Assessing the Effect of Land Use Change on the Hydraulic Regime of Lake Awassa

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Abstract

For the past years increases in population pressure, government policy and external influences have caused a consistent change in the land cover of the Lake Awassa catchment. The change has come about mainly due to deforestation as is the case in many other areas of Ethiopia. The effects of land cover changes have had an impact on the water balance of the catchment by changing the magnitude and pattern of runoff, peak flow and ground water levels. This study is mainly focused on the assessment of the hydrological response of the catchment in relation to the land cover data of 1965 and 1998 using a Geographic information system (GIS) integrated with the hydrologic modeling. The result of the remote sensing assessment on the land cover of the catchment indicated that natural vegetation decreased by 11,768 ha or 9.06 % between years 1995-1998. This was mainly due to the expansion of agriculture and urban area. Plantation expansion was 20,661 ha or 13.56 % and also urbanization increased by 1,310 ha or 0.89 %. Based on these results, the inflow records were analysed statistically to evaluate if changes in the land cover affected the hydrological response of the catchment. The results of the analysis indicate that the average inflow to Lake Awassa in 1998 was 3.15 m^3/sec or 99.34MCM, whereas in scenario year 2017 the average inflow will be 3.5m^3/s or 110.38MCM. So because of the land cover change the flow will increase by 0.35 m^3/s, that is, 11.04MCM.

Key words: Lake Awassa, SWAT

1. INTRODUCTION

Flood risk is among the most severe risks to human lives and properties, and has become more frequent and severe with local economic development. As the watershed becomes more developed, it also becomes more hydrologically active, changing the flood volume and runoff components as well as the origin of stream flow. In turn, floods that once occurred infrequently during pre-development periods have now become more frequent and more severe due to the transformation of the watershed from rural to more urban land uses. The forecast and simulation of floods is therefore essential for planning and operating civil protection measures and for early flood warning.

Land cover changes commonly are highly pronounced in developing countries that are characterized by agriculture based economics and rapidly increasing human population. Meyer and Turner (1994) discussed that land cover changes are caused by a number of natural and human driving forces. Whereas natural effects such as climate change are only apparent over a long period of time, the effects of human activities are immediate and often direct. Of the human factors, population growth is the most important in Ethiopia (Hurni, 1993 as cited in Tekele and Hedlund, 2000), as is common in developing countries. Some 85% of the population of lives in rural areas and directly depend on the land for their livelihood. This means the demand for land is increasing as population increases.

Population growth causes degradation of resources that rely on the available land and the interaction between them is very complex. Interactions can contribute positive or negative effects on the resources. People demand land for food production as well as for housing, and it is common practice to clear the forest to make areas for farming and housing. The result is that land cover and land use are changed due to daily human intervention. Hence, understanding how land cover change can influence the lake basin hydrology will enable planners to formulate policies to minimize the undesirable effects of future land cover changes.

Land cover changes may have immediate and long-lasting impacts on terrestrial hydrology (Calder 1993) and alter the long term balance between rainfall and evapotranspiration and the resultant runoff.

In the short-term, destructive land use change may affect the hydrological cycle either through increasing the water yield or through diminishing, or even eliminating, the low flow in some circumstances (Croke et al., 2004). Saveniji (1995) suggested that in the long-term the reduction in evapotranspiration and water recycling arising from land cover changes may initiate a feedback mechanism that results in a reduction of rainfall.

Study of lake level fluctuation with respect to land cover dynamics enables an assessment of the sustainability of land use systems, because lake level reflects the hydrological state of the entire watershed. As stated by Calder (2002), the hydrological impact of land cover changes is a referencing issue and much research is necessary.

The information can be applied to forecast the likely effects of any potential changes in land cover on water resource systems. Generally, it is appropriate to use satellite remote sensing and a Geographic Information System (GIS) integrated with the hydrological modeling to analyse the hydrological response due to the land use change.

2. STUDY AREA

Lake Awassa is located 6033'-7033'N latitude and 38022'-39029'E longitude. It has an altitude of 1680 m. Lake Awassa has an area of 88 km2, and its watershed area has 1432 sq.km. Lake Awssa has a maximum depth of 22 m and a mean depth of 11 m. The Tikurewuha River at the north eastern shore is the only perennial stream (Halcrow 2008).

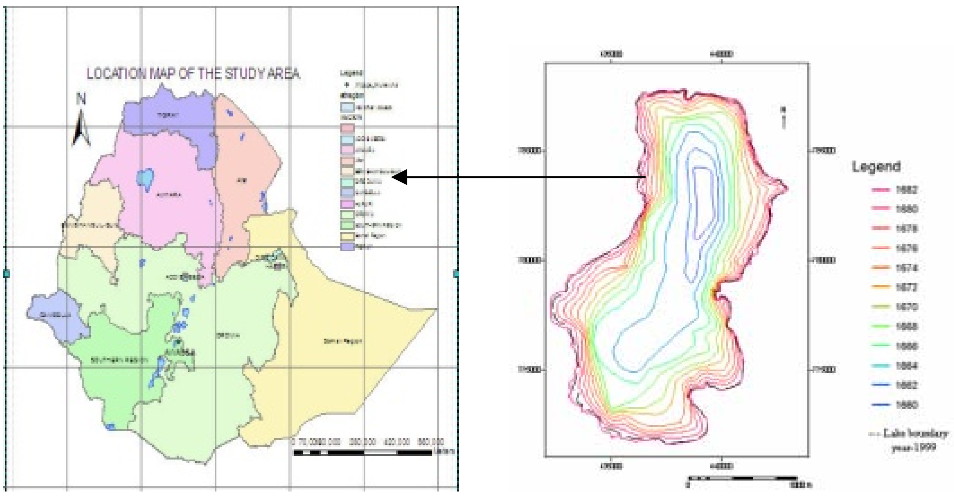

Figure 1: Location of Lake Hawassa

3. HYDROLOGY OF THE CATCHMENT

The surface area of Lake Cheleleka was about 12 km^2 in 1972, but currently it has completely disappeared as a result of siltation. The lake floor, which once was covered by water, is now filled with sediment transported from the eastern highlands as a result of deforestation that has taken place over the last 30 years. Prior to the filling up of the basin with silt, Lake Cheleleka used to serve as a sediment trap for the Tikurewuha River that flows into Lake Awassa. As a result of losing this function as a sediment trap, water and sediment load to Tikurewuha go now directly into Lake Awassa (W.W.D.S.E.2001).

4. METHODOLOGY

The methodology of this study is summarised in a form of a flow chart as shown in Figure 2. The flow chart depicts the steps followed in carrying out the modeling of the lake level changes.

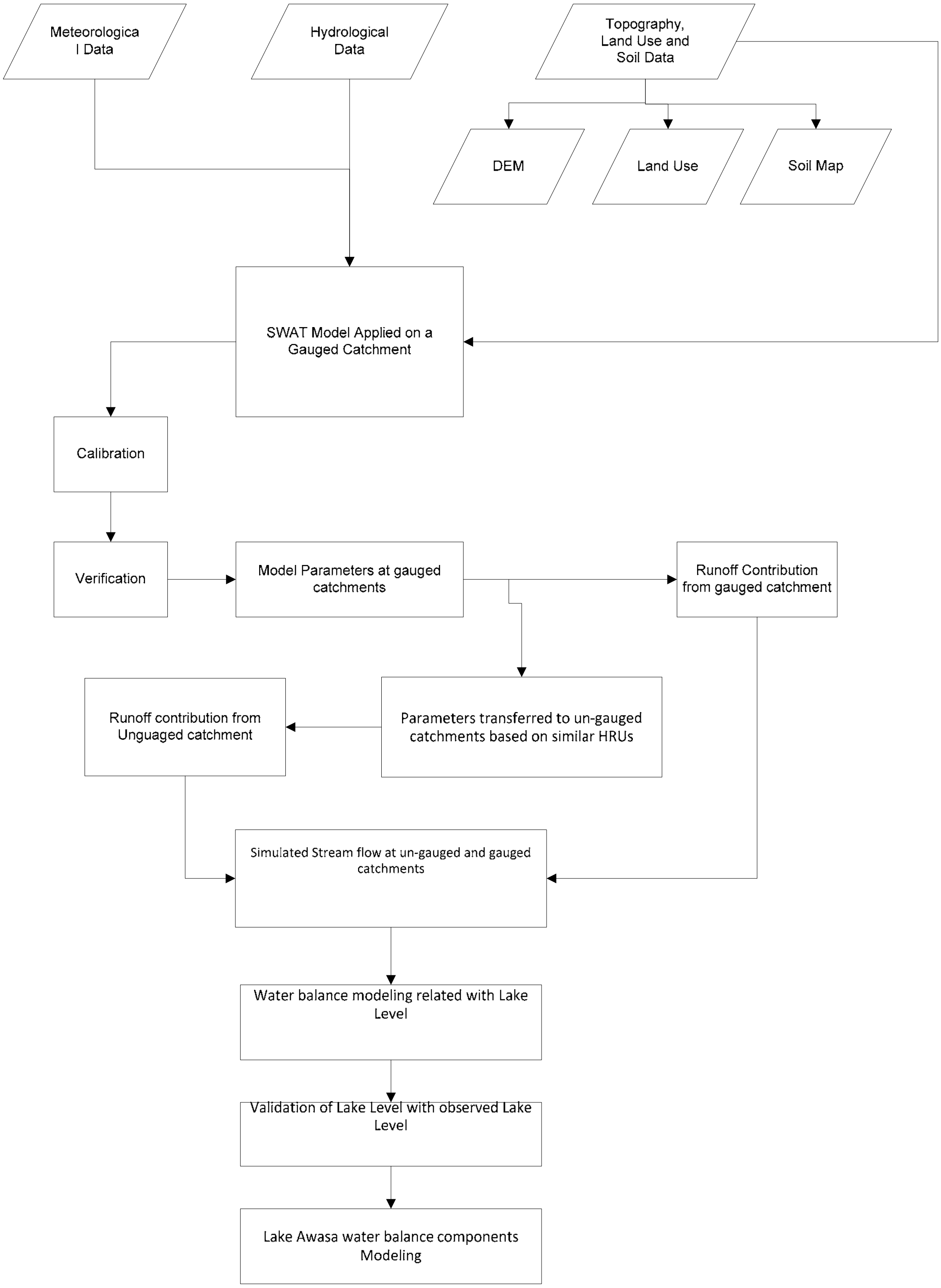

Figure 2: Simplified flow chart of the Methodology adopted in the

5. DATA AVAILABILITY AND ANALYSIS

5.1. Hydrological Data

The hydrological model SWAT largely depends on hydro-meteorological data such as precipitation, temperature, relative humidity, wind speed and solar radiation, and hydrological data such as river discharge. The model allows the input of values for daily precipitation, maximum/ minimum air temperatures, solar radiation, wind speed and relative humidity from records of observed data or data generated during the simulation.

5.1.1. Filling in missing weather data

The ability of SWAT to reproduce observed stream hydrographs is greatly improved by the use of measured precipitation data. For this research, the weather information used was for the period 1998-2007. Missing weather data are left undefined and a negative (-99.0) inserted for missing data. This value tells SWAT to generate its own weather data for that day. In this case, daily values for weather are generated from average monthly values. The model generates a set of weather data for each sub basin. The same weather generator technique has been applied for filling in maximum, minimum temperature, wind speed, relative humidity and solar radiation.

5.2. Streamflow Data

Daily stream flow data within Lake Awassa Basin were collected by the Ministry of Water Resources (MoWR). The data collected has missing discharge data that can be summarized in the following table (where is this?). Even though long records of time series data are available, a concurrent data set for all the stations from a period of 1998-2002 has been used for model calibration and from 2004-2006 used for model validation.

5.3. Spatial Input Data

Topography is defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution. The DEM is one of the essential inputs required by SWAT to delineate the watershed into a number of sub watershed or sub basins. The DEM is used to analyze the drainage pattern of the watershed, slopes, stream lengths, and widths of channel within the watershed. The raw DEM was processed and projected using ARCGIS 9.3 and Arc Map 9.3 version software package.

5.4. Land Use / Land Cover Data

In order to simplify the model, six land cover types were implemented for the area: Urban, Cultivated land, Water, Natural Vegetation, Grassland, and Marshland. Surface runoff occurs whenever the rate of water falling on the ground surface exceeds the rate of infiltration. The infiltration rate will decrease as the soil becomes saturated. When the application rate is higher than the infiltration rate, surface depression starts to fill. If the application rate continues to become higher than the infiltration rate and all the surface depressions have been filled, surface runoff will initiate (Neitsch 2002).

Table 1: Land covers in Lake Awasa catchment in 1965 and 1998 (Halcrow 2008)

		1965		**1998**	
S. No.	Land use Type	**Area (ha)**	**%**	**Area (ha)**	**%**
1	Urban	490	0.34	1800	1.23
2	Cultivated land	40586	28.41	61247	41.96
3	Water	10000	7.00	10000	6.85
4	Natural vegetation	67198	47.03	55430	37.98
5	Grassland	13723	9.61	10171	6.97
6	Marshland	7592	5.31	7306	5.01
	Total	**142,873**		**145954**	

5.5. Soil

The soils of the sub-basin are primarily deep, medium and fine textured Chromic and Haplic Luvisols in the south and east on a rolling to hilly topography with mixed perennial and annual cultivation. In the centre of the sub-basin, extending into the Wendo Koshe Hills, the soils are Chromic and Eutric Cambisols, moderately deep to deep and medium textured with poorly drained, fine textured Vertic Cambisols in the Cheleleka wetlands. To the north and west of the lake the soils are moderately deep to deep, well to excessively drained Vitric Andosols, with small areas of very shallow Leptosols.

6. ESTIMATION OF TOTAL INFLOW TO LAKE AWASSA

6.1. Modeling Tikurewuha Watershed

Tikurewuha River is the only perennial river in the basin which empties its flow into Lake Awassa. It has a catchment area of 74176 ha and its elevation ranges from 1681 to 2984m +MSL. A sensitivity analysis has been done on the builtin extension program embedded in SWAT. The sensitivity analysis has been carried out for 27 parameters. Only a few sensitive parameters were considered.

Table 2: Initial and final adjusted value of optimized parameters for gauged catchments

S.No	Parameters	Default Value	Final Value
1	REVAPMN	1	0.116
2	GWQMIN	-500	30
3	SOL_K	890	60
4	ALPHA_BF	0.048	0.1
5	ESCO	0	0.1
6	EPCO	0	0.1
7	CANMX	0	10
8	RCHRG_DP	0.05	0.016

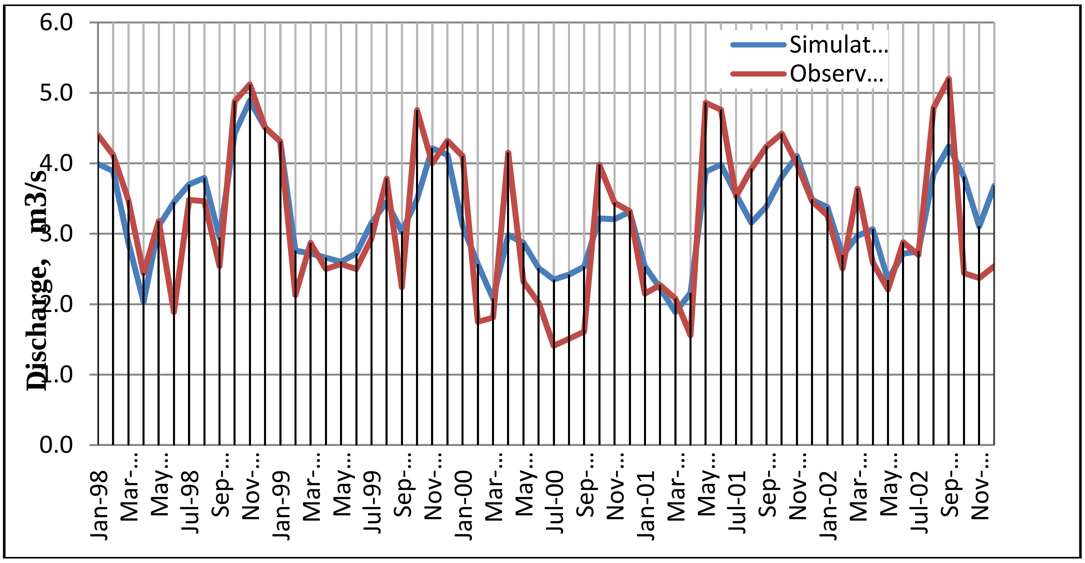

Figure 3: Observed and Simulated hydrograph of Tikure Wuha River at Awassa Bridge, Period (1998-2002) – Calibration Period

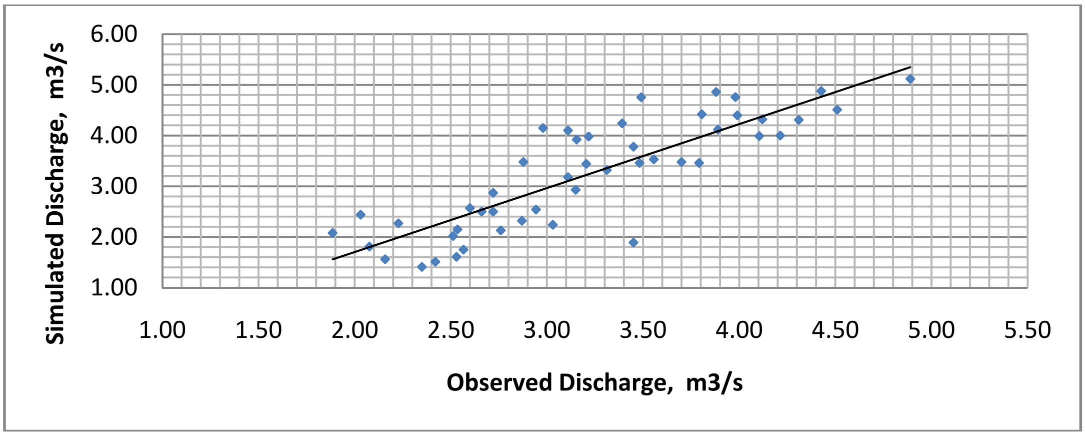

Figure 4: Scatter plot of Observed and Simulated discharge for Tikurewuha River during calibration period

6.2. Runoff estimation for gauged and un-gauged catchments

A SWAT model estimates runoff for un-gauged catchments by assigning HRUs to the sub-catchments. Sub-catchments with the same HRUs have the same responses for runoff generation, and in this research, after the gauged watersheds were modelled the lumped parameters were transferred directly to un-gauged watersheds and their runoff estimated. From the model output for the calibration period (1998-2002) the Tikurewuha catchment contributed 54.9 MCM/year. From the total average rainfall falling on the un-gauged catchments, about 44.44 MCM/year of rainfall was converted into surface runoff. A larger proportion of the rainfall was lost due to evapotranspiration and to ground water.

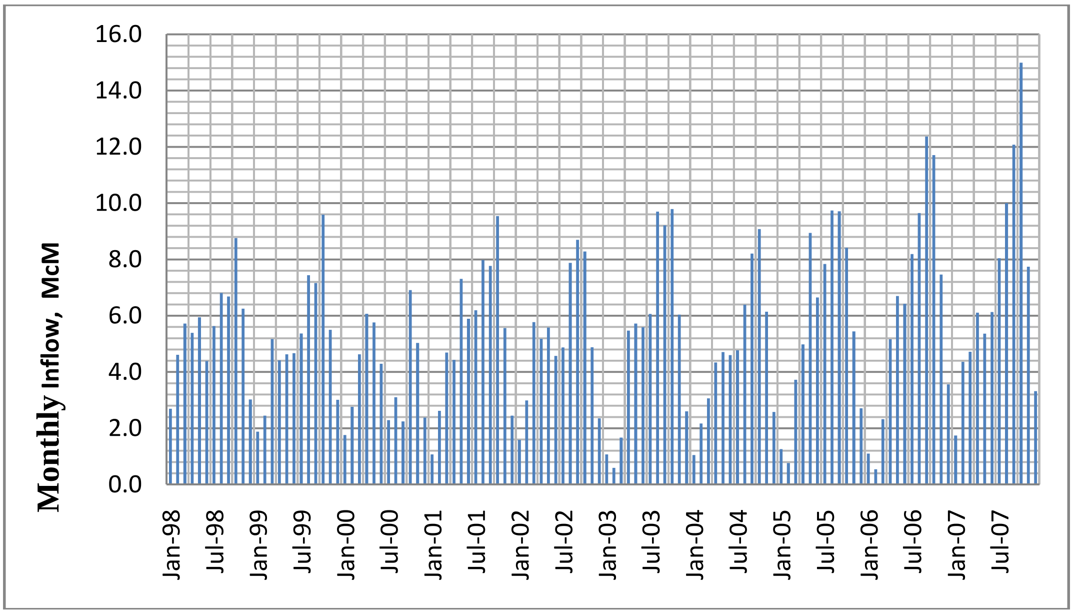

Figure 5: Inflow graph of Lake Awassa

6.3. Evaporation and Rainfall over the Lake

Monthly evaporation and monthly rainfall over the Lake have been estimated using the Aerodynamic method and Awassa's gauging station respectively. The annual average rainfall over the lake was found to be 998.5mm/year and from Aerodynamic method the average annual evaporation from the lake was found to be 1787.93mm/year.

6.4. Water Balance Simulation

The basic equation used in the water balance is:

Change in storage = Total inflow – total outflow - losses

$$S_t = S_{t-1} + I(t) + P(t) - O(t) - E(t) + G_{in} - G_{out}$$

where: St = Lake storage volume at the end of current month

St-1 = Lake storage volume at the end of previous month

I (t) = Simulated inflow volume from gauged and un-gauged catchments at current month

O (t) = Outflow volume at the lake outlet

P (t) = Areal rainfall volume on the lake surface

E (t) = Evaporation volume on the lake surface

Gin = Ground water inflow into the Lake at the end of current month

G_{out} = Ground water outflow from the Lake at the end of current month

The water balance terms were computed using an EXCEL spread sheet model.

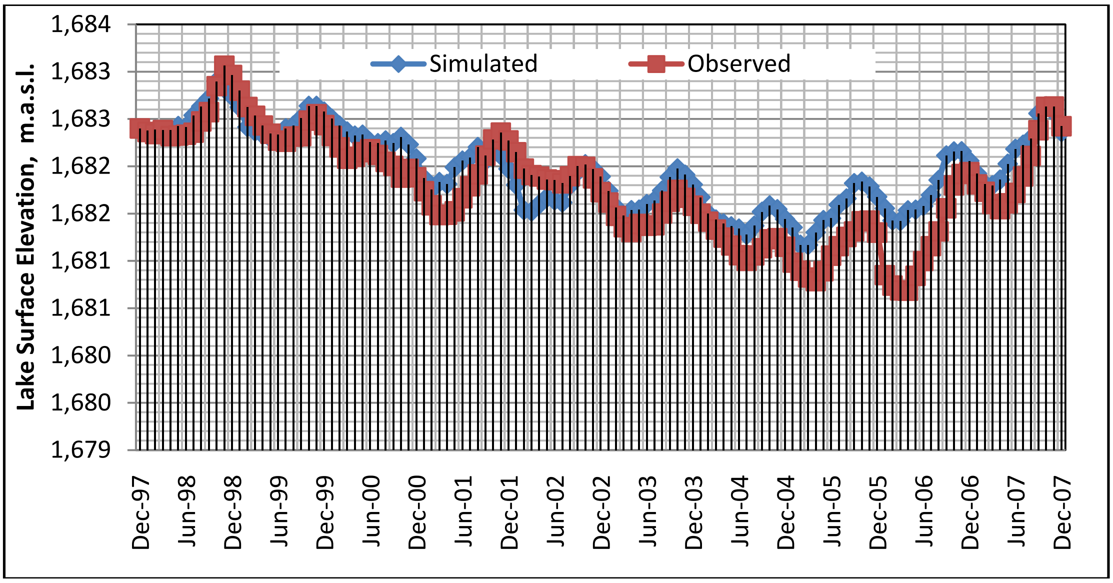

Figure 6: Observed and Simulated Lake Level for the period 1998-2007

Table 3: Water Balance Components

Water balance components	mm/year	MCM/Year
Lake areal rainfall	+988.5	+98.9
Gauged River inflow	+549.1	+54.9
Un-gauged river inflow	+444.4	+44.44
Lake Evaporation	-1787.93	-178.93
Change in storage	+192.7	+19.27

7. LAND USE CHANGE SIMULATION

Land cover change is highly affected by human-induced activities rather than natural events. Today, it is mainly agricultural expansion, burning activities or fuel wood consumption, deforestation, expansion of grazing land, some construction works and urbanization which cause land cover changes. Consequently, such changes may have great impacts on the catchment by altering the hydrological processes such as infiltration, groundwater recharge, and base flow and run-off. The assessment of these alterations is at the core of this work. The land use dynamics of the sub-basin that can be grouped under four main headings, even though they are all interrelated to some degree:

- Population pressure
- Climate change
- Government policy
- External influences

From the study of Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project, the most vulnerable areas in land cover change are those subject to deforestation and plantation expansion. According to the Project the future scenarios were mapped by selecting the predicted medium and high probability classes for each of these two changes in land cover. The percentage forest area at risk of deforestation and plantation encroachment in future is calculated by linear regression from the percentage of land use in 1965 to 1998.

Table 4: Forecasting the change in land use at 2017

Land use type	land use of 1965 (ha)	land use of 1998 (ha)	land use of 2017 (ha)
Urban	490	1800	2554.242
Cultivated Land	40586	61247	73142.73
Natural vegetation	67198	55430	48654.48

From this, the natural vegetation decreases by 11,768 ha, the cultivated land increases by 20,661 ha and the urban area increases by 1,310 ha in the period of 1965 to 1998. From this, the fraction of the plant growth (FRGRW1) for the case of cultivated land and natural vegetation changes at the rate of its corresponding land cover change, and for the case of urbanization the fraction total impervious area in urban land type (FIMP) is multiplied by its corresponding land cover change.

Table 5: Correction factor of the land cover data

Land use type	1998 (Default value)	2017
Cultivated Land (FRGRW1)	0.15	0.11
Natural vegetation (FRGRW1)	0.05	0.08
Urban (FIMP)	0.4	0.63

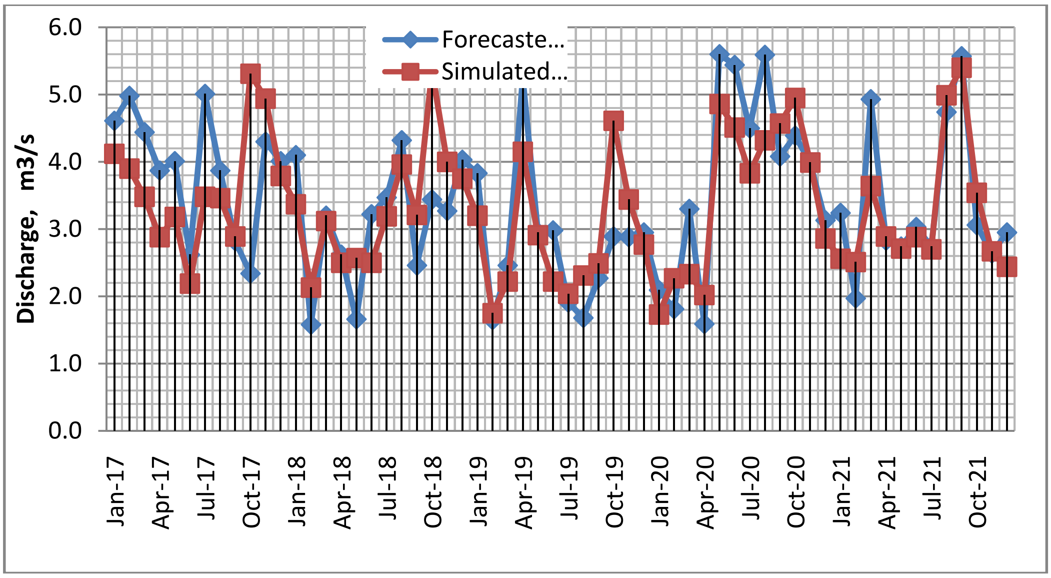

Figure 7: Simulated and Forecasted Discharge

In the graph, the discharge with the 2017 land use change is slightly greater than that of 1998. The 1998 land cover has an average discharge 3.15 m^3/sec where as the simulated land cover 2017 has an average discharge 3.50 m^3/sec. This is the expected output, because with the expansion of urban and deforestation, the result is an increase surface runoff, which has effect of raising the lake level.

8. CONCLUSIONS AND RECOMMENDATION

In this study due emphasis has been given to the estimation of runoff contribution from gauged and un-gauged catchments using the semi distributed model known as SWAT. Based on the SWAT watershed delineation the catchment area was found to be1,412 sq.km. Considering the whole watershed in the basin, about 54.81 % of the total watershed is gauged and 45.19 % is un-gauged. After modeling the gauged watershed, calibrated parameters were transferred to the un-gauged watershed by lumping the parameters for the same hydrologic response units (HRUs). The model output indicates that the annual inflow volume is estimated to consist of 54.9 MCM (55.51%) from the gauged watershed and about 44.44 MCM (44.49 %) from the un-gauged watershed. The annual average potential evapotranspiration, actual evaporation of the catchment, and precipitation are estimated to be 814.9, 519.8, 956.9 mm respectively.

Sediment yield carried into the lake and the water abstraction from the lake were neglected in the calculations of this research.

A general assessment of the roles of future land use change and variability on the lake water level were provided by incorporating the past trends ib deforestation, plantation and urbanization.

Generally, the data base created would enable further improvement or new research in monitoring the lake water quality and in carrying out sediment studies for the basin. The SWAT model is applicable in Lake Awassa basin and the results can be used for planning and management of water resources.

The SWAT model is calibrated using observed flow data at gauging station. In order to improve the model performance, the weather stations should be improved both in quality and quantity. Hence, it is highly recommended to establish a good network of both hydrometric and meteorological stations.

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