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Climate change impact on Lake Tana water storage, Upper Blue Nile Basin, Ethiopia

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ABSTRACT

Temperature and precipitation trend fluctuations influence the components of the hydrological cycle and the availability of water supplies and their resulting shifts in the balance of lake water (lake level). Quantile mapping was applied to correct temperature biases, and power transformation was applied for rainfall correction. The performance of the HBV model was evaluated through calibration and validation using objective functions (RVE, NSE) and provide RVE of 3.7%, -1.27%, 1.05%, -0.72%, 8.9% and -0.68 during calibration and RVE of -1.5%, 6.93%, -3.04%, 8.796%, -5.89% and 8.5 % during validation for Gumara, Kiltie, Koga, Gilgel Abay, Megech and Rib respectively, While the model provided NS of 0.79, 0.63, 0.72, 0.803, 0.68 and 0.797 during calibration and NSE of 0.8, 0.64, 0.7, 0.82, 0.801 and 0.82 during validation for Gumara, Kiltie, Koga, Gilgel Abay, Megech, and Rib respectively. The simulated Lake level showed adequate agreement to the observed with NS and RVE of 0.7 and 6.44 % respectively. The result confirmed that over lake evaporation and rainfall increase for all future scenarios. The ungauged surface inflow is also increased shortly scenarios while gauged surface inflow increased for RCP4.5 (the 2070s) and RCP8.5 (2040s) and decreased for RCP4.5 (2040s) and RCP8.5 (2070s). The decreased in gauged surface water inflow is due to a decrease in inflow for Gilgel Abay, Koga and Gumara gauged catchments. Lake storage results showed a decrease in all future scenarios of all-time horizons.

Key Words: Climate change impact, CORDEX, RCP, RCM, GCM, Scenario, CMIP5, Upper Blue Nile Basin.

1. INTRODUCTION

Temperature fluctuations and changes in precipitation trends influence the components of the hydrological cycle and the availability of water supplies in general. Climate change is a change in the state of the climate that can be identified by a change in the statistical distribution of weather variables, such as high temperature, minimum temperature, and rainfall, usually for decades or centuries in future times. The extent and seasonality of precipitation are

altered by global temperature and atmospheric circulation rises and may contribute to an overall increase in the rate of evaporation and change in precipitation pattern (Nigatu, Rientjes, and Haile, 2016).

Climate change and its instability have many impacts on the hydrological cycle and, thus, on the world's hydrological and water supply systems. This reality has been confirmed by the Intergovernmental Panel on Climate Change, and greenhouse gases have played a major role in global and regional climate change (Oakes, 2009). The introduction of these gases into the atmosphere has disrupted the atmosphere's natural composition (Atique L, Mahmood I and Atique F, 2014).

According to Maghsood *et al.*, (2019) Climate instability in the world can be defined in terms of temperature rise, sea-level rise, precipitation change, and severe drought and flooding. Global surface temperature increases at the end of 21 century (2081-2100) are expected to reach 1.5°C for RCP4.5, RCP6, and RCP8.5 relative to 1850-1900, and warming will exceed 2°C for RCP6 and RCP 8.5, but not exceed 2°C for RCP 4.5. Compared to the previous century (1986-2005), the global mean surface temperature rise at the end of 21 century (2081-2100) is set to be 0.3°C to 1.7°C for RCP2.6, 1.1°C to 2.6°C for RCP 4.5, 1.4°C to 3.1°C for RCP 6, and 2.6°C to 4.8°C for RCP8.5.

The IPCC assessment study on warming over land in Africa has risen over 50-100 years, according to Stocker *et al.*, (2013) and the surface temperature has also increased over the past hundred years by 0.5°C-2°C, and the pattern of rainfall in Africa has changed from year to year. In some parts of western Africa, most likely decreases in rainfall occurred with an observed decrease in average rainfall of 25-50 mm per decade from 1951-2010, but some parts of eastern and southern African countries experienced an increase in annual average rainfall of 5-50 mm per decade. In eastern Africa, however, the pattern of rainfall varies significantly over time, and location (spatial and temporal variability of rainfall) has occurred.

In Ethiopia, the annual average temperature trend has increased by 0.37°C every ten years over the last four decades, which is comparatively lower than the global increase in temperature. During the second half of the 1990s, the majority of temperature rises occurred (Jol, Raes, and Menne, 2009). In the dry and hotspot areas of the nation located in the Northern, Northeastern, and Eastern regions, the temperature rise was more dominant. As these areas are dry and mainly exposed to flooding during intense and regular rainfall occurring in highland areas of Ethiopia, the lowlands of Ethiopia are highly affected. Future country temperature forecast in the mid-range IPCC scenario shows that the mean annual temperature rise in Ethiopia will rise from 0.9 to 1.1°C by 2030, from 1.7 to 2.1°C by 2050, and from 2.7 to 3.4°C by 2080 compared to the standard 1961 to 1990 that provides the country economy with a sustained risk (Zenebe *et al.*, 2011). With regard to hydrology, by contributing to changes in the components of the hydrological cycle, climate change can cause major impacts on water supplies. The variations in temperature and precipitation, for example, may have a direct effect on the amount of evapotranspiration and the increasing rate of evaporation allows for the loss of the runoff portion and the volume of runoff to be allocated as storage for

various consumptions for reservoirs. Consequently, the spatial and temporal availability of water supplies can be dramatically altered and, by offering a missing balance between demand and supply aspects, can impact agriculture, industry, hydropower capacity, and urban growth.

The Lake Tana basin is under pressure for irrigation, domestic water supply, fisheries, and navigation due to various competitive users. In addition to these facts, recent climate studies have shown that several areas of the lake basin and the upper Blue Nile basin are climate-sensitive, meaning that climate change will have a major effect on river water supplies. Although the impact of various global climate change scenarios is expected, in most parts of the world the exact form and extent of the impact associated with local scale or catchment scale are not studied (Gornall *et al.*, 2010). In addition, under GCM-RCM models of CMIP5 of the AR5, the Lake Tana sub-basin is not well studied, so assessing the effect of climate change under the newly developed scenarios and GCM-RCM combinations for the Lake Tana sub-basin would be able to understand the magnitude of the effects on water resources.

Not directly discussed was the assessment of the implications of the RCP scenario for the upper Blue Nile basin. There are several water supplies projects under development and planning in the upper Blue Nile basin, such as reservoirs and water facilities, including the Lake Tana sub-basin. Since climate change may impact the demand and supply sides of this water resource project, further studies could provide empirical evidence on the implications of the RCP scenario for this in the basin's construction and planned water resource projects, including Lake Tana reservoir (Haile *et al.*, 2017).

Even though, in addition to climate fluctuations, factors that decrease the availability of water supplies increase, demand for fresh water rises from day to day as population growth rises from year to year and the socio-economic aspects of the population are enhanced, thereby affecting agricultural development and reducing the demand needed for various water supply projects. Therefore, well-planned programs and studies in water resource management should be carried out to balance the demand and supply sides of various water resource projects in action and to be adopted for the future (Enku, 2009).

Quantitatively estimating the shift in the water balance of Lake Tana allows us to have a good water management activity and to use well-performed rules and curves of reservoir service, taking into account the minimum lake level and the demand needed for downstream projects. Between the water levels of Lake Tana and outflows to the downstream projects that consider the effect of climate change on the lake system, optimized use of water resources in the Lake Tana will be carried out.

1.1. Description of Study Area

The Lake Tana basin covers approximately 15000km² area from which the Lake Tana covers an area of approximately 3000 km². The basin is located 564 km in the North-west highland at Lake Tana from the capital city Addis Ababa. The basin consists of wide-area coverage of ungauged catchments and has altitude varying from 1784 at the Lake Tana level and to about 3400m in the mountainous area of the eastern part of the lake in Ribb catchment. The basin consists of nine gauged rivers and ten ungauged rivers. Among the gauged rivers Megech, Ribb, Gumara, and Gilgilabay rivers are considered

as main rivers of the basin and cover more than 93% of the inflow to Lake Tana (Figure 1). The only outflow of the basin is the Abay River (Blue Nile river) covering 7% of the Blue Nile flow at the Ethiopian-Sudan border (Conway, 2000). There is great uncertainty regarding the contribution of ungauged catchments of the basin to the Lake Tana water balance components.

Figure 1: Location of the study area

2. METHODOLOGY AND MATERIALS

The methodology of this study consists of Extraction and processing of future climate data from Coupled Model Intercomparison Project phase 5(CMIP5) RCM (RCA4) ensemble output of CORDEX-Africa under Representative Concentration Pathways (RCP2.6, RCP4.5and RCP8.5), HBV model parameter

regionalization, rainfall-runoff modeling Using HBV model, estimation of upstream water abstraction from dams, estimation of lake water balance components and storage for observed, baseline and future period.

2.1. Data used

The metrological data was collected from the National Metrological Agency at the Bahir Dar branch. In this study, daily rainfall records of eighteen stations for the year from 1988 to 2005 were used to calibrate, validate the model, and correct biased for the climate simulations in the analysis of current and future climate simulations. The hydrological data were also collected from the Ethiopian Ministry of Water, Irrigation, and Energy (MOWIE) hydrology department. CORDEX Africa GCM –RCM UNDER CMIP 5 for RCP4.5 and RCP 8.5 output data were downloaded from <https://esgf-data.dkrz.de/search/cordex-dkrz>.

2.2. Bias Correction for Regional Climate Model Data

For this study, power transformation was used to correct rainfall, and the quintile mapping approach is used to correct temperature. Normal distribution function was used for temperature corrections associated with Quantile mapping.

2.3. HBV- Model calibration and validation

Like other similar conceptual models, HBV-96 model parameters have to be estimated through calibration. Generally, model calibration involves the determination of model parameters that gives the best possible correspondence between observed and simulated runoff from a catchment. Among the different approaches for calibrating the model to identify the optimum parameter set; manual calibration is functional for this model. Calibration of model parameters is done from (1988-1996) for Koga catchment, (1997-2002) for Kiltie catchment, and (1988-1999) for the reaming gauged catchments of LTSB following a procedure specified in the SMHI manual using 2/3 of the year for calibration and 1/3 of the total year data for validation purpose. Sensitivity analysis for the model was applied by manually changing the value one optimized model parameter at a time having a reasonable bounded range of common intervals (i.e., both increasing and decreasing to the right and left respectively). For this study, the value of each optimized model parameter was increased and decreased up to 60% having a common interval of 20% and then the plot of this increased and decreased values versus the model performance evaluation criteria's (i.e., NSE, RVE, or R2) for each model parameters were done and those parameters having steep slopes were considered as most sensitive parameters and those having gentle slope were considered as less sensitive optimized parameters (Table1).

Table1: Model parameter space in SMHS HBV model (Ragab and Bromley, 2010)

	Starting - value	Approximate interval	Comments
Fc	Range-Value	100-1500	maximum soil moisture storage(mm)
Lp	1	< 1	Limit for the potential evapotranspiration
Beta	1	1-4	The exponent in the equation for discharge from the zone of soil water
K4	0.01	0.001-0.1	Recession coefficient for lower response box
Perc	0.5	0.01-6	Percolation from the upper to the lower response box(mm)
Khq	0.09	0.005-0.5	Recession coefficient for upper response box
Alfa	0.9	0.1-1.5	Measures of none-linearity to the response of the upper reservoir
Cflux	0.5	0- 2	Maximum capillary flow from the upper response box to soil moisture zone (mm/day)

2.4. Evaluation of Model Results

During calibration and validation of models, there has to be a criterion of whether the simulation is within the acceptable range or not. So, in IHMS/HBV the mainly used model evaluation criteria are:

1. By simply inspecting simulated and observed hydrograph
2. Relative volume error (RVE)

The relative volume error results that lie in between +5% and -5% indicate that the model performs well while relative volume error results lying between -10% and +10% indicate that the model performs reasonably. It was computed by the following formula.

$$RVE = \frac{\sum_{i=1}^n Q_{si}(i) - \sum_{i=1}^n Q_{oi}(i)}{(\sum_{i=1}^n Q_{oi}(i))} * 100 \quad 1$$

Where: - Q_{oi} is observed discharge, Q_{si} is the simulated discharge.

3. Nash-Sutcliffe Efficiency

The Nash-Sutcliffe efficiency is used to evaluate the overall agreement of the shape of the simulated and observed hydrograph (i.e., whether the shape of the simulated hydrograph replicates the observed or not). NSE measures the efficiency of the model by relating the goodness of fit of simulated data to the variance of observed (measured) data. If the value is in a range of 0.6 to 0.8 the model performs reasonably, values in arrange of 0.8 to 0.9 the model performs well and NSE value in arrange of 0.9 to 1 the model performs extremely well (Wale, 2008). It can be computed through the following formula.

$$NSE = 1 - \frac{\sum_{i=1}^n (Q_{oi} - Q_{si})^2}{\sum_{i=1}^n (Q_{oi} - Q_{om})^2} \quad 2$$

Where Q_{oi} is the observed discharge, Q_{om} is the mean of observed discharge and Q_{si} is the simulated discharge.

2.5. Ungauged Catchment Model Parameter

Ungauged catchment model parameters are evaluated from gauged catchments through the regionalization approach. Even though the term regionalization has been interpreted by different scholars differently (Blöschl and Sivapalan, 1999) defines regionalization is the process of transferring information usually model parameter from a comparable catchment (here gauged one) to the area of interest (the ungauged one for the cases here).

3.5.1 Establishing the Regional Models

The calibrated gauged catchment rainfall-runoff models are used to derive the relationship between model parameters and their PCCS via the techniques of the regionalization approach. As has been mentioned by (Hirp, 2005) regression analysis is a common technique to establish a relationship between model parameters and their associated PCCs. Regression analysis is a statistical tool to establish a relationship between one or more variables usually called the independent and dependent variables. In the regionalization approach, the main problem is when there is a limited number of gauged catchments. In reality, increasing the number of well-gauged catchments can increase the reliability and efficiency of the regional model. Selection of catchments to be used for establishing regional models' values for RVE should be smaller than +5% or -5% and NSE values greater than 0.6 and RVE may be smaller than +10% or -10 for reasonably perform conditions.

2.5.1. Regression Analysis

Simple linear regression: The model for simple regression looks as such.

$$Y = \beta_0 + \beta_1 X_1$$

3

The relationship developed between model parameters and physical catchment characteristics tells us how changes in physical catchment characteristics will affect the hydrological response (Merz and Blöschl, 2004). If the relationship developed between the PCCs and optimized model parameters are well statically significant and meaning full from a hydrological point of view hence the regional model will be used further for the prediction of ungauged model parameters and finally discharge for ungauged catchments will be computed using the HBV model. To establish a regional model between optimized model parameters and physical catchment characteristics, the first correlation analysis between MPs and PCCs is computed.

To optimized the simple relation of MPs and PCCs the strength and significance of the relationship has to be tested well. The significance of the test has been done by the t-test (equation 4). The relationship will be tested for the null hypothesis stating that the two variables are independent and the specific hypothesis stating that correlation between these variables is not zero. The simplest formula for computing the appropriate t-value to test for the significance of correlation coefficients employs the t-student distribution.

$$t_{cor} = \frac{r}{\sqrt{(n-2)/(1-r^2)}}$$

4

Where: - t_{cor} is t value of correlation r : is correlation coefficient and n : is the sample size

The null hypothesis (H_0) and the specific hypothesis (H_1) are:

H_0 : $\rho=0$ the correlation between model parameters and physical catchment characteristics is zero.

H_1 : $\rho \neq 0$ the correlation between model parameters and catchment characteristics is not zero.

If $t_{cr} > t_{cor}$ the null hypothesis is accepted (the parameter is not associated with catchment characteristics in the population).

If $t_{cr} < t_{cor}$ the null hypothesis is rejected (the parameter is associated with catchment characteristics in the population).

Where t_{cr} is the critical t value obtained from the t-student table depending on the degree of freedom and the level of significance α usually 5% significance level.

To test the hypothesis is the critical value of the t-test has to be calculated experiments usually used either 5% (0.05) or 10% (0.1) significance level. Even if the choice of appropriate significant level is subjective and different from discipline to discipline mostly used significance level is 0.05 (5%). And for this study 5% significance level and two-tailed tests of $n-2$ degree of freedom are adopted $t_{cr}=2.132$ (critical value from t-distribution table). Solving equation 3.17 for $t_{cr}=t_{cor}$, $r=0.73$ where a correlation coefficient greater than 0.73 will be significant at a 95 % significance level.

Multiple regression: The model for multiple regression is given by

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad 5$$

Where: - β_1 , β_2 , and β_n are regression coefficients, β_0 is intercepting for the regression line, X_1 , X_2 , X_n are the independent variables (PCCs) and Y is the dependent variable (model parameter). In multiple regression analyses, it is possible to predict dependent variables from the asset of different multiple independent variables. In statistical methods, the order for which the independent variables (PCCs) to be entered into the model or out of the model will be tested according to the strength of their correlation with the dependent variables (model parameters). During multiple regression analyses, either forward entry method or backward elimination method or both may be applied at a time.

2.5.2. Test of Strength

A test of significance of individual coefficients: Using the t- student test, the importance of a regression equation can be checked. T_{cal} is the ratio to the corresponding standardized error of the calculated partial regression coefficients and is available in the Excel ANOVA table.

$$Y' = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_n X_n \quad 6$$

Ho, specific: $\beta_1=0$

H1, specific: $\beta_1 \neq 0$

Ho, specific: $\beta_2=0$

H1, specific: $\beta_2 \neq 0$

Ho, specific: $\beta_3=0$

H1, specific: $\beta_3 \neq 0$

Ho, specific: $\beta_n=0$

Hn, specific: $\beta_n \neq 0$

If $t_{cr} > t_{sta}$ Ho, specific is accepted for the specific regression equation

If $t_{cr} < t_{sta}$ H1, specific is accepted for the specific regression equation

Where t_{cr} is the critical t-value obtained from t-table depending on the degree of freedom (n-2) significance level α , n is the number of samples. t_{sta} is the t-value of relation from the ANVO table.

A test of the overall significance of a regression: Instead of measuring individual coefficients, all the hypothesis that all the real regression coefficients are nil is checked and thus none of the independent variables helps to explain the dependent variable variance. By using the F-test, the overall importance of the relationship is checked.

$$Y' = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \dots \beta_n X_n \quad 7$$

Ho: $\beta_1=0, \beta_2=0, \beta_3=0, \beta_n=0$ all the regression coefficients of model parameters and physical catchment characteristics is zero accepting the null and rejecting the specific hypothesis.

H1: $\beta_1 \neq 0, \beta_2 \neq 0, \beta_3 \neq 0, \beta_n \neq 0$ all the regression coefficients of model parameters and physical catchment characteristics are not zero hence rejecting the null and accepting the alternate (specific hypothesis).

If $F_{cr} > F_{cal}$ the null hypothesis is accepted (hence parameter is not associated with catchment characteristics in the population).

If $F_{cr} < F_{cal}$ the null hypothesis is rejected (hence parameter is associated with catchment characteristics in the population). Where F_{cr} is T value determined from F-table depending on the level of significance α , n and p providing that α , is the level of significance, is the number of sample and p, is the number of regression coefficients. And F_{cal} is t value of the regression from the ANOVA table.

R^2 (Coefficient of determination): Concerning the given data sets, the quality of fit of the regression equation is clarified by R^2 called the determination coefficient provided by,

$$R^2 = \frac{SS_{regression}}{SS_{total}} \quad 8$$

Where the sum of the square for the regression is SS regression, and the sum of the square for the total taken from the ANOVA table is SS total. R^2 values approaching 1 provide a strong estimator of the data for the regression equation. Thus, 100% of the total variance in the data set is clarified by the regression equation.

2.6. Water Balance Components

Inflow from gauged and ungauged catchments, the outflow from the lake, Overlake evaporation, and over lake precipitation are components of water balance considered for Lake Tana for this study and take account of upstream abstractions from key irrigation and hydropower projects setting groundwater components as zero in the water balance equations.

2.6.1. Lake Precipitation

Thiessen polygon was used to estimate lake rainfall for the observed, baseline, and future periods. Gauged stations near and around the Lake were used for the analysis of rainfall over the lake to simulate lake water balance (storage). The baseline and future period grids in the lake were computed using the Thiessen polygon approach.

2.6.2. Inflow Contribution from Gauged Catchments

Parameters for nine measured catchments have been determined through calibration and validation processes. Therefore, daily inflows from the calculated catchments for the baseline scenario (i.e. 1976-2005) and future scenarios of RCP4.5 and RCP8.5 scenario level were estimated using the calibrated model parameters.

2.6.3. Inflow Contribution from ungauged Catchments

Parameters for six gauged catchments were calculated using model parameters transferred from gauged catchments to ungauged ones through the regional model regionalization approach by establishing a consistent relationship between physical catchment characteristics and gauged catchment model parameters and then using the established gauged model parameter equations as a function of PCCs. Therefore, daily inflows from the ungauged catchments were calculated for the baseline scenario (i.e. 1976-2005) and future RCP4.5 and RCP8.5 scenarios using the calibrated model parameters, daily rainfall, daily mean temperature, and long-term monthly evapotranspiration of each ungauged catchment.

2.6.4. Outflow Component

To estimate changes in lake storage overtime for the baseline, further outflow from the period 1976-2005 at Bahir Dar station was taken and the minimum environmental release given by previous studies is considered for future scenarios considering upstream irrigation projects. In this study, outflow from the Lake Tana to Abay River and outflow from the lake to the hydropower of Tana belles were also taken and considered.

A. Outflow through Chaira-Chairra to Abby River and Tana belle's hydropower

In this analysis, the outflow from the Lake to the Abay River and the outflow from the Lake to the Tana Belles hydropower projects were considered.

By transferring a mean annual discharge of 2804.1Mm³ based on 2012 and 2013 data collected from the project, the Tana Belles hydropower plant was taken as outflow components (Dessie *et al.*, 2017). For these studies, this value has been explicitly used and implies constant demand shortly. Therefore, in the coming future scenarios, the mean annual outflow from Lake Tana to the Tana Belles hydropower project has been taken to be 2084.1Mm³.

For the baseline period (1976-2005), the outflow portion from the Lake to Abay river was considered from the data collected at the Ministry of Water while the outflow for future scenarios was correlated with the full development of large-scale and small-scale irrigation projects only released from the environment (allowance to preserve the downstream environment, ecology, and habitats) was considered to be dependent on the full development of large-scale irrigation projects. The allowance to maintain the aesthetic benefit of the Blue Nile fall from the Lake outflow is not considered here. As the Tana Belles is not operational, the only outflow portion was an outflow via Chaira-Chairra weir to Blue Nile fall for the baseline span (1976-2005).

B. Lake Evaporation

The standardized and well-accepted approach for assessing evaporation over the lake is Penman-combination. Even though penman-combination is well known as a standard method by various researchers due to the requirement for different input variables, and input variables such as relative humidity, sunshine hour, and wind speed are not available in the climate model for this analysis, it is therefore impossible to directly use the method. Using the principal stations available within and close to Lake Tana for the period 1988-2005 over lake evaporation has been estimated by Penman-combination and evaporation over the Lake for the baseline period (1976-2005) were computed by the Enku method.

Climate parameters used in the penman –combination formula such as sunshine, relative humidity, and wind speed is taken from the principal stations (Gondar and Bahir Dar). Then an equation has been developed that showed Evaporation over the lake by penman-combination is expressed as a function of evaporation over the lake by (Enku and Melesse, 2013). Hence over Lake Evaporation for the baseline and future periods is computed using the formula developed by penman-combination as a function of temperature-based estimates. According to Hari, (2016) the Penman method is given by equation 9 which computes evaporation over the water surface.

$$PET = \frac{AHn + EaY}{A + Y} \quad 9$$

Albedo for water surface is recommended to be 0.05, the study carried out by wale et al, (2008) on Lake Tana using satellite image (MODIS) analysis over the lake for the period from 1994-2003 which is the base period considered in this study has been determined an average albedo value of 0. 058. Hence in this study, an average value of 0.054 was taken for analysis.

Surface evaporation was determined by Enku and Melesse method which entirely depends on maximum temperature and is given by the equation.

$$ETO = \frac{(TMAX)n}{k} \quad 10$$

Where T_{max} is the maximum temperature, n is 0.25 which is locally calibrated and k is a function of the mean of maximum temperature for both wet and dry period conditions. Therefore, after determining over lake evaporation based on penman equation-9 using Bahir Dar meteorological data for the period 1994-2005 and estimating evapotranspiration over the lake based on the Enku method equation -10 for the baseline period from 1976-2005 a relationship was developed between Penman's-combination and Enku method. The relation using regression is given by.

$$ETp = 0.336 + 1.05 * ETE \quad 11$$

Providing the coefficient of determination (R^2) values of 0.81. Where ETP is over lake evaporation by penman-combination and ETE is evaporation over the lake based on maximum temperature only (evaporation determined by Enku's). Hence over lake evaporation for the climate data (i.e., for the baseline period and future scenarios) was determined by the relation developed above computing evaporation on maximum temperature based and inserting the values in place of ETE for equation -11.

C. *Upstream abstractions*

For this study large- and small-scale irrigation projects giving services and implemented to the near future and domestic demand from Gilgel Abay and Megech dams have been considered. In computing future upstream abstraction demand amount by reservoirs, a simple water balance equation has been used and is given.

$$\frac{S}{\Delta t} = Is - Os \quad 12$$

Where I_s is an annual inflow to the reservoir in (m³/s) and O_s is an outflow from reservoirs', the inflow component includes annual inflow to the reservoir and rainfall on the reservoir in m³/S and the outflow component includes annual irrigation and domestic demand, evaporation over the reservoirs, environmental release, and spillover in m³/s. Future evaporation on upstream reservoirs has been computed by making the relationship between T_{max} -based estimates of evapotranspiration and the Penman-combination method. Climate data such as relative humidity, sunshine, mean temperature, and wind speed were taken from the observed meteorological station available in the water shade area where upstream dams (reservoirs) are located. The observed period taken was 1994 to 2005 for Jemma, Megech, Koga, and Gilgel Abay dams and, from 2004 to 2005 for Rib and Gumara dam.

The long-term monthly evaporation over dam-reservoirs for the period specified above have been estimated by penman-combination and the long-term evapotranspiration for the base period (1976-2005) was also computed by Enku and Melesse (T_{max} based estimates). Finally, a regression equation has been developed describing evaporation over the reservoirs by pen-man combination as a function of evaporation by Enku and Melesse (T_{max} -based estimate of evaporation). An albedo value of 0.05 was taken for all reservoirs in computing evaporation by penman-combination as recommended for the water surface by (Hari, 2016).

The relationship made between Penman-combination evaporation estimation and Enku evaporation estimation for upstream reservoirs considered in this study is given (in Table 2) for Gilgel Abay and Jemma, Gumara, Koga, Rib, and Megech reservoirs.

Table2: Relationship b/n penman and Enku's evaporation estimations

Dams(reservoirs) considered	Developed equation	Coefficient of determination(R^2)
Gilgel Abay	$ETo(pen - man) = -2.52664 + (1.47 * ET - Enku)$	0.97
Jemma	$ETo(pen - man) = -2.52664 + (1.47 * ET - Enku)$	0.97
Gumara	$ETo(pen - man) = -1.556 + (1.669 * ET - Enku)$	0.89
Koga	$ETo = 0.192162 + (0.840741 * ET - Enku)$	0.87
Rib	$ETo = 1.141498 + (0.848268 * ET - Enku)$	0.83

Hence based on the above relationship for all reservoirs and using future Tmax evaporation have been estimated by the Enku method and then put that value in the place of ET-Enku in the above equations evaporation over reservoirs were computed step wisely. Monthly demand and environmental flow data, elevation-area-capacity curves were obtained from the project feasibility study. To account for small-scale irrigation abstractions the total irrigable area is estimated by previous studies in between 10% and 11% of the total sub-basin excluding the Lake. This study has taken the average figure to be 10.5% of the total sub-basin area excluding the Lake. The total area excluding the Lake is 11976.80 Km² and 10.5% of the total irrigable area is 1257.6Km². The total area covered by large-scale irrigation is 856. 77Km².Hence the area covered by small-scale irrigation is the deducted value of large-scale irrigation coverage from the total irrigable area in the basin on average of 10.5% and is estimated to be 400.79km². The large-scale irrigation demand above ranges between 988 - 657. 5mm, considering the average value demand for small-scale irrigation is taken to be 799 mm.

3. RESULTS AND DISCUSSIONS

3.1. Model results

3.1.1. Sensitivity of Model Parameters

The sensitivity analysis of the model was performed based on the results of NS and RVE using graphical plots and visualizing changes (steeply change or gentle change) in Gumara, Kiltie, Koga, Gilgel Abay, Megech, and Rib catchments. Sensitive model parameters are different from one to another (i.e., a model parameter that is more sensitive in one water shade might be less sensitive to other water shades). For Gumara, Kiltie, Koga, Gilgel Abay, Megech, and Rib catchments the most sensitive parameters were BETA, FC, and LP while ALFA, CFLUX, K4, KHQ, and PERC are less sensitive. The extent of sensitivity of model parameters varies from one catchment to another. This is due to variation in catchment characteristics and variations due to topography, and rainfall characteristics.

3.1.2. Calibration

For this study model calibration result shows good performance for Gilgel Abay and Rib watersheds with NS greater than 0.8 and RVE value in between -5% and +5%while for Koga, Kiltie, Megech, and, Gumara the model showed reasonable acceptance with NS greater than 0.6 and RVE value ranges in between -10 and 10%. For gauged catchments having small areas such as Gemero, Garano, and Gelda calibration result was not satisfactory. Hence for small area catchments, rainfall-runoff time series cannot be considered exact and the model parameters of those catchments cannot be used for any types of regionalization approach, and streamflow in the future period from this catchment is computed by assuming as ungauged catchments and transferring

model parameters from catchments providing satisfactory performance results (Table 3). The calibration results of Gilgel Abay and Gumara have been displayed respectively in Figure 2.

Table 3: Model parameter and performance results during the calibration period

	ALFA	BETA	CFLUX	FC	HQ	K4	KHQ	LP	PERC	NS	RVE
Gumara	0.200	1.0000	0.400	400	6.2	0.0015	0.10	0.7	0.600	0.79	3.70
Kiltie	0.010	1.5000	0.009	1000	3.8	0.0010	0.20	0.3	0.900	0.63	-1.27
Koga	1.100	1.5000	0.001	1300	4.3	0.0010	0.05	0.9	0.010	0.72	1.05
Gemero	0.008	1.5000	0.001	1500	5.9	0.0009	0.20	0.3	0.001	0.19	-0.33
Garno	0.200	2.0000	0.001	1500	6.2	0.0010	0.10	0.8	0.100	0.24	1.57
Gelda	0.500	0.0010	0.001	200	35.0	0.0800	0.10	0.8	6.000	0.11	-29.24
Gilgel Abay	0.400	2.0000	0.400	200	7.2	0.0012	0.09	0.8	1.600	0.80	-0.72
Megech	0.900	1.2000	0.100	500	3.4	0.0010	0.10	0.9	0.200	0.68	8.98
Rib	0.554	1.1450	0.350	800	2.2	0.0010	0.10	0.3	0.139	0.80	-0.69

Figure 2: Comparison of observed and simulated discharge during calibration period for Gilgel Abay (A), Gumara (B), for the period (1989-1999),

The simulated and observed hydrograph above for the optimized parameter shows good agreement in representing the base flow, Rising limb, and recession limb for all catchments (Figure 2). As shown on the hydrograph the simulated discharge is underestimated while the observed discharge is overestimated. This might be due to rainfall variability in representing the areal rainfall of the area and in some gauged station recorded data show peak value there might be typing errors. The overall calibration result showed good agreement according to the performance evaluation criteria (RVE and NS).

3.1.3. Validation

In this study, the result of model validation performs reasonably as the calibration period shows. The NS and RVE performance of the model validation for Gumara and Megech showed an increase in their performance relative to the calibration period, for Kiltie, Koga Rib, and Gilgel Abay NS value showed an increment in model performance whereas RVE kept in a reasonable range. The overall validation results showed reasonable results having an NS value greater than 0.6 and RVE value ranges between -10% and 10%. NS value for Gumara, Kiltie Koga, and Gilgel Abay. Megech and Rib are 0.8, 0.64, 0.7, 0.82, 0.801 and 0.82 while RVE value is -1.5, 6.93, -3.04, 8.79, -5.89 and 8.5 respectively. Figure 3 shows the validation results of Gilgel Abay and Gumara, respectively.

Figure 3: Comparison of observed and simulated discharge during the validation period for G/Abay (A), Gumara (B), from (2000-2005),

As shown in (Figure 3) the simulated and observed hydrograph showed good agreement in representing the base flow, rising limb, and recession limb of hydrograph components. Hence the validation of the model confirms the model parameters optimized during the calibration period the performance of the model during calibration and validation has shown good performance. Even though the model performance showed good agreement the model underestimates the simulated discharge. This might be due to rainfall variation that is not exactly representing the area rainfall, and other reasons may also be typing errors that provide peak discharge for observed data.

3.2. Results of Regionalization

3.2.1. Simple linear regression

The correlation coefficient has been computed between model parameters and physical catchment characteristics to define the significance of each relation. When the correlation coefficient lies outside the critical values t_{cr} (-0.73 to 0.73) the corresponding correlation between MPs and PCCs is significant.

Hence the null hypothesis is rejected. The correlation matrix analysis between model parameters and catchment characteristics shows 25 significant relations out of 279 correlations indicating significant relations by bold. All volume controlling and shape controlling parameters have at least one significant relationship with catchment characteristics. In Table 3 significant correlation coefficients are presented and marked as bold.

3.2.2. Multiple Regression

Multiple regression analysis: In reality using multiple regression associated with multiple independent variables provides better results than the simple regression approach where one independent variable involves the regression equation. To optimize the linear relations developed multiple regression with forwarding entry or backward removal method has been computed. Multiple regression analysis will help us to make multiple relations of the dependent variable for multiple independent variables. Optimization of catchment characteristics will be carried out by removing catchment characteristics that are highly correlated to each other. This was done based on forwarding entry and backward removal. The relation associated with the model parameter as a function of physical catchment characteristics has been selected based on the above-mentioned criteria (Table4).

Table4: Statical characteristics of model parameters regression equation

Parameters	R ²	F	Final equations
ALFA	0.89	12.8	$Alfa = 2.59 - 0.04 * cultivatd\ land + 0.012 * \% \text{ of level}$
BETA	0.85	22.52	$Beta = 0.21 + 0.83 * dry$
FC	1	1101800	$FC = 1904.9 - 34.83 * Nitosols - 11.3 * \% \text{ hill} - 196 * Fluvisols - 60.5 * urban$
K4	0.98	82.4	$K4 = 0.0006 + 2E - 05 * \% \text{ of luvisols} + 0.00052 * \% \text{ of Fluvisols}$
PERC	0.98	85.9	$PERC = -1.37 + 1.47 * dry - 0.42 * \% \text{ of marshland}$
KHQ	0.99	75.6	$KHQ = -0.11 + 0.001 * average\ slope + 0.001 * vertisols - 0.016 * \% \text{ of forest land} + 0.11 * dry$

LP	0.93	8.9	$L_p = 1.8 + 0.05 * \% \text{ of forest land} - 0.012 * \% \text{ of the vertisols} - 0.012 * \text{average slope}$
HQ	0.87	9.92	$HQ = -10.99 + 12.9 * \text{climate index} + 1.4 * \% \text{ urban area}$
CFLUX	0.91	41.4	$C_{\text{flux}} = -0.09 + 0.00032 * \text{area}$

3.2.3. Estimation of Model Parameters for Ungauged Catchments

In this study area, a total of 10 ungauged catchments and not well-gauged catchments have been identified. Four of them are downstream of simulating gauged catchment, three of them are those which are not well gauged and the remaining three are not gauged (Derma, Tana-west, and Abagenen). Hence model parameters for these ungauged catchments are computed by inserting their appropriate PCCs values into the established regional model, and then finally putting model parameters and other input parameters associated with climate, vegetation zone, and area into the hydrological model (HBV) discharge for each ungauged catchment have been predicted (Table 5).

Table 5: Model parameters for ungauged catchments

Ungauged-catchment	Beta	FC	Cflux	Hq	Alfa	K4	Perc	Lp	Khq
Abagenen	0.992	1483	0.021	1.398	1.036	0.001	1.392	0.499	0.064
Derma	1.006	910	0.067	2.019	0.842	0.001	2.273	0.005	0.148
Garno	0.718	1170	0.011	1.613	1.475	0.001	0.468	0.467	0.063
Gelda	0.977	1311	0.01	3.449	0.552	0.001	0.136	0.597	0.022
Gemero	0.887	1308	0.022	2.414	1.781	0.001	0.262	0.45	0.094
Gilgel Abay	1.074	1542	0.499	4.824	1.011	0.001	0.64	0.259	0.103
Gumara	0.721	1295	0.002	1.9	1.301	0.001	0.595	0.948	0.101

Megech	1.061	1319	0.035	3.972	1.512	0.001	1.48	0.042	0.152
Rib	0.681	1013	0.064	0.541	1.343	0.001	0.533	0.627	0.081
Tana west	0.901	564.3	0.08	0.534	0.445	0.001	0.142	0.797	0.008
Garno	0.808	773.9	0.071	1.225	0.957	0.001	0.308	0.548	0.062
Gelda	0.973	969.5	0.091	2.15	0.231	0.001	0.014	1.165	0.075
Gemero	0.855	1010	0.05	0.291	1.237	0.001	0.224	0.397	0.087

3.2.4. Validation of Simulated Lake Level with Observed Lake Level

To confirm the accuracy of the estimated water balance components of Lake Tana the observed mean monthly water level time series data for the Lake for the period from 1998- 2002 has been compared with that of simulated lake level computed based on the form of equation 4.1 described in the equation without the closure terms (Figure 4).

$$H(t) = H(t - 1) + P(t) - E(t) + \frac{Is(t) - Qs(t)}{A(t)} \quad 13$$

Where H (t) and H (t-1) represents Lake level for the current and previous month in meter respectively, P (t) is over lake rainfall in meter E (t) over Lake evaporation in meter, Is (t) and Qs (t) is the inflow and outflow respectively in Mm³ per month, A (h) is the Lake surface area in km² corresponding to the Lake level at the current time step.

The area-elevation capacity curve relation developed by (Wale *et al.*, 2009) bathymetric survey has been used to compute area at the current step (validation period) and is given by the following relationships

$$E = 1.21 * 10^{-13} * V^3 - 1.02 * 10^{-8} * V^2 + 6.20 * 10^{-4} * V + 1774.63 \quad 14$$

$$A = 7.93 * 10^{-11} * V^3 - 5.81 * 10^{-6} * V^2 + 1.65 * 10^{-1} * V + 1147.51 \quad 15$$

Where: - A is the area in km² and V is the volume in Mm³. Using equations 13, 14, and 15 Lake Level has been computed. The graph below shows simulated and observed Lake Level for the period 1998 to 2002 on a monthly based.

Figure 4: Simulated and observed Lake Level

The performance for simulated Lake Level has been evaluated based on relative volume error (RVE) and Nash-Suctlife (NS) value providing 6.44 and 0.7 for RVE and NS respectively. The simulated Lake level result showed in the range of reasonably good for further analysis providing RVE (between -10 and 10) and NS greater than 0.6.

The misfit between the simulated and observed Lake level may be due to uncertainties on hydro-meteorological records or due to abstraction of water from springs, rivers, and from the Lake for a different purpose that is not taken into account. Further uncertainty related to Lake Evaporation estimation, ground-surface water, and related to un-account losses may be the reason for misfit. As we see from the graph especially for the period from 2001 to 2002 Lake Level decreased from previous periods.

3.3. Overall Water Balance Components

3.3.1. Inflow from Ungauged catchments

The annual ungauged inflow indicates the systematic increase and decreases in the future time horizon, as shown in figure -5 for RCP4.5 and 8.5 scenario 2040s and 2070s-time horizon. Horizon RCP4.5 scenario indicates a decrease in an annual surface water inflow of between 4.5-29.3 percent for some of the years at each time, 4.4-35.6 percent for the 2040s and 2070s respectively, and on the contrary, some of the years indicate a rise in annual surface inflow of between 0.61-113.1 percent, 3.3-79.9 percent for the 2040s and 2070s respectively relative to the baseline scenario. The annual ungauged inflow

indicates the systematic increase and decreases in the future time horizon, for RCP8.5 scenario 2040s and 2070s-time horizon. Horizon RCP8.5 scenario indicates a decrease in an annual surface water inflow of between 2.22-32 percent for some of the year, 8.7-33.74 percent for the 2040s and 2070s, and on the contrary, some of the years indicate a rise in annual surface inflow of between 7.84-95.9 percent, 3.27-65.5 percent for the 2040s and 2070s respectively relative to the baseline scenario respectively (Figure 5).

Figure 5: Change in annual ungauged inflow for RCP-4.5 and 8.5 scenarios as compared to the base

3.3.2. Inflow from gauged catchments

The annual calculated inflow indicates the systematic increase and decreases in the future time horizon, as shown in figure -6 for the RCP4.5 and 8.5 scenario 2040s and 2070s-time horizon. Horizon RCP4.5 scenario for some of the year at each period shows a decrease in an annual surface water inflow of between 0.36-41.24 percent, 2.02-48.4 percent for the 2040s and 2070s, and on the contrary, some of the years show a rise in annual surface inflow of between 0.43-73.99 percent, 4.9-49.98 percent for 2040s and 2070s respectively relative to the baseline scenario. The annual calculated inflow indicates the systematic rise and decreases in the future time horizon, for RCP8.5 scenario 2040s and 2070s-time horizon. Horizon RCP8.5 scenario shows a decrease in an annual surface water inflow of between 0.43-30.192 percent, 1.2-44.4 percent for the 2040s and 2070s respectively for some of the years at each time, and on the contrary, some of the years show a rise in annual surface inflow of between 2.51-73.4 percent, 0.64-65.5 percent for the 2040s and 2070s respectively compared to the baseline scenario (Figure 6).

Figure 6: Change in annual gauged inflow for RCP 4. 5 and 8.5 scenarios as compared to the base

3.3.3. Lake Evaporation

For the baseline and future scenario, over-lake evaporation was calculated using the relationship formed by the Penman and Enku process. The long-term monthly evaporation of the lake from all-time horizons of RCP-4.5 and RCP-8.5 scenarios indicates a growing pattern. Evaporation increases in the range of 3.6-7 percent, 4.5-19.02 percent for RCP-4.5 scenario for the 2040s and 2070s respectively. The long-term potential of Lake Evaporation rises by 4.55-9.94 percent, 9.27-24.71 percent for the 2040s- and 2070s-time period, respectively, for the RCP-8.5 scenario. In general, evaporation over the lake indicates a systemic rise throughout the entire period in the future scenario (Figure 7).

Figure 7: Changes in the mean monthly future Lake evaporation over 30 years for the RCP-4.5 and 8.5 scenarios.

3.3.4. Lake Rainfall

In the lake and around the lake, the rainfall grid data was averaged to be weighted to the lake for the baseline scenario and RCP-4.5 and RCP-8.5 future scenarios. Rainfall over Lake shows no clear rise or decrease pattern for RCP 4.5 rather increased to a certain year and decreased for other years. For RCP 4.5 Lake precipitation rises in the range of 0.014-63.7 percent, 1.66-38.03 percent for the 2040s and 2070s, and on the contrary decreases in the range of 0.99-28.2 percent, 0.98-28.07 percent for 2040s and 2070s respectively.

For RCP 8.5 Lake precipitation decreases in the range of 0.87-32.6 percent, 0.12-36.2 percent for the 2040s and 2070s and contrary rises in the range of 3.31-64.14 percent, 0.45-49.62 percent for 2040s and 2070s future time horizon respectively (Figure 8).

Figure 8: Changes in annual rainfall for RCP -4.5 and 8.5 scenarios as compared to the baseline scenario.

A. Upstream Abstractions

As a large quantity of water is abstracted and will be abstracted shortly, it is important to consider all the expected and suggested irrigation in the Lake water balance report. In the Lake Water Balance Computation, both large-scale and small-scale irrigation abstractions were taken into account in this analysis. The annual demand for irrigation, domestic demand, and environmental release for the estimation of annual dam water abstraction was taken from the project feasibility study report.

A simple water balance equation has been implemented to account for the annual abstraction providing storage is inflow amount minus outflow amount. For each reservoir, the inflow components for the various time horizon scenarios, RCP4.5-2040s, RCP4.5 -2070s, RCP8.5 -2040s, and RCP8.5 -2070s were calculated based on the area ratio approach from the nearest measuring station. Flow for Rib dam is transferred from Rib gauged station at Bridge site in the Bahir Dar to Gondar asphalt way, inflow for Megech reservoir is taken at Megech gauged station near Azezo downstream of the dam, and inflow for Gumara, Gilgel Abay, Koga, and Jemma was also transferred by area ratio from Gumara gauged station near Bahir Dar, Gilgel Abay gauged station, Koga gauged station, and Koga gauged station respectively.

Using the areal proportion of the respective watershed to the reservoir area, precipitation and evaporation over the reservoir have been calculated. The total amount of water abstracted was taken as the annual net storage plus the annual demand (the amount of water that was deducted as an outflow portion in the Lake water balance computation). The total irrigable area of 400.79 km² and 799 mm of annual average demand has been estimated for small-scale

irrigation and the total abstraction of water demand by small-scale irrigation is estimated at 320.2Mm³. This number in the coming future has been predicted to be constant.

3.4. Projected Future Lake Water Balance Computation

On an annual basis, the lake water balance was carried out. Water balance research or assessment without taking into account the effects of climate change can provide better interpretation if it is conducted every month, but the impacts of climate change must be conducted on a 30-year annual average based on the world meteorological organization. This is because it would smooth the effect of climate change by increasing the time and offers the incorrect inference to what degree the impact of climate change changes the water balance (storage) of the Lake. For the various RCP scenarios of different time horizons, Table -6 shows the summer of water balance components with predicted percentage change and the overall change in storage. Based on the inflow and the outflow of Lake Tana, the water balance has been determined. The total amount of inflow from gauged and ungauged catchments and, Lake Rainfall, are the inflow components both in the baseline and future scenario.

Outflow elements for the baseline and future scenario have been accounted for differently. The outflow portion of the baseline scenario (1976-2005) includes lake evaporation and outflow to the Blue Nile River reported by the Ministry of Water and Irrigation for the period 1976-2005 at Bahir Dar station. The minimum environmental release permitted for Blue Nile fall for environmental protection, outflow to Tana Belles Hydropower project, and large-scale and small-scale irrigation abstractions is for potential scenarios (RCP 4.5 and 8.5 of the 2040s- and 2070s-time horizon).

For the reference duration from (1976-2005) and two RCP scenarios of the two time horizons (the 2040s) and (2070s), the lake water balance was estimated. To estimate total inflow to the lake, the amount of total average thirteen-year inflow from nine gauged and ten ungauged was taken. Surface inflow for the future time horizon is calculated based on the dynamically downscaled rainfall, temperature, evapotranspiration, and model parameters calibrated (Table 6).

Table 6: Overall water balance components (Mm³) and future percentage change (%) from the baseline

lake water balance components	Base- period	RCP-4.5(2040s)	RCP-4.5(2070s)	RCP-8.5(2040s)	RCP-8.5(2070s)
ungauged- inflow	2366.6	2612.6(+10.4%)	2691.1(+13.7%)	2712.5(+14.6%)	2739.1(+15.7%)

Gauged- inflow	3662.0	3617.5(-1.2%)	3667.5(+0.1%)	3772.2(+3%)	3655.4(-0.2%)
Lake rainfall	3873.3	4029.6(+4%)	4096.4(+5.8%)	4123.3(+6.5%)	4256.1(+9.9%)
Lake- evaporation	4662.1	4947.1(+6.1)	5065.1(+8.6%)	4983.2(+6.9%)	5307.6(+13.8)
Outflow to Blue Nile	3721.7	863.0	863.0	863.0	863.0
Outflow to Tana Belles	0.0	2804.1	2804.1	2804.1	2804.1
Large scale Abstractions	0.0	129.70	129.68	129.67	129.71
Small scale Abstractions	0.0	320.2	320.2	320.2	320.2
storage change	1518.1	1195.7(-21.2%)	1272.9(-16.1%)	1507.8(-0.7%)	1225.9(-19.2%)

The + sign indicates an increase in percent relative to the baseline and the -sign also indicates a percent decrease. In general, the ungauged surface water inflow result for all RCP scenarios of different time horizons shows an increasing trend while gauged surface water inflow shows a decreasing trend for RCP4,5(the 2040s) and RCP8.5(2070s) and an increasing trend for RCP4.5(2070s) and RCP8.5(2040s). Rainfall and evaporation over the Lake for all RCP scenarios and time horizons show an increasing trend from the baseline period. The increasing trend for over Lake rainfall for all RCP scenarios shows a similar trend with the previous study for the A1B scenario by (Nigatu, Rientjes, and Haile, 2016). The ungauged surface water inflow for all RCP scenarios also shows good agreement with previous SRES scenarios done and gauged surface water inflow shows a similar trend for all RCP scenarios except RCP4.5-2040s and RCP8.5-2070s as previous studies using SRES scenario by (Nigatu, Rientjes, and Haile, 2016). The Lake water balance storage in all RCP scenarios for all time horizons shows a decreasing trend.

4. CONCLUSION

This study shows that there is a hydrological influence on the Lake water balance from climate change. For RCP 4.5 over Lake Rainfall shows neither consistent increase nor decrease trend rather increased to some year and decreased for other years.

The simulated Lake level for the period 1998- 2002 shows reasonable performance with the observed Lake level having an RVE value of 6.44% and an NS value of 0.7. For RCP 4.5 Lake rainfall increases in arrange of 0.014-63.7 percent, 1.66-38.03 percent for the 2040s and 2070s respectively in contrary decreases in arrange of 0.99-28.2 percent, 0.98-28.07 percent for 2040s and 2070s future time horizon respectively. For RCP 8.5 Lake rainfall decreases in arrange of 0.87-32.6 percent, 0.12-36.2 percent for the 2040s and 2070s respectively in contrary increases in arrange of 3.31-64.14 percent, 0.45-49.62 percent for 2040s and 2070s future time horizon respectively. The long-term monthly Lake evaporation for RCP-4.5 and RCP-8.5 scenario of all-time horizons shows an increasing trend. Evaporation increased in the range of 3.6-7 percent, 4.5-19.02 percent for the 2040s and 2070s respectively, for the RCP-4.5 scenario. For the RCP-8.5 scenario, the long-term future Lake Evaporation increases in arrange of 4.55-9.94 percent, 9.27-24.71 percent for the 2040s- and 2070s-time horizon respectively. In general, evaporation over the lake indicates a systemic rise throughout the entire period in the future scenario.

In each time horizon RCP4.5 scenario, some of the years show a decrease in an annual surface water inflow of 4.5-29.3 percent, 4.4-35.6 percent for the 2040s and 2070s, and on the contrary, some of the years show a rise in annual surface inflow of 0.61-113.1 percent, 3.3-79.9 percent for the 2040s and 2070s, relative to the baseline scenario. The annual ungauged inflow illustrates the systematic increase and decreases in the future time horizon for RCP8.5 scenario 2040s and 2070s-time horizon. Horizon RCP8.5 scenario shows a decrease in an annual surface water inflow of between 2.22-32 percent for some of the years at each time, 8.7-33.74 percent for the 2040s and 2070s, and on the contrary, some of the years show a rise in annual surface inflow of between 7.84-95.9 percent, 3.27-65.5 percent for the 2040s and 2070s, relative to the baseline scenario. The RCP4.5 scenario indicates a decline in the annual inflow of surface water of 0.36-41.24 percent, 2.02-48.4 percent for the 2040s and 2070s respectively. In contrast to the baseline scenario for RCP8.5 scenario 2040s and 2070s-time horizon, some of the year's show an increase in annual surface inflow between 0.43-73.99 percent, 4.9-49.98 percent for 2040s and 2070s respectively, and some of the year's show an increase in annual surface inflow between 0.43-73.99 percent. Horizon RCP8.5 scenario shows a decrease in an annual surface water inflow of between 0.43-30.192 percent, 1.2-44.4 percent for the 2040s and 2070s respectively for some of the years at each time, and on the contrary, some of the years show a rise in annual surface inflow of between 2.51-73.4 percent, 0.64-65.5 percent for the 2040s and 2070s compared to the baseline scenario.

The ungauged surface water inflow shows a growing trend for the all-time horizon of RCP 4.5 and RCP-8.5, the 2040S and 2070s, while the gauged surface water inflow shows a rising trend for RCP4.5 (2070s) and RCP8.5 (2040s) and shows a decreasing trend for RCP4.5 (2040s) and RCP8.5 (2070s).

The reduction in the gauged surface water inflow from the gauged Gilgel Abay, Koga, and gauged Gumara watershed would result from decreases in surface inflow. For all RCP scenarios and time domains, the Lake storage demonstrates a decreasing pattern. For all RCP scenarios and time horizons, this may be attributed to a rise in the evaporation of the Lake. Again, a decline in the Lake storage scenario for RCP4.5 (the 2040s) and RCP8.5 (2070s) will occur as a result of a decline in gauged surface water inflow for that scenario and time horizon. For RCP4.5 (the 2070s) and RCP8.5 (2040s), as a consequence of increasing evaporation and irrigation abstractions, scenario reduction in lake storage with increasing ungauged surface water inflow and over lake rainfall will occur.

Declarations

Conflict of interest: We (Authors) have to declare that; we have no known personal relationships that could have appeared to influence the work reported in this paper.

Ethical statement: The authors state that the research was conducted according to ethical standards and we declare that this manuscript is original, has not been published before, and is not currently being considered for publication elsewhere.

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Author contribution statement: Melsew A. Wubneh¹, Tadege A. Worku², Fitamlak T. Fekade¹, Tadele F. Aman², Mekash S. Kiflelew² conceived the presented idea. The corresponding author Melsew Amsalu developed the theory and performed the computations. Other authors have reviewed the work and made an edition.

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