Estimating Surface Water Inflow into Lake Lego, a Closed Basin in Northeastern Ethiopia

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Abstract

Background: A surface water hydrologic characteristic of closed drainage basin of Lake Lego is not yet well-known amid constant reductions in depth and area over the last 72 years.

Objective: Predicting the amount of surface water inflow into the terminal Lake Lego and evaluating its impacts on Lake Morphometric parameters.

Materials and Methods: Weather (daily precipitation, minimum and maximum temperature), geospatial image (digital elevation model and land use and cover), physical and chemical soil characteristics and existing land management data were used. Soil and Water Assessment Tool and ArcGIS computer models were used for the analyses.

Results: The basin generated 304.3 mm of average annual surface runoff while the contribution of the baseflow was only 91.8 mm of water. In aggregate, the basin contributed an average surface water inflow of 21,984,159 $m^3\ y^{-1}$ during the simulation period. The trend in precipitation was insignificant for the duration of analysis while the lake water volume has been reducing at the rate of 2,817,680 $m^3\ y^{-1}$ for the same period. The declining lake water was affecting Lake Morphometric parameters. The depth, surface area, and volume of the lake were shrinking at the rate of 0.128 m y^{-1}, 3.8 ha y^{-1} and 0.29% y^{-1}, respectively. The water residence time of the lake was estimated as 45 years.

Conclusion: The results of the study revealed the contribution of surface water inflow into the lake and its impacts on depth, area and volume of the lake. The findings provide valuable information for policy development and decision making for implementation of integrated water resource management in the watershed and enhance streamflow into the lake.

Keywords: Ankerkah River; Baseflow; Ethiopia; Lake Lego; SWAT

1. Introduction

Mountain Lake Lego ('Lego' is also locally named and spelled as 'Hayq', Haik or 'Hayk', as stated in some literature), lying in a closed hydrological basin, is a highland freshwater body that provides a visually scenic look to northeastern part of south Wollo Region. Lake Lego, which is an extremely productive Nile Tilapia (*O. niloticus*) fishing environment, has become a source of livelihoods for thousands of people from the lake community and nearby towns. Basic morphometric parameters of Lake Lego had not been known until 1940. Morandini in 1941 (Baxter and Golobitch, 1970) explored the maximum depth and surface area of the lake for the first time as 88.2 m and 2,302 ha, respectively. Late bathymetric and land use and land cover studies carried out by Hassen Mohammed *et al.* (2013, 2015) indicated that the lake experienced reductions in depth and surface area by 6.8 m and 56.3 ha, respectively over the last 72 years.

Lake Floor pollen and charcoal analyses (Darbyshire *et al.,* 2003) provided evidence that the vegetation of the lake drainage basin shrunk due to human influence during the last 3000 years. Lamb *et al.* (2007) investigated the oxygen and carbon isotope compositions of sedimentary carbonates, which formed in Lake Lego for a 2000-year period. The result demonstrated the isotopes were mainly influenced by evaporative enrichment rather than surface and groundwater inflows due to reduced rainfall (Lamb *et al.,* 2007; Ghinassi *et al.,* 2012). Stratigraphical, geomorphological, and geochronological dating analyses reconstructed the Late Holocene lake-level fluctuations and paleohydrological history of Lake Lego. The result

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highlighted the presence of shoreline fluctuations during the last 3500 years and three main droughts occurred during the Little Ice Age (Ghinassi *et al.,* 2012).

Studies conducted in the past 80 years are largely morphometric conducted on lake dimensions. Streamflow studies on the lake have mostly lagged behind. Research findings show ecohydrologic condition of lake basins related to their streams or rivers falls within the realm of limnology, is now understood (Schäfer *et al.*, 2016). Although the traditional perception of freshwater degradation has been usually linked to pollution, increasing human activities in a watershed have more profound effects on environmental quality. Most river basins in the world have been dramatically modified due to unsustainable development of agriculture, grazing, deforestation, and urbanization (United Nations Environmental Protection (UNEP), 2004).

Lake Lego has been increasingly declining in depth, area and volume (Molla Demlie *et al.,* 2007; Hassen Mohammed *et al.,* 2013). There has not been water abstraction for municipal consumption, industrial use, irrigation, or power generation from the Lake. In reality, for a lake watershed where 26% of its geographical area is occupied by water (watershed to surface area ratio = 2.9), the source of water to the lake is dominated by precipitation falling on the lake. However, inflows through a river, streams and overland are the second sources of lake water. Ankerkah River, which drains 50.1% of the landscape of the lake basin, was used to permanently feed the Lake until sometime in the 1960s (Hassen Mohammed *et al.,* 2013) by receiving overflow from upstream Lake Hardibo. The river is now intermittent where the channel is empty in the driest months of May and June. No gaging station at the river and no lake level recorder is installed to monitor streamflow and observe lake level variations. In the face of continuous lake surface area decline, the quantity of inflow of water from its closed watershed into the downstream lake was not yet systematically predicted with mathematical models, either. Methods used to estimate surface water inflow for sites where no streamflow data are monitored include drainage-area ratio method, regional statistics, regression and watershed hydrologic modeling (Emerson and Dressler*,* 2002; Douglas *et al.,* 2005). Examination of the magnitude and quantitative changes in surface water inflow entering into the lake provides information about the persistent modification of Lake Morphometric parameters, which is necessary for planning use of the water resources as well as sustainable use of lake water.

According to the concept of ecohydrology and its scientific foundations towards Lake Basin Management (Zalewski and Robarts, 2003), the possibility of augmenting ecosystems resilience to anthropogenic changes can be achieved through the manipulation of biota and hydrologic interactions in a lake landscape. In this study, a connection among the lake and its watershed was established by examining the intimate link between what happens in the lake with what is happening in its watershed as a manifestation of ecohydrologic principle. The objectives of this study were, therefore, to predict the amount of surface water inflow occurring on the basin and evaluate what has been going on the Lake Morphometric parameters due to streamflow position.

2. Materials and Methods

2.1. General Description of the Study Area

Lake Lego watershed forms the uppermost part of the Awash River Basin with a hydrological area of 8623 ha. Geographically, it is bounded between 39.6816°–39.8108° E longitudes and 11.2374°–11.3855° N latitudes in the northeast escarpment of south Wollo Zone, northeastern Ethiopia at the western margin of the Afar triangle (Figure 1). The lake is centripetal with an area of 2246 ha and a maximum depth of 81.4 m (Hassen Mohammed *et al.,* 2013, 2015). Physiographically, the basin is situated in *Woyna Dega* (Mid-land) and *Dega* (Highland) Agro-Ecological Zones (AEZs) (1500–2300 and 2300–3200 meters above sea level, respectively), where the lake and adjacent low-lying plains in the basin are surrounded by an elongated block of Graben Mountains, which descends downwards to provide a space for the Lake.

The *Dega* section, in the upstream 11.8% of the basin, is dominated by very steep mountains with a pronounced stream dissection and high local relief. The fluvial Ankerkah River that starts in the upper farmlands underlies this section. Ankerkah River is the primary tributary of Lego Lake, although the lake also receives nominal flows overland and through a series of thirty tributaries all-round the lake. The lake used to drain to the Millie River, which flows east into Awash River before it descends in depth and is converted into a closed drainage basin with no outlet (Molla Demlie *et al.,* 2007). Relatively plain land, with some hill slopes in the middle, is the 88.2% *Woyna Dega* section in the downstream of the basin. This land occupies the water body and is less dissected landscape than the *Dega* section with low local relief. The moisture regime of the site comprises four-rainfall patterns: the small rainy season, very dry spell, big rainy season, and dry season. The mean annual precipitation is 1135.8 mm and the mean annual minimum and maximum temperatures are 10.5 and 25.9 ^{o}C, respectively averaged over 56 years (1962 to 2017) data record at Hayq town station. The farming system of the study area comprises rainfed agriculture and small livestock holdings.

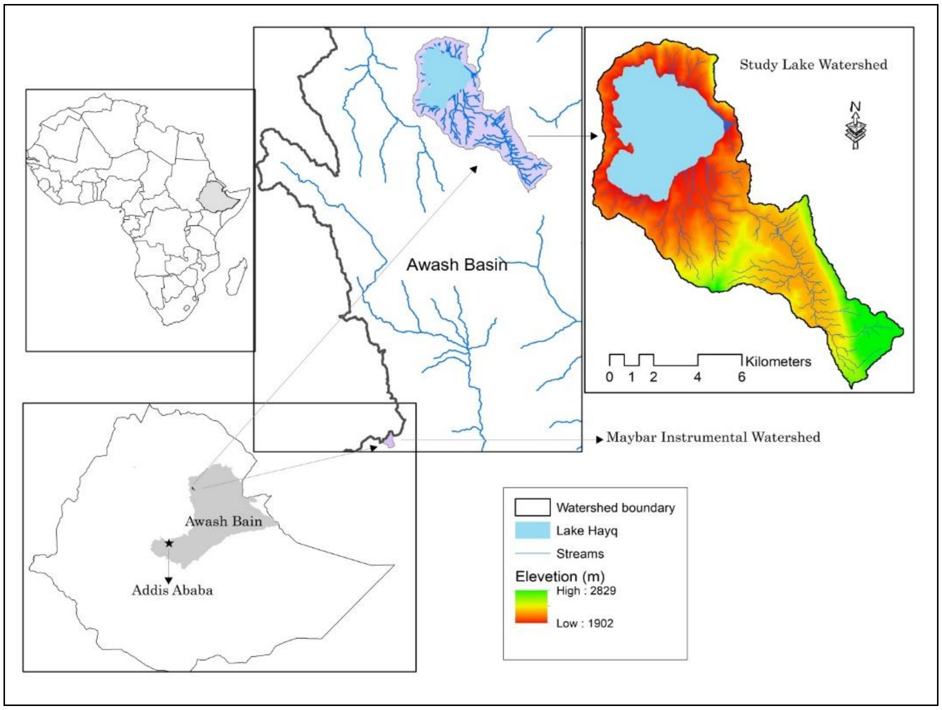

Figure 1. Location map of the study watershed.

2.2. Data, Methods and Analyses

Gathering a combination of input information that actually has been occurring in the basin was done to accurately predict the movement of water. Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) with a resolution of 30 m was obtained from open access site (http://dds.cr.usgs.gov/srtm/). National Meteorological Service Agency (NMSA) supplied the climatic elements (daily precipitation, maximum and minimum air temperature), covering a span of 10 years (2008 to 2017), from Hayq and Kombolcha Class 2 and 1, respectively climate stations. The data from Kombolcha station were used to build weather generator database file using WGNMaker Macro and pcpSTAT computer algorisms to fill in missing rainfall and temperature data of Hayq town station. Hargreaves Method (Hargreaves *et al.,* 1985) was used to calculate the potential and actual evapotranspiration. Historical records of precipitation data, in parallel with this study simulation period, was used for annual rainfall trend analysis. Trend analysis of rainfall time series were evaluated with Graphical Method.

Land cover data were obtained by visually interpreting Google Earth Image captured in 2017 on-screen. The spatial land cover interpretation was improved with Global Positioning System (GPS) receiver assisted groundwork by collecting ground control points. Generally, seven land use/land cover classes were identified (Figure 2) based on Land Cover Classification System (LCCS) (Food and Agriculture Organization (FAO), 2000). The seventh land use/cover class, *Orchard,* is pieces of enclosed land planted with fruit trees where 99% of it covers stimulant perennial crop called *Khat* (*Catha edulis*). It is sorted and portrayed here on the map to show its aggressive expansion from 0.27% in 2007 to 4.0% in this study at a cost of annual cropland.

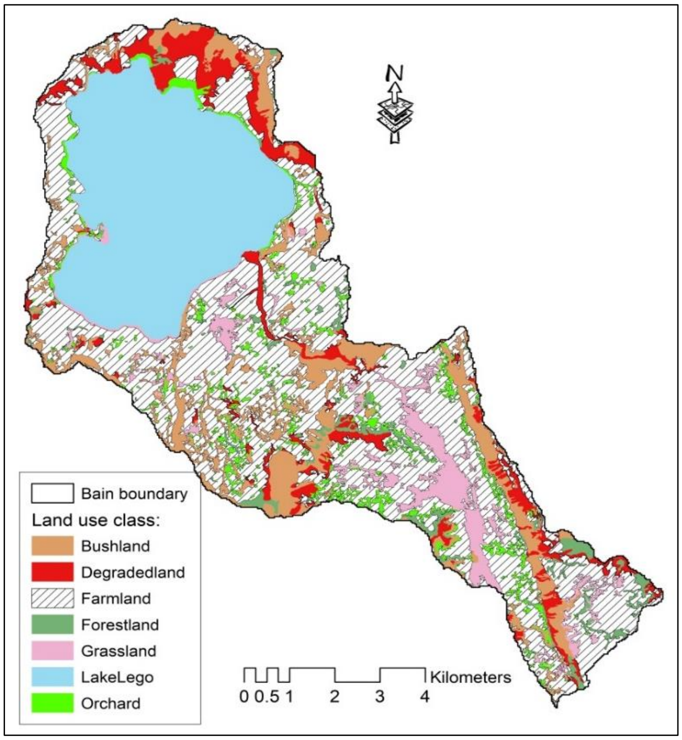

Figure 2. Land use/land cover distribution of Lake Lego Basin captured in 2017.

Physical and chemical soil characteristics were collected from: (1) secondary data review (Eastern Amhara Soil Study Corridor conducted in 2015) and (2) *in situ* description of soil surface characteristics and other primary soil parameters according to the guidelines of FAO (2006). Information from the two sources was used to identify five primary soil-mapping units. The third source of soil data was laboratory analyses of soil samples. Six soil profile pits were dug on soil types of representative sites (Figure 3), apparent horizons were identified on which undisturbed, and disturbed soil samples were taken on each layer for laboratory analyses. Texture (Pipette Method), Organic Carbon (Walkley and Black Method), Hydrologic Soil Group based on Natural Resource Conservation Service (NRCS) (2007), Bulk density (Core Ring Method), Field capacity (Sand box Method), Hydraulic conductivity (Constant head Method) and Organic Matter, Permanent Wilting Point, Available Water Capacity, Porosity, Soil Albido, Soil Erodibility (K) and Soil Crack Volume (Pedo Transfer Function) were determined according to the standards set by different researchers (Williams, 1995; Sahlemedihn Sertse and Taye Bekele, 2000; Saxton and Rawls, 2006; NRCS, 2007).

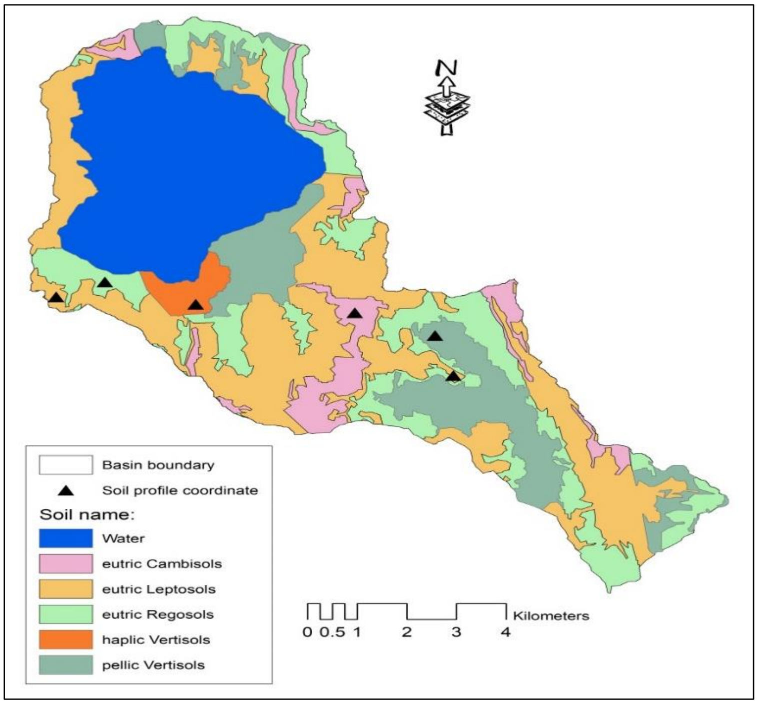

Figure 3. Soil types and profile locations of Lake Lego Basin.

Land management operations, such as bunds constructed within Lake Basin were located spatially. Other management operations, like vegetative filter strip along streamlines and around the lake, strip cropping, residue management, contouring, etc., were recorded in the field. Support practice factor (P_{USLE}) were estimated for all land use/covers based on land management status and slope ranges according to Wischmeier and Smith (1978), Haan *et al.* (1994), Hurni (1986), and Neitsch *et al.* (2011). Main channels' geometry (width and depth) and characteristics (bed and bank material and cover condition) were exhaustively measured in the field.

All outlets of defined streams and Ankerkah River were captured and manually added during modeling process to quantify streamflow movement through the channel network of the lake basin, via their exits that enter into the lake. In addition, landscapes with no defined channels bordering the lake, which directly supply overland flow to the lake, were clipped from the surface runoff map to estimate the net runoff entering the lake from these polygons.

Streamflow (inflow) and other water balance components of the lake watershed were predicted with Soil and Water Assessment Tool (SWAT) model for monthly time-step using comprehensive data input mentioned above. SWAT model was chosen for various reasons: First, SWAT has been already successfully applied for streamflow for a wide range of scales and environmental conditions around the globe (Gassman *et al.,* 2007). Second, SWAT has been effectively calibrated and validated in various hydrometric watersheds of Ethiopia for streamflow (Shimelis Gebriye *et al.,* 2010a, 2010b; Degefie Tibebe and Woldeamlak Bewket, 2011; Lemann *et al.,* 2016). Third, SWAT can model watersheds with no monitoring data (e.g. stream gaging data) (Neitsch et al., 2011). Fourth, SWAT model was calibrated, validated and underwent uncertainty analyses at Maybar gaging station for streamflow by Hassen Mohammed *et al.* (2016).

Soil Conservation Research Project (SCRP) watersheds have the longest and most accurate record of rainfall, runoff, soil loss, and sediment yield and streamflow data available in Ethiopia. Maybar is one of the sites located in the Upper Awash River Basin (SCRP, 2000). Maybar instrumental watershed and Lake Lego Basin are neighborhood, located within the same upstream Awash River Basin (Figure 1). Both watersheds are dominated by agriculture, with soil and water conservation structures built to control soil erosion to assist the rainfed subsistence farming.

In SWAT, surface runoff was simulated using a modified curve number method (Soil Conservation Service (SCS), 1972) at Hydrologic Response Unit (HRU) level. The mean annual watershed value of water balance components averaged over the whole simulation period (2012 to 2017) was calculated with the following Equation (Neitsch *et al.,* 2011):

$$SW_f = SWi + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - ET_a - W_{seep} - Q_{gw}\right) \quad (1)$$

Where, $SW_f$is final soil water content (mm); $SW_i$is initial soil water content on the day i (mm); t is time (days); $R_{day}$is amount of precipitation on day i (mm); $Q_{surf}$is amount of surface runoff on day i (mm); $ET_a$is amount of actual evaporation on day i (mm); W_{seep} is the amount of percolation and bypass flow exiting the soil profile bottom on a day i (mm); and Q_{gw} is the amount of return flow on a day i (mm).

Streamflow was routed through the drainage channel system using a variable storage method (Williams, 1969). The lake morphometric parameters were estimated using a combination of methods. The present lake surface area was updated using detailed interpretation of Goggle Earth Image as mentioned in *Section 2.2*. The lake area was used to estimate present lake depth using regression equation (Eq. 2) and this depth was used to estimate present volume using established bathymetric data (*3D Grid File*) by Hassen Mohammed *et al.* (2013) for Lake Lego.

$$A = -0.09d^2 + 362.5d - 3608.2 \quad (2)$$

Where, *A* is an area of lake surface in ha and *d* is depth in m. For an enhanced modeling outcome, the watershed was partitioned into a number of subwatersheds and HRUs. A total of 375 subwatersheds and 3963 HRUs were created by discretizing the basin at 15 ha very fine critical source area to benefit the simulation, because different areas of the watershed were dominated by land uses, soils and slopes dissimilar enough in variety to impact hydrology. Precipitation is the most dominant factor among climate variables in affecting surface water inflow in the lake basin. Annual trend analysis of rainfalls observed at Hayq town station, which covered from 1962 to 2017 years, where this study period falls into, were carried out with graphical method (Sen, 2012).

3. Results and Discussion

3.1. The Hydrologic Variables of Lake Lego Basin

The results of hydrologic variables aggregated at the Lake Basin level are shown in Table 1. These constituents are mean annual water balance components of the watershed averaged over the whole simulation period (2012 to 2017). The data gives an image of how basin annual rainfall was converted into different hydrologic components while moving through the continuum of the soil, vegetation and atmosphere.

Table 1. Mean annual values of water balance components of Lake Lego Basin.

Variable	SW_f	SW_i	R_{year}	Q_{surf}	ET	W_{seep}	Q_{gw}	$SW_f - SW_i$
Amount (mm)	36.4	33.8	1135.8	313.5	574.4	37.7	207.6	2.7
Rainfall (%)	–	–	–	27.6	50.6	3.3	18.3	0.2

Almost half of the total rainfall (R_{year}) (50.6%) released through evapotranspiration (*ET*) is a significant water loss from the drainage basin, which characterizes 88.2% *Woyna Dega* and 11.8% *Dega* AEZs with a mean elevation of 2,199 m a.s.l. and relatively warm climate (mean annual temperature = 18.2 °C). The bimodal rainfall regime of the area enables the growing of annual crops twice a year that increases transpiration and surface runoff. The rainfall-runoff link of the basin accounted for 27.6%, which is relatively low because 25.6% of the basin is water body, which does not generate runoff and 43% of the area is under slope class of 0–8%. The runoff coefficient is analogous to similar study carried out in neighboring Maybar instrumental watershed by Hurni et al. (2005) who obtained surface runoff of 27% of rainfall. Groundwater contribution (Q_{gw}) (18.3%) and deep percolation to the shallow and deep aquifer (W_{seep}) (3.3%) are also small proportions, which does not maintain plant water requirement in dry weather condition. The initial soil water content (SW_i) is less by 0.2 mm than the final soil water content (SW_f), which indicated that the soil moisture status right away before simulation was comparatively drier than soil moisture condition at the end of the simulation.

3.1.1. Surface runoff and baseflow of the landscape component of the lake basin

The landscape part of the Lake Basin generated 304.3 mm of annual average surface runoff, which varied from 17.9

mm on forest fields to 708.1 mm on degraded lands over the entire simulation period. Runoff is the major (76.8%) streamflow component, while it accounts the second largest proportion (27.6%) of rainfall. Catchments that are smaller than 1000 km² have runoff coefficients of less than 30% (Nyssen *et al.,* 2004; Hurni *et al.,* 2005). High runoff is generated in July and August (Figure 4) in major rainy seasons where agricultural soils are denuded and are easily detached by raindrop impact and transported with runoff to the receiving lake.

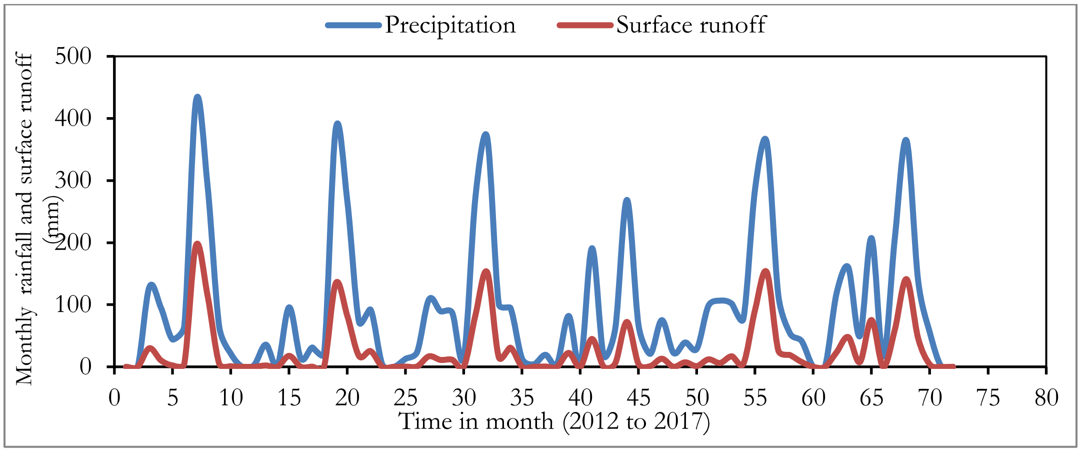

Figure 4. Monthly rainfall and simulated surface runoff in Lake Lego Basin.

Baseflow is fed by 30 ephemeral stream channels and Ankerkah periodic river that link the watershed and the lake hydrologically. With respect to location, runoff is high in the northern, southwestern, central west and along Ankerkah River below Tibina Bridge (Figure 5), because these areas are degraded lands characterized by 80% of Hydrologic Soil Group "D". The baseflow contribution (23.2%) to the downstream lake water is generally low. Baseflow is extremely low in degraded lands and farmlands (0.0–13.0%) as compared to vegetated areas (13–44%) where runoff is taken place in reverse. Generally, landscape part of the lake basin generate low cumulative annual water inflow due to high but short-lived runoff during rainfall seasons and low groundwater flow during the rest of the year. Analogues to this study, Tibebe Tigabu *et al.* (2018), in his work of streamflow time series in the Lake Tana Basin, resulted in decadal mean water level decrease due to surface water inflow reduction between the 1990s and 2000s. However, there was significant variation in mean annual streamflow and lake water level from decade to decade.

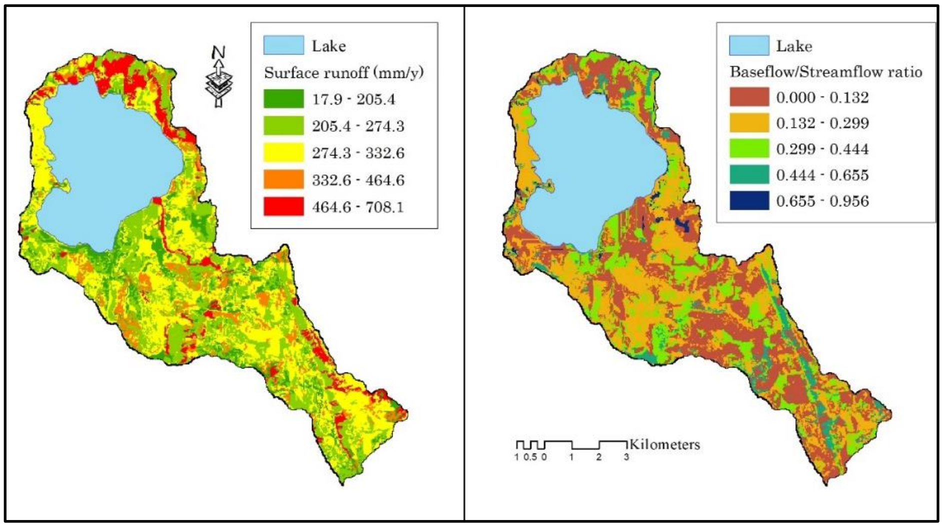

Figure 5. Surface runoff and baseflow spatial distribution in the lake basin.

Lake Lego watershed size (small and fan-shaped) and degradability may make baseflow liable to shrink. In addition, change in streamflow (runoff and baseflow) could link to land use types and constant transformation (for e.g., farmlands constituted 45% and increased at the rate of +19.2% in 2017). Information on surface runoff or baseflow of lakes is important to improve land use condition and agricultural water management that alleviate decreasing trends of surface water inflows (International Lake Environment Committee Foundation (ILEC), 2005). In doing so, Figure 5 can provide insight into the availability and distribution of surface runoff and baseflow situations, and can be used to plan and implement intervention measures that enhance hydraulic properties of the soil (bulk density and hydraulic conductivity) which improve streamflow into the downstream lake eventually.

3.1.2. Routed streamflow through the stream network in the lake basin

The annual average routing of water flows from the lake basin landscape to the lake through 31 outlets marked with red spots (Figure 6) were predicted for the simulation period, as depicted in Table 2. The mean annual routed streamflow amount into Lake Lego via the 31 defined stream channels was 21,508,821 m^3. Moreover, field-slope polygons with no defined channels bordering the lakeshore were clipped (Figure 6) and overland runoff generated from them into the lake was calculated. The mean annual overland runoff volume from these polygons was estimated as 475,338 m^3. The total mean annual quantity of surface water inflow during the simulation period generated from contiguous landscape of the basin was then 21,984,159 m^3 entering each year into the lake, which is equivalent to the mean annual flow of 0.7 m^{3}s^{-1}.

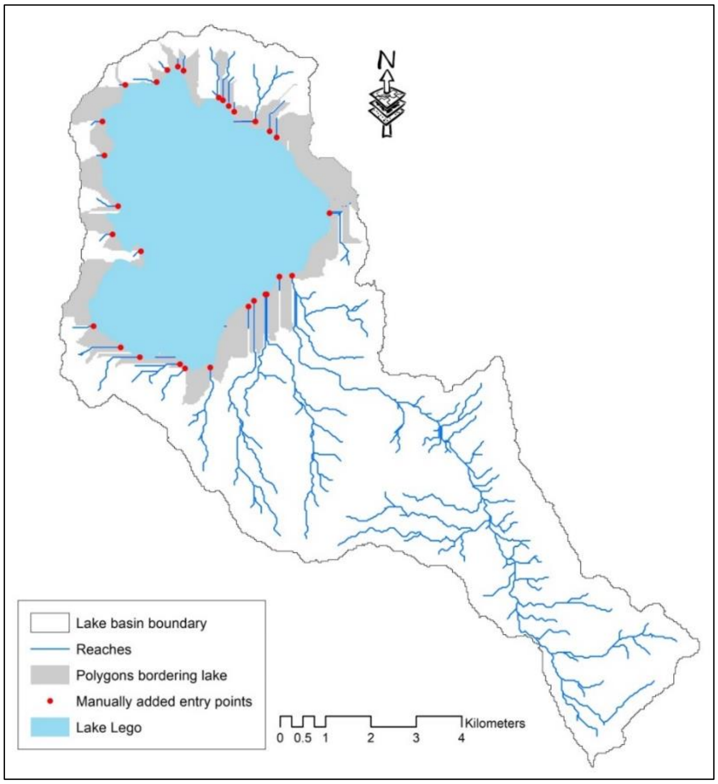

Figure 6. Drainage network, inlet points and field-slope polygons of Lake Lego Basin.

Table 2. Average annual streamflow entering Lake Lego through defined streams.

ID	Outlet number	Sub-basin area (ha)	Flow (m^3 s^{-1})	Volume (m^3)
1	1	15.6	0.00173	54,639
2	2	27.9	0.00417	131,531
3	3	18.9	0.00306	96,651
4	8	42.7	0.00757	238,851
5	11	15.8	0.00163	51,324
6	19	67.3	0.01186	374,358
7	23	41.9	0.00765	241,471
8	27	23.6	0.00397	125,375
9	31	18.5	0.00347	109,404
10	37	148.6	0.02299	725,675
11	38	20.8	0.00253	79,954
12	39	23.1	0.00397	125,218
13	43	16.6	0.00274	86,488
14	46	16.1	0.00205	64,708
15	105	25.5	0.00306	96,525
16	128	19.6	0.00287	90,528
17	145	26.0	0.00316	99,776
18	150	65.6	0.00816	257,537
19	151	22.8	0.00442	139,453
20	166	16.0	0.00182	57,479
21	169 (Ankerkah River)	3216	0.3891	12,281,863
22	188	25.7	0.00265	83,741
23	189	16.5	0.00199	62,814
24	195	42.0	0.00593	187,116
25	206	98.7	0.01168	368,677
26	210	146.1	0.01686	532,182
27	216 (Gido Stream)	557.8	0.06556	2,069,388
28	217	70.2	0.00734	231,749
29	218	57.9	0.00782	246,805
30	221 (Fecha Stream)	445.7	0.04955	1,564,036
31	228 (Ulaula Stream)	178.0	0.02007	633,505
	Total/average	5,527.4	0.02198	21,508,821

Mean monthly simulated streamflow time series graph produced during the simulation period, 2012 to 2017, is drawn in Figure 7. Hydrographs generated in July, August and September occurred during the main rainy season, were the highest peaks where the 2015 flow peak was relatively low due to drought occurrence. The lowest hydrographs were generated in May and June dry season.

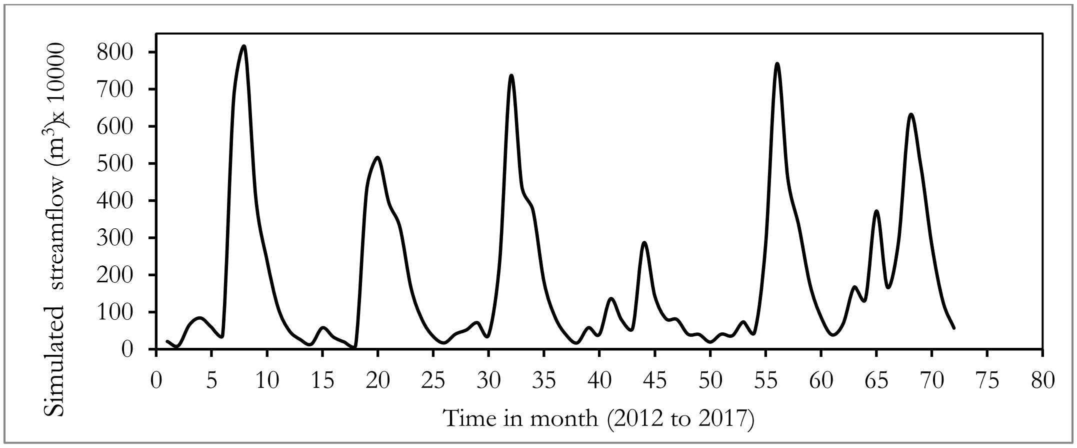

Figure 7. Simulated monthly streamflow time series graph of Lake Lego Basin.

3.2. Precipitation of the Lake Basin

Annual rainfall of the 56-year record (1962−2017) observed at Hayq town station was analyzed for a trend. Ninety-five percent of rainfall time series were in between +5% and –5% trend boundary lines or very close too (Figure 8). Five percent of the data scatter was placed above +5% and below -5% trend margin lines due to intra-annual variability. For example, in March during the small rainy season and in August in the major rainy season of the 1984 drought year, only 14.4 and 33.6 mm of rainfall were received, respectively. Likewise, 2015 was a drought year, and 1962, 1964, 1998 and 2010 were years with abundant rainfall in the basin.

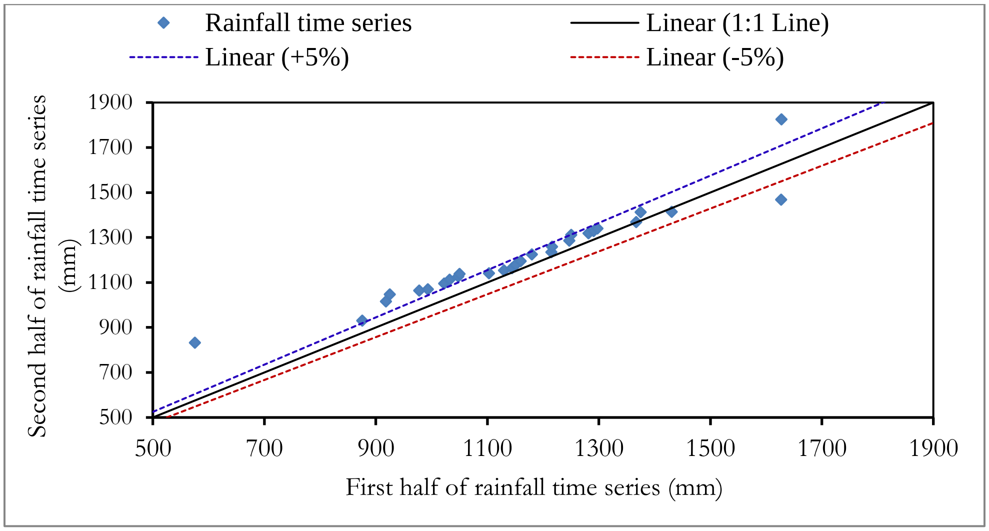

Figure 8. Graphical trend of annual rainfall for Lake Lego Basin.

The rainfall trend analysis revealed that there was no distinct tendency in annual rainfall change, except seasonal variability within the observation years. A similar study conducted by Tibebe Tigabu *et al.* (2018) in the Lake Tana Basin showed that there was no significant trend in the seasonal and annual basin-wide average rainfall at all observation stations while the mean annual streamflow and lake water level were varying significantly from decade to decade. In aggregate, no trend occurred in rainfall that affected surface water inflow entering the lake during the simulation period of this study.

3.3. Implications of Low Flow Regime on Lake Morphometric Parameters

The lake is intimately connected with its drainage basin; consequently, the declining flow regime in the lake basin has been affecting the lake size (depth, area and volume). In this study, land use and land cover extent was updated after 10 years of the first land cover analyses carried out by Hassen Mohammed *et al.* (2015) (Table 3). The long-term study discovered that Lake Lego surface area was continuously diminishing by 225 ha at the rate of 3.8 ha y^{-1} in a 60-year period.

Table 3. Trend in surface area extent of Lake Lego.

Year of survey	Area (ha)	Number of years between surveys	Change in area (ha)	Rate of change (ha y^{-1})
1957	2430	NA	NA	NA
1986	2324	29	–107.0	–3.7
2007	2246	21	–78.0	–3.7
2017	2205	10	–41.0	–4.0
Total/Average	–	60	–225.0	–3.8

By substituting the present lake planar area, 2205 ha, into Equation 2, which is displayed on Figure 9, the current maximum depth (80.4 m) of the lake was estimated. The present lake volume (984,848,192 m^3) was calculated with

Surfer Golden software using the estimated present depth and past echo-sounder generated three-dimensional *Grid File* built by Hassen Mohammed *et al.* (2013). The mean annual surface water inflow (21,984,159 m^3) has been primarily causing the volume of the lake to dwindle from 1,007,389,635 m^3 surveyed by Hassen Mohammed *et al.* (2013) to 984,848,192 m^3 in present-day estimate (Figure 9), provided that there was no subsurface outflow in the form of seepage through tectonic faults. There are few springs emanating from the same mountain wall the lake water is stored in the west but facing the other side of the lake basin.

Therefore, the rate of volume reduction was 2,817,680 m^3y^{-1} during the last six successive years (2010 to 2017) of prediction. In other words, the mean annual surface water inflow of 21,984,159 m^3 was insufficient to maintain the previous lake water capacity and was affecting morphometric parameters. Apportioning the present lake volume decline (2,817,680 m^3) by the present lake surface area (22,050,000 m^2) at an elevation of 1901.7 m a.s.l would give a depth reduction rate of 0.128 m y^{-1}. Consequently, the lake has been constantly shrinking in surface area (3.8 ha y^{-1}) and volume (0.29% y^{-1}). If this scenario continues with the same status and other variables affecting Lake Basin remain constant, the lake will vanish in 350 years. The water residence time was calculated as the present volume of the lake divided by mean annual water inflow to provide an indication of the average time water spend in the lake. The residence time of Lake Lego was 45 years, where the longest is 440 years for Lake Tanganyika and the world average for lakes is 17 years (ILEC, 2005).

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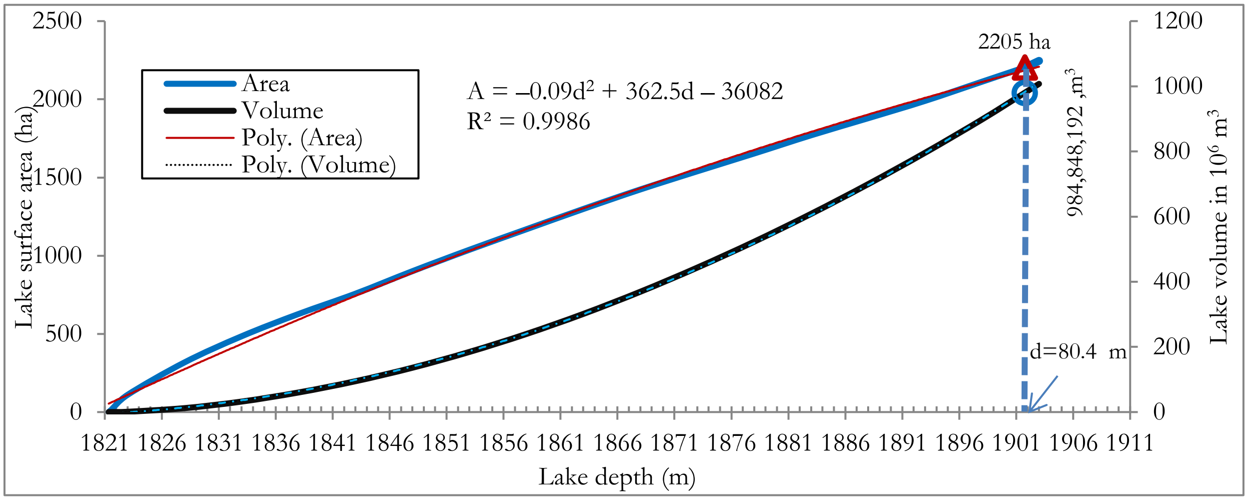

Figure 9. Capacity curves – volume and area versus elevation (depth) of Lake Lego.

The amount of annual surface water inflow, 21,984,159 m^3, into the lake was generally low when compared to the amount of annual precipitation, 25,047,287 m^3, falling over the lake. Similar to this result, Winter (1995) reported that the inflow of some lakes, with small upstream catchment, is dominated by the precipitation on the lake. Studies of Tibebe Tigabu *et al.* (2018) and Ye *et al.* (2018) revealed that annual streamflow series of most stations in Lake Tana and Poyang Lake, respectively show 'weaker' or 'very weak' persistence, i.e., the lakes' basins seem to enter into an increasing process under inter-decadal scale, while decreasing under the inter-annual scale. A study by Walling and Fang (2003) reported that approximately 22% and 9% of the world's rivers have shown a statistically significant decrease in baseflow and an increase in annual runoff, respectively, where most rivers maintain the status quo. Likewise, the Lake Lego drainage system was generating a nearly constant inflow of water for this mid-term length of analyses period although the inflow amount could not keep the lake morphometric status measured eight years ago.

4. Conclusion

In this study, the well-established semi-distributed SWAT model, in combination with geospatial processing tools, was successfully applied to predict surface water inflow into Lake Lego for the period of six years (2012 to 2017). Field measurements, soil laboratory results, climate elements, and geospatial input datasets were used. The major findings were generation of 21,984,159 m^3y^{-1} mean surface water inflow from lake basin into the lake with no long-term trend for the simulation period while the lake water volume has been reducing at the rate of 2,817,680 m^3y^{-1}. The mean annual water inflow is insufficient to maintain the existing lake volume capacity and affecting Lake Morphometric parameters such as its depth, surface area, and volume to shrink at the rate of 0.128 m y^{-1}, 3.8 ha y^{-1} and 0.29% y^{-1}, respectively. The results indicated the need for integrated participatory lake basin management to increase annual streamflow into the lake to maintain its storage capacity. Hydrogeologic studies need to be conducted in the future to bridge the remaining knowledge gaps by investigating subsurface outflow losses from the lake through tectonic faults and other outflows.

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6. References

Baxter, R.M. and Golobitch, D.A. 1970. A Note on the limnology of Lake Hayq, Ethiopia. *Limnology and Oceanography,* 15: 144–148.

Darbyshire, I., Lamb, H. and Mohammed Umer. 2003. Forest clearance and regrowth in Northern Ethiopia during the last 3,000 years. *The Holocene,* 13: 537–546.

DegefieTibebe and Woldeamlak Bewket. 2011. Surface runoff and soil erosion estimation using SWAT model in the Keleta watershed, Ethiopia. *Land degradation and development,* 22 (6: 551–564.

Douglas, G.E., Aldo, V.V. and Ann, L.D. 2005. Evaluation of Drainage-Area Ratio Method used to Estimate Streamflow for the Red River of the North Basin in North Dakota and Minnesota. Reston, Virginia. http://www.usgs.gov/publication/ sir/20055017. Accessed on 11 August 2019.

Emerson, D.G. and Dressler, V.M. 2002. Historic and unregulated monthly streamflow for selected sites in the Red River of the North Basin in North Dakota, Minnesota and South Dakota. Reston, Virginia. http://agris.fao.org/agris-search/search.do. Accessed on 21 June 2020.

FAO (Food and Agricultural Organization). 2000. Land covers classification System: Classification Concept and User Manual. FAO/WFP. Rome. https://www.fao.org/3/x0596e/x0596e00.htm. Accessed on 15 December 2019.

FAO (Food and Agricultural Organization). 2006. Guidelines for soil description. World Soil Resources Reports, Land and Water Division. FAO, Rome. Pp. 110.

Gassman, P.W., Reyes, M., Green C.H. and Arnold, J.G. 2007. The Soil and Water Assessment Tool historical development, applications, and future directions. *Transaction of the American Society of Agricultural and Biological Engineers,* 50: 1211−1250.

Ghinassi, M., D'Oriano, F., Benvenuti, M., Awramik, S., Bartolini, C., Fedi, M., Ferrari, G., Papini, M., Sagri, M. and Talbot, M. 2012. Shoreline fluctuations of Lake Hayk (northern Ethiopia) during the last 3500 years. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 366: 209−226.

Haan, C.T., Barfield, B.J. and Hayes, J.C. 1994. *Design Hydrology and Sedimentology for Small Catchments.* 1st edition. Academic Press, San Diego. Pp. 603.

Hargreaves, G.L., Hargreaves, G.H. and Rile, J.P. 1985. Agricultural benefits for Senegal River Basin. *Journal of Irrigation and Drainage Engineering,* 111: 113−124.

Hassen Mohammed, Assefa Mekonen, Gete Zeleke and Tena Alamirew. 2016. Streamflow prediction uncertainty analysis and verification of SWAT model in a tropical watershed. *Environmental Earth Sciences,* 75: 1–16.

Hassen Mohammed, Mohammed Assen, Assefa Mekonen and Tena Alamirew. 2015. Detecting land use/land cover changes in the Lake Hayq (Ethiopia) drainage basin, 1957–2007. *Lakes Reservoir Research and Management,* 20: 1–18.

Hassen Mohammed, Tena Alamirew, Assefa Mekonen and Mohammed Assen. 2013. Bathymetric study of Lake Hayq, Ethiopia. *Lakes Reservoir Research and Management,* 18: 155–165.

Hurni, H. 1986. Guidelines for Development Agents on Soil Conservation in Ethiopia, 1st edition. Community Forests and Soil Conservation Development Department, Addis Ababa. Pp. 100.

Hurni, H., Kebede Tato, and Gete Zeleke. 2005. The Implications of changes in population, land use and land management for surface runoff in the Upper Nile Basin of Ethiopia. *Journal of Mountain Research and Development,* 25: 147−154.

ILEC (International Lakes Environment Committee Foundation). 2005. Managing lakes and their basins for sustainable use. A report for lake basins managers and stakeholder, Kusatsn. Pp. 166.

Lamb, H.F., Leng, M.J., Telford, R.J., Tenalem Ayenew and Mohammed Umer. 2007. Oxygen and carbon isotope composition of antigenic carbonate from an Ethiopian lake, a climate record of the last 2,000 years. *The Holocene,* 17: 515−524.

Lemann, T., Gete Zeleke, Amsler, C., Giovanoli, L., Suter, H. and Roth, V. 2016. Modeling the effect of soil and water conservation on discharge and sediment yield in the upper Blue Nile Basin, Ethiopia. *Applied Geography,* 73: 89−101.

Molla Demlie, Tenalem Ayenew and Wohnlich, S. 2007. Comprehensive hydrological and hydrogeological study of topographically closed lakes in highland Ethiopia. The case of Hayq and Ardibo. *Journal of Hydrology,* 339: 145–158.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R. 2011. Soil and Water Assessment Tool Theoretical Documentation, version 2009, Texas A and M University College Station. Pp.618.

NRCS (Natural Resource Conservaation Service). 2007. National Engineering Handbook. Washington, DC, USA. http://directives.sc.egov.usda.gov/. Accessed on 12 August 2011.

Nyssen, J., Poesen, J., Moeyersons, J., Deckers, J., Haile, M. and Lang, A. 2004. Human impact on the environment in the Ethiopian and Eritrean highlands−A state of the art. *Earth Science Reviews,* 64: 273–320.

Sahlemedihn Sertse and Taye Bekele. 2000. *Procedures for soil and plant analysis.*1st edition. Technical paper, No. 74, National Soil Research Center, Addis Ababa. Pp. 110.

Saxton, K.E. and Rawls, W.J. 2006. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. *Journal of American Soil Science Society,* 70: 1569−1578.

Schäfer, M., Dietrich, O. and Mbilinyi, B. 2016. Streamflow and lake water level changes and their attributed causes in Eastern and Southern Africa, state of the art review. International *Journal of Water Resources Development,* 32: 853–880.

SCRP (Soil Conservation Research Project). 2000. Area of Maybar, Wello, Ethiopia: Long-term Monitoring of the Agricultural Environment 1981–1994. Centre for Development and Environment, Berne, Switzerland in association with the Ministry of Agriculture, Addis Ababa, Pp. 90 pp.

SCS (Soil Conservation Service). 1972. Hydrology. National Engineering Handbook. https//directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=18393.wba. Accessed on 25 April 2009.

Sen, Z. 2012. Innovative trend analyses methodology. *Journal of Hydrologic Engineering,* 17:1042–1046.

Shimelis Gebrye, Dargahi, B., Srinivasan, R. and Assefa Mekonen. 2010a. Modeling of Sediment Yield from Angeni Guaged Watershed, Ethiopia Using SWAT Model. *Journal of American Water Resources Association,* 46: 514−526.

Shimelis Gebrye, Srinivasan, R., Assefa Mokonen and Dargahi, B. 2010b. SWAT model application and prediction uncertainty analysis in the Lake Tana Basin, Ethiopia. *Hydrologic Process,* 24: 357−367.

Tibebe Tigabu, Hörmann, G., Wagner, P.D. and Fohrer, N. 2018. Statistical analysis of rainfall and streamflow time series in the Lake Tana Basin, Ethiopia. *Journal of water and climate change,* 1: 1–17.

UNEP (United Nations Environmental Program). 2003. Phyto–technologies–A technical approach in environmental management. freshwater management series. https://wedocs.unep.org/20.500.11822/9159. Accessed on December 26, 2020.

Walling, D.E. and Fang, D. 2003. Recent trends in the suspended sediment loads of the world's rivers. *Global Planet Change,* 39: 111–125.

Williams, J.R. 1969. Flood routing with variable travel time or variable storage coefficients. *Transaction of American Society of Agricultural Engineers,* 12: 100−103.

Williams, J.R. 1995. The EPIC Model. Pp. 909–1000. *In*: Singh, V.P. (ed.). *Computer models of watershed hydrology*. Highland Ranch publisher, CO. USA.

Winter, T.C. 1995. Hydrological Processes and the Water Budget of Lakes. Pp. 37−62. *In*: Lerman, A.D., Imboden, M. and Gat, J.R. (eds.). *Physics and* *chemistry of lakes.* 1stedition, Springer, Berlin, Heidelberg, Germany.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting rainfall–erosion losses: A guide to conservation planning. Agriculture Handbook No 282. USDA-ARS, Washington DC. Pp. 66.

Ye, X., Xu, C.Y., Li, X. and Zhang, Q. 2018. Comprehensive evaluation of multiple methods for assessing water resources variability of a lake–river system under the changing environment. *Hydrology research,* 48: 332−343.

Zalewski, M. and Robarts, R. 2003. Ecohydrology – A new paradigm for integrated water resources management. *SIL News, Supplement*, 40: 1–5.