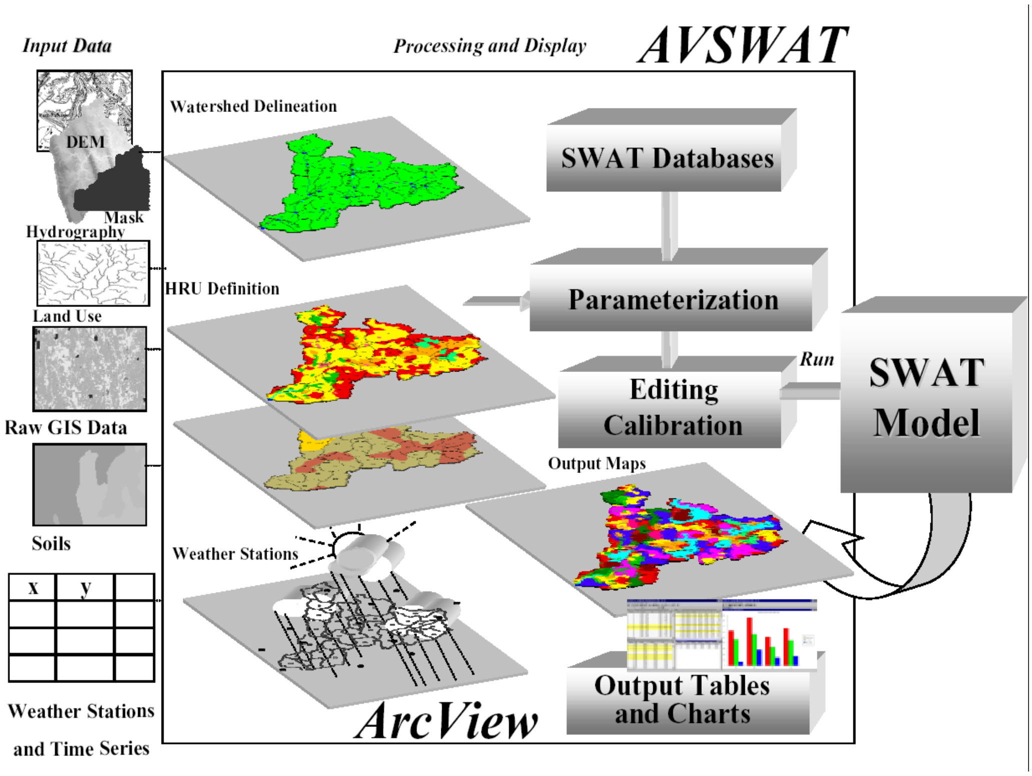


Figure 1: Shows the processing and display of SWAT model.

3. RESULTS AND DISCUSSIONS

3.1. Land Use/Land Cover Change Analysis

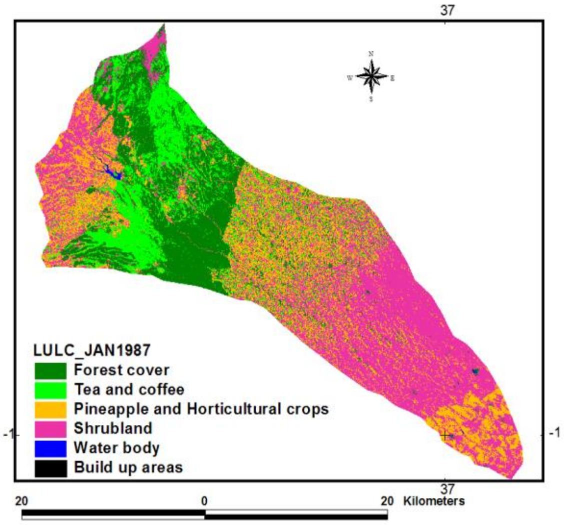
After the analysis of LandSat MSS, TM and ETM images of Thika River Catchment for the years 1987 and 2000, land use/land cover maps shown in Figure 2 were obtained. The area of the catchment covered by each land cover type for 1987 and 2000 are also shown in Table 3.1

Table 3.1: Land use /land cover areas change statistics.

Land cover type	Area in1987 (km^2)	Area in2000 (km^2)	Change in Area (1987-2000) (km^2)	Change (%)
Forest	175	115	-60	-36
Tea and coffee field	136	131	-5	-3.7
Pineapple and horticultural crops	191	259	68	32
Shrubland	341	320	-21	-7.5
Water Surfaces	1	2	1	100
Built up areas	12	29	17	141
TOTAL	856	856		

Table 3.2: Summary of the available stream flow data in Thika River Catchment.

Gauging Station	River	Daily mean flow(m^3/s)	Period recorded
4CB04	Thika	10.2	1995-1999
4CB05	Kayuyu	1.31	2005-2006



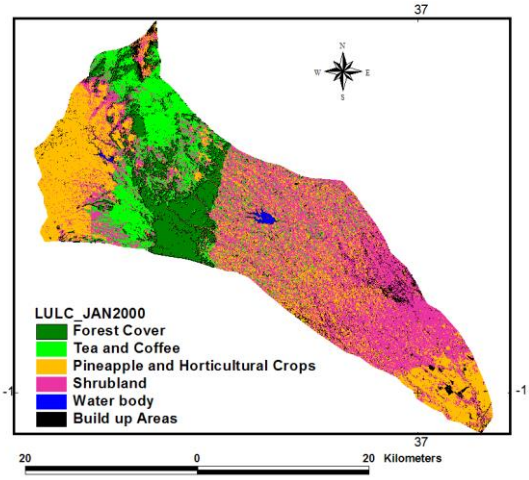


Figure 2: Land cover maps prepared for 25th Jan 1987 and 21st Jan 2000

These land cover maps were prepared for the two separate years 1987 and 2000 to compare the activities that had risen and the extent of change within the 13years duration.

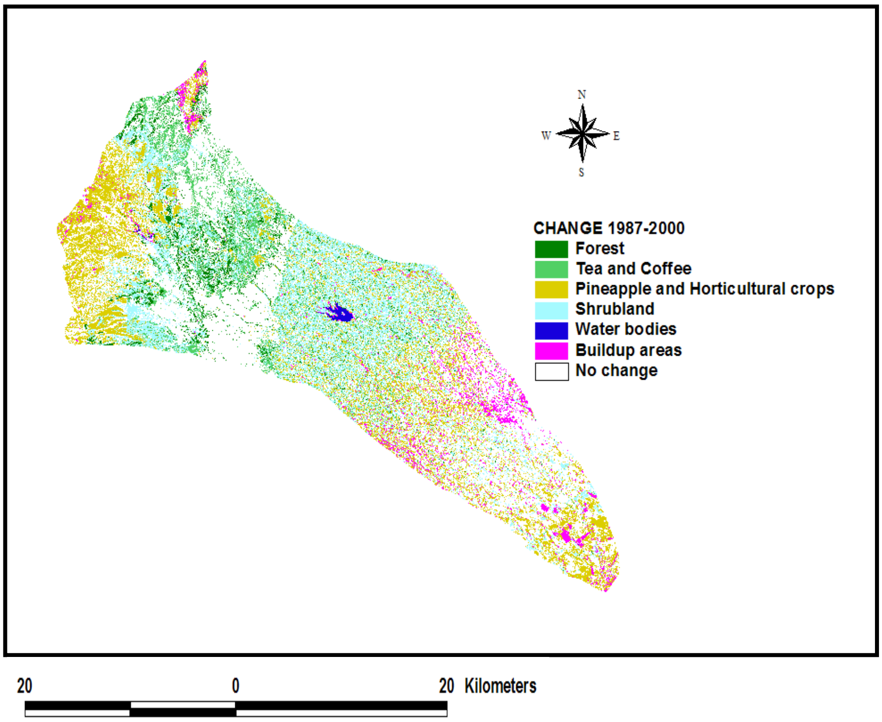


Figure 3: Changes in landuse/landcover 1987-2000

The changes in land cover between 1987 and 2000 are presented in Figure.3. The map was developed using image differencing technique in GIS with the use of Idiris Kilimanjaro software.

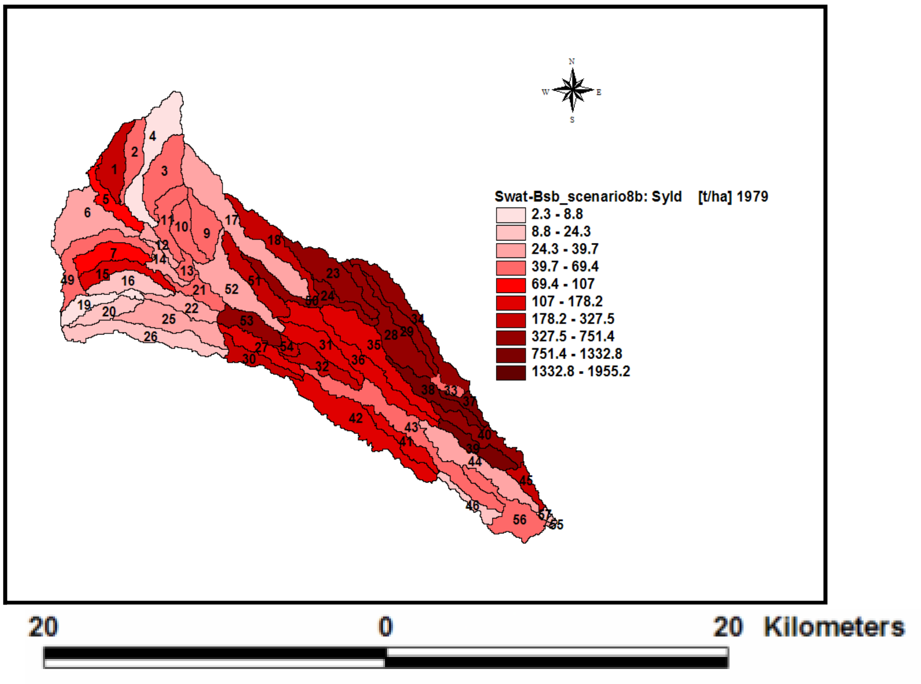


Figure 4: Simulated Sediment yield from each sub-catchment for the year 1979.

Different parts of the catchment have varying sediment yields depending on the land cover and land use and human activities in a given part. Sediment yield is highest in sub-catchments 28, 29, 34, 37, 38. In these sub-catchments, there is intensive cultivation on hilly areas without much attention to soil conservation measures giving rise to high surface runoff as shown in Figure 4 produced when SWAT model was run.

4. CONCLUSION AND DISCUSSION

The Thika River Catchment has in a period of 13 years (1987-2000) undergone a tremendous changes in land cover with the natural cover of forests, shrubland and coffee and tea land being opened up for other uses. The forest cover, shrubland and tea and coffee have decreased by 36%, 7.5 % and 3.7 % respectively. The aerial coverage of pineapple and horticultural crops, water bodies and built up areas have increased by 32%, 100% and 141% respectively. Deforestation is mostly occurring on the highlands forests whereas opening of land for agriculture is in the upper midland and along the river channels. The calibrated SWAT model performed well in simulating stream flow and sediment yield with a coefficient of determination of 0.82, despite scarcity of adequate data in the catchment. It captured the stream flow and sediment yield fairly accurately across the catchment and especially at the catchment outlet gauging station. However due to lack of continuous sediment data, the simulation results of sediment yields can only be taken as indicators of the likely trends rather than absolute values. The scenario studies indicated that increasing forest cover would substantially reduce sediment yield and modulate stream flow.

5. ACKNOWLEDGMENT

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