Climate Change Impact on Water Balance of Lake Hawassa Catchment

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Abstract

This study assessed the impact of climate change (cc) on the water balance of the Lake Hawassa catchment. The CMhyd (Climate model data for hydrologic modeling) model was used to correct biases of the Representative Concentration Pathways (RCP) scenarios for 2050's (2041–2070) and 2080's (2071–2100). The impact of cc on water balance components was analyzed by Soil and Water Assessment Tool (SWAT) model and its very good performance during the calibrate and validate periods, respectively are coefficient of determination (R^2) 0.61 and 0.88 and Nash-Sutcliffe efficiency (NSE) 0.81 and 0.85. Projected precipitation (ppt) decreased by 11.4% and 8% in RCP4.5 and 20.67% and 15% in RCP8.5 respectively in 2050s and 2080s. The projected minimum and maximum temperature (Tmin&Tmax) is increased by 26.2% and 15.6% under RCP4.5 and increased by 45.8% and 29.5% under RCP8.5 respectively. The future water balance of Lake Hawassa catchment under RCP4.5 and RCP8.5 by the end of 2100; ppt decreased by 12% and 27%, surface runoff increased by 10% and decreased by 16%, lateral discharge decreased by 39% and 50%, water yield decreased by 27% and 46%, evapotranspiration (ET) increased by 23% and 21% and potential evapotranspiration (PET) increased by 77% and 75.3% respectively. The increment in temperature and the decrement in ppt resulted increment in PET largely because the water holding capacity of air is increased. Moreover, the climatic variations and human influence the water balance of the study has affected. Therefore, constantly monitored and updated sustainable water resources management is needed in the area.

Background

The concentration of greenhouse gases is the driving force for the warming temperature in the world which increases the water holding capacity of the air parallelly also increases potential evaporation (Cherie, 2013). The reason behind this is industrialization and population growth increment in alarming rate. Current IPCC, (2018) report dedicates global warming is likely to reach 1.5^{0}c between 2030 and 2052, if it continues to increase at the current rate. Also, in this report human activities are estimated to have caused approximately 1^{0}c of global warming above pre-industrial levels, with a likely range of 0.8^{0}c to 1.2^{0}c. And also the developing country like Ethiopia, which is less flexible to adjust the economic structures and agriculturally dependable, will be more vulnerable to cc (Margreet and Vicent , 2010). These all show the cc impact is not only a problem of developing countries, but it is the whole universe's attention-seeking issue.

Climate Modelling and Hydrologic modelling

It is known that the general circulation model (GCM) and regional circulation model (RCM) are able to produce time series for a set of climate variables under different emission scenarios (Da Cunha et al., 2007). But which model is preparable accordingly is one main question that should be answered by many investigators and needs great attention too. Not only but also many gaps exist between climate modeling and hydrologic modeling (Xu, 1999). Under climate scenarios basin hydrological simulation technology is the main tool to solve the hydrological variables information (Nan et al., 2011). The recommended approach for cc projection due to the inherent uncertainty of the climate system and the inevitable existence of model error, the multi-model ensemble is stated in the CMIP3 and CMIP5 by IPCC (Randall et al., 2007, Jones et al., 2011 and Daramola, et al., 2017). IPCC on Fifth Assessment Report (AR5) has introduced a new span of the range of plausible radiative forcing scenarios and are called RCPs (Jubb et al., n.d. and Viola et al., 2015). Which is the latest projection scenarios descriptions and publications of; RCP2.6 (Vuuren et al., 2011), RCP4.5 (Clark et al., 2007), RCP6 (Fujino et al., 2006), and RCP8.5 (Riahi et al., 2007) clearly stated by Vuuren et al., (2011). These scenarios will also provide an important reference point for new research with technological and economical models. Many cc impacts studies on hydrology have been taken in Ethiopia; for example, cc impacts on the hydrology of Gilgel Abay catchment in Lake Tana by Abdo et al., (2009) under Hadley Centre Coupled Model3 (HadCM3)-GCM for A2 and B2. In which ppt showed no systematic increase or decrease but streamflow projection by HBV for the 2080s revealed that the runoff volume will be decreased by 11.6% and 10.1% respectively for both scenarios. The finding conducted by Habtom (2009) in the Gilgel Abay reservoir under HadCM3 GCM; the mean annual temperature and ppt increase by 0.53% and 0.82% respectively and reservoir open water evaporation is increased to 6% in the 2080s. The other study was taken by Haileyesus, (2011) cc impact on the hydrology of Abay basin using climate model of RegCM3 revealed that ppt both increasing and decreasing trend but increasing trend in PET in the future.

Water balance is used to calculate the change in the amount of ppt that goes into discharge, evaporation, and storage. There are various methods and models to calculate the water balance of the hydrological system (Devi et al., 2015). However, physically-based models as SWAT, SHE (System Hydrologique European), and tRIB (TIN-based Real-time basin simulator) need a large number of parameters to describe the physical characteristics of the catchment and suffer from scale relation problem (Tina, 2016). While the SWAT model is not like the other can generate water quantity and quality depending on LuLc and soil type under different climatic conditions. In countries like Ethiopia, there is a shortage of long-term observational data series to use sophisticated models; SWAT is computationally efficient and requires minimum data (Setegn et al., 2008, Tekabe and Adane, 2016). The model SWAT has advantages in predicting cc effects on water-related and hydrological processes over long periods, it's a continuous-time river basin scale model and gives in HRU for each sub-watershed (Hydrologic Response Unit) (Yin et al., 2016, Ranjan and Ralph, 2001, Mehan et al., 2017, Yin, et al., 2016, Pignotti et al., 2017). Like most other models, SWAT compares simulated data with the observed data to calibrate the model through parameter evaluation (Caroline, 2013). SWAT Calibration and Uncertainty Program (SWAT-CUP) is an interface program developed to provide calibration, validation, and sensitivity analysis.

Water balance assessment of Lake Hawassa catchment

The shift in ppt and temperature patterns affect the hydrology process and availability of water resources (Nan et al., 2011 and Belay, 2014, Chaemiso et al., 2016). Water resource availability change affects water management allocation and reliability (Girma, 2008). The Lake water has been abstracted for supplementary irrigation, the total amount of water abstraction is negligible compared to all other water balance components (Mulugeta et al., 2017). For better management of the Lake water, the hydrologic components which play a significant role in the Lake level fluctuations need to be understood (Gebreegziabher, 2004 and Lijalem et al., 2007). Understanding the Lake level fluctuation, the knowledge of the Lake's water balance, and its response to cc adding human intervention in the hydrologic regimes is required (Habtom, 2007). Water balance is the inter-relationships between components (Vedran et al., 2017). Actually, water balance components can be affected by climate, LuLc, soil, and all other physical characteristics (cc & Sustainability Committee, 2015).

Lake Hawassa is considered fresh, not like other closed lakes with Alkaline contents in it. Solomon, (2016) indicated in his finding ppt and runoff was affected by cc in this Lake and these changes resulted in increased floods and drought. In which future freshwater availability will be impacted and the freshwater level will rise. Studying Lake water, the hydrologic components play a significant role in the Lake level fluctuations (Gebreegziabher, 2004). As the study by Habtom, 2007 water balance of Lake Hawassa catchment runoff will increase and evaporation will decrease the main reason is LuLc changes. Wondimagegn (2013) projected future climate variables for Lake Hawassa by using A2a and B2a emission scenarios in which there is a significant increasing trend for both Tmin&Tmax, no significant increasing or decreasing ppt trend; mean annual increasing by 1.65% from open water evaporation, and the SWAT simulation of total mean annual inflow volume for the 2020s might rise significantly up to 6.14% and 5.9% respectively for both scenarios. The study was taken by Biruk (2017) water availability by using hydrologic engineering centers- hydrologic modeling system (HEC-HMS) model and all climate models under Coordinated Regional Climate Downscaling Experiment (CORDEX)-Africa program for both RCP4.5 and RCP8.5 showed an increment and decrement up to 27% and 31% respectively in Bilate catchment.

Water balance at the global or regional level must be updated since climate variability parameters mainly changing continually. Lake Hawassa is one of rift valley Lake and the Lake level trends is varying, there should be given attention for the lake body preservation and future cc to have effective adaptation measures to be taken. Many studies have been conducted in the Lake Hawassa catchment (e.g., Mulugeta et al., 2017, Wondimagegn, 2013, Gebreegziabher, 2004). However, research on cc which affects the water balance components (surface runoff, groundwater, lateral flow, water yield, and evaporation) is unprecedented in the catchment and not recently. Concurrent the human influence and climatic variations on the water balance of an area cannot be taken as it's the final rather the process must constantly be monitored, controlled, and updated which is essential to increase awareness and encourage the current protection of the environment. The main objective of this study is to assess the impact of cc on the water balance of Lake Hawassa catchment under HadGEM2-ES climate model output of RCP scenarios. Which helps to gives awareness and preparedness before any natural disaster occurs and to take appropriate measures to adapt cc.

Materials And Methods

Description of the study area

Lake Hawassa catchment as part of the central rift valley system of Ethiopia has an area and perimeter of 1462 km2 and 248 km respectively. An altitude ranges from 1668 meters to 2987 meters above mean sea level and is found about 273 Km south of Addis Ababa the capital city of Ethiopia. The lake catchment/basin lies between two regional government states of Sidama and Oromia. And it is located between latitude 6048’45” to 7049’54” N and longitude 38016’34” to 38043’26” E (Fig.1). The majority of the sub-basin is flat to gently undulating but bounded by steep escarpments with hillier areas in the eastern part. The region is characterized by a dry sub-humid climate, with annual mean rainfall and temperature are about 990 mm and 19.5 c respectively. The ppt pattern is the monomodal type with only one dry season. The main rainy season in the catchment area is from May to October and the dry season goes from November to February. Information regarding soil physical and chemical properties was acquired from food and agricultural organization (FAO) and which is harmonized in the world soil database. The major soil type in the area is; Chromic Luvisols, Eutric Nitosols, Chromic Vertisols, Eutric Fluvisols, Lake portion, Lithosols, Marsh portion, Molic Andosols, Orthic Luvisols, and Vertic Andosols. But the majority of the area is Eutric Fluvisols (Fig.2). On the other hand, LuLc from the Ministry of Water Irrigation and Electricity (MoWIE) of Ethiopia fall under twelve classes (Fig.3). The dominant LuLc classes names and the percentage areal coverage are; annual crop 62.1%, sparse forest 20.1%, water body 6.4%, closed shrubland 5.1%, open shrubland 3.93%, settlement 1.56%, open grassland 0.42%, wetland 0.22%, closed grassland 0.14%, moderate forest 0.06%, dense forest 0.05% and bare soil 0.01%.

Data Types and Sources

Corrected climate data and SWAT hydrological model were used to assess the future cc impact on water balance components of Lake Hawassa catchment. Successfully to accomplish the study we used both temporal and spatial data. The temporal daily data for the year 1989-2018 of Haisawita, Shashemane, Wondo, and Yirba second class and Hawassa first-class climate stations were from Ethiopia National Meteorological Agency (NMA) and Hawassa Regional Meteorological Agency (RMA). And Hawassa station used for weather generator in SWAT model. The discharge data of the Dato gage station for the year 1990-2002 was from MoWIE and was used for SWAT model simulation. Again, the spatial data are soil map and DEM of SRTM with a resolution of 30 meters and LuLc from FAO (food and agricultural organization), http://earthexplore r.usgs.gov and MoWIE respectively. The dynamically downscaled daily-based RCPs data of ppt, Tmin&Tmax for the historical and future periods were freely obtained from http://cordexesg.dmi.dk/esgf-web-fe/ CORDEX Africa database under HadGEM2-ES Global climate model. The RCA4 regional model of RCP4.5 and RCP8.5 with different grid points is interpolated to Lake Hawassa catchment for both med term (2050’s) and end-term (2080’s). Because these pathways or arrangements carry us to the future conditions on social, economic, political features.

Methodology

Missed observed data due to lack of appropriate records, shifting of station location and processing may lead to incorrect and ambiguous results and obviously contradict the actual situation. So, to solve such a problem in this study we used the normal ratio method as its easiness and greater than 10% gap of the annual mean ppt between the station to be filled and the adjoining stations. After that, the data consistency and homogeneity were checked by double mass curve and RAINBOW software analysis to detect the data at a site has been subjected to a significant change in magnitude due to natural and human factors. So, both double mass curve and RAINBOW software analysis of ppt and discharge data of the study assured that they are consistent, homogeneous, and from the same population. On the other hand, CMhyd bias correction procedures were used to minimize the discrepancy between observed and simulated climate variables on a daily time step. CMhyd is a tool that can be used to extract and bias-correct data obtained from global and regional climate models. It is highly recommended to apply an ensemble approach, i.e., to use bias-corrected data provided by several climate models and downscaling methods (Teutschbein and Seibert, 2010 and 2012). And hydrological simulations are driven by corrected simulated climate data and observed climate data reasonably well. So, in this study, we used CMhyd (Fig.4) for bias correction to minimize the discrepancy of future and historical ppt and Tmin&Tmax for both RCP4.5 and RCP8.5. Then climate model is statistically checked between observed and simulated using excel sheet analysis with root mean square error (RMSE), the mean absolute error (MAE), and the relative error (RE). So, their performance is checked between projected climate and observed data by using statistical and the best performing and the worst one is selected depending on the values from statistical measures.

Assessing the impact of clime change on water balance components

Studying the hydrologic consequences of change in climatic variables, the SWAT model is mostly used. And the variables such as terrain, land use, soil characteristics, and state of moisture in the soil govern the process and it simulates hydrological outputs based on a changing climate. Water yield; - as SWAT model is defined as the total amount of water leaving HRU and entering the main channel during the time step or simply what is left of water input after subtracting ET losses. Ppt is the amount of ppt the catchment is going to have monthly or annually. Surface runoff; - SWAT provides two methods for estimating surface runoff whenever the rate of ppt exceeds the rate of infiltration: the soil conservation service (SCS) curve number and the curve number (CN) method. The CN method was used for this study because we don't have the sub-daily data to use the Green and Ampt infiltration method. This method assumes CN I at wilting point, CN II at field capacity, and a CN III of 100 at saturation point and then modified daily based on soil moisture. Peak runoff rate; - SWAT calculates the peak runoff rate (maximum volume flow rate passing a particular location during a storm event) with the modified rational method. Evapotranspiration (ET); - is to include all processes by which water at the earth's surface is connected to water vapor. PET is introduced as a part climate classification scheme, which would occur from a large area uniformly covering with growing vegetation that has access to an unlimited supply of soil water and that was not exposed to advection or heat storage effect. Hence FAO Penman-Monteith method is preferable to compute PET for the study because it considers different climatic parameters. Groundwater; - SWAT has two assumptions simulating the groundwater balance. Shallow-unconfined aquifer and a deep-confined aquifer, the unconfined shallow aquifer is contributing to flow in the main channel or reach of sub-basin. Whereas the deep-confined aquifer is the amount of water percolating from a shallow aquifer into a deep aquifer. Routing; - SWAT uses Manning's equations to define the rate and velocity of flow. Water is routed through the channel network using the variable storage routing method or the Muskingum routing method by the kinematic wave model. Variable storage is the common method and this study used this method. Simulation of the hydrology of a watershed is done in two separate components on the land and routing phase of the hydrologic cycle; respectively controls the water movement in the land and water is routed in the channels network of the watershed. And it commuted as follows;

$$SWt = SWo + \sum_{i=1}^{t}(Rday - Qsurf - Ea - Qseep - Qgw)$$

Where: SWt = the final water content (mmH2O)

SWo=the initial soil water content on day i(mmH2O), t=time

=is the amount of ppt day i (mmH2O)

=is the amount of surface runoff on a day i (mmH2O)

=is the amount of evaporation on day i (mmH2O)

=is the amount of water entering vadose zone from the soil profile on day i(mmH2O)

=is the amount of ground water flow on day i (mmH2O).

SWAT model setup and Model preparation

The SWAT model needs weather data in a format that is acceptable. The input for SWAT model spatial data is; DEM, Soil, Land use land cover shapefiles, and temporal data are; meteorological and streamflow. The spatial data were processed by using Arc GIS 10.4 and ARCSWAT 2012 version and temporal data by sophisticated excel spreadsheet. For missing data of weather, there is a weather generator using ppt value generate temperature, sunshine hour, relative humidity, and solar radiation of the station with missing values. Automatically SWAT model delineates catchment and sub-catchment by using DEM and define the location of the stream network. It also predicts the land phases of the hydrologic cycle separately for each HRU and routes to obtain the total loadings of the sub-watershed. Then the multiple HRUs for each sub-watershed method was adopted as it better describes the heterogeneity within the watershed and as it accurately simulates the hydrologic processes. Within Lake Hawassa catchment there is only one streamflow gage station which does not represent the total lake water balance component. To eliminate this complication, we divided and delineate the catchment into both gaged and ungaged. After that, the percentile of the water balance of the catchment considered the sum of both; generated from the model. The delineated Tikurwuha watershed simulation at Dato station was done, then the sensitive parameters are feed for the ungaged catchment. With land use, soil and slope map overlay in 15%, 20%, and 15% respectively. Here we used the slope has four classifications; 0-2, 2-15, 15-30, and greater than 30 for both gaged and ungaged catchment. The catchment for gaged SWAT number of HRU is 80 and has 38 sub-basins which have area coverage of 640km2 and for ungaged catchment, the number HRU 79 has 26 sub-basin and 517km2 area coverage. The ungaged part of Lake Hawassa catchment streamflow was estimated after calibrating gaged station and the sensitive parameters which area for gaged catchment was updated, using the option of edit SWAT input sub-basin data. Then watershed data updating the sensitive parameter which were on the gaged catchment. As from previously studied result piezometric map southern, eastern and north-western upland are the recharge areas while the northern and the southwestern part of the catchment are the discharge areas for the Lake in the form of groundwater.

SWAT model performance evaluation

Sensitivity analysis is a method to determine which parameters of the model have the greatest impact on the model result. Model parameters impacted by topography, geomorphology of landscape, size of the watershed, land use variation, and human are ranked based on their contribution to an overall error in model prediction. Model calibration is a systematic process of adjusting model parameter values until model results match acceptably the observed data and model validation is a process of testing model ability and effectiveness to simulate observed data other than the used for calibration with acceptable accuracy without changing calibrated model values. This study was used automatic calibration and validation developed in SWAT and SWAT-CUP software with the semi-automated program SUFI2 (Sequential Uncertainty Fitting ver.2). And finally, calibration and validation model performance were checked via Nash-Sutcliffe efficiency (NSE), Coefficient of determination (R2), and Percent bias (PBIAS).

$$\text{Coefficient of correlation } R^2 = \frac{\sum_{i=1}^{n}(Qobs-\bar{Q}obs)2-\sum(Qsim-\bar{Q}sim)2}{\sum(Qobs-Qsim)2}$$

Where $Qobs$ is observed discharge

$\bar{Q}obs$ is the mean of observed discharge

$Qsim$ is simulated discharge

$\bar{Q}sim$ is mean of simulated discharge

$$\text{Nash-Sutcliffe efficiency (NSE)} = 1-\frac{\sum(Qobs-Qsim)2}{\sum(Qobs-\bar{Q}obs)}$$

$$\text{Percent bias (PBIAS)} = \frac{\sum(Qobs-Qsim)2}{\sum Qobs}$$

Results And Discussion

Bias Correction

This study used the main climate parameters of ppt and both Tmin&Tmax under the considerations of observed (1989-2018), historical (1989-2005), and future period (2141-2100) under RCP4.5 and RCP8.5. Then CMhyd model bias correction was applied for five ppt and two temperature (Hawassa and Haisawita) stations to correct depending on the observed period and the result was evaluated mean monthly. The CMhyd bias correction results between five observed stations and model outputs of RCPs ppt statistical performance evaluation by RMSE, MAE and RE assured in Table.1 that the bias-corrected values are much closer to the observed values. Also, the graphical representation of Hawassa station as an example presented here in the Fig.5 a, b and c depicts the RCPs output of ppt, and Tmin&Tmax before bias corrections may lead to huge uncertainty for hydrological analysis especially June, July, August, and September months these are true for other stations. The mean monthly Tmax of this station raw data shows comparatively good relation with the corrected and observed but Tmin is higher in all months and this is true for the other stations too in the study. Respectively areal mean monthly raw, observed and bias-corrected ppt, Tmin&Tmax bar graph in Fig.5 a, b and c shows satisfactory acceptable and reasonably well. So according to Teutschbein and Seibert (2012 and 2013), bias correction procedures are used to minimize the discrepancy between observed and simulated of each station climate variable on a daily time step and simulations driven by corrected simulated climate data and observed climate data reasonably well.

Future areal mean annual, monthly, and seasonal ppt of the catchment

The long year areal mean annual ppt trend over the catchment shows an insignificantly decreasing trend pattern in the observed period but increasing trend pattern both in RCPs (Fig.6 a and b). The percentage change of areal mean annual projected ppt in the 2050s and 2080s will be decreased by 11.4% and 8% respectively under RCP4.5 and under RCP8.5 decreased by 20.7% and 15% respectively compared to the base period. According to Fig.7 future long year, areal mean annual ppt over the catchment projection change under both RCP4.5 and RCP8.5 will be decreased by 9.7% and 17.8% respectively over the catchment. On another hand over the catchment under both emission scenarios the areal mean monthly ppt expected is extremely lower in the months of January, February, March, April, May, and December but from the months of June to November expected to increase. And also, there is less amount of ppt is expected in the catchment in the Bega seasons under both RCPs and in the Belg season under RCP8.5. whereas in the Kiremt season under both RCPs and in the Belg season under RCP4.5 future ppt will show an increment all over the catchment. In which the seasonal percentage change of ppt compared to the base period under RCP4.5 is decreased to 53.6% in the Bega and increased by 24% and 3.4% in the Kiremt and Belg seasons respectively. Under RCP8.5 the expected percentage change of future seasonal ppt is decreased by 62.3% and 5% in the Bega and Belg seasons respectively but in the Kiremt season, 16.4% increment will be expected.

Future mean annual and seasonal Tmin&Tmax of the catchment

Also, the areal mean annual Tmin&Tmax trend graph has shown in Fig.8 for two future projections are significantly an increasing trend. The result, in general, implies that the trend has shown an increasing trend for the Tmin&Tmax over the area but Tmin shows more increasing weightage than Tmax and which proved that there was obvious warming up tendency. The projected annual mean Tmin under RCP4.5 and RCP8.5 is increased by +26.2% and +45.8% respectively in the catchment. Whereas the projected mean annual Tmax under RCP4.5 and RCP8.5 increased by +15.6% and +29.45% respectively. According to the result in the future over the catchment both mean annual Tmin&Tmax increment will be expected and the catchment is going to face meteorological drought. Generally, the relative percentage change of Tmin&Tmax of RCP8.5 is greater than the RCP4.5 for all the months over the catchment.

The future cc projection of Tmin, Tmax, and ppt under emission scenarios of RCP4.5 and RCP8.5 was assessed. As it is discussed above depending on mean annual expected ppt under RCP4.5 during the 2050s and 2080s increment by -11.4% and -8% respectively and under RCP8.5 increment by -20.67% and -15% respectively. According to the graphical representation (Fig.7) of areal mean monthly ppt reveals inconsistent negative and positive increment patterns for all RCPs in the future periods. Which is an ensemble with the study of (Gadissa et al., 2018) on the effect of cc on the loss of Lake Volume of the Rift valley of Ethiopia, using the ensemble mean of five regional climate model (RCM) in the CORDEX, as the result was mean projected ppt will be increased by -7.97% and -2.55% under RCP4.5 and RCP8.5 respectively. Under decreased ppt, the catchment expected Tmin&Tmax is increasing. The study is consistent with the study of (Tesfalem et al., 2018) on the hydrology of Lake Ziway catchment using CMIP5 RCP scenarios annual decrement of rainfall during the 2050s and 2080s was 2.7% and 1.6% respectively. In generally projected areal mean annual Tmin&Tmax positive increment over watershed which is similar to the investigation has been taken in the Rift-Valley basin by (Belay et al., 2012) were, increased extreme daily temperature events prevailed for future scenarios. The maximum amount of temperature change from RCP 8.5 is due to the fact that RCP 8.5 produces more greenhouse gas as compared to RCP 4.5, which is medium and low in greenhouse gas production (Riahi et al., 2011). Furthermore, inter-annual and intra-seasonal rainfall variability in the watershed is accompanied by a significant warming trend in temperature, and reduction of ppt can challenge agricultural products, and an increment in ppt again can lead to unexpected flooding during this season.

Impact of climate change on water balance of Lake Hawassa catchment

Sensitivity analysis

The SWAT analysis was carried out for objective parameters with simulated and measured streamflow of Dato station by using the SUFI-2 algorithm within the uncertainty ranges of 95%. The objective function (i.e., the sum of the squared errors between the observations and the simulation) was calculated during each run, and the performance of the model was checked. The results of the sensitivity analysis gave the degree of sensitivity of parameters and the parameter bound which was important for the manual and auto-calibration activities. The parameters are ranked using two types of sensitivity analysis one at a time (local) which is performed by changing values one at a time and the problem with it is that the correct values of other parameters that are fixed are never known. And the second is global sensitivity which is performed by allowing all parameter values to change which has the disadvantage that it needs a large number of simulations. The user determines which variables to adjust based on expert judgment or on sensitivity analysis. The p-factor is the percentage of the measured data bracketed by the 95ppu. The smaller r-factor, which quantifies the thickness of the 95ppu, the smaller the uncertainties and the better calibration work. Doing the iteration work is to have the value of p-factor close to 1 and r-factor to be close to 0. From the 26 parameters that may affect the hydrology of the catchment the most 10 sensitive parameters which have shown lower p and higher t-stat are selected based on the objective function the iteration in the simulation produces. In this study, the iteration was for 500 simulations and 5 iteration periods in which the parameters which are sensitive are selected. The 10 most sensitive parameters have a meaningful effect on the monthly flow simulation of the gaged River. Curve number CN, Soil Bulk density SOL-BD, Depth from the soil surface to bottom of layer SOL-Z, Soil evaporation compensation factor ESCO, Manning's n value for the main channel CHN2, Mean Slope steepness HRU-SLP were relatively highly sensitive parameters that significantly affect surface runoff while Groundwater delay (GW-DELAY), and base flow Alpha factor (ALPHA BF) were other parameters that mainly influence base period (Table.2).

Model calibration and validation

The calibration of the model was performed in SWAT-CUP by using statistical measures for ten years (01/01/1991-31/12/1999) considering the warm-up period of one year (01/01/1990-31/12/1990). The validation for the model was done without changing the parameters that were used for calibration and it was done for three years starting from 01/01/2000-31/12/2002.

NSE, R2, and PBIAS statistical performance measure values for both calibration and validation period in the Table.3 showed very good and are widely acceptable. On the other hand, the SWAT-CUP model calibration and validation graphically depict very well in Fig.9 a and b respectively in which both graphs clearly showed that the SWAT model well performed

Water balance components under climate change

Lake Hawassa has gaged streamflow only for Dato station, for that reason water balance is studied for two catchments; gaged catchment in Dato station and ungaged catchment which is west of the Lake Hawassa. The analysis was done after updating the sensitive parameters in the Dato catchment to ungaged catchment. The water balance component simulations were analyzed for two emission scenarios for both catchments by using the updated sensitive parameters. Sub-watersheds with the same HRUs have the same responses for Water yield generation and after being modeled the gaged watersheds lumped parameters were transferred directly to ungaged part in this research work, and hence, inflow from ungaged part has been estimated (Shewangizaw and Yonas, 2010).

Water balance for gaged and ungagged catchment under climate change

Annual water balance component

Future water balance components of gaged and ungaged catchment were assessed under RCP4.5 and RCP8.5 emission scenarios for both 2050s and 2080s compared to base period Table.4. In which future water balance components revealed in the gaged catchment that; under RCP4.5 during 2050's and 2080's; ppt -13.6% and -12%, Surface runoff +7.7% and +8.9%, Lateral flow -43.1% and -40.4%, Groundwater flow -58.9% and -56.5%, water yield -27.4% and -25.4%, ET +23% and +24% and PET +74% and +83%

respectively, whereas under RCP8.5 ppt -21.2% and -16.6%, Surface runoff +1.1% and +10.4%, Lateral flow -52.5% and -46.9%, Groundwater flow -71.8% and -66%, Water yield -37.7% and -30.2%, ET +23% and +19.1% and PET +78% and +87.3% respectively. Also in future ungaged catchment water balance components under RCP4.5 during 2050’s and 2080’s negative and positive increments are; ppt -13.9% and -40%; surface runoff +6.7% and -47.2%; lateral flow -35.5% and -53.5%; groundwater flow -62.3% and -78.6%; water yield -28.4% and -62.9%; ET +18.1% and +17.8% and PET +69.9% and +67.4% respectively; and under RCP8.5 ppt -11.4% and -35%, surface runoff +12.1% and -37.4%, lateral flow -33% and -47.4%; groundwater flow -60.8% and -73.5%, water yield -25.2% and -55.4%; ET +19.8% and +17.5% and PET +78.3% and 76.2% respectively.

According to Table.4 ungaged parts of Hawassa lake catchment water balance components assessment result shows the comparatively similar with gaged catchment under two emission scenarios (RCP4.5 and RCP8.5). This indicates in the future the ppt in the catchment going to face is getting reduced; under decreased ppt, the surface runoff is increased under both emission scenarios of RCP4.5 and RCP8.5. Surface runoff occurs when ppt exceeds infiltration capacity, in the projected years the population growth and technological development which were considered when climate emission scenarios developed increases the runoff capacity directly. Looking at the quantity of gaged catchment groundwater contribution will decrease in great number, so preparedness is needed for the allocation of water resources. Generally, under both RCPs Water balance components of Surface runoff, ET and PET will be increased whereas ppt, Lateral flow, Groundwater flow, Water yield will be decreased.

The sum total water balance which the catchment going to face is determined by summing gaged and ungaged catchment water balance components since the water balance that was generated are considered with the respective areal descriptions. Lake Hawassa is a closed catchment and Lake with no surface water outflow. The Lake is fed both by few ephemeral streams on the northwest and western side of the catchment and by the Tikurwuha river, which is the only perennial river, enters Lake Hawassa draining the Cheleleka swamp on the northeast side (Gebreegziabher, 2004). The water balance components from gaged catchment yield a higher amount proportionally compared to ungaged catchment. But for the ET and PET has lower values.

Seasonal water balance component

The future Belg, Kiremt, and Bega seasons water balance components of Lake Hawassa catchment under RCP4.5 and RCP8.5 projections are revealed in the Table.5. In which respectively Belg, Kiremt and Bega seasons; ppt increment by -56.6%, +21.4% and -0.3% under RCP4.5 and -66.6%, +0.8% and -15.25% under RCP8.5; Surface runoff incremenby-55.6%, +40.8% and +79.7% under RCP4.5 and -70.9%, +12.8% and 35.2% under RCP8.5; Lateral discharge increment by -70.8%, -34.5% and -18.8% under RCP4.5 and -77%, -45.5% and -31.7% under RCP8.5, water yield increment by -68.4%, -17.2% and -0.1% under RCP4.5 and -78.9%, -36.6% and -26.9% under RCP8.5; ET increment by +31.3%, +42.5% and -9.8% under RCP4.5 and +28.4%, +40% and -10.5% under RCP8.5; and PET increment by +91.9%, +96.8% and +52.3% under RCP4.5 and +92%, +99.3% and +51.9% under RCP8.5. Generally, from the result, we can inspect ppt, Surface runoff, Lateral discharge and water yield under both projections for Belg will increase in the future. In Kiremt season under both projections water balance will increase except in Lateral discharge and water yield. Whereas in Bega season of both projections shows decrement in water balance in the catchment except in Surface runoff and PET. PET shows greater values for both seasons of Belg and Kiremt under both emission scenarios. This indicates water balance in the catchment is expected to be lower in these seasons as ppt.

Discussion of water balance component over Lake Hawassa catchment under climate change

The impact of cc on the water balance of all over lake Hawassa catchment under both projections presented in the Fig.10 shows in the future there is a decrement in ppt, lateral flow, groundwater flow, and water yield in the 2050s and 2080s. But there is an increment in ET and PET under both RCPs in the 2050s and 2080s and surface runoff will increase in 2050s and decrease in 2080s under both scenarios. Ppt controls the water balance (Nitsech et al, 2011) but under decreased ppt surface runoff will be increased in the future in both projections in the 2050s. In this aspect, runoff occurs when ppt exceeds the infiltration capacity, in the projected year and emission scenario consideration the population growth, and technological development, alter the concentration of carbon and increases pavement of road and that alters the hydrological cycle. The continuous rainfall process causes the soil moisture to increase, which leads to the decrease of water infiltration rate, when the rainfall intensity is greater than the infiltration rate, the filling begins. Once the surface is filled, the surface runoff will be generated. But under RCP 8.5 surface runoff decreases as ppt decreases and that is the cause for the decrease of Water yield which is by 32.2% and 41.3% respectively for the 2050s and 2080s respectively (Fig.10). Water Yield is decreasing for both projection periods under RCP4.5 and RCP8.5, but the percentage change of RCP8.5 decreases highly to 49% that is a great loss. The water yield calculation was by summing up surface runoff, lateral flow into the stream, and groundwater contribution to stream with consideration of transmission losses reduced. Lateral flow decreases under both emission scenarios in which ppt decreases and temperature increases and that reduces the water content of the soil. Comparing Groundwater percentage change depending on emission scenarios, both emission scenario states decreasing but on high range emission scenario, the decrease is up to 69.3% compared to the base period. The future groundwater discharge for Lake Hawassa is decreasing to 69.3% for the 2050s under RCP8.5. The change in ppt which means a change in the amount of effective rainfall will alter recharge, but so will a change in the duration of the recharge season. But PET and ET are showing a highly increasing percentage of from 20% to 81.2%, the deduction is consistent with the climatic prediction for temperature which stated increasing for future and that is the cause for PET and ET. Due to the higher temperature, PET rises, but the SWAT calculation for the soil show more water stress for the plants, so the difference between PET and ET rises when the vegetation is considered as a constant in the projection period (Fink and Koch, 2014).

Under changing climate, the water balance components of Lake Hawassa catchment in this study under both projections of RCP4.5 and RCP8.5 shows there is going to be loss of the water availability, thus higher decrement is going to be faced if global warming is going in the same pattern. These findings are consistent with the study by (Leta et al., 2016) on water balance components in the Heeia watershed under changing climate. Generally, the annual relative changes of water balance in the study showed a decreasing trend, except for ET and PET over the catchment. Compared to water balance for Lake Hawassa catchment by (Gebreegziabher, 2004), using WTRBLN and developed on basis of Thorn Waite and Mather soil water, calculated some water balance for the total catchment Rainfall, ET and Runoff is with higher amount Rainfall and lower runoff values are overestimated, compared to the water balance this study considered. Again, this study is lined with (Lijalem, 2006) study on water availability of Lake Ziway watershed using HadGCM3 the total mean annual inflow volume into Lake Ziway might decline significantly in A2a and B2a emission scenario. The result is consistent with the study by (Tarekegn and Tadege, 2006) on Lake Tana using CCCM and CFD3 GCMs studied the water availability and predicted annual runoff might decline. The study is also lined with (Elias, 2016), a study on Lake Chamo cc on water balance using RCM for the future time horizon of the 2030s and 2090s, in which the future expected annual inflow is decrement under A1B. Water balance at the global or regional level must be updated since cc is likely affecting the amount and distribution over time. Without an accurate water balance, it is not possible to manage the water resources of a catchment.

Since this study focuses on water balance components change under emission scenario, the change is compared to the quantity on the base period. The percentage change of water balance over Lake Hawassa catchment by the end of 2100 in Table.6 indicated that ppt decreased by 12% and 27%, surface runoff increased by 10% and decreased by 16%, lateral discharge decreased by 39% and 50%, groundwater discharge decreased by 59% and 72%, water yield decreased by 27% and 46%, ET increased by 23% and 21% and PET increased by 77% and 75.3% respectively under RCP4.5and RCP8.5. When working on the water balance, it is inevitable to face the fact that the appearance of water within a watershed is a highly dynamic and variable process, both spatially and temporally. Due to the human influence, change of the water bodies, and climatic variations, the water balance of an area cannot be taken as final. The process must constantly be monitored, controlled, and updated. The major role of each water balance is long-term sustainable management of water resources for a given area.

Conclusions And Recommendations

Conclusions

The effect of cc on Water balance components of Lake Hawassa catchment is studied. Climatic variables that are mostly considered affecting the hydrologic components are ppt and temperature. Depending on the mean annual expected ppt during the 2050s and 2080s under RCP4.5 compared to the base period will decrease by 11.4% and 8%, under RCP8.5 decreases by 20.67% and 15% respectively. Future long year areal mean annual ppt over the catchment projection change under both RCP4.5 and RCP8.5 will be decreased by 9.7% and 17.8% respectively over the catchment (Fig.7). But the projected ppt under both emission scenarios doesn’t show a significant trend but the change is observed when comparing to last year. The annual projected temperature for both Tmax&Tmin under both emission scenarios of RCP4.5 and RCP8.5 has the same pattern and significantly increasing trend. The projected annual mean Tmin under RCP4.5 and RCP8.5 is increased by +26.2% and +45.8% respectively in the catchment. Whereas the projected mean annual Tmax under RCP4.5 and RCP8.5 increased by +15.6% and +29.45% respectively. Annual Tmax&Tmin trend shows increasing for both in both RCPs.

The water balance of the catchment is important; it is the driving force behind all the processes in SWAT because it impacts plant growth and the movement of sediments, nutrients, pesticides, and pathogens. And the cc's impact on water balance components was assessed for both gaged and ungaged catchment in the aspect of annually, seasonal change, and monthly assessed. In this study for total catchment, water balance components are summed since the respective quantity obtained was considering the areal description. By the end of 2100 under both projections of RCP4.5 and RCP8.5, comparing the components with base period, the future ppt the catchment going to face under RCP4.5 is by 12% and under RCP8.5 is by 27% decrement (Table.6). And surface runoff increased by 10% under RCP4.5 and decreased by 16% under RCP8.5, which is one of the effects of cc to cause flooding or drought. The consideration of RCP4.5 is its stabilization without overshoot pathway but the scenario of RCP8.5 corresponds to the rising radiative forcing pathway and it corresponds to a scenario with no climate policy baseline and comparatively high greenhouse gas emission. The continuous rainfall process causes the soil moisture to increase, which leads to the decrease of water infiltration rate, when the rainfall intensity is greater than the infiltration rate, the filling begins. Once the surface is filled, the surface runoff will be generated. The PE and PET increased under both emission scenarios, for ET the percentage increase was 23% under RCP4.5 and 21% under RCP8.5 by the end of 2100. The increase in temperature generally resulted in an increase in potential evaporation, largely because the water holding capacity of air is increased. Due to the human influence, change of the water bodies, and climatic variations, the water balance of an area cannot be taken as final. The process must constantly be monitored, controlled, and updated. The major role of each water balance is long-term sustainable management of water resources for a given area. Under cc the water balance components of Lake Hawassa catchment, ppt decreases while temperature, PET, and ET increase highly, and water yield also decreases to on higher percentage compared to past periods and which will affect the lake levels and depending on the society and the water animals. So, the policymakers and management have desirable to adopt systematic and modernized water allocation for different purposes and worldly acceptable Lake level fluctuation. The water balance for both historical and future climatic conditions was done on the past LuLc so the future study should consider lately LuLc change according to the climatic variability.

Declarations

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Conflicts of interest/Competing interests; - All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.   This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue. Thus, the Authors have no conflicts of interest to disclose.

Availability of data and material; - The DEM data freely available in http://earthexplore r.usgs.gov and the dynamically down scaled daily based RCPs climate data for historical and future period are freely from http://cordexesg.dmi.dk/esgf-web-fe/ CORDEX Africa database.

Code availability; - Not applicable

Authors' contributions; - We equally developed, analyzed, interpreted, adjusted throughout each task from the very beginning to the end. And we authors read and approved the final manuscript.

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Abbreviations

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CC Climate Change

CMhyd Climate Model Data for Hydrologic Modeling

CN Curve Number

CORDEX Coordinated Regional Climate Downscaling Experiment

DEM Digital Elevation Map

ET Evapotranspiration

FAO Food and Agricultural Organization

GCM Global Climate Model

GIS Geographic Information System

HadCM3 Hadley Centre Coupled Model3

HadGEM2-ES Hadley Global Environment Model2-Earth System

HRU	Hydrologic Response Unit
IPCC	Inter governmental Panel on Climate change
LuLc	Land use lands cover change
MAE	Mean Absolute Error
MoWIE	Ministry of Water and Irrigation Engineering
NMA	National Meteorological agency
NSE	Nash-Sutcliffe efficiency
PET	Potential Evapotranspiration
PPT	Precipitation
R^2	Coefficient of determination
RMA	Regional Meteorological Agency
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RE	Relative Error
RMSE	Root Mean Square Error
SUFI2	Sequential Uncertainty Fitting Version 2
SCS	Soil Conservation System
SWAT	Soil and Water Assessment Tool
SWAT CUP	Soil and water assessment tool Calibration and Uncertainty program
Tmin&Tmax	Minimum and Maximum Temperature

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Tables

Table.1 Statistical performance evaluation of model outputs and observed ppt data over study

Stations	*Statistical*	*ppt*				ppt	
		Raw	Corrected	*Stations*	*Statistical*	Raw	Corrected
Hawassa	RMSE	108.7	39.05	Yirba	RMSE	75.4	41.44
	MAE	84.35	29.58		MAE	63.07	35.838
	RE	0.267	-0.0144		RE	-0.36	-0.05
Haisawita	RMSE	61.6	57.65	Shashemane	RMSE	67.6	47.56
	MAE	49.85	47.29		MAE	60.41	40.32
	RE	-0.24	-0.00459		RE	-0.14	-0.038
Wondo	RMSE	98.8	52.88				
	MAE	78.41	43.96				
	RE	0.155	-0.054				

Table.2 Results of sensitivity parameters which affects the watershed.

Rank	Parameters	Lower	Upper	Fitted value
1	v_ALPHA_BF	0	1	0.71
2	r_CN2	35	98	35.00
3	r_SOL_Z	0.05	400	120.53
4	r_CHN2	0.01	30	22.87
5	v_ESCO	0	1	0.70
6	r_HRU_SLP	0	1	0.50
7	v_GW_DELAY	0	50	35.05
8	v_GW_REVAP	0.02	0.2	0.05
9	REVAPMN	0	1	0.76
10	r_SOL_BD	0.9	2.5	1.67

Table.3 Performance of calibration and validation

	Calibration	Condition	Validation	Condition
PBIAS	-6.7	Very good	-3.4	Very good
NSE	0.81	Very good	0.85	Very good
R^2	0.61	good	0.88	Very good

Table.4 Future annual water balance percentage change for gaged and ungaged catchment

Water balance	Gauged				Ungaged			
	RCP4.5		RCP8.5		RCP4.5		RCP8.5	
	2050's	2080's	2050's	2080's	2050's	2080's	2050's	2080's
PREC	-13.6	-12.0	-21.2	-16.6	-13.9	-40.0	-11.4	-35.0
SURQ	7.7	8.9	1.1	10.4	6.5	-47.2	12.1	-37.4
LATQ	-43.1	-40.4	-52.5	-46.9	-35.5	-53.5	-33.0	-47.4
GWQ	-58.9	-56.5	-71.8	-66.0	-62.3	-78.6	-60.8	-73.5
WYield	-27.4	-25.4	-37.7	-30.2	-28.4	-62.9	-25.2	-55.4
ET	23	24	23	19.1	18.1	17.8	19.8	17.5
PET	74	83	78.0	87.3	69.9	67.4	78.3	76.2

Where; *PREC- stands for ppt* *SURQ-is surface runoff*

LATQ- is the lateral flow into the stream *GWQ- is ground water contribution*

ET- is for ET *PET- is for PET*

WYield- Stands for water yield

Table.5 Seasonal water balance component of the catchme*nt*

	RCP 4.5			RCP 8.5			
Seasons	Belg	Kiremt	Bega		Belg	Kiremt	Bega
PCP	-56.6	21.4	-0.3	-66.6		0.8	-15.2
SURQ	-55.6	40.8	79.7	-70.9		12.8	35.2
LATQ	-70.8	-34.5	-18.8	-77.0		-45.5	-31.7
WYield	-68.4	-17.2	-0.1	-78.9		-36.6	-26.9
ET	31.3	42.5	-9.8	28.4		40.0	-10.5
PET	91.9	96.8	52.3	92.0		99.3	51.9

Table.6 Long year water balance of Lake Hawassa catchment under future projections

Water balance components	% Change under RCP4.5 by the end of 2100	% Change under RCP8.5 by the end of 2100
PCP	-12%	-27%
SURQ	+10%	-16%
LATQ	-39%	-50%
GWQ	-59%	-72%
WYield	-27%	-46%
ET	+23%	+21%
PET	+77%	+75.3%

Figures

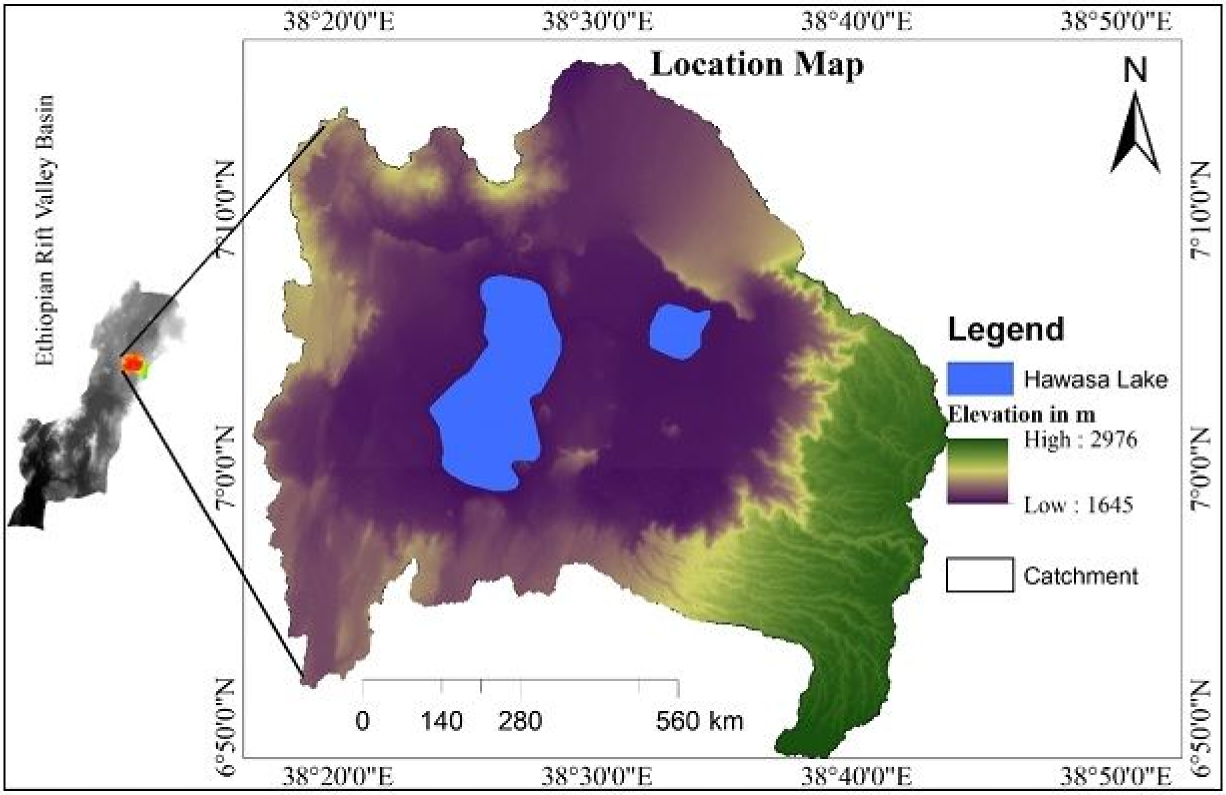

Fig.1 Location map of Lake Hawassa catchment.

Figure 1

See image above for figure legend

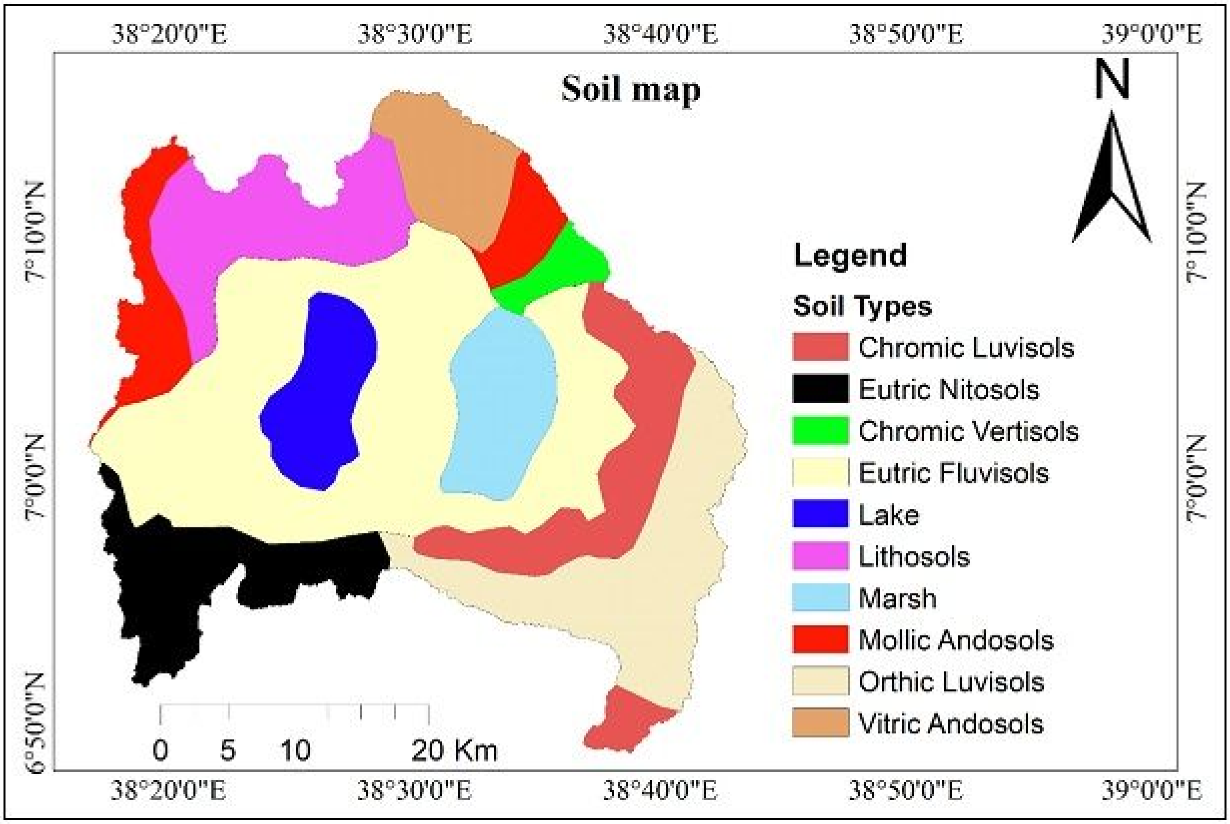

Fig.2 Soil Map of Lake Hawassa catchment

Figure 2

See image above for figure legend

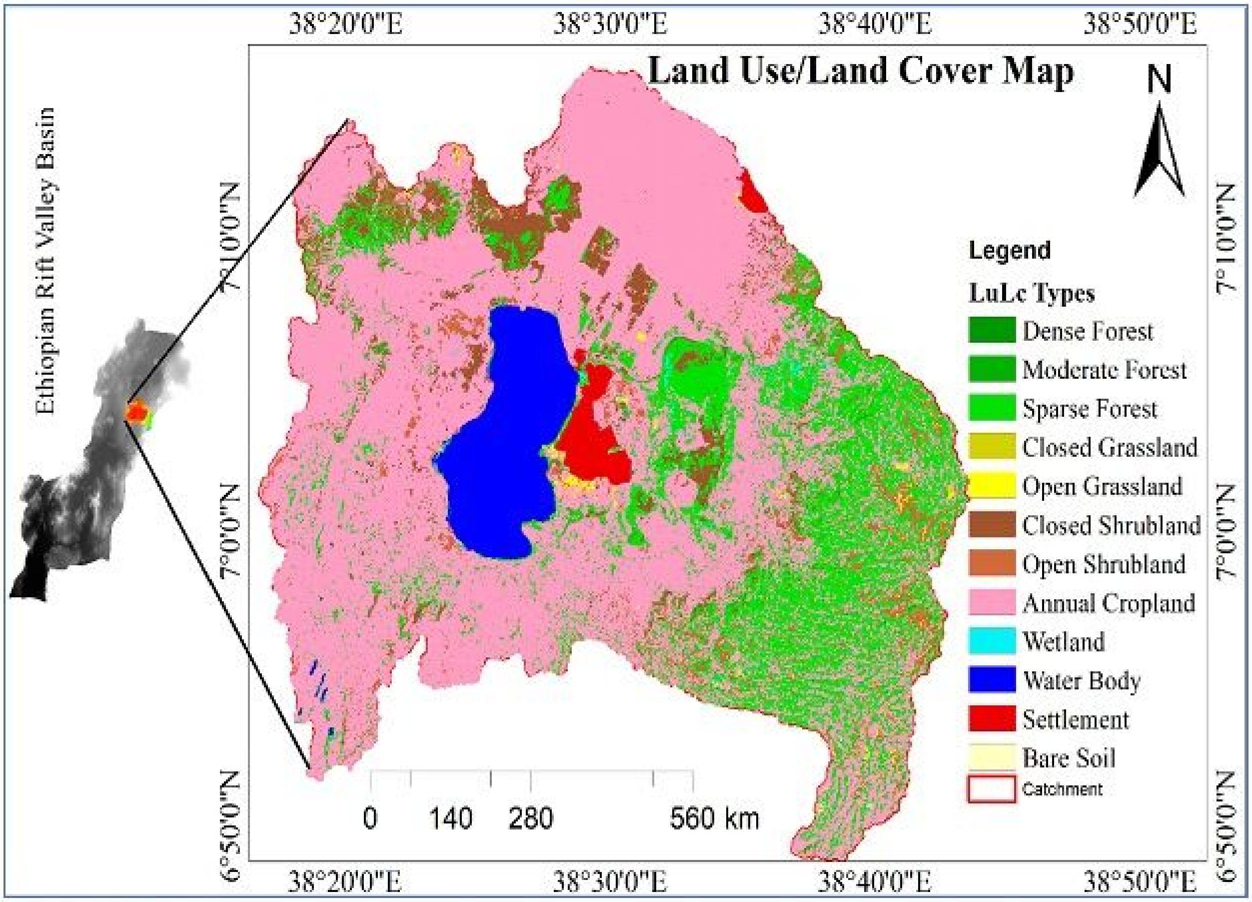

Fig.3 LuLc Map of Lake Hawassa catchment

Figure 3

See image above for figure legend

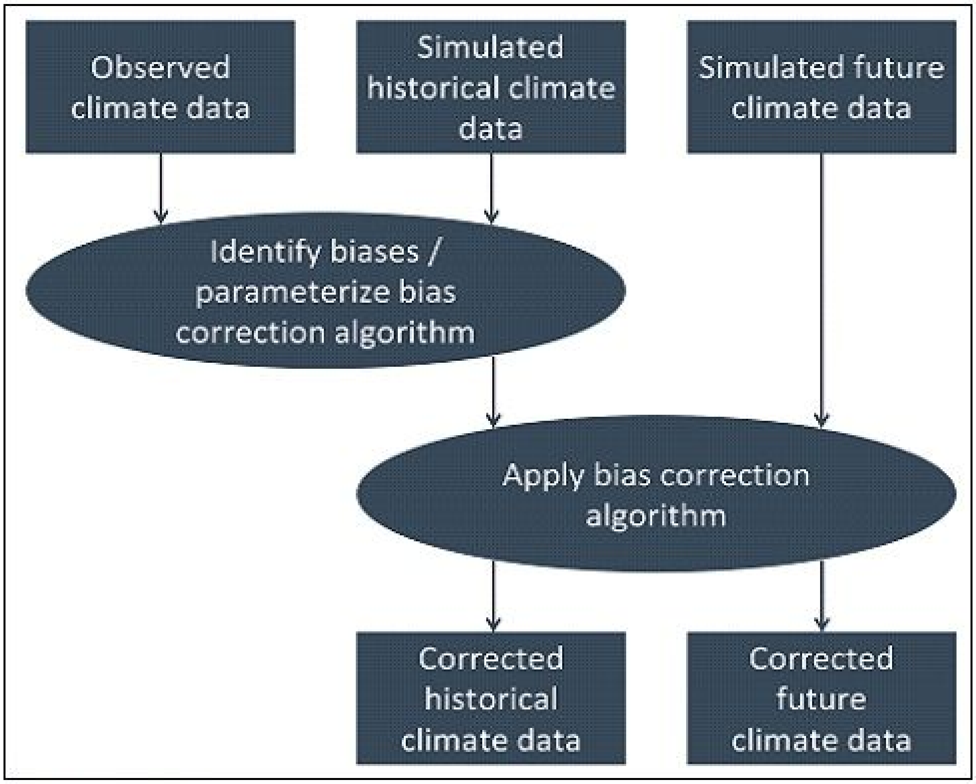

Fig.4 Bias correction frameworks

Figure 4

See image above for figure legend

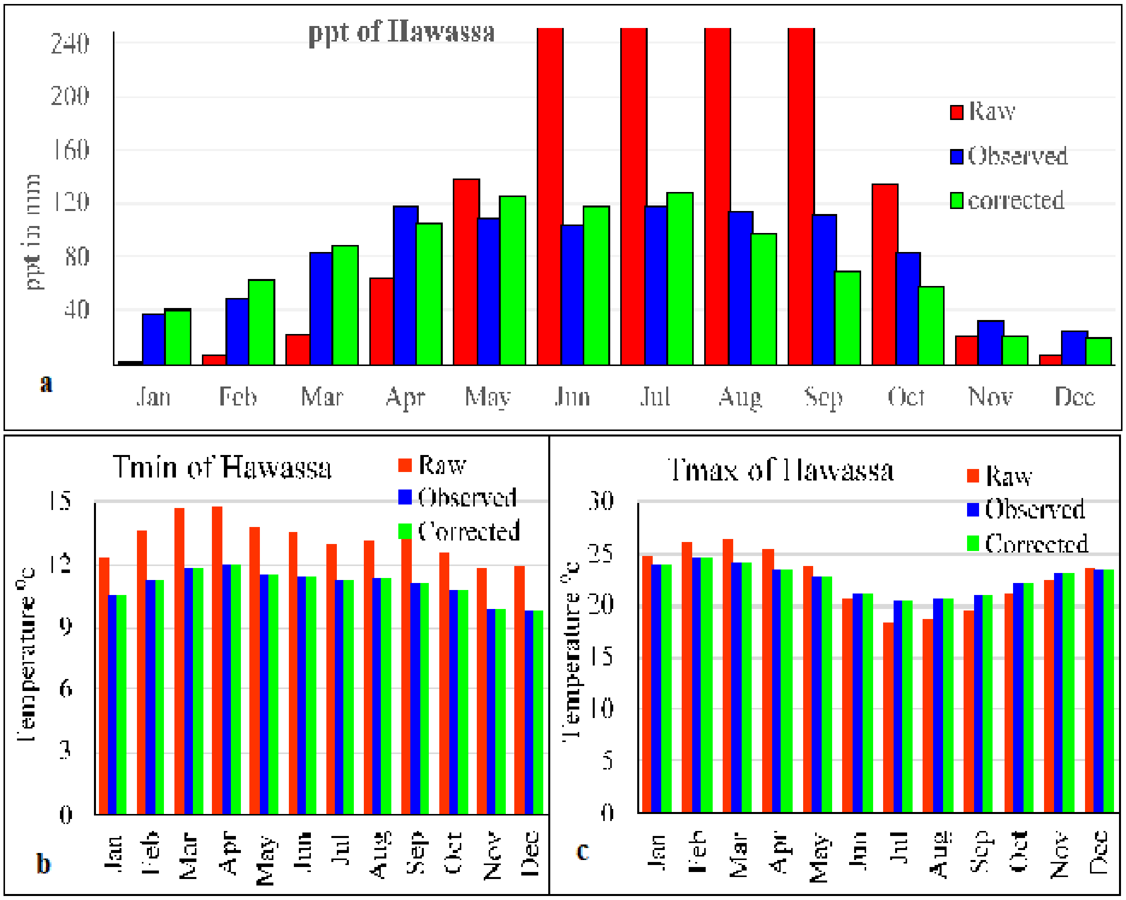

Fig.5 a, b and c the graph between raw, observed and bias corrected ppt, Tmin&Tmax

Figure 5

See image above for figure legend

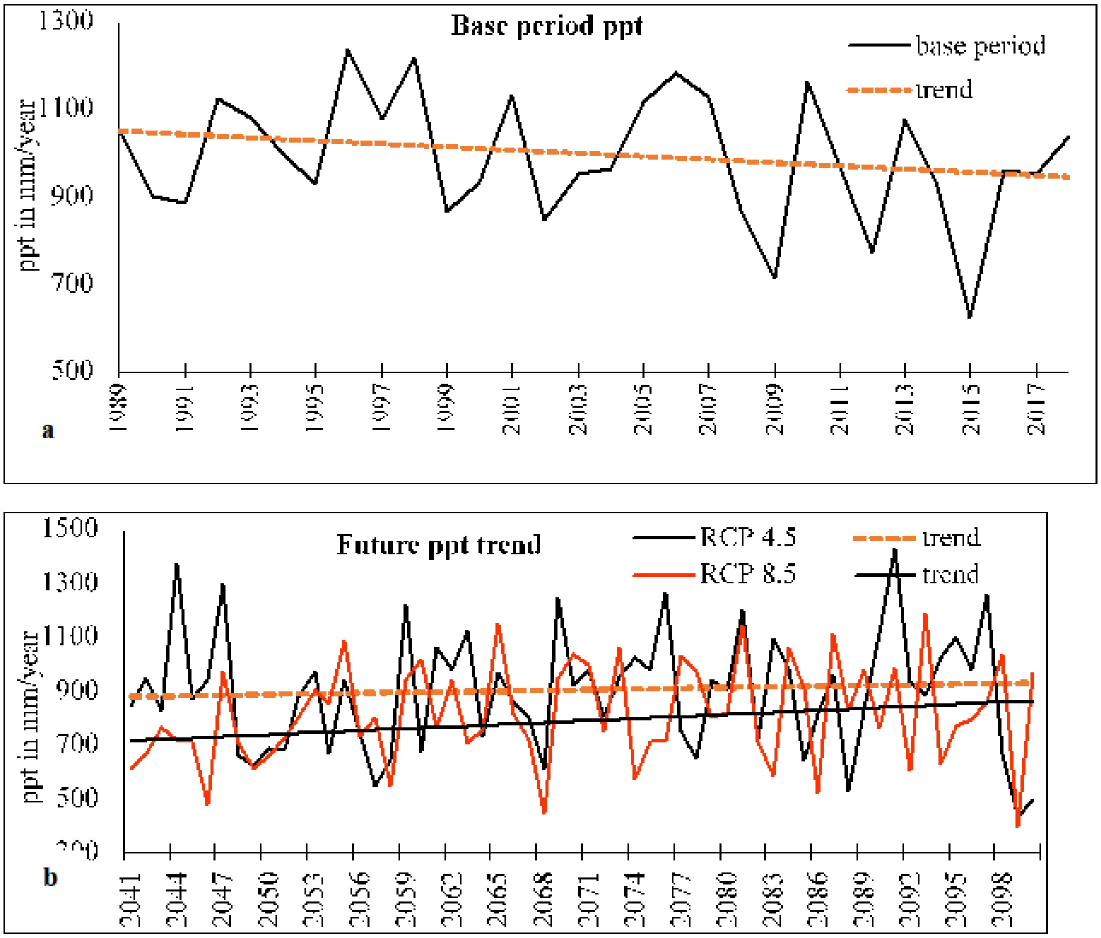

Fig.6 a and b the long year mean annual ppt trend of observed and future two RCPs

Figure 6

See image above for figure legend

Figure 7

See image above for figure legend

Figure 8

See image above for figure legend

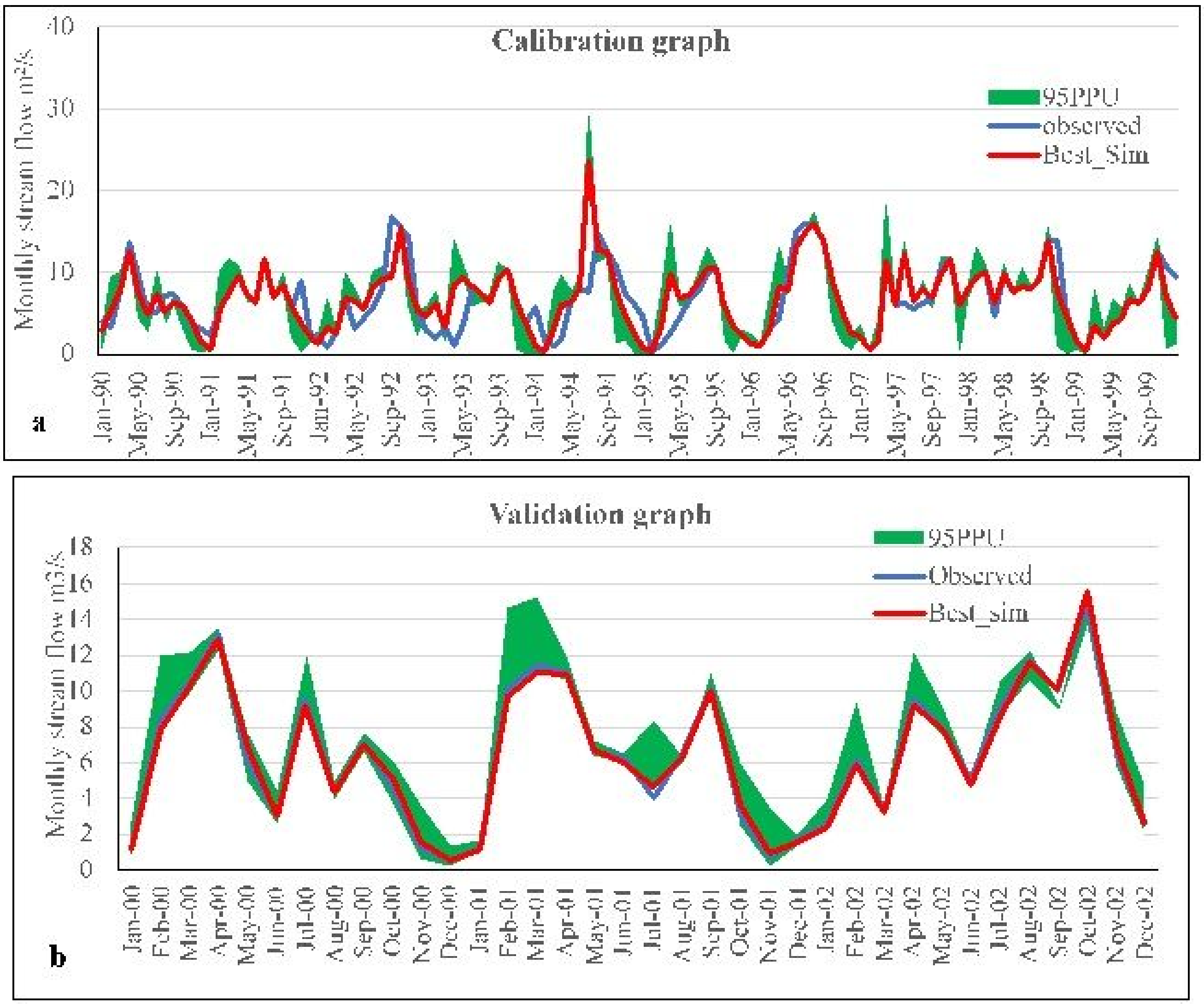

Fig.9 a and b Hydrograph of observed, simulated and prediction during validation (2000-2002)

Figure 9

See image above for figure legend

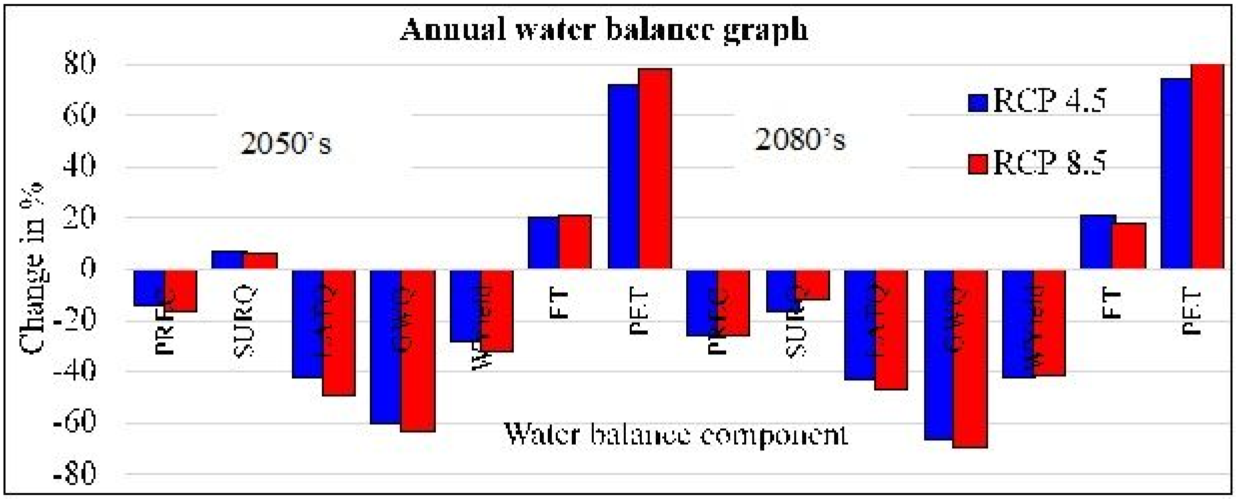

Fig.10 Annual water balance component over Lake catchment under both RCPs projections

Figure 10

See image above for figure legend