Assessment of Cause of Water Level Change of Lake Kivu and its impact at downstream

Submitted to Arbaminch University in partial fulfillment
of an M.Sc. degree in Hydrology and Water Resources.

By Agabe Sam

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DECLARATION

I, Agabe Sam, declare that this thesis is my original work and it has not been presented by me or any university for similar or any other degree award.

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Signature

Date…………………………………………

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CERTIFICATION

The undersigned certify that they have read the thesis entitled “**Assessment of Cause of Water Level Change of Lake Kivu and its impact at downstream”** and hereby recommended for the acceptance by the Arbaminch University in partial fulfillment of the requirements for the Degree of Master of Science in Hydrology and Water Resources Management.

Supervisor

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ABSTRACT

The Kivu Lake level is subjected to high fluctuations during the recent years.
The aim of this research was to identify the causes for the fluctuations in Lake Level. SWAT model was used to generate water balance components of Lake catchment.
The results, using the reference period 1976 to 1990, indicate that the mean annual rainfall over the lake is 1266 mm and the mean annual evaporation from the lake is 583 mm. When compared with lake level changes, there is imbalance of 21%. Adding this amount to the calculated evaporation, it was possible to reconstruct the inflow variation into the Lake from 1976 to 1990 and the water balance of the lake. Sensitivity analysis shows that the discrepancy in the balance is most likely due to water abstraction from the lake as some of water is used for domestic supply around the lake and minor abstracts

In this research, the water balance of Lake Kivu is carried out using the SWAT rainfall runoff model. The inflow from the catchment into the lake has been generated using SWAT model. Evaporation is estimated using Penman formula. Rainfall over the lake is estimated from the catchment rainfall employing the two classes ‘A’ gauging stations around the lake as weather generating stations to fill the gaps in the other rain stations.

Finally the main cause for high Lake level fluctuation is found to be the rainfall variability analyzed with hydrological components in their variability trends especially in the second rainy season in October, November and December , there is also an effect of land cover(land degradation/deforestation) change responsible for ground flow decreasing trend particularly western part of the catchment of which a big percentage of inflow potential is base flow.

Abbreviations and acronyms:

SOL_ALB : α_{soil}: moist soil albedo
MAX TEMP : T_{mx}: Daily maximum temperature (°C)
MIN TEMP : T_{mn}: Daily minimum temperature (°C)
SOL_RAD H_{day}: Daily solar radiation reaching the earth’s surface (MJ m^{-2} d^{-1})
TMPMX : Average maximum air temperature for month (°C)
TMPMN : Average minimum air temperature for month (°C)
SOL_Z: z : Depth from soil surface to bottom of layer (mm)
SOL_BD ρ_b : Moist bulk density (Mg m^{-3} or g cm^{-3})
SOL_ALB : Moist soil albedo
MAX TEMP : T_{mx}: Daily maximum temperature (°C)
MIN TEMPT_{mn}: Daily minimum temperature (°C)
LU/LC : Landuse/Land cover
FAO : Food and Agriculture Organization
GIS : Geographic Information System
HRU : Hydrologic Response Unit
DEM : Digital Elevation Model
CN : Curve Number
ET : Actual Evapotranspiration
PET : Potential Evapotranspiration (mm)
PRECIP : Precipitation (mm)
GW_Q : Ground water flow (mm)
SURQ : Surface runoff (m^3/sec)
LATQ : Lateral flow (mm)
MPMN TMPMX: Average or mean daily maximum air temperature for month (ºC).
TMPMN: Average or mean daily minimum air temperature for month (ºC).
TMPSTDMX: Standard deviation for daily maximum air temperature in month (ºC).

TMPSTDMN: Standard deviation for daily minimum air temperature in month(ºC).
PCPMM: Average or mean total monthly precipitation (mm H2O).
PCPSTD: Standard deviation for daily precipitation in month (mm H2O/day).
PCPSKW: Skew coefficient for daily precipitation in month.
PR_W1: Probability of a wet day following a dry day in the month.
PR_W2: Probability of a wet day following a wet day in the month.
PCPD: Average number of days of precipitation in month.
SOLARAV: Average daily solar radiation for month (MJ/m2/day).
DEWPT: Average daily dew point temperature in month (ºC).
WNDAV: Average daily wind speed in month

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1 INTRODUCTION

1.1 Location of the Study Area

Lake Kivu is located in the Great Lakes region of Africa. It lies on the border between Rwanda and the Democratic Republic of Congo. It lies between latitudes -1º 42´ 27´´ S and 2º 0´ S and longitudes 29º 0´ E and 29º 15´ 51´´ E as shown in Figure 1-2 Location of the Study AreaLake Kivu is situated about 18 km south of the Nyiragongo. It covers an area of about 2400 km², the maximum depth is 485 m and the water volume amounts to 500km³.

Lake Kivu empties into the Rusizi River, which flows southwards into Lake Tanganyika. Lake Kivu region has a temperature varying between 15ºc and 17ºc with abundant rains. The volcanoes region has lower temperatures reaching less than 10 ºC in some areas like Virunga and Kalisimbi highlands (northern part of the catchment).The annual rain fall over Lake Kivu varies between 1000 mm to 1400 mm per year.

Figure 1-1 Re-Labeled Satellite Image on the catchment, courtesy of NASA

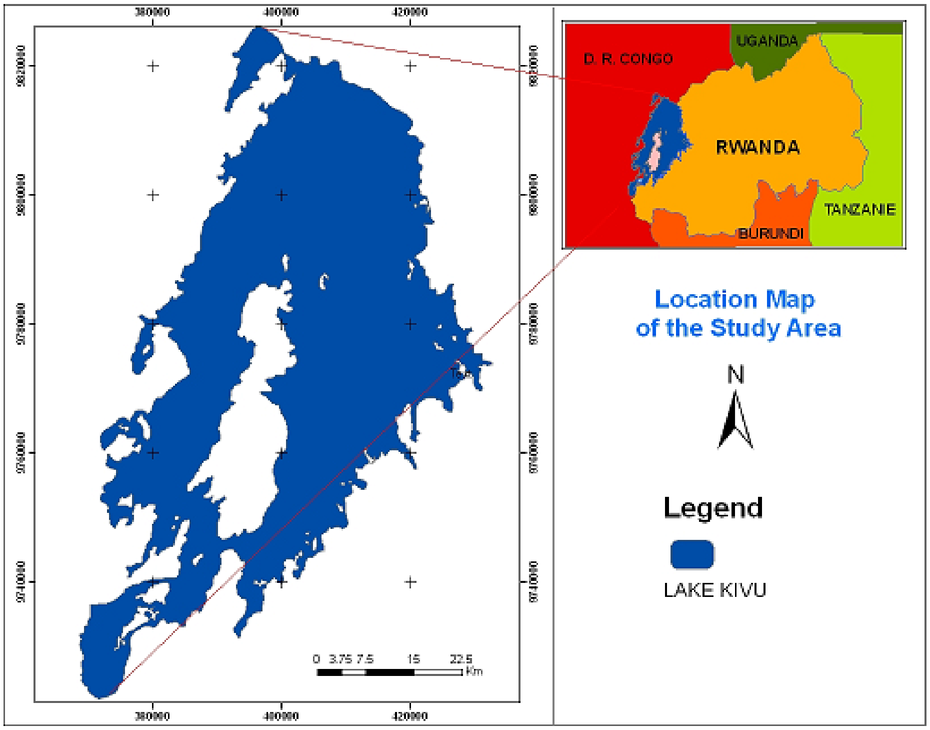

Figure 1-2 Location of the Study Area

The basin of the Lake Kivu has an area of 6884km² from existing records, 7224km² from swat model delineation. The mean elevation of the lake water surface is 1460 m.a.s.l. The lake is fed through four perennial rivers, namely, Sebeya, Koko, Sake, Kalehe and a network of streams from sub basins that flow into Lake Kive. Rusizi River forms the outlet of Lake Kivu at comparatively narrow point at the Southern end of the Lake Kivu.

A hydropower station located 3 kms downstream of the lake supplies power to Rwanda, Congo and Burundi. Moreover, the lake caters for the water supply of the towns Gisenyi, Kamembe and Cyangugu in Rwanda as well as Goma and Bukavu in Congo partly.

1.2 Climate

The lake Kivu Basin has is tropical climate , moderated in some places by altitude variation between 1530 m and 1600m with warm to cool temperature with the annual temperature ranging from 13°C in the highlands to 17°C in the south of the basin. This variation in elevation significantly starts from the south of the basin to the northern part of the basin towards the nyiragongo and virunga volcanic mountains.

The climate is generally characterized into two main alternating rainy seasons and dry seasons. The first rainy season appears from March to April and the second rainy season is observe from October to December while the firs dry period(minor) is observed from January to February and the second dry period appears in June, July, Aug. and Sept. each year. The average annual precipitation over the catchment is 1300mm. Rain fall recorded by rain gages indicates that the northern region of the lake has a tendency for more rainfall than the southern region.

1.3 Statement of Problem

It is observed that the water level of Lake Kivu has recently reached to its lowest level of 1460m.a.s.l.The Lake level fluctuation used to be approximately one meter between the years 1941 and 1993 under normal climatic conditions. But water level of Lake Kivu has fallen down dramatically by 1.2 meters from 1994 to 2006 below the average lake level (SINELAC, 2006).

The situation is further aggravated by local sedimentation in the river reach between the lake outlet and the location of the hydropower station (dam),see annex 22a, poor local settlement of people along the banks of the river leading to directing soil into the lake while leveling their plots, absence of a control gate at the outlet of the lake to regulate the water level and outflow from the lake, cultivation of crops around the dam causing silting of the dam reducing its volume meant for hydropower generation (SNELAC-condition assessment report), increase in wash load from surrounding catchment into the lake during the heavy rain season, and intense human activity on western part of the lake,ref. annex22c. It has been observed that when the intake gates of the dam are opened, there is a significant reduction of water level in the lake. Hence, this research tries to address this set of problems as much as possible.

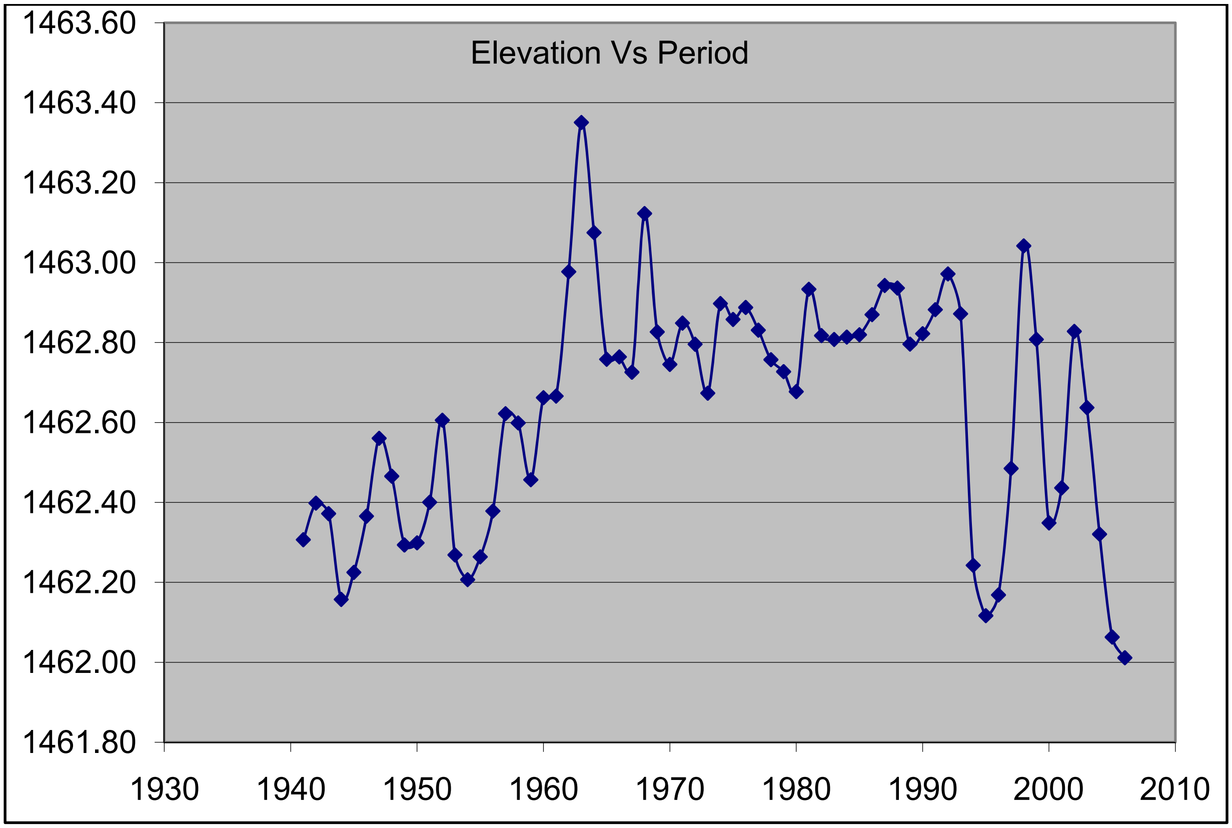

Figure 1-3 Lake water level fluctuation

The trend of the water level fluctuation shows increasing trend from 1940 to 1960 while reducing trend significantly observed from 1990 to 2007

1.4 Objectives of the research

The main objectives of the study are to assess the cause of Lake Kivu water level reduction in recent years and the effect of the same problem on Rusizi hydropower generation. The specific objectives are to generate inflow series, carry out the water balance analysis of Kivu Lake.

1.5 Scope of the study

The scope of the study is structured into five chapters. Chapter one highlights the background of the study area and the objective of the research. Chapter Two deliberates on the literature review whereas Chapter Three illustrates the methodology employed. Chapter Four discusses the simulation, results, and their interpretation in detail. Chapter Five elaborates model tuning and stabilization, Chapter Six tackles on water balance and Chapter Seven provides the summary, conclusion and recommendations for further research.

2 LITERATURE REVIEW

2.1 Lake Water Balance

Lake water balance and causes of lake level drops have been investigated by various researchers ((Kull, 2006), (Nathenson, 1992), (Yin & Nicholson, 1999)). The water balance of a Lake is fundamental to understanding of various processes in the lake such as fluxes of dissolved constituents in the lake and calculating the amounts of dissolved constituents added by the inflow of thermal water. Some of the lakes have no outlets and some have an outlet which has a considerable influence on their hydrology. Water balances could be based on yearly precipitation and lake-level data , monthly or daily data. It has been in a number of cases that daily data are inadequate to accurately define the water balance.

The yearly water balance is comprised of water supply from rainfall and inflow from the catchment of the lake, and water loss from leakage and evaporation in most of the cases (Nathenson, 1992). The inflow to a lake can be expressed as a function of the precipitation on the lake. Leakage and evaporation could be taken as proprtional to the long term average precipitation. Hence, the water balance falls down the determination of a proportionality constant. Using this methods, (Nathenson, 1992) found a good result for Lake Crater.

Lake Victoria Basin Commission (Secretariat, 2006) also investigated the changing trends of the meterological and hydrological regimes in Lake Victoria. Moreover, the declining water levels and its causes ; and the impacts of the reduced water levels on the economy and ecosystem. ECA (Secretariat, 2006) defined the water budget as a comparision of input and output quantities of hydrologica processes. It further outlines that the study of water balance is used to understand the variation in the quantities of water in the lake over time, to help in the allocation of water for differrent uses, to assis in managing the lake water resources, understand water quality dynamics , pollutant transport and pollution loading into the lake. It is asserted that the main input hydrological processes which formthe major sources of water into a lake are rainfall over the lake and discharges into the lake from the catchments. In this work, the authors summarizes the inflow into and the outflow from lake Victoria.

It has been even suggested that the operating policy for hydropower generation at Owen falls dam impacted the Lake Victoria water balance and the rule curve had to be consulted in order to assess the lake level drop.

Kull,(2006) also investigated the recent sever drops in Lake Vicoria and attributed the changes partly to prevailing drought and partly o over releases for hydropower production In the conclusion drawn on this paper, it was stressed that the lack of public information on dam releases, dam operations and river flows is disturding and makes it difficult for outsiders to soundly judge implemented and proposed hydroeclectric projects on the Victoia Nile.

The hydrology of Lakes especially the outflow is long been a topic of disagreement among hydrologists and engineers ((Kull, 2006). (Yin & Nicholson, 1999) underscored the discrepancy that may exist between water balance estimates and lake level fluctuations. The problem appears to be in the estimation of rainfall over the lake surface since it the largest term in the water balance which is very difficult to assess the ground water and seepage scenarios.

This study sought to investigate what factors have contributed and to what extent to recent water level drops in Lake Kivu. Data has for some time been kept out of the public eye, but recently released reports as well as on-line resources that it is necessary to take up the analysis of the situation.

Assessment of cause of water level includes the water balance for Kivu Lake which is modeled using Swat model with inputs of daily precipitation data, Temperature (max & min), sun radiation and relative humidity recorded at the gauges around the Kivu basin and water level variations on the lake. Total water direct on the lake from precipitation is calculated numerically and inflow from the draining area is found by inflow generating model (SWAT Model, routing into the reservoir (lake)). Evaporation from the Lake, E_t (mm/day), other losses (Lt) including outflow from the reservoir (mm) ,abstraction from the lake and diversion from steams (mm) Abs etc

Hence, SWAT will be used in this study to simulate the inflow of the Lake Kivu using globally available soil, topography, and land use and weather data.

2.2 Soil and Water Assessment Tool (SWAT)

SWAT – Soil and Water Assessment Tool is a continuous time hydrological model used for river basin, catchments or watershed modelling. SWAT is a spatially distributed model, as it can be used for different scale. It is also a semi-physically based model because it incorporates physical processes which take place within a catchment. However, it lumps together parts of catchment which have same soil and land cover properties. The main processes are precipitation, evapotranspiration, runoff, groundwater flow and storage in a catchment and their interaction. It also includes vegetation growth and management practices occurring in the catchment. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling etc. Are directly modelled by SWAT using this input data.

2.3 Water Balance

The driving force of SWAT is the water balance. The water balance is an accounting of the inputs and outputs of water. The water balance of a catchment is determined by calculating the input , output and storage change at the Earth’s surface. To accurately predict the movement of pesticides, sediments or nutrients, the hydrologic cycle is simulated by the model must conform to what is happening in the watershed.

Simulation of the hydrology of a watershed can be separated into two major divisions as shown in **Figure 2-**. The first division is the land phase of the hydrologic cycle. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each subcatchment. The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, etc though the channel network of the watersheds to the outlet.

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$SW_t = SW_o + \sum(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$ ----------------------**equation1-1**

where

SW_t	the final soil water content
SW_0	the initial soil water content on day i
t	the time (days)
R_{day}	the amount of precipitation on day i
Q_{surf}	the amount of surface runoff on day i
E_a	the amount of evapotranspiration on day i
W_{seep}	the amount of water entering the vadose zone from soil profile on day i
Q_{gw}	the amount of return flow on day i

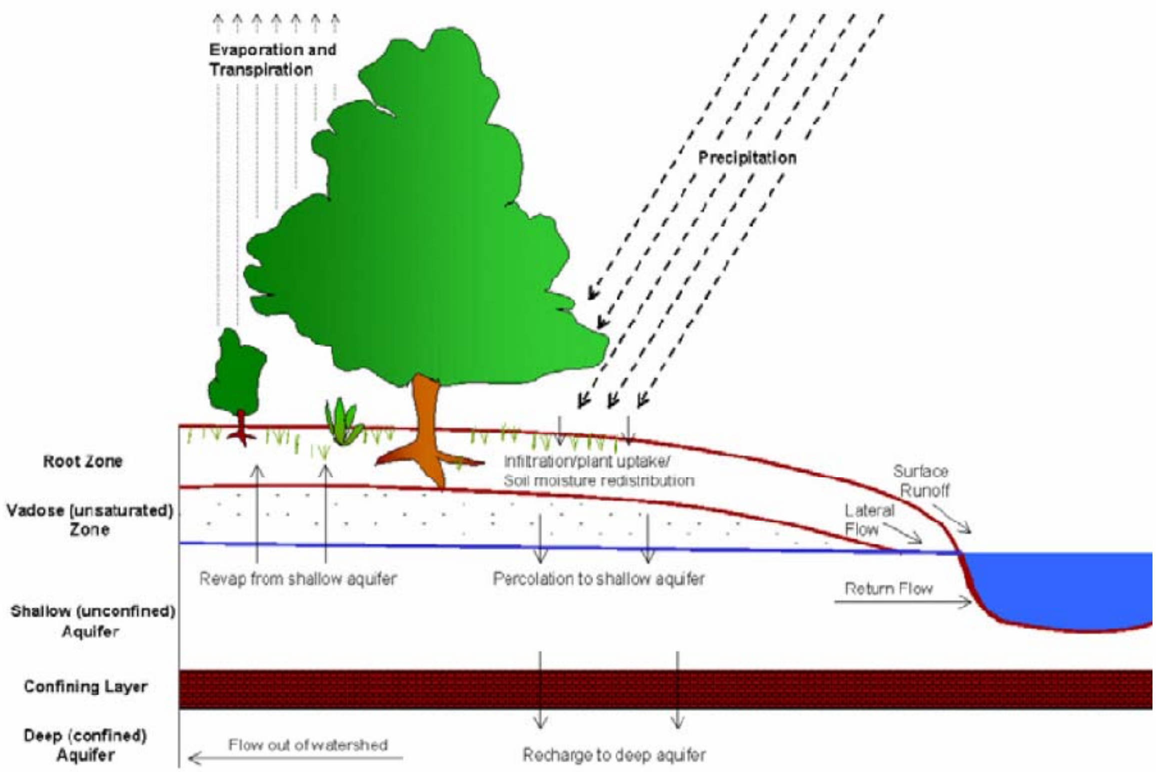

Figure 2-1: SWAT hydrologic cycle

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance. The water balance of each HRU in SWAT is represented by four storage volumes: snow, soil profile, shallow aquifer and deep aquifer.

Once water is introduced to the system as precipitation, the available energy, specifically solar radiation, exerts a major control on the movement of water in the land phase of the hydrologic cycle. Processes that are greatly affected by temperature and solar radiation include snow fall, snow melt and evaporation.

The energy balance is also considered in SWAT for Energy balance of all incoming energy and outgoing energy from the catchment necessary for a stable system. Difference of incoming energy and outgoing energy is the energy stored in the system. The incoming energy from the sun is used by plants for their growth and to evaporate water on the surface and evapotranspiration. The outgoing energy is the energy radiated by the earth surface and the difference is stored in the soil. Energy balance and water balance are related by evapotranspiration process.

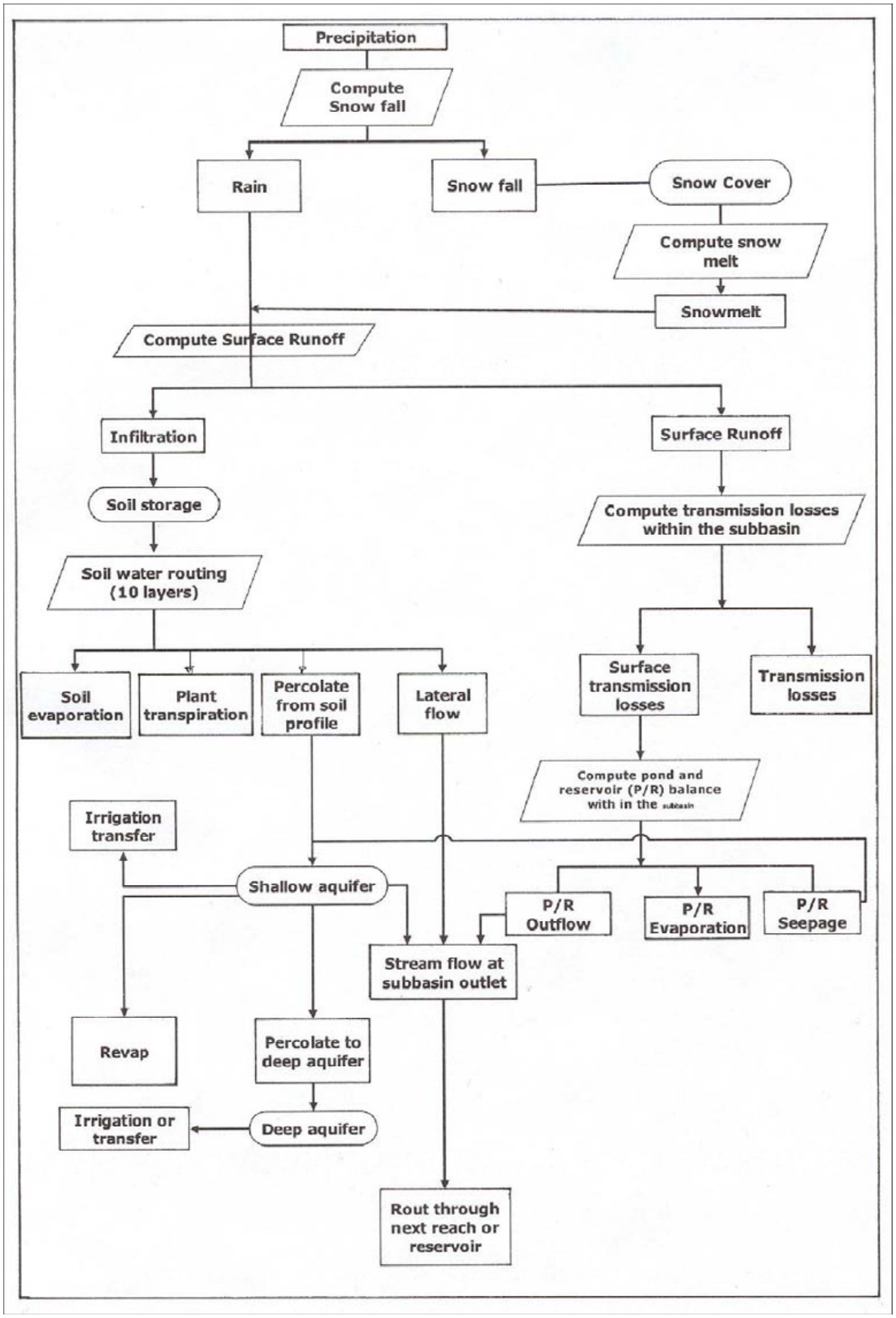

Figure 2-2: **Over view of SWAT hydrologic component (Adapted from Arnold et.al, 1998)**

2.4 Climate data

Climate of a watershed provides the moisture and energy inputs that control the water balance and determine relative importance of different components of hydrologic cycle. Climatic variables required by SWAT comprise of daily precipitation, minimum-maximum air temperature, solar radiation, wind speed and relative humidity as inputs from records of observed data or generated during the simulation.

2.5 WXGEN weather generation

SWAT model requires daily values of precipitation, minimum-maximum air temperature, solar radiation, relative humidity, and wind speed where user can provide as time series input files or provide only monthly statistics summarized over a number of years. SWAT includes the WXGEN weather generator model (Sharpley et al., 1990) to generate climatic data or to fill in gaps in measured records. The occurrence of rain fall on a given day has a major impact on relative humidity, temperature and solar radiation for a day. Weather generation first independently generates precipitation for a day. Once the total rain fall for a day is generated, the distribution of rain fall with a day is computed. Then, maximum temperature, minimum temperature, solar radiation, relative humidity are also generated based on the presence or absence of rain fall for a day and finally wind speed is generated independently refer. Annex13.

2.6 Hydrological processes

Hydrological processes which take place with a catchment can be explained using water balance or water routing from the time it enters the catchment and leaves. Before that we should understand Hydrologic Response Units (HRUs) used in SWAT. These include the unique combinations of land use and soil in sub basins, there are used in SWAT, because of being simply simulated by lumping all similar soil and land use areas into a single response unit. Most of hydrological processes take place in HRUs level and the water balance is simulated at this level before water is routed to sub basins reaches and then to the watershed level.

As precipitation falls, it may be intercepted and held in the vegetation canopy or fall to the soil surface. Canopy storage is the water intercepted by vegetative surface where it is held and made a available for evaporation. In SWAT, canopy storage is modeled using curve method. SWAT allows the user to input the maximum amount of water can be stored in the canopy at the maximum leaf area index for the land cover. This value and the leaf area index are used by the model to compute the maximum storage at any time in the growth cycle of the land cover/crop. When evaporation is computed, water is first removed from canopy storage. After the water reaches ground surface, infiltration takes place, infiltration refers to the entry of water into the soil profiles from the ground surfaces. There are different rates of infiltrations depending up on the available water and soil profiles. From maximum infiltration rate at the beginning, the soil becomes wet and the infiltration decreases with time until it reaches a steady value which corresponds to the saturated hydraulic conductivity of the soil. In SWAT, infiltration is simply calculated as the difference between the amount of rain fall and the amount of surface runoff. The infiltration rate is used to calculate the redistribution. The redistribution or continued of water soil profile computation of infiltration is based on soil properties (hydraulic conductivity, soil components,...) which are stored in SWAT soil database.

A part of precipitation goes back to atmosphere by evapotranspiration. Evapotranspiration is a collective term for all processes by which water in the liquid or solid phase at or near the earth's surface becomes atmospheric water vapor. Evapotranspiration includes evaporation from lakes and rivers, bare soil and vegetation surfaces ; evaporation from within the leaves of plants(transpiration); and sublimation from ice and snow surfaces. SWAT model computes evaporation from soils and plants separately as described by Ritchie (1972). Potential soil water evaporation is estimated as a function of potential evapotranspiration and leaf area index (area of plant leaves relative to the area of the HRU). The model offers three options for estimating potential evapotranspiration:

Hargreaves (Hargreaves et al.1985), Priestly-Taylor, (Priestly and Taylor 1972) and Penman – Monteith (Monteith.1965)

For soil, water flows to channel or river. Lateral subsurface flow, or interflow, is stream flow contribution which originates from the surface but above the saturated zone. In SWAT, lateral subsurface flow in the soil profile (1-2m) is calculated simultaneously with redistribution. The process is called surface runoff.

2.7 Data collection and analysis

Introduction

In this chapter, the data collected to carry the water balance are discussed. The data collected include rainfall, temperature, relative humidity, sun radiation and stream flow. Land use, soil maps are also collected and reclassified. The status of the data and their possible deployment for the modelling will be discussed at length hereunder

2.8 Rainfall data

There are about 14 meteorological stations around Lake Kivu basin from which recorded data were collected for the study but only two Class I stations at Kamembe_Aero and Gisenyi_Aero are capable of recording rainfall, temperature, humidity, radiation and evaporation and the remaining station (Class 4) can only record rainfall. The general limit on the stations is the short period of recording where most stations have data from 1976 up to 1990, and this was due to war which disturbed the systems and destroyed most of the stations. Beside the limitation of years, there is also shortage of meteorological stations on western part of the Lake Kivu basin (on the side of DR Congo) as indicated in the location map of Figure 2-.

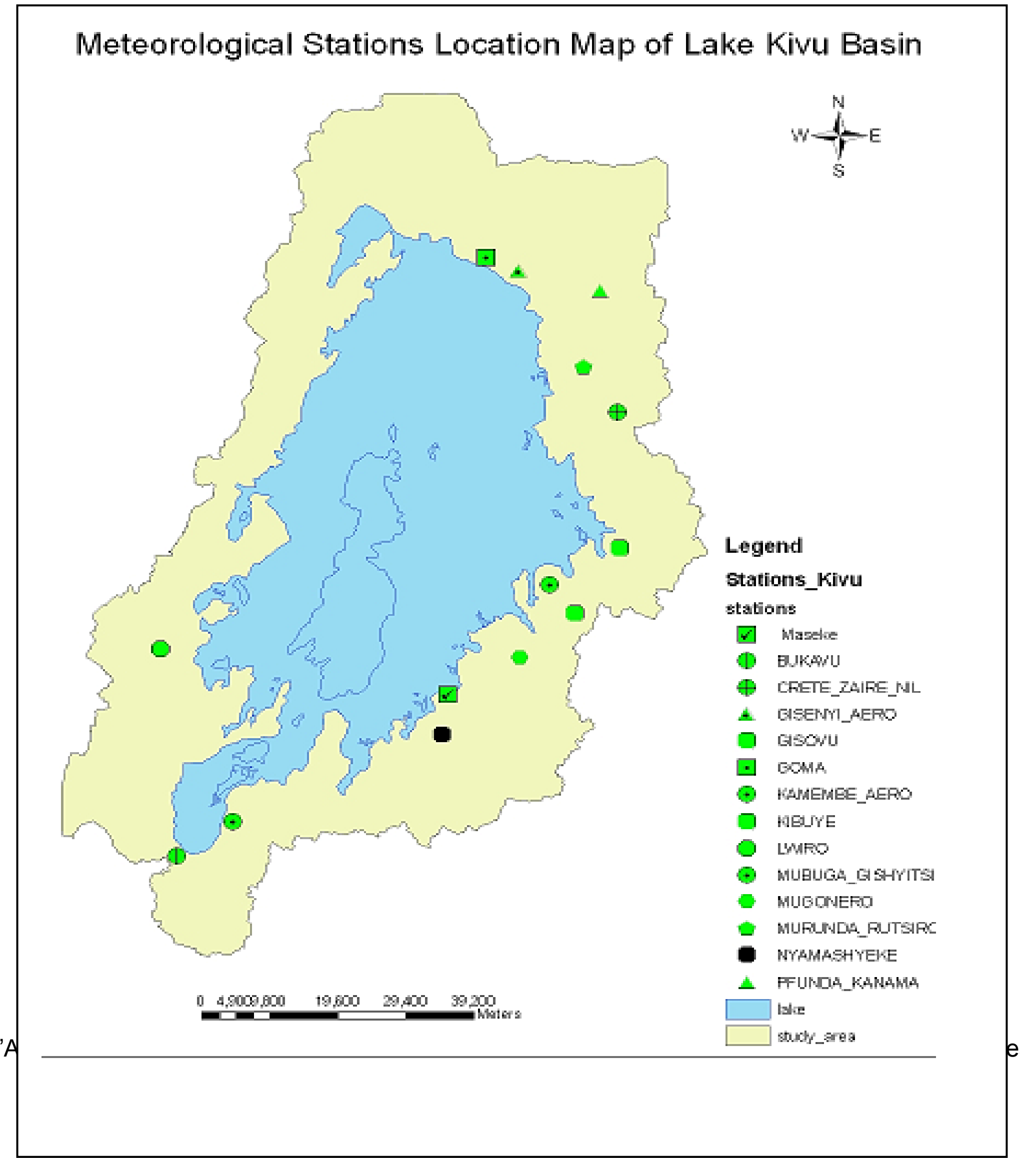

Figure 2-3 Location of Meteorological Stations

2.9 Filling Missing Data

For the purpose of deriving complete and representative data, all the data are arranged in the proper excel data processing format based on their historical recording periods and similar altitudinal zone as shown in Table 1-1.

Table 1-1 Summary of Rainfall stations data

Code	Station name	*Location*	Lat.	Altitude	Period (No-years)
1A	Kamembe Aero	*Kamembe*	2.28	1591	33
2B	Nyamasheke	*Kagano*	2.20	1500	32
3C	Maseka-Kirambo	*Kirambo*	2.18	1465	28
4D	Bukavu	*Bukavu*	2.27	1580	15

5E	Mugonero	*Gishyita*	2.11	1600	26
6F	Mubuga	*Gishyita*	2.08	1650	49
7G	Kibuye	*Gitesi*	2.03	1470	39
8H	Crete Zaire-Nil	*Rutsiro*	1.58	2300	17
9I	Murunda	*Rutsiro*	1.55	1875	28
10K	Pfunda	*Kanama*	1.41	1480	12
11L	Goma	*Goma*	1.45	1540	18
12M	Gisenyi Aero	*Rubavu*	1.4	1554	34

The strategy for filling in missing data was to assemble station groups having similar range of elevations and climatological records above 30 years. The method assumes that the variation of the annual rainfall of given time is linear with elevation and seasonality. Thus, each station contains one or more base stations (key) with a near correlation value to complete historic or filled in record for the station. The method is expected to fill about 1/3 of the data gap and the estimated values have accuracy from 75-80 percent (US hydrological Center, 1971).

Based on Table 1-1 above, five stations have been found to consist of climatologiccal records above 30 years, and are found within similar altitudinal range of 1400 to 1700 m.a.s.l. as shown in Table 1-2. The rest of the stations which do not fulfill the selection criteria would be reconstructed with reference to the selected base station.

The daily mean value computed from historic records is also used to fill the gaps of the base stations to fill in the missing data of target station. In such a case, again both the target and corresponding values must be representing equal data period.

Table 1-2 Base period, Elevation and Monthly Rainfall

Code of	Elevation	Periods	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

Station														
1A	1591	33	4.47	4.95	15.57	15.07	13.06	0.87	0.38	1.72	13.68	15.35	16.02	14.37
2B	1500	32	3.31	4.78	14.50	14.99	12.97	1.04	0.65	1.83	13.42	15.04	15.05	13.50
6F	1650	49	3.96	4.32	15.03	15.32	13.82	1.50	0.63	2.16	14.22	14.49	15.50	14.32
7G	1470	39	3.69	4.82	15.38	16.46	13.84	1.65	0.93	1.90	13.82	14.43	15.25	14.11
11L	1540	34	2.47	2.96	13.62	14.85	13.37	1.80	0.82	1.93	13.60	14.51	13.98	13.01

In using Table 1-2, stations are correlated among each other and Kamembe Aero (code-1A) is found to be the station with highest correlation value as a best base station. In the same manner, each station correlates well with the closest base station and is used to fill in the missing data. In most cases, the closet correlation and location of the station is the best in replacing the estimated value.

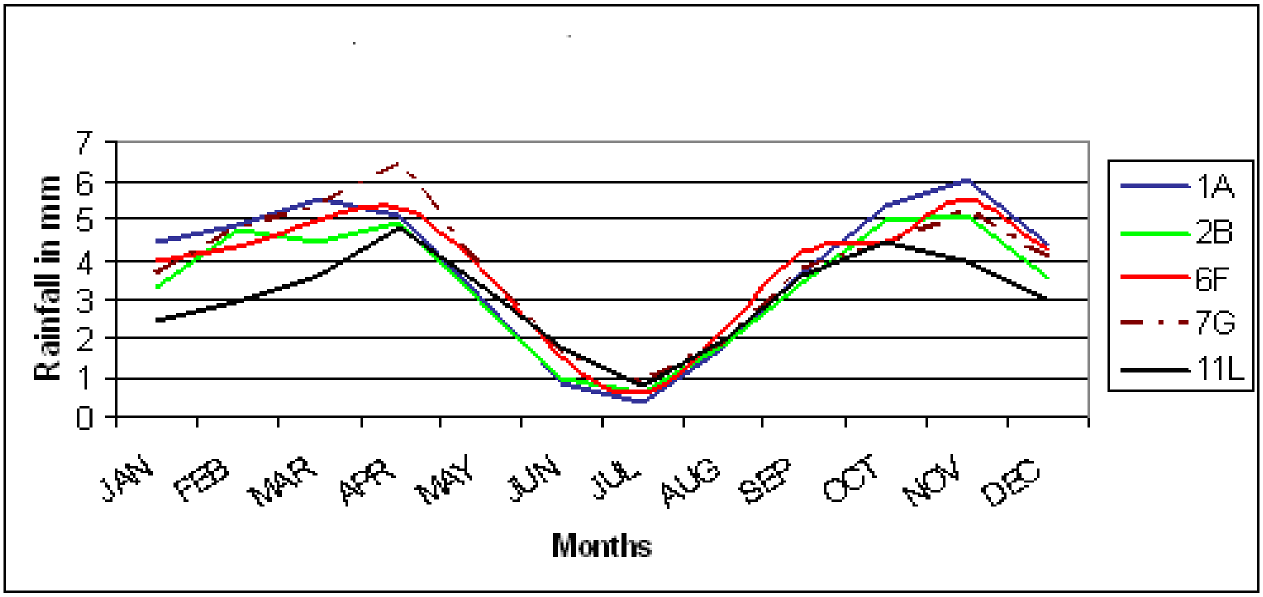

Figure 2-4 Profile of rainfall distribution and variation of altitude for selected stations.

1A, 2B, 6F, 7G, and 11L: rainfall station codes indicated in table 2-1 above.

Figure 2- indicates that from mid June up to mid August, in all of the stations, the mean daily rainfall distribution and its seasonality are exhibited by low rainfall amount below 2.0 mm. While from September to January and February to May, the rain is increasing above 6.0 mm with maximum peak in April and November**.**

The above graph indicates that from Mid- June up to Mid –August, in all of the stations, the mean daily rainfall distribution and its seasonality are exhibited by low rainfall amount below 2.0 mm. While in September to January and February to May, the rain is increasing above 6.0 mm with maximum peak in April and November**.**

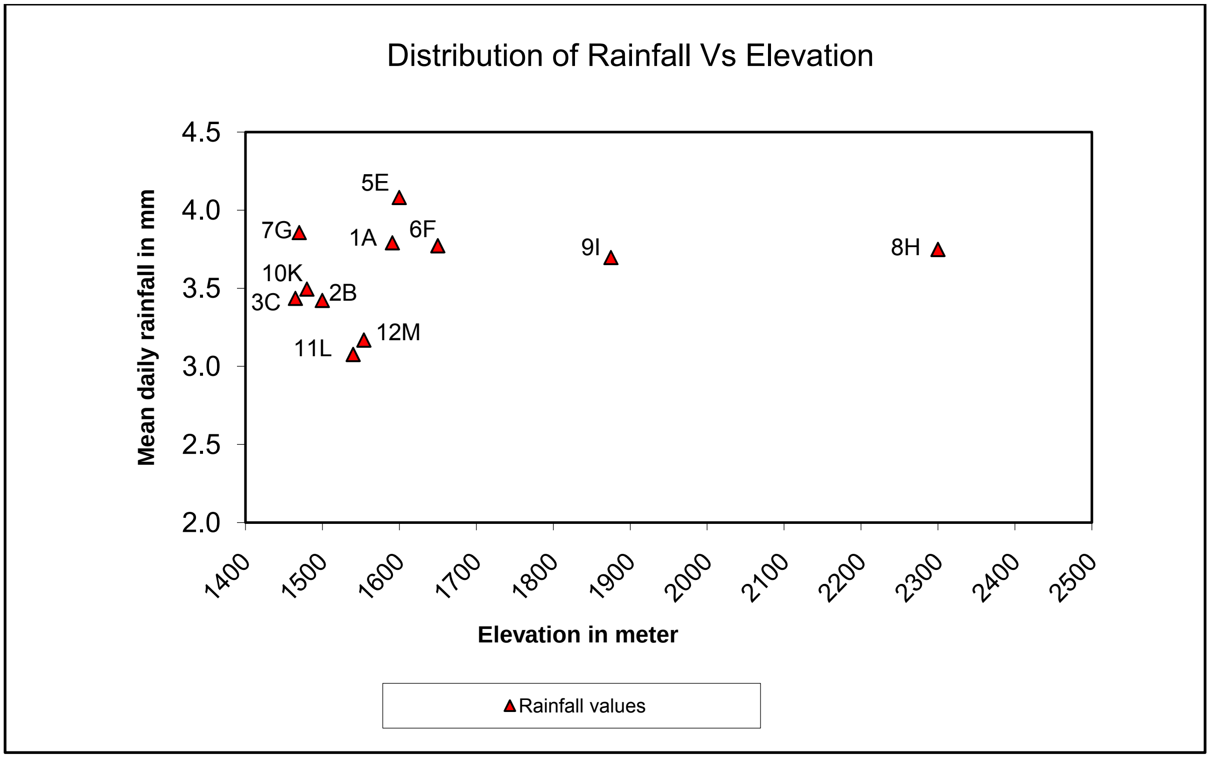

Figure 2-.5 Distributions of Stations Compared with Altitudinal Ranges

From the figure above most of the stations distributions are positioned in the altitudinal ranges of 1400-1700 with above 3.o mm of rainfall values. Therefore, the effect of the topography and the recording period are essential in the reconstruction of the data gap in order to represent the study area. In the previous correlation results and the geographical similarity shown in figure 1.1, the selected base station Kamembe Aero(code-1A)s is situated as closest reference for filling of missed data in another stations

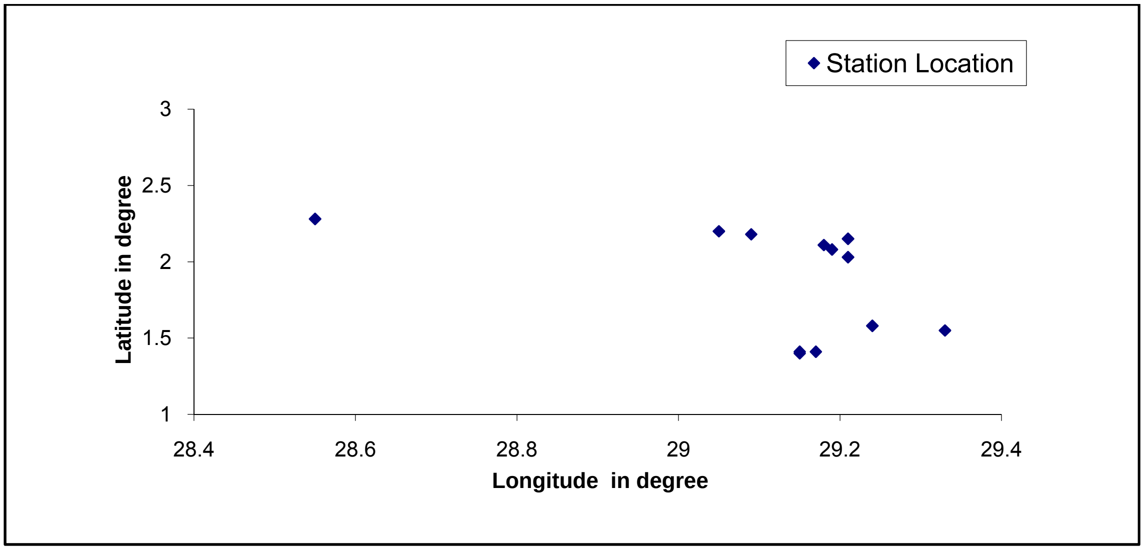

Figure 2-.6 Locations and Distribution of Stations

Most of the stations are concentrated in the same geographical positions. So that, their closeness can help to use the infilling by selecting each other as a base station.

Table 1-3: Stations correlation with mean daily rainfall

Correlation Monthly based	0.85	0.82	0.71	0.76	0.45	0.78	0.49	-0.01	-0.14	0.59	0.87
		0.82	**0.71**	**0.76**	**0.45**	**0.78**	**0.49**	**-0.01**	**-0.14**	**0.59**	**0.87**
			0.71	0.76	0.45	0.78	0.49	-0.01	-0.14	0.59	0.87
				0.76	0.45	0.78	0.49	-0.01	-0.14	0.59	0.87
					0.45	0.78	0.49	-0.01	-0.14	0.59	0.87
						0.78	0.49	-0.01	-0.14	0.59	0.87
							0.49	-0.01	-0.14	0.59	0.87
								-0.01	-0.14	0.59	0.87
									-0.14	0.59	0.87
										0.59	0.87

Correlation of five stations(1A,2B,6F,7G and 11L)

Station code	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Correlation
1A	4.472	4.945	5.57	5.07	3.1	0.87	0.38	1.72	3.7	5.35	6	4.37	0.974
2B	3.314	4.781	4.5	4.99	3	1.04	0.65	1.83	3.4	5.04	5	3.5	0.955
6F	3.956	4.323	5.03	5.32	3.8	1.5	0.63	2.16	4.2	4.49	5.5	4.32	0.964
7G	3.691	4.818	5.38	6.46	3.8	1.65	0.93	1.9	3.8	4.43	5.2	4.11	0.905
11L	2.471	2.958	3.62	4.85	3.4	1.8	0.82	1.93	3.6	4.51	4	3.01	0.901

3 METHODOLOGY

3.1 Hydrological model selection

Many comprehensive spatially distributed hydrologic models have been developed in the past decade due to advances in hydrologic sciences, Geographical Information System (GIS) and remote sensing. Among the many hydrologic models developed in the past decade, the Soil and Water Assessment Tool (SWAT), developed by Arnold et. Al. (1993) has been used extensively by researchers. This is because SWAT

I. Uses readily available inputs for weather, soil, land and topography,
II. Allows considerable spatial detail for basin scale modelling, and
III. It is capable of simulating crop growth and land management scenarios.

SWAT has been integrated with GRASS GIS, with ArcView GIS and ArcGIS , the hydrologic components of the model have been validated for numerous watershed under varying hydrologic conditions.

Arnold and Allen (1996) compared multiple components of water budget including surface runoff, groundwater flow, groundwater ET, ET in the soil profile, groundwater recharge, and groundwater heights simulated by the SWAT model with measured data for three Illinois watersheds (122 – 246 km^2). The predicted data compared well with the measured data for each component of the water budget and demonstrated that the interaction among different components of the model was realistic. Most components of the water budget are within 5% of the measured data and nearly all were within 25%.

3.2 Lake Kivu Basin Hydrologic Modelling.

The Lake Kivu hydrologic model was built using SWAT. The set up of the model was done using AVSWAT, which is SWAT interface under ArcView that allows the user to build a project from scratch, build the required input data and analyze the output data from SWAT. The model set up process on AVSWAT follows this order: watershed delineation and determination of hydrologic parameters of sub-basins, land use and soil survey for HRU definition, then specification of climatic data time series which would be used for simulation. After that AVSWAT build input files which would be used for simulation. All these steps are explained in this section.

3.3 Watershed delineation

The watershed delineation was done automatically by AVSWAT but some preparations of the DEM were done beforehand in ArcGIS, in order to remove sinks and no data cells from the original DEM. This helps to improve the delineation and streams definition especially when there are some regions covered by water such as lakes, swamp areas or wetlands, whereby the reflection of Electromagnetic radiation used by satellite sensors is poor.

The first step of watershed delineation is DEM setup. This concerns analysis od DEM of the watershed which would be used by AVSWAT to define the watershed. The DEM should be projected as shown below. In a case, the DEM covers a large area than the area of interest, a mask should be provided to set boundaries of the focus area. Also to improve the watershed delineation a stream network can be superimposed onto the DEM to define the location of the stream network. This feature is useful in situations where the DEM does not provide enough detail to allow the interface to accurately predict the location of the stream network. For the Lake Kivu basin. Neither mask nor stream network were used, because there was a preprocessing.

3.4 Projection used in grid maps

The projection used on above mentioned grid maps for entire Africa is Lambert Equidistant azimuthal (reference latitude: 33°, central meridian: 0°). This projection is able to present the whole Earth in a single map and with constant radial scale (distances increase linearly from the center of projection) .The azimuthal equidistant projection can be used to make reasonable maps of extended areas of the world, summarized data given in table 4-1 below..

Table 1-4 Lake Kivu DEM coordinate system

Projection	Transverse Mercator
Geographic coordinate system	WGS_1984 –UTM_ZONE_36S
Longitude of Projection Center	33
Latitude of Projection Center	00
Scale factor	0.9996
Datum	D_Arc_1960
False Easting	500000
False Northing	10000000
Distance Units	Meters
Resolution	90 x 90
Std dev.	31.6293

3.5 Stream delineation

There are four main rivers that flow into Lake Kivu namely: Sebeya, Koko, nyamasheke,Karehe and Sake and some major streams with principal a tributaries and 44 sub basins were considered for inflow generation from all main streams. The stream definition was based on the outflow at the downstream of the lake which is only measured discharge and simulated discharge were used for calibration and validation of the model and the same parameter values were applied in all sub basins. Hence the threshold area or stream drainage area required to define the beginning of a stream was chosen in iterative way.

3.6 Outlet and Inlet definition

The objective of the definition of outlets is to determine subbasins. AVSWAT proposes outlets according to the stream definition, but there is a possibility of changing them from user defined points. It is in that sense that each sub basin was given its outlet with white shed at the entrance of the main channel into the lake. A table of outlets was provided, which has the additional outlets of sub basins. The outlet locations correspond to rain gauge stations or of monitoring stations in the basin. In total there are 16 outlets in which one is inflow monitoring stations. At these outlets a comparison of measured flows and output flows of the model would be done. Sub basins are delineated from these outlets and each subbasin is assigned one stream.

3.7 Calculation of sub-basins parameters

After outlet definition, comes computation of sub-basin parameters, which will be used further in the model. Mainly, geomorphic parameters for each sub-basin are calculated together with its relative stream reach.

3.8 Soil and land use

Land use and soil data are used by hydrologic models to determine the area and the hydrologic parameters of each land-soil category simulated within each sub basin. Soil and land use information are specified in SWAT as either grid or shape file. The land-use and soil themes were projected in the same projection as the DEM used in the watershed delineation. The used soil map used is from FAO world and East Africa soil classification has a scale of 1:2,500,000. The FAO soil classification defines 28 major soil groups, and their physical and chemical properties, texture and slope. The land use map has a resolution of 1 km resolution and 25 different types of land cover.

The soil and land use maps are classified and then overlaid in order to make combinations and distributions of types of soil and their corresponding land use for the each sub basin in the watershed. After the classification, follows the HRU parameterization, which defines HRUs in each sub basin. The number of HRUs per sub basin varies according to the sub basin surface area and types of soil and land use in the sub basin. SWAT allows to limit the minimum percentage of soil and land use to be used for HRU definition. For Lake Kivu basin, the threshold was fixed to 10 and 20% for land use and soil respectively.

3.9 Hydrology and climate data

SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. The user may choose to read these inputs from a file or generate the values using monthly average data summarized over a number of years. In this study, only precipitation and temperature data were provide, other climatic data have been generated by SWAT using its weather generator WXGEN.

3.10 Weather stations

The weather stations used are indicated in the Table 1-1 above. Each weather station has geographic location, altitude, average monthly rainfall, and average number of rainy day per month, minimum and maximum temperature, wind speed and solar radiation. These data are used by WXGEN to estimate missing data by the model, or interpolate data between stations.

3.11 Model set up

All processes which take place in watershed are represented by specific input files. Each file contains input parameters that SWAT uses during simulation. The input parameters or files can be divided into three different levels. The first batch of parameters is defined for the whole watershed, the next group of parameters operates on sub basin level, and the last group is defined for each HRU.

In this study the SCS runoff curve number option was used to estimate surface runoff from precipitation. The SCS curve number method is a simple, widely used and efficient method for determining the amount of runoff from a rainfall. The curve number is a function of the soil's permeability, land use, slope and antecedent soil water conditions. The potential evapotranspiration was estimated using Hargreaves method, which is a simple method which uses only temperature, latent heat of vaporization and extraterrestrial radiation. The channel water routing method used is variable storage method.

All processes which take place in watershed are represented by specific input files. Each file contains input parameters that SWAT uses during simulation. The input parameters or files can be divided into three different levels. The first batch of parameters is defined for the whole watershed, the next group of parameters operates on sub basin level, and the last group is defined for each HRU.

The available stream flow data have been divided into two periods (Table 3-5). The first period from 1981up to 1985, plays a role of setting up initial conditions for the calibration of the model, and the second period from 1985 up to the 1988 data was used for the validation of the model before simulation results are considered realistic..

Table 3-5 Calibration and validation periods

Stream flow period	1976-1990
Calibration period	1981-1984
Validation period	1985-1989

The period classified, above was basing on the recorded period on the gauged sub basin at the outlet with recorded flow data from 1981 up to 1989 as shown in the table 3-5 a above. The remaining sub basins are none gauged.

3.12 Model output

A number of output files are generated in every SWAT simulation. These files are:

- summary input file (input.std)
- summary output file (output.std)
- HRU output file (output.hru)
- sub basin output file (output.sub) and
- main channel or reach output file (output.rch)

The detail of the data printed out in each file is controlled by the print codes in the master watershed file (file.cio). The output can be printed as daily values or summarized over a month or a year.
The detailed results of the outputs are all annexed with this report for reference.

The weather generator input file contains the statistical data needed to generate representative daily climate data for the sub-basins. Climatic data will be generated in two instances: when the user specifies that simulated weather will be used or when measured data is missing.

TMP_{MX} (mon): Average or mean daily maximum air temperature for month (ºC).
It is calculated as:

$$\mu mx_{mon} = \frac{\sum_{d-1}^{N} T_{mx,mon}}{N} \text{ --- } (1.2)$$

Where, μmx_{mon} is the mean daily maximum temperature for the month (^0C), Tmx_{mon} is the daily maximum temperature on record d in month mon (^0C), and N is the total number of daily maximum temperature records for month mon.

TMPMN (mon): Average or mean daily minimum air temperature for month (ºC) and is computed using the following formula:

$$\mu mn_{mon} = \frac{\sum_{d-1}^{N} T_{mx,mon}}{N} \text{ --- } (1.3)$$

Where, μmn_{mon} is the mean daily minimum temperature for the month (^{0}C), $T_{mn,mon}$ is the daily minimum temperature on record d in month mon (^{0}C), and N is the total number of daily minimum temperature records for month mon.

TMPSTDMX (mon): Standard deviation for daily maximum air temperature in month (ºC) and is computed as:

$$\sigma mx_{mon} = \sqrt{\frac{\sum_{d-1}^{N} \left(T_{mx,mon} - \mu mx_{mon}\right)^2}{N-1}} \text{ --- } (1.4)$$

Where, σmx_{mon} is the standard deviation for daily maximum temperature in month mon (ºC), Tmx,mon is the daily maximum temperature on record d in month mon (^{0}C), µmxmon is the average daily maximum temperature for the month (^{0}C), and N is the total number of daily maximum temperature records for month mon

TMPSTDMN (mon): Standard deviation for daily minimum air temperature in month (ºC) and is Calculated as:

$$\sigma mn_{mon} = \sqrt{\frac{\sum_{d-1}^{N} \left(T_{mn,mon-} - \mu mx_{mon}\right)^2}{N-1}} \text{ --- } (1.5)$$

Where ,$\sigma mn_{,mon}$ is the standard deviation for daily minimum temperature in month mon (ºC),

$T_{mn,mon}$ is the daily minimum temperature on record d in month mon (^{0}C), μmn_{mon} is the average daily minimum temperature for the month (^{0}C), and N is the total number of daily minimum temperature records for month, mon.

PCPMM (mon): Average or mean total monthly precipitation (mm H2O).
Calculated based on following formula:

$$\bar{R}_{mon} = \frac{\sum_{d-1}^{N} R_{day,mon}}{yrs} \text{ -- } (1.6)$$

where,R_{mon} is the mean monthly precipitation (mm H2O), $R_{day,mon}$ is the daily precipitation for record d in month mon (mm H2O), N is the total number of records in month mon used to calculate the average, and yrs is the number of years of daily precipitation records used in calculation.

PCPSTD (mon): Standard deviation for daily precipitation in month (mm H2O/day). Calculated based on following formula:

$$\sigma_{mon} = \sqrt{\frac{\sum_{d-1}^{N} \left(R_{day,mon} - \bar{R}_{mon} \right)^2}{N-1}} \text{ -- } (1.7)$$

Where σ_{mon} is the standard deviation for daily precipitation in month mon (mm H2O), R_{mon} is the mean monthly precipitation (mm H2O), $R_{day,\ mon}$ is the daily precipitation for record d in month mon (mm H2O), N is the total number of records in month mon used to calculate the average, and yrs is the number of years of daily precipitation records used in calculation.

PCPSKW (mom): Skew coefficient for daily precipitation in month, n Calculated based on following formula:

$$g_{mon} = \frac{N \cdot \sum_{d-1}^{N} \left(R_{day,mon} - \bar{R}_{mon} \right)^{3}}{(N-1)(N-2)(\sigma_{mon})^{3}}$$ --------------------- (1.8)

Where g_{mon} is the skew coefficient for precipitation in the month, N is the total number of daily precipitation records for month mon, R_{day}, mon is the amount of precipitation for record d in month mon (mm H2O), R_{mon} is the average precipitation for the month (mm H2O), and σ_{mon} is the standard deviation for daily precipitation in month mon (mm H2O). (Note: daily precipitation values of 0 mm are included in the skew coefficient calculation).

PR_W (1, mon): Probability of a wet day following a dry day in the month. Calculated based on following formula:

$$P_i(W/D) = \frac{days_{W/D,i}}{days_{dry,i}}$$ -------------------- (1.9)

Where Pi (W/D) is the probability of a wet day following a dry day in month i, daysW/D,i is the number of times a wet day followed a dry day in month i for the entire period of record, and $days_{dry}$,i is the number of dry days in month i during the entire period of record. A dry day is a day with 0 mm of precipitation. A wet day is a day with > 0 mm precipitation.

PR_W (2, mon): Probability of a wet day following a wet day in the month.
Calculated based on following formula

$$P_i(W/W) = \frac{days_{W/Wi}}{days_{wet,i}}$$ -------------------- (1.10)

Where Pi (W/W) is the probability of a wet day following a wet day in month i, daysW/W,i i is the number of times a wet day followed a wet day in month i for the entire period of record, and dayswet,i is the number of wet days in month i during the entire period of record. A dry day is a day with 0 mm of precipitation. A wet day is a day with > 0 mm precipitation.

PCPD (mon): Average number of days of precipitation in month.

Calculated based on following formula:

$$\bar{d}_{wet,i} = \frac{days_{wet,i}}{yrs} \text{ -------------------------------------- (1.11)}$$

Where dwet i, is the average number of days of precipitation in month i, dayswet, i is the number of wet days in month i during the entire period of record, and yrs is the number of years of record.

RAINHHMX (mon): Maximum 0.5 hour rainfall in entire period of record for month (mmH2O). This value represents the most extreme 30-minute rainfall intensity recorded in the entire period of record.

SOLARAV (mon): Average daily solar radiation for month (MJ/m2/day).

Calculated based on following formula:

$$\mu rad_{mon} = \frac{\sum_{d-1}^{N} H_{day,mon}}{N} \text{ -------------------------------------- (1.12)}$$

Solar radiation reaching the earth’s surface for day d in month mon (MJ/m2/day), and N is the total number of daily solar radiation records for month mon.

DEWPT (mon): Average daily dew point temperature in month (ºC).

Calculated based on following formula:

$$\mu\, dew_{mon} = \frac{\sum_{d-1}^{N} T_{day,mon}}{N} \text{ -- (1.13)}$$

Where μ_{dewmon} is the mean daily dew point temperature for the month (ºC), $T_{dew,mon}$ is the dew point temperature for day d in month mon (ºC), and N is the total number of daily dew point records for month mon.

WNDAV (mon): Average daily wind speed in month (m/s).

Calculated based on following formula:

$$\mu wnd_{mon} = \frac{\sum_{d-1}^{N} \mu_{wnd,mon}}{N} \text{-------------------------------- (1.14)}$$

Where μwndmon is the mean daily wind speed for the month (m/s), μwnd,mon is the average wind speed for day d in month mon (m/s), and N is the total number of daily wind speed records for month calculations for all above refer annex13.

3.13 SWAT Surface Runoff Volume

SWAT provides two methods for estimating surface runoff:

- The SCS curve number method (SCS 1972)
- The Green & Ampt infiltration method (1911).

The SCS curve number method is to be adopted for it is less data intensive than the Green Ampt model. It is an empirical model, which is based on the following equation.

$$Q_{surf} = \frac{\left(R_{day} - I_a\right)^2}{\left(R_{day} - I_a + S\right)} \text{--- (1.15)}$$

Where:

- Q_{surf} is the accumulated runoff or rainfall excess (mm H2O),
- R_{day} is the rainfall depth for the day (mm H2O),
- I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H2O), and
- S is the retention parameter (mm H2O). The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention Parameter is defined as:

$$S = 25.4\left[\frac{100}{CN} - 10\right]$$ ---------------------------------- (1.16)

Where, CN is the curve number for the day.

The initial abstractions, Ia, is commonly approximated as 0.2S.

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)}$$ -------------------------------------- (1.17)

Runoff will only occur when $R_{day} > I_a$. Detail descriptions about CN are given in the SWAT theoretical documentation, 2005.

Time of Concentration

The time of concentration, t_{conc}, is a time within which the entire sub-basin area is discharging at the outlet point. It is calculated by summing up both the overland flow time of the furthest point in the sub-basin to reach a stream channel (t_{ov}) and the upstream channel flow time needed to reach the outlet point (tch):

$T_{con} = t_{ov} + t_{ch}$--- (1.18)

The overland flow time (t_{ov}) is computed as:

$$t_{ov} = \frac{L_{slp}}{3600 * V_{ov}}$$ -- (1.190)

Where:

L_{slp} is the average sub basin slope length (m),

V_{ov} is the overland flow velocity (m/s), and

3600 is a unit conversion factor.

The overland flow velocity for a unit width along the slope is calculated by using the Manning's equation:

$$V_{ov} = \frac{q_{ov}^{0.4} * slp}{n^{0.6}}$$ --- (1.20)

Where:

q_{ov} is the average overland flow rate (m3/s),

Slp is the average slope of the sub basin (m/m),

n is Manning's roughness coefficient of the sub basin.

Assuming an average flow rate of 6.35 mm/hr and substituting the equation of Vov into t_{ov}, the simplified equation of the overland flow becomes:

$$t_{ov} = \frac{L_{slp}{}^{0.6} * n^{0.6}}{18 * slp^{0.3}} \text{ -- } (1.21)$$

Channel flow time is computed as:

$$t_{ch} = \frac{L_c}{3.6 v_c} \text{ --- } (1.22)$$

Where:

L_c is the average flow channel length (km),

V_c is the average flow velocity (m/s), and

3.14 A unit conversion factor.

The average flow channel length is calculated as:

$$L_c = \sqrt{L * L_{cem}} \text{ --- } (1.23)$$

Where:

L is the channel length from the furthest point to the sub-basin outlet (km),

L_{cem} is the distance along the channel to the sub basin centroid (km).

Assuming $L_{cem} = 0.5L$, and using the Manning's equation for V_c for a trapezoidal channel with side slope of 2:1 and bottom width to depth ratio of 10:1, channel flow time becomes:

$$t_{ch} = \frac{0.62 * L * n^{0.75}}{(Area^{0.125}) * SLP_{ch}{}^{0.375}} \text{ --- } (1.24)$$

Where:

t_{ch} is the time of concentration for channel flow (hr),

L is channel length from the most distant point to the sub basin outlet (km),

n is Manning's roughness coefficient for the channel,

Area is the sub basin area (km^2), and

SLP_{ch} is the channel slope

4 RESULTS AND DISCUSSION

As water balance represents the relationship between the lake's input (direct rainfall and tributary flows), output (evaporation and outflow), and the resultant change in water stored in the lake and thus change in lake level for a given period of time.

4.1 DEM (Digital Elevation Model)

The raw DEM of the Lake Kivu catchment with resolution of 1km at elevation ranging from 631m up to 4483m above the sea level was provided by GIS Centre (Centered at National University of Rwanda) in fig 3-3 below. It has been processed and reconditioned using Arc Hydro tool after viewing the limits of streams network in the study area in 3D feature found in Arc GIS. Mask for the study area was created by digitizing the area of interest from whole DEM of the region and used in the 'Watershed delineation; together with the streams layer, it was also used to segment the watershed into connected sub-watersheds. Refer figure 3-1.

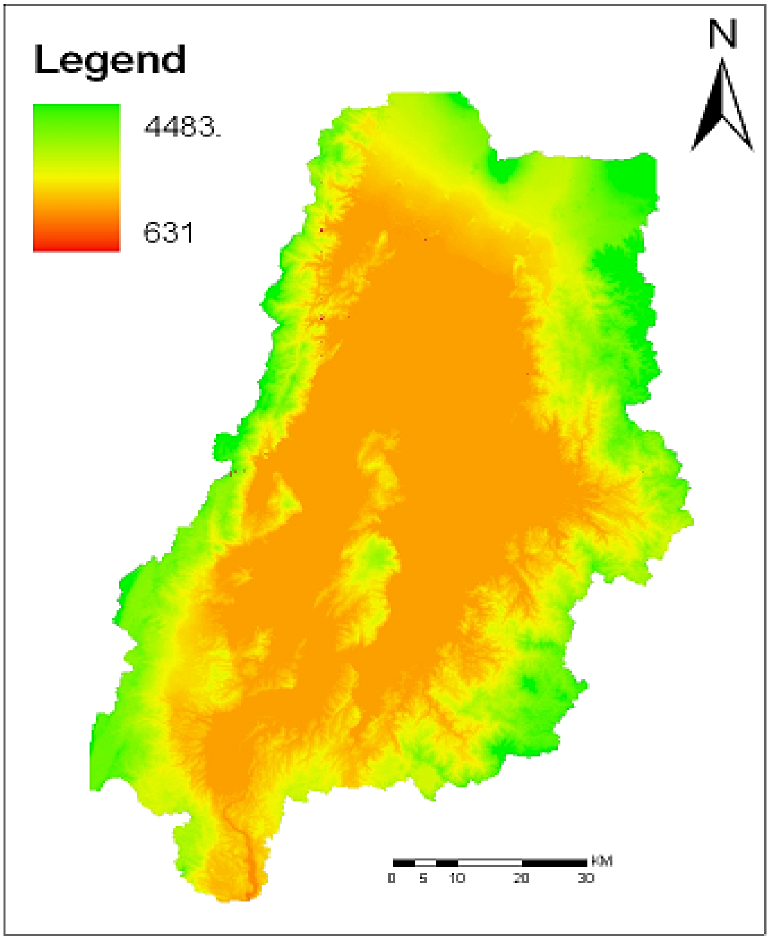

Figure 3-1 Digital Elevation Model of Lake Kivu Basin

4.2 Masking feature

Considering the physical and hydrological Nature of the Lake Kivu system, narrowing from the north to south wards of the study area to the outlet which River Rusizi was preferred. The masking feature was used to eliminate areas outside of the study area. Only the area included in the mask was relevant and was used in calculations. When a masking map grid was displayed, the stream network was delineated only for the area of the DEM covered by the masking map grid, figure 3-2 below.

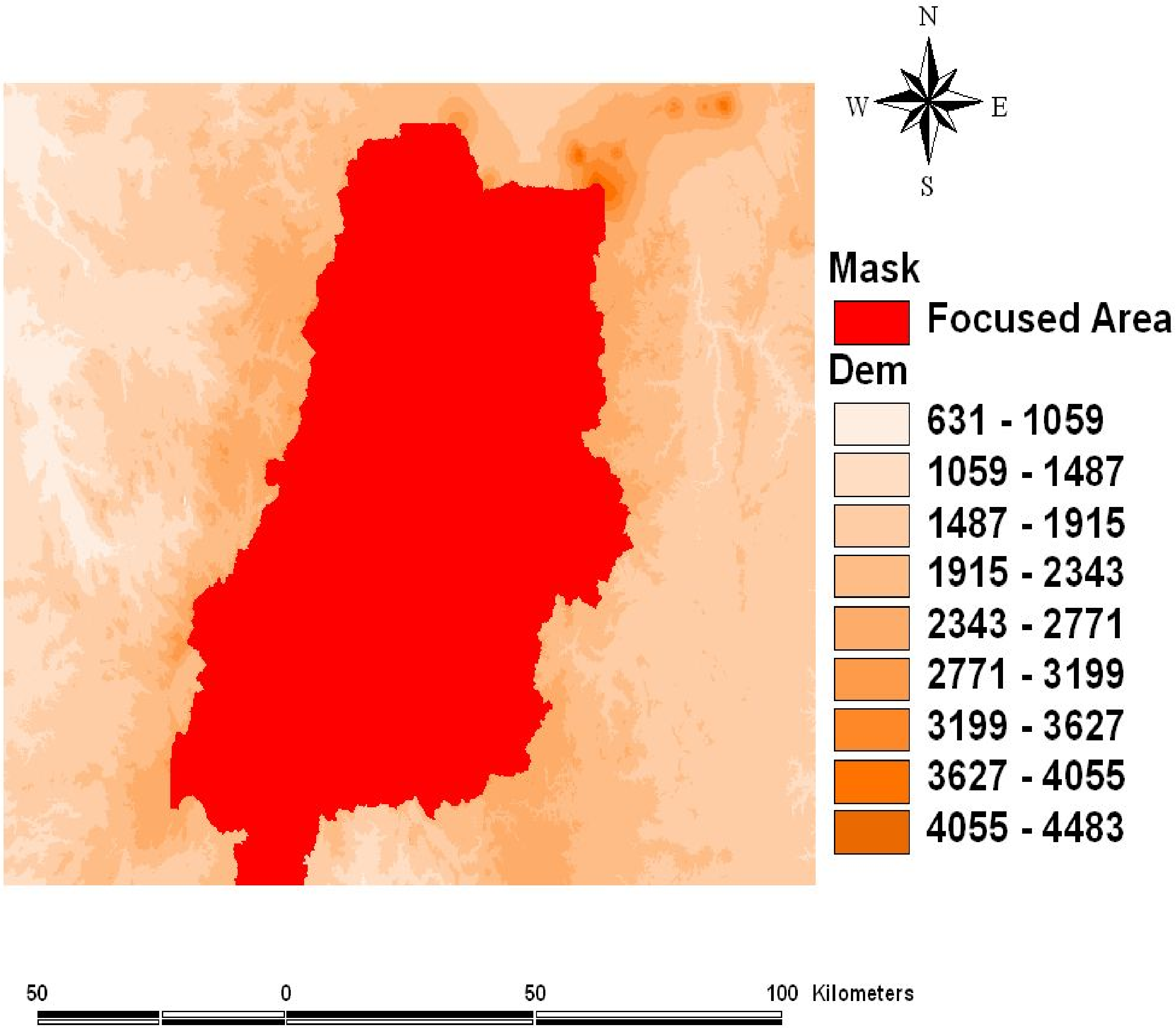

Figure 3-2 : Masking feature for the study area

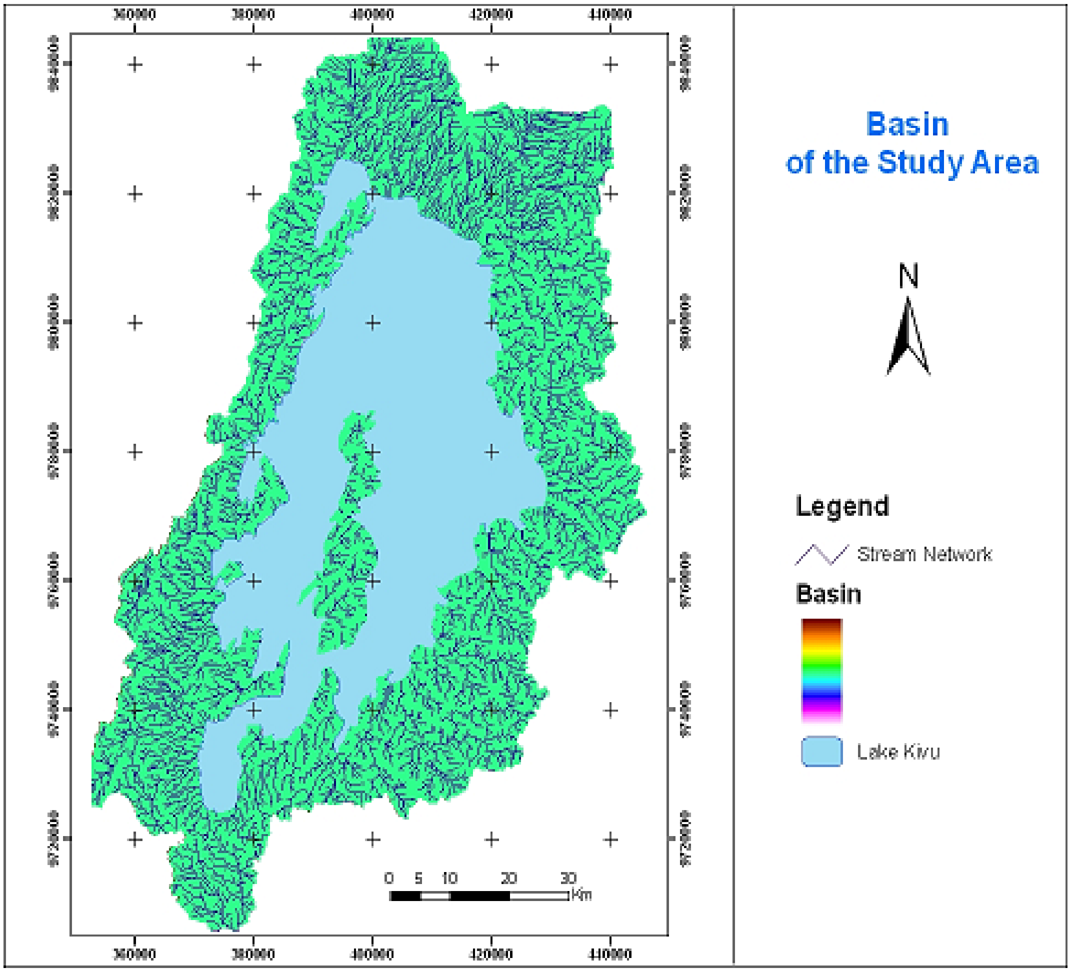

Figure 3-3 Streams network

Using masking feature, the network of streams in the catchment that flow into the lake were delineated using Arc GIS tool. It is characterized by a very dense network of rivers and perennial streams but the minor streams were discarded by making adjustments on threshold at 2000 ha in order to avoid empty streams not to confuse the model on the drainage slope,

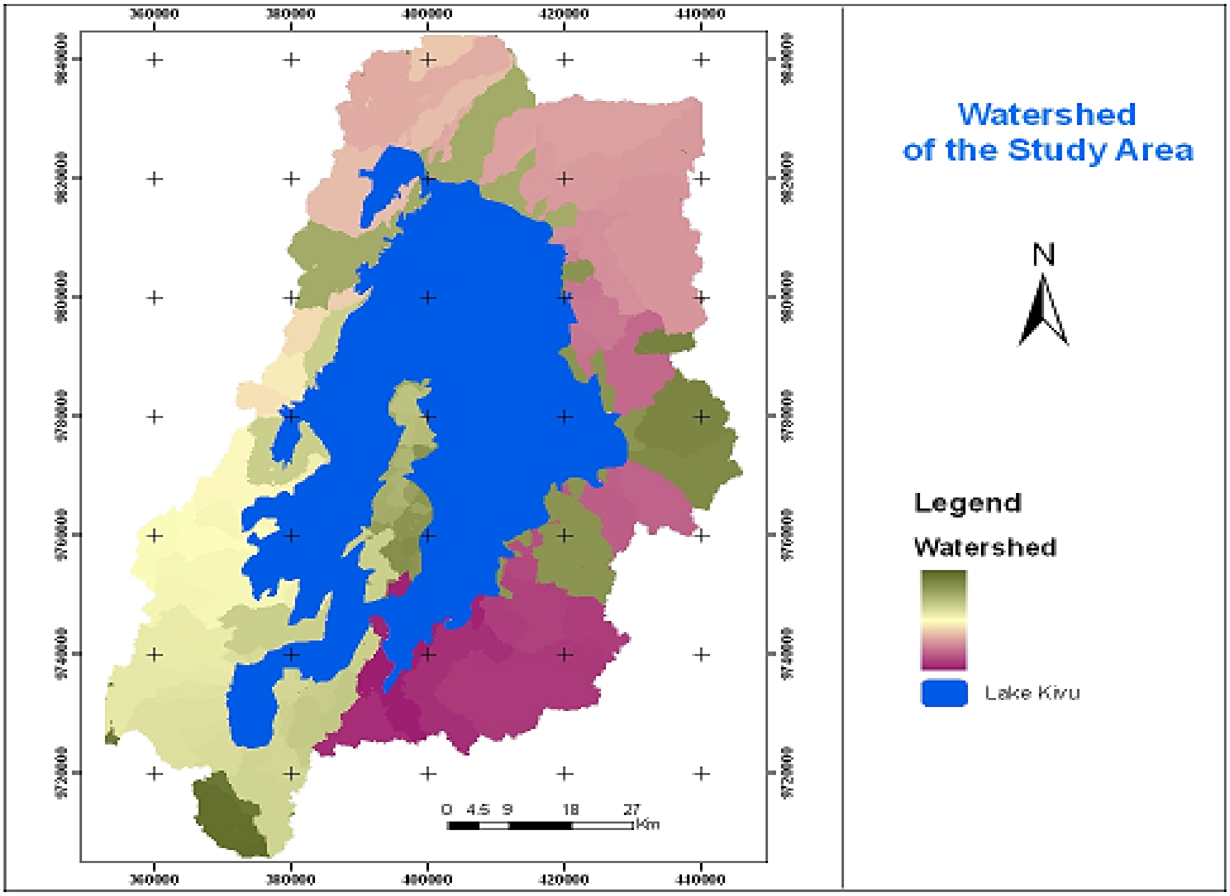

Figure3-4: Watershed of Lake Kivu basin

The watershed of Kivu basin has landscape characterized by a nearly unbroken series of mountains and hills both sides with a gentle slope from the northern part of the catchment to words southern. The greenish shed shows the valleys with swampy bear ever saturated soils or network of perennial streams

4.3 Land use and Soil Layers

Incorporated layers of land use and soil were used to determine land use/soil class combinations and their distributions for the delineated watershed(s) and sub-watersheds. SWAT requires these data to determine the area and the hydrological parameters of each land use and soil category

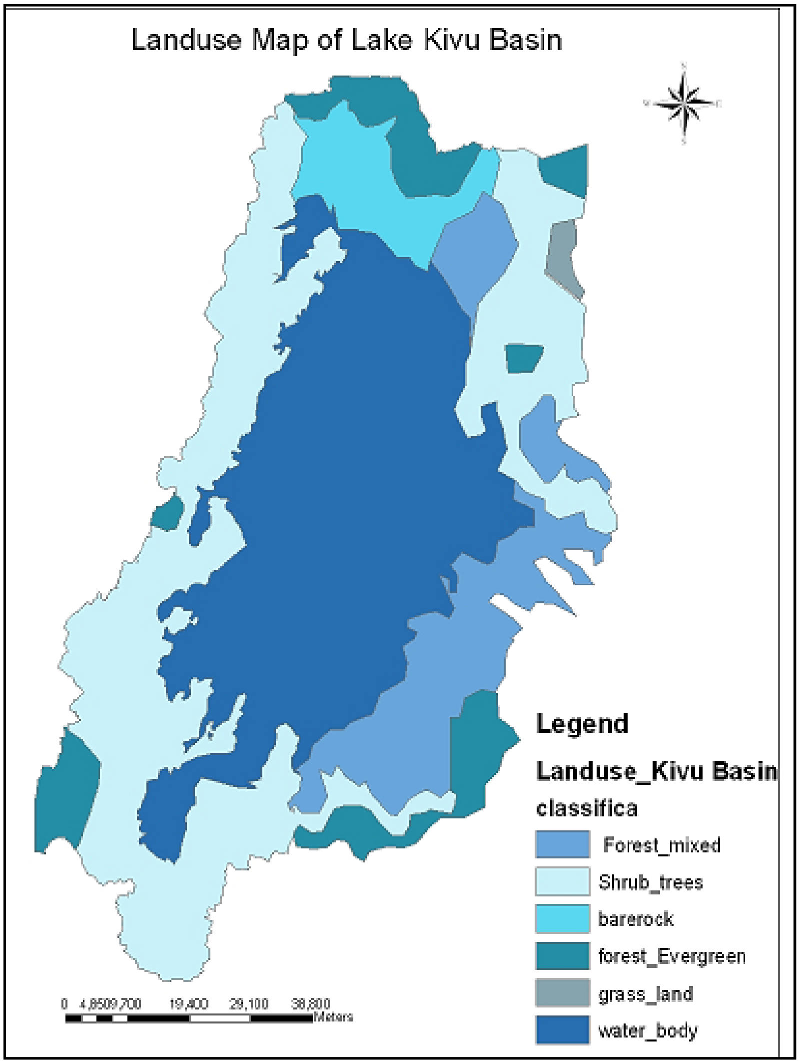

Figure 0-1 Land Use land cover Map of Lake Kivu Basin

4.4 Land use and Land Cover

Both landuse and soil classification maps were derived from FAO maps by georefeencing them and merging together both landuse/cover of Rwanda and DR Congo, then digitize with a help of mask to bound the study area. Similarly, both FAO soil maps of Rwanda and DR Congo were merged together and delineated using masking feature to classify the soil in the study area.

Land use in the Lake Kivu Catchment is dominated by shrub trees and forest mixed which cover 44%. Other important land use types are forest ever green, forest mixed, bare rock, and shrub trees with 13, 6.2, 8.3,% and 4.8% respectively. Water body covers 36.7% of the total area of the watershed of 7224km² as per swat model delineation.

The dominant land use of the watershed is rain fed agriculture and cultivated land is in various forms including, cultivated land with scattered trees.

Cultivated land with trees and shrubs are seasonally cultivated lands. More than three quarters of all land in the southern northern west (Bukavu, Goma cities) of watershed has already been brought under urban and local settlement while other urban settlements in the northern east, southern east and eastern parts(Gisenyi,Kamembe and Kibuye cities) covers more than quarter of the watershed, approximately and mentioned only cities more closer to the lake. The major crops grown in the watershed are Irish potato, banana, maize, cassava other cereals. Bush or shrub land, grazing land, forest/wood land and wetland/swap are other land cover types in the watershed.

The farming system in the watershed is mixed farming system dominantly in some parts of the basin in some form or another.. The agricultural or farming operation is mostly traditional in which land is ploughed using local tools.

4.5 Soil data

Based on FAO classification system, six soil types namely, Lithic leptosol, mollic andisol, humic cambisols, lithic leptosols, luvic pheozems, humic alisols types of the soils with varying soil depth ranging from 50mm to 150mm are common soil types in Kivu Watershed.

The soil textures in the Lake Kivu Basin are found to be dominated by sandy clay and clay loam soil textures in the eastern and western parts of the catchment while northern part bears the rocky /coarse gravel and sandy clay loam in the southern parts.

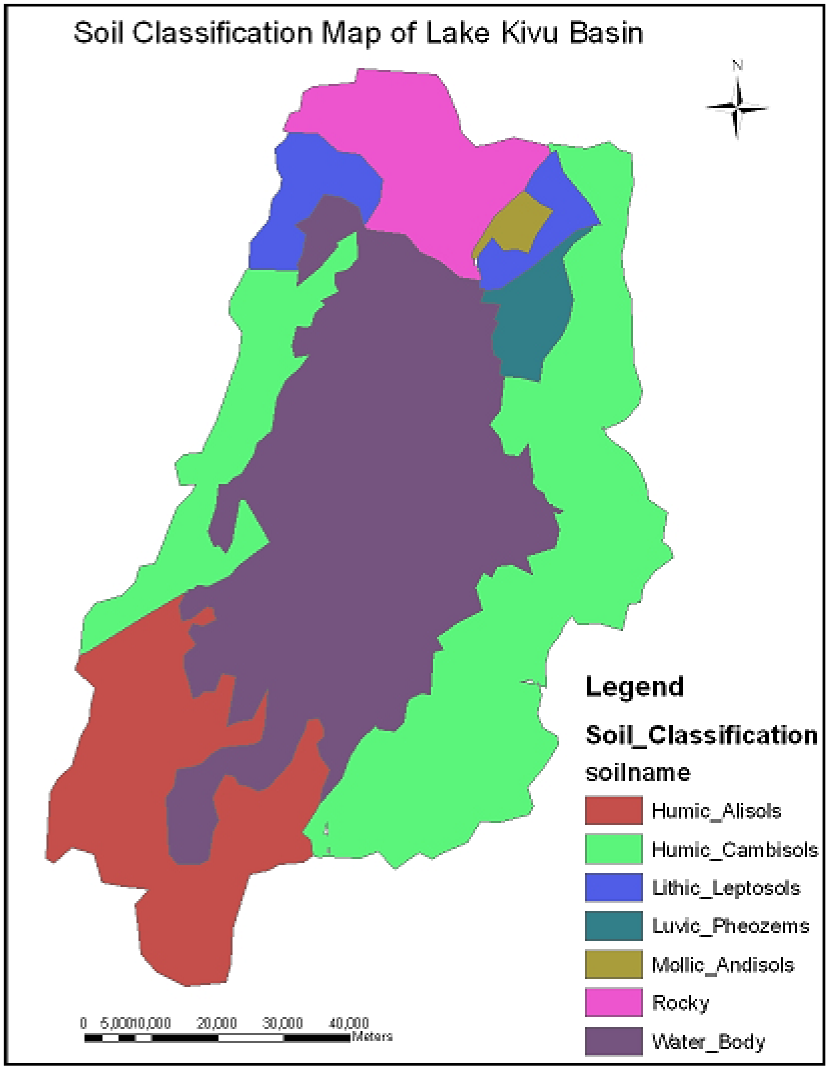

Figure 0-2 Soil Classification Map of Lake Basin

Humic cambisols are distributed dominantly in the eastern and western parts of the watershed, especially areas on hills where the land is too steep. They are inevitably high-risk soils and occur wherever conditions are not favorable for other soil processes than weathering to take place. They are brown in color and shallow to moderately deep soil.

4.6 FLOW SIMULATION OF KIVU WATERSHED

After setting all the SWAT files required, each file contains input parameters that SWAT uses during simulation. The files in the data base include daily hydrological data, landuse table, soil tale, station location, and other parameters. Since the lake is a complicated physical feature, it needs to model separately, in this case, the simulation was performed on the whole catchment reservoir inclusive while providing outlet at each subbasin and main outlet at the end of the main channel of the subbasin(reservoir outlet) numbered 43. There are 47 subbasin considered in simulation of inflow see fig4-1a below. Each subbasin generated inflow, outflow, ground flow, surface runoff, potential evapotranspiration, evaporation in the Kivu catchment.

Elevation of the Kivu watershed is in the range of 631 – 4483meters with
mean elevation of 1767.19 7 meters and with standard of 358.524 meters.
Land use was reclassified into 6 broad categories, which are compatible with the SWAT naming convention. These are RNGB, RNGE, WATR, FRSE, and FRST
Covering: 37.97%, 0.58%, 38.25%, 8.32%, and14.88%
of the Kivu Watershed respectively. There are 5 soil categories found inside Kivu Watershed namely: Humic Cambisols (Humic_Ca), Lithic Leptosols (Lithic_Le), Lake, Luvic Phoezems (Luvic_Ph), Rocky,
Humic Alisols (Humic_Al) and Mollic Andisols (Mollic_An),
and the soil categories cover 31.74%, 4.77%, 38.89%, 2.50%, 8.04%, 1%, 13.20% and 0.850% respectively. As discussed in the previous parts of this work refer annex 23.

These soil classes are supplemented by estimated physical properties such as available soil water, saturated hydraulic conductivity etc. The Kivu watershed was delineated into 47 sub-basins by assuming a flow accumulation threshold of 2000ha, which were further divided into 21 HRUs. During delineation process using SWAT, one main watershed outlet was manually added. Simulated flow at the outlet was compared with the observed flow statistically and graphically.

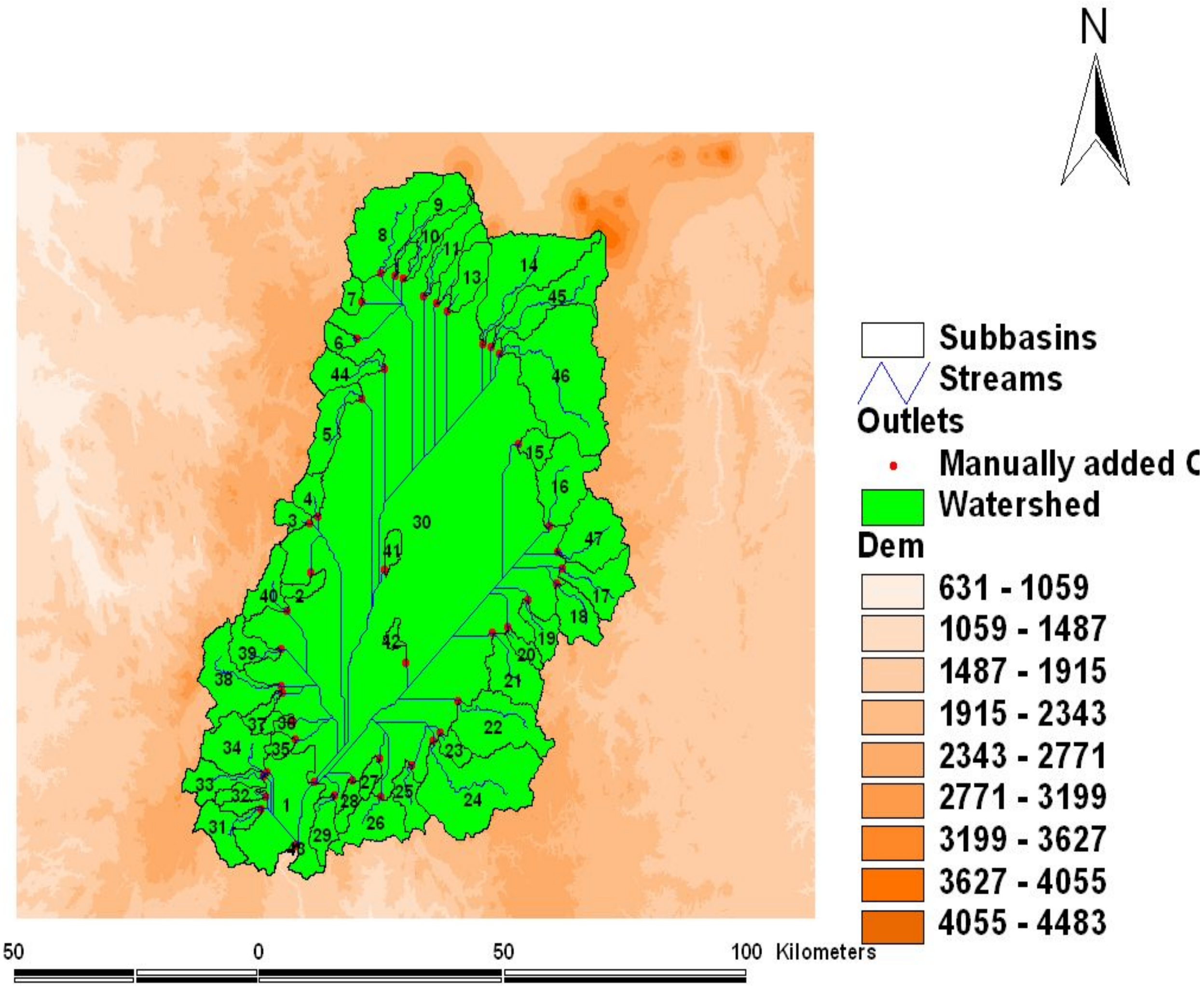

Figure 4-3 Swat generated subbasins in Lake Kivu basin

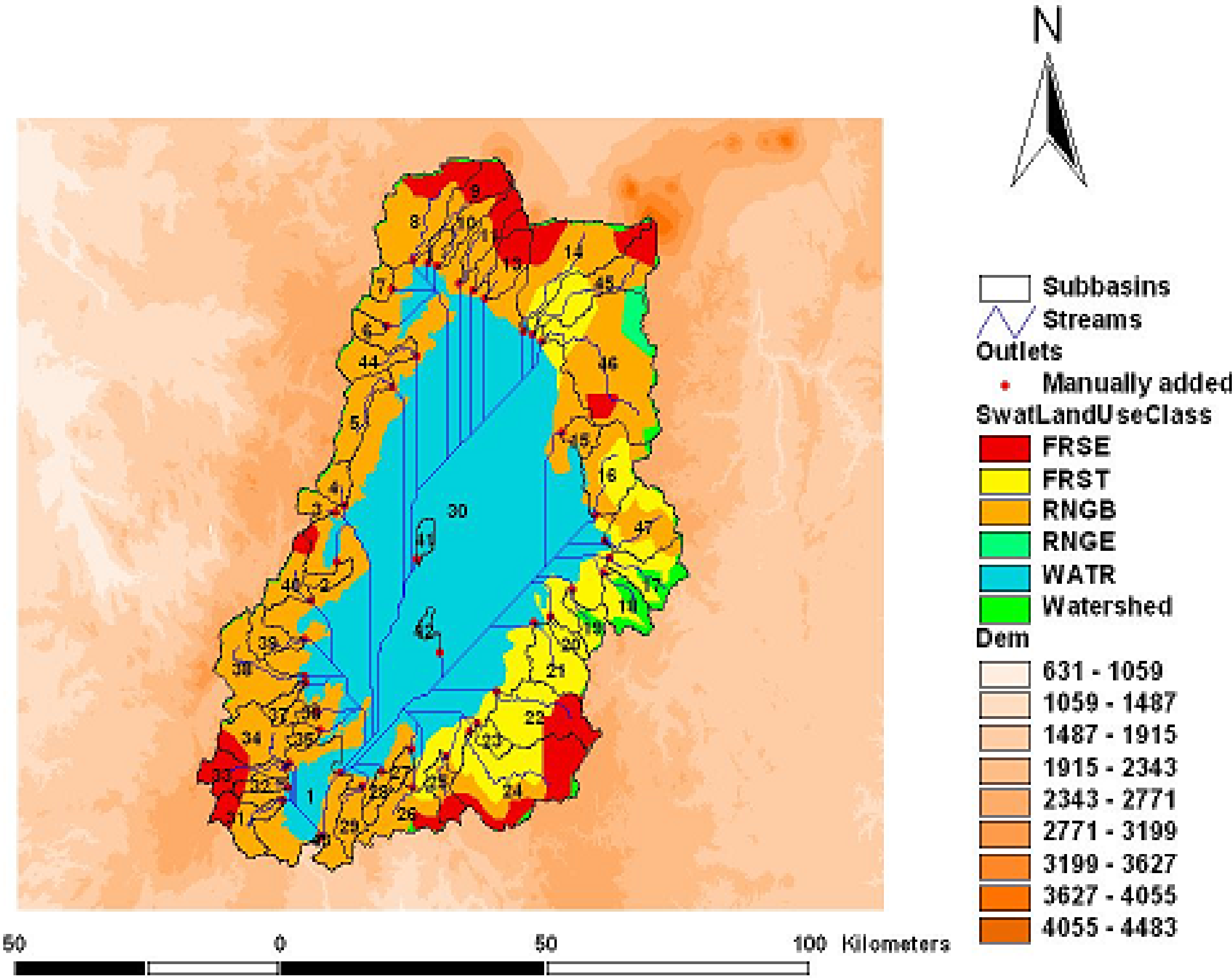

Figure 4-4: Landuse in partner with streams

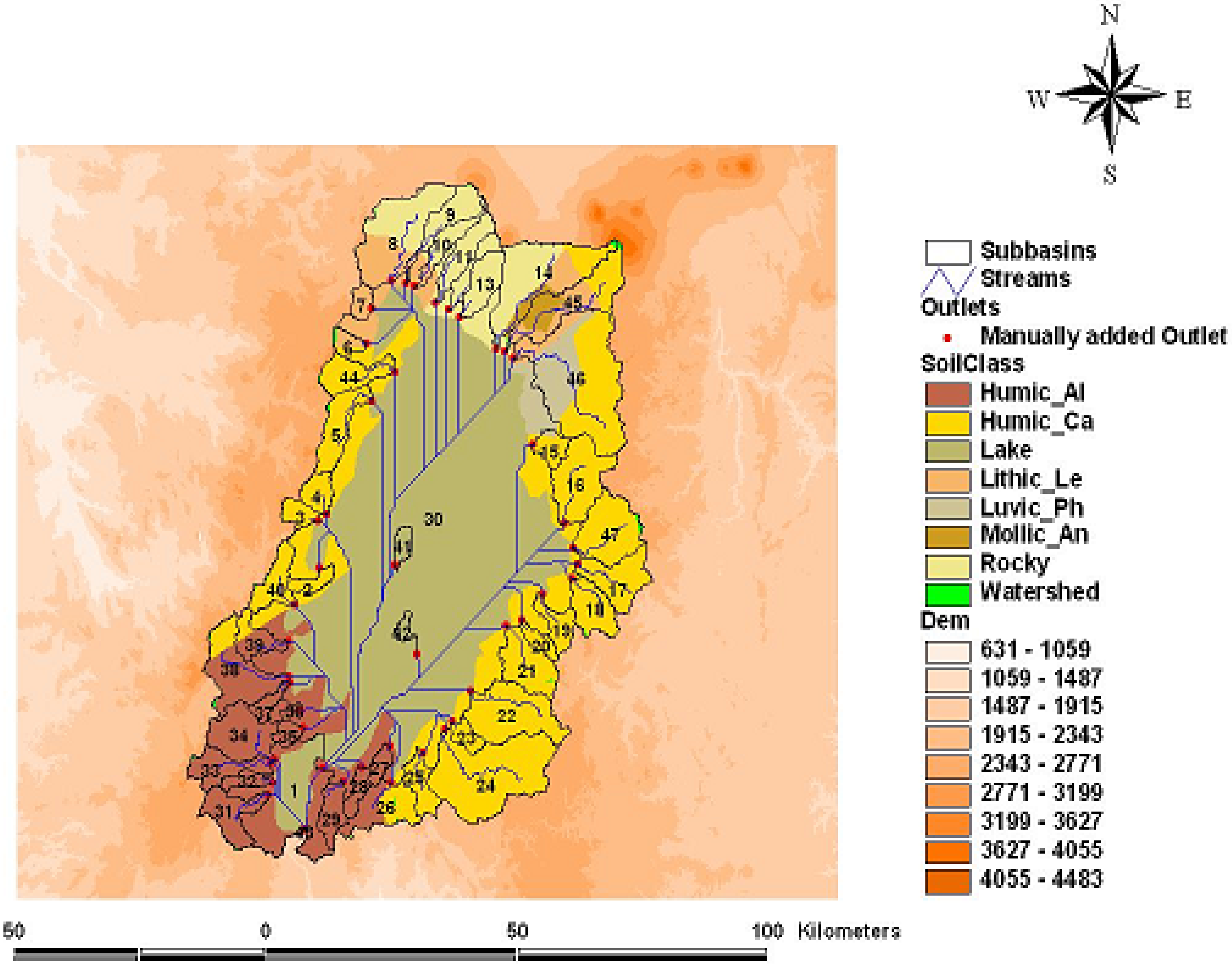

Figure 4-5 Main streams network delineated in their repective subbasins and soil types.

The streams discharge flowing from different subasins of the catchment meet in reservoir(lake) forming the stream strings in the lake and the flow continues towards the outflow of the reservoir numbered 43 at the down stream see fig4-1a above.Subbasins are numbered from 1 up to 47, number 30 represents the lake coverage,1 is cummulative outlet of integrated flow in the reservoir as the model showa in the discharge output where as 41 and 42 are showing flow out from the Ijwi island located almost in middle of lake Kivu. The simulation out fit hydrographically is shown below.

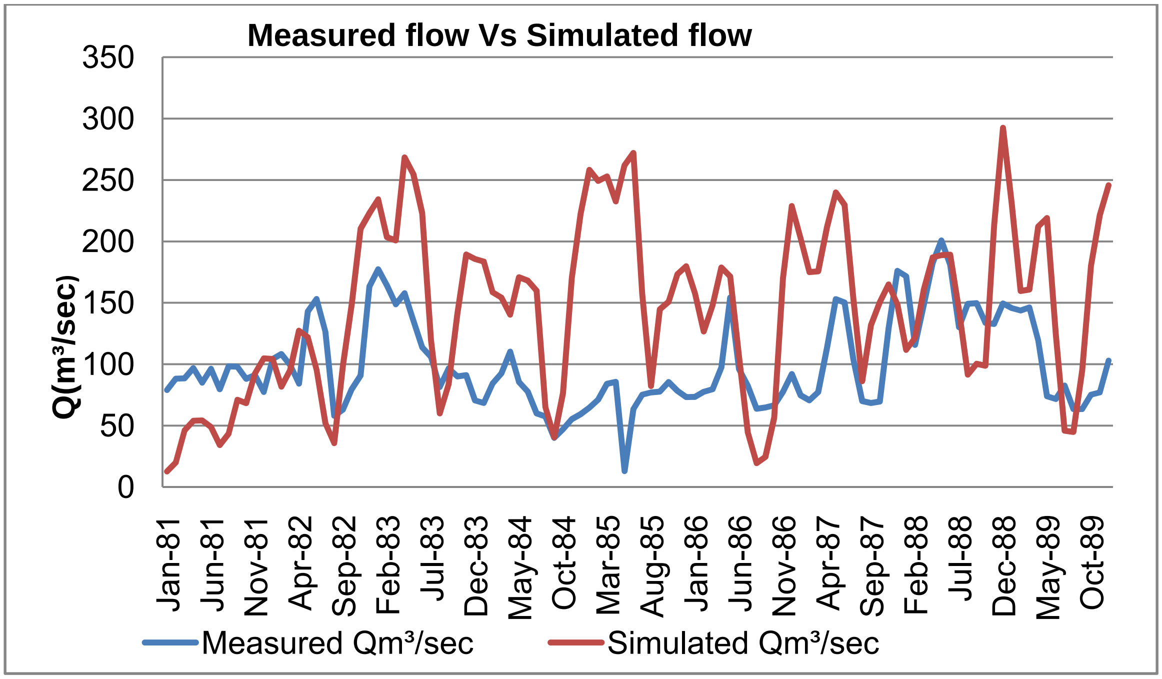

Figure 5-0: Measured and Simulated discharge hydrograph

The hydrograph fitting in fig.4-1b is for the simulated and measured discharge at the main outlet of the lake from 1981 to 1989

The simulation is before calibration of Kivu watershed parameters. Hydrograph shape of simulated and measured, however the SWAT simulated values are overestimated especially in the peak months of October and November in almost all of the simulation period and the model efficiency values for the default simulation therefore are: r^2=0.41, E_{NS}=-3 and D=63 which is not acceptable.

This problem of mismatch of measured flow to simulated flow and poor efficiency is most likely to be so due to lack of proper observation/measurement of discharge especially during the high rain storm/peak period where as the model takes care of simulation of discharge at the maximum and minimum p months, similarly, this may be so due landuse/landcover change of the watershed

Whereas the efficiency values after exhaustive parameter adjustment have become; r^2=0.5001for the range of four year and R^2=0.63 within the range of one and a half years. E_{NS}=-2.36 and D=45.18 .The attainability of reasonable efficiency is in the lower range of standards. The best trial values or percentages of parameters that give the best calibration, i.e. best efficiency in each their respective simulation are: CN-II (-25%), rchrg_dp (0.25), GWQMN (50mm and 100 for some subbasins), ALPHA_BF)(). GWREVAP (0.1), ESCO (0.90), sol_z (25%) and SOL_AWC (-25%). Furthermore the hydrograph after flow calibration in Kivu watershed bears another shape and trend in the calibration phase below.

4.6.1 Sensitivity analysis

Sensitivity is measured as the response of an output variable to a change in an input parameter with the greater the change in output response corresponding to a greater sensitivity. Sensitivity analysis evaluates how different parameters influence a predicted output. Parameters identified in sensitivity analysis that influence predicted outputs are often used to calibrate a model. Sensitivity tests and preliminary model run were carried out in order to identify the most sensitive model parameters. To avoid over parameterization, only the most sensitive parameters were adjusted in model calibration. Eight sensitive parameters were identified: five of these mainly affect the surface runoff (CN2, SLOPE, Sol_K, Soil_Z and Sol_AWC), the remaining two affects base flow generation (GWQMN and ALPHA_BF). \During the manual calibration range of values for some sensitive parameters has been identified without losing their physical meaning in reality. These parameters are CN2, Slope, ALPHA_BF and GWQMN.

Table 2-0 Sensitive Parameters of the Model

Number	Parameter code Name	Mean
1	CN2	4.69
2	Sol_z	2.61
3	Sol_k	1.67
4	Rchrg_dp	1.39
5	Sol_AWC	1.38
6	GWQMN	1.3
7	SLOPE	0.116
8	ALPHA_BF	0.123
9	ESCO,EPCO	0.90, 0.90

The model calibration was found to bring about a good agreement between measured discharges and simulated discharges after several adjustments on above tabled parameters and results are shown in calibration phase output below

4.6.2 Calibration phase

The calibration was performed by manually changing the parameters through the interface until the correlation of the measured and simulate discharges is at the level of acceptance though not satisfactory. In that way, the further use of the interface could be for further changes, output data processing. The quickest way is probable to update the tables.

Much effort has been done to see the physical meaning of the proposed parameter value change before accepting the result. The assumption made here is the parameters are uniform in space, which is not the case in reality. This assumption would affect the model performance especially in large catchments.
In the calibration process the curve number CN2 in all HRUs has been decreased by 25 percent.

The decrease of the curve number will increase the retention parameter as explained in section 3.3.5 so lower runoff generated in the catchment. Since 37.97 percent of the land coverage in the basin is range brush land, this change will not bring lose of physical meaning even though the change is applied in a lumped way to all 57 HRUs in the catchment. The CN for each HRU depicted in Annex 4. The slope has been increased by 2 % in eastern, western sub-basins. Relative increase over the entire basin except northern part., the time of concentration will be reduced which is true in highly elevated catchment. The change made on slope in each HRUs during calibration also presented in Annex12.

The available water capacity in the soil, sol_AWC has been decreased by about 20% in order to balance the surface runoff with ground water but still surface runoff remain lower than ground water due to the nature of the watershed where the runoff takes reverse direction of the reservoir, then creates base flow finally into the lake. However, the change in this parameter will affect the layer of evaporation demand and therefore the surface runoff is also affected, The lower the sol_AWC value, the lower the layer evaporation demand. Normally, in the steep catchment having well defined drainage, the evaporation loss is very small over sub basins but much more over the lake and relatively ground water revaporation in subbasins due to land degradation.

The Alfa_BF has been decreased in some subbasins and HRUs from 0.048 to 0.018 and 0.009. This parameter is the base flow recession constant *gw,* and is a direct index of groundwater flow response to changes in recharge. The increase of α *gw* from 0.048 to 0. 018. Means that the land response to recharge has changed from moderate to slow–rapid to check the reaction to surface runoff and found that by the nature of topography in subbasins 31, 32, 33, 34, 35, 36, 37, 38, 39 in south west of watershed, recharge the reservoir in land response of percolation/infiltration, increasing ground water potential where as runoff balances 10% to ground water in subbasins from 20 to 29 south east of watershed. And both parts of watershed contribute much flow to the reservoir.

The ESCO value is the soil evaporation compensation coefficient, which allows modifying the depth distribution used to meet the soil evaporative demand. An increase or a reduction of the evaporation from soil using ESCO parameter can change surface runoff. The shape and the trend of calibration hydrograph is showed in fig.4-1c below.

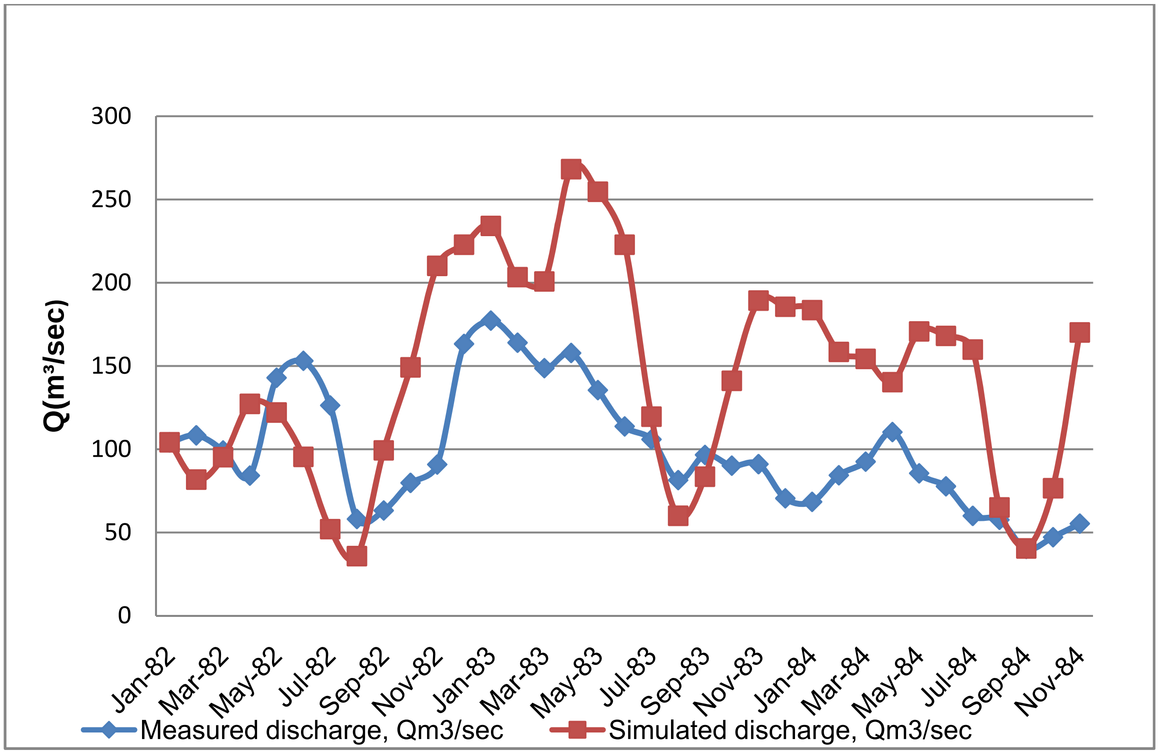

Figure 5-1: **Measured and Simulated flow Hydrograph after Calibration (1982-1984)**

The fitting of measured and simulated discharge is bearing the some deviation after the calibration however, correlation coefficient(R^2) between both data has reached on acceptable value of 0.63, Nash-Sutcliffe efficiency coefficient (E_{NS}) is -2.36 and standard deviation (D) is 45 The Nash-Sutcliffe Efficiency measures the relative magnitude of the residual variance (‘noise’) to the variance of the flows). It is used as a performance measure to evaluate the goodness of fit of the simulated flows compared to the measured flows. The realized deviation between the measured stream flow and simulated stream flow is due to poor type of the observed discharge which is not reliable as mention in previous discussion about the data quality. This requires proper observation of flow during the minimum and maximum rain period (min. and max. storm). And this will help to achieve proper evaluation of any change in the watershed.

The trend of discharge in the watershed after the calibration is showing a decreasing trend for both observed and simulates discharge from Kivu watershed. This change in the discharge yielding is most likely due to land cover change to land settlement which has affected the land recharging rate into the reservoir especially in subasins possessing high ground water potential in western part of watershed that drains into the lake. This ground water potential is facilitated by the range land with drainage nature that when it rains, runoff does not head towards the lake, instead, it runs off opposite direction and there after get blocked by the nature like gouges that finally turns into the reservoir in form of baseflow. Ground presentation in demonstrated in the next section.

4.6.3 Model validation

The Model validation was performed at outlet of the Kivu watershed similar to that of the calibration-using stream flow data. Calibration and validation of the model is a key factor in reducing uncertainty and increasing user confidence in its predictive abilities, which makes the application of the model effective to achieve watershed management goals.

In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices, the model must be first Calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set performs reasonably well under an independent data set. Provided the model predictive capability is demonstrated as being reasonable in the calibration and validation phase, the model can be used with some confidence for future predictions under somewhat different management scenarios.

The calibrated parameters of Lake Kivu watershed outlet are further checked for validated for years 1985 to 1989 and the resulting model efficiencies in this case are found to be; R^2=0.45, E_{NS}=-3 and D=63. This shows that the model goodness on the calibration compared to validation and valid for all of the simulation years.

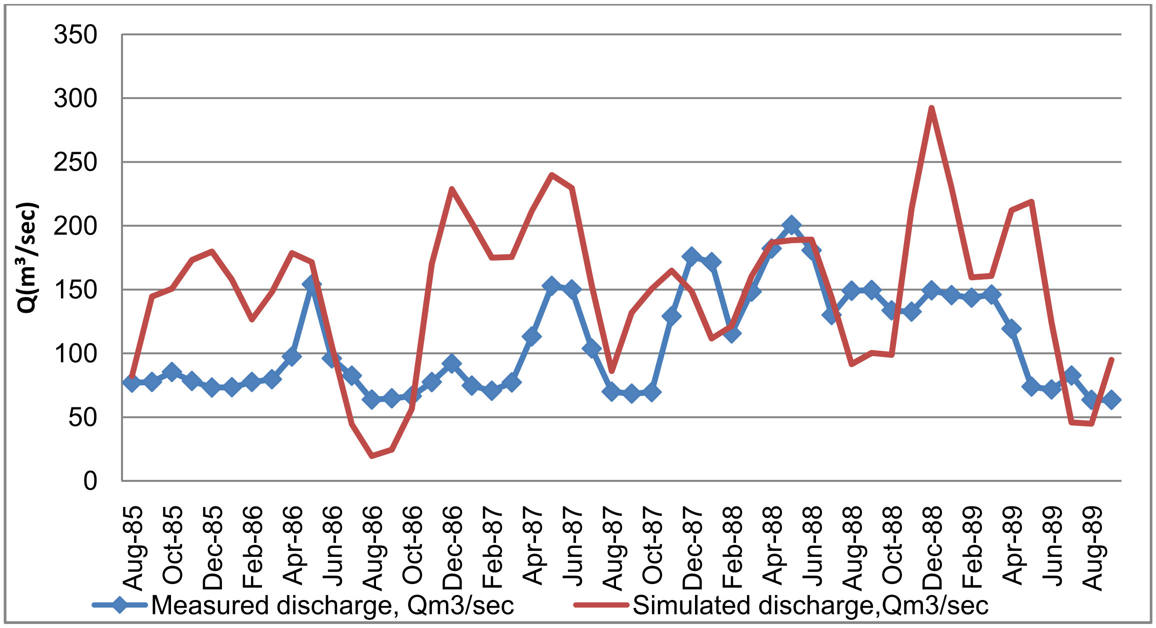

Figure 5-2: Validation hydrograph for measured and simulated discharge (1985-1989)

Although the correlation coeficiency (R2) during calibration and validation period is attained at the minimum level of acceptance, the slope of the hydrograph Indicates that there is over estimation of stream flow during both periods.

The plot of simulated and observed stream flow during calibration period and validation shows the decreasing trend in the streams flow but much more decreasing trend is significant in calibration hydrograph. This implies response in the land cover change/landuse or change in the rainfall partnership in the watershed .There is also a difference in the efficiency where the calibrated period shows better efficiency than validation. This may be resulted from limited weather or flow data used as an input to the model. Except two weather generator stations, most of the stations have only rain fall and temperature data and some of the stations including weather generator stations have many missing weather data which were left to be estimated and filled by the model's weather generator. Using estimated data may influence the simulation output. Moreover, errors in measurement of flow may be another reason for the variation between measured and simulated flows at peak discharges.

Briefly, reasonable performance of the model in the Validation period indicates that the

fitted parameters during calibration period listed in table 4-3 can be taken as a representative set of parameters for Kivu watershed and further simulation and evaluation of alternative scenario analysis can be carried out for other periods using the SWAT model.

4.6.4 Catchment water balance

Generally in a rift valley system tectonic activities are intensive and geological processes are more dynamic. The nature and behavior of Lake Kivu catchment is more complex. However, to understand how the land use and climatic changes could have contributed to the lake level fall, simplified hydrologic relations of surface and sub-surface of the catchment have been calibrated and validated. Variables like water capacity in the root zone for different land use types are assigned by an average value weighted by the area covered with particular land use study area.

In this case, this sub topic is focused on the water yield in all subbasins in the watershed where the generated parameters such as ground flow, surface runoff, lateral flow, evapotranspiration are monthly tabulated in table ……. and used in water balance. In this water yield balance scenario, ground water is contributing 70% of total yield and 90% ground water in subbasin in south west part of kivu watershed and surface runoff contributes 26.6% of the same total yield while

0.4% seems to be lost seepage or infiltration or revaporation and the total water yield in the watershed in terms of depth is 7787.411mm

The water yield is calculated as follows:

Water yield= surface runoff + *lateral flow* + *base flow – losses – abstractions----2.*

WYLD = SURQ + GWQ --2-1

Where,

WYLD is water yield (mm) in each subbasin

SURQ is surfaced runoff, Q (mm)

GWQ is ground water flow, Q (mm)

LATQ is lateral flow, Q

This shows the ground water component of water balance. Ground water Comprises lateral flow and base flow. The ground water recharge varies from 20 to 700mm. The region of watershed with higher precipitation has also high ground water recharge.The yield of a subbasin is known as water yield, and is the net amount of water thatleaves the subbasin and contributes to stream flow in the reach. Losses include evaporation and water loss from reach by transmission through the streambed. Abstractions include water use and irrigation. Figure 5-10 gives the water yield of every subbasin. The water yield ranges from 40 to 660 mm. The lowest water yields correspond to subbasins with lakes, whereby evaporation rate is high. The water yield balance for each subbasin has been performed with application of above equation. In the processes of analyzing the potential contribution *of each subbasin and ground water contribution is higher than surface runoff as indicated in the table3 subbasins numbered from 31 t0 40, in southwest of watershed. They possess high ground water potential due to topographic influence and the basin flow transmission (base flow interaction) from the next catchment(Congo basin is suspected.*

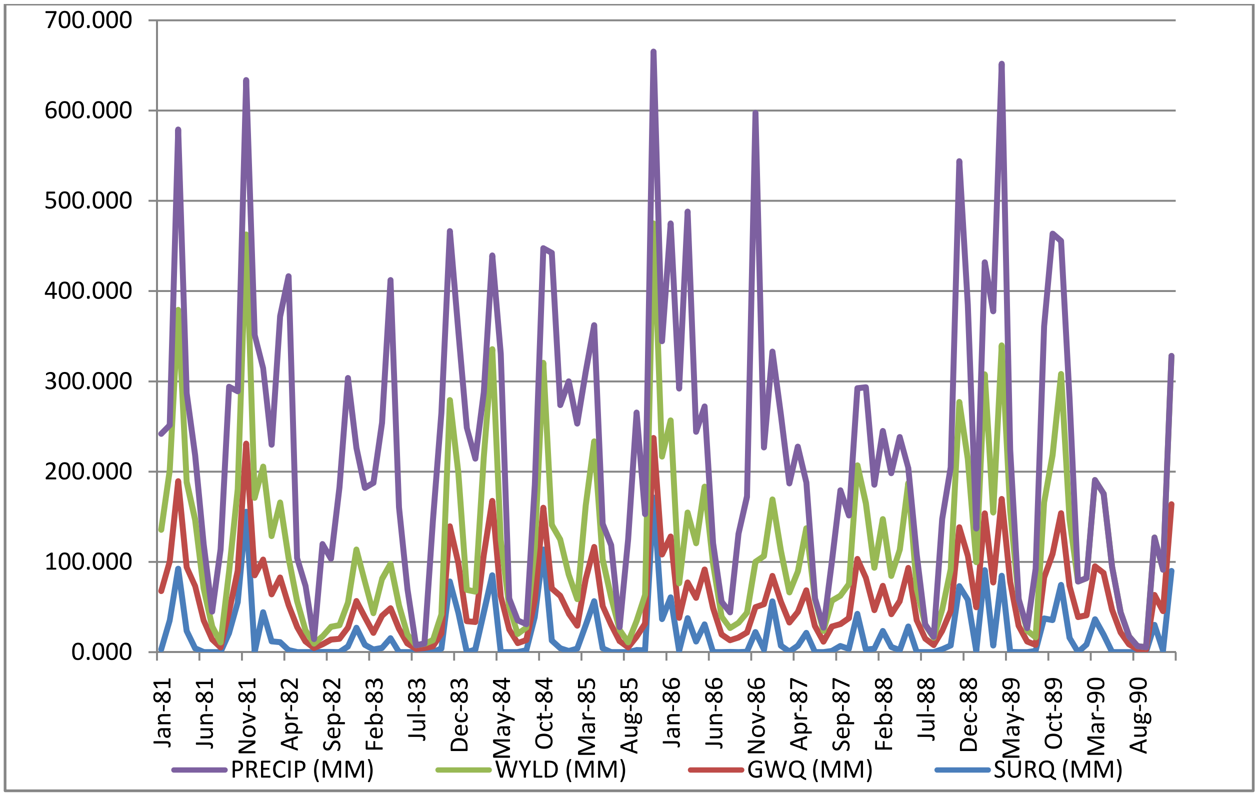

Figure6-0 Contribution of ground water, surface runoff with precipitation to water yield before final calibration.

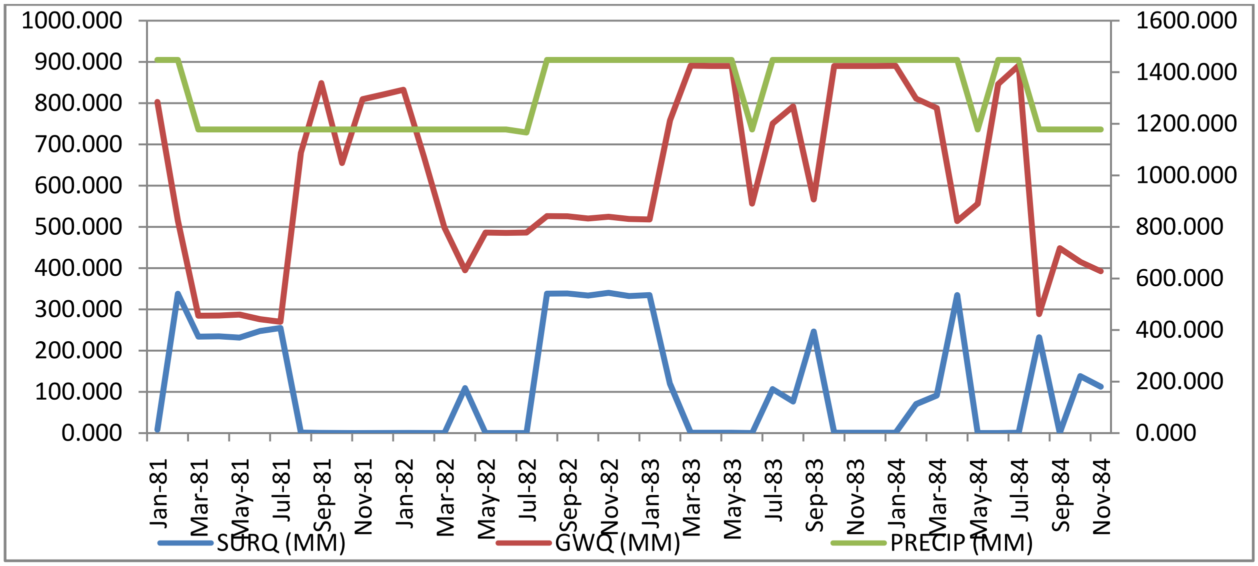

Figure 6-1: Hydrograph relationship between the precipitation, ground water and surface runoff after calibration

This graphical presentation shows the tendency of water yield components variation and the trend in the watershed. There is a big deviation between the ground water contribution and surface flow contribution as shown in hydrograph fig (6-0) and fig.(6-1a) where the first one from (1981- 1989) is after warm up simulation and represents the trend and watershed response to wards the surface flow and subsurface flow to the reservoir which are dependants of precipitation and the second hydrograph is derived from calibration period(1981-1984) and both of them are showing the a slight variation in precipitation and tendence to decreasing behavior significantly from 1984 – 1989, though there is increasing shape in between, the decreasing trend is not constant.

Table2.1: Relevant hydrologic components estimated by SWAT model

Precipitations (mm)	1447.78
Surface Runoff (mm)	115.55
Ground Water flow (mm)	615.75
Lateral flow (mm)	576.36
Shallow Aquifer recharge (mm)	50
Deep Aquifer recharge (mm)	500
Actual Evapotranspiration (AET) (mm)	
Potential Evapotranspiration (PET) (mm)	2848.74
Average annual inflow (m^3/sec)	148.86
Total annual flow into Lake Kivu(m^3/sec)	1338.12
Average annual outflow (m^3/sec)	138.5

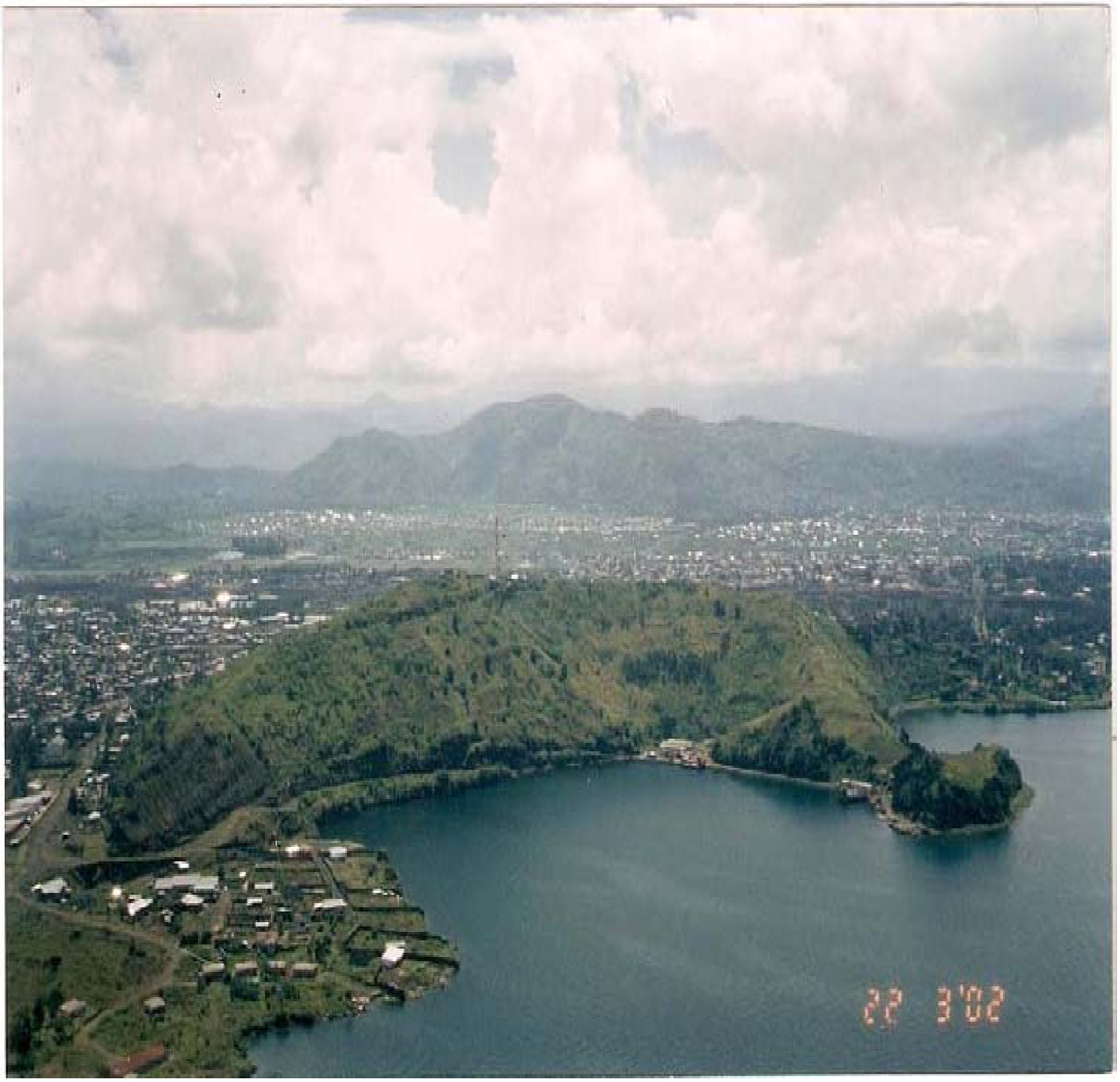
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Figure 7-0: Shows the land cover change to urban land and topographic influence to surface runoff in western part of Lake Kivu watershed. It blocs runoff towards the lake, instead takes the reverse but finally comes back in form of base flow.
Figure source; Natural disasters and hazards in the Lake Kivu basin, western rift valley of Africa (report)

Table3.0: shows water yield balance in sub watersheds (mm).

SUBBASIN. NUMBER	Area	SURQ	LATQ	GW_Q	WYLD	BAL. CHECH	(CONT%)
1	263.23	89.30	144.19	7225.15	7369.34	7458.64	2.34
2	23.17	3082.84	4636.87	90.36	7810.07	7810.07	2.48
3	28.93	2080.84	2561.12	65.18	4707.14	4707.14	1.50
4	36.72	2088.50	2566.71	65.24	4720.46	4720.46	1.50
5	81.16	2054.49	2587.52	65.20	4707.21	4707.21	1.50
6	23.17	2211.17	2484.25	35.32	4730.74	4730.74	1.50
7	24.01	2277.43	2429.89	20.10	4727.43	4727.43	1.50
8	193.97	11.98	6115.46	172.64	6300.08	6300.08	2.00
9	66.44	0.89	7637.49	247.36	7885.73	7885.73	2.51
10	44.10	2.39	5893.04	232.76	6130.21	6128.18	1.95
11	59.98	0.14	7283.53	271.83	7555.50	7555.50	2.40
12	34.50	0.36	7384.02	270.32	7654.70	7654.70	2.43
13	62.64	0.37	7488.82	268.79	7757.98	7757.98	2.47
14	214.95	2.14	6029.95	196.09	6228.18	6228.18	1.98
15	35.17	0.14	4483.12	88.21	4571.47	4571.47	1.45
16	129.48	970.41	3553.17	79.03	4602.61	4602.61	1.46
17	94.11	0.00	4376.08	90.84	4466.92	4466.92	1.42
18	70.70	0.00	4368.21	90.80	4459.01	4459.01	1.42
19	41.93	0.00	4375.35	90.85	4466.19	4466.19	1.42
20	23.43	3097.48	4734.71	90.81	7923.01	7923.01	2.52
21	96.11	3099.83	4733.25	90.80	7923.89	7923.89	2.52
22	158.57	3047.73	4684.09	90.76	7822.57	7822.57	2.49
23	25.86	3113.49	4722.85	90.82	7927.16	7927.16	2.52
24	278.00	3032.81	4673.59	90.68	7797.08	7797.08	2.48
25	47.93	3052.39	4663.05	90.70	7806.14	7806.14	2.48
26	91.43	1087.40	6825.53	99.11	8012.04	8012.04	2.55
27	20.80	7.99	8016.56	103.88	8128.43	8128.43	2.58
28	26.61	7.78	8010.19	103.84	8121.81	8121.81	2.58
29	45.55	7.58	8008.80	103.84	8120.22	8120.22	2.58
30	3571.54	0.00	5008.18	0.00	5008.41	5008.18	1.59
31	74.95	975.07	6755.21	98.35	7828.63	7828.63	2.49
32	24.47	698.59	7125.96	99.97	7924.52	7924.52	2.52
33	65.42	2252.72	5098.46	91.04	7442.22	7442.22	2.37
34	105.45	7.69	8008.71	103.85	8120.25	8120.25	2.58
35	20.56	7.89	8010.46	103.85	8122.20	8122.20	2.58
36	13.37	7.76	8010.49	103.85	8122.10	8122.10	2.58
37	22.43	7.66	8011.54	103.86	8123.05	8123.05	2.58
38	135.98	638.74	7299.60	101.01	8039.35	8039.35	2.56
39	48.36	831.09	7093.82	100.19	8025.10	8025.10	2.55
40	61.62	3055.16	4625.40	90.23	7770.79	7770.79	2.47

41	20.65	0.00	5004.08	0.23	5004.31	5004.31	1.59
42	11.92	0.00	7616.48	0.32	7616.79	7616.79	2.42
43	0.26	8.27	8020.22	103.89	8132.39	8132.39	2.59
44	67.98	2065.91	2598.81	65.29	4730.00	4730.00	1.50
45	151.30	5.18	4034.26	334.75	4374.19	4374.19	1.39
46	359.28	1223.99	3737.82	65.48	5027.29	5027.29	1.60
47	126.77	1000.92	3533.45	78.70	4613.06	4613.06	1.47
Total Area(Km^2):**7224.97**						314544.96	99.97 (Water yield)

Symbols in table: SUB is subasin, LATQ: Lateral flow Q, GWQ: ground water, Q, WYLD: water yield, BAL: Balance, Cont%: Contribution percentage

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4.6.5 Water Yield balance from each subasins

As discussed in the previous parts of this thesis, the water yield balance was showing high ground water potential.

A certain percent of total rainfall leaves the area as surface runoff (direct storm runoff). The remaining part, which is effective rain, goes to the soil as infiltration and when water holding capacity of the soil fills surplus water percolates to groundwater. When the atmospheric demand is not met by the effective rain water is withdrawn from the soil moisture by evapotranspiration. Evapotranspiration from the soil depends on the capacity of the soil to retain moisture. The drier the soil is, the more difficult it becomes to extract water. Groundwater store acts as a buffer and causes a delay in the groundwater runoff. Therefore only fixed fractions of the surplus of the current month and water detained in the previous month become part of the groundwater flow. The direct storm runoff and groundwater runoff together form total predicted catchment outflow. In this case, three zones of Kivu watershed bears high contribution to the total water yield which results in discharge that is used to produce hydropower at the downstream. These zones comprise subbasins in south west, south east and northern part of the watershed. South west subbasins include subbasin number 31 up to 40 with the representative of number 38 bearing high potential of

409.922m3/sec (1528.581mm) annually.

The water yield of this zone is dependent on the ground water which is almost 90% and 10% surface runoff, this is due to topographic influence where the surface runoff takes opposite direction of the reservoir but it returns back in form of subsurface flow. Only the small portions of land cover that its surface can flow towards the lake. In the same subbasins that flow interaction is suspected where the base flow from the adjacent catchment is likely to occur. This condition is basing on the quantity of ground water analyzed in the different simulations that all come up with almost the same results and even in period where precipitation is in the period. The reduction trend in its water yield looks most probably due to land cover change where the drainage area land cover has largely changed to urban land and local land settlement and this affects the recharging mechanism of the sub watersheds.

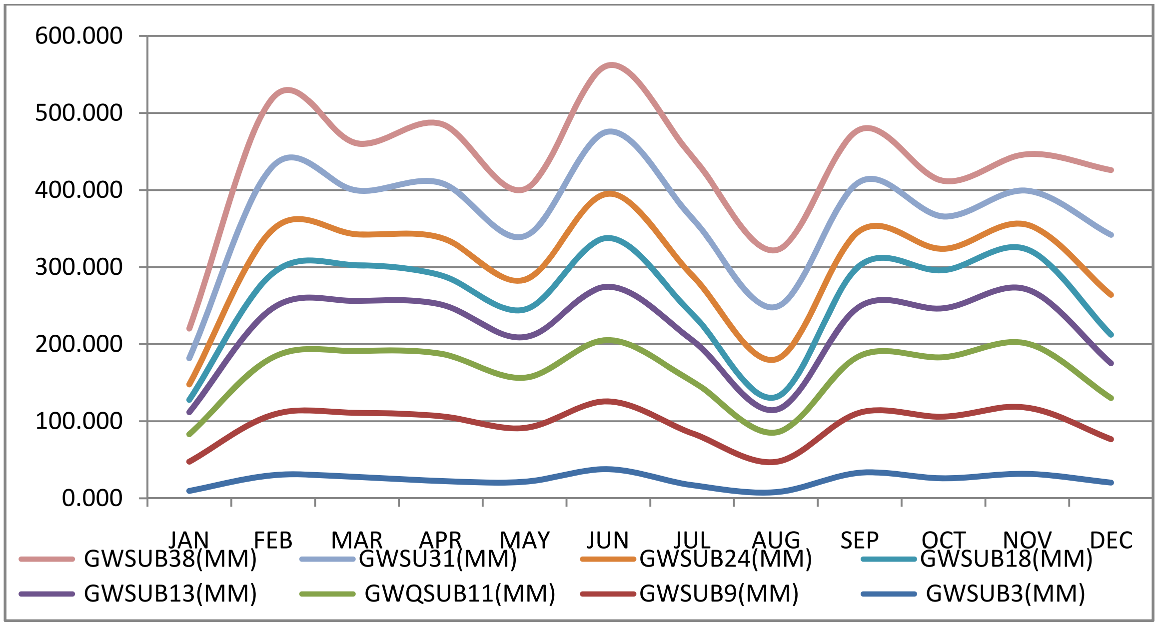

Figure 7-1: Ground water hydrograph in subbasins selected to represent others

The trend in this scenario indicates the decreasing behavior in the ground water yield. And it is a alarming problem since west and south west parts of Lake Kivu watershed recharge the Lake in form of ground flow due topographic influence as discussed in the previous part of this thesis. The declining trend in all cases is occurring in the maximum peak of the second rainy season which is October and November after the first maximum peak in March and April which is somehow in sustainable condition.

The south east zone also includes subbasin number 22 up to 29, represented by subbasin number 24 which contributes 789.720m3/sec (2944.834mm) which is 2.56% of the total inflow into the reservoir.. In this zone, there is balance in contribution to the flow both ground flow and surface runoff compared to other subbasins, surface runoff contributes 40% and 60% of subbasin contribution and the whole zone yields 15.01% and subbasin 2.48% of the watershed. This balance has been maintained due to being adjacent to game park Nyungwe and Gishwati game parks which are under the care of tourism authority, however , the surface runoff is showing the increasing trend which indicates the that there is land cover change such as deforestation around the lake due human activities. And this scenario shows the decreasing trend in monthly surface runoff as the hydrograph below shows the behavior in the watershed.

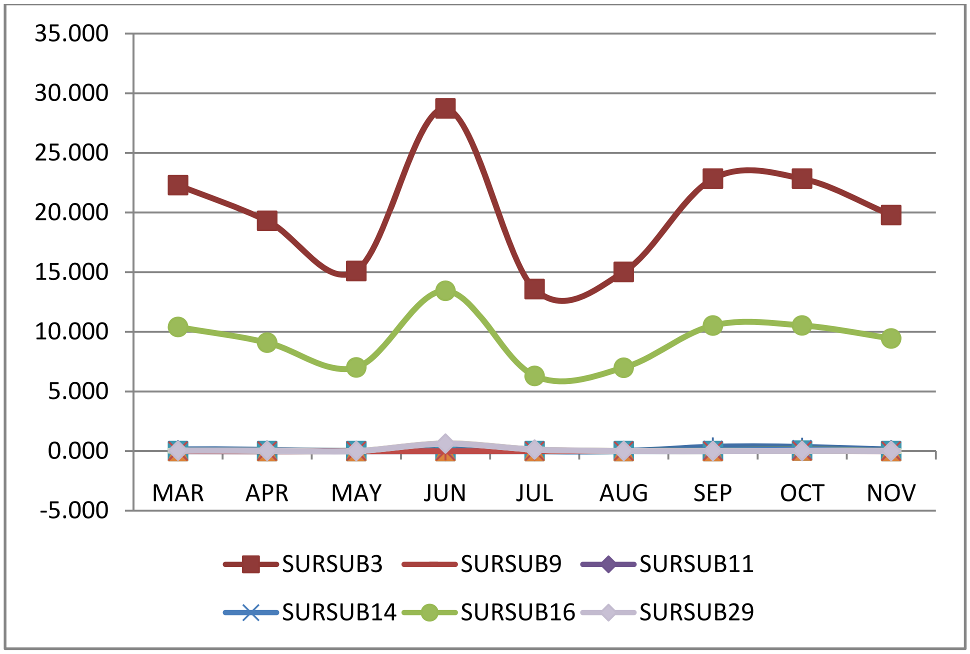

Figure 7-2 Surface runoff hydrograph for representative subbasins with high surface flow.

And topography on this side(south east of watershed) influences the flow towards the reservoir. The surface runoff hydrograph shows also the decline trend of rainfall in the usual months of maximum peak which used to be October and November.

For the generated flow, see the monthly table in annex 18

Northern zones formed of subbasins number from 8 to 16 and 45 inclusive are characterized by the lateral flow, according to the swat simulation results.

This saturated zone and an impermeable or semi-permeable layer at a shallow depth rainfall will percolate vertically until it encounters the impermeable layer then the water ponds above the impermeable layer forming a saturated zone of water is the source of water for lateral subsurface flow.

Lateral subsurface flow in the soil profile (0-2m) is calculated simultaneously With percolation. SWAT incorporates a kinematic storage model for subsurface flow developed by Sloan et al. (1983) and summarized by Sloan and Moore (1984). A kinematic storage model is used to predict lateral flow in each soil layer by simulating subsurface flow in a two-dimensional cross-section along a flow path down a steep hills lope. The model accounts for variation in conductivity, slope, and soil water content. It also allows for flow upward to an adjacent layer or to the surface and finally the flow directs into the stream even before the reaching the reservoir particularly in the case of above mentioned subbasins in Kivu watershed. The subbasins numbered 8, 9,10,11,12,13,14,15 in figure 4-1a in the northern part of watershed have the contribution capacity of 17.19% of the flow of the study area which is 205.115m³/sec (54083.85mm in depth) with1177.697mm precipitation annually, at an area of 451.34km²

4.6.6 Water Balance on Lake Kivu

Water balance on the reservoir is analyzed in terms o

This part of the thesis presents an estimate lake water balance. The water balance is derived from SWAT model using the generated infoowl, which was calibrated and compared with measured stream flow at the outlet. The water balance on the lake has been analyzed in terms of discharge to volume. The equation used is as follows:

$\Delta S = Vinflow + Vpcp - VET - Vout$---2.1

Where,

ΔS is a change in storage, Vinflow is volume inflow, Vpcp is direct rainfall in terms of volume, VET is actual evapotranspiration in terms of volume and

The water balance includes precipitation, potential and actual evapotranspiration, and runoff. The results are presented into two parts: the average monthly and annual values for the whole watershed and average annual values for each subbasin and annual outflow simulated is 138.5m^3/sec while the measured one is 90.4m^3/sec, with annual rainfall 1447.69mm ,actual evapotranspiration 467.78 mm,there is over estimation in discharge as discussed in previous chapter in this thesis and this difference in discharge may be due to maximum peak period that is take care during the simulation which looks to be not care in the observed data.. The results were compared with existing statistics at the outlet, no data available for individual subbasins in the watershed. Water balance analysis was found reasonably consistent in the watershed but with some imbalance of 21% on the lake water balance which is most likely due to water supply from the lake to the surrounding towns water use small factories like soft drink brewery .For the computation table, refer table in annex 17.

Precipitation variation 1976 to1990

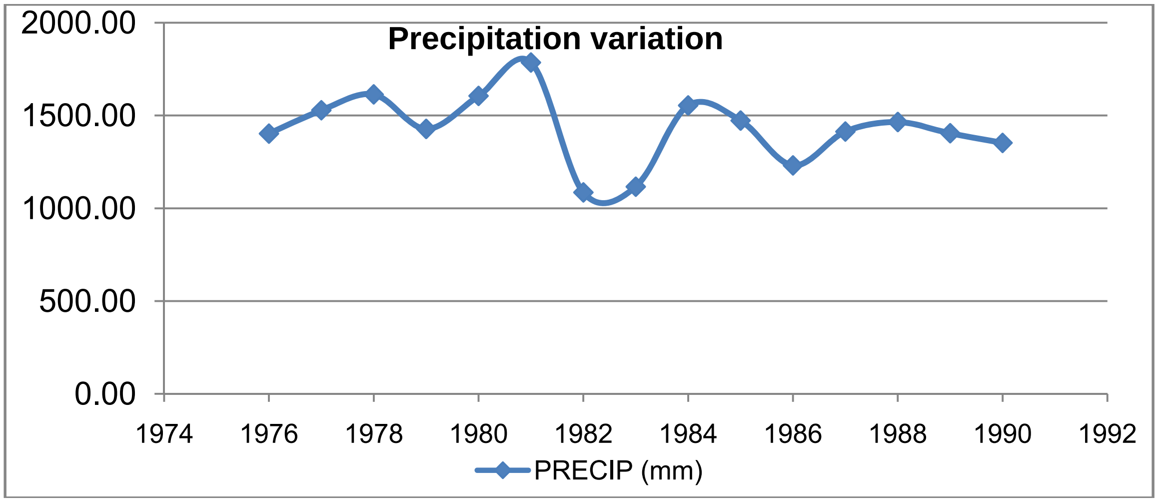

Figure 2-2: Precipition hydrograph from 1976 – 1990.

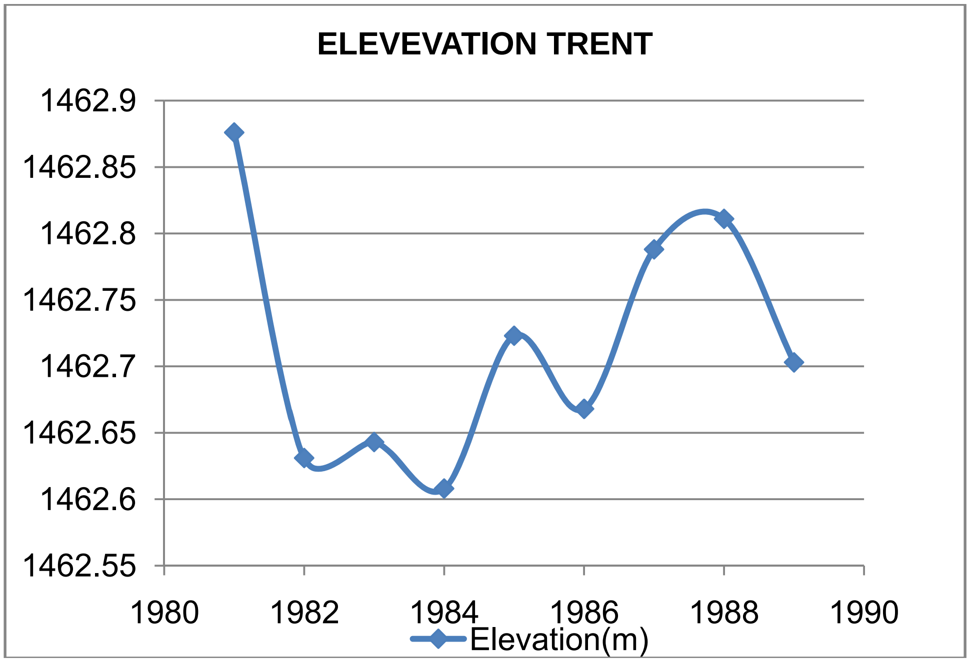

Figure 6-3: Lake water level fluctuation hydrograph

Both two graphs above show the maximum decreasing trend in 1980 mostly for Lake water level and raise in 1981 in both hydrographs, and then a slight decline in rainfall much for water level and the situation worsens again from 1988 and above. This is likely to be Landcover change that changes hydrologic response. See the combined lake level and precipitation variation below.

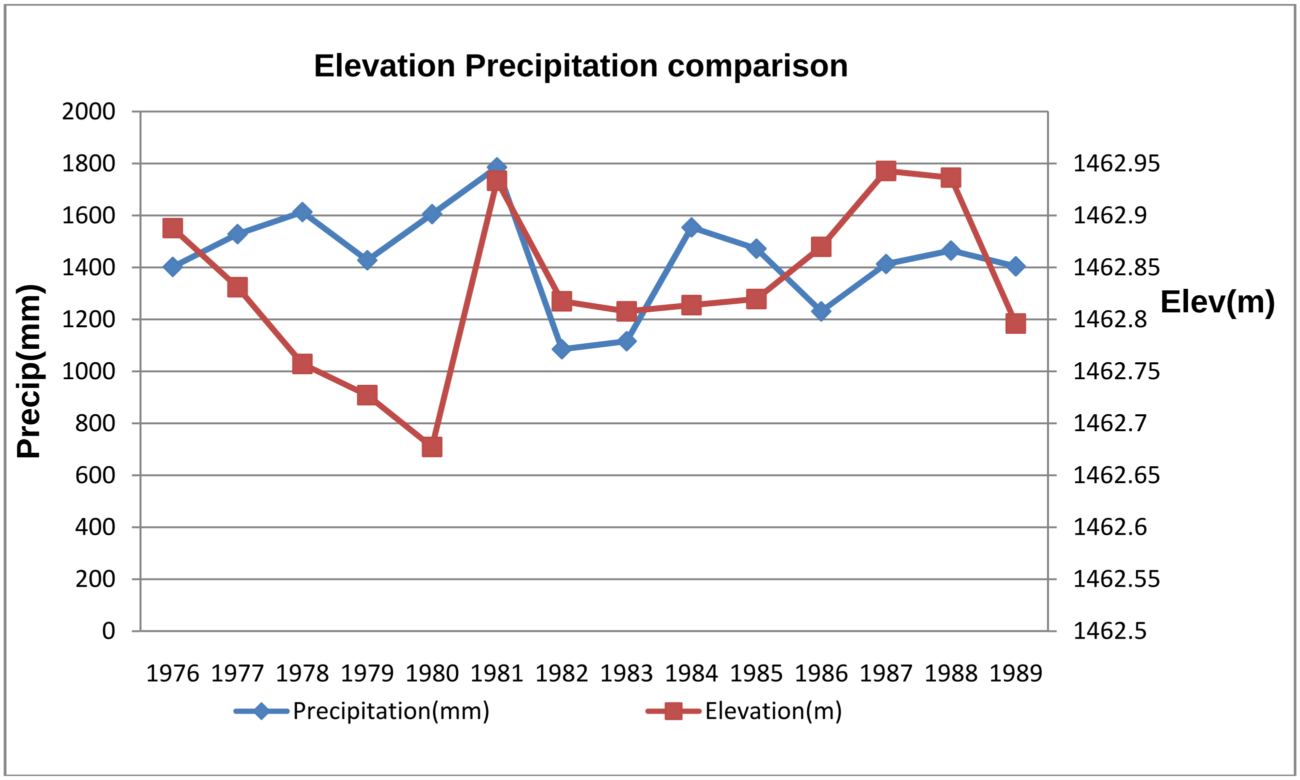

Figure 6-4: Lake water level and precipitation variation hydrograph

According to the trend for lake water level fluctuation and rainfall variation, rain fall has declined by 0.6 percent with 15 years we can say that the decline is not only in rainfall partnership, there is also an effect of land cover change responsible for ground flow decreasing trend. The case of rise in rainfall partnership and water level remains low may be due to decline in underground water particularly in recharging of western subbasins of Kivu watershed which depend on the ground water as discussed in previous section of this thesis. When both units hydrologically respond differently in the watershed, it happens to observe variation in rise and fall in Lake water level and precipitation. Generally, the sensitivity of runoff to rainfall changes is very similar to results in other 'impacts.

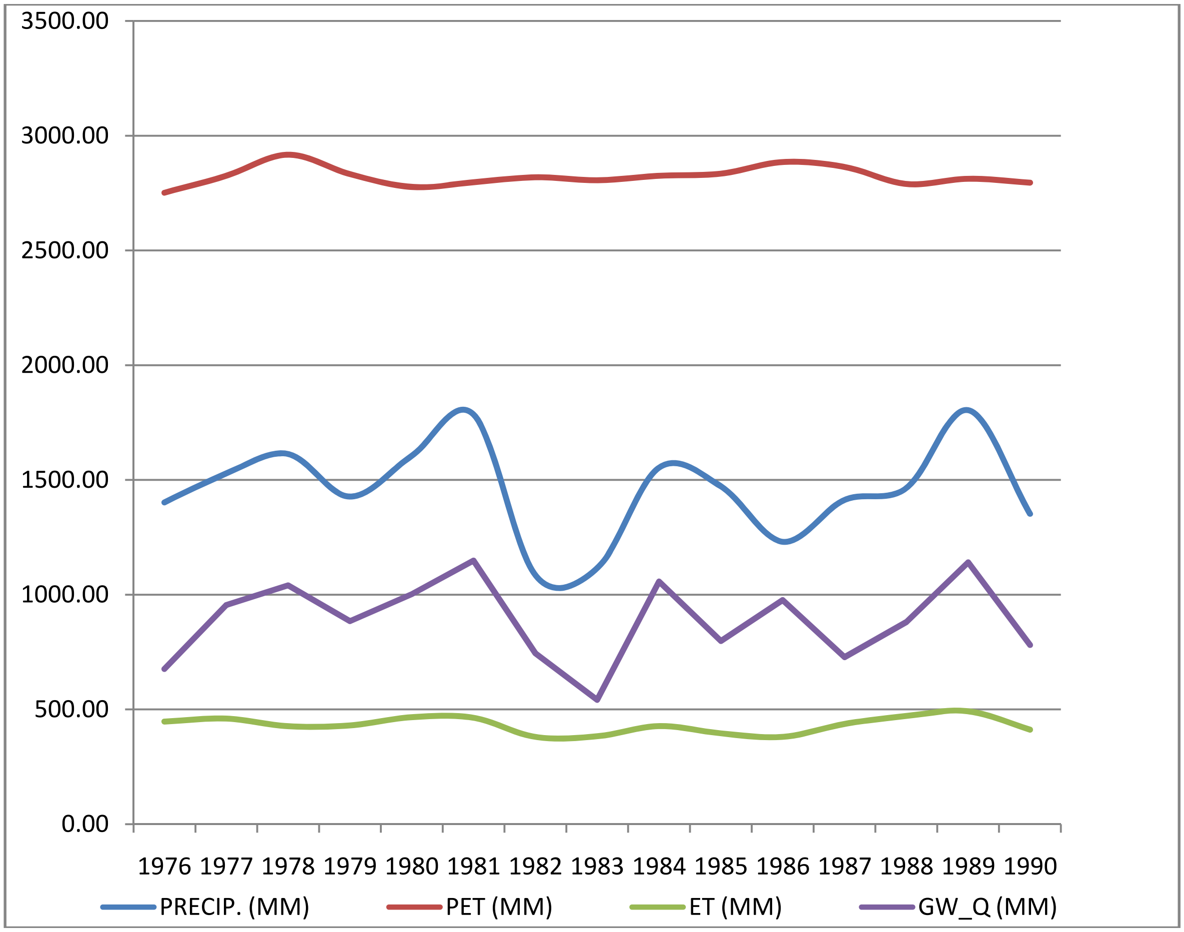

Figure 6-5: Average annual precipitation, potential evapotranspiration, actual evapotranspiration and ground water relationship.

Annual actual evapotranspiration follows the same trend slightly as precipitation, but as much as potential evapotranspiration which is reasonable,

On the other hand, the evapotranspiration did not vary much during the analysis periods and actual evapotranspiration is around 480mm per year, this is explained by low variation of temperature either daily or annually. Hence, a dry year would correspond to a severe drought shows average annual precipitation and evapotranspiration. The driest years are 1978, 1982, 1984,, 1988 and 1990, and the precipitation height is almost 1000mm. The wettest years are 1981 and 1988 with 1600mm of precipitation and this return period of highest storm appears after seven years, according to study period of 15year. This shows a high variability in precipitation.

For g round water, the seasonal variation of ground water flow follows closely the decreasing trend of precipitation which is a clear indicator of the response of ground water to precipitation. It is direct compared to runoff which shows a lag between precipitation and ground water (Figure 6-1a).

6. SUMMARRY, CONCLUSION AND RECOMMENDATION

6.1 Summary, Conclusion

On the analysis of generated inflow from the Lake Kivu watershed into the lake, the south east and northern subbasins generate much quantity into the lake. The water balance study was the first of its kind for such a large lake. The calibration of the water balance model was based on only one flow gauged station. It should have been based on as many gauging stations as possible.

Characterization of watersheds, understanding the biophysical, hydrological and hydraulic problems and proposing pertinent intervention measures to control degradation, improving land and water productivity, enhancing ecological and environmental functions in developing countries are serious challenges due to absence of relevant information and data.

Even though the problem of lake level water recognized from gross decline estimates and field observations, quantitative information and data are required at micro watershed level for developing alternative watershed management plans and for decision making.

In this thesis, attempts were made to characterize and generate in flow of Lake Kivu AND to investigate the factors aggravating Lake water level change, identification of flow potential source areas, and finally quantitative information on the extent of water level decline and the possible remedial measures are presented for Kivu Watershed.

The suitability and performance of the model was evaluated using manual calibration and validation statistics. A good agreement between measured and simulated monthly stream flow at the outlet of Lake Kivu watershed which was demonstrated by the correlation coefficient (R2 = 0.63)

Nash-Sutcliffe model efficiency (ENS = -0.2.36) and mean deviation (D = 45 for calibration period and R2 = 0.51 ENS = -0.3 and D= 60for validation periods.

The model over estimated simulated flow by 15 % and under estimated by 0.2 % for calibration (1981 -1984) and validation periods (1985-1989) respectively.

Considering the acceptable limits of statistical model evaluation criteria; the result indicates a good a match between measured and simulated inflow or water yield 63% through calibration, it was possible to successfully develop a model for Lake Kivu watershed to predict inflow, out flow, runoff, water yield(base flow, lateral flow)/ground water

The SWAT model prediction verified that about 70 % flow from lake Kivu watershed is ground water. For 15 years simulation result indicates that the simulated long term annual average of 148.68m3/sec inflow into the lake with annual total discharge of 1338.12m3/sec and the long term average annual outflow simulated of 106.9m3/sec and the measured mean annual flow of 90.4m^3/s .There is a difference of 16.6m3/sec over estimated which is 15.4% over simulated. The model is most likely to be correct basing on the condition observed on the measured data where the model takes care during the maximum and minimum peak months (March, April, October and November) of which maximum peak is less cared on the field measurement.

The sub watershed that produce the highest flow or water yield are: 20,21 22,23,24, 25, 26, 27,28 29, 31,32,33,34,35,36,37,38,39,40, 2,8.9.10,11,12,13, ,and 14 in their order of importance contributing watert yield to the lake
.The least amount of flow or water yield is generated from sub
watersheds (3,4,5,6,7,8,15,16,17,18,and19)

SWAT model results revealed that the baseflow is an important component of the totals discharge within the study area and is usually greater than the surface runoff. From the annual average water balance, it arises that 1045 mm of precipitations fall within the watershed for both the calibration and validation period. The surface runoff is about 72 mm (approx. 17% for the runoff coefficient), while the base flow is about 110 mm (54% of total water yield).

To investigate the driving factors that influencing Lake water level decline;

The hydrological responses in each subbasins were analyzed in terms of the percent of landuse/cover, dominated by range brush , soil type and texture also dominated by humic cambisols, cropland and type of crop , average slope and slope length were determined for each of the sub watersheds .It is evidenced that sub watersheds that produce high flow or water have a greater percent of natural vegetation cover with sustainability of ecosystem which is south east part of the watershed and surface runoff is found in the deforested areas and agricultural land dominated, analysis of sensitive parameters, calibration of the same parameters till the model was tuned to stable condition for water yield quantification in each subasin.

Characterization of flows in sub watersheds for which most subbasins bear high ground flow potential in sub watershed as indicated in previous section and analysis found out to be affected by the change of land cover to human settlement land especially western part of watershed or change in rainfall partnership or deforestation due to human activities.

According to the trend for Lake water level fluctuation and rainfall variation, it evidences also the decreasing trend in rainfall over the watershed which leads to the decrease in inflow from watershed to the lake, affecting the lake volume hence negatively impacting downstream at rusizi hydropower production. the decline is not only in rainfall partnership especially in the second rainy season in October, November and December , there is also an effect of land cover change responsible for ground flow decreasing trend. The case of rise in rainfall and water level remains low may be due to decline in underground water particularly in recharging of western subbasins of Kivu watershed where the base flow interaction from adjacent watershed is likely to be occurring as discussed in previous section of this thesis. Generally, the sensitivity of runoff to rainfall changes is very similar to results in other ‘impacts.

6.2 Recommendations and limitations

Overall, SWAT performed well in simulating run off and on monthly basis at the watershed scale and thus can be used as a planning tool for watershed management.

The study can be further extended to similar watersheds in the region or other similar areas and can bridge the gap of adequate information between processes at the micro watershed and large watershed level.

Model prediction output depends on the quality of input data .One of the constraint in conducting this research work was lack of measured discharge on subbasins.

The flow data used for this study were generated from swat model and the only measured discharge at the outlet of which the quality is not so much reliable.

Hence, responsible bodies should give due attention to the time and frequency of flow Measurement**,** recording reliable data.

Since rainfall data is estimated based on ground stations, it is very likely that the rainfall over the lake is not estimated to the required level of adequacy. Hence, the used of satellite data like that of TRMM should be employed in future research.

The research falls short of deriving the stage-storage curve of the lake because of lack of time and adequate data like lake contours which are incomplete to real results. This could have been possible to generate the variation in lake level by guide curve. However, this could be carried out in the future.

There should be continuous and increased monitoring of the lake. This assists in addressing the management challenges of the lake catchment.

It is noted that there a release of water for hydropower generation. The release curve or regulating curve for operation at downstream the Rusuzi hydropower station should be researched into.

For the optimization of the hydropower generation along the Rusizi River, the construction of a regulating weir at the outlet of the lake is required. The construction of a gated weir can help to exploit the huge volume that goes away during the peak period.

In order to protect lake Kivu against the volcanic lava that flows direct into the lake during active period of the Nyiragongo volcanoes refer annex 22b, the construction of the canal to divert lava to the selected area or valley of less important than the Lake which is the power generating engine for three riparian countries.

The effect of soil erosion and sediment accumulation in the lake need to be investigated.

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8. ANNEX

Annex1

3	RNGB	Range brush	GB(FP)	Primarily Grazing and Browsing with some fuel wood production
4	WATR	Water body		water body
5	AGRL	Agricultural	IAC	Intensive Annual Crop production.
6	FRSE	Forest-evergreen	TMFP	Managed Timber and Fuel wood production
7	PAST	Pasture	G	Grazing
8	URBN	Urban Land	RCI	Residential, Commercial and Industrial land uses with secondary land uses of fuel wood and crop production and grazing. (Urban Areas.)
9	AGRL	Agricultural	IPAC	Intensive Perennial and Annual Crop production
10	AGRL	Agricultural	MAC	Moderate Annual Crop production
11	WETL	Wetlands	DGF(NC)	Dry season grazing, wet season fodder, fishing and nature conservation
12	RNGB	Range brush	GB(FP)/MC	Grazing and Browsing (with some fuel wood production) and scattered cultivation
13	FRSE	Forest-evergreen	TM(NC)	Managed Timber production with an ancillary role as Nature Conservation

Annex2

Table 4 SCS Soil Group Classification [22]

Soil Group	Texture Description
Group A	Deep sand, deep loess, aggregated silts
Group B	Shallow loess, sandy loam
Group C	Clay loams, shallow sandy loams, soils low in organic contents, soils usually high in clay contents
Group D	Heavy plastic clays, Soils that swell significantly when wet, certain saline soils

Annex3

Table 5 Description of Soil Physical and Chemical Properties Required by SWAT

Name	Description
NLAYERS	Number of layers in the soil (min 1 max 10)
HYDGRP	Soil hydrologic group (A, B, C, D)
SOL_ZMX	Maximum rooting depth of soil profile
ANION_EXCL	Fraction of porosity from which anions are excluded
SOL_CRK	Crack volume potential of soil [optional]
TEXTURE	Texture of soil layer [optional]
SOL_Z	Depth from soil surface to bottom of layer
SOL_BD	Moist bulk density
SOL_AWC	Available water capacity of the soil layer
SOL_K	Saturated hydraulic conductivity
SOL_CBN	Organic carbon content
CLAY	Clay content
SILT	Silt content
SAND	Sand Content
ROCK	Rock fragment content
SOL_ALB	Moist soil albedo
USLE_K	Soil erodibility (K) factor
SOL_EC	Soil Elecrical Conductivity

Annex4

Table 7 Slope extensions added to soil mapping units in the above table

Slope& topography

Code	Slope class	Topography
a	0-2 %	Flat to almost flat
b	2-5 %	Gently undulating/gently sloping
c	5-8 %	Undulating/sloping
d	8-15 %	Rolling/strongly sloping
e	> 15	moderately steep to very steep

Annex5

Table 8 Soil Textural Classes of RVLB and Their Codes Used in Soil Mapping Units

Code	Texture class
0	Optional (Water body)
1	fine textured (clays, silty clays, sandy clays, clay loam and silty clay loam)
2	medium textured (loams, sandy clay loams)
3	Coarse textured (sands, loamy sands, silty loams and sandy loams)

Annex6

Table 9 SCS Soil Group Classification [and Default values of Soil Bulk Density used in SWAT model. [1]

Soil Group	Texture Description	Average Bulk Density
Group A	Deep sand, deep loess, aggregated silts	1.27
Group B	Shallow loess, sandy loam	1.24
Group C	Clay loams, shallow sandy loams, soi Is low in organic contents, soils usually high in clay contents	1.22
Group D	Heavy plastic clays, Soils that swell significantly when wet, certain saline soils	1.1

Annex7

Table 10 Available water capacity of the soil layer (sol_awc (mm/m)) [15]

Soil Texture classes	Available water in mm/m of depth
Coarse sands	20-65
Fine sands	60-85
Loamy sands	65-110
Sandy loams	90-130
Fine sandy loams	100-170
Silt loams	150-230
Silty clay loams	130-160
Silty clay	125-170
Clay	110-150
Peats and Mucks	160-240

Annex8

Table 11 Soil Organic Carbon content (sol_cbn (%soil weight)) [15]

Textural Classes	Average Organic carbon content
Sand	0.9
Loamy sand	1
Loamy silt	1.6
Sandy loam	1.3
Loam	1.7
Silty loam	1.7
Clay	1.9

Annex9

Table 12 Saturated hydraulic conductivity of each texture class was estimated from the following two tables (Rawls et al, 1982)

Texture class	Saturated hydraulic conductivity(mm/hr)	Texture class	Saturated hydraulic conductivity (mm/hr)
Sand	210.0	Clay loam	2.3
Loamy sand	61.1	Silty clay loam	1.5
Sandy loam	25.9	Sandy clay	1.2
Loam	13.2	Silty clay	0.9
Silt loam	6.8	Clay	0.6
Sandy clay loam	4.3		

Annex10

Sandy Loam, Fine sandy loam	Moderately coarse	Loamy	Moderately Rapid	14.11-42.34	121.91-364.95
Very fine loam, loam, silt loam, loam	Medium		Moderate	4.23-14.11	36.55-121.91
Clay loam, sandy clay loam, silly clay loam,	Moderately Fine		Moderately Slow	1.41-4.23	12.18-36.55

Annex11

Table 14 Moist soil albedo (SOL_ALB) based on Taylor and Ashcroft (Natural Resources Conservation Service Soil Survey Staff, 1996, National soil survey handbook,Title 430-VI, US Government Printing Office, Washington, D.C.) and Soil Erodibility (USLE_K) (Hurni, 1985 and Stewart et al,1975))

Soil Color	Albedo1	Soil Colour	Soil Erodibility (K)
Brown	0.13	Black	0.15
Red	0.14	Brown	0.20
Black	0.09	Red	0.25
Gray	0.13	Yellow	0.30
Yellow	0.17		

Table 15 Plausible Values of Daily Mean Short-Wave Solar Radiation Reflection Coefficient (Albedo) For Broad Land Classes (Hand Book of Hydrology, David R. Maidment, 1993)

Land cover class	Short-wave radiation reflection coefficient (∝)
Open water	0.08
Tall Forest	0.11-0.16
Tall farm crops (e.g. sugar cane)	0.15-0.20
Cereal crops (e.g. wheat)	0.20-0.26
Short Farm Crops (e.g. sugar beet)	0.20-0.26
Grass and pasture	0.20-0.26
Bare soil	0.10 (wet)-0.35 (dry)
Snow and ice	0.20 (old)-0.80 (new)

Annex12

Table 4-2: the range of boundaries of hydrological parameters used in swat

parameter	Parameter code	Rank	Boundary		Relative sensitivity	Category of sensitivity
			Lower	Upper		
Initial SCS CN II value	CN2	1	-25%	25%	2.5	Very high
available water capacity(mm water/mm soil)	SOL_AWC	2	-25%	25%	0.849	High
Average slope Steepness(m/m);	SLOPE	3	-25%	25%	0.401	High
Saturated hydraulic conductivity(mm/hr)	SOL_K	4	-25%	25%	0.331	High
Threshold water depth in shallow aquifer for flow(mm)	GWQMN	5	0.00	5000	0.182	Medium
Maximum canopy storage (mm)	canmx	6	0.00	10.00	0.155	Medium
Base flow Alpha factor (days)	ALPHA_BF	7	0.00	1.00	0.12	Medium
Deep aquifer percolation fraction	Rchrg.dp	8	0.00	1.00	0.119	Medium

Soil evaporation compensation factor	ESCO	9	0.00	1.00	0.099	Medium
Soil Depth(mm)	SOL_Z	10	-25%	25%	0.062	Medium

Annex13

Table 6-1 Computed Weather Generator Statistic and Probability Values.

Month	TMPMX	TMPMN	TMPSTDMX	TMPSTDMN	PCPMM	PCPSTD	PCPSKW
Jan	25.19	15.33	0.62	0.85	142.87	63.53	1.431
Feb	25.54	15.47	0.94	0.70	154.72	46.71	0.019
Mar	25.24	15.54	0.63	0.59	191.55	58.80	-0.024
Apr	24.78	15.77	0.64	0.55	174.85	65.05	0.500
May	24.69	15.73	0.68	0.55	94.62	40.24	0.739
Jun	25.05	14.84	0.72	0.57	33.45	18.03	-0.450
Jul	25.66	14.07	0.86	0.63	6.94	11.47	2.519
Aug	26.56	14.94	0.83	0.74	61.67	48.02	-0.006
Sep	26.00	15.33	0.92	0.70	119.65	32.23	-0.120
Oct	25.12	15.48	0.66	0.78	171.50	37.31	0.638
Nov	24.58	15.33	0.55	0.61	186.09	45.50	-0.243
Dec	24.86	15.36	0.65	0.68	134.63	40.19	-0.294

Table6-2

Month	PR_W1	PR_W2	PCPD	RAINHHMX	SOLARAV	DEWPT	WNDV
Jan	0.40	0.63	15	46.10	35.19	15.4	3.73
Feb	0.57	0.47	16	16.28	36.83	15.5	3.79
Mar	0.89	0.64	17	22.63	37.78	15.4	4.00
Apr	0.35	0.54	19	8.91	37.14	15.5	3.66
May	0.35	0.57	11	7.96	35.45	15.7	3.81
Jun	0.11	0.00	4	2.83	34.37	15.9	4.04
Jul	0.12	0.40	1	3.24	34.81	16.0	3.61
Aug	0.12	0.40	6	6.16	36.26	16.0	3.56
Sep	0.33	0.50	12	12.14	37.31	15.6	4.11
Oct	0.50	0.76	19	16.69	36.87	15.4	3.71
Nov	0.47	0.53	21	20.60	35.46	15.4	3.70
Dec	0.37	0.42	17	21.86	34.55	15.5	3.91

Table 6-3

Dew Pt Temperature and Monthly Averages of Tmax, Tmin , PCP, SKW & Rh

	TMPMX	TMPMN	TMPSTDMX	TMPSTDMN	PCPMM	PCPSTD	PCPSKW
Jan	25.48	15.02	0.51	0.46	81.87	27.82	0.178
Feb	25.70	15.19	0.75	0.63	94.47	32.84	0.481
Mar	25.65	15.34	0.61	0.55	132.13	37.44	0.638
Apr	25.26	15.68	0.50	0.48	173.40	63.41	0.369
May	25.13	15.42	0.49	0.46	110.40	38.74	-0.260
Jun	25.24	14.44	0.79	0.57	46.33	50.00	1.509
Jul	25.51	13.83	0.82	0.65	23.40	20.27	1.046
Aug	26.15	14.58	0.95	0.51	73.00	56.51	1.059
Sep	26.28	14.97	0.85	0.42	106.73	39.63	-0.782
Oct	25.88	14.29	0.64	0.64	127.00	32.56	1.296
Nov	25.20	14.15	0.43	0.47	141.20	37.20	0.500
Dec	25.25	14.28	0.68	0.60	84.13	34.01	0.595

Table 6-4

Period	PR_W1	PR_W2	PCPD	RAINHHMX	SOLARAV	DEWPT	WNDV
Jan	0.55	0.70	12	5.85	35.52	15.7	3.81
Feb	0.46	0.63	15	7.65	37.04	15.7	3.80
Mar	0.70	0.67	18	17.99	37.83	15.6	3.46
Apr	0.50	0.88	21	32.84	37.02	15.5	3.63
May	0.36	0.71	15	13.94	35.20	15.5	3.50
Jun	0.00	0.00	6	0.00	34.07	15.8	3.74
Jul	0.24	0.50	4	21.14	34.54	15.9	3.86
Aug	0.29	0.76	9	35.08	36.09	16.1	3.64
Sep	0.40	0.60	14	35.08	37.30	16.0	3.51
Oct	0.60	0.44	19	9.90	37.03	15.7	3.74
Nov	0.57	0.50	21	10.35	35.75	15.4	3.68
Dec	0.33	0.69	14	7.65	34.90	15.5	4.19

EVOLUTION OF WATER LEVELS OF LAKE KIVU.

SINCE 1941 - 2006 *1460*

1460 + Table value

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg(m)
1941	2.14	2.16	2.21	2.32	2.47	2.54	2.44	2.26	2.19	2.20	2.29	2.45	2.31
1942	2.44	2.34	2.38	2.50	2.65	2.63	2.42	2.36	2.30	2.22	2.24	2.33	2.40
1943	2.43	2.49	2.44	2.36	2.43	2.50	2.41	2.27	2.27	2.30	2.29	2.29	2.37
1944	2.28	2.34	2.38	2.24	2.26	2.19	2.15	1.96	1.98	1.98	2.04	2.11	2.16
1945	2.09	2.13	2.15	2.16	2.22	2.36	2.34	2.25	2.24	2.23	2.24	2.31	2.22
1946	2.30	2.30	2.29	2.43	2.49	2.57	2.44	2.34	2.29	2.28	2.31	2.36	2.37
1947	2.38	2.42	2.47	2.59	2.75	2.78	2.69	2.61	2.52	2.51	2.49	2.53	2.56
1948	2.49	2.51	2.51	2.51	2.59	2.58	2.51	2.41	2.37	2.37	2.39	2.36	2.47
1949	2.33	2.34	2.30	2.36	2.46	2.42	2.32	2.20	2.15	2.19	2.21	2.25	2.29
1950	2.30	2.31	2.30	2.38	2.48	2.48	2.36	2.23	2.19	2.19	2.20	2.20	2.30
1951	2.24	2.28	2.29	2.45	2.55	2.54	2.47	2.37	2.32	2.36	2.39	2.56	2.40
1952	2.66	2.58	2.52	2.57	2.82	2.90	2.74	2.58	2.54	2.51	2.46	2.39	2.61
1953	2.34	2.31	2.31	2.35	2.44	2.37	2.33	2.18	2.15	2.14	2.13	2.18	2.27
1954	2.15	2.14	2.15	2.25	2.38	2.42	2.32	2.19	2.12	2.11	2.12	2.14	2.21
1955	2.18	2.24	2.28	2.39	2.44	2.34	2.24	2.17	2.15	2.26	2.24	2.24	2.26
1956	2.32	2.38	2.38	2.40	2.51	2.48	2.44	2.25	2.24	2.29	2.40	2.46	2.38
1957	2.47	2.50	2.58	2.66	2.83	2.87	2.76	2.68	2.55	2.50	2.53	2.53	2.62
1958	2.61	2.64	2.64	2.64	2.76	2.77	2.65	2.54	2.50	2.48	2.46	2.50	2.60
1959	2.56	2.55	2.54	2.56	2.61	2.59	2.43	2.28	2.26	2.30	2.31	2.51	2.46
1960	2.55	2.65	2.70	2.82	2.84	2.75	2.66	2.55	2.58	2.61	2.63	2.62	2.66
1961	2.57	2.59	2.67	2.74	2.76	2.71	2.61	2.52	2.54	2.57	2.73	2.99	2.67
1962	3.11	3.11	3.05	3.06	3.19	3.18	3.06	2.94	2.92	2.93	2.06	3.12	2.98
1963	3.18	3.23	3.23	3.25	3.62	3.80	3.59	3.38	3.26	3.19	3.19	3.30	3.35
1964	3.32	3.27	3.21	3.32	3.35	3.24	2.96	2.89	2.79	2.83	2.87	2.86	3.08
1965	2.86	2.82	2.82	2.89	2.95	2.87	2.72	2.59	2.59	2.58	2.71	2.72	2.76
1966	2.71	2.75	2.86	2.92	2.98	2.91	2.76	2.62	2.72	2.71	2.61	2.63	2.76
1967	2.75	2.67	2.50	2.70	2.86	2.95	2.87	2.72	2.59	2.62	2.67	2.86	2.73
1968	2.92	3.01	3.17	3.31	3.42	3.39	3.28	3.14	2.98	2.94	2.99	2.98	3.12
1969	3.00	3.07	3.06	3.03	3.04	2.93	2.78	2.62	2.59	2.58	2.61	2.64	2.83
1970	2.65	2.72	2.81	2.99	2.08	3.00	2.90	2.80	2.77	2.75	2.73	2.77	2.75
1971	2.80	2.80	2.79	2.81	2.96	2.97	2.87	2.77	2.80	2.82	2.89	2.94	2.85
1972	2.96	2.93	2.95	2.96	2.94	2.89	2.79	2.64	2.58	2.56	2.62	2.77	2.80
1973	2.69	2.68	2.69	2.71	2.81	2.83	2.66	2.54	2.56	2.60	2.65	2.68	2.67

1974	2.74	2.75	2.73	2.89	2.96	3.03	3.12	2.98	2.96	2.89	2.89	2.87	2.90
1975	2.86	2.85	2.83	2.87	2.93	2.93	2.84	2.76	2.77	2.86	2.91	2.93	2.86
1976	2.90	2.87	2.85	2.89	2.95	3.01	2.89	2.83	2.86	2.85	2.86	2.89	2.89
1977	2.84	2.82	2.85	3.01	3.05	2.98	2.89	2.73	2.70	2.65	2.70	2.76	2.83
1978	2.75	2.75	2.84	2.92	2.97	2.88	2.75	2.69	2.62	2.61	2.63	2.68	2.76
1979	2.70	2.81	2.80	2.84	3.02	2.94	2.80	2.65	2.58	2.50	2.55	2.55	2.73
1980	2.48	2.55	2.61	2.62	2.71	2.87	2.81	2.66	2.61	2.64	2.73	2.83	2.68
1981	2.85	2.81	2.88	3.03	3.14	3.12	2.95	2.88	2.88	2.89	2.89	2.88	2.93
1982	2.85	2.83	2.80	2.90	2.99	2.99	2.80	2.66	2.63	2.67	2.76	2.95	2.82
1983	2.92	2.87	2.82	2.88	2.94	2.85	2.75	2.68	2.64	2.70	2.80	2.85	2.81
1984	2.94	2.99	3.02	3.03	3.01	2.86	2.73	2.64	2.61	2.62	2.62	2.70	2.81
1985	2.67	2.70	2.71	2.91	3.08	3.07	2.94	2.79	2.72	2.70	2.77	2.79	2.82
1986	2.87	2.92	2.93	2.99	3.09	3.03	2.91	2.75	2.67	2.67	2.80	2.80	2.87
1987	2.84	2.89	2.96	3.04	3.11	3.13	2.96	2.83	2.79	2.84	2.95	2.98	2.94
1988	2.94	2.91	3.00	3.00	3.18	3.07	2.92	2.85	2.81	2.82	2.89	2.86	2.94
1989	2.85	2.87	2.85	2.84	2.83	2.81	2.80	2.74	2.70	2.69	2.76	2.82	2.80
1990	2.87	2.96	3.00	3.07	3.06	3.00	2.72	2.64	2.58	2.64	2.61	2.68	2.82
1991	2.70	2.76	2.78	2.89	2.97	3.06	2.96	2.86	2.80	2.90	2.91	2.96	2.88
1992	3.08	3.02	3.02	3.20	3.20	3.19	3.04	2.81	2.82	2.38	2.95	2.97	2.97
1993	2.93	2.95	3.01	3.03	3.10	3.25	3.16	2.79	2.53	2.69	2.53	2.51	2.87
1994	2.49	2.45	2.46	2.39	2.36	2.28	2.22	2.08	1.95	1.96	2.14	2.14	2.24
1995	2.16	2.19	2.19	2.19	2.31	2.21	2.12	2.05	1.93	1.96	2.04	2.07	2.12
1996	2.03	2.03	2.07	2.22	2.21	2.26	2.24	2.14	2.16	2.18	2.21	2.26	2.17
1997	2.31	2.34	2.41	2.57	2.74	2.73	2.62	2.50	2.39	2.30	2.35	2.54	2.49
1998	2.82	3.05	3.13	3.22	3.28	3.28	2.62	3.10	2.96	3.03	3.03	2.96	3.04
1999	3.04	3.02	2.97	3.04	3.03	2.93	2.74	2.58	2.59	2.58	2.55	2.59	2.81
2000	2.64	2.62	2.60	2.64	2.60	2.50	2.36	2.06	1.93	1.95	2.06	2.19	2.35
2001	2.32	2.32	2.34	2.49	2.53	2.52	2.45	2.33	2.35	2.38	2.56	2.61	2.44
2002	2.81	2.83	2.90	2.93	3.15	3.11	2.85	2.75	2.69	2.60	2.64	2.64	2.83
2003	2.68	2.64	2.61	2.62	2.80	2.80	2.67	2.54	2.56	2.57	2.57	2.55	2.64
2004	2.54	2.48	2.50	2.58	2.64	2.29	2.18	2.15	2.13	2.07	2.07	2.18	2.32
2005	2.21	2.17	2.24	2.17	2.25	2.17	2.00	1.92	1.91	1.93	1.93	1.82	2.06
2006	1.82	1.83	1.87	1.99	2.20	2.10	2.02	2.00	1.98	1.95	2.09	2.25	2.01

Annex15

LONG TERM MONTHLY PRECIP

MONTH	precip_sub2	precip_sub3	precip_sub4	precip_sub5	precip_sub6	precip_sub7	precip_sub8
JAN	99.961	78.210	78.210	78.210	78.210	78.210	78.210
FEB	142.845	113.532	113.532	113.532	113.532	113.532	113.532
MAR	124.266	109.807	109.807	109.807	109.807	109.807	109.807
APR	130.410	95.408	95.408	95.408	95.408	95.408	95.408
MAY	89.461	78.345	78.345	78.345	78.345	78.345	78.345
JUN	151.015	140.449	140.449	140.449	140.449	140.449	140.449
JUL	169.186	74.994	74.994	74.994	74.994	74.994	74.994
AUG	120.505	85.038	85.038	85.038	85.038	85.038	85.038
SEP	87.872	104.346	104.346	104.346	104.346	104.346	104.346
OCT	85.828	107.332	107.332	107.332	107.332	107.332	107.332
NOV	115.179	96.850	96.850	96.850	96.850	96.850	96.850
DEC	131.180	93.387	93.387	93.387	93.387	93.387	93.387
precip	1447.707	1177.697	1177.697	1177.697	1177.697	1177.697	1177.697

Annex16

precip_sub9	precip_sub10	precip_sub11	precip_sub12	precip_sub13	precip_sub14	precip_sub15
78.210	78.210	78.210	78.210	78.210	78.210	78.210
113.532	113.532	113.532	113.532	113.532	113.532	113.532
109.807	109.807	109.807	109.807	109.807	109.807	109.807
95.408	95.408	95.408	95.408	95.408	95.408	95.408
78.345	78.345	78.345	78.345	78.345	78.345	78.345
140.449	140.449	140.449	140.449	140.449	140.449	140.449
74.994	74.994	74.994	74.994	74.994	74.994	74.994
85.038	85.038	85.038	85.038	85.038	85.038	85.038
104.346	104.346	104.346	104.346	104.346	104.346	104.346
107.332	107.332	107.332	107.332	107.332	107.332	107.332
96.850	96.850	96.850	96.850	96.850	96.850	96.850
93.387	93.387	93.387	93.387	93.387	93.387	93.387

precip_sub20	precip_sub21	precip_sub22	precip_sub23	precip_sub24
99.961	99.961	99.961	99.961	99.961
142.845	142.845	142.845	142.845	142.845
124.266	124.266	124.266	124.266	124.266
130.410	130.410	130.410	130.410	130.410
89.461	89.461	89.461	89.461	89.461
151.015	151.015	151.015	151.015	151.015

169.186	169.186	169.186	169.186	169.186
120.505	120.505	120.505	120.505	120.505
87.872	87.872	87.872	87.872	87.872
85.828	85.828	85.828	85.828	85.828
115.179	115.179	115.179	115.179	115.179
131.180	131.180	131.180	131.180	131.180
1447.707	1447.707	1447.707	1447.707	1447.707

precip_sub33	precip_sub34	precip_sub35	precip_sub36	precip_sub37	precip_sub38
99.961	99.961	99.961	99.961	99.961	99.961
142.845	142.845	142.845	142.845	142.845	142.845
124.266	124.266	124.266	124.266	124.266	124.266
130.410	130.410	130.410	130.410	130.410	130.410
89.461	89.461	89.461	89.461	89.461	89.461
151.015	151.015	151.015	151.015	151.015	151.015
169.186	169.186	169.186	169.186	169.186	169.186
120.505	120.505	120.505	120.505	120.505	120.505
87.872	87.872	87.872	87.872	87.872	87.872
85.828	85.828	85.828	85.828	85.828	85.828
115.179	115.179	115.179	115.179	115.179	115.179
131.180	131.180	131.180	131.180	131.180	131.180
1447.707	1447.707	1447.707	1447.707	1447.707	1447.707

precip_sub41	precip_sub42	precip_sub44	precip_sub45	precip_sub46	precip_sub47
78.210	99.961	78.210	78.210	78.210	78.210
113.532	142.845	113.532	113.532	113.532	113.532
109.807	124.266	109.807	109.807	109.807	109.807
95.408	130.410	95.408	95.408	95.408	95.408
78.345	89.461	78.345	78.345	78.345	78.345
140.449	151.015	140.449	140.449	140.449	140.449
74.994	169.186	74.994	74.994	74.994	74.994
85.038	120.505	85.038	85.038	85.038	85.038
104.346	87.872	104.346	104.346	104.346	104.346
107.332	85.828	107.332	107.332	107.332	107.332
96.850	115.179	96.850	96.850	96.850	96.850
93.387	131.180	93.387	93.387	93.387	93.387
1177.697	1447.707	1177.697	1177.697	1177.697	1177.697

Annex17

Water Balance of the Lake Kivu Catchment

Flowout,(mm)	787162212
Q/A(Runoff)(mm)	291541.56
Runoff/1000000	0.2915416
Runoff(mm)	291.54156
PCP(mm)	1447.69
ET(mm)	467.78
ET+Outflow(mm)	874.54156
PCP-ET+Outflow(mm)	391.45844
(PCP-ET+Outflow)/PCP	0.21092089

Water Balance on the Lake			79%
Area_lake(km2)	3571		
pcp	1447.696889	4203067000	
et	647.78	1670156700	
inV	107.6	9296640	
outV	106.7	9218880	
∆S		2532988060	
			2.532988
			0.709322
			2.581596
			0.002193
			0.219337
			21.93%

Annex18

Monthly inflow for each subasin in the lake catchment

SUBASIN_No	outlet	2	3	4	5	6	7	8	9	10	11	12	13
JAN	43.002	0.39	0.26	0.33	0.743	0.21	0.21	2.260	1.002	0.492	0.857	0.501	0.924
FEB	99.363	0.81	0.58	0.74	1.630	0.46	0.50	4.964	2.061	1.080	1.775	1.034	1.902
MAR	156.721	0.62	0.55	0.70	1.553	0.45	0.45	4.973	2.167	1.134	1.898	1.104	2.027
APR	169.731	0.71	0.46	0.59	1.303	0.37	0.38	4.873	2.175	1.110	1.898	1.105	2.032
MAY	138.156	0.51	0.40	0.51	1.141	0.32	0.33	4.075	1.810	0.866	1.532	0.897	1.658
JUN	122.017	0.84	0.74	0.94	2.101	0.60	0.62	5.511	2.318	1.089	1.908	1.120	2.077
JUL	146.953	0.80	0.34	0.43	0.949	0.26	0.27	3.979	1.736	0.977	1.572	0.910	1.664
AUG	128.900	1.20	0.47	0.60	1.351	0.37	0.38	3.966	1.588	0.765	1.297	0.761	1.411
SEP	178.654	0.57	0.62	0.79	1.752	0.49	0.51	4.999	2.040	1.070	1.746	1.018	1.873
OCT	158.333	0.40	0.54	0.69	1.524	0.45	0.47	4.857	2.085	1.103	1.825	1.062	1.949
NOV	165.949	0.50	0.57	0.72	1.597	0.45	0.46	5.359	2.229	1.208	1.951	1.133	2.079
DEC	154.53	0.76	0.43	0.54	1.21	0.34	0.3	3.514	1.481	0.768	1.277	0.745	1.374
SUM(QM3/SEC)	1662.3	8.16	6.00	7.63	16.8	4.81	4.9	53.3	22.6	11.6	19.53	11.3	20.97
SUB_AREA(KM²)	263.23	23.1	28.9	36.7	81.1	23.1	24	194	66.4	44.1	59.98	34.5	62.6

SUBASIN_No	14	15	16	17	18	19	20	21	22	23	24	25	26
JAN	2.456	0.291	0.987	0.585	0.438	0.261	0.374	1.536	2.521	0.414	4.484	0.783	1.535
FEB	5.419	0.710	2.577	1.661	1.245	0.740	0.812	3.331	5.466	0.898	9.607	1.666	3.343
MAR	5.494	0.606	2.317	1.695	1.271	0.755	0.627	2.577	4.224	0.693	7.416	1.282	2.392
APR	5.366	0.568	2.006	1.384	1.036	0.617	0.720	2.950	4.847	0.794	8.507	1.472	2.908
MAY	4.415	0.515	1.798	1.305	0.980	0.581	0.526	2.163	3.524	0.581	6.170	1.065	2.247
JUN	5.915	0.836	3.286	2.323	1.742	1.035	0.879	3.606	5.875	0.972	10.222	1.763	3.344
JUL	4.471	0.439	1.595	1.237	0.925	0.551	0.842	3.455	5.611	0.929	9.761	1.680	3.146
AUG	4.253	0.672	2.483	2.003	1.501	0.892	1.273	5.218	8.600	1.407	14.950	2.571	5.724
SEP	5.429	0.745	2.725	1.934	1.451	0.861	0.599	2.459	4.003	0.661	6.969	1.198	2.497
OCT	5.368	0.635	2.380	1.780	1.350	0.793	0.436	1.788	2.877	0.481	4.979	0.856	1.734
NOV	5.887	0.701	2.747	1.892	1.415	0.843	0.538	2.205	3.568	0.595	6.184	1.064	1.900
DEC	3.844	0.498	1.819	1.373	1.022	0.612	0.774	3.182	5.174	0.857	9.049	1.563	3.169
QM3/SEC	58.317	7.217	26.720	19.171	14.376	8.541	8.402	34.471	56.288	9.281	98.298	16.963	33.939
SUB_AREA(KM²)	214.95	35.17	129.5	94.11	70.7	41.9	23.425	96.11	158.6	25.86	278	47.93	91.43

Monthly inflow for each subasin in the lake catchment

SUBASIN_No	27	28	29	On-lake	31	32	33	34	35	36	37	38	39
JAN	0.346	0.442	0.757	37.009	1.185	0.393	0.961	1.752	0.342	0.222	0.373	2.268	0.808
FEB	0.777	0.993	1.699	83.432	2.674	0.886	2.189	3.933	0.767	0.499	0.837	5.006	1.774
MAR	0.538	0.686	1.174	143.981	1.910	0.627	1.642	2.718	0.530	0.345	0.579	3.533	1.260
APR	0.672	0.859	1.470	154.221	2.327	0.770	1.927	3.402	0.664	0.432	0.724	4.339	1.540
MAY	0.537	0.687	1.177	126.116	1.806	0.602	1.427	2.724	0.531	0.346	0.580	3.403	1.200
JUN	0.763	0.975	1.669	203.833	2.697	0.886	2.295	3.862	0.753	0.490	0.822	4.968	1.767
JUL	0.712	0.910	1.558	130.159	2.529	0.830	2.168	3.607	0.703	0.458	0.767	4.660	1.659
AUG	1.421	1.816	3.109	195.400	4.668	1.568	3.549	7.197	1.403	0.913	1.531	8.821	3.089
SEP	0.598	0.764	1.308	165.208	2.027	0.675	1.627	3.028	0.591	0.384	0.645	3.783	1.334
OCT	0.410	0.524	0.898	149.156	1.387	0.462	1.106	2.078	0.405	0.264	0.442	2.616	0.924
NOV	0.421	0.539	0.922	156.011	1.520	0.496	1.328	2.133	0.416	0.271	0.454	2.775	0.996
DEC	0.742	0.949	1.624	137.470	2.548	0.844	2.079	3.759	0.733	0.477	0.800	4.763	1.685
QM3/SEC	7.937	10.144	17.364	1681.996	27.277	9.040	22.298	40.193	7.839	5.099	8.553	50.936	18.037
SUB_AREA(KM²)	20.8	26.609	45.55	3571.541	74.949	24.47	65.42	105.4	20.56	13.37	22.43	135.98	48.36

SUBASIN_No	40	41	42	43	44	45	46	47	
JAN	1.046	0.000	0.000	42.743	0.627	0.979	3.648	0.969	164.742
FEB	2.156	0.000	0.177	99.084	1.372	2.815	7.748	2.522	375.734
MAR	1.647	0.411	0.356	156.451	1.306	2.582	7.052	2.283	537.323
APR	1.897	0.461	0.391	169.453	1.097	2.222	6.456	1.968	577.227
MAY	1.363	0.382	0.327	137.889	0.958	2.084	5.475	1.762	469.482
JUN	2.232	0.632	0.469	221.741	1.769	3.556	9.481	3.228	752.596
JUL	2.132	0.340	0.407	146.689	0.799	1.950	4.804	1.560	504.904
AUG	3.197	0.523	0.907	228.700	1.136	2.708	6.801	2.444	775.527
SEP	1.515	0.518	0.347	178.379	1.475	3.071	8.154	2.680	605.802
OCT	1.077	0.496	0.264	158.089	1.282	2.696	6.990	2.373	534.712
NOV	1.332	0.492	0.276	165.676	1.344	3.076	7.891	2.560	564.689
DEC	2.014	0.390	0.421	154.270	1.021	2.020	5.510	1.877	526.268
QM3/SEC	21.608	4.644	4.343	1859.164	14.188	29.760	80.009	26.226	532.417
SUB_AREA(KM²)	61.62	20.65	11.9	0.2592	67.983	151.3	359.3	126.8	7224.965

Annex19

LONG TERM MONTHLY PRECIP OVER EACH SUBASIN

SUBASINNo	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
JAN	100.0	100.0	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	80.6	100.0
FEB	142.8	142.8	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	106.4	142.8
MAR	124.3	124.3	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8	123.7	124.3
APR	130.4	130.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	87.3	130.4
MAY	89.5	89.5	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	79.4	89.5
JUN	151.0	151.0	140.4	140.4	140.4	140.4	140.4	140.4	140.4	140.4	140.4	140.4	140.4	140.4	140.4	140.4	140.4	140.4	132.6	151.0
JUL	169.2	169.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	87.3	169.2
AUG	120.5	120.5	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	58.8	120.5
SEP	87.9	87.9	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	108.3	87.9
OCT	85.8	85.8	107.3	107.3	107.3	107.3	107.3	107.3	107.3	107.3	107.3	107.3	107.3	107.3	107.3	107.3	107.3	107.3	98.1	85.8
NOV	115.2	115.2	96.9	96.9	96.9	96.9	96.9	96.9	96.9	96.9	96.9	96.9	96.9	96.9	96.9	96.9	96.9	96.9	113.2	115.2
DEC	131.2	131.2	93.4	93.4	93.4	93.4	93.4	93.4	93.4	93.4	93.4	93.4	93.4	93.4	93.4	93.4	93.4	93.4	90.7	131.2

LONG TERM MONTHLY PRECIP OVER EACH SUBASIN

SUBASINNo	20	21	22	23	24	25	26	27	28	29
JAN	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
FEB	142.8	142.8	142.8	142.8	142.8	142.8	142.8	142.8	142.8	142.8
MAR	124.3	124.3	124.3	124.3	124.3	124.3	124.3	124.3	124.3	124.3
APR	130.4	130.4	130.4	130.4	130.4	130.4	130.4	130.4	130.4	130.4
MAY	89.5	89.5	89.5	89.5	89.5	89.5	89.5	89.5	89.5	89.5
JUN	151.0	151.0	151.0	151.0	151.0	151.0	151.0	151.0	151.0	151.0
JUL	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2
AUG	120.5	120.5	120.5	120.5	120.5	120.5	120.5	120.5	120.5	120.5
SEP	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9
OCT	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8
NOV	115.2	115.2	115.2	115.2	115.2	115.2	115.2	115.2	115.2	115.2
DEC	131.2	131.2	131.2	131.2	131.2	131.2	131.2	131.2	131.2	131.2

SUBASIN	31	32	33	34	35	36	37	38	39	40
JAN	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
FEB	142.8	142.8	142.8	142.8	142.8	142.8	142.8	142.8	142.8	142.8
MAR	124.3	124.3	124.3	124.3	124.3	124.3	124.3	124.3	124.3	124.3
APR	130.4	130.4	130.4	130.4	130.4	130.4	130.4	130.4	130.4	130.4
MAY	89.5	89.5	89.5	89.5	89.5	89.5	89.5	89.5	89.5	89.5
JUN	151.0	151.0	151.0	151.0	151.0	151.0	151.0	151.0	151.0	151.0
JUL	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2
AUG	120.5	120.5	120.5	120.5	120.5	120.5	120.5	120.5	120.5	120.5
SEP	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9
OCT	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8
NOV	115.2	115.2	115.2	115.2	115.2	115.2	115.2	115.2	115.2	115.2
DEC	131.2	131.2	131.2	131.2	131.2	131.2	131.2	131.2	131.2	131.2

SUBASIN	41	42	43	44	45	46	47	
JAN	78.2	100.0	100.0	78.2	78.2	78.2	78.2	4200.3
FEB	113.5	142.8	142.8	113.5	113.5	113.5	113.5	6032.4
MAR	109.8	124.3	124.3	109.8	109.8	109.8	109.8	5521.8
APR	95.4	130.4	130.4	95.4	95.4	95.4	95.4	5316.1
MAY	78.3	89.5	89.5	78.3	78.3	78.3	78.3	3950.0
JUN	140.4	151.0	151.0	140.4	140.4	140.4	140.4	6846.8
JUL	75.0	169.2	169.2	75.0	75.0	75.0	75.0	5797.7
AUG	85.0	120.5	120.5	85.0	85.0	85.0	85.0	4821.7
SEP	104.3	87.9	87.9	104.3	104.3	104.3	104.3	4512.9
OCT	107.3	85.8	85.8	107.3	107.3	107.3	107.3	4519.2
NOV	96.9	115.2	115.2	96.9	96.9	96.9	96.9	5008.2

DEC	93.4	131.2	131.2	93.4	93.4	93.4	93.4	5293.6

Annex20

Annual inflow and outflow

Year	Inflow m3/sec	Outflow m3/sec
1976	36.539	36.17
1977	64.211	63.84
1978	95.952	95.55
1979	123.01	122.59
1980	220.383	219.96
1981	124.69	124.27
1982	154.36	153.95
1983	118.3	117.90
1984	244.53	244.15
1985	141.74	141.357
1986	136.5	136.11
1987	84.863	84.48
1988	196.3	195.90
1989	136.84	136.44
AVG	135.55	135.15
SUM	1182	1178.42

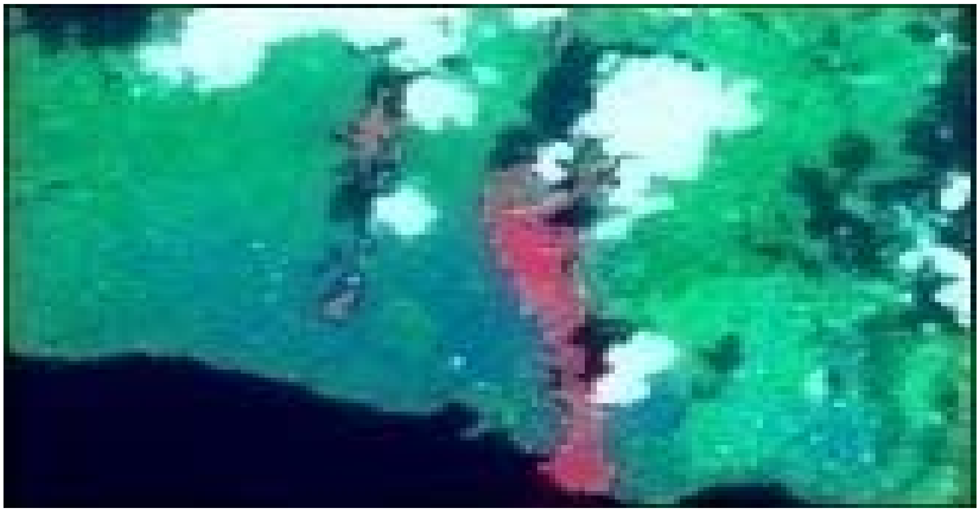
Annex21

Long term monthly

MONTH	ET	PET	SURQ(mm)	T_GW_Q(mm)	LATQ(mm)
JAN	38.923	231.904	323.807	1128.238	35.560
FEB	47.858	240.598	501.735	2795.857	56.470
MAR	38.228	242.685	468.087	2392.380	51.554
APR	37.690	242.776	461.306	2636.724	49.038
MAY	35.532	244.638	307.159	2173.541	37.602
JUN	43.955	227.582	613.628	3175.915	67.460
JUL	49.032	235.928	520.611	2503.993	48.796
AUG	37.215	226.497	376.106	2011.372	42.944
SEP	30.533	238.696	375.988	2623.101	44.937
OCT	35.369	236.593	366.958	2080.918	44.373
NOV	39.355	235.731	411.818	2250.917	47.402
DEC	34.095	239.550	472.629	2551.506	50.226

Annex22

Annexe22a showing the local sedimentation due to local settlements at the banks of river rusizi at the outlet of Lake Kivu western part of watershed



A annex22b showing lava flow into lake Livu during active period of nyiragongo volcano

Annex 23

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Detailed LANDUSE/SOIL distribution    SWAT model class         Tue Sep 16 17:55:54 2008

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                                                     Area [ha]         Area [acres]

Watershed                                       722496.4956       1785324.9655

-----------------------------------------------------------------------------------------------------------------
                                                          Area [ha]             Area [acres]    %Wat.Area

LANDUSE
                          Range-Brush --> RNGB        274360.0979         677957.5198   37.97
                        Range-Grasses --> RNGE          4186.7927          10345.7741    0.58
                              Water --> WATR         276328.8012         682822.2843   38.25
                    Forest-Evergreen --> FRSE         60106.3020         148525.6775    8.32
                        Forest-Mixed --> FRST        107514.5018         265673.7097   14.88

SOIL
                                     Humic_Ca             229318.3560        566657.1236    31.74
                                    Lithic_Le               34477.0376        85194.4838     4.77
                                       Lake              280970.4433        694292.0140    38.89
                                     Luvic_Ph              18093.7207       44710.4885      2.50
                                       Rocky              58079.7380      143517.9365      8.04
                                     Humic_Al             95387.9791       235708.4659     13.20
                                    Mollic_An               6169.2208        15244.4531      0.85
```