SEDIMENT AND NUTRIENT LOADING INTO LAKE KIVU: A CASE STUDY LWIRO MICRO-CATCHMENT, DEMOCRATIC REPUBLIC OF CONGO

BY

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DECLARATION

I, BAGALWA MASHIMANGO, declare that this MSc thesis is a result of my own research effort, with original work apart from where acknowledged. It has never been submitted for a degree in this or any other University.

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DEDICATION

I would like to dedicate this work to my family, my wife Marie MUNENE BORA UZIMA, my children Enock WANI, Ghyslain IRENGE, Ghyslaine FWAMBE and Benit RUOTT, all the BAGALWA's and Bovic UTRAGAN families who have tirelessly loved and supported me. I can never thank them enough except to thank GOD the Almighty for the gift of being the son of such caring and loving parents. God is my strength and my saviour and He is with me every step of the way, and yes, there are a lot of times when only his footsteps can be seen walking through me.

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Abstract

Lake Kivu is one of the deepest lakes in Africa with a maximum depth of 485 m and the most fragile and highly sensitive ecosystems in the African Great Lakes region in term of gaseous content. During the last decade, an increase in pollution loading was observed in the lake contributing to eutrophication, decreased dissolved oxygen and increased methane (CH_4) and carbon dioxide (CO_2) levels. Estimation of pollution loading including nutrient and sediment yield in the micro-catchment is a prerequisite for developing the best micro-catchment management plan for the Lake-wide basin. The objectives of this study were to; determine land use/land cover changes in Lwiro micro-catchment for the last 25 years and; to estimate the contribution of the different nutrient and sediment sources to the pollution loading into the River Lwiro. Time series of the Landsat images (1987, 2001, 2010) were classified into four categories: forest, buildup areas, wetland and small scale farmland area. SWAT model was used to estimate pollution loading from different sources into the River. Results show that land use/ cover in the study area have changed substantially from 1987 to 2010. The forests decreased by 23%, while wetlands, small scale farmland and Built-up areas increased by 2.11; 0,88 and 2.29 % respectively. A good agreement between observed and simulated discharge, sediment yield and nutrient load during the study period was observed using SWAT model. The coefficient of determination (R^2) for the monthly runoff, TSS, TP and TN were obtained as 0.56; 0.79; 0.66 and 0.86 respectively, during the period of study. ArcSWAT simulated results show that sediment and runoff high yield was generated by small scale farmland and forest area respectively. Sensitization about best management practices should be conducted in order to reduce nutrient and sediment loads due to erosion into the River Lwiro micro-catchment.

CHAPTER 1. INTRODUCTION

1.1 Background

Lake Kivu is one of the deepest lakes in Africa and the most fragile and highly sensitive ecosystems in the African Great Lakes region (Newman 1976; Kling *et al.*, 2006; Tassi *et al.*, 2009). It is one of the three known exploding lakes due to its content in carbon dioxide (CO_2) and methane (CH_4) and is characterized by millennial time scales violent vegetation turnovers (Schmid *et al.*, 2010; Borges *et al.*, 2011). The danger in the Lake Kivu system is that limnic eruption (or violent degassing) which happened in Lakes Monoun and Nyos in Cameroun may also take place. Since the measurements in the 1970s, $^{14}CCH_4$ and $\delta^{13}CCH_4$ changes indicate that methane produced from organic material has increased (Pasche *et al.*, 2011), saturating 40% of the Lake. In the deep layers of Lake Kivu, large amounts of CO_2 and CH_4 (300 Km^3 and 60 Km^3, respectively, at 0°C and 1 atm) are dissolved (Schmid *et al*., 2005; Doevenspeck, 2007; Borges *et al.*, 2011). More carbon and nutrient inputs through erosion and atmospheric deposition will certainly exacerbate its degradation and instability threatening the livelihood of two million people depending on the basin resources (Schmid *et al.*, 2010). A major difference from those other lakes is that the volume of contained gas in Lake Kivu is approximately 1000 times greater than the Cameroonian lakes that erupted and the pressures are even greater because of the greater lake depth (Vodacek *et al.*, 2010).

Nutrients loadings into Lake Kivu are mainly linked to the rapid growth of population, deforestation and soil erosion within the Lake Basin (Muvundja *et al.*, 2009; Borges *et al.*, 2012). CO_2 is mainly geogenic, two thirds of the CH_4 originates from anoxic bacterial reduction of CO_2 and one third from anaerobic degradation of settling organic material (Schoell *et al.*, 1988; Pasche *et al.*, 2011). In the last few decades, the lake has undergone significant changes in chemistry and biology as a result of growing human interference and pollution from domestic, industrial and agricultural activities which lead to a deterioration of water quality (Johnes, 1996; Muvundja *et al.*, 2009). The increasing sediment and nutrients loading also pose severe threats to biodiversity and the stability of the Lake basin (Cohen *et al.*, 1993; Irvine *et al.*, 2003).

Lake Kivu catchment has in past decade experienced political instability, refugee migration due to civil war, large-scale land clearance for agriculture, firewood and timber harvesting

(Majaliwa *et al.*, 2010). These have exacerbated soil erosion and nutrient loadings into Lake Kivu. Agriculture has been identified as the leading source of non-point source pollution (Andrew, 1990). Cultivation on very steep slopes is often coupled with poor land management, such as lack of erosion control structures, overgrazing and burning (Hecky *et al.*, 2003; Onyango *et al.*, 2005). In Lake Kivu basin, the hydrological SWAT model was used for modeling of the external nutrient load (Muvundja *et al.*, 2009). However, the contribution of each source, hotspot areas, temporal trends in pollution loading, the cause-effect relationship between land use/cover and pollution loading is not yet established in River Lwiro micro-catchment.

1.2 Research problem statement

Lake Kivu has been receiving considerable interest recently due to the high concentrations of CO_2 and CH_4 in the water column. It has experienced dramatic changes in its history (Schmid *et al.*, 2010). The high population density (more than 350 habitats per square kilometer) and increasing population pressure threaten the natural environment because of the growing logging and cultivation activities (Bagalwa *et al.*, 2013c). Additionally, urbanization, industrial activities, poverty in rural and peri-urban areas, and uncontrolled dumping of waste have increased concentrations of pollutants including nutrients and sediment in the lake system (Bagalwa *et al.*, 2013a). Land is intensively used with 70% of the land being used for agriculture and 20% for the other activities; irrigated sugar cane field located in the swamp area covers about 10% (Bagalwa *et al.*, 2013b). Deforestation induces severe soil erosion, wetlands are drained, channels are silted, and the lake water is being polluted and the trend of lake pollution is on the increase. The consequence of this is eutrophication, water borne diseases and the increase of concentration of CH_4 and CO_2. Recent works have shown that rivers are major sources of pollution of the Lake Kivu (Bagalwa, 2006; Muvundja *et al.*, 2009; Bisimwa, 2009; Bagalwa *et al.*, 2013a, b). It was observed that the external pollution input from rivers is high in some micro-catchments. The contribution of the rivers can reach about haft of the total input into Lake Kivu. These rivers are conveying eroded sediments from the micro- catchment. Bagalwa (2006); Muvundja *et al.* (2009); Bisimwa (2009); Bagalwa *et al.*, (2013a, b) speculate that rivers Kahuwa and Lwiro are the most polluted rivers on the D.R Congo side. In order to develop a successful pollution abatement programme, there is need to identify the major source of sediment and nutrient loading as well as sustainable land management practices. This study focuses on the identification of non-point and point pollution hotspot sources in the Lwiro micro-catchment.

1.3 Objectives

1.3.1 General objective

The major objective of this research is to assess the magnitude of pollution loading into Lake Kivu on the Democratic Republic of Congo side, in order to inform decision makers on the best management of the Lake Kivu catchment.

1.3.2 Specific objectives

- To determine land use/cover changes in Lwiro micro-catchment within the last 25 years.
- To assess the physico-chemical characteristics of the river Lwiro
- To determine the magnitude of nutrients and sediment loading into lake Kivu via river Lwiro
- To identify the major runoff, sediments and nutrients hotspot sources in river Lwiro micro-catchment

1.4 Research questions

- What is the magnitude and trends of land use/cover changes in River Lwiro micro-catchment?
- What are the physico-chemical characteristics of the water in River Lwiro?
- What is the magnitude of nutrient loading to Lake Kivu catchment provided by River Lwiro?
- What are the major nutrient sources in River Lwiro micro-catchment?

1.5 Conceptual Framework on the Problem

Due to various land use forms, waste is generated and surface runoff transports the sediments and pollutant loads into the water body which contributes to deterioration in water quality.

Therefore structural assessment of pollution load is presented in this conceptual framework (Figure 1).

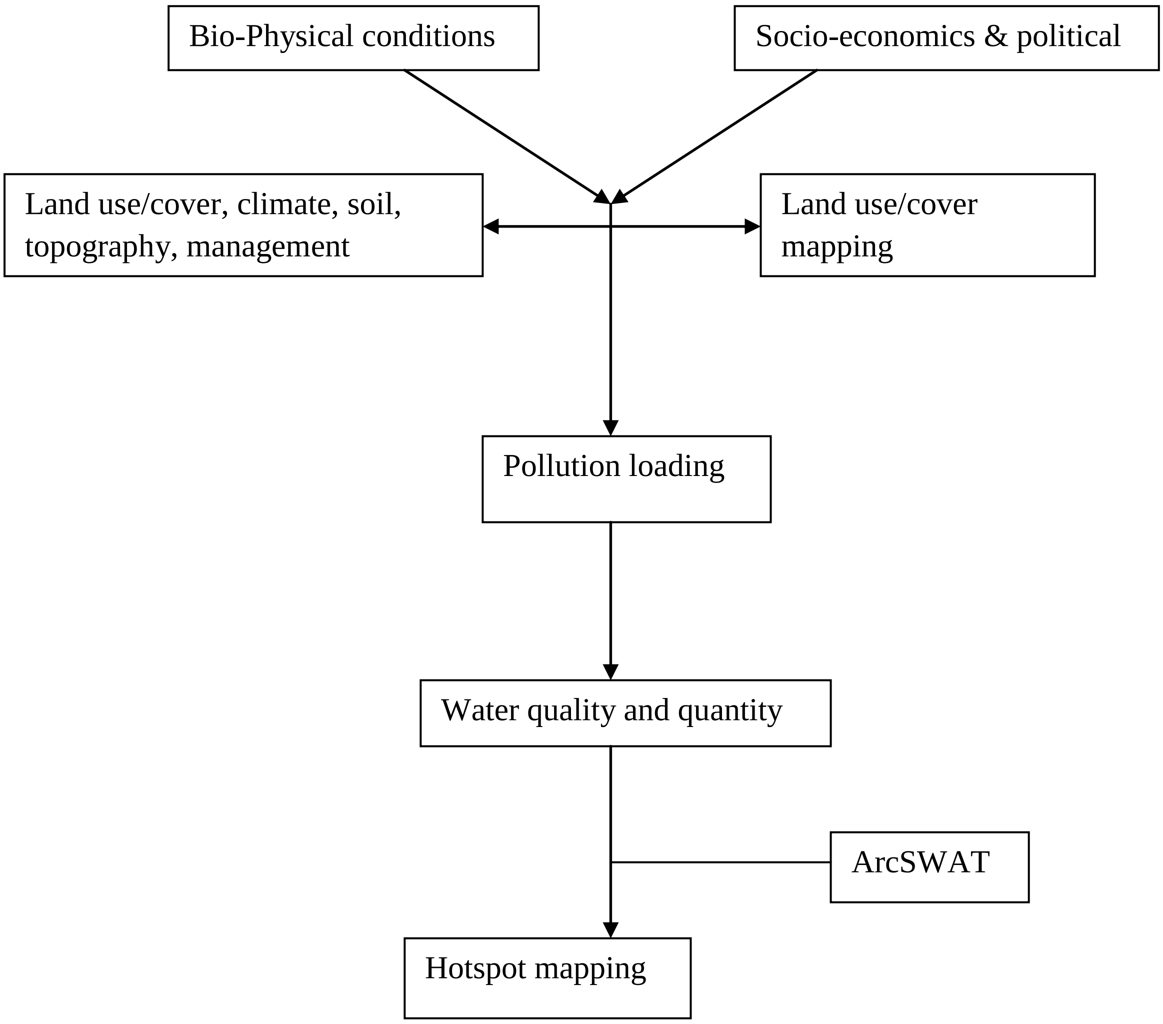


Figure 1: Conceptual framework

Bio-physical factors (soils, land-use/cover and management, topography and climate) and socio-cultural and political conditions are sources of pollution loading in aquatic ecosystems which causes soil erosion, pollution loading thus impacting soil and water quality. To determine innovative ways of pollution abatement, field data collection and use of SWAT model were instrumental in this study.

1.6 Organization of the thesis

The presentation of the thesis includes six chapters. Chapter one gives an introduction and background information about the study. Chapter two introduces the study in the context of existing literature on land use/cover change and water pollution. Chapter three describes the characteristics of the study areas and the methods used to achieve the objectives. Chapter four presents the results obtained, chapter five discusses the major findings of the study with reference to existing knowledge, and relates them to the objectives, central questions and overall framework of the study. Finally, chapter six presents the conclusions and recommendations for further research based on the results and discussions.

CHAPTER 2: LITERATURE REVIEW

2.1. Operational definitions

Water pollution: is the degradation of water quality as measured by biological, chemical, or physical criteria.

Pollutant load: is the mass or weight of pollutant transported in a specified unit of time from pollutant sources to a waterbody.

Nutrient pollution: is the process where too many nutrients, mainly nitrogen and phosphorus, are added to bodies of water and can act like fertilizer, causing excessive growth of algae.

N**utrient load:** refers to the total amount of nitrogen or phosphorus entering the water during a given time, such as "tons of nitrogen per year.

Hotspots erosion or sediment: are defined as the parts of a catchment with the highest erosion rates and highest sediment transport capacities (McDowell and Srinivasan, 2009).

Nonpoint source pollution: is water pollution that is caused by widely dispersed sources of pollutants. Non-point source water pollution, once known as "diffuse" source pollution, arises from a broad group of human activities for which the pollutants have no obvious point of entry into receiving watercourses.

Point source pollution: is a stationary location or fixed facility from which pollutants are discharged or emitted or any single, identifiable discharge point of pollution, such as a pipe or a ditch.

Land cover: is the ecological state and physical appearance of the land surface (e.g. forests, small scale farmland, built-up area, woodlands, grasslands, etc…).

Land use: is the manner in, which human beings employ the land and its resources (e.g. for agriculture, grazing, logging, etc…).

2.2. Land use/cover changes

Land use/cover is one of the most important fields of human induced environmental transformation, with an extensive history dating back to antiquity (Wolman and Fournier, 1987; Lambin *et al.*, 1999). It has emerged as a global phenomenon and perhaps the most significant regional anthropogenic disturbance to the environment especially in the 20^{th} Century. In Africa, dramatic land use/cover changes now take place within a few decades and it has the fastest rate of deforestation in the world as a result of overdependence on primary resources (Ademiluyi *et al*, 2008). Recent studies of land cover changes in West-Africa showed that agricultural expansion is the most dominant trajectory of land-cover change (Wood *et al.*, 2004; Braimoh and Vlek, 2005) which involves loss of savannas and forests. Lambin *et al.*, (2003) reported that, though land use changes occur mainly due to conversion of pristine forests to agricultural uses (deforestation) or the destruction of natural vegetation by overgrazing, leads to desert conditions (desertification). Changes in the condition and composition of the land-cover affect climate (IPCC, 2001), biogeochemical cycles, energy fluxes (Melillo *et al.*, 2003) and also livelihoods (Vitousek *et al.*, 1997). In the Lake Kivu catchment land cover has significantly changed during the past three decades due to rapid population increases (Muvundja, 2010). Assessing land use/cover dynamic needs current technologies such as geographical information systems (GIS) and remote sensing. These techniques are based on digital change detection on multi-temporal and multi- spectral remotely sensed data as a means to understanding landscape dynamics, detect, identify, map, and monitor differences in land use/ cover patterns over time, irrespective of the causal factors.

2.3 Pollution loading into freshwater

The increase in demand for water for domestic, industrial and agricultural use has led to an increase in water consumption and contributed to the degradation of the water quality (Ferriera *et al.*, 2004). As water degradation results mainly from chemical changes, a standard method for assessing quality has been relayed on water chemistry. Water pollution, brought about by the discharge of wastes into water bodies has been responsible for impairing the different uses to which water could be put to many parts of the world. In some cases, pollution further renders the water totally unusable regardless of its availability. A lot of information is available on the physical, chemical and bacteriological of water pollution (Scheren *et al.*, 1994; Downing *et al.*, 1999; Scheren *et al.*, 2000; Hecky *et al.*, 2003; Ferreira *et al.*, 2004; Bagalwa *et al.*, 2013a, b).

In Lake Kivu basin, the extent of nutrient load as well as water runoff pollution, and its potential impact on the lake has not been extensively studied except the work of Bagalwa (2006). The study indicated that the parameters that are most sensitive to changes in land use and disturbance in the watershed of Lwiro river are suspended solids, DO and BOD_5. Other nutrients such as phosphorus, nitrogen, carbon and silica that can also exhibit a response to land use changes but have not been studied yet. Basima *et al.*, (2006), sampled the Kahuwa River which is another tributary of the lake and found that the river carries high organic loads mainly from municipal sewage. Bisimwa, (2009) conducted a study to determine the major pollution inflow routes and assess suitability of water for domestic, industrial, recreational and other uses in the lake's littoral zones. The study indicated that the Kahuwa River is the principal source of pollution load into Lake Kivu in Bukavu micro-catchment. Muvunja *et al.*, (2009), reported that catchment degradation caused by deforestation for agriculture and disposal of domestic wastes from urban areas as the current major constraints of water quality in Lake Kivu basin. The reduction of incoming nutrients, monitoring and prevention of future degradation can be the best strategy to improve the quality of the water in Lake Kivu. Sources of nutrients and their concentrations have not been determined in Lwiro river micro-catchment.

2.4 Partition of pollution loading

Pollution sources into aquatic systems can be either point sources or non-point sources. Point sources of pollutants are associated, as the name suggests, with a point location such as toxic-waste spill site while non-point sources are diffuse (Loague and Corwin, 2005). Historically, point source pollutants have received the greatest attention, both publicly and scientifically, because of the conspicuous severity of their impacts at a localized point (Loague and Corwin, 2005).

Non-point sources of pollution result from agricultural activities (e.g. irrigation and drainage, applications of pesticides and fertilizers, runoff and erosion); urban and industrial runoff; erosion associated with construction; mining and forest harvesting activities; pesticide and fertilizer applications for parks, lawns, roadways, and golf courses; road salt runoff; atmospheric deposition; livestock waste; and hydrologic modification (e.g. dams, diversions, channelization, over pumping of groundwater, siltation) (Loague and Corwin, 2005; Onyango *et al.*, 2005).

Atmospheric deposition represents an important non-point source of nutrient and can significantly alter nutrient budgets of sensitive water ecosystems (Bootsma *et al.*, 1996; Bootsma *et al.*, 1999; Tamatamah *et al.*, 2005; Langenberg *et al.*, 2003; Muvundja *et al.*, 2009). The available data on nutrient dynamics (Downing *et al.*, 1999; Bootsma *et al.*, 1996; Lacaux *et al.*, 1992; Tamatamah *et al.*, 2005; Langenberg *et al.*, 2003) in the African Great Lakes suggest that the atmosphere plays a significant role in supplying nutrients and carbon to these ecosystems. Bootsma *et al.* (1999) estimated the dissolved nitrogen and phosphorus load into Lake Malawi from the atmosphere to be higher than from rivers. Scheren *et al.*, (1994) suggested that the increase in phosphorus was primarily due to increases in atmospheric deposition from forest burning and wind erosion. Hecky *et al.*, (2006) argue that atmospheric sources likely account for 60 % of total P loading to Lake Victoria. Scheren *et al.*, (2000) also reported for 36 % of the total phosphorus input into Lake Victoria due to atmospheric deposition.

Inappropriate allocation of land utilization types such as cultivation on very steep slopes is more often coupled with poor land management, such as lack of erosion control structures, overgrazing and burning as one of the major causes of soil erosion related water pollution (Andwew, 1990; Bootsma *et al.*, 1996).

2.5 Sediment, Phosphorus and nitrogen pollution

2.5.1 Phosphorus

Phosphorus (P) is an important nutrient for agriculture and animal production (Hedley and Sharpley 1998). It has more biological functions than any other nutrient (Beede and Davidson 1999), being a component of DNA, cell membranes, and Adenosine Triphosphate (ATP), which is the molecule responsible for storing and providing energy. In plants, P increases seed production, grain yield, stalk strength, root growth, and disease resistance (Norfleet 1998, Jacobson, 2012). Despite its beneficial role in food production, excessive P levels can negatively affect aquatic life and humans. Phosphorus occurs in dissolved organic and inorganic forms or attached to sediment particles. Phosphates, the inorganic form, are preferred for plant growth, but other forms can be used when phosphates are unavailable (Bootsma and Hecky, 1999). When phosphorus remains in the sediments it is generally not available for use by algae; however, various chemical and biological processes can allow sediment phosphorus to be released back into the water. Phosphorus can come from different sources as present in the cycle (Figure 2).

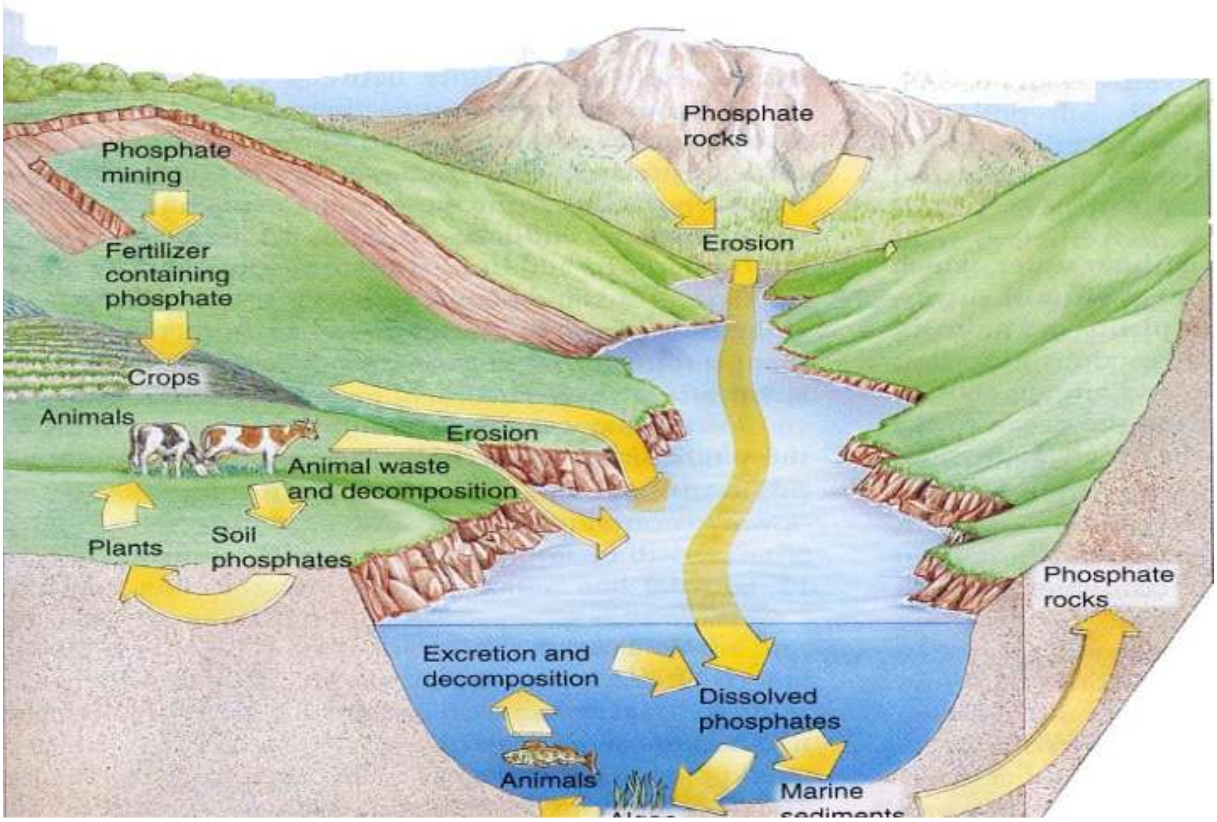


Figure 2: Phosphore cycle

(http://vincejtremante.tripod.com/cycles/phosphours.htm)

Runoff from agricultural fields can deliver large amounts of P to surface waters, where, under natural conditions, it is frequently a limiting nutrient. This P enrichment causes prolific aquatic plant and algae growth and subsequent eutrophication of receiving surface waters (Corell 1998). Bacterial decomposition of the large amounts of biomass produced in eutrophic systems consumes oxygen and causes hypoxic conditions. Chronic hypoxia can shift fish community structure towards low oxygen tolerant species (Dauer 1993), reduce fish fecundity and growth or cause death (Brungs 1971). Proliferation of algal in the aquatic ecosystem can also causes reduction of water clarity. Reduced water clarity can shift fish species composition in lakes from desirable species to less desirable fish (Egertson and Downing 2004) by inhibiting the hunting success of sight-oriented feeders (Bruton 1985).

2.5.2 Nitrogen

Nitrogen is essential to the production of plant and animal tissue. It is used primarily by plants and animals to synthesize protein. Nitrogen enters the ecosystem in several chemical forms and also occurs in other dissolved or particulate forms, such as tissues of living and dead organisms. Nitrogen can exist in the atmosphere or as a dissolved gas in water, and at elevated levels can have harmful effects on humans and animals. Nitrates in water can cause severe illness in infants and domestic animals. Common sources of excess nitrate reaching lakes and streams include septic systems, animal feed lots, agricultural fertilizers, manure, industrial waste waters, sanitary landfills, and garbage dumps. The nitrogen cycle (Figure 3) is of fundamental importance in all ecosystems, but especially so in freshwater environment because of the potential for available nitrogen to control the rate or level of primary productivity (Ward, 1996).

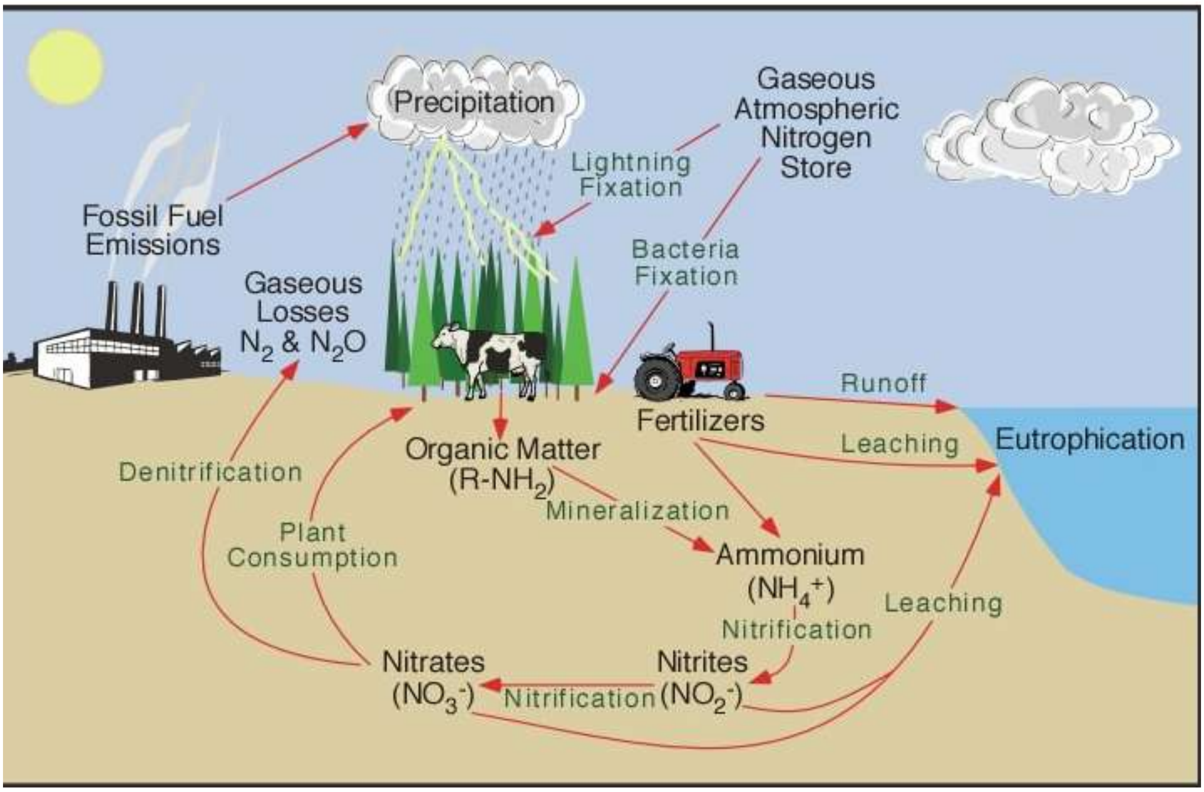


Figure 3: Nitrogen Cycle

(http://www.physicalgeography.net/fundamentals/9s.html)

2.5.3 Sediment

Sediment is occurring in water by soil erosion process. This process occurs by detachment (erosion), transport, and deposition of soil by the action of moving water or wind. Water erosion rates are affected by the rainfall energy, soil properties, slope, slope length, vegetative and residue cover, and land management practices (Jacobson, 2012). Sediment can also negatively affect aquatic and human communities. Total suspended sediment reduces water clarity, thereby producing the same negative effects discussed above with eutrophication. Studies have shown that total suspended sediment can reduce fish survival by decreasing reproductive success (Burkhead and Jelks 2001; Sutherland 2007). Total suspended sediment also absorbs sunlight, thereby raising water temperature; a problem for temperature-sensitive organisms. In addition, sediment accumulation can reduce habitat for bottom-dwelling invertebrates. The resulting shift in the invertebrate community can negatively affect growth and survival of juvenile fish (Suttle *et al.*, 2004). In addition, other pollutants like fertilisers, pesticides, and heavy metals can get attached to the soil particles and be transported into the water bodies, causing algal blooms and lead to depleted oxygen levels, which pose a risk to aquatic life.

2.6 Water discharge and sediment yield hotspot

SWAT (Soil and Water Assessment Tool) is a watershed model for predicting the water discharge and sediment yields in a micro-catchment with varying soils, land-use and management conditions over long periods of time (Arnold *et al*., 1993). In SWAT model, a catchment is divided into several micro-catchments, each of which is further divided into several hydrological response units (HRUs) (van Liew and Garbrecht, 2003; Neitsch *et al*., 2005). Each HRU represents a portion of land area within the micro-catchment that consists of unique land cover, soil, and management combinations (Flugel, 1995). The determination of the HRU is primarily based on the topography and the structure of stream network within the studied micro-catchment. Water discharge and sediments yield for the different micro-catchments simulated using SWAT provide the hotspots areas in the micro-catchment which are defined as the parts of a micro-catchment with the highest erosion rates and highest sediment transport capacities (McDowell and Srinivasan, 2009; Meshesha *et al.*, 2012). The identification of hotspots allows managers with limited resources to develop a targeted response directed at the areas that pose the highest risk rather than spreading their resources equally across the landscape (McDowell and Srinivasan, 2009; Verstraeten *et al.*, 2002). This identification requires a basic understanding of the spatial patterns, rates, and processes of soil erosion and sediment transport at the scale of a micro-catchment. The SWAT model was used to identify sediment, runoff and nutrient hotspot area in the Lake Tanganyika basin the DRC side (Azanga, 2013). Hotspots areas were localized in the lower part of the micro-catchment and small patches in the middle of the micro-catchment. In Uganda the land use contribution and average export was high in degraded range lands with patches of annuals land (Majaliwa, 2005) in the Lake Victoria, while cultivated land and woodlot had high sediment yield River Atari micro-catchment in Kyoga basin (Sirike, 2013). For Ethiopia, the sediment yields value ranges from 2 to 18 t/ha/yr (Hurni, 1985, Meshesha *et al.*, 2012).

CHAPTER 3: MATERIALS AND METHODS

3.1 Description of study area

3.1.1 Geographical location

Lake Kivu is one of the Great Lakes of Africa with 2700 Km^2 of area and maximum depth of 480 m. There are serious concerns about a thermally driven limnic gas outburst due to high concentrations of dissolved CO_2 and CH_4 at great depth in the permanently stratified water column (Deuser *et al.*, 1973; Tietze *et al.*, 1980). Damas (1937) classified Lake Kivu as a "sodium-potassium-magnesium-bicarbonate" lake. The surface water temperature is averaging 23.5°C (Sarmento *et al.*, 2006) and the temperature increases with depth due to sub-aquatic flows (Degens *et al.*, 1973). The Dissolved oxygen is permanently stratified in deeper waters (Damas 1937; Lorke *et al.*, 2004).

The Lwiro micro-catchment is located on the eastern flank of Lake Kivu, between latitude 2°15' and 2°30'S and longitudes 28°45' and 28°85' E. Its headwaters are the Kahuzi-Biega National Park mountain region, at an altitude of 2000 m. The 84 km^2 river basin is bordered on the east by Lake Kivu and on the west by the Kahuzi mountain forest (Figure 4). This micro-catchment of Lwiro river, the principal tributary of the Lake Kivu, covers 4 localities namely Irhambi/Katana, Bugorhe, Luhihi and Bushumba in the territory of Kabare, province of South-Kivu, Democratic Republic of Congo. Rainfall is about 1500 mm annually (Bagalwa and Baluku, 1997). The soil comprises clay and rich volcanic soil, which is easily eroded by surface runoff. The geological composition is of Precambrian metamorphoses sediments (metamorphic rocks) and Preterozoic platform sediments (Cahen and Lepersonne, 1967). Verhaeghe (1964) describes metamorphic limestone and numerous travertines along Lake Kivu and Lake Edward. Carbonates for the production of cement are also found north and north-west of Lake Kivu.

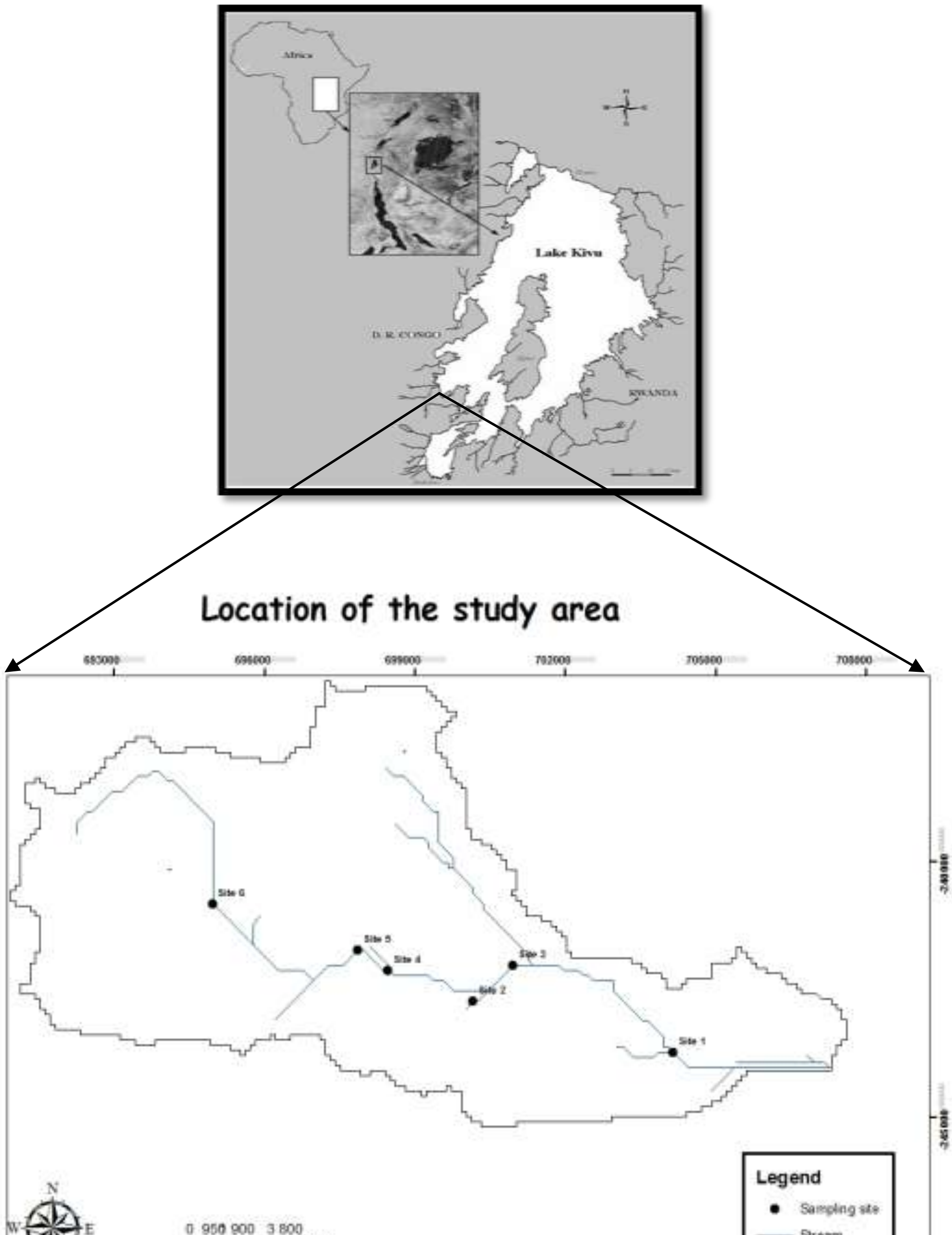


Figure 4: River Lwiro micro-catchment, Lake Kivu

3.1.2 Sampling sites localization

The Lwiro River is approximately 27.2 Km long and has a mean width of 7 m (Bagalwa, 2006). A total of four stations (Figure 4) were selected on the basis of their accessibility throughout the year on the main river (Sites 1, 3, 4 and 6); and two stations (Sites 2 and 5) on the tributaries of the river were used to collect data for estimation of point source pollution from agriculture and industrial area respectively.

Site 6 (Kayandja) stands at 1680 m above mean sea level (amsl), near the Bukavu- Goma road, approximately 14.8 Km downstream from the spring and between an irrigated sugarcane field and a coffee plantation on the main river. People use the site for bathing, animal drinking and washing. The substratum is composed of mud and small stones. The vegetation consists of a mixture of emergent macrophytes, *Commelina diffusa*, *Pennisetum purpureum* and *Riparia* sp.

Site 5 (Myanzi-Lwiro) is at 1700 m amsl. The stream is a tributary of River Lwiro and passed through irrigated and agricultural area. The substratum is composed principally of mud. The fields are composed of varieties of crops including vegetables, tomatoes, beans, maize and others. At the upstream, constructed ponds are made for fish farming by the surrounding population. The vegetation at the edge of the stream is usually removed during the time of cultivation.

Site 4 (Buhandahanda) is located 200 m at outlet of the Kalengo stream at 1644 m amsl in the main river. The border of the river is covered by *Pennisetum purpureum*.

Site 3 (outlet of coffee industry) was located at 1640 m amsl, and the outlet of the coffee industry and washing of minerals such as Colombo-tantalite and cassiterite. The channel is covered by a banana plantation and pours directly into River Lwiro without treatment.

Site 2 (Kakondo) was located at 1640 m amsl and 26 Km downstream. It is also, located near a coffee-processing factory that discharges wastewater into the river. The substratum is composed of mud and stones. A natural forest constituted by trees covered this site and make sufficient shade.

Site 1 (Fomulac), was located 500 m upstream of the river at an elevation of 1460 m amsl. The site is dominated by sugarcane; while the river shore-line is covered by *Cynondon dactylon* and *Pennisetum purpureum*. The river passes through irrigated sugarcane fields.

Temperature and pH were measure in situ while water samples were collected for laboratory analysis at each site on every day of sampling.

3.2 Research approach

3.2.1 Determination of land use/cover trends in the Lwiro river micro-catchment

3.2.1.1 Satellite images acquisition

The study used data of Landsat TM/ETM images (1987, 2001 and 2010) which were subjected to unsupervised classification and change analysis to determine land use/cover changes. Standard image processing techniques of extraction, layer stacking, geometric correction/ georeferencing and change detection were performed on the three Landsat TM images obtained on different dates. They served as the primary data for this study. The rationale for using these years come from the fact that it was within these periods that major changes such as migration of people from rural to urban and refugees from Rwanda, economic increase in the area, and expansion of agricultural land were made. The 1987 and 2010 images were geometrically corrected to a common Universal Transverse Mercator coordinate system, Datum WGS 1984; Zone 35, based on a 1:50,000 topographic map scale, the 2001 image used as the MASTER image.

3.2.1.2 Image classification

The satellite images were classified into land use classes (Figure 5). Four land use/cover classes were used to classify the images (Anderson *et al.*, 1976; Kabba and Li, 2011). The classes are: built-up (impervious layers such as residential and commercial services, office blocks, educational centers, hospitals, manufacturing industries, motor roads, rails and among others); wetland; agriculture (all cultivated areas such as farmlands, crop fields including vegetable gardens, plantations, fallow plots) and forest (protective forests, timber forest, economic forest, firewood forest and forests of special use). Using ArcView GIS version 3.2 software, the unsupervised classification system, using maximum likelihood algorithm was performed on the images. Google earth, and data collected during field trips (training sites/ground control points using GPS) served as reference data. The delineated micro-catchment polygon was superimposed on the classified images to establish the locations of each land use and land cover type (Coppin and Bauer, 1996; Lillesand and Kiefer, 1987).

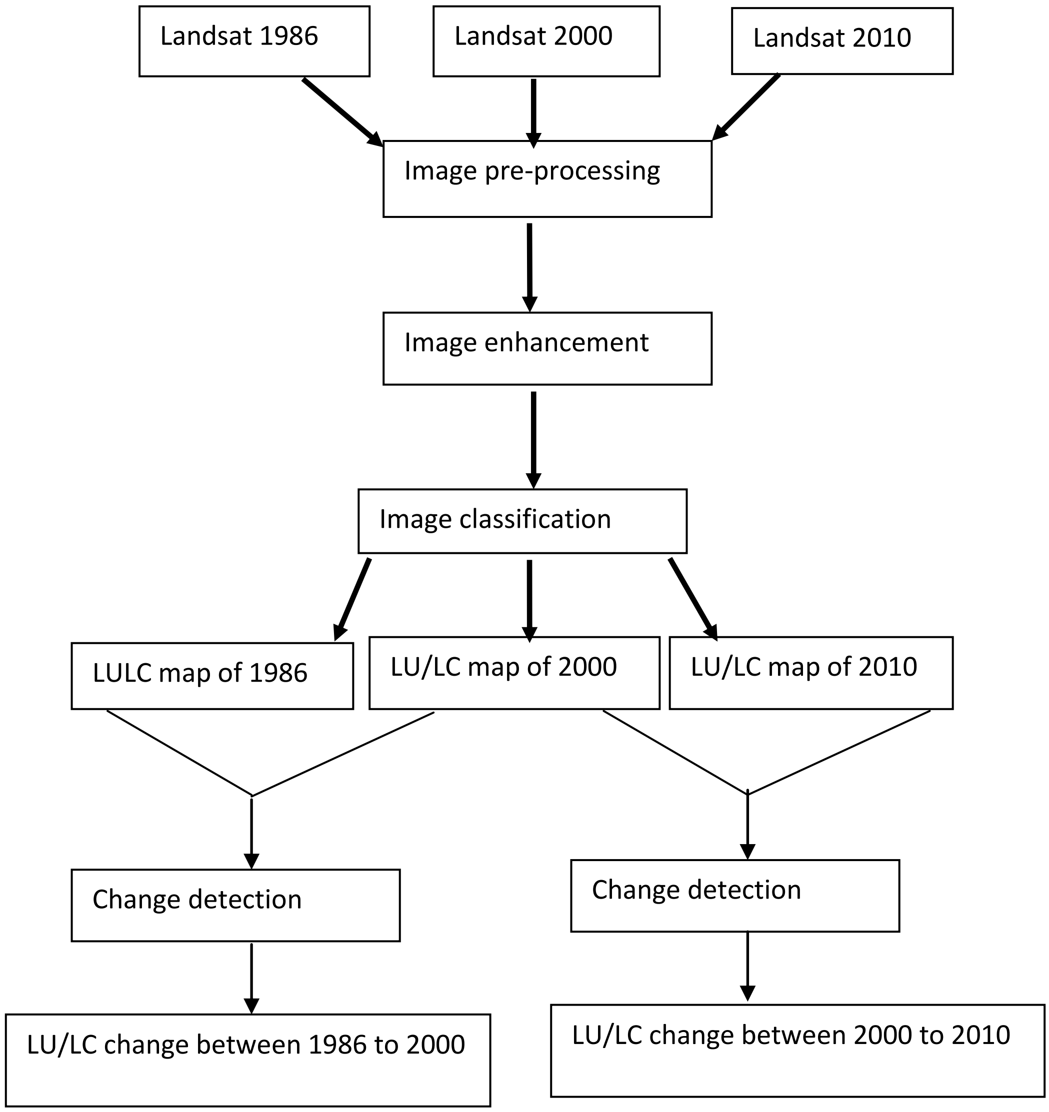


Figure 5: Methodology of Land use/cover evaluation

3.2.1.3 Determining land use/cover changes in Lwiro river micro-catchment

The analysis of land use/ cover changes in Lwiro micro-catchment was based on 24-years long time series Ortho-rectified and cloud free Landsat TM/ETM images of 8 Mars 1987 (path 170/row 60), 1 January 2001 (path 170/row 60) and 2010. The spatial resolutions of the images are 30 m X 30 m. All images were registered to the UTM WGS84 projection, zone 35N using coordinate system projection. Images taken in the short dry season (January–March) were utilized because of the highest contrast of spectral signatures of tree cover and that of undergrowth (grass, herbs) (Kiunsi and Meadow, 2006).

Time series LANDSAT images of 1987, 2001 and 2010, were imported in ILWIS 3.3 Academic software for initial image clustering. The Ortho-rectified satellite image was subjected to unsupervised classification. Unsupervised classification was used because of more information present in unsupervised than in supervised classification (Jensen, 1996). The land use/cover of the micro-catchment was obtained by clipping using micro-catchment boundaries. Ground truthing was done to improve the overall accuracy of the classification. Contingency table method and historical land use/cover reconstruction was done to assess the accuracy of the classified output (Curran and Williamson, 1985). The land cover classification scheme followed in this micro-catchment is:

- Small scale farmland: crop fields, pasture, bare fields, grass land, fallow land;
- Forest: deciduous forest land, evergreen forestland, mixed forest land, tree plantation;
- Built-up area: Residential, commercial, industrial, mixed urban, administration office
- Wetland: No-forested wetland.

Individual classification of two image dates minimizes the problem of normalizing for atmospheric and sensor differences between two dates (Singh, 1989). Accuracy dependency of the classification's results is the main disadvantage of this method. Poor classification accuracy of individual classification leads to propagation of uncertainties in the change map, which results in inaccurate information of land-use changes.

3.2.1.4 Assessment dynamics of land use/cover change pattern

In order to assess dynamics of land use change pattern, regression analysis was done 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. The change rate of single land use/ cover type was determined according to Peng *et al.* (2008) procedures:

$$K_1 = \frac{[U_b - U_a] \times 100\%}{U_a \times T} \qquad (1)$$

Where K_1, is the land use/cover dynamics degree, measuring the change rate of the target land use/cover type, U_a and U_b are the area of the target land use/cover type at the beginning and the end of the study period respectively and T is the study period, which is usually measured with the unit of year.

3.2.2 Assess the physico-chemical characteristic of the river Lwiro

To assess the physico-chemical characteristic of water samples were collected in 1 liter pre-washed plastic bottles separately at a fixed time, in the morning hours (6 h30’ to 10 h00’) for nutrients, Chemical Oxygen Demand (COD) and alkalinity from July 2011 to December 2013. Collection water samples were stored in the refrigerator to avoid any microbial decomposition. Physico-chemical parameters such as pH, surface water temperature, oxygen demand, speed and discharge were measured *in situ*. In addition, discharge was estimated from width, depth, and water velocity measurements using a fixed gauge (Lymnometer). Water velocity was obtained as an average of 5 measurements done in a cross-section of the stream using a flow meter (Global water apparatus). pH was measured in the field by pre-calibrated portable pH meter (GPH 014) and temperature was measured using a thermometer. At each site, two water samples were collected in pre-washed glass bottles for measurement of Dissolved Oxygen (DO) and five-day Biological Oxygen Demand (BOD_5). DO (mg/L) was measured following the iodometric Winkler’s method after fixation in the field (Golterman *et al.*, 1978, APHA, 1989). BOD_5 was measured as the decrease in DO after incubation in the dark at 20 ºC for five days. Total alkalinity (meq/L) was determined by titration with 0.1 N HCl; Suspended Sediment (mg/L) was estimated by filtration of 1 L of water through analytical filter paper (Whatman 589, 185 µm pore size) which was dried at 105 ºC and pre-weighed. Chemical oxygen demand (COD) was measured by titration after oxidation by potassium dichromate in 50 % sulfuric acid at reflux temperature with sodium thiosulphate. Total phosphorus was measured using persulphate digestion and molybdate method, total nitrogen, ammonia by colorimetric indophenols bleu method, nitrate and nitrite by colorimetric method after zinc reduction and cadmium reduction respectively. Water for these analyses was filtered through Whatman GF/F filter (Wetzel and Liken, 2000). All measurements were made in duplicate. The results presented in this study are average values of the water samples collected at each point (Plate 2). Secondary data was collected at the Laboratory of the Department of Biology at the Centre de Recherche en Sciences Naturelles of Lwiro, Democratic Republic of Congo for physico-chemical parameters from August 2011 to June 2012.

Plate 1: Laboratory analysis of samples at the Centre de Recherche en Sciences Naturelles/Lwiro (20 August, 2013)

3.2.3 Estimation of pollution loading into Lake Kivu from river Lwiro micro-catchment

3.2.3.1 Rivers and runoff nutrients load estimation

Water from Lwiro River, runoff from domestic use, industries, agricultural and business activities was analyzed for major nutrients (P and N). Water samples were collected biweekly from July 2012 to December 2013. Four sites at main Lwiro River, two sites: one at point source for runoff from agriculture use and one from the coffee factory were sampled biweekly for water quality analysis (Bagalwa, 2006). A standard method for examination of water and waste water (Golterman *et al.*, 1978; APHA, 1997) was adopted at all the sites for collecting discharge and water quality data throughout the stretch of the Lwiro River and discharge point (Plate 1).

Plate 2: Staff gauge established in River Lwiro micro-catchment (19 August, 2013)

Pollutant loads from the anthropogenic and industrial sectors was calculated according to the monthly means concentrations of chemical and the means discharge of effluents using the generic equation (1). (Taniguchi *et al.*, 2003; Kao *et al.*, 2005; Gao, 2008).

$$\mathbf{L = aQ^b} \qquad \mathbf{(2)}$$

L being the pollutant load, **a** and **b** are constant numbers and **Q** is the discharge.

Calculation of load for suspended sediment and nutrient were done by linear interpolation of concentration measurements between sampled dates to provide a monthly estimate of concentration that was then multiplied by the monthly discharge recorded at the sampling point. The rate of accession load is defined as ratio of load at observation point and load at source point. The difference gives the accession load which is the contribution of the point source to the main stream (Taniguchi *et al.*, 2003). The accession load was estimated to specify the origin of pollutants of the River Lwiro.

3.2.3.2 Atmospheric deposition estimation

Wet and dry deposition of P and N were estimated using field measurements. Atmospheric deposition collector was installed at Lwiro station located in the micro-catchment of the river Lwiro. To estimate the total wet N and P deposition for the station the mean deposition rates was multiplied by Rt/Rs, where Rt is the total monthly rainfall (mm) and Rs is the amount of rainfall collected for the analysis (mm). To determine the annual dry deposition over the entire micro-catchment, the average of the daily rates were multiplied by the micro-catchment surface (84 Km^2) and the number of dry days per year, determined as 201 days/year, based on the long-term meteorological record in the region (Muvundja *et al.*, 2009). Dry deposition was assumed to be negligible on days with rain (Bootsma and Hecky, 1993). Wet annual deposition on the micro-catchment was estimated by summing the total measured deposition, and multiplying this sum by a correction factor determined as the total annual rainfall divided by the rainfall that was collected.

According to the topography of the micro-catchment, dry atmospheric deposition was collected at the station of Lwiro. A sampling bucket was placed on elevated structures (on the roofs of the Laboratory) with at least 10 m between the sampler and the nearest tree. Dry deposition was sampled biweekly a month for one year due to the cost of analysis (Bootsma *et al*., 1996, Mladenov *et al.*, 2012). The sampling collectors for dry deposition have the capacity not less than 3 L. Deionized water was exposed for 24 hours when there is no rain.

Wet deposition was sampled in a bowl of at least 5 L. The sampling frequency was about one or two sample per month if there is rain.

After nutrient analyses, the nutrient deposition rate for rain event is calculated using the equation bellow:

$$D = \frac{CV}{A} \qquad (3)$$

Where

D = nutrient deposition (umol m^{-2})

C = nutrient concentration in sample (umol /L)

V = total volume of collected rainfall (L)

A = surface area of collection bucket (m^2)

And the dry deposition rates were also calculated by:

$$D = \frac{24\ CV}{AH} \qquad (4)$$

Where

D = nutrient deposition (umol m^{-2}/day)

C = nutrient concentration in sample (umol /L)

V = total volume of sample at end of collection period (L)

A = surface area of collection bucket (m^2)

H = number of hours that sample basin was deployed

3.2.4 Identification the major runoff, sediments and nutrients hotspot sources in river Lwiro micro-catchment

3.2.4.1 Hydrological data collection

3.2.4.1.1 Precipitation data acquisition

Precipitation data was obtained from the Geophysical Department of the Center of Research in Natural Sciences at Lwiro. Daily data of precipitation was collected during the 1st January 1990 to June 2013. The data was entered in excel sheet and used as in a SWAT input.

3.2.4.1.2 Collection of streamflow data

A Limnometer was installed at the outlet of the river Lwiro and daily collection of data on speed, depth and width was recorded to calculate the discharge. Discharge was computed from width, depth, and water velocity measurements using the floating method. Water velocity was obtained as an average of 15 measurements done in a cross-section of the stream using a floater and water flow (m^3/s) was estimated (Azanga, 2013). For the runoff from agriculture and industrial sector, the discharge was calculated twice a month.

3.2.4.2 Modeling pollution loads by SWAT model

3.2.4.2.1 SWAT Description

In the study, for the watershed analysis, a physically and spatially distributed modeling tool called ArcSWAT2005 was used. It is a conceptual model, an ArcGIS-ArcView extension and a graphical user input interface for the SWAT which is a river basin, or watershed, scale model developed by Arnold for the USDA Agricultural Research Service (ARS). It is a watershed scale, continuous-time model that processes on a daily time step. SWAT is designated to predict the impact of management on water sediment, nutrient and pesticide yields in ungauged catchment (Arnold *et al.*, 1998). It is physically based model and uses readily available inputs. It is an efficient tool for handling large amount of information in databases and computing. It can be used to predict and assess long term impacts on the hydrology of a watershed. It helps for simulating a high level of spatial detail by partitioning larger catchments into smaller micro-catchments.

The major model components of SWAT are weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. One of the many advantages of SWAT is that it can be used to model watersheds with less monitoring data. It can also be used to assess predictive scenarios using alternative input data such as climate, land use practices, and land cover on water movement, nutrient cycling, water quality, and other outputs. For simulation SWAT needs basic input digital data of topography, land use/cover, soil properties and the weather and land management of a study area.

The main part of SWAT analysis can be performed in ArcSWAT 2005 interface. Geographical Information System (GIS) is used as an auxiliary and a preprocessor to the SWAT modeling process. ArcMap interface of ArcView can be used for managing and processing spatial data which were used as SWAT input data in a project. Spatial data including digital elevation model (DEM), thematic map layers of land use/cover and soil data are necessary data to perform hydrological water balance analysis of a basin in SWAT. The DEM is used to gain the topographical characteristics of an area which are required by SWAT modeling and has direct impact on hydrological cycle. The land use/cover map is used to categorize vegetation types that have impact on the hydrological process of the area. The soil map is used to identify physical and chemical characteristics of various soils that have a major role in the hydrological process of an area. Whereas weather data can be entered in SWAT interface following the reclassification of land use/cover and soil data, it is important for calculating the water balance components in each HRU in the watershed.

3.2.4.2.2 Data processing

The land use/cover and soil map layers provided spatial information of the study area for the watershed-modeling program. Both maps were provided by extracting large dataset obtained from Africa maps after importing them into ArcGIS interface (Barasa *et al.*, 2011). Similar attribute classes of the two extracted maps that had different names either because of spatial variability or have no distinct difference in terms of hydrological prospect had been reclassified and renamed before they were used for further task. By doing this the same classes were assigned in the same name and the comparable classes were also combined into one name. To let all the layers be geometrically aligned and fit to the study area, they were geo-referenced to the corresponding coordinate projection of the study area which is East African spatial reference called Datum_UTM_Zone_35N.

3.2.4.2.3 Delineation of the micro-catchment area and SWAT Analysis

To define the working area on the DEM, manually drawn and edited mask was used. Based on the extent of the mask the DEM processing took place, the stream network and the micro-catchment outlets were defined. Kakondo, the gauge station inside the basin, was manually added and defined as an outlet. The watershed was delineated into micro-catchments. Subsequently, the geomorphic parameters for each micro-catchment were calculated. The land use/cover and soil map were imported into the interface and reclassified. This was done using ArcMap interface. Both land use and soil were reclassified again in ArcSWAT interface. Therefore, during reclassification, land use/cover classes which did not exist in SWAT data base were substituted by classes which exist in SWAT data base and have similar hydrological properties. The soil map of the study area was reclassified according to ArcSWAT requirements. Food and Agriculture Organization of the United Nations (FAO) soil classification system which was supported by other additional methods was used to determine soil types and properties of each soil class.

In the next step, all the reclassified three maps were overlaid. This procedure helped to determine land use / cover /soil /slope class combination and distribution for the delineated watersheds and each respective sub-watershed. Then, the micro-catchments were divided into Hydrologic Response Units (HRUs) by assigning the threshold values of land use/cover and soil percentage.

3.2.4.2.4 Weather Data

Daily time-series of weather data, which includes precipitation and maximum and minimum air temperature data, is required for the SWAT modeling. The climatic data used in the study was obtained from the Geophysic Department of the Center of Research of Natural Sciences of Lwiro. The period was approximately twenty two years precipitation data for the station. From January 1st 1990 to June 30th 2013 including 1 year of warm up period, was used for SWAT simulation. To deal with the weather data, it should be stored in a specific tabular and supportive file format of ArcSWAT. In this case they were stored in DBF format which is read by ArcSWAT interface. The geographical coordinate's name of the weather station of the study area was introduced into ArcSWAT database. The data has provided the most representative precipitation data available.

3.2.4.2.5 SWAT simulation

In the next task, the database files containing the information needed to generate default input for SWAT model were built. In SWAT, once the default input database files are built, the necessary parameters values can later be entered and edited manually. The HRU distribution was also modified whenever it was needed. The soil parameters values of each type of soil were entered. SWAT simulation run was carried out on the January 1990-December 2013 climate data. One year data was kept as warm up period. The warm-up period is important to make sure that there are no effects from the initial conditions in the model. The lengths of warm-up period differ from micro-catchment to micro-catchment. It mainly depends on the objective of the study. The run output data was imported to database and the simulation results were saved in different files of SWAT output. The file named basins.rch contains stream-flow and water quality parameters in streams and rivers. It is used for SWAT model calibration since most of the observations of the watershed's behavior are obtained by measuring these parameters. The basins.sbs file stores yearly outputs from HRU's.

3.2.4.2.6 Calibration

Model inputs like dynamic forcing data and values of parameters are associated with a number of uncertainties (Holvoet *et al.*, 2004). Therefore model calibration is an important task to improve the result of model simulation. It is a process of tuning parameters which help to improve models predictive accuracy. Since models should be developed with regard to a process described by different parameters, a result in a calibration represents a calibration that represents the system being modeled. Most calibrations are supported by sensitivity analysis which avoids performing calibration on non-effective parameters. Sensitivity analysis helps to determine the sensitivity of parameters by comparing the output variance due to input variability. It also facilitates selecting important and influential parameters for a model calibration by indicating the parameters that shows higher sensitivity to the output due to the input variability.

SWAT was calibrated based on the biweekly measured discharge, sediment, nitrate, and total phosphorous loads at the watershed outlet at Kakondo site. Water discharge was measured continuously. Concentrations of sediments (total suspended sediments), total nitrogen and total phosphorous in the river water were determined in biweekly composite flow proportional samples. Corresponding biweekly loads were calculated as the product of biweekly average water discharge time's concentration.

Additional to calibrating model result, the calibration process helps to verify the degree of sensitivities of the SWAT parameters which are resulted from sensitivity analysis process. Calibration can be performed in two ways: either manually or automated. In ArcSWAT2005 Manual Calibration Helper is used for making adjustment to parameters across a user defined group of HRUs or micro-catchment (Arnold *et al.*, 2005). Auto Calibration and Uncertainty of ArcSWAT2005 is used for automated calibration. It has two dialogue boxes namely Auto-Calibration Input and Auto-Calibration Output (Van Griensven and Meixner, 2004). The earlier allows performing the automatic model calibration by selecting a simulated model and a micro-catchment were a discharge outlet is located. The latter provides option to refine to the out parameters for an analysis. The streamflow observed data from 01 August 2011 to 30 June 2013, derived from Lwiro gauging station was used for auto calibration.

3.2.4.2.7 Validation of the model

Validation process using an independent set of observed data is necessary to comprehend the degree of the certainty of the model prediction. Model performance in calibration and validation periods may not be similar. Recent studies revealed that there are a number of difficulties of climate model validation. This is because of the complexity of the nature of climate and time dependent uncertainties of modeling dataset. Another reason is that hydrologic condition in the calibration period may not be the same as the hydrologic condition during the validation period (Beven, 2006; Zhang and Lu, 2009). The arithmetic ensemble mean and Bayesian Model Averaging (BMA) methods can be used to account and assess such calibration and validation models differences. To assess the performance, the methods estimate values of the difference in properties in calibrated and validated models. In a good performance, the estimated values must match with the expected coverage percentage.

In case of single models predictions, the simple arithmetic ensemble mean (i.e. R^2 and *NSE*) can be used.

The validation was carried out using the calibrated parameters. For model validation the remaining observed streamflow data from 01 July 2012 to 31 December, 2013 were used. In the validation process, the model was run with input parameters set during the calibration process without any change. Following the validation process, the model performance assessment methods were reused to test the model performance.

3.2.4.2.8 Determination of annual water discharge and sediment yield hotspot area in the river Lwiro micro-catchment

The annual water discharge and sediment yield hotspot was determined by analyzing hotspot areas over the river Lwiro micro-catchment during the period of the study (August 2011 to December 2013). The SWAT model represents the large scale spatial heterogeneity of the studied area by dividing the micro-catchment into micro-catchments. Each micro-catchment is parameterised using a series of HRUs (hydrologic response units) which are a particular combination of land cover, soil and management. Soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices are simulated for each HRU and then aggregated for the micro-catchment by a weighted average. Physical characteristics, such as slope, reach dimensions, and climatic data are considered for each micro-catchment. Estimated water discharge and sediment yield loading obtained for each micro-catchment are then routed through the river system. In this study, the river Lwiro micro-catchment was subdivided into 7 micro-catchments and HRUs. River Lwiro micro-catchment parametrisation and the model input were derived using the SWAT ArcView 3.2 Interface (Coppin and Bauer, 1996; Lillesand and Kiefer, 1987), which provides a graphical support to the disaggregation scheme and allows the construction of the model input from digital maps. The basic data sets required to develop the model input are: topography (DEM for Lake Kivu), soil (soil map from FAO), land use (four main classes: Wetland, Built-up area, Forest and small scale farm land) and climatic data (for meteorological station located at the Department of Geophysics at Lwiro).

3.3 Data analysis

The trend in land use/cover was assessed using linear regression analysis. A one-way analysis of variance (ANOVA) was carried out to test for temporal and site differences. The paired – t – test was used to evaluate seasonal differences. Person's correlation coefficient was calculated to establish the relationship between the parameters and some hydrological variables.

The model predictions were evaluated for both the calibration and validation periods using two statistical measures: coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (NSE). The R^2 value is an indicator of strength of relationship between the measured and simulated values. The Nash-Sutcliffe coefficient, (NSE), measures how well the daily simulated and measured flows correspond. The NSE parameter takes values between $-\infty$ and 100%, the latter corresponding to a perfect fit; while a zero value means that the model yields the same performance as a one-parameter "no-knowledge" model always predicting the average observed streamflow. The model prediction is considered unacceptable if the R^2 values are close to zero and the NSE values are less than or close to zero. If the values equal one, the model predictions are considered perfect. Generally, R^2 and NSE values greater than 0.5 are considered acceptable; however, explicit standards have not been specified for assessing model predictions using these statistics (Neitsch *et al*., 2000; Levesque *et al.*, 2008; Jain *et al.*, 2010; Kimwaga *et al.*, 2011).

CHAPTER 4. RESULTS

4. 1. Magnitude of land use/ cover changes

The results from the interpretation of the satellite images show that there have been significant changes in the land use. The results show that land use/cover in the study area changed substantially from 1987 to 2010 (forest decrease to 23 %, wetland increase about 2.1%, small scale farmland 0.8 % and built-up area 2.2 %). Figure 6 shows the three land use/ cover maps 1987, 2001 and 2010 that have been generated from Landsat TM imagery classification.

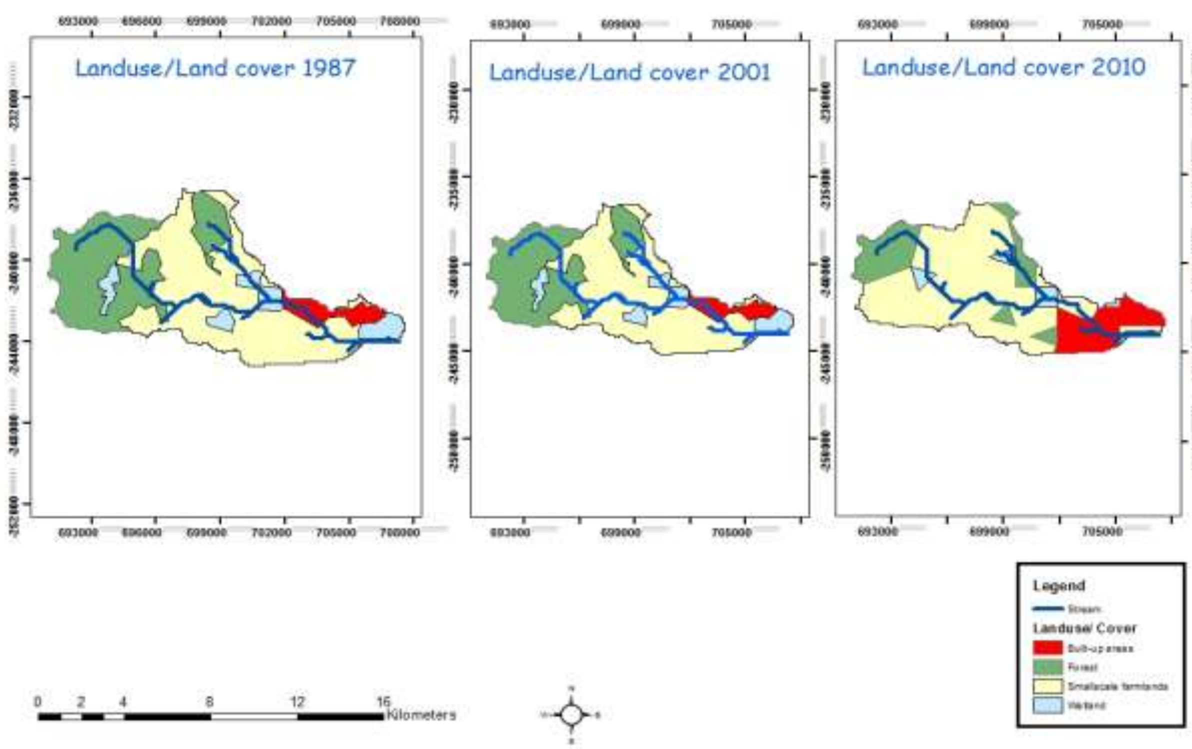


Figure 6: Land use/cover maps in River Lwiro micro-catchment 1987, 2001 and 2010

There has been a decrease in the forest areas and the increase in small scale farmland over the past two decades. The portion of each land use/cover class is shown in figure (7).

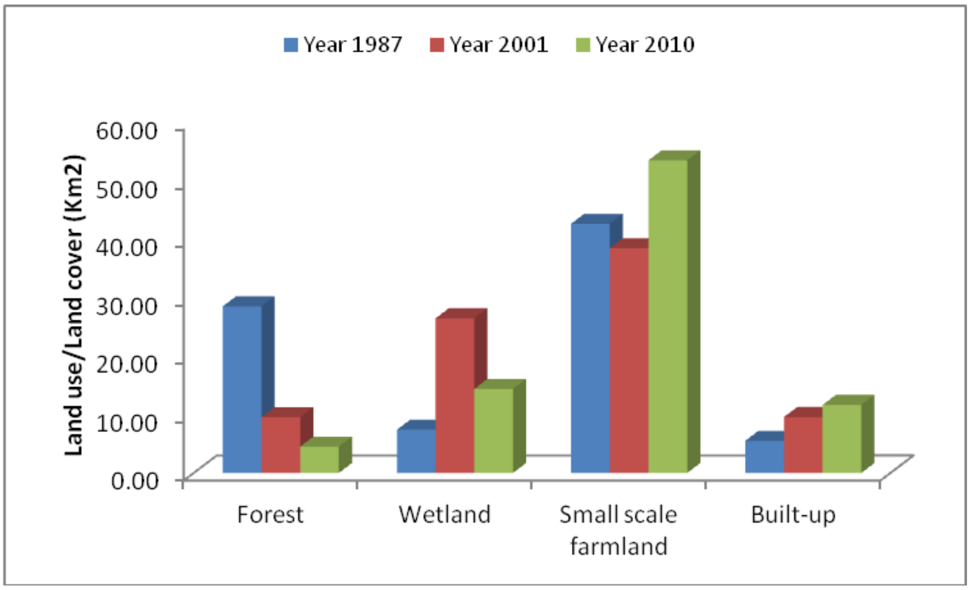


Figure 7: Change in land use/cover between 1987 and 2010 in River Lwiro micro-catchment

Figure 7 reveal the changes in land use/cover that have been taking place in 1987, 2001 and 2010 in the basin. On the land use/cover map of year 1987 the total forest coverage class was 33.9 % of the total area, the small scale farmland 50.7 %, wetland 8.8 % and built-up area 6.6 %. For the results in 1987, small scale farmland was the dominant land use/cover in the micro-catchment. On the land use/cover map of year 2001, the small scale farmland (45.8 %) and forest (11.3 %) was reduced but built-up area (11.4 %) and wetland (31.5 %) was increased. On the land use/cover map 2010, forest (5.4 %) and wetland (17.1 %) decreased but built-up area (13.9 %) and small scale farmland (63.6 %) increased. The changes observed in the forest are probably due to high demand of wood and food during the refugee movement in the micro-catchment. This also caused increase in small scale farmland in the micro-catchment. But also, the growth of population is another cause of increased cultivated land in demand for new cultivated land which in turn resulted into shrinking on other types of land use/cover of the area. In general, during the twenty three years period the forest land decreased by 28.5 % where as the small scale farmland increased by 12.9 %. Table 1 show the area coverage of each land use/cover class in the three different years.

Table 1: Rates of change in land use/cover types in River Lwiro micro-catchment

	Year 1987		Year 2001		Year 2010	
Classes	Km^2	%	Km^2	%	Km^2	%
Forest	28.5	33.9	9.5	11.3	4.5	5.4
Wetland	7.4	8.8	26.4	31.5	14.4	17.1
Small scale farmland	42.6	50.7	38.5	45.8	53.5	63.6
Built-up area	5.5	6.6	9.6	11.4	11.6	13.9

The rates of change differed between land use/cover types and from different years. In year 1987, the percentage of small scale farmland (50.74 %) was higher than other classes. The lowest class was built-up area. At that period people were migrating to towns and the rural areas were depopulated. The area was covered by vegetation and trees. The year 2001, we observed a decreased in forest and an increase in wetland. This increase in 2001 of wetland area is due to political instability in the micro-catchment and the land was not utilized by population for agriculture purpose. People were interested in cutting forest for wood for sell and neglected the other classes such as small scale farmland and wetland but some construction begun to take place in the micro-catchment. Many families come from the insecure land to construct near the city of Katana were insecurity does not take place. In year 2010, as population was growing, as shown by the built-up area (13.9 %), the small scale farmland also increased up to 63.9 % in the micro-catchment. The index of $K1$ measuring annual net increasing rates of land use/cover types is presented in the figure 8.

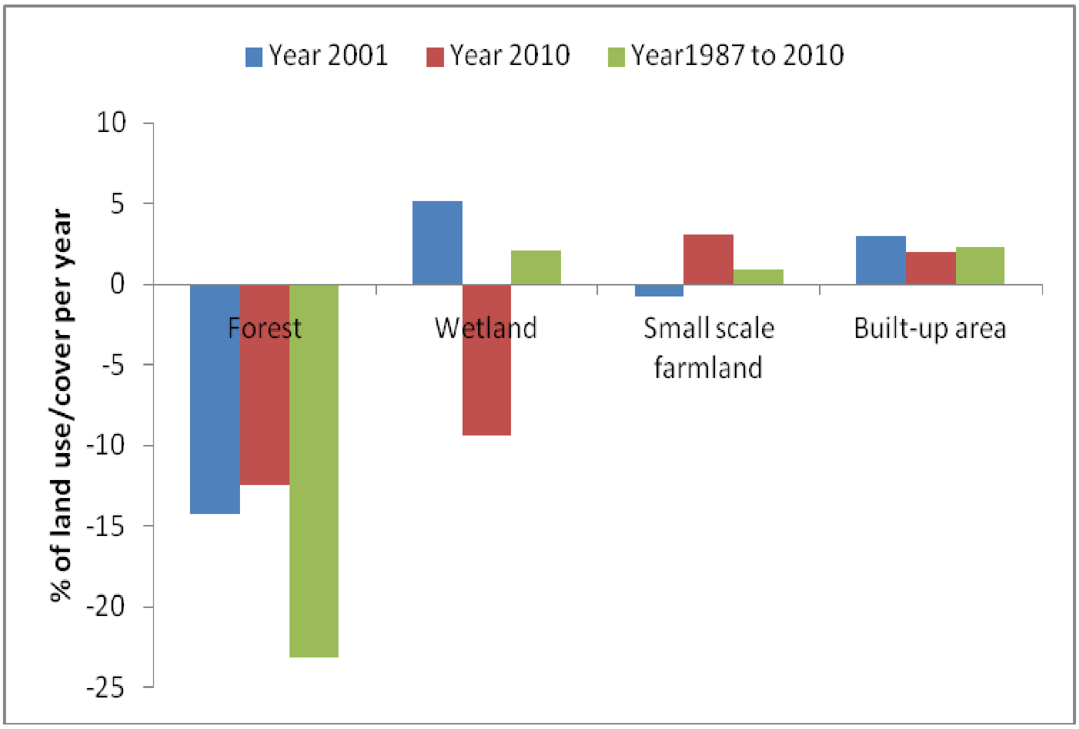


Figure 8: Dynamics of land use/cover in River Lwiro micro-catchment

Figure 8 shows that in the two years considered, the forest decreased all the year and built-up area is increased. However, built-up area decreased in 2010 due to the insecurity in the micro-catchment. In general, forested area in the micro-catchment decreased while as other classes such as built-up areas and wetlands increased gradually from 1987 to 2010.

4.2 Water quality of River Lwiro micro-catchment in Lake Kivu basin

4.2.1 Physico-chemical parameters of water in River Lwiro

The mean monthly variation of BOD_5, COD and discharge at the outlet is presented in the figure 9. BOD_5 concentrations did not significantly vary from one month to another for the measurement carried in the period of study ($P>0.05$). Discharge presented a peak in May while COD showed three peaks in April, July and September.

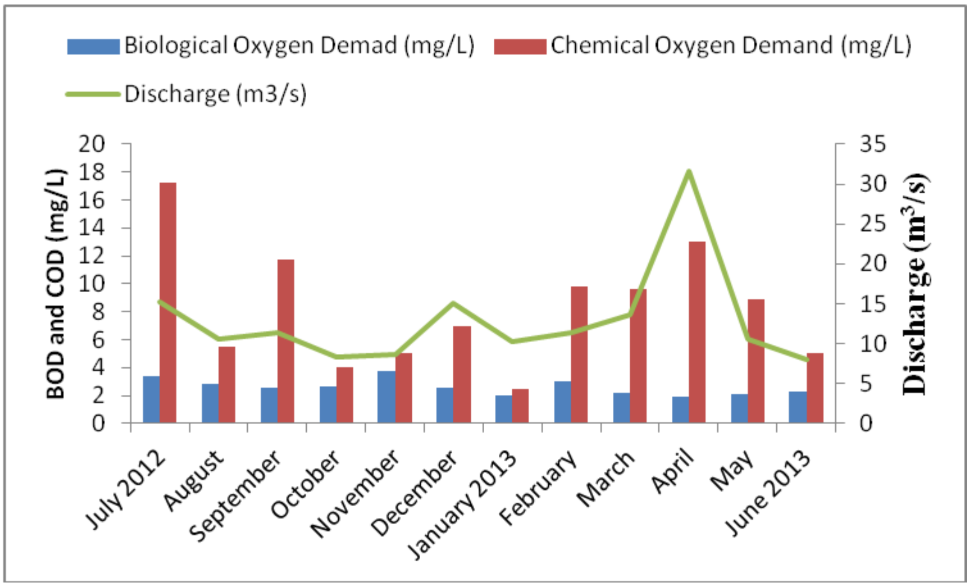


Figure 9: Monthly variation of discharge and BOD5, COD at the outlet of River Lwiro micro-catchment

Similarly TP did not vary significantly with months; while TN followed the trend of the discharge (Figure 10). TSS presented a peak in August, January and April.

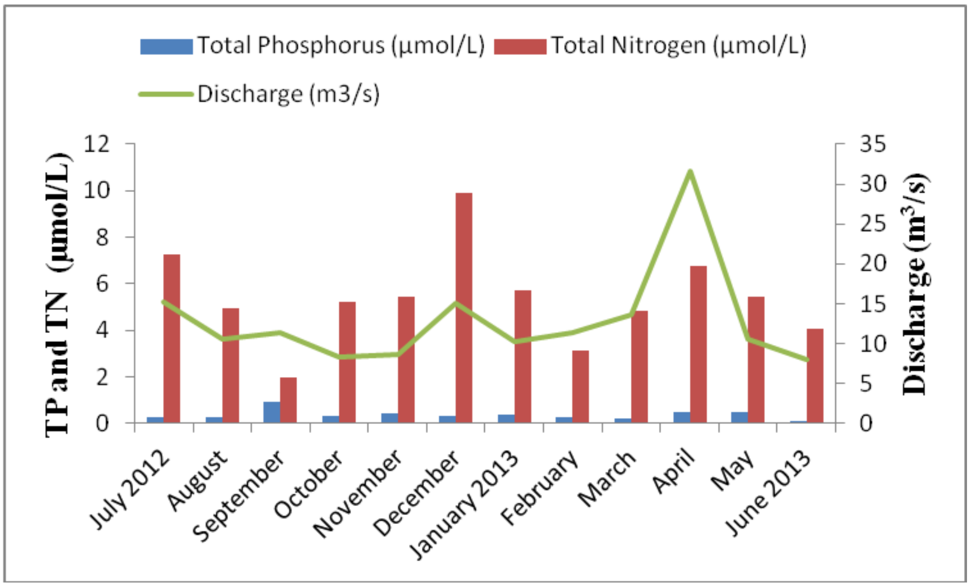


Figure 10: Monthly variation of discharge, TP and TN at the outlet of River Lwiro micro-catchment

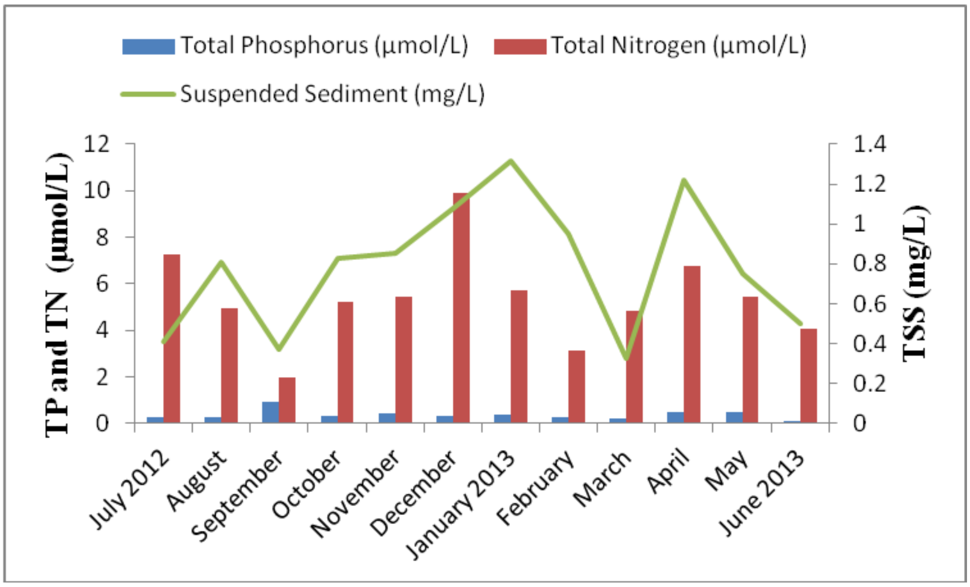


Figure 11: Monthly variation of TSS, TP and TN at the outlet of River Lwiro micro-catchment

It is observed that TP is high in September 2012, April and May 2013 during the rainy season and TN shown a pick July 2012 and December 2012. TSS was also high in January 2013 and April 2013 during the rainy season.

Table 2: Mean physico-chemical parameters of River Lwiro micro-catchment (Mean ± SE)

Parameter	Agricultural	Industrial +Agric.	Outlet	UNECE[1]
Temperature (°C)	20.14 ± 0.86	19.02 ± 1.09	18.46 ± 1.03	< 37
pH	7.91 ± 0.41	6.94 ± 0.57	7.95 ± 0.43	6.5 to 8.5
Dissolved Oxygen (mg/L)	4.94 ± 0.97	2.68 ± 1.64	5.40 ± 0.55	6
Alkalinity (mg/L)	33.08 ± 11.01	21.33 ± 9.25	17.79 ± 5.44	250
Total Suspended Sediment (mg/L)	0.81 ± 0.36	1.15 ± 0.36	0.78 ± 0.32	20
Biological Oxygen Demand (mg/L)	2.7 ± 0.77	1.08 ± 0.83	2.61 ± 0.57	50
Chemical Oxygen Demand (mg/L)	9.05 ± 2.55	13.13 ± 6.26	8.27 ± 3.77	10 - 20
Total Phosphorus (µmol/L)	0.33 ± 0.12	1.89 ± 1.76	0.38 ± 0.16	0.6 – 1.28
Soluble Reactive Phosphorus (µmol/L)	0.27 ± 0.16	1.32 ± 1.32	0.23 ± 0.16	NA
Total Nitrogen (µmol/L)	7.75 ± 4.29	33.95 ± 31.27	5.40 ± 1.63	50 – 100
Ammonia (µmol/L)	0.98 ± 0.75	7.32 ± 9.30	0.54 ± 0.26	NA
Nitrate (µmol/L)	2.81 ± 1.62	8.54 ± 8.36	1.88 ± 1.20	< 45
Discharge (m^3/s)	0.67 ± 0.38	0.12 ± 0.11	12.89 ± 3.98	NA

(n = 24)

[1]Source: ECE (Economic Commission for Europe) standard limit values of surface freshwater quality for the maintenance of aquatic life (UNECE 1994)

NA: Not available

The mean value of selected physico-chemical parameters of water in the river are within the range proposed by UNECE (1994) for aquatic life, and showed a variation between the sites during the year. Effluent dominated by industrial and agricultural activities had relatively high values in terms of TP, SRP, TN, NH_4^+ and NO_3^-. Most of the parameters were relatively low at the outlet. Pearson's correlation of between the physico-chemical parameters of the three samples sites are presented in Table 3.

Table 3: Pearson's correlation coefficient of different physico-chemical parameters at the outlet of River Lwiro micro-catchment

	TSS	BOD_5	COD	Disch	TP	SRP	TN	NH_4^+	NO_3^-	Temp	pH	DO	Alkal
TSS	1												
BOD_5	-0.99	1											
COD	1.00	-0.98	1										
Disch	-0.59	0.47	-0.65	1									
TP	1.00	-1.00	0.99	-0.51	1								
SRP	1.00	-0.99	0.99	-0.56	1.00	1							
TN	1.00	-0.99	1.00	-0.59	0.99	1.00	1						
NH_4^+	1.00	-0.99	1.00	-0.58	1.00	1.00	1.00	1					
NO_3^-	1.00	-0.98	1.00	-0.64	0.99	1.00	1.00	1.00	1				
Temp	-0.13	0.27	-0.05	-0.73	-0.22	-0.16	-0.12	-0.13	-0.06	1			
pH	-1.00	1.00	-0.99	0.53	-1.00	-1.00	-1.00	-1.00	-0.99	0.19	1		
DO	-1.00	0.97	-1.00	0.66	-0.98	-0.99	-1.00	-0.99	-1.00	0.03	0.99	1	
Alkal	-0.23	0.37	-0.16	-0.65	-0.32	-0.27	-0.22	-0.24	-0.17	0.99	0.30	0.14	1

Some parameters are strongly correlated ($r > 0.91$) such as SS and COD with nutrient (P and N) but the other parameters in general were strongly and not significantly correlated ($r < 0.31$). TSS is strongly positively correlated with COD, TP, SRP, TN, NH_4^+, NO_3^- and strongly negatively correlated with BOD_5, pH and DO. The correlation of BOD_5 is contrary to the correlation of TSS. It is strongly negatively correlated with COD, TP, SRP, TN, NH_4^+, NO_3^- and positively correlated with pH and DO. COD is similarly correlated to TSS. Discharge is negatively correlated with the entire nutrient but positive correlation is recorded with pH and DO. TP, SRP, TN, NH_4^+, NO_3^- are strongly positively correlated between them but negatively correlated with others parameters. Alkalinity is weakly correlated with all other parameters investigated in this study.

4. 2.2 Total Suspended Sediment, nutrient and others pollutants loading in River Lwiro micro-catchment

The annual load of selected parameters in the Lwiro micro-catchment is presented in the table 4.

Table 4: Annual load of selected water quality parameters in River Lwiro micro-catchment (Mean ± SE)

	Upstream	Agriculture	Indus+Agriculture	Outlet
Total Suspended Sediment (t/yr)	66.92 ± 10.69	17.42 ± 4.40	4.60 ± 1.32	319.22 ± 40.79
Biological Oxygen Demand (t/yr)	303.98 ± 27.68	59.16 ± 9.41	4.31 ± 3.03	1063.48 ± 72.32
Chemical Oxygen Demand (t/yr)	1267.77 ± 117.43	193.45 ± 30.98	52.29 ± 22.66	3365.94 ± 474.75
Total Phosphorus (t/yr)	34.76 ± 3.66	7.23 ± 1.54	7.56 ± 6.38	157.15 ± 21.19
Soluble Reactive Phosphorus (t/yr)	21.45 ± 3.21	5.88 ± 2.02	5.28 ± 4.79	95.81 ± 20.60
Total Nitrogen (t/yr)	634.79 ± 75.48	166.13 ± 52.10	135.14 ± 113.14	2196.87 ± 205.08
Ammonium (t/yr)	108.91 ± 24.95	21.16 ± 9.12	29.14 ± 33.66	223.03 ± 32.89
Nitrate (t/yr)	266.40 ± 56.94	60.45 ± 19.71	34.01 ± 30.25	766.84 ± 151.98

The Total Suspended Sediment, nutrient and other pollutants loading in the different sites are different from one site to another. The agricultural effluent has high loading of selected water quality parameters than the industrial effluent. Results show that biological oxygen demand (BOD_5), chemical oxygen demand (COD) and Total Suspended Sediment load are lowest on the industrial effluent than agricultural effluent. Total Phosphorus load is approximately the same in industrial and agriculture effluents but the variation seem to differentiate them. The same observation is also valuable for Soluble Reactive Phosphorus. Total Nitrogen is high in agricultural than in industrial effluent and same observation for nitrate. But for ammonium, the high load was observed in industrial effluent. The Total Suspended Sediment, nutrient and other pollutants load are high at the outlet compared to the input from agriculture and industrial load.

The annual chemical parameter load calculated by L-Q formula is presented in the table 5.

Table 5: Loading of some chemical parameters using Generic Equation

	Site 6	Site 5	Site 4	Site 3	Site 2	Site 1
BOD_5 (t/yr)	1096	228	2438	238	3322	4956
COD (t/yr)	676	185	1575	166	2480	3022
TP (t/yr)	20019	5239	22951	4262	55659	69281
TN (t/yr)	3435	667	2963	919	6047	7034
TSS (t/yr)	8401	1906	6274	1073	21168	24183

The annual load from the agriculture effluent (Site 3) was COD (185 t/yr), TP (5239 t/yr) and TSS (1906 t/yr), while the annual load from industrial effluent (Site 4) was for BOD_5 (238 t/yr) and TN (4262 t/yr). The differences of chemical parameters are probably due to agriculture activities between the sites and the River Kabindi which is connected to the main River Lwiro, 500 m from the outlet.

The rate of chemical accession load at Site 4 was calculated from agriculture and anthropogenic discharge at site of Myanzi (site 5), at Site 2 (Kakondo), from industrial discharge (Site 3) and at Kakondo outlet (Site 1), from source of the river at Upstream (Site 1).

Table 6: Load accession of BOD_5, COD, TP and TN for 3 sites in River Lwiro

	BOD_5 (t/yr)	COD (t/yr)	TP (t/yr)	TN (t/yr)	TSS (t/yr)
Site4	6	8	11	4	6
Site2	161	42	14	13	46
Site1	4	3	5	4	5

The rate of accession load is defined as ration of load at observation point to load at source point. Load accession of different pollutants presented in Table 6 shows that Kakondo (site 5) industry provided a high load rate of all pollutants followed by the Mwanzi effluent (site 5) and finally the outlet (site 6). The site 4 of Industrial contribute with respectively 160.70; 42.18; 13.93; 13.06 and 46.48 t/yr of BOD_5; COD; TP; TN and TSS. The industrial load is high followed by the agricultural and the natural one. Pollutants derived from industrial source and agriculture sources were decomposed and then generally pollutant load decreases down the stream. Therefore, observed load is smaller than load at source point. Generally, observation load from source is calculated from source load and rate of accession load.

4. 2.4. Atmospheric deposition of nutrients

Monthly variation in concentration of dry and wet atmospheric deposition in the micro-catchment of Lwiro River is presented in the Figure 12 for Dry atmospheric deposition and Figure 13 for Wet atmospheric deposition.

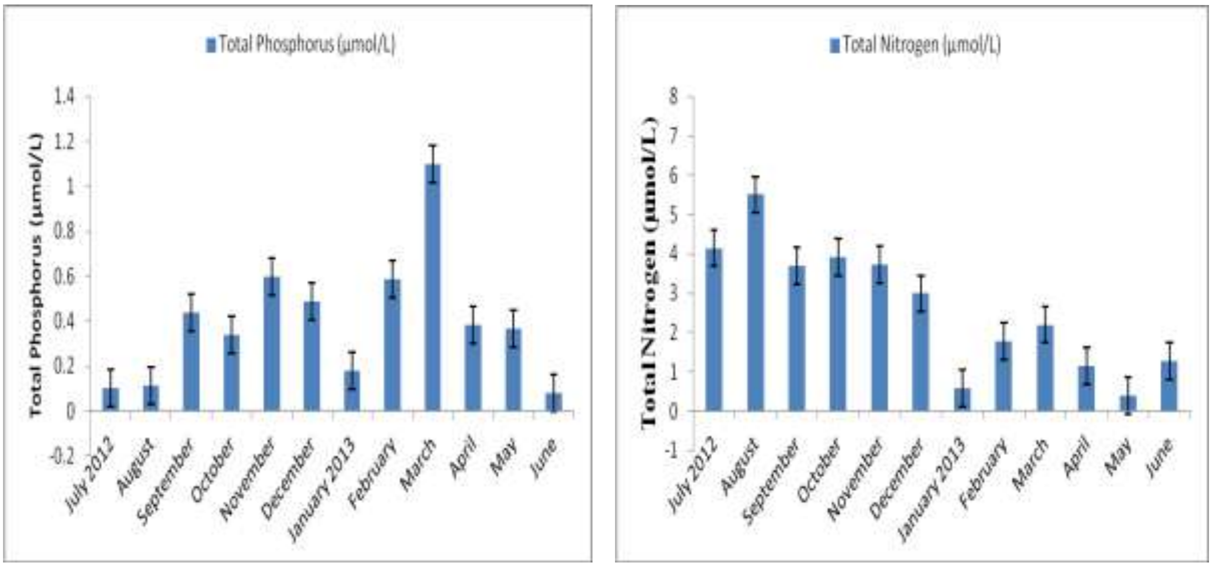
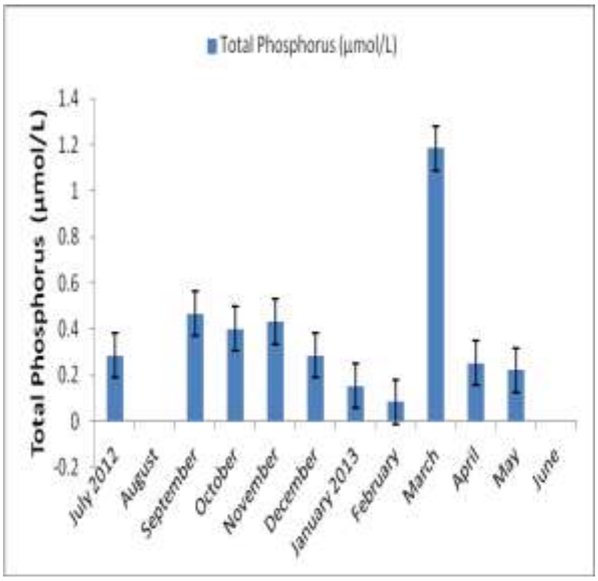


Figure 12: Monthly variation of concentration of dry atmospheric deposition in the micro-catchment of River Lwiro



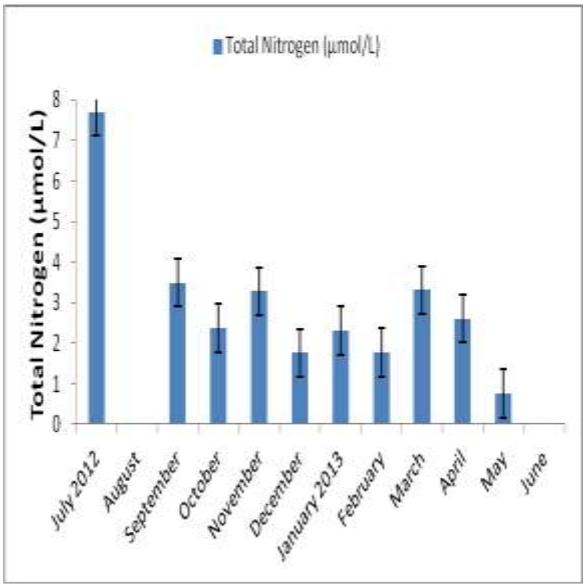


Figure 13: Monthly variation of concentration of wet atmospheric deposition in the micro-catchment of River Lwiro

The monthly mean concentration of nutrients in dry and wet deposition varied during the period of this study. The concentration of dry deposition compared to wet deposition is not significantly different (t= 16.82, p = 0.03 for TN and t= 38, p = 0.016 for TP). The high concentration of TP was recorded during the wet season in March for both dry and wet deposition but the high concentration of TN was recorded in July for Wet deposition and for August in Dry deposition both in dry season. Pollution loading in dry and wet deposition in the micro-catchment is presented in table 7.

Table 7: Mean dry and TN load in River Lwiro micro-catchment

	Mean Dry TP load (t/event * 10^{-3})	Mean Dry TN load (t/event* 10^{-3})
July 2012	0.51	0.39
August	0.40	0.37
September	1.67	0.27
October	0.80	0.73
November	1.91	0.22
December	1.45	0.17
January 2013	0.60	0.04
February	2.71	0.16
March	4.56	0.17
April	1.18	0.07
May	2.93	0.06
June	0.71	0.22

This table shows that the mean dry TP and TN loading in River Lwiro micro-catchment varied from one month to another. The maximum loading of TP is recorded in March and the minimum in August during the dry season. For the loading of TN in the Lwiro micro-catchment the high loading was recorded in July 2012 and the lowest in January during the rain season. Table 8 presents the mean loading of TP and TN in wet atmospheric deposition.

Table 8: Mean wet TP and TN load in River Lwiro micro-catchment

	Mean TP load (t/event)	Mean TN load (t/event)
July 2012	0.013	0.305
August	-	-
September	0.026	0.191
October	0.002	0.014
November	0.017	0.100
December	0.003	0.016
January 2013	0.003	0.044
February	0.005	0.181
March	1.680	0.285
April	0.219	0.251
May	0.056	0.018
June	-	-

The high TP load (1.680 t/event) was observed in March during the rain season while the lowest value was recorded in October (0.002 t/event) in the Lwiro micro-catchment. For the TN load in the Lwiro micro-catchment, the high value was recorded in July 2012 (0.305 t/event) and the lowest in October 2012 (0.014 t/event). No rain was sampled in August 2012 and June 2013.

Table 9: Annual atmospheric deposition load of TP and TN in River Lwiro micro-catchment

	TP (t/yr)	TN (t/yr)
Annual dry load	0.366	0.043
Annual wet load	3.079	16.312

The annual load for TP was about 8 times high in wet atmospheric deposition than in dry and for TN it was 37 times high.

4.3 SWAT model results for water discharge, sediment and nutrients in River Lwiro micro-catchment/ Lake Kivu basin

4.3.1 Water discharge

The monthly water discharge was calibrated for the period 01/07/2012-31/06/2013 and validated for the period 01/08/2011-31/12/2013 at the outlet of River Lwiro. The mean daily data was used to calibrate water discharge while the mean biweekly data was used to validate water discharge. The main SWAT parameters that were adjusted are related to the groundwater recession time (GW_DELAY) (Figure 14). In general, the total water amount and the flow peaks are well simulated, except the flood event at February-April and the end of year 2013. In addition, in some years the base flow at the end of the dry season is partially underestimated.

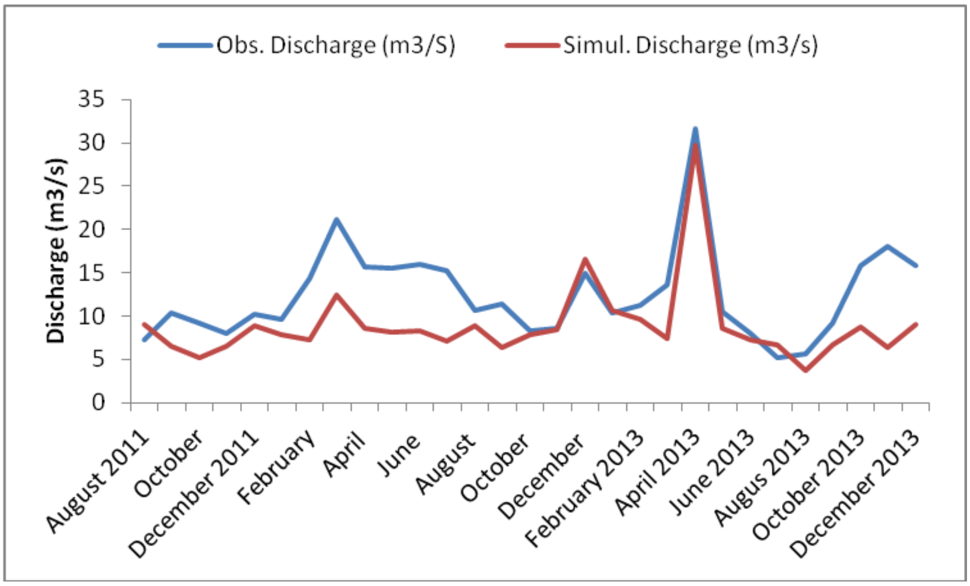


Figure 14: Measured and simulated monthly water flow at the outlet of River Lwiro

The simulated long term average water discharge at the outlet of the River Lwiro micro-catchment was 8.9 m^3/s. These values are in agreement with the available average measures of 12.5 m^3/s (average of the period 2011-2013).

4. 3.2 Water quality

Monthly data was used to calibrate TSS at the outlet of River Lwiro micro-catchment. Total nitrogen and total phosphorus concentration were present at the micro-catchment outlet. For nutrient calibration, monthly values were considered. From the analysis of the model monthly simulations it appeared that observed TSS was higher than the simulated values. A peak of observed values is in April 2013. In general the trend is observed in simulated and observed TSS data from River Lwiro micro-catchment (Figure 15).

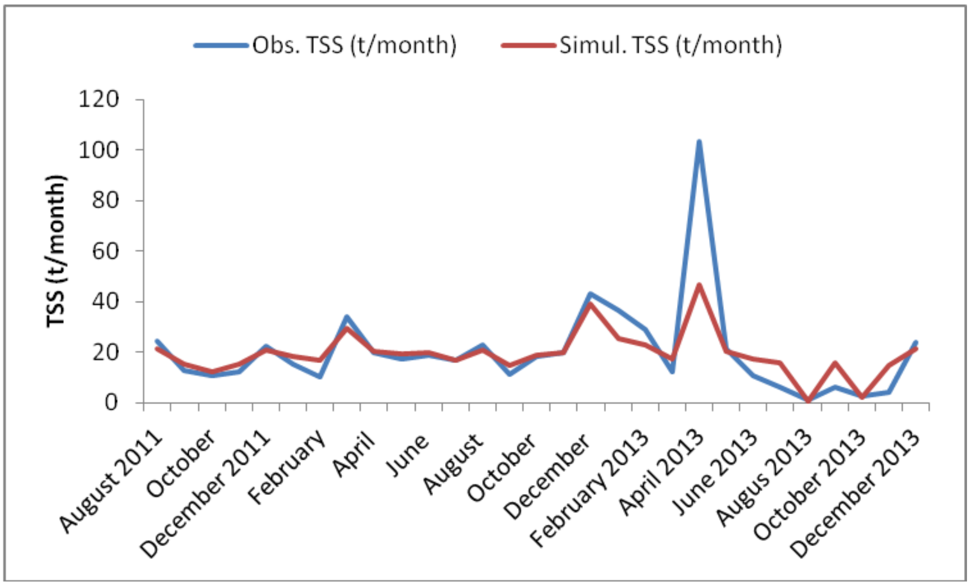


Figure 15: Measured and simulated daily total suspended sediment at the outlet of River Lwiro

For simulated nutrient (TN and TP) for calibration period were compared to monthly measured nutrient loads from River Lwiro micro-catchment.

Simulated values and observed values of TSS to the outlet of River Lwiro are linearly correlated with a significantly higher coefficient of determination R^2 = 0.7925 and a NSE = 0.607 (Figure 16)

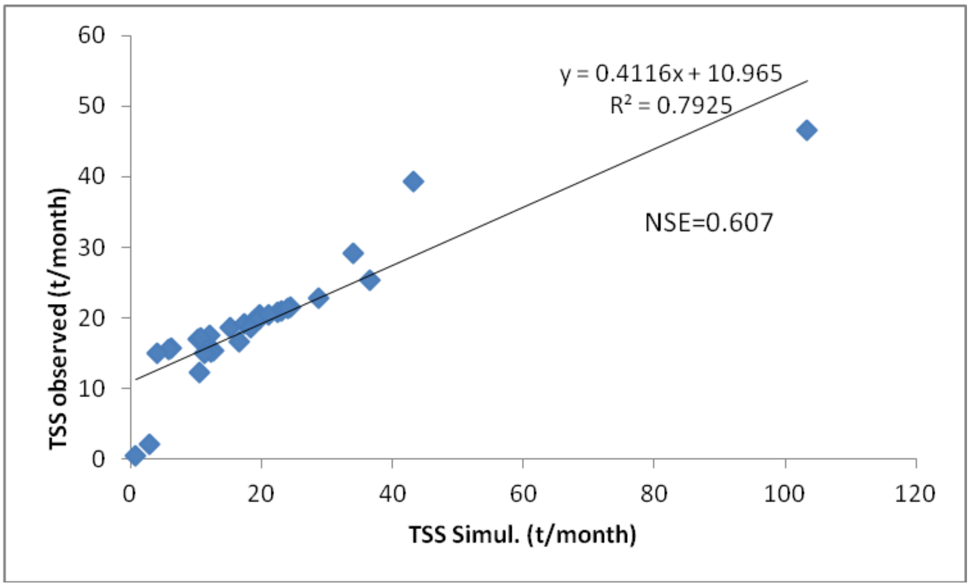


Figure 16: Coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) for simulated sediment on a monthly basis

Figure 17 show the results for monthly phosphorus predictions at the outlet.

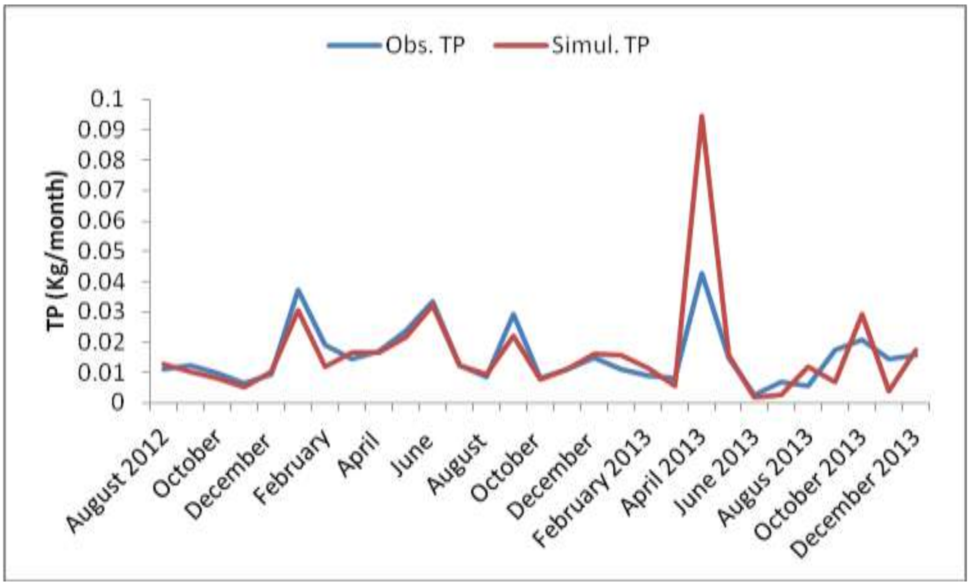


Figure 17: Measured and simulated monthly TP concentration at the outlet of River Lwiro

This figure reveals that simulated TP is higher than the observed TP data but it has the same trend as present in TSS curve. A peak is also observed in April 2013.

Simulated values and observed values of TP to the outlet of River Lwiro are linearly correlated with a significantly moderate coefficient of determination R^2 = 0.6559 and a NSE = 0.24 (Figure 18)

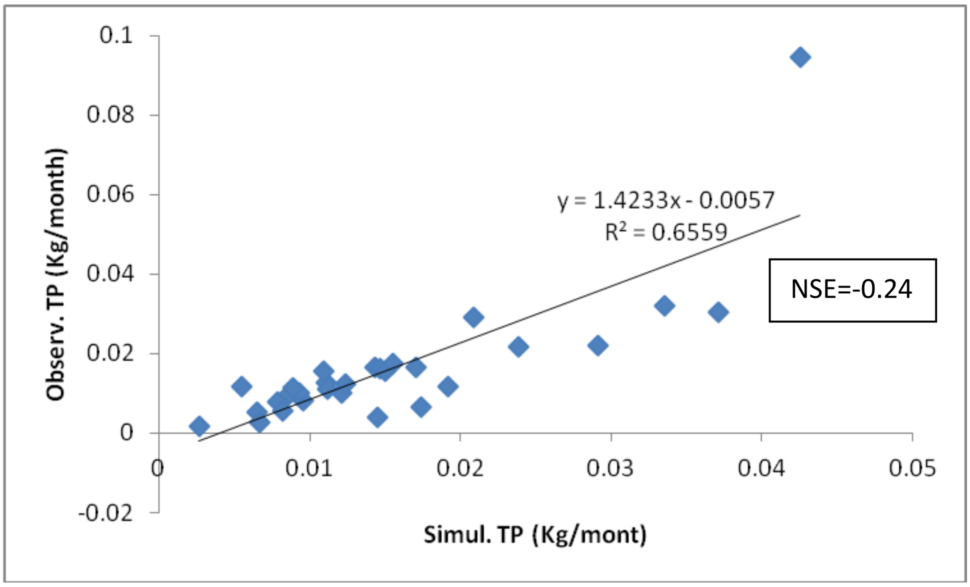


Figure 18: Coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) for TP on a monthly basis

Figure 19 show the results for monthly Nitrogen predictions at the outlet.

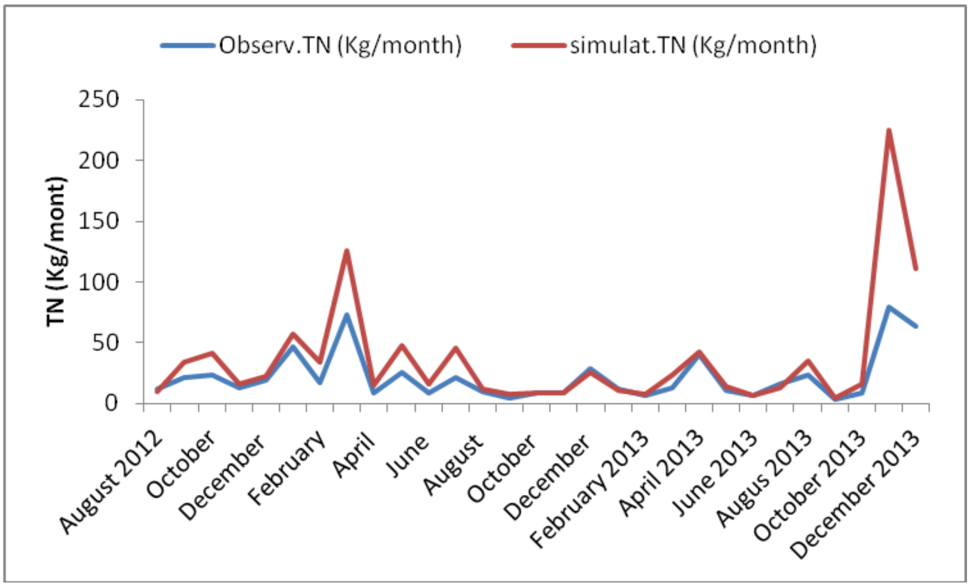


Figure 19: Measured and simulated monthly TN concentration at the outlet of River Lwiro

Figure 19, over predicted values of TN were observed and they were higher than the observed measurement. For nitrogen, some of the simulated values were in the good range, except for some peaks. It is interesting to note that the model was able to capture the higher variability of concentration in the outlet of Lwiro river micro-catchment. In the case of phosphorus, the number of peaks overestimated increases. Unfortunately, these hypotheses could not be further investigated because of the lack of data.

Simulated values and observed values of TN to the outlet of River Lwiro are linearly correlated with a significantly higher coefficient of determination R^2 = 0.8562 and a NSE = 0.69 (Figure 20)

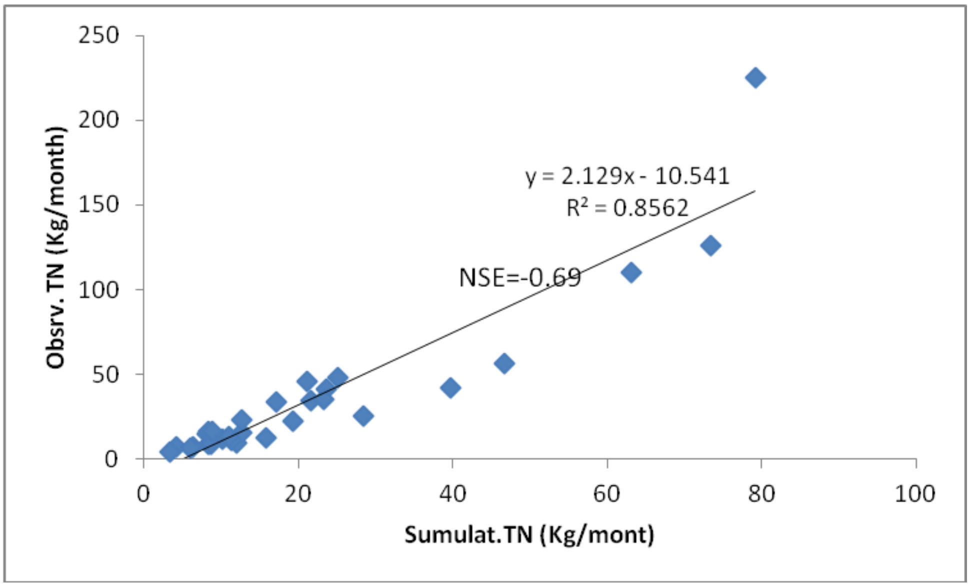


Figure 20: Coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) for TN on a monthly basis

The results of water quality show that the model could be used to estimate annual values of TSS, TN and TP, being aware of the data limitations. Consequently, in the application for scenario analysis, the model predictions should be considered more as an indication of trends than of absolute values, considering the scarce availability of data.

4. 4 Runoff and sediment yield hotspot areas in River Lwiro micro-catchment

Runoff yield hotspot areas for different micro-catchment of the River Lwiro are given in Figure 21.

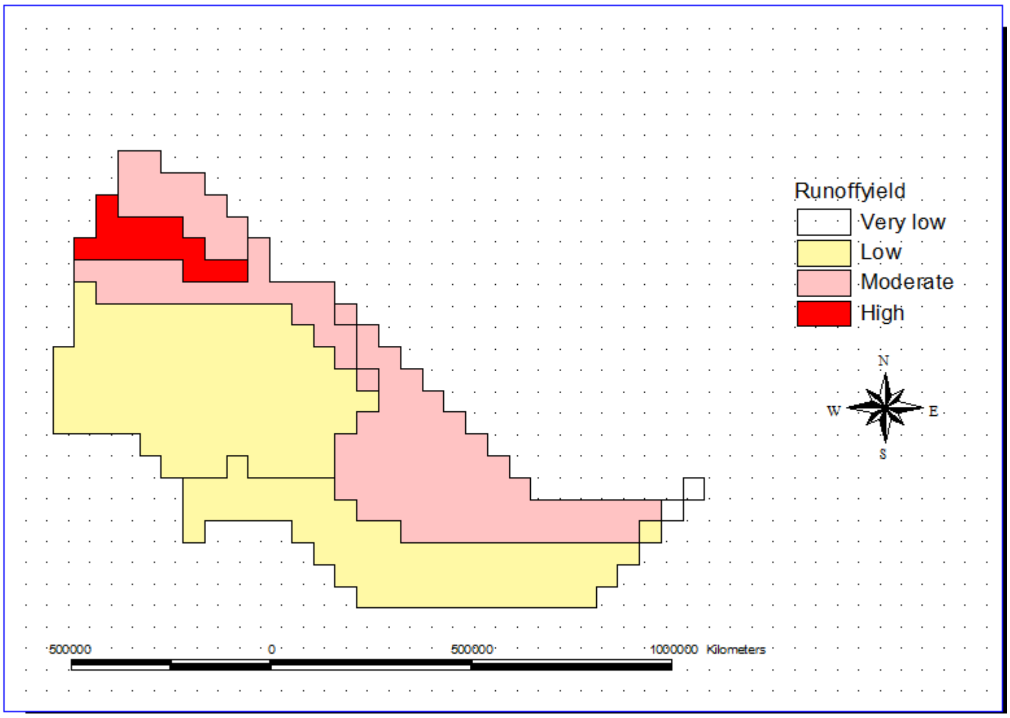


Figure 21: Runoff yield map in the River Lwiro micro-catchment

Runoff yield generated by different land use in the micro-catchment is present in Figure 22.

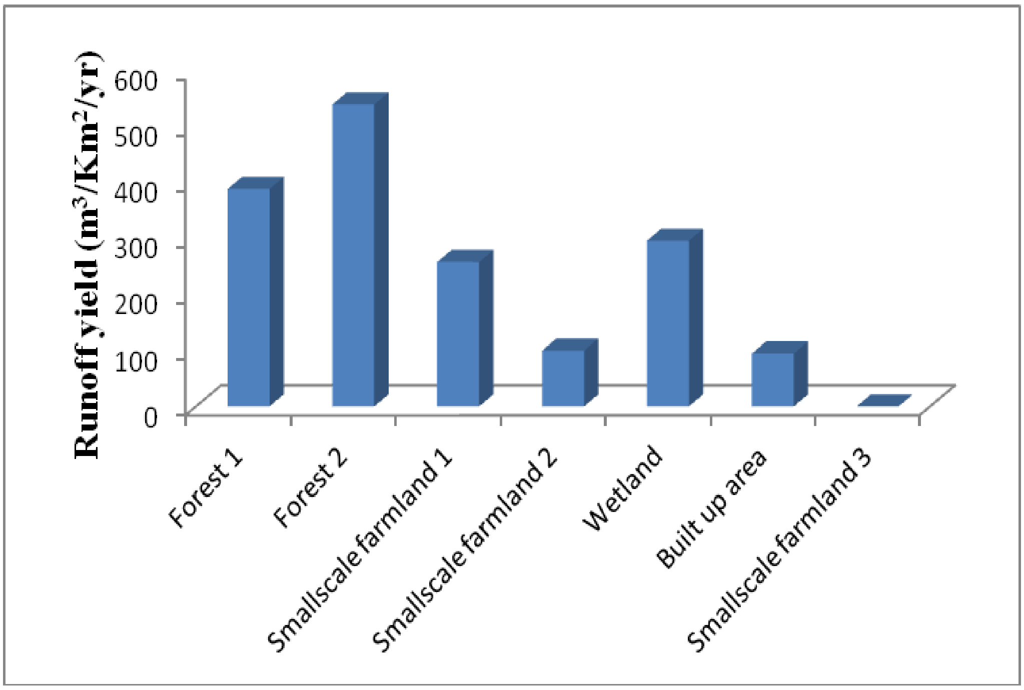


Figure 22: Runoff yield of different land use in River Lwiro micro-catchment

Figures 21 and 22, low annual runoff yield was generated in small scale farmland 2 and built-up areas (100.03 – 94.83 $m^3/km^2/yr$ respectively) covering about 47.65 Km^2 (56.68 %) of the River Lwiro micro-catchment. The high annual runoff yield (539.62 $m^3/km^2/yr$) was obtained in a forested area which covered 4.28 Km^2 (5.09 %) of the River Lwiro micro-catchment. No contribution of runoff yield (0 $m^3/km^2/yr$) is observed in one of the small scale farmland covered 0.61 Km^2 (0.72 %) of the micro-catchment. This micro-catchment is located at a flat area. The forested areas and wetland are the main contributors of annual runoff yield in the River Lwiro micro-catchment.

Sediment yield refers to the amount of sediment exported by a basin over a period of time. Sediment yield hotspot areas for the River Lwiro micro-catchment is given in Figure 23.

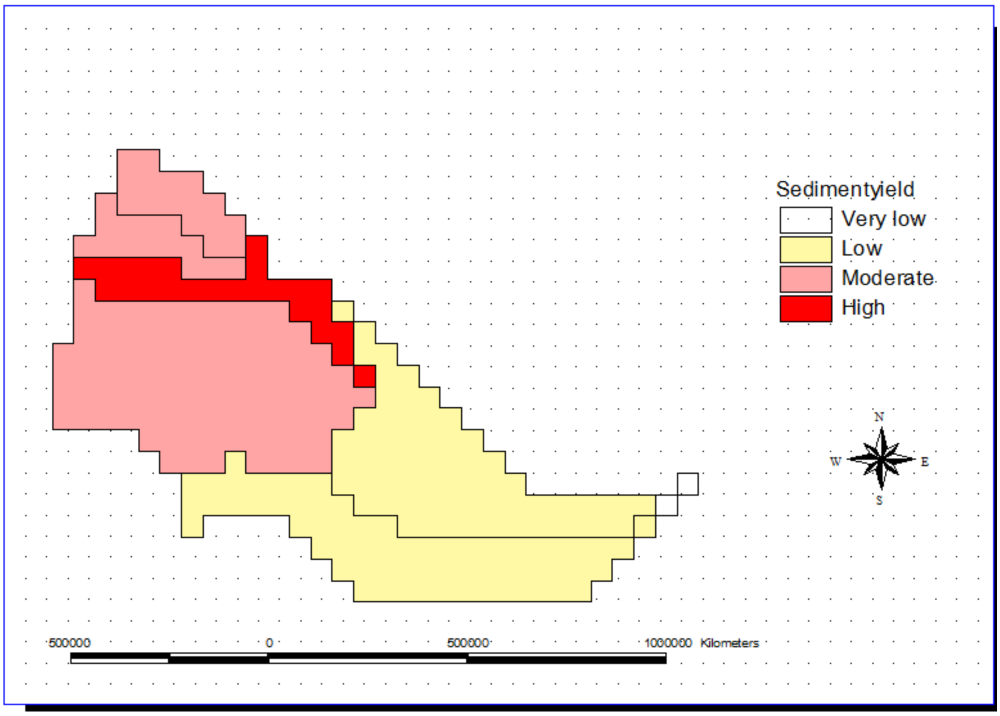


Figure 23: Sediment yield map in the River Lwiro micro-catchment

Sediment yield generated by different land use in the micro-catchment is present in Figure 24.

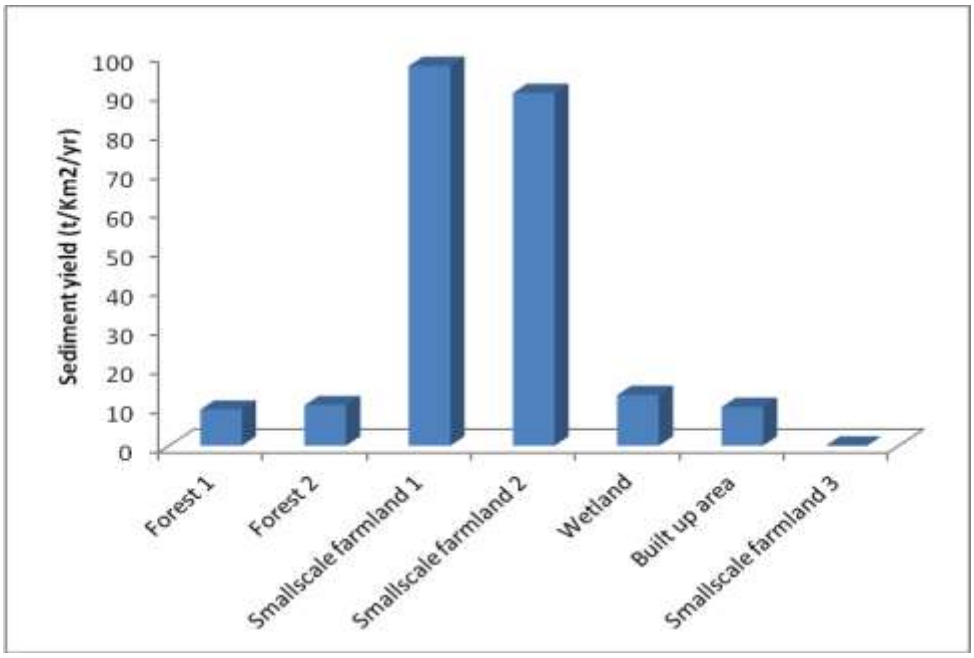


Figure 24: Sediment yield of different land use in River Lwiro micro-catchment

Low sediment yield was recorded at small scale farmland 3 in the micro-catchment of the River Lwiro which has 0.61 Km^2 (0.72 %) while high sediment yield was recorded in a small scale farmland 1 of 7.33 Km^2 (8.73 %). The vegetation on the river bank is removed during the cultivated period causing high sediment in area with high slop **(Plate 3).**

Plate 1: Removal of vegetation around the river bank for agriculture (19 August 2013)

A moderate sediment yield was recorded at the forested area and small scale farm land area. Low sediment yield was found in the remained area (wetland and built-up area) in the River Lwiro micro-catchment. The built-up area is much scattered in the micro-catchment and than their contribution for sediment yield is low.

CHAPTER 5: DISCUSSION

5.1 Land use/cover change in Lwiro micro-catchment

Land use/cover in the study area has changed substantially from 1987 to 2010. The forests decreased by 23 %, while wetlands, small scale farmland and Built-up areas increase by 2.1 %, 0.9 % and 2.3 % respectively. The main reason behind the land use/cover changes include; rapid population growth, rural to urban migration, reclassification of rural areas as urban areas, poverty, ignorance of biophysical limitations, and use of ecologically incompatible technologies (Mallupattu *et al.*, 2013). In the River Lwiro micro-catchment, the classification of image and the change analysis recorded in the Lwiro micro-catchment showed that, in the period of 1987–2010, the areas covered by forest and grasslands decreased compared to built-up area and small-scale farming which increased. The reductions were largely attributed to the intensifications of small-scale farming and the Rwandese refugee coming in the Lwiro micro-catchment in 2004. This intensified agriculture in the area destroyed forests as people were looking for charcoal for energy (Karume, 2010).

In tropical countries, Mertens and Lambin (2000) and Agrawal (1995) observed that the increase of population is followed by expansion of agriculture and leading to natural land-cover clearance. It has also been noticed that construction and movement of population in a specific area increases the rate of land-cover clearance. In Lwiro micro-catchment forest land converted to small scale farming land and built-up areas is also due to these changes. From 1987 to 2010, the dynamics of reduction of forest is higher than in others classes. This has a consequence of loss of natural ecosystem and biodiversity (Meyer and Turner 1994; Lambin *et al*. 2001). The increase in agricultural land is a welcoming trend to water quality.

The digital image classification coupled with GIS has demonstrated its ability to provide comprehensive information on the direction, nature, rate, and location of land use/cover changes as a result of rapid farming and urbanization (Barasa *et al.*, 2011; Mohan *et al.*, 2011). However, the issue of class uncertainties in image classification has not been examined in this work. Although the land use/cover maps have a reasonably high overall accuracy, the accuracy of different classes varies.

5.2 Contribution of different nutrient and sediment sources

5.2.1 Physico-chemical characteristics of River Lwiro water.

Physico-chemical properties of the River Lwiro varied from one tributary to another. The tributary (micro-catchment) with industries and agricultural activities tended to have higher concentration values of TSS, TP and TN compared to the tributary with agricultural activities alone. However, the main outlet of the micro-catchment had relatively lower concentration values than both micro-catchments in terms of TN and TSS.

The higher concentration values of TP, TN and TSS for micro-catchment with industries and agricultural activities compared to the tributary with agricultural activities alone is in line with results from Senus *et al.*, (2004); Meybeck *et al.* (1996); Bagalwa *et al.*, (2013a). The finding of these research revealed that industries point sources are contributed heavily in the pollution of water resources. TP was high in the industrial site (1.89 ± 1.76 µmol/L) but low values were recorded in others sites which are below the UNECE (1994) standards limit. Phosphorus, an element necessary for plant growth, is the main cause of eutrophication. Even minimal phosphorus content (some 0.25 µmol/L) in water can constitute a pollutant. Thus, according to the UNECE, (1994) classification of surface water, water is considered fairly eutrophic as of 0.64 µmol/L. Kakondo industry formally used to treat coffee is now used also to treat mineral and this new activity can increased water pollution. This is probably the source of phosphorus recorded in the samples but also human excreta and detergents considered as the second natural origin of phosphate (Golterman, 1993) is pointed. During the dry season, the concentration of phosphorus is lower than in wet season. The input of this nutrient by erosion of excreta and dead material in the micro-catchment occur in the wet season in September, April and May and the concentration of phosphorus increased. Phosphorus is analyzed as soluble phosphate or as total phosphorus. It quickly develops into such low soluble forms as apatite mineral. Much of the phosphorus is absorbed into particles and suspended matter (Rosli and Yahya, 2012). As a result, soil acts as a phosphorus reservoir restricting the impact of excess supplies. A very strong correlation was observed between TSS and this nutrient. Nutrients are transported to the river water by sediments runoff. Then the increased of sediments in river Lwiro is directly linked with the increased of nutrients. All the physico-chemical parameters investigated in this study was within the limit of WHO (2003)

and UNECE (1994). The results of the present study shown that the correlation between selected physico-chemical parameters and sites are positive ($F = 16.13$, $p = 0.001$).
Results show that the annual BOD_5, COD, TSS and nutrient load were lowest on the industrial effluent, in domestic and agricultural effluent than those recorded at the outlet, except for NH_4^+ which was high in industrial effluent than in agricultural one. These findings reveal that diffuse source is the main source of pollutant in Lwiro micro-catchment. This shows that the runoff directly to the river also contributed to the general load. Erosion occurring in the River Lwiro micro-catchment is the main source of TSS as observed by Meybeck *et al.* (1996). A weak positive correlation between discharge and TSS load ($r = 0.36$) has been noticed. Pearson's correlations help to understand the nature of the physico-chemical variables and their species speciation in River Lwiro. It is observed that an increase in concentration of pollutants will occur during the beginning of farming. Correlation analysis is very useful in establishing the physico-chemical parameters association within sites in a given study area (Thirupathaiah *et al.*, 2012). This analysis was done in an attempt to find out which of the parameters are associated and common to various sampling sites within the study area. It is proved that TSS and COD loads are very strongly associated with nutrient. Temporal variation and site difference between TSS ($F= 5.543$, $p< 0.005$), TP ($F= 8,597$, $p< 0.005$) and TN ($F= 7.638$, $p< 0.005$) load were significant different.
The maximum of TSS load was recorded in dry season whereas the maximum discharge in wet season. This observation was attributed to the activities of population in this period of agriculture. TSS load is affected by natural conditions (soil erosion, streambed resuspension) and can be affected by human activities (construction, timber havesting, certain agricultural practices and hydraulic alteration). It is linked to the transport through river systems of nutrients (especially phosphorus), metals and a wide range of industrials and agricultural chemicals (Senus *et al.*, 2004). TSS levels and fluctuation influence aquatic life from phytoplankton to fish, reduce water clarity, light penetration in the water column and is a useful indicator for assessing the effects of land use changes and engineering practices in watercourses (Senus *et al.*, 2004; Bisantino *et al.*, 2011). Nutrients are required to sustain life, but excess nutrient loads can upset the nutrient cycle balance resulting in changes in water quality harmful to organisms (Aldous *et al.*, 2005). Most TN recorded in the sample is possibly from the farmlands and may be in the form of nitrate washed with the sediment into the river. The high load of nitrate in the agricultural effluent can be attributed to this phenomenon and the high NH_4^+ recorded in the industrial effluent can be attributed to the

decomposition of dead peel of coffee discharge in the effluent. However, Bagalwa (2006) found that TSS concentration is high in African rivers than in River Lwiro micro-catchment because the rivers that drain in Lwiro micro-catchment drain in rural areas and some time pass through wetlands where they reduce at certain degree the TSS, nutrients and others physico-chemical parameters loads before they arrive in the main river. But as a result of cultivation on steep hill slopes, the minimal application of soil conservation measures and deforestation, it appears that the input of organic material to rivers has been accelerated in the River Lwiro micro-catchment. This impact may affect the biodiversity and soil fertility and as a consequence result into a decline crop yield in the micro-catchment. The disturbance of natural vegetation at the shoreline of the rivers in an agricultural region will impact seriously the water quality.

The difference between concentrations of physico-chemical parameters in the River Lwiro micro-catchment is attributed to land-use/cover change, biogeochemical conditions in the micro-catchment.

Several authors (Makundi, 2001; Sajjad and Iqbal, 2012; Kimwaga *et al.*, 2012) have observed that there is a positive correlation between land use/ cover change deterioration of water quality in the micro-catchment area. Increase in agricultural land would generally increase the average surface runoff. According to Larsson, (2002) clearing of forest enhanced surface runoff loaded with suspended sediment into the rivers. It is well established that dissolved oxygen budget of a river is direct indicator of its biological state as was also suggested by Lamb (1985).

Study on physico – chemical characteristics of River Lwiro suggest that the various parameters depend on the biogeochemistry of the study area, the wastewater released by Kakondo industry and runoff water from small scale farmland around the micro-catchment. The pH of water is directly related to carbonate and bicarbonate ions present in it, which is closely associated with CO_2 pressure and the ionic strength solution (Shraddha *et al.*, 2011). Generally the obtained pH values fall within the limit value of WHO (2003) and UNECE (1994). The River Lwiro micro-catchment has a neutral pH that varies from site to site between 6.05 and 8.9 as other rivers in Africa (Iwuoha and Osuji, 2012; Loko *et al.*, 2013; Bagalwa *et al.*, 2013a).

It is well established that dissolved oxygen budget of a river is a direct indicator of its biological state as was also suggested by Lamb (1985). The combination of low temperature, high current velocities and low disturbance of the site is likely to ensure high dissolved oxygen at the site 1 (6.2 ± 0.46 mg/L). A considerable reduction in dissolved oxygen was observed at the agricultural effluent (4.94 ± 0.97 mg/L) and industrial effluent (2.68 ± 1.64 mg/L). Downstream from site 5 (Kakondo), dissolved oxygen seems to stabilize and decrease gradually until the outlet (5.4 ± 0.55 mg/L). These variations were also observed in others works in the region and elsewhere (Jonnalagadda and Mhere, 2001; Kathikeyani *et al.*, 2002; Hecky *et al.*, 2003; Bagalwa, 2006; Bagalwa *et al.*, 2013a; Bagalwa *et al.*, 2013b, Loko *et al.*, 2013). All these studies showed that DO decreased downstream but BOD_5, SS and temperature increased downstream. Dissolved oxygen values in the river water was low as observed also in the Ebrié lagoon of Côte d'Ivoire range between 4.25 mg/L and 4.57 mg/L (Loko *et al.*, 2013).

5.2.2 Contribution of the different sources

Small scale farming was the major source of sediment in the micro-catchment while forest was generating much of the runoff because the forest is located on high altitude in slop (<3 %) and the soil is volcanic soils which permit the infiltration. Average annual total suspended sediment load from River Lwiro micro-catchment from 2011 to 2013 were averaging 252.49 t/yr compared to the estimated suspended sediment load simulated 237.25 t/yr and the results showed good agreement with their estimations. Mean annual total N and P loads from Lwiro river micro-catchment from 2011 to 2013 were respectively 0.2 and 270.34 Kg/yr compared to the simulated loading for an average of 0.2 and 456.09 Kg/yr. These results are very low compared to results obtained elsewhere (Hurni, 1985; Majaliwa, 2005; Walling, 2008; Meshesha *et al*., 2012; Azanga, 2013) in quasi-similar environment.

The difference is attributed to the nature of soil, topography, the type and distribution of land use/cover and rainfall. The soils of the Lwiro micro-catchment were deep and with high infiltration capacity (volcanic soils) compared to those of Kalamabenge which were shallow and with erodibility in nature (sandy soils). Topographic is also a major driving factor for sediment yield (Wasson, 2002). In River Lwiro micro-catchment, the high slope (< 3 %) is located at the upper part of the micro-catchment as for the Kalimabenge micro-catchment but the difference is that this part for Lwiro river micro-catchment is covered by forest retention of erosion. The land cover in Kalimabenge micro-catchment was removed and increased the runoff and sediment yield (Azanga, 2013). Also the small scale farmland which is recognized to be potential source of sediment yield is located in the flat areas with low slope to generated erosion. Previous studies suggest that land use/cover change can affect the soil erodibility and sediment source (Woodward and Foster, 1977) as well as the amount of sediments generated by soil erosion (Yang, 2004). The transformation of land use/ cover by human action in the River Lwiro micro-catchment affect the sediment yield as observed in other regions (Millennium Ecosystem Assessment, 2005; Memarian *et al.*, 2013). Niu *et al.*, (2005) and Gumindoga (2010), found that land use/ cover change affect the different hydrological component like interception, infiltration and evaporation, thereby influencing runoff generation (both process and volume) and streamflow regimes. High water discharge yield was found in the forest area in the River Lwiro micro-catchment at the headwater region, but for Kalimabenge micro-catchment the high runoff yield was found in the outlet,. In River Lwiro micro-catchment, the headwater region is covered by forest which affects positively the rate of infiltration and contributes to recharge the base flow and contributes to the high runoff yield. In that forest where the river take source, rainfall is high compared to other part of the micro-catchment (Bagalwa *et al*., 2012).

CHAPTER 6: CONCLUSIONS AND RECOMMANDATIONS

6.1 CONCLUSIONS

From this study we can conclude that:

- Land use/ cover in the study area have change substantially from 1987 to 2010. The forests decreased by 23 %, while the wetlands, small scale farmland and Built-up areas increases by 2.1 %, 0.9 % and 2.3 % respectively.
- The studied physico-chemical parameters show that the quality of the water in river Lwiro is still below the critical level to be qualified polluted. The major sources of pollutants are anthropogenic activities, agricultural runoff and industrial effluent.
- The mean value of selected physico-chemical parameters of water in the river are within the limit range for aquatic life, and showed a variation between the sites during the year. Effluent dominated by industrial and agricultural activities had relatively high values in terms of TSS, TP, SRP, TN, NH_4^+ and NO_3^-. The concentration of dry deposition compared to wet deposition is not significantly different (t= 16.82, p = 0.03 for TN and t= 38, p = 0.016 for TP). But it is a source of the nutrient in the micro-catchment.
- Small scale farming was the major source of sediment in River Lwiro micro-catchment while forest was generating much of the runoff. High annual runoff yield (539.62 $m^3/Km^2/yr$) was obtained in a forested area while high sediment yield was recorded in small scale farmland in the River Lwiro micro-catchment.
- Runoff hotspots were forests on shallow soils and steep slopes while sediment hotspots were small scale farmland on steep slopes.

6.2 RECOMMENDATIONS

It is recommended that:

- It is vital to continue the monitoring water quality and quantity in River Lwiro micro-catchment, in order to have long-term data which can be used to for modeling and hence, planning purpose. An integrated watershed management approach should be adopted for Lwiro and other micro-catchments of DR. Congo. .
- Best management practices should be promoted in order to reduce nutrient and sediment load due to erosion into the River Lwiro micro-catchment.

- SWAT is a tool that can be applied in Lwiro micro-catchment to simulate the impact of agricultural management practices to reduce sediment and nutrient load by different scenarios. These capabilities should be explored in future work.
- Atmospheric nutrient deposition into the lake should be monitored and be combined with the measurements of nutrient fluxes from other sources in order to construct a whole lake nutrient budget.
- Sharing the finding with legislators and managers of water and sanitary in low level about the effect of pollution in the micro-catchment.

6.3 FURTHERS WORKS

- Best Management Practice (BMP) were not examined carefully due to time constraints. Then, further research can focus in this area.
- Wet and Dry deposition contribute a lot in the nutrient loading to the Lwiro river micro-catchment but the sources and pathways of the atmospheric deposition was not examined in this study and need further investigations.
- In the study we analyzed industrial point source pollution; further studies can be concentrated on other point sources (e.g. cities and hospitals) and linear features such as roads.

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