Effect of Land Use Changes on Sediment Load in the Zagbo River Catchment in Southern Benin

Olanrewaju Lawal[1], Thomas Gaiser, Karl Stahr

Institute for Soil Science and Land Evaluation, University of Hohenheim, D-70599 Stuttgart-Germany

1. Introduction

Agriculture is the most important economic sector in Benin, 60% of the active population is engaged in agricultural activities. There has been an increase in cultivated surface in Benin from 1,080,000 ha in 1961 to 1,717,000 ha in 1994, which means a relative increase of 59 % (FAO, 1997). Benin's population is unevenly distributed. More than two-thirds of the people live in the south, where population densities are among the highest in West Africa.

The Abomey plateau on which the Zagbo catchment area is located, is heavily influenced by its history as central territory of a formerly important kingdom. It has a population density of 225 inhabitants per km^2 according to the 1992 census. Nowadays, the plateau is characterised by soil degradation, scarcity of forest cover and low agricultural yields.

In the original farming systems of southern Benin there was abundant fallow land, which made it possible to practice shifting cultivation. However, due to population pressure and migration, land became scarce and as a result cropping intensity has increased and fallow period shortened. With this increasing population pressure and increasing cropping intensity, farming systems are changing from semi-permanent to continuous cropping system thus making the traditional ways of restoring soil fertility via fallow impracticable, consequently resulting in reduction of agricultural productivity. The challenge is to bring to a halt the negative trend in agricultural productivity due to soil loss and soil degradation, and to reverse the deterioration of the productive base (soil).

The Soil and Water Assessment Tool (SWAT) is a model developed to predict the effect of different land management scenarios on water quality, sediment yield and pollution by agricultural chemicals in large complex watersheds with varying soils, land use and management conditions over long periods of time. This research applies the SWAT model to the Zagbo catchment area in Southern Benin to quantify changes in

- the hydrologic parameters - water yield, soil moisture etc., and
- the sediment load into the water bodies

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[1] Corresponding author, Email: hypery2kus@yahoo.com

based on the changes in land use over the years.

In order to assess the sediment load on a regional scale, which may arise from such anthropogenic activities, a geographic information system of the relevant surface properties was generated for regional modeling using the SWAT model.

2. Materials and Methods

2.1 Study Area

The Zagbo river catchment is located in the Abomey-Bohicon region. This region is situated in the south of the Zou department (state) and covering an area of 1487 km^2, the Abomey plateau stretches 43 km EW between 1°53’ and 2°27’ eastern longitude and 37 km NS between 7°00' and 7°23' northern latitude. It is limited by the Zou river and the Zagnanando plateau in the east, in the west by the Couffo river and the Aplahoue plateau, in the north by crystalline outcrops of Dan and in the south by the Lama depression.

The Abomey-Bohicon region belongs to the Guinea-Congolian vegetation zone (Wezel & Böcker, 2000). This zone is characterized by a mosaic of forest and savannas, where most of the original vegetation has been replaced by secondary grasslands or savannas due to human intervention.

2.2 Material

The AVSWAT-2000 (Di Luzio *et al.*, 2002) an ArcView extension and a graphical user interface for the SWAT (Soil and Water Assessment Tool) model was used for the modeling. The AVSWAT-2000 ArcView extension evolved from AVSWAT, an ArcView extension developed for an earlier version of SWAT (Di Luzio *et al.*,1998).

The system has components for complete and advanced watershed delineation, definition of Hydrologic Response Units (HRU), and the latest version of the SWAT model with a relative interface.

The database for the modelling operations covers the Zagbo river catchment and consists of the following geographic information stored in a relation database management system:

- Soil association map - BENSOTER (Weller, 2002)
- Digital elevation model derived from Topographic Map of Benin (IGN, 1968)
- Meteorological data from Bohicon weather station and FAOCLIM 2 Database (FAO, 2001)

- Land use/land cover map of 1954 and 1988 (IBS-Uni-hohenheim, *2000*)
- Streamlines of Zagbo river digitized from topographic map of Zangnanado area (IGN, 1987)

The soil data structure follows the concept of the SOTER approach (FAO, 1995) and the World Reference Base of Soil Resources. 3 soil associations were identified within the Zagbo catchment area (Table 1).

Table 1: Properties of selected soil associations within the Zagbo catchment

Soil Assoc. Horizon No.	Depth (mm)	Bulk Density (g/cm^3)	Org. Carbon (%)	Particle Size Distribution (%)			USLE K-value	Sat. Hydr. Cond. (mm/hr)	Soil AWC (%vol)	Soil Albedo
				Clay	Silt	Sand				
BJ20										
1	50	1,20	0,98	43,3	38,9	17,8	0,20	6,70	0,16	0,09
2	200	1,12	1,15	60,3	18,5	21,2	0,07	9,30	0,13	0,08
3	500	1,26	0,30	41,5	42,4	16,1	0,20	2,10	0,16	0,13
4	1000	1,30	0,17	38,5	38,0	23,5	0,20	1,70	0,15	0,14
BJ26										
1	250	1,41	0,93	16,2	24,0	59,8	0,20	24,90	0,12	0,09
2	650	1,26	0,33	50,8	17,8	31,4	0,10	1,40	0,12	0,09
3	1000	1,25	0,20	55,4	18,0	26,6	0,10	1,10	0,13	0,14
BJ28										
1	200	1,53	0,97	8,2	8,6	83,2	0,19	75,70	0,10	0,09
2	600	1,31	0,52	39,5	7,9	52,6	0,10	1,80	0,09	0,12
3	1000	1,31	0,34	43,3	13,1	43,6	0,13	1,40	0,11	0,12

The major land use consists of farmland and fallow (maize), gallery forest, tree and shrub savanna, settlement and woodlands (Table 2). Extraction of necessary climatic data (Table 3) was carried out and the daily rainfall was obtained from the Bohicon weather station, which is the closest weather station to the Zagbo catchment.

Table 2: Land use/cover distribution of Zagbo Catchment area

Land Use	**Area Covered 1954 (ha)**	**Land Use**	**Area Covered 1988 (ha)**	**Change in %**
Farmland & Fallow	4927,21	Farmland & Fallow	4631,77	-5
Gallery Forest	462,64	Gallery Forest	0	-100
Plantation	0	Plantation	37,06	+100
Settlement	28,42	Settlement	472,75	+95
Shrub Savanna	106,13	Shrub Savanna	218,25	+51
Tree Savanna	45,60	Tree Savanna	191,13	+76
Woodland	3,51	Woodland	22,55	+84

2.3 Methods

The Zagbo river catchment covers an area of about 5574 hectares, and after the processing of the DEM and the streamlines by SWAT 8 subbasins were identified. The model also automatically creates an outlet for each of these subbasins and the main outlet of the entire watershed was manually identified to be the point at which the river empties into the main Oueme river.

Runoff is predicted separately for each hydrological response unit (HRU) and routed to obtain the total runoff for the watershed. This increases the accuracy of load predictions and provides a much better physical description of the water balance. A five percent threshold value was specified for both the land use and soil data to determine the number and kind of HRUs in each subbasin. Land uses that cover a percentage of the subbasin area less than the threshold level are eliminated. After the elimination process, the area of the remaining land uses is reapportioned so that 100% of the land area in the subbasin is modeled. This was thought to be realistic to avoid over generalization by using the dominant land use and soil class. Thus a total of 30 and 32 HRUs were created for 1954 and 1988 respectively. Each of the HRU represents an area with unique land use and soil class combination.

The sediment yield and sediment concentration for each subbasin was estimated with the SWAT model (Version AVSWAT2000). Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams,1975).

Table 3: Summary of weather data used for the model simulation (long term averages)

Months	Tmax (°C)	Tmin (°C)	Precipitation (mm)	Solar Radiation (MJ/m^2 day)	Dew Point (°C)	Wind Speed (m/s)
Jan.	33,66	21,43	2	18,17	21,73	2,03
Feb.	34,93	23,07	32	19,85	20,97	2,45
Mar.	34,66	23,53	66	19,51	23,33	2,44
Apr.	32,92	23,20	126	19,51	23,77	2,06
May	31,84	22,95	133	18,92	23,55	2,07
Jun.	30,09	22,03	152	17,58	23,02	2,21
Jul.	28,74	21,57	121	15,41	22,20	2,39
Aug.	29,18	21,21	100	14,65	21,76	2,40
Sept.	29,83	21,68	131	15,49	22,77	2,10
Oct.	30,99	21,93	99	19,09	22,95	1,71
Nov.	33,33	22,24	21	19,22	22,83	1,55
Dec.	33,20	21,48	14	17,33	20,58	1,76

The effect of land use changes was estimated by keeping constant the weather data (rainfall) while only landuse was changed. The simulation run was made for a maximum of five years (two years before the year of interest and 2 years after). This was done to exclude the effect of inter-annual weather variability and provide adequate information for statistical data analysis. The printout frequency was set to monthly. Output from the simulation was subjected to statistical analysis to achieve the objectives of the study. Variables are analyzed to check the differences between study periods (Paired T-test). The analysis was carried out on the mean monthly values.

3. Result and Discussion

The result of the analysis of variance for 1954 and 1988 (Table 4a&b) land use pattern revealed that only sediment yield (n = 96) was significantly different ($P \leq 0.05$) among the subbasins within the catchment area. Subbasin 2 exhibits a significantly different (higher) mean monthly sediment yield for both periods compared to any other subbasin.

Table 4a: Analysis of variance of sediment yield (1954 land use pattern)

Parameters	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Sediment yield	Between Groups	31,91	7	4,56	2,84	0,01
	Within Groups	141,35	88	1,61		
	Total	173,26	95			

Table 4b: Analysis of variance of sediment yield (1988 land use pattern)

Parameters	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Sediment yield	Between Groups	43,29	7	6,18	2,85	0,01
	Within Groups	191,26	88	2,17		
	Total	234,55	95			

Mean monthly soil water was found to be lowest (for both periods) in Subbasin 2. This could be traced to the high value of bulk density ($1.53 g/cm^3$ – topsoil) of the predominant soil association - BJ28 (84% of subbasin 2). The high bulk density could also be implicated in generating higher water yield due to reduced infiltration. The predominant land use (85%) under farmland (and fallow) could as well generate a lot of sediment from this subbasin. The predominant soil association (BJ28) was also reported by Weller (2002) to belong to the major sloping terrain of southern Benin (with high to moderate slope steepness).

Estimated mean monthly sediment yield (Fig. 1) for the 1954 land use pattern was found to be slightly higher than that of 1988 for all subbasins except subbasins 1 and 2. This is due to the replacement of gallery forest by farmland (& fallow) and settlement in subbasins 1 and 2. Mean (estimated) monthly sediment concentration (Fig. 2) in the reach shows only slight difference except for subbasin 4 and 7. The difference in subbasin 4 may be attributed to the emergence of high density settlement and disappearance of gallery forest thus allowing sediment to reach the channel more easily than in the 1954 land use pattern. Also the degradation of the stream channel could have contributed to this increase in concentration.

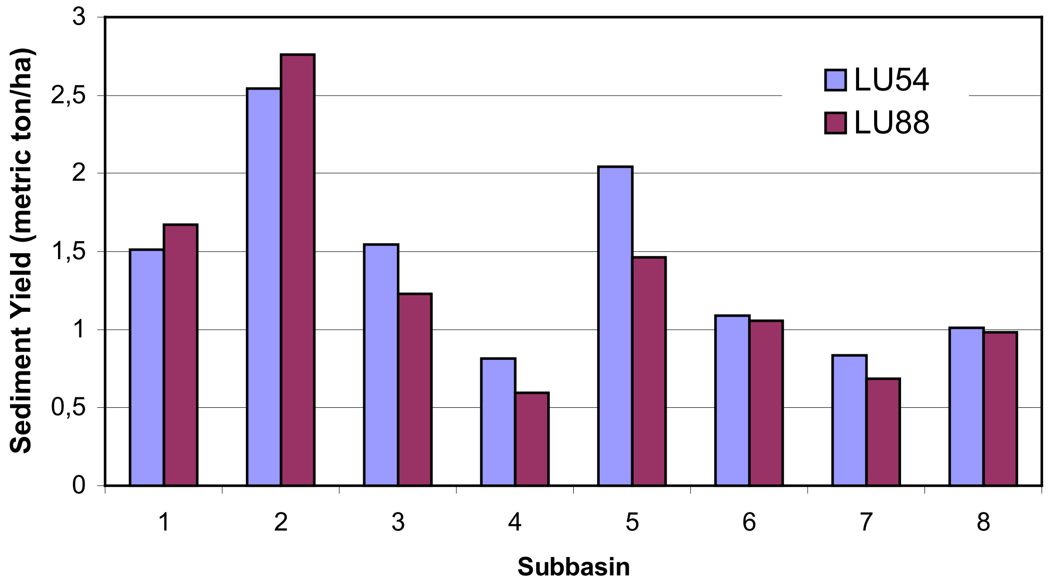

Figure 1: Estimated mean monthly sediment yield per subbasin for 1954 (LU54) and 1988(LU88) land use/cover.

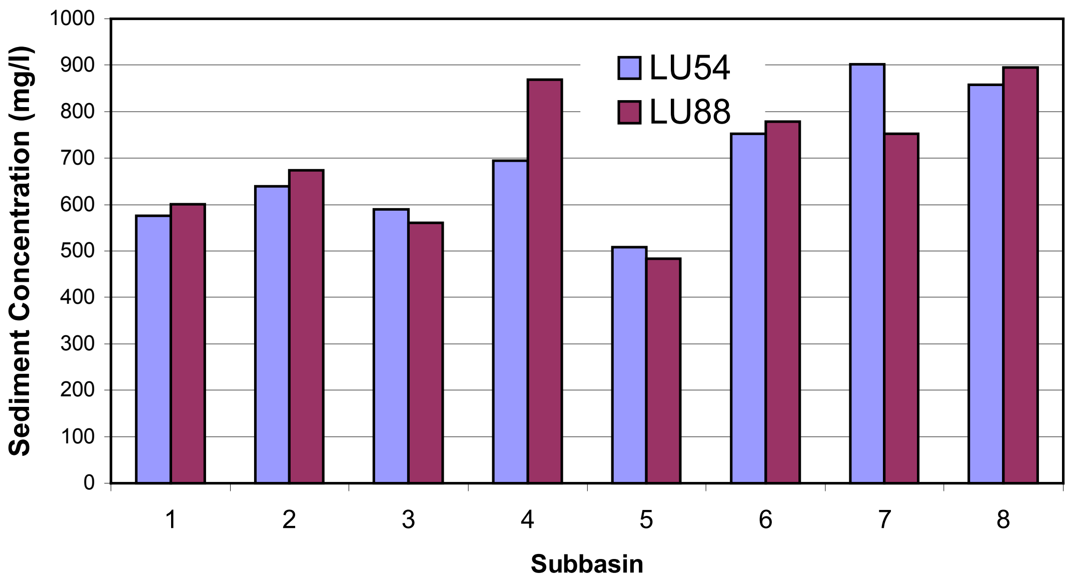

Figure 2: Estimated mean monthly sediment concentration per subbasin for 1954 (LU54) and 1988(LU88) land use/cover.

The analysis revealed that there was a significant difference ($P<0.05$) for sediment yield while there was no significant difference between the sediment concentrations for the two land use patterns. Sediment yield (mean monthly) showed a very slight reduction from 1954 to 1988 (land use patterns). But a look at the confidence interval of the paired difference (0,05 –0,19 $t.ha^{-1}$) showed that this difference is not really environmentally significant. Therefore differences observed in sediment yield could not have any significant impact on the catchment area (i.e. at the catchment scale). It is noteworthy also that there was an increase in sediment concentration but the difference was insignificant ($P \leq 0.05$) which could have been brought about by the increase in runoff or channel erosion as there is a complete loss of gallery forest on the river banks.

4. Conclusion

The SWAT model was found to be useful in identifying effect of land use changes on hydrological properties and sediment yield. The SWAT model simulation for the Zagbo catchment provides an estimate of changes in selected hydrological characteristics and sediment yield for the major land use patterns given the rainfall in Southern Benin (Bohicon) and the soil associations identified for this area (BJ20, BJ26 and BJ28). From the simulation results it could be concluded that:-

- Sediment yield was the only parameter that differs among the subbasins for all the data sets, thus indicating subbasins where measures for erosion control needs to be implemented. The order of need (subbasin) for erosion control in the catchment was identified: 2>1>5>3>6>8>7>4,
- Changes in land use from 1954 to 1988 land use pattern caused a slightly lower sediment yield and a higher but an insignificant difference in sediment load (from 1954 – 1988 land use pattern),

The input parameters used for the simulation are subjected to considerable uncertainty. However, for the case studied estimates of water balance components are relatively robust as they are based on observed daily rainfall data. The model is quiet flexible, thereby making it possible to use available information. The quality of the prediction could definitely be improved, if more data are available like data on water use, groundwater (characteristics), more detailed soil map and use of more weather stations (due to high variability of rainfall). The inability of the model to delineate the HRU on the map reduces the possibility to examine in detail the attributes that characterize each HRU and how they change over time. This also reduces the possibility for assessment of spatial variability of the parameters tested, as they are all lumped together into one value for each subbasin. Also the databases on land cover and land use as well as tillage are quite inadequate as they contain only major economic crops in the USA and other developed countries. The same can be said of the tillage implements. Allowing the inputs to vary within a realistic range also reduced uncertainty in the model inputs that could be attributed to spatial variability and measurement.

Unfortunately the accuracy of the predictions could not be rigorously tested. They should thus be considered as well based working hypotheses, which may be modified or refined as additional data become available. Therefore, further studies will be suggested to test the accuracy of the predictions using water discharge rates and sediment concentration, from gauging stations.

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