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Land-use and land cover, sediment and nutrient hotspot areas changes in Lake Tanganyika Basin

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ABSTRACT
The impact of global land use and land cover changes in relation to climate change and declining biodiversity has been a subject of interest in the recent years. Nonetheless, there is limited data capturing trends in land use and land cover changes in the Tanganyika catchment. This study characterized the trend in land use/ cover changes and examined the change in sediment and nutrients hotspot areas in the Kalimabenge micro-catchment, for the last 40 years. Land use/cover change was quantified and reconstructed by analyzing a series of Landsat images taken in 1973, 1986, and 2010 using the Integrated Land and Water Information System (ILWIS) 3.3 software and field observations. Both supervised and non-supervised classifications were used in the classification of the Landsat images in order to obtain the land use/cover change map. Sediment and nutrient loading into the Kalimabenge micro-catchment were modeled using ArcSWAT software integrated in ArcGIS 9.3. ArcSWAT was calibrated using two years field observations at the river outlet into Lake Tanganyika. Results showed that the dominant land use/covers in the micro-catchment are cultivated land, followed by forest/tree plantations, grassland and built-up area. Grassland/savannah has declined gradually over time, forest/woodlot land increased gradually, built up areas acreage remained quasi similar, cultivated land followed a quadratic trend. The partial sources of sediments, runoff and phosphorous changed for the last 4 decades. These sources areas first decreased in 1986 and then increased in 2010.

Key words: Deforestation, Lake Tanganyika, pollution loading, soil erosion, South-Kivu, Uvira

RESUME
L'impact des changements globaux dans l'utilisation des terres et la couverture végétale en rapport avec les changements climatiques et la réduction de la biodiversité a été un sujet d'intérêt ces dernières années. Néanmoins, il existe des données limitées reproduisant les tendances dans les changements de l'utilisation des terres et de la couverture végétale pour le bassin versant de Tanganyika. Cette étude a caractérisé la tendance dans les changements de l'utilisation des terres et de la couverture végétale et a examiné le changement dans les régions à point chaud de sédiments et de nutriments dans le micro-bassin versant de Kalimabenge, pour les quatre dernières décennies. Le changement dans l'utilisation des terres et dans la couverture végétale a été quantifié et reconstruit en analysant une série d'images Landsat prises en 1973, 1986 et 2010 en utilisant le logiciel ILWIS 3.3 qui est un système intégré d'information sur l'eau et la terre et en utilisant les observations sur le terrain. La classification supervisée et celle non supervisée ont été utilisées dans la classification des images Landsat afin d'obtenir la carte de changement dans l'utilisation des terres et la couverture végétale. Les chargements des sédiments et des nutriments dans le micro-bassin versant de Kalimabenge ont été modélisés à l'aide du logiciel ArcSWAT intégré dans ArcGIS 9.3. ArcSWAT a été calibré en utilisant des observations sur le terrain de deux ans à l'exutoire de la rivière dans le lac Tanganyika. Les résultats ont montré que l'utilisation des terres et la couverture végétale dominante dans le micro-bassin versant sont les terres cultivées, suivies par la forêt/les plantations d'arbres, les prairies et les agglomérations urbaines. La prairie et la savane ont diminué progressivement au cours du temps, la forêt et les espaces boisés ont augmenté progressivement, la superficie des zones d'agglomération urbaine est restée quasi similaire et les terres cultivées ont suivi une tendance quadratique. Les sources partielles

de sédiments, de ruissellement et du phosphore ont changé durant les quatre dernières décennies. Ces zones sources ont d'abord diminué en 1986, puis elles ont augmenté en 2010.

Mots clés: Deforestation, Lake Tanganyika, pollution loading, soil erosion, South-Kivu, Uvira

INTRODUCTION

Over the last decades there has been increasing interest in the impacts of global land use and land cover changes (Wood *et al.*, 2004). These changes are associated with a wide variety of issues, including declining biodiversity (Darkoh, 2003), change in hydrology and ecosystem services, global climate change, food insecurity, and land degradation. Human activities are recognized worldwide as the causes of these changes (Timberlake, 1985; Biswas *et al.*, 1987; Houghton, 1994; Moser, 1996; de Koning *et al.*, 1999; Kok *et al.*, 2001). Several studies (Elkholm, 1994; Isabirye *et al.*, 2001; Albinus *et al.*, 2008; Kusimi, 2008) have shown significant association between land use changes and horizontal expansion of agricultural land, settlements and industries, fuelwood gathering and logging in Africa. In the last few decades, conversion of grassland, woodland, wetlands and forest into cropland, pasture, built up area, plantations and industrial areas has risen dramatically in the tropics (Houghton, 1994; Majaliwa *et al.*, 2010; Ouedraogo *et al.*, 2010; Barasa *et al.*, 2011). Many factors cited as causes of land use change in Africa, include inappropriate farming practices on fragile lands without conservation measures (Kajembe *et al.*, 2005), rapid local population growth or migrations (Bilsborrow, 1992; Lombardozzi and O'Reilly; Swanson, 1996), inadequate land tenure, overstocking (Kajembe *et al.*, 2005), over-exploitation of natural resources (Emerton *et al.*, 1998; Kyambadde *et al.*, 2004; Schuyt, 2005), shifting cultivation in forests, and the use of firewood or charcoal as fuel by the poor (Babanyara and Saleh, 2010).

Lake Tanganyika is one of the richest fresh water ecosystems in the world. However, it is among the most highly sensitive and fragile ecosystem in the Africa Great Lakes Region (Bruton and Merron, 1990; O'Reilly, 2002; Snoeks *et al.*, 2000). Currently it possesses a unique type of flora and fauna of global interest (Harrison *et al.*, 1982) but its basin has been experiencing significant land-use/cover changes in the last five decades due to anthropogenic activities (Alin *et al.*, 2002; Downing *et al.*, 1999; O'Reilly, 2002) and most especially deforestation and wildfire (Cohen *et al.*, 2005). The latter are induced by humans in search of firewood and new land for farming (Mashalla, 1988). Large-scale land clearing for cultivation and large-scale timber harvesting for fuelwood have been reported to be the root causes of deforestation carried out by local people and refugees in order to satisfy their need for food and energy (Cohen *et al.*, 1993a; Cohen *et al.*, 1993b). In the last fifteen years political instability, tribal and ethnic conflicts, and repetitive wars, causing migration of populations have aggravated the already fragile conditions in the region (Black *et al.*, 2008; Majaliwa, 2008; Bagalwa *et al.*, 2015).

Changes in land-use/cover, poor management of the micro-catchment compounded with climate change have enormously contributed to increased soil erosion and pollution related loadings into the fresh surface waters of Lake Tanganyika (O'Reilly *et al.*, 2003; Rosenzweig *et al.*, 2008). Sediment and nutrients loading from watersheds towards the river water is a function of the size of the river micro-catchment, its topography, climate, soil characteristics and vegetation cover and their distribution and the nature and quality of other human activities (Gorgula and Connell, 2004; Houlahan and Findlay, 2004; Jha *et al.*, 2004; Liu *et al.*, 2004; Puigdefábregas, 2005; Thomasa *et al.*, 1999; Young *et al.*, 1989; Turner, 1993). Values of 300 to 700 t/ha/yr have been reported in Rwanda, on 20 to 60% slopes (Roose and Ndayizigiye, 1997). In the Lake Tanganyika basin like other lake basins in the region, non-point agricultural land sources of pollution have been identified as a major source of sediment and nutrients in surface waters (Cooke and Prepas, 1998; Devito *et al.*, 2000; Majaliwa and Magunda, 2004).

In the late 1970s, a concerted effort was made in the management of the Lake Tanganyika catchment in Eastern Democratic Republic of Congo (DRC) through afforestation. This approach coupled with promotion of energy efficient technology was supposed to yield significant environmental and economic benefits (Black and Sessay, 1997; Kristy and Susan, 2002). Unfortunately, these reform attempts were thwarted by a series of exogenous shocks including sectorial and uncoordinated nature of actions and lack of adequate implementation of strategy. The strategy did not take into account the demographic pressure on forest resources and the evolution of household energy consumption. Thus, when the region suffered from the scarcity or lack of electricity and the unavailability of kerosene, significant changes occurred in terms of land-use/cover in the region (Elkan, 1988).

Several scholars report that the Lake's basin is undergoing deforestation at an alarming rate; around 50% of the central areas have been cleared of their natural vegetation, leading to increased erosion (Cohen *et al.*, 2005; Cohen *et al.*, 1993b; Jorgensen *et al.*, 2006; Lambin *et al.*, 2003). However, very few studies have tried to quantify the amount of sediments and nutrients loading into the Lake waters due to the on-going land-use/cover change, and identify the sources of these sediments and nutrients in the DRC side. This study therefore characterizes the trend in land use/ cover changes, and examined the changes of sediment and nutrients hotspot areas in Kalimabenge micro-catchment for the last four decades. This information could be used to design a quick restoration strategy of the micro-catchment and the Lake Tanganyika catchment in general.

MATERIALS AND METHODS

Description of the study area

The D.R.C. catchment of the Lake Tanganyika Basin covers about 40,000 km^2 representing approximately 20% of the all basin (Mölsä *et al.*, 1999). This study was conducted in the river Kalimabenge micro-catchment located in the North-West region of Lake Tanganyika basin in Democratic Republic of Congo (DRC). The micro-catchment of river Kalimabenge was delineated using the SRTM digital elevation model using AVSWAT in ArcView 3.3 (Figure 1).

The river drains into the Lake Tanganyika through Uvira City which lies between the Burton Bay in the South and the plain of Ruzizi in the North. This micro-catchment is located between 3°20 'and 4°20' South latitude and 29°00' and 29°30' East longitude. It is bounded in the west by the Eastern side of Mitumba Mountains and in the East by Lake Tanganyika. The region is characterized by permanent and temporary numerous small rivers, of which Kalimabenge is one of the most important, flowing into Lake Tanganyika (779 m absl) and running down the longitudinal slopes of 10 to 12% in areas with steep slopes (Ilunga, 2006). Kalimabenge River rises in the Mitumba Mountains at 2360 m of altitude and flows into the Lake Tanganyika along the direction NE-SW and NW-SE. It is about 22 km long and 5 meters wide (Grzybowski, 1984; Kakogozo *et al.*, 2000). Soils of the Lake Tanganyika North-East Region are derived from Precambrian rocks, ancient lacustrian alluvions and recent fluvial alluvions (Kakogozo *et al.*, 2000) and the dominant vegetation is grassland on the slope of Mitumba Mountains (Ilunga, 1984). South Kivu region has a population density of 21 people per Km^2 (Odada *et al.*, 2004) while Uvira District, part of South Kivu, has a relatively high density of 27 people/ Km^2, where the 16 Km^2 of Uvira Town is inhabited by 150 000 people representing a density of 9375 inhabitants per Km^2 (Ilunga,2006). The Lake Tanganyika region has a humid tropical climate characterized by the alternation of two unequal seasons: the rainy season and the dry season. Temperature in the valley of Lake Tanganyika ranges

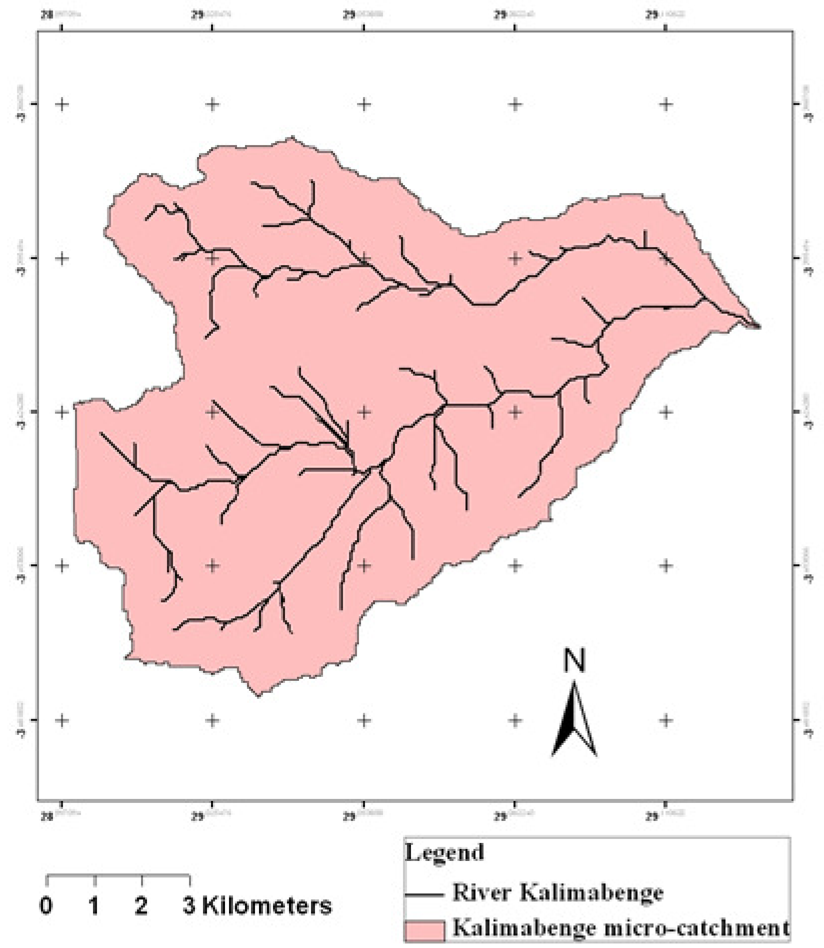

Figure 1: The micro-catchment of river Kalimabenge in the district of Uvira, DRCongo

between 25 ° C and 20° C with an average annual value of 24 °C and Year 2010 appears to be the rainiest of the study area for the period from 2002 to 2010 with an annual rainfall of 1386 mm. The main growing seasons for annual crops is September-October for the first growing season and in February-March for the second season (Meadows and Zwick, 2000). Cropping in wetlands is done generally during the dry season in June and July.

RESEARCH APPROACH

Land-use/cover change and its trend

Land use/cover change and its trend in the Kalimabenge micro-catchment was determined by analyzing three sets of ortho-rectified satellite images (Landsat TM/ ETM, 1973, 1986 and 2000) taken in the dry season including (p186r062) for 1973, (p173r62_5t19860719) for 1986 (p173r062_7t20000615) for 2000 using ILWIS 3.3 software (Integrated Land and Water Information System). Both supervised and non-supervised classifications were used in the classification of the Landsat images in order to obtain the land use/ cover map for each year. Seven broad classes were considered in the classification namely: Forest, small scale cultivation, woodland, water bodies, built up area, grassland and bare ground (Majaliwa, 2008). The 1973 and 1986 land use/cover of the area was reconstructed using both the classified map and local knowledge obtained through targeted interviews. To obtain the 2010 map a land-use/cover map of the micro-catchment was clipped from the USGS (2005) land-use map and updated using field observations. To determine the accuracy of the classification, a sample of pixels was selected and then visited (or vice versa), in order to build a confusion matrix. Kappa index was determined to verify the precision of classification (Fung and Chan, 1994). The overall accuracies of 0.7; 0.75 and 0.8 were obtained for the 1973, 1986 and 2000 images, respectively. In order to assess the trend in land use change, regression analysis was used by fitting a regression curve on the series of land use types for the analyzed years. The fitness of the regression equation was determined by the regression coefficient and the significance of the relationship.

Determination of sediment and nutrients hotspot dynamics

The dynamics of sediments and nutrients hotspots was determined by assessing the trajectory of the hotspot centre of gravity over the three studied periods ([1973-1986], [1986-2000] and [2000-2010]). Sediment and nutrients hotspots were estimated using the Soil Water Assessment Tool (SWAT) software integrated in ArcGIS, based on the Digital Elevation Model (DEM), land-use/cover, soils, and climate. The SRTM DEM was obtained from the UNADRA dataset at College of Agricultural and Environmental Sciences (CAES) of Makerere University. Preliminary soil maps were obtained from SOTER dataset at CAES and were updated using field data. Transects cutting across the different units were laid down and soil cores were dug close to the boundaries. Climate data was obtained from Uvira Research Centre of Hydro-biology (CRH). Gap filling techniques were used to populate the dataset for the period presenting missing data using the AgMERRA dataset from NASA.

Water quality and quantity monitoring

Water samples from the river were taken at the bridge-river level located at a distance of approximately 900 m from the Lake Tanganyika. Physico-chemical parameters such as temperature, electrical conductivity, pH and total dissolved solids (TDS) were measured in situ using a Cambo pH and EC apparatus. All other parameters were analysed at the Hydro- biology Research Centre of Uvira using standard techniques. In addition, a staff gauge was installed near the bank of the river to measure water levels. Both water flow and water levels were measured twice a day at 9.00 a.m. and 5.00 p.m. for twelve months, using a global water flow meter-Flow probe FP01. The rating curve was then generated for the river to predict flow for previous years when flow measurements were not taken.

SWAT predictions

The SWAT predictions were calibrated using 2006 and 2008 field data and validated using 2010 field dataset. The output of the model was re-classified using the FAO (1990) criteria for sediments (Table 1). Runoff classes used in this study are presented in Table 1.

Data analysis

To determine land-use/cover change trend regression techniques were used in Genstat Discovery 3rd Edition. Tables and histograms were generated from the descriptive statistics obtained using cross tabulation tool in SPSS. For water quality and modeled data ANOVA in Genstat Discovery 3rd Edition was used test for difference between monthly data, and between the observed and predicted water quality and quantity parameters for the different years. The correlation between water discharge and rainfall was also determined using Genstat Discovery 3rd Edition.

RESULTS

Magnitude and trends of Land use/cover changes in Kalimabenge

The distributions of land-use/cover in Kalimabenge micro-catchment covering an area of 9666.7 ha are shown in Figures 2.1, 2.2 and 2.3, and Table 5. During 1973, the most predominant land use was cultivated land (55.8%) followed by grassland (36.6%), built-up areas (7.2%) and forest/woodlands (0.4%). Cultivated

Table 1: Sediment and runoff yield classes

Classes	Very low	Low	Moderate	High	Extremely High
Sediment yield (t/Km^2/yr)	0-200	200-1000	1000-5000	5000-9000	>9000
Runoff yield (% of annual precipitation)	0-0.01	0.01-0.1	0.1-10	10-25	>25

Table 2: Distribution of land use in Kalimabenge micro-catchment

Year	1973		1986		2010	
Land use	Area (ha)	%	Area (ha)	%	Area (ha)	%
Built-up areas	692.7	7.2	710.5	7.3	707.8	7.3
Grassland/savannah	3541.9	36.6	2752.7	28.5	1895.4	19.6
Cultivated lands	5392.1	55.8	5720.7	59.2	5072.7	52.5
Forest / woodlands	40.0	0.4	582.8	6	1990.8	20.6
Total	9666.7	100%	9666.7	100%	9666.7	100%

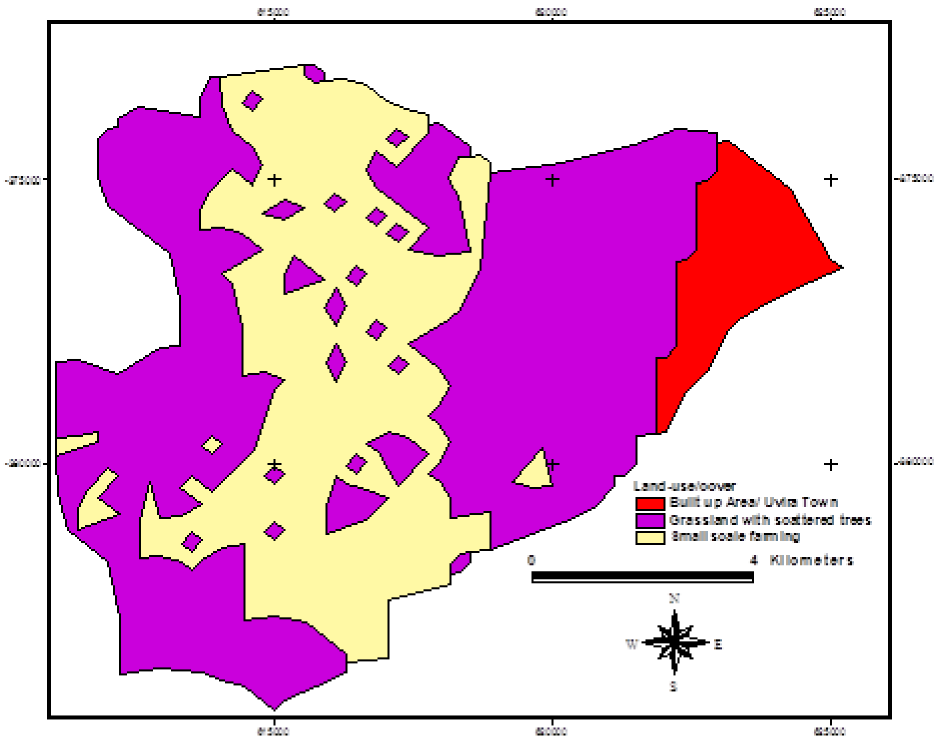

Figure 2.1: Distribution of the different land use/cover in Kalimabenge Micro-catchment, 1973

land remained the dominant land use/cover for the other two periods and represented 50.2% and 52.5% of the micro-catchment; respectively for the year 1986 and 2010. It was followed by grassland for the three periods. Built up area remained almost constant. Forest/ woodland remained relatively lowest compared to the other land-use/cover for the two periods 1973 and 1986, before increasing in 2010. Overtime, forest significantly increased linearly (R^2=0.99; y=0.55t-1092.8; p=0.05); grassland/savannah significantly declined gradually (R^2=0.98; y=0.45t+920.38; p=0.09); cultivated land tended to decline linearly (R^2=0.40; y=0.11t+280.49) though not significantly (p>0.05).

Physico-chemical properties of river Kalimabenge

Variations of temperature, conductivity, pH and flow of the river Kalimabenge waters in 2010 are presented in Table 3. During the observation year 2010, the temperature of Kalimabenge waters ranged between 18.4 ° C and 22.5 ° C with an annual average of 20.7 ° C and electrical conductivity ranged between 65 ìs/cm and 115 ìs/cm with an annual average of 99.1ìs/

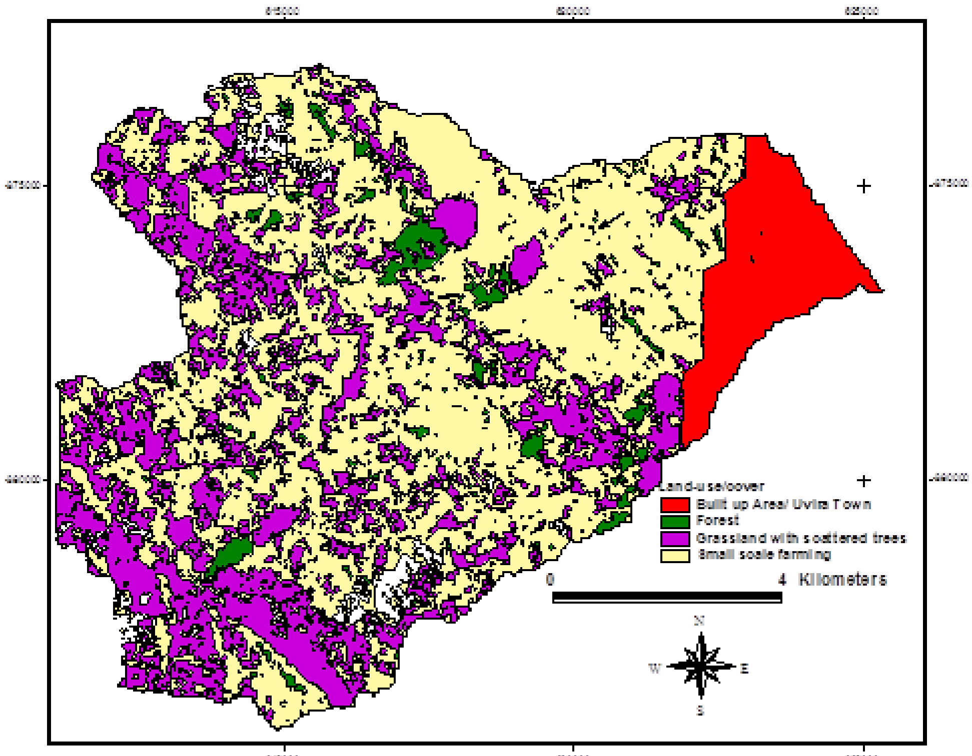

Figure 2.2: Distribution of the different land use/cover in Kalimabenge micro-catchment, 1986

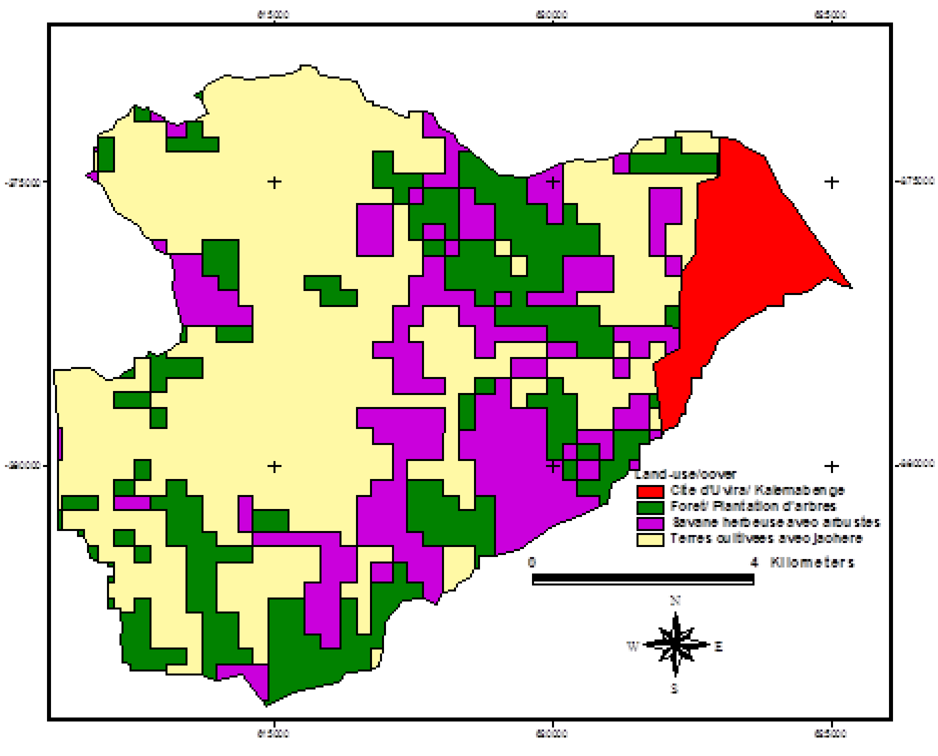

Figure 2.3: Distribution of the different land Use/cover in Kalimabenge micro-catchment, 2010

cm. The average value of pH (7.3) is close to the value 7 to that of freshwater. In addition, the pH values observed are between 7.1 and 7.8. This range of pH is between 5 and 9 which are the limits within which normal development of flora and fauna seems to be enabled. Water flow in river Kalimabenge decreased from January (maximum: 11.3m^3/s) to July (minimum: 3.6m^3/s) before increasing with an annual value of 7.1m^3/s. Water flow and rainfall were moderately correlated linearly with the coefficient of determination R^2 = 0.594 (Figure 3). Periods from January to April 2010 and from November to December 2010 were of rainy season with January the rainiest month while the dry season was from May to October with July and

October the driest months. The month of May was of weak rainfall but with appreciable water flow paradoxically.

Suspended sediment and nutrients concentration

Correlation between Total suspended solids TSS and rainfall, total phosphorous TP and total nitrogen TN concentration, and water flow are shown in Figures 4, 5, 6 and 7. Total suspended TSS solids showed better linear correlation with rainfall (R^2=0.70) and TP (R^2=0.67) while very weak correlation with TN (R^2=0.099) and water flow (R^2=0.239). During the 2010 period, the TSS presented a parabolic shape with a strong coefficient of determination R^2= 0.933.

Sediments, TN and TP Loads

During 2010, sediment, total nitrogen (TN), and total phosphorous (TP) loads ranged from 2.53 to 67.46 10^3 t / year, from 68.7 to 1147.4 t / year and from 11.5 to 387.9 t / year respectively, in the river Kalimabenge (Figure 8). Changes in TP load and sediment load have a parabolic trend with R^2=0.983 and R^2=0.992 respectively and present the minimum in August while those of TN load reach the maximum in April and the

Table 3: Physico-chemical properties of water in river Kalimabenge (2010)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature [p C]	21.1	20.9	20.8	20.2	21.6	20.7	19.4	18.4	19.8	21.0	21.8	22.5
Conductivity [ìs/cm]	115	112	111	105	81	91	98	105	111	100	65	96
pH	7.1	7.1	7.1	7.2	7.6	7.4	7.6	7.1	7.1	7.1	7.8	7.5
Flow [m3/s]	11.3	9.5	10.1	10.6	10.3	5.7	3.6	3.9	5.1	4.5	5.2	5.6

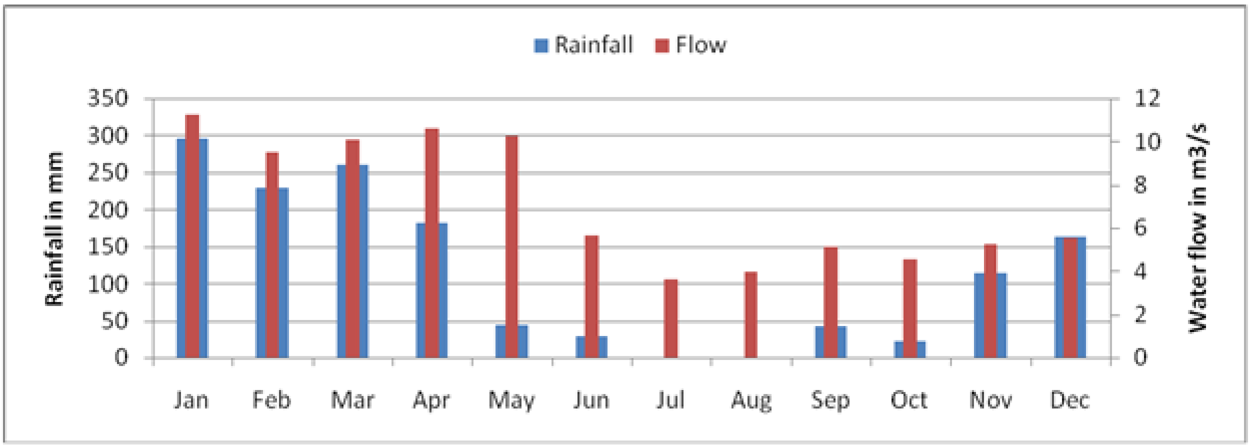

Figure 3 : Water flow in river Kalimabenge and rainfall at Uvira Town in 2010

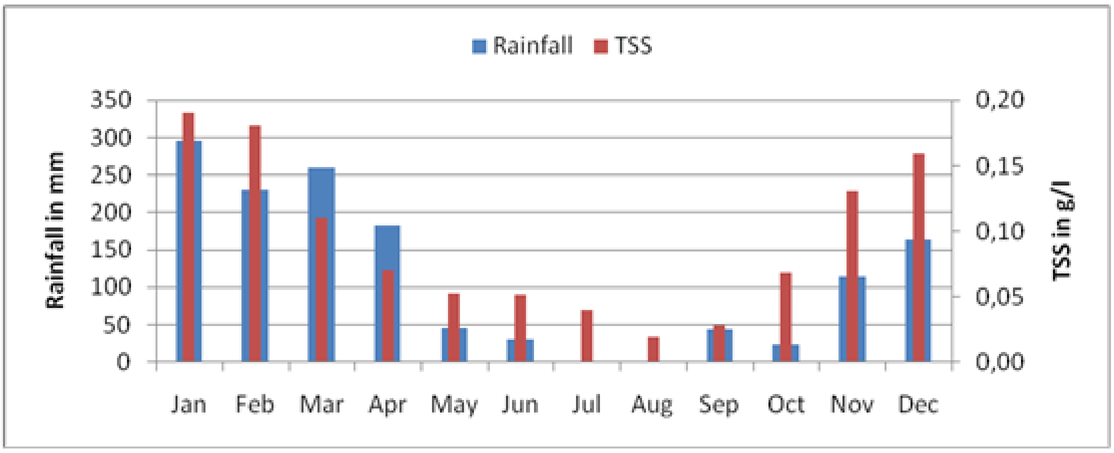

Figure 4: Rainfall at Uvira Town and TSS in river Kalimabenge water, 2010

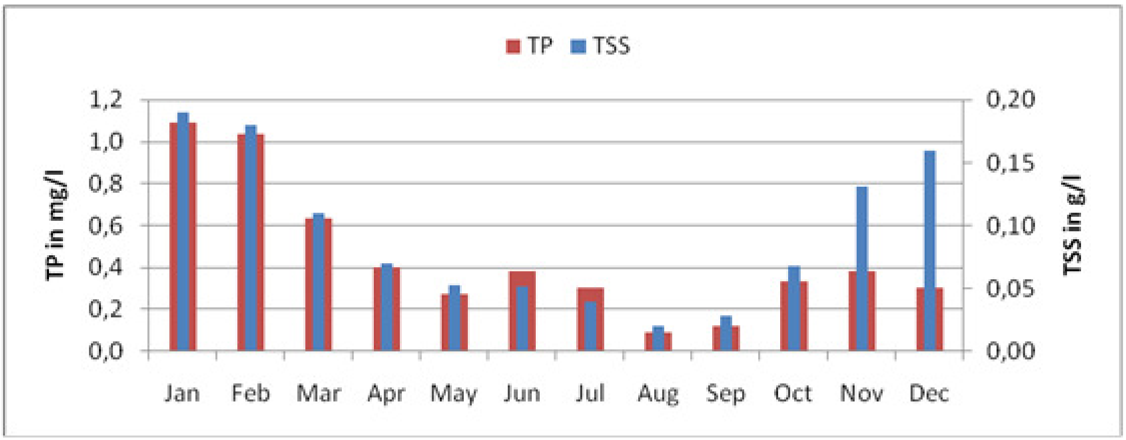

Figure 5: Total suspended solids and total phosphorous in river Kalimabenge water, 2010

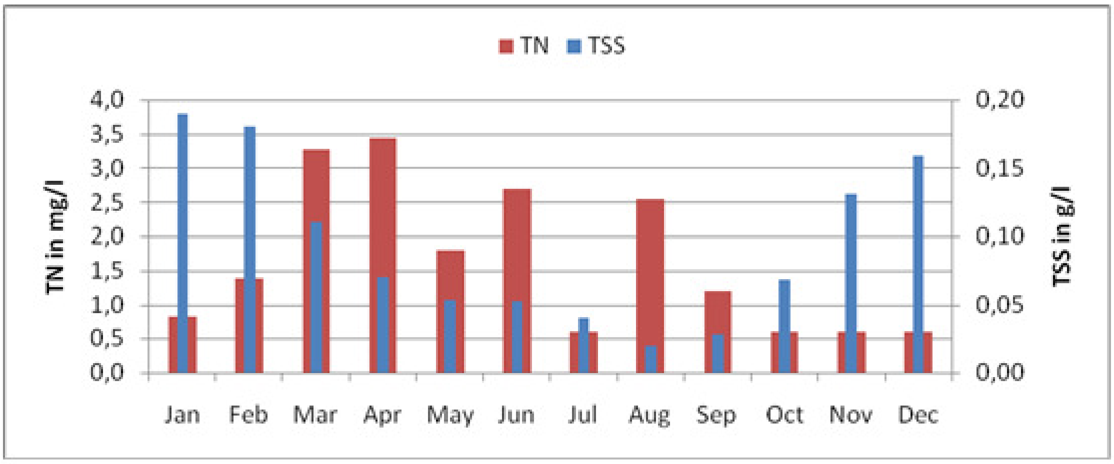

Figure 6: Total suspended solids and total nitrogen in river Kalimabenge water, 2010

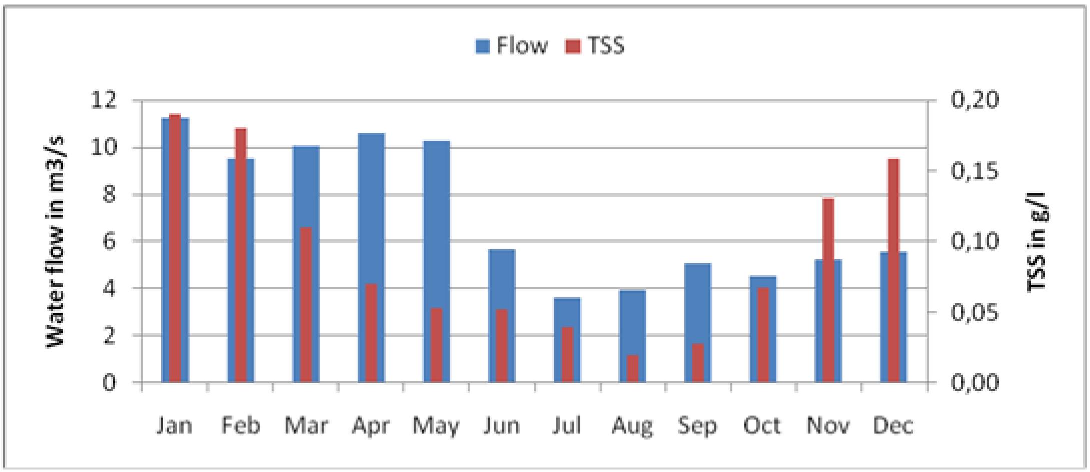

Figure 7: Total suspended solids and water flow in river Kalimabenge, 2010

minimum in July before becoming nearly constant from October to December.

Validation of flow, sediments and nutrient predictions using SWAT

Results obtained for the SWAT Model validation are summarized in Figures 9, 10, 11 and 12. The predicted values and observed values for water flow in the River Kalimabenge were linearly correlated with a moderate coefficient of determination R^2 = 0.616 (Figure 9); for sediment, highly correlated with a correlation of determination R^2 = 0.94 (Figure 10); for nitrogen discharge, weakly correlated with a coefficient of determination R^2 = 0.007 (Figure 11); for discharge of organic phosphorus to Lake Tanganyika, linearly correlated with a significantly higher coefficient of

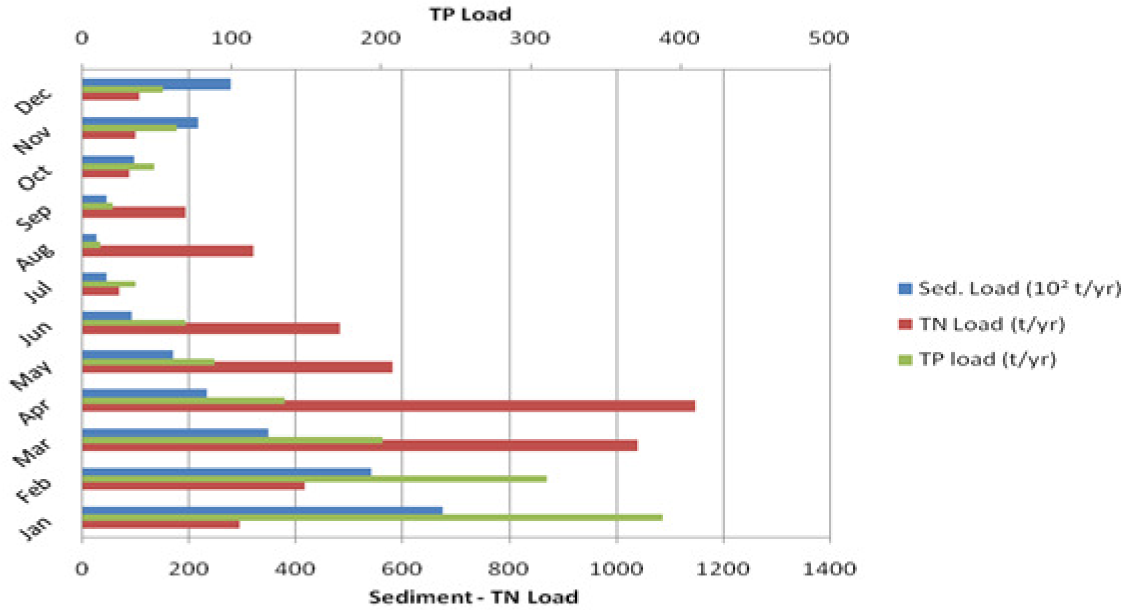

Figure 8: Sediments, total nitrogen and total phosphorous loads in the River Kalimabenge

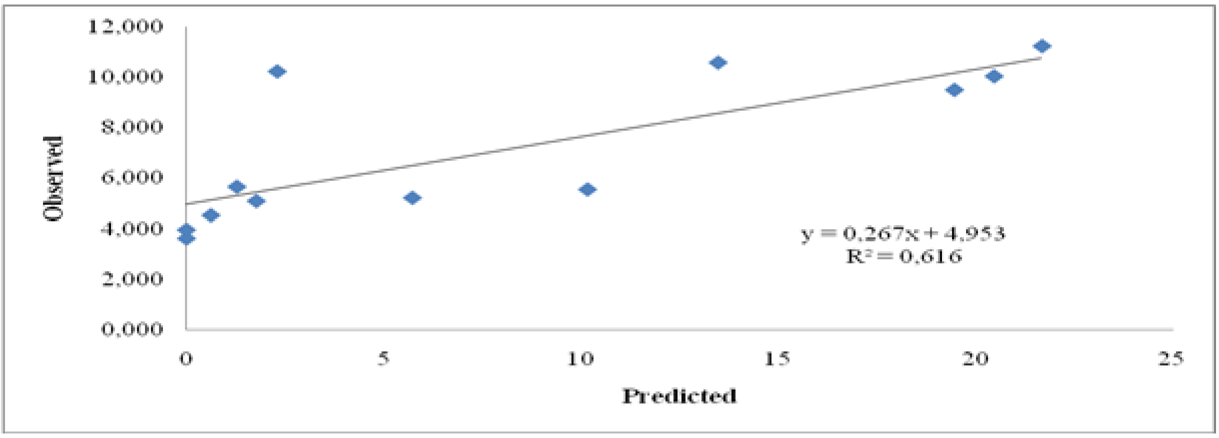

Figure 9: Predicted and observed values of flow out of the River Kalimabenge during 2010

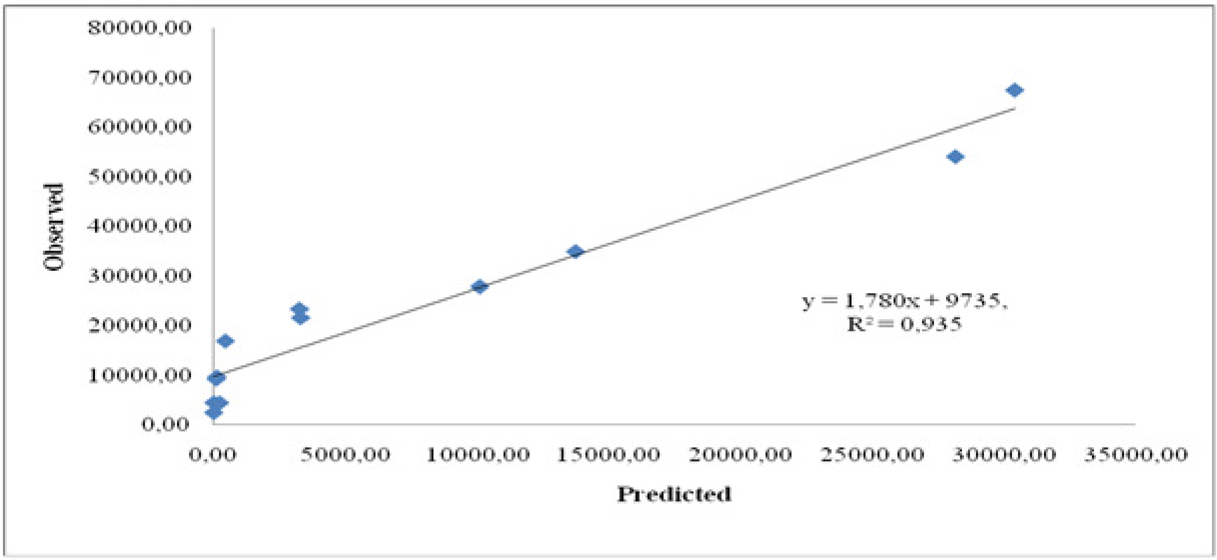

Figure 10: Predicted and observed values of sediment out of the River Kalimabenge during 2010

determination R^2 = 0.913 (Figure 12). SWAT results showed that simulated water flow, sediment load, and P load fit very well measured data in the average monthly values with better coefficients of determination but simulated N load deviated compared to observed N load with a weak coefficient of determination. On the other hand, the Student t-test applied in comparing means of simulated and observed values confirmed that there was no significant difference at p=0.05.

Sediment and nutrient yield hotspot areas dynamics
Sediment, phosphorous, and flow yield hotspot areas for the three periods are given in Figures 13, 14 and 15 respectively. In 1973 the upper part of the catchment (25.58 km^2), the lower part of the catchment (the heavily settled part of the micro-catchment: 1.13 km^2) and a small patch in the middle of the micro-catchment (0.23 km^2) were highly yielding sediment into the Lake Tanganyika. This represented 27.6% of the micro-catchment. In 1986, only 9.73 km^2 of the upper and 1.05 km^2 of the lower part of micro-catchment were yielding more sediment into the Lake. The hotspot area for sediment was reduced to only 10% of the micro-catchment; hence representing 59% reduction of the hotspot areas. In 2010, almost all sediment contributing areas of 1973 were re-activated. The total sediment hotspot area in 2010 was of 29.01 km^2, representing an increment of 8.6% in the sediment hotspot area with reference to 1973 and of 190% with regards to 1986 sediment yield hotspot areas.

In 1973, low phosphorous yield was generated in the all sub-basins of the Kalimabenge micro-catchment. In 1986, the TP-yield high contributing area covered 26.97 km^2 (27.9% of micro-catchment) emerged in the south eastern part of the micro-catchment. This unit disappeared in 2010, but a small patch emerged in the central part of the micro-catchment (2.3 km^2). This represented 2.4% of the micro-catchment. TP-yield of this particular part increased substantially since 1973 to date.

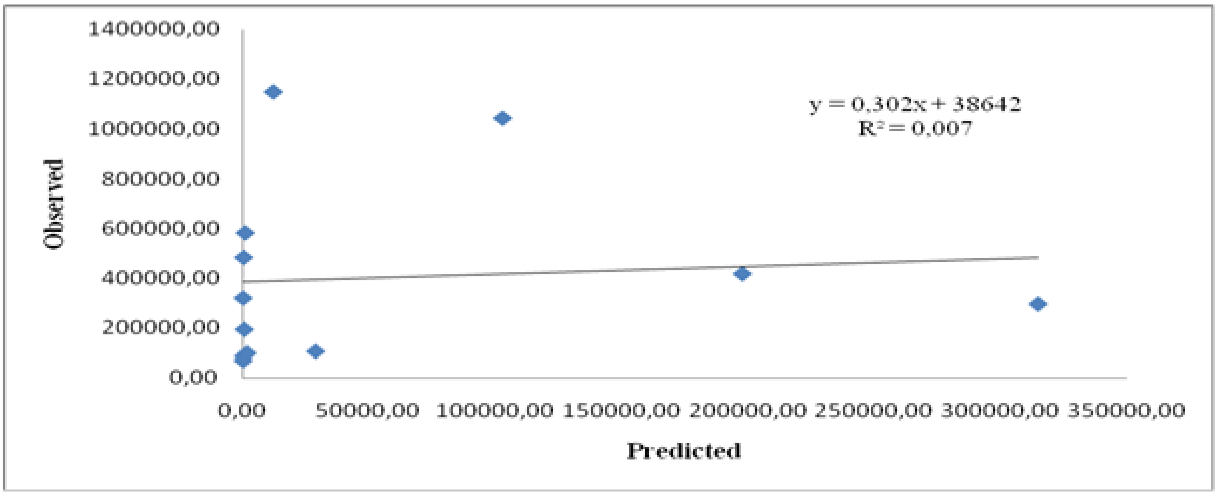

Figure 11: Predicted and observed values of nitrogen load in the Kalimabenge during 2010

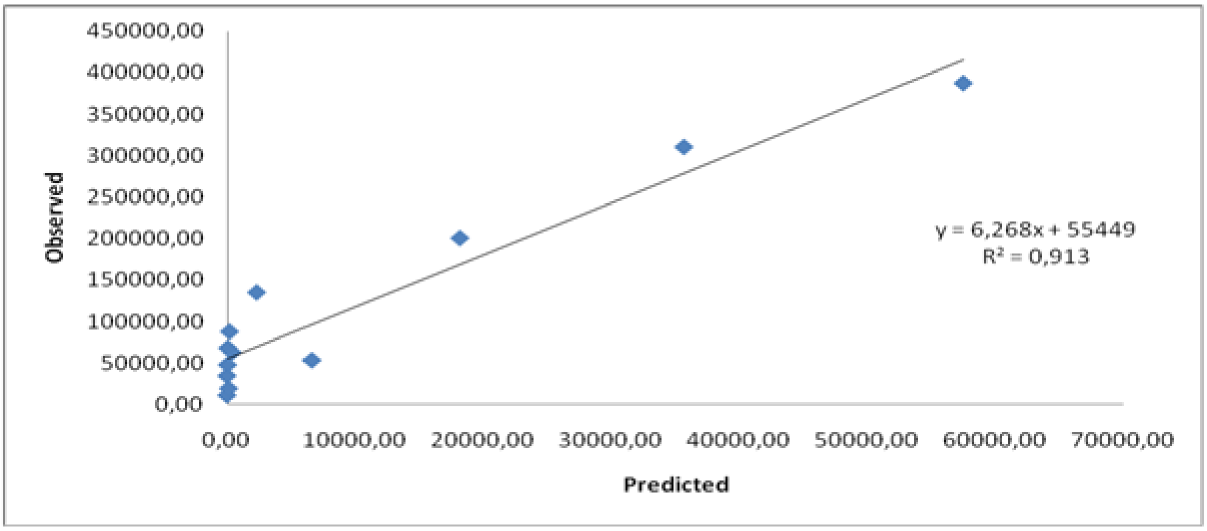

Figure 12: Predicted and observed values of organic phosphorus load in the river Kalimabenge during 2010

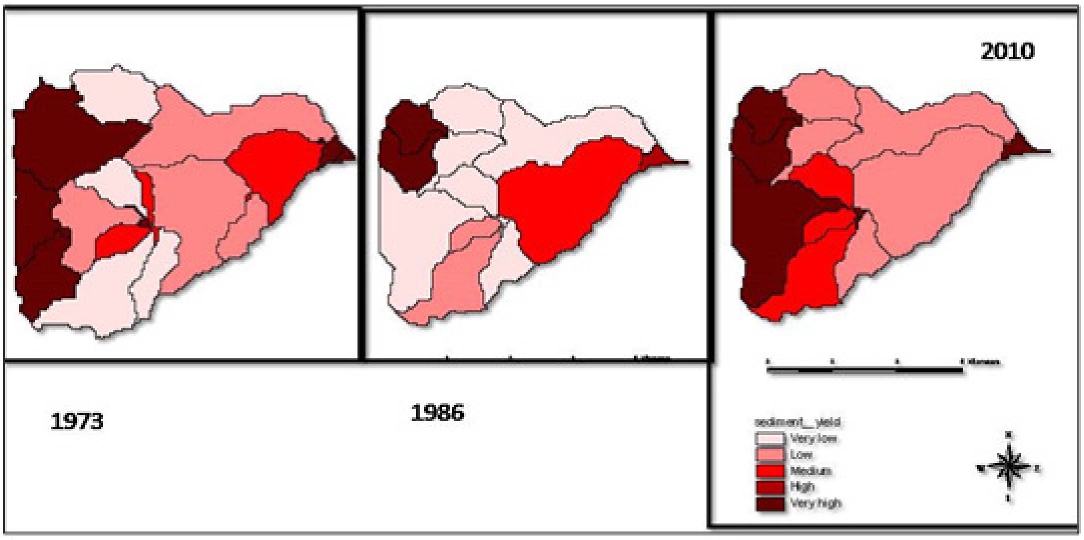

Figure 13: Sediment yield map in the Kalimabenge micro-catchment during the period 1973, 1985 and 2010

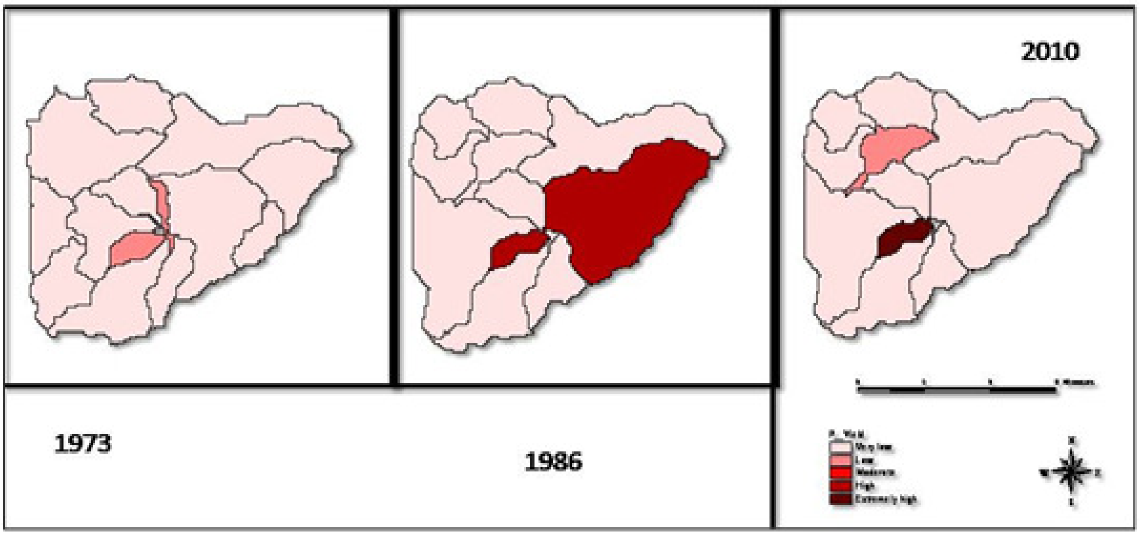

Figure 14: Total phosphorus yield in the Kalimabenge micro-catchment

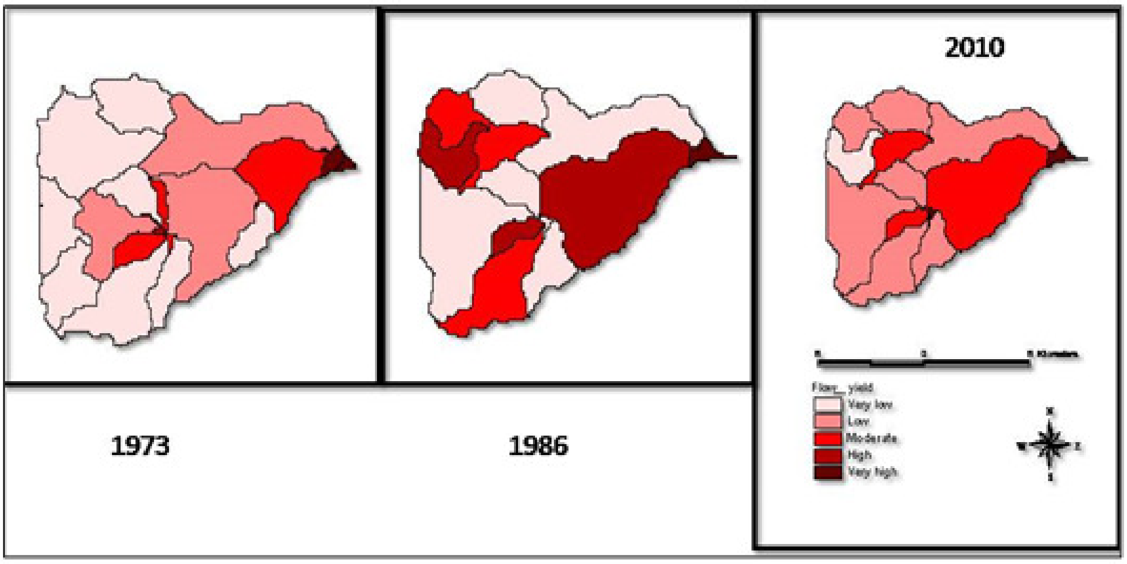

Figure 15: Flow yield in the Kalimabenge micro-catchment

In 1973, the flow yield hotspot area was concentrated around the outlet of the river Kalimabenge and covered 1.05 km^2. This represented 1.08 % of the all micro-catchment. In 1986, new additional hotspot areas developed upstream and around the centre of the micro-catchment and covered a total of 32.30 Km^2. In 2010, the distribution of hotspot areas was very similar to that of 1973 period.

DISCUSSION

Land use/cover changes trend in the Kalimabenge micro-catchments

Grassland/savannah linearly declined in the Kalimabenge micro-catchment at the expense of Forest/woodlands, whereas built up areas remained quasi unchanged. This is in line with observations made by several authors earlier (Bagalwa *et al.*, 2014) for grasslands/savannah but contradict observations by Fermon (2007), Cohen (1991) and Bagalwa *et al*. (2015) concerning the forest/woodland and built up areas. Cohen (1991) reported that 40 to 60 per cent of the land originally covered by forests in the central basin of the Lake Tanganyika and almost 100 percent had been cleared in the north basin. Indeed, during the last four decades, forest was completely devastated by the population looking for firewood, charcoal and land for subsistence farming or grazing. Fermon (2007) also reported that all the mountains in this area were particularly denuded of trees with a density which reduces from South to the North of Lake Tanganyika Basin. This explains why grassland was seen as the most predominant land use in the North-West region of the Lake Tanganyika basin during the study period (1973 to 2010). However, due to afforestation programme initiated around 1986, forest/woodland were spreading across the micro-catchment. Bagalwa *et al.* (2015) observed that wars and flux of refugees in the region had contributed to forest clearance in some places for fuelwood and timber in Lwiro peri-urban area of Lake Kivu. Political wars and tribal conflicts linked to regional insecurity since 1995 caused the population to abandon the high mountains leaving place for regeneration of forest during the last decade. Although positive changes in area covered by trees and shrubs are large compared to other land uses in the micro-catchments, forest still occupies a relatively small portion of all the micro-basin, most of the micro-basin being occupied by the built-up areas, cultivated areas and grasslands/savannas. The reforestation campaigns are also the basis of the reappearance of some tree plantations or woodlands while the expansion of the city of Uvira is increasing due to population growth and new construction of houses in areas formerly covered by vegetation. The region has the highest population in the Lake Tanganyika Basin with an annual rate of natural increase of 3.2% and a density of 21 inhabitants per km^2 (Odada *et al.*, 2004). The highland areas remain the zone of non-intensive agriculture and livestock especially cattle.

Sediment and nutrients hotspot areas dynamics

Sediment yields observed in Kalimabenge micro-catchment averaged 2.387 t $ha^{-1}yr^{-1}$. These observations were similar to those reported by Bagalwa *et al.* (2015) in Lwiro micro-catchment in eastern DRC and Majaliwa *et al.* (2004) in Bukoora micro-catchment in Uganda; and those observed in several micro-catchments in North American basins. Sediment concentration of the river waters in this study had large values ranging from 0,011 g / l to 0,475 g / l. This is due to the distribution of land-use/cover and their management, the topography and the soil of the micro-catchment. Sebahene *et al.* (1999) found that the river Ruzizi which is one of the largest tributaries of Lake Tanganyika located in the Northwest region of the basin, carried a big amount of suspended sediment, ranging from approximately 0.22 g / l to 2.46 g / l during the dry season and rainy season respectively due to the extent of the basin that it drains and its flat topography compared to the river Kalimabenge. This has a significant environmental effect at the outlet where turbidity is high and prevents light penetration in the lake water.

Values of total phosphorus yield and total nitrogen yield for Kalimabenge were 0.012 t $ha^{-1}yr^{-1}$ and 0.042 t $ha^{-1}yr^{-1}$ respectively. There were relatively higher than values observed in micro-basins of the same size from major agricultural lands in the Lake Victoria region (Magunda *et al.*, 2003). Nutrient concentrations for the river of this study did not exceed 3.43 mg / l for nitrogen and ranged between 0.061 mg / l and 1.093 mg / l for phosphorus. These values are relatively lower compared to those of the region (Magunda *et al*., 2003) and Australia (Peters and Donohue, 1999). This is due to less intensive agricultural activities with minimum inputs and the type of soils (Magunda *et al.*, 2003).

The partial sources of sediments, runoff and phosphorous in Kalimabenge changed with periods. Sediment partial contributing areas were different from runoff contributing areas. They reduced in size in 1986 and returned to their 1973 patterns and size in 2010. Total phosphorus partial contributing areas increased in 1986 before reducing to a quasi-similar pattern in 1973. The non similarity of sediment and runoff contributing areas in the catchment corroborate reports from other studies (Moore *et al.*, 1976; Campbell, 1985; Baade, 1996; Majaliwa *et al.*, 2004). However, the change in partial contributing areas for sediments and runoff is attributed to the 1986 afforestation efforts conducted in the region and particularly in the micro-catchment, the change in land-use/cover during the civil war and climatic fluctuations.

Erosion studies in experimental plots in Chile demonstrated the role of vegetation cover in sediment yield (Espinozaand and Fuentes, 1983a; Espinoza *et al.*, 1983b). Dieckmann *et al.* (1989) found that a decrease of 30% of vegetation cover may cause an increase of sediment yield by 90%. During the period the illegal electrical connection to the national grid coupled with the outdated nature of the facility contributed to the slowdown of the electrical plant facility. This accelerated cutting of eucalyptus plantations trees which had emerged in many parts of the DRC side of the Tanganyika basin. The reverse situation was produced with the repeated civil wars in the eastern part of DRC pushing many people out of the forested zones towards the built up areas. This contributed significantly to change in land use/cover within the Lake Tanganyika catchment.

The climatic variability effects have been reported in Lake Tanganyika (O'Reilly, 2003). Temperature has increased by 0.31^{o}C in deep-water and monthly average of cool windy season speed declined by 30% from its values of 1970. Over the last two centuries, an analysis of rainfall variability in the Lake Tanganyika suggests that historical fluctuations in the Lake Tanganyika are generally explained by variations in catchment temperatures (Nicholson, 1999). Thus, variations in sediment yield can also be explained by climate change in the region, especially rainfall change; indeed, during the last decade, abundant rainfall above normal was observed in the Kalimabenge micro-basin in 2010 compared to other years.

CONCLUSION AND RECOMMENDATIONS

In light of the above results and discussions it can be concluded that:

(i) Grassland, forest, built-up and cultivated land were the major land use/cover in the Kalimabenge micro-catchment located in the northwest region of Lake Tanganyika Basin. Forest cover significantly increased in the last four decades. In the Kalimabenge micro-catchment cultivated land is the most predominant land use while built-up area did not change.

(ii) The partial sources of sediments are not necessarily sources of runoff in Kalimabenge. They changed in 1986 and returned to the 1973 pattern in 2010. Phosphorus high yielding sources emerged in 2010. Built up area remained a partial source of sediment, runoff and phosphorus. A maximum of 32.30 Km^2 has contributed to sediment, runoff and phosphorus in the last four decades.

Recommendations

(i) Grassed strips have agro-environmental advantage in reduction of soil erosion, preservation of river water quality, diversification of the landscape and land cover, and biodiversity enrichment. The establishment of grassed buffer strips along 10 meters of food crops and grassed areas of roughly 50 meters along studied rivers will conserve the water quality of rivers and reduce excessive erosion in the region.

(ii) Reforestation of the region during the years 1970-80 was achieved with eucalyptus tree species which are not agro-environmental tree species. Reforestation of the area with local tree species and prohibition of growing food crops on steep slopes offer a better way of environmental management.

(iii) Local authorities should encourage and promote the use of improved stoves or undertake a wide electrification program in the region, rich in hydrography, in order to overcome the problem of deforestation which, over time, may cause precipitation decrease or soil erosion increase.

(iv) Strategic land management planning should be developed by the Government, in collaboration with the population.

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STATEMENT OF NO CONFLICT OF INTEREST

We the authors of this paper hereby declare that there are no competing interests in this publication.

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