



# Integrated water resources management under climate change scenarios in the sub-basin of Abaya-Chamo, Ethiopia

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## Abstract

In this study, the impact of climate change on surface water availability and its allocation system was carried out within Bilate watershed in the Abaya-Chamo sub-basin of Rift Valley Lakes Basin in Ethiopia. Predicted rainfall and temperature time series data were obtained from regional climate outputs of Coordinated Regional Climate Downscaling Experiment (CORDEX)-Africa for the three representative concentration pathways (RCP) scenarios (RCP2.6, RCP4.5, and RCP8.5) for the four time periods (2015–2020, 2021–2025, 2026–2030 and 2031–2035). The result revealed that the future maximum and minimum temperature can be increased during all three scenarios. However, precipitation showed an increase or decreasing trend in future scenarios at different time scales. Further, SWAT model was calibrated and validated to simulate the future streamflow under RCP2.6 and RCP8.5 scenarios. WEAP model was employed for integrated water resources allocations under selected climate change scenarios. The SWAT model performance was found satisfactory during calibration [correlation coefficient ( $R^2$ ) = 0.77, Nash–Sutcliffe efficiency (NSE) = 0.755, percent deviation (D) = 2.558] and validation period ( $R^2$  = 0.798, NSE = 0.778, D = -3.93). The model output shows that there may be an annual decrease in flow upto -12.1 and -16.21% for RCP2.6 and RCP8.5 scenarios. The annual surface water availability was found to be 570 million cubic meter (MCM) in the Bilate watershed for the current accounted year 2015. However, the current utilization of these resources is very limited about 51.49 MCM (9.03%) in the basin including domestic, livestock and minor agricultural activities. Furthermore, four scenarios were developed based on different set of assumptions in the basin up to 2035. It was estimated that total annual consumption will be around 14.53, 20.43, 37.47 and 44.46% for the reference, scenario one, two and three, respectively. This study also determines the environmental flow requirements (25% of the mean annual flow volume) to maintain the basic ecological functioning in the basin and regulate flow for downstream uses. This study was found that integrated water resources management strategy in the basin could utilize water resources potential effectively in the future. Therefore, this study is useful for the different stakeholders in the study region for the optimal allocation of water resources under climate change scenarios.

**Keywords** Water resources allocations · Climate change · WEAP model · SWAT · Ethiopia

## Introduction

The water plays an important role in supporting productive human activities such as agricultural, energy and industrial production, sanitation, transportation services, fishing, and tourism etc (UNEP 2009). The global water demand will primarily grow due to population and economic growth, rapid urbanization and the increasing demand for food and energy (GWP 2009). Therefore, assessing water resource availability of relevant spatial and temporal scales is of importance (Yang and Zehnder 2007) as well as an ability to assess the availability of freshwater resources has been

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an issue of importance in most countries for many decades (WMO 2012).

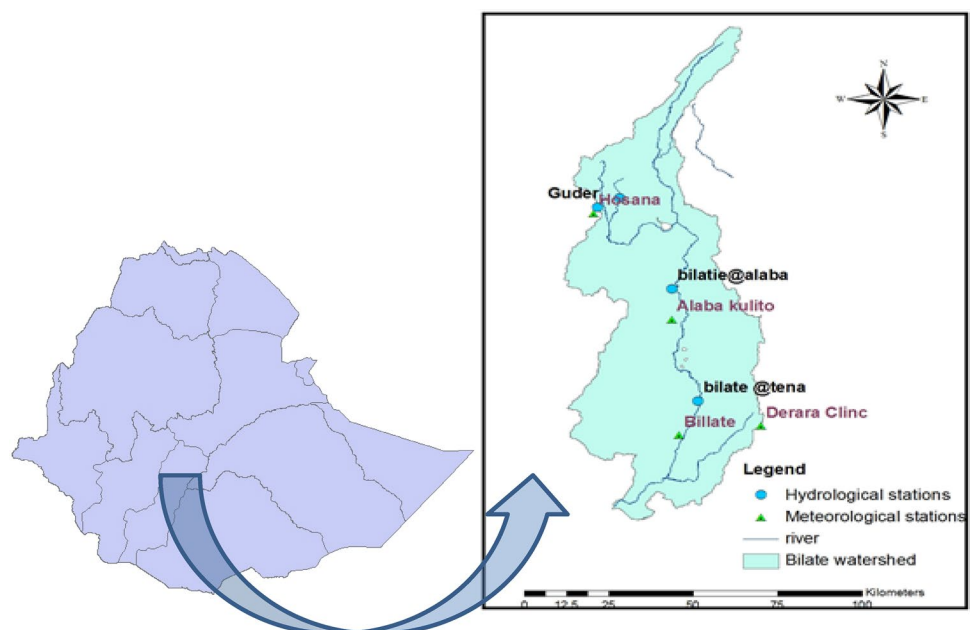
Many researchers have done studies on water resource availability at different spatial and temporal scales ranging from watersheds to river basins scales in worldwide (e.g. Tadesse 2006; Daniel et al. 2011; Flint et al. 2012; Sethi et al. 2015; Liu et al. 2017). These studies indicated that assessment of water resources was undertaken at the watershed and basin scales in many countries for better water resources planning and management. Water systems should be designed to meet present and future water demands while maintaining a range of hydrologic variation necessary to preserve the ecological and environmental integrity of the basin (Loucks 1997). Due to high water demand from population growth, degradation of the rivers and pollution of surface and groundwater sources, and the loss of potential sources of freshwater supply due to use of an old and unsustainable water management practices (Wang 2005). The complexity of the water allocation task and the increasing pressure on water resources (increasing demand and variability) has stimulated the revision of water allocation goals and means in many countries (Roa-García 2014). The effective water allocation and management requires an understanding of water availability and reliability with considering the equity, efficiency, and sustainability as the key principles in water allocation (UNESCAP 2000).

Surface water is the primary source of water. Knowing the potential, availability, and use of surface water would help to increase the productivity of agriculture, improved ways and means of the traditional water management systems, increase drinking water supply and the hydroelectric power generation in the coming future. The Bilate river is

used as an important source for food, drinking and agriculture water, wildlife, grazing and water for livestock, and as a repository for human and agriculture. This makes the issue of water resource availability very crucial for effective water resources management and improves livelihoods. In countries like Ethiopia, where agriculture serves as a backbone of the economy as well as ensures the wellbeing of the people, the availability of water resource is quite essential. In the northern part of Abaya-Chamo basin, a multipurpose project is under construction. Also, the expansion of agricultural land and residential area, land degradation of a significant portion of the watershed by overgrazing became pertinent features of the basin. Therefore, the need for water is highly increasing. Hence, modeling the hydrology of basin is required for effective water resource management strategy under the climate change scenarios.

Water allocation models are useful for simulating scenarios of situations encompassing complicated hydrological, environmental and socio-economic factors (McCartney 2007 cited in Mayol 2015). They can provide insights into the likely impacts of different development options (McCartney and Arranz 2007). Therefore, the present study was utilized Soil and Water Assessment Tool (SWAT) and Water Evaluation and Planning (WEAP) model to assess the impact of climate change on surface water resources potential (water availability) and different water allocation scenarios (water demand management strategies) within Bilate watershed. These allocation strategies were aimed to meet various sectorial water demands under climate change scenarios in future.

**Fig. 1** Location of the study area



## Materials and methods

### Study area

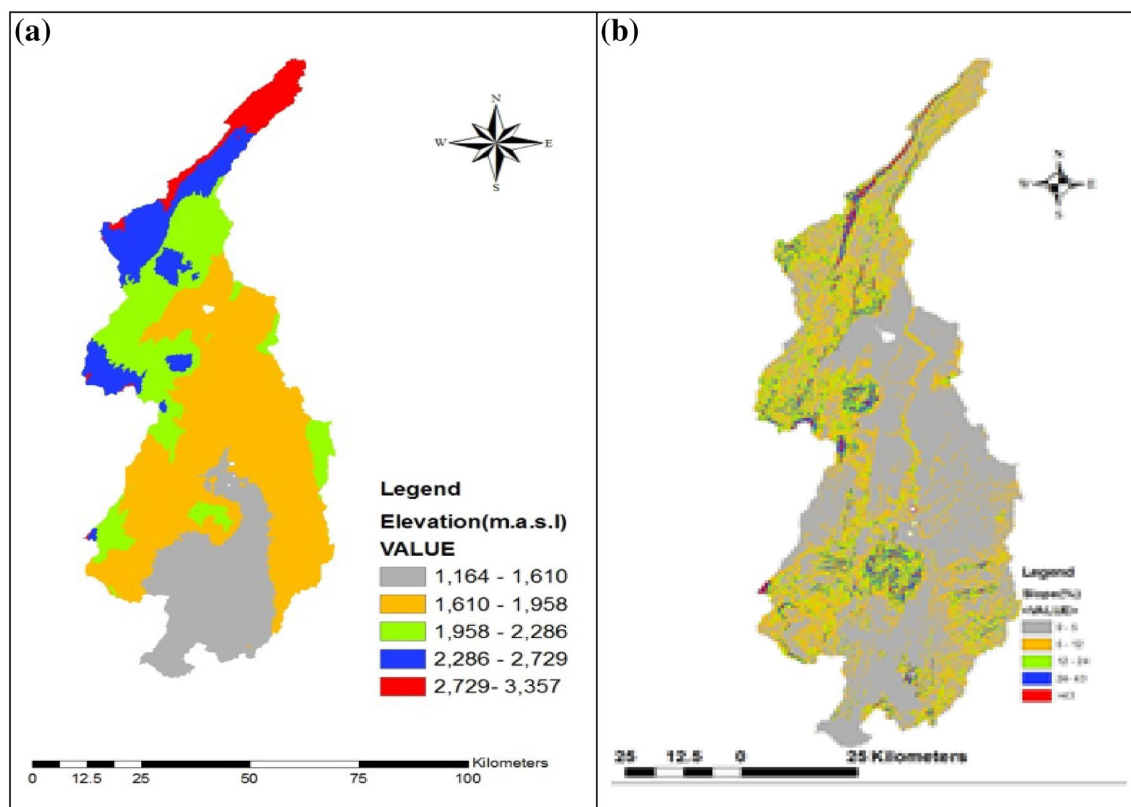
Bilate watershed is located in the southwestern part of Ethiopia and it is one of the major watersheds in the Ethiopian Rift Valley Basin. It has a drainage area of 74,536 km<sup>2</sup> and geographically the basin is located between 6°38'18"N–8°6'57"N latitudes and 37°47'6"E–38°20'14"E longitude (Fig. 1). The Bilate river is the main perennial river that flows in the basin. It originates from the Guragie Mountain and flows south into lake Abaya. Its main tributaries are the Weira river with its seasonal tributaries (Urulicho and Guracha) flowing south and the Guder river which originates near Hossana and flows east to join Bilate at the outlet of Boyo swamp. The maximum stream length is about 197 km. The mean minimum and maximum annual flows of the Bilate river varies between 0.82 and 22.33 m<sup>3</sup>/s at Weira, 1.2–31.25 m<sup>3</sup>/s at Alaba Kulito and Bilate Tena (Dimtu) is 3–45.7 m<sup>3</sup>/s.

The watershed is usually classified into three sub-basins: the upper, middle and lower sub-basins, where total annual rainfall varies between 1280 and 1339, 1061–1516, and 769–956 mm, respectively. Generally, in the highlands of

Bilate watershed, the mean annual temperature varies from 11 °C in August to 22 °C in March/April, while the temperature variation in the lower part of Bilate is higher and ranges between 16 °C in July to 30 °C in January and March. The elevation of Bilate watershed ranges between 3347 metres above sea level (m.a.s.l.) in the north and 1408 m in the south with a mean elevation of 2013.4 m (Fig. 2). The dominant soil in the basin includes vertic andosols with sandy loam in the middle sub-basin, Chromic luvisols from clay to sandy loam in upper sub-basin, chromic vertisols in the lower and sandy loam to loam pellic vertisols in the upper and middle sub-basin, eutric nitosols, eutric fluvisols in the middle and lower sub-basin and Lithosols in the upper and lower sub-basin of sandy soils; deep red to brownish soil associated with vertic andosols cover the rolling hills plains around Alaba to Wolyta Sodo (Fig. 3). The watershed is mainly covered by the exposed surface, forest, grassland, intensively cultivated, marshland, moderately cultivated, shrubland, urban area and water body (Fig. 4).

### Data used

The primary and secondary data such as streamflow, land use/land cover (LULC), topography, soil data were collected from the Ministry of Water Irrigation and Electricity (MoWIE).



**Fig. 2** a Topography and b Slope of Bilate watershed

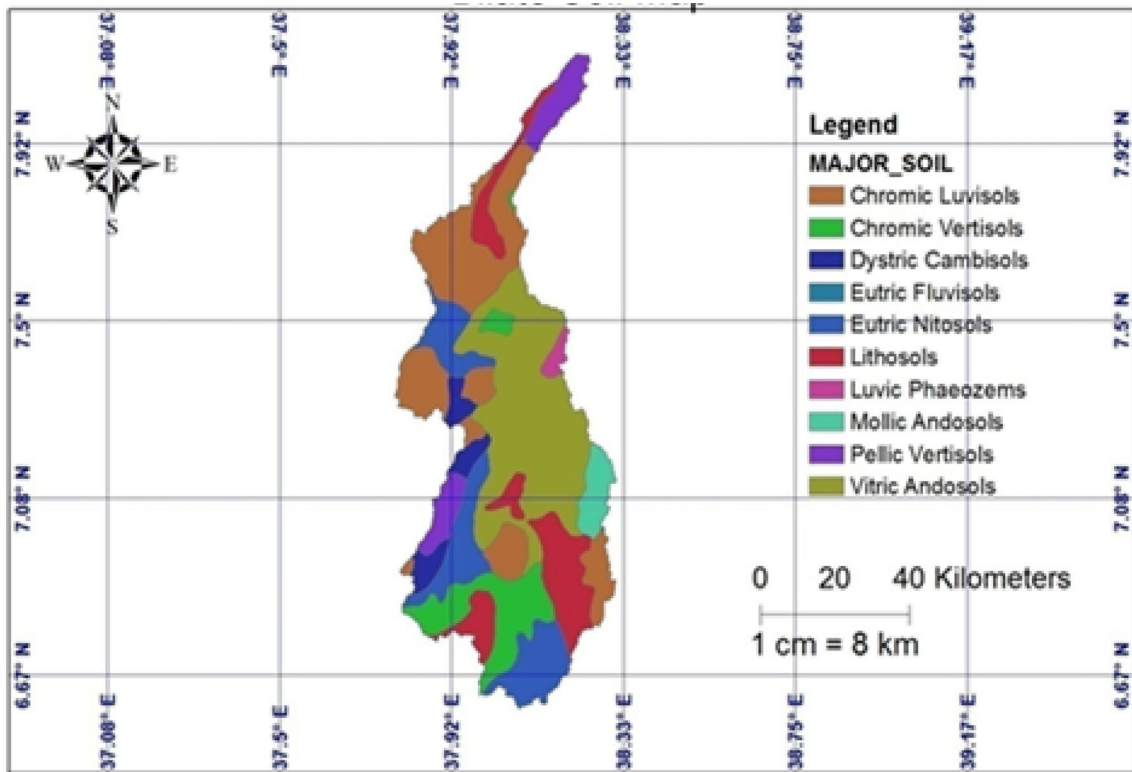


Fig. 3 Soil of Bilate watershed

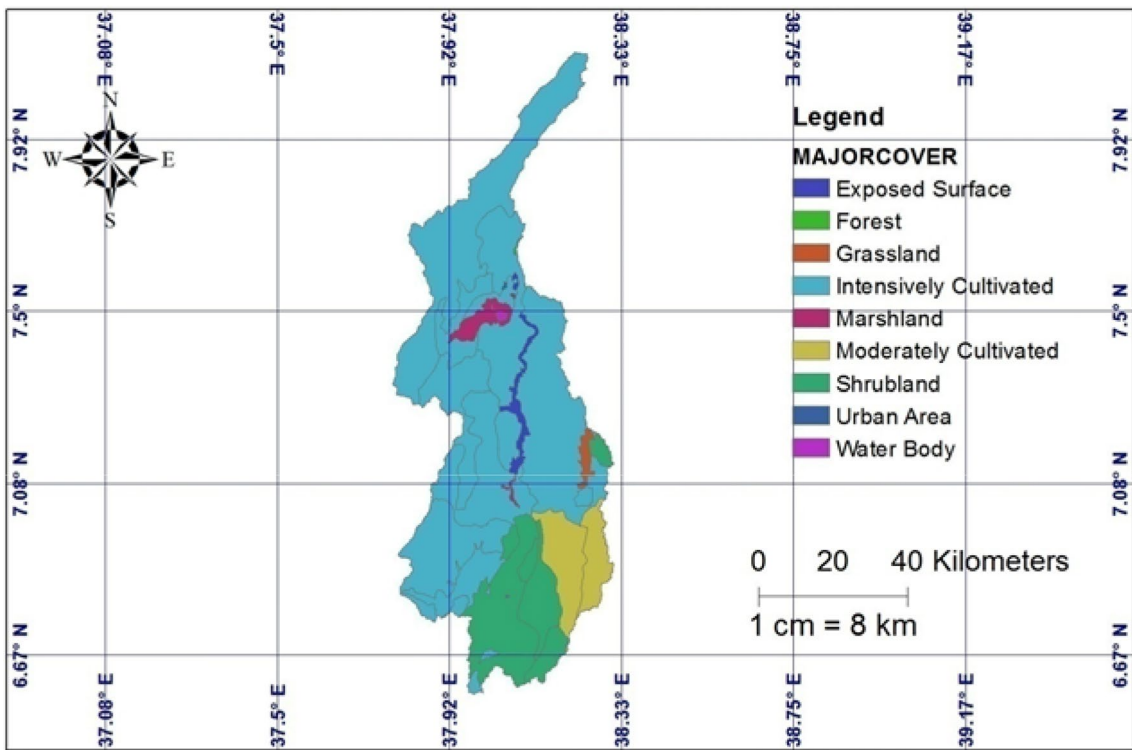


Fig. 4 Land cover/use map of Bilate watershed (FAO, 2011)

These data were used for characterizing the sub-basin. The daily rainfall and temperature data were collected from the National Meteorological Agency (NMA) of Ethiopia. The five stations were selected for this study such as Alaba kulito, Bilate farm, Hossana, Bodity and Wulibareg station. Gauging station near Bilate Tena was selected for calibration and validation of the model, which is located at the outlet of the watershed. The observed streamflow of gauging station near Bilate Tena (1995–2014) was used to estimate the surface runoff in Bilate watershed. Important socio-economic information such as agriculture, domestic water supply, demographic surveys and water-use were collected from different governmental offices in the region. Agriculture information was collected from zone and weredas agriculture offices, the demographic data from the weredas Bureau of Statistics and Rift Valley Lake Basin (RVLB) master plan, and the water use data were collected from the MoWIE (zone and wereda office).

This study was carried out using 5th Coupled Model Inter-comparison Project (CMIP5) model (i.e. HadGEM2-ES model) output. The downscaled rainfall and average, minimum and maximum temperatures for the period 1951–2100 was obtained from Coordinated Regional Climate Downscaling Experiment (CORDEX)-Africa database. The data correspond to three RCP Scenarios (RCP2.6, RCP4.5, and RCP8.5). These RCP scenarios were named according to radiative forcing target level for 2100. The RCP2.6 scenario represents the radiative forcing trajectory, which goes to a peak level of  $3 \text{ W/m}^2$  ( $\sim 490 \text{ ppm CO}_2$ ) before 2100, followed by a decline. The selected pathway declines to  $2.6 \text{ W/m}^2$  by 2100 (van Vuuren et al. 2011). It aims at limiting the increase of global mean temperature to  $2^\circ\text{C}$  above the pre-industrial period. The RCP4.5 scenario describes the stabilization without overshoot pathway to  $4.5 \text{ W/m}^2$  ( $\sim 650 \text{ ppm CO}_2$ ) at stabilization after 2100 (Clarke et al. 2007). RCP8.5 scenario corresponds to the rising radiative forcing pathway leading to  $8.5 \text{ W/m}^2$  ( $\sim 1370 \text{ ppm CO}_2$ ) by 2100 (Riahi et al. 2007). It corresponds to a scenario with no climate policy baseline and comparatively high greenhouse gas emissions. The eight RCM grids cells cover the study area (Fig. 5). The selected RCP data were subjected to bias corrections. The future climate data is projected from CORDEX-Africa data sets. Often, outputs of regional climate models cannot be directly used for impact assessment as the computed variables may differ systematically from the observed ones. Therefore, the bias correction was applied to compensate for any tendency to overestimate or underestimate the mean of downscaled variables. In this study, the seasonal analysis was carried out based on local seasonal classification schemes for Belg (short rainy season: February–May), Kiremt (main rainy season: June–September) and Bega (dry season: October–January) (Gebere et al. 2015).

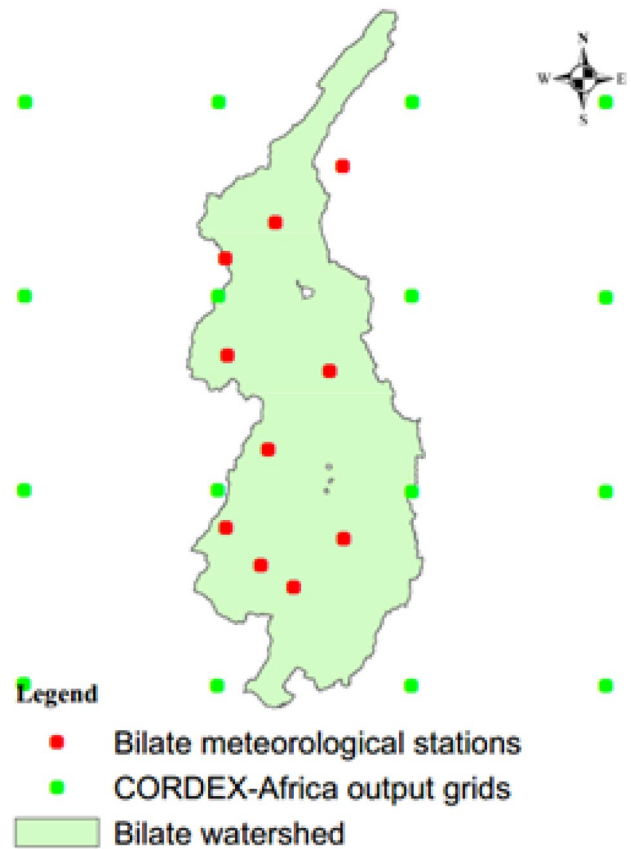


Fig. 5 Location of CORDEX-Africa output grids for the study area

## Methods

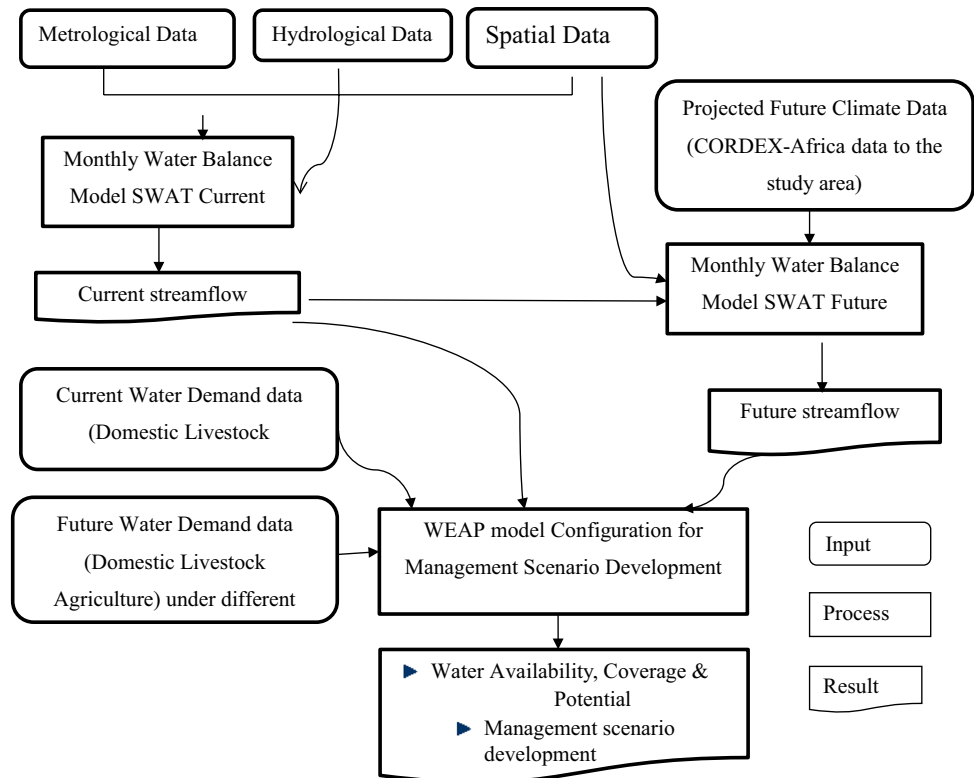
The conceptual framework of this study is presented in Fig. 6 and discussed in subsequent sections.

### SWAT model applications

#### SWAT model description

The SWAT model is one of the most recent models developed at the United States Department of Agriculture Agricultural Research Service (USDA-ARS) during the early 1970s. SWAT model is semi-distributed physically based simulation model to predict the impacts of land use change and management practices on hydrological regimes in watersheds with varying soils, land use and management conditions over long periods and primarily as a strategic planning tool (Arnold et al. 1998; Neitsch et al. 2005). SWAT model has also been successfully applied in the many basins and at watershed scales in different regions of the World (e.g. Sang 2005; Githui et al. 2009; Chaemiso et al. 2016; Setyorini et al. 2017).

**Fig. 6** Conceptual framework of the study



### SWAT model setup

The model setup was involved five steps: (1) data preparation, (2) sub-basin discretization, (3) HRU definition, (4) parameter sensitivity analysis, (5) calibration and uncertainty analysis. The required spatial datasets were projected to the same projection called WGS 1984\_UTM Zone 37N under the Universal Transverse Mercator (UTM) projections for Ethiopia using ArcGIS 9.3. The LULC data were reclassified into SWAT LULC types. The SWAT codes for the different categories of LULC were feed manually on the map as per the required format. The soil map was linked with the soil database. The watershed delineation process was performed. For the stream definition, the threshold based stream definition option was used to define the minimum size of the sub-basin.

### Sensitivity analysis, calibration, and validation

The sensitivity analysis in this study was undertaken by using a built-in tool in SWAT that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) design method (Morris 1991). After the analysis, the mean relative sensitivity (MRS) of the parameters was used to rank the parameters and their category of sensitivity was also defined based on the Lenhart et al. (2002) classification such as very high, high, medium and small. Dilnesaw (2006) indicated that there can be a significant variation of hydrological processes

between individual watersheds. Therefore, this justified the need for the sensitivity analysis made for each of the sub-watersheds in the study area. The analysis involved a total of 26 parameters. Model simulations were evaluated by using mean, standard deviation, regression coefficient ( $R^2$ ), and the Nash and Sutcliffe efficiency (NSE). A combination of both manual and automatic calibration method was used for the model simulation. First manual calibration was used mainly for annual water balance and it was followed by automatic calibration. The calibration was done using historical records of the 5 years (2003–2007). However, the simulation was run for 6 years, where the first year (Jan 1st, 2002 to Dec 31st, 2002) was used to “warm-up” the model. The measured streamflow data of Bilate river were used to validate the model for the period of 2008–2010. The performance of the model was checked using statistical performance indicators.

### Simulation of future streamflow

SWAT was applied to simulate the impacts of climate change on river flow by assuming that changes in the precipitation, temperature and land use in the future from baseline period which will affect flow volume. The future climate variables such as daily precipitation, maximum and minimum temperatures were provided as an input to the SWAT model. Other climate variables such as wind speed, solar radiation, and relative humidity were assumed to be constant throughout the future simulation periods. The SWAT simulation for the

year 2006–2014 was considered as a baseline period for the climate change impact assessment. SWAT model was then re-run for the future periods with the downscaled output of climate variables and assumed land use changes.

### WEAP model application

WEAP model was used for the water resources allocations and to meet the different water demands. This model was utilized for the integrated water resources management (IWRM) and found to be effective, useful, easy to use, affordable, and readily available to the broad water resources community (Yates et al. 2005a). In addition, the data structure and level of details can be easily customized to meet the requirements of a particular analysis and to reflect the limits imposed in a data-scarce environment (Yates et al. 2005b). The surface water availability (supply) and demand were estimated using the WEAP model (Fig. 7). This model was used to simulate the alternative scenarios of different development and management options in the future. The application was defined by time frame, spatial boundaries, and system components. This study adopted a baseline scenario using the demand data of 2015, and simulated streamflow

for the years 2006–2014. The modeling framework for this study includes the estimation of monthly discharges, water demand, and water allocation to meet demands of different sectors.

### Current water requirements and demands

The current water requirements were assessed for various needs in the sub-basin. Hydropower and environmental requirements (non-consumptive) together with three consumptive uses; domestic, livestock and agriculture were identified in the sub-basin. Water demand analysis was performed by using the disaggregated end-use based approach using WEAP model. The water requirement was calculated at each demand node or by the evapotranspiration based irrigation demand in the physical hydrology module. The demands for domestic, livestock and agriculture entities were estimated based on a disaggregated accounting approach for various measures of social and economic activities. The other water requirement such as mining, heavy industry was not included as demand sites. Standard water use method was selected in the simplest case, where the user determines an appropriate activity level (e.g. persons, heads, hectares)

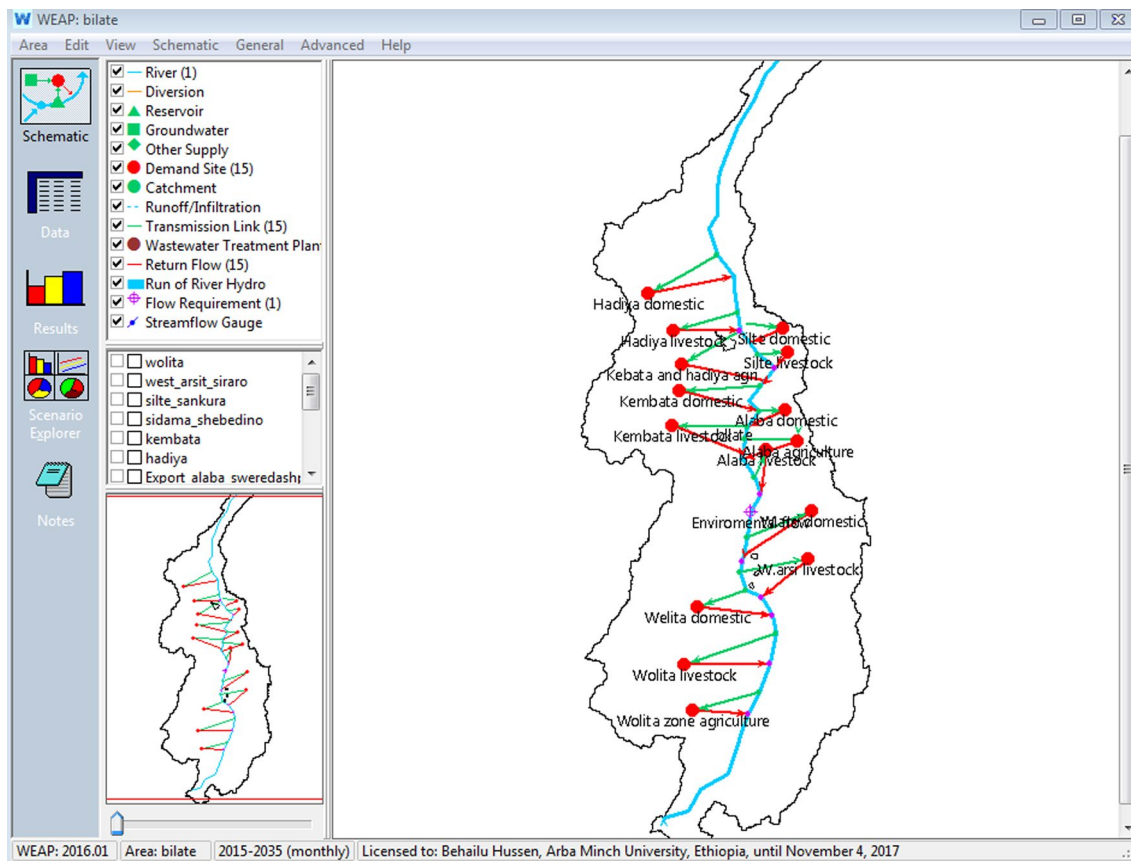


Fig. 7 Schematic diagrams showing the configuration of the WEAP model for demand sides of Bilate watershed

of land) for each disaggregated level and multiplies these by the appropriate annual water use rate for each activity. In this study, it was assumed that there is no monthly variation in estimated water requirement of domestic and livestock uses.

### Domestic water demand

The domestic water supply requirement within the watershed is primarily concentrated in the urban and rural area of the sub-basin. However, urban and rural are generally concentrated close to major water sources such as permanent rivers, ephemeral streams (seasonal). The total consumptive water requirement was based on the population census of 2007 wereda (district) level. Domestic daily demands of urban and rural were estimated to be 60 and 20 litres/capita/day, respectively (RVLB 2009). The industrial sector in the sub-basin is small-scale industries with a low water consumption rate, which was considered under domestic demands.

### Livestock and crop water demand

There are no recent counts of livestock population density, but many pastoralists are moving with their large herds of cattle and other livestock in response to the annual regime of the Bilate river. The sub-basin was extensively utilized by the communities for livestock grazing. Livestock water requirement rate was given as the unit 25 and 10 litres/head/day for cattle and goat/sheep, respectively. CROPWAT which was developed by Food and Agricultural Organization (FAO) was used to estimate the crop water requirements for existing and proposed irrigation schemes. According to RVLB master plan, there is 8000 ha previously identified irrigation schemes but not yet fully implemented for the main crops such as maize, cotton, and vegetables. As a result, these crops were chosen to estimate the crop water requirement for proposed irrigation.

### Future water demands in the Bilate watershed

Scenarios are defined as an alternative or a set of assumptions based on increasing population and future development or policies. Changes in these assumptions could grow water demands. However, scenarios in the WEAP model encompasses any factor that can change over time including those factors, which may change due to particular policy interventions, and reflect different socio-economic assumptions. Scenario projections for this study were established in the WEAP model based on the RVLB master plan. These all scenarios were adopted with some change in agricultural water consumption and domestic water consumption rate, but consumption rate of livestock will remain constant.

### Reference scenario

The reference scenario is the scenario in which the current situation was considered. The total population within the basin was projected around 2,367,049 for the year 2015 based on Census 2007 data. The current account (the year 2015) was extended to the future (2016–2035). No major changes were imposed in this scenario. It was assumed a linear change in population increase.

### Scenarios one

In this scenario, the exploitation of irrigation potential was considered based on pre-identified irrigation development sites which were increased from 4000 to 10,000 ha (Awulachew et al. 2012) by the year 2035. The water consumption rate for domestic and livestock was assumed to be constant.

### Scenario two

The exploitation of all potential irrigation areas was identified by the Awulachew et al. (2012), which can be expected to be 37,294 ha by the year 2035. The rate of water consumption by domestic and livestock remained constant.

### Scenario three

If the irrigation potential in the basin is developed and water consumption per capita is increased by the double for urban and rural demand. Moreover, the water consumption rate for livestock remained constant.

### Water requirement for non-consumptive uses

Since there is no hydropower generation existing at present and no data for the proposed dam in the sub-basin, the only water requirement for non-consumptive uses was considered as environmental flow requirement. An environmental flow is one of the important components in water resources planning, management, and allocation. The sustainable environmental flow benefits the health and maintenance of the aquatic ecosystem. Generally, the environmental flow requirement was found between 10% (lowest limit) to 35% (fair/good habitat conditions) (Smakhtin and Anputhas 2006). Similarly, in Blue Nile river, the environmental flow was found to be 22% of the mean annual flow to maintain the basic ecological functioning (Shiferraw and McCartney 2008). The environmental flow in this study was assigned to be 25% of mean annual runoff, where streamflow is required at a point on a river to meet the different ecosystem related water demands such as maintaining river water quality, fish, and wildlife etc.



## Results and discussions

### Climate change scenarios

#### Rainfall

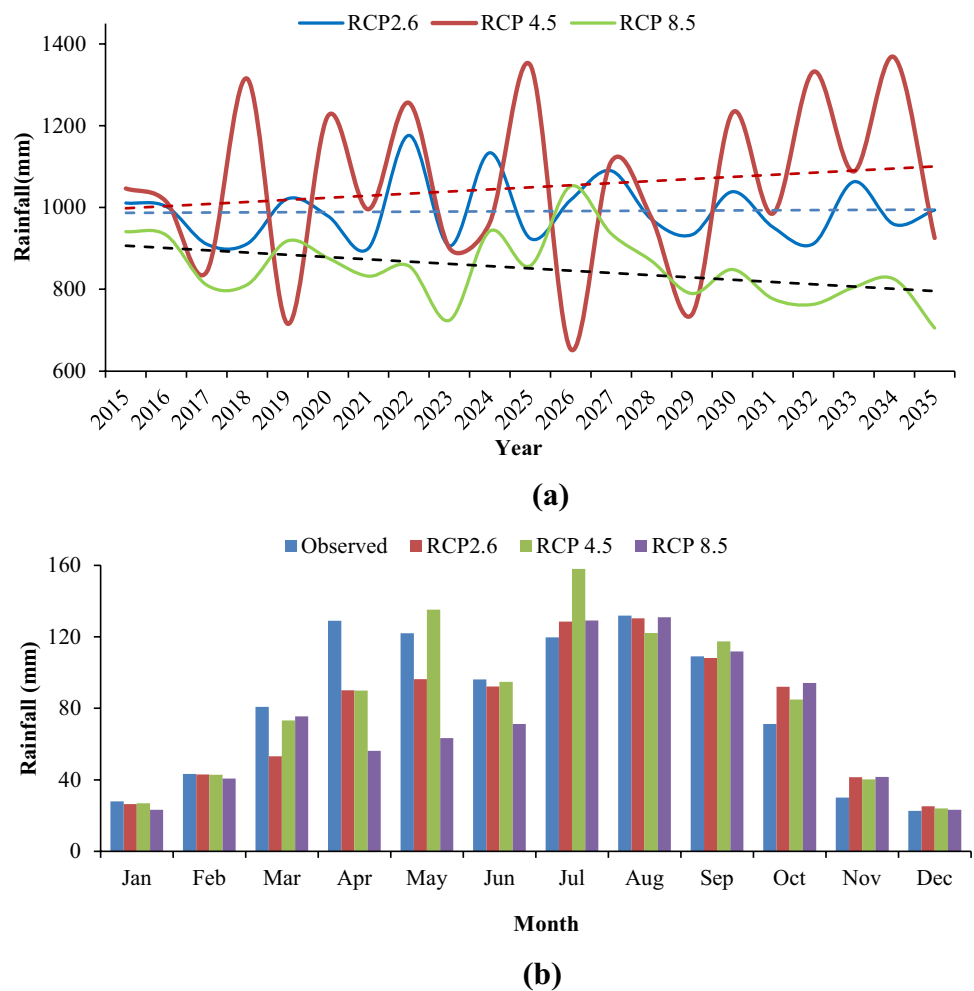
The result of the inter-annual pattern of rainfall for the RCP2.6, RCP4.5, and RCP8.5 scenarios are presented in the Fig. 8a. It clearly indicated that in RCP2.6, the rainfall is not highly affected while there can be an increase and decrease of the rainfall in RCP4.5 and RCP8.5, respectively. This uncertainty in the long-term inter-annual pattern of total annual rainfall necessitates the need to look into monthly distribution to understand the effect of climate change. The analysis of the monthly distribution of rainfall for the three scenarios provides a clearer picture of the trend of rainfall pattern. The monthly pattern for scenarios RCP4.5 and RCP8.5 clearly indicated that the rainfall can be decreased in the rainy season months (Belg and Kiremt) and increased in the dry months (Bega)

(Fig. 8b). The decrease in rainfall was found more pronounced in Kiremt season. The analysis shows the seasonal shift can be large in the RCP8.5 (Fig. 8b). In general, the monthly analysis shows that the usual onset and cessation of the rainy season can be affected including the quantity in the wet and dry periods. This could have tremendous implications on both rainfed agriculture and surface water availability for irrigation.

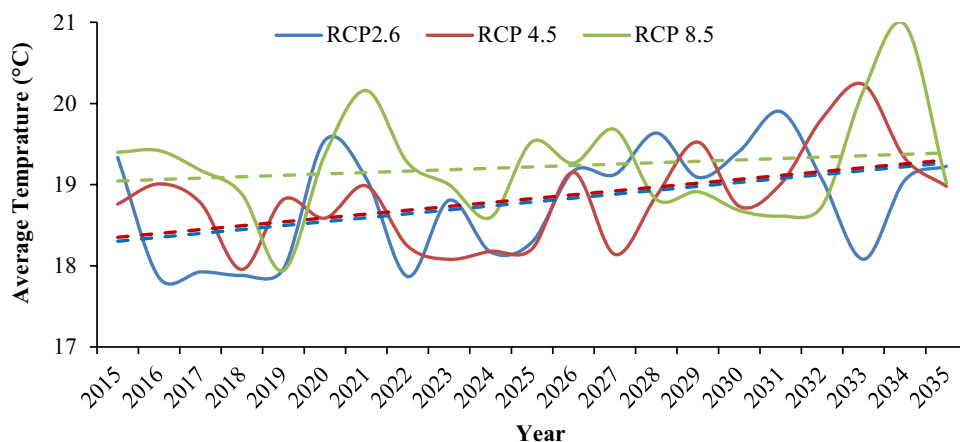
#### Temperature

The pattern of change in average temperature from 2015 to 2035 is presented in Fig. 9. The average temperature for all scenarios can be found an increasing trend, but a higher rate of increase can be expected in the RCP8.5 scenario. Figure 9 clearly shows the increase in average temperature can be anticipated more than 1.6 and 1.5 °C for RCP8.5 and RCP4.5 scenario, respectively. The increase in the RCP2.6 scenario was found to be less than 0.6 °C (Fig. 9). The annual trend of increase in temperature may be results the higher evapotranspiration and reduction in soil moisture content (i.e. water

**Fig. 8** The inter-annual bias rainfall and average monthly rainfall patterns (2015–2035) for the three RCP scenarios



**Fig. 9** Inter-annual average temperature patterns by scenario and year



stress conditions). This needs to be addressed through appropriate adaptation measures. The average monthly pattern of change in temperature for the three scenarios is presented in the Fig. 10a–c. All the monthly patterns for the three scenarios were shown an increase in temperature. The least was found for RCP2.6 and maximum for the RCP8.5 scenario. The difference with the observed average temperature can be expected maximum for the period 2031–2035, which can be expected 4.56 °C in the month of April.

The minimum temperature can range from 12.9 to 14.7 °C for RCP8.5, 12.5 to 14.6 °C for RCP4.5 and 12.3 to 14.9 °C for RCP2.6 (Fig. 11). This indicated that the maximum and minimum temperature difference in minimum temperature can be expected to 2.6 and 1.8 °C, respectively. The monthly pattern of change in minimum temperature for the three scenarios is presented in Fig. 12a–c. All the monthly patterns for the three scenarios showed an increase in temperature. The change in minimum temperature can be expected maximum (6 °C) and minimum (less than 1 °C) in the month of April August for the period 2031–2035, respectively. The maximum temperature can be expected between 23.5 and 26.5 °C for RCP8.5, 23–25.5 °C for RCP4.5 and 22.5–25 °C for RCP2.6 (Fig. 13). The monthly pattern of change in temperature for the three scenarios is presented in the Fig. 14a–c. The monthly maximum temperature can be increased during all the three scenarios.

## Hydrological modeling using SWAT

### Sensitivity analysis

The sensitivity analysis was carried out using 26 parameters to characterize the Bilate watershed using the SWAT. These parameters with ten intervals of a Latin Hypercube (LH) sampling (260 iterations) were used for the sensitivity analysis and only ten parameters were shown significant effects on the monthly flow simulation of the watershed. The first ten parameters were shown a relatively high sensitivity, being

the evapotranspiration the most sensitive. The most sensitive parameter controlling the streamflow in the watershed were found evapotranspiration, total AQ recharge, percolation, shallow AQ recharges, total water yield, surface runoff, baseflow, deep AQ recharges, transmission losses and groundwater evaporation (Table 1).

### Model calibration and validation

The calibration and validation results were found in a good agreement between the simulated and observed monthly flows at the outlet of the watershed (Fig. 15). The satisfactory model performance was observed during both the calibration [correlation coefficient ( $R^2$ ) = 0.77; Nash–Sutcliffe efficiency (NSE) = 0.755 and percent deviation ( $D$ ) = 2.558] and validation period ( $R^2$  = 0.798, the NSE = 0.778, and  $D$  = -3.93). These results are in good agreement with Santhi et al. (2001).

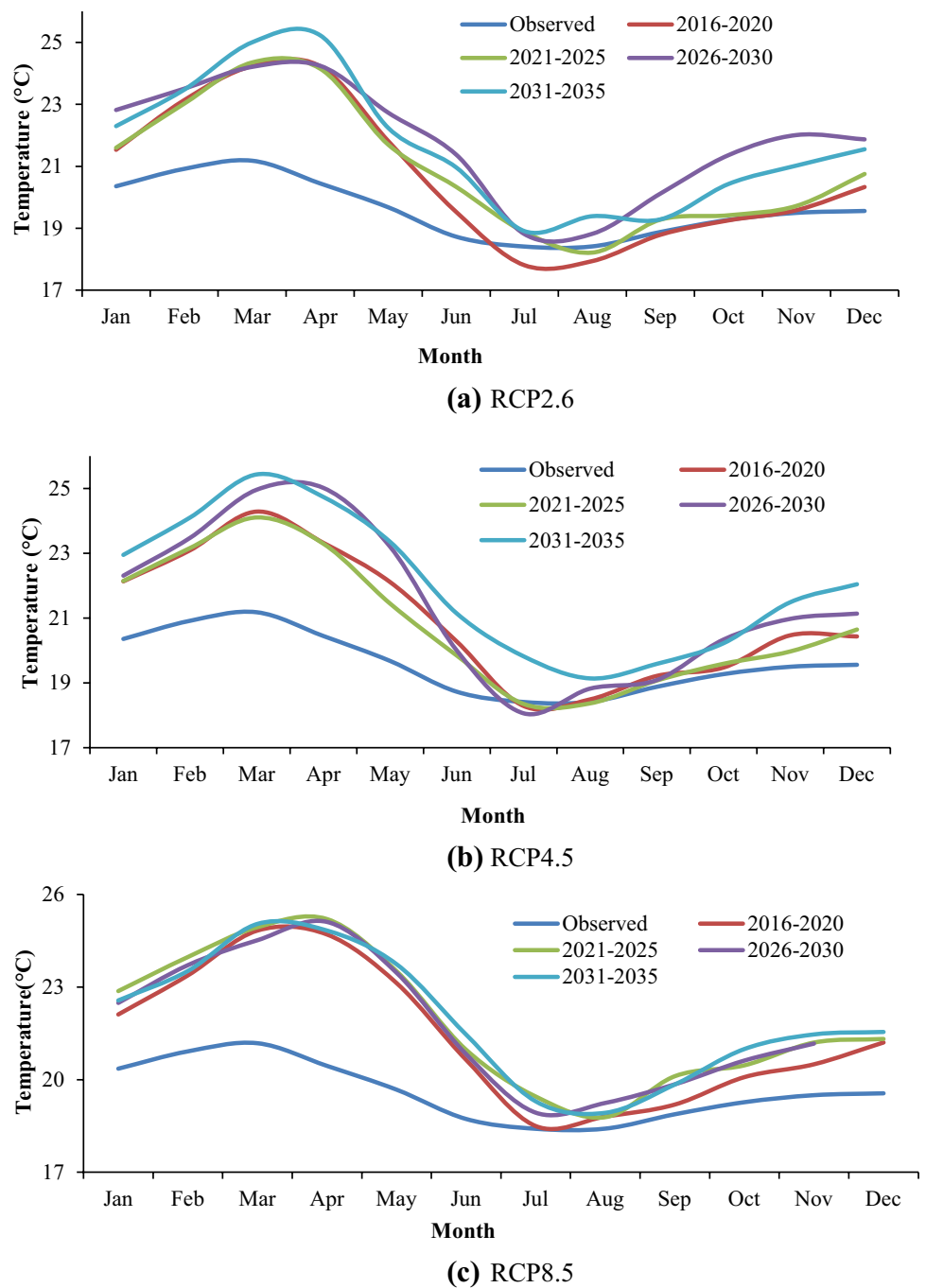
### Surface water availability

The total annual river flow of Bilate river at Tena was simulated using SWAT model and found to be 570 Mm<sup>3</sup>. The highest monthly average flow was occurred in the month of October (89.2 Mm<sup>3</sup>) and the lowest was found in the month of January (13.14 Mm<sup>3</sup>). Average annual water balance for both calibration and validation period was revealed that the largest portion of the average annual precipitation (77.3%) falling in the watershed was lost through the evaporation (Table 1). This indicates that the evapotranspiration parameter was most sensitive than any other hydrologic parameter, which governs the sub-watersheds water balance.

### Impact of climate change on future flow

The impact of climate change on future flow was analyzed on a monthly, seasonal and annual basis from Bilate river. The future flow was analyzed for RCP2.6 and RCP8.5 scenarios.

**Fig. 10** Monthly average temperature change pattern by period for RCP2.6, RCP4.5, and RCP8.5



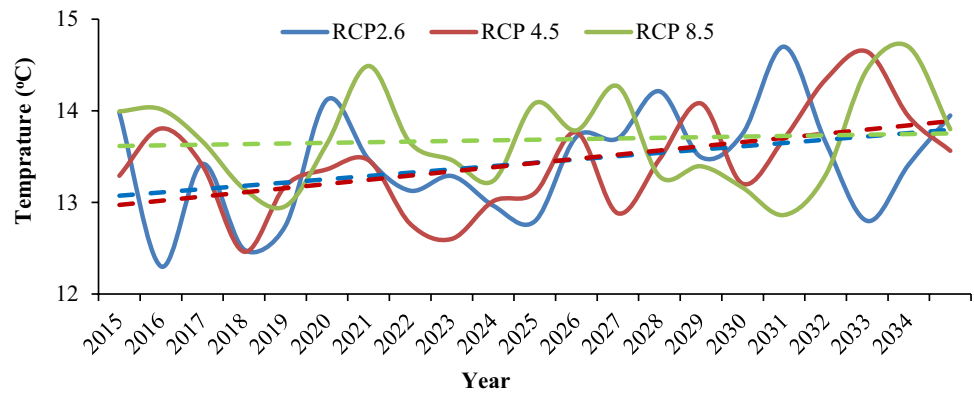
The impact of climate change was assessed by considering the SWAT simulated flow as the baseline (2002–2014) and the future flow was simulated for the period 2015–2020, 2021–2026, 2027–2030.

**Monthly flow**

Under the RCP2.6 scenario, flow can be decreased in the months of January, March, July, August, and September during the period 2015–2020. The significant increasing

flow can also be expected during May, June and October months. In this scenario, the monthly flow may be expected to decrease up to 30.7% and increase up to 27.7% (Fig. 16a). Similar flow pattern was observed under the RCP8.5 scenario for the years 2016–2020. The decrease in monthly flow can be expected during January, March, July, August, and September which may be decreased up to 36.07% and the increase can be expected up to 25.52% (Fig. 16b). During 2021–2025 for both scenarios, a monthly flow can be decreased up to 34.63 and 39.0%, while monthly flow

**Fig. 11** Inter-annual bias corrected minimum temperature pattern by scenario and year



may be increased up to 4.53 and 1.16% for RCP2.6 and RCP8.5 scenarios, respectively (Fig. 16b). In 2026–2030, a decreasing trend may be expected for both RCP2.6 and RCP8.5 scenarios. In the RCP2.6 scenario, the monthly flow can be increased up to 33.75% and decreased up to 34.42%. For RCP8.5 scenario, the pattern of monthly flow may be increased up to 33.56% and decrease up to 37.10% (Fig. 16b). Generally, a monthly variation of flow in the watershed can be decreased during the future periods. The future precipitation can be decreased during rainy seasons. Therefore, the flow can be decreased during the period (2015–2020, 2021–2025, 2026–2030 and 2031–2035).

### Seasonal and annual flow

During the Belg season, the percentage change in flow can be expected to +0.56, –6.2, –24.51 and –29.61% during the periods 2015–2020, 2021–2025, 2026–2030 and 2031–2035 for RCP 2.6 scenario, respectively (Fig. 17a). For RCP8.5 scenario, the percentage change in flow can be expected to +1.46, –9.5, –19.15 and –47.88% during the same periods, respectively (Fig. 17b). During the Kiremt season, the projected flow can be decreased to –17, –17.24, –17.26 and –18.2% during the selected future four periods for the RCP2.6 scenario, respectively (Fig. 17a). For RCP8.5 scenario, the flow may be expected to change –27, –24.79, –23.87 and –33.91% during the selected time periods, respectively (Fig. 17b). Similarly, the future Bega season flow can be changed to +3.37, –22.86, +10.06 and +7.72% and 16.44, –25.33, +9.32 and +19.51% for the selected time periods under the RCP2.6 and RCP8.5 scenario, respectively (Fig. 17a, b). This result shows that maximum flow reduction can be expected from the rainy season of Kiremt. During the selected periods, the annual flow can be changed by –7.36, –16.35, –11.22 and –13.48% and –8.45, –21.53, –13.51 and –22.06% for the RCP2.6 and RCP8.5 scenarios, respectively (Fig. 17b).

### Water demand management

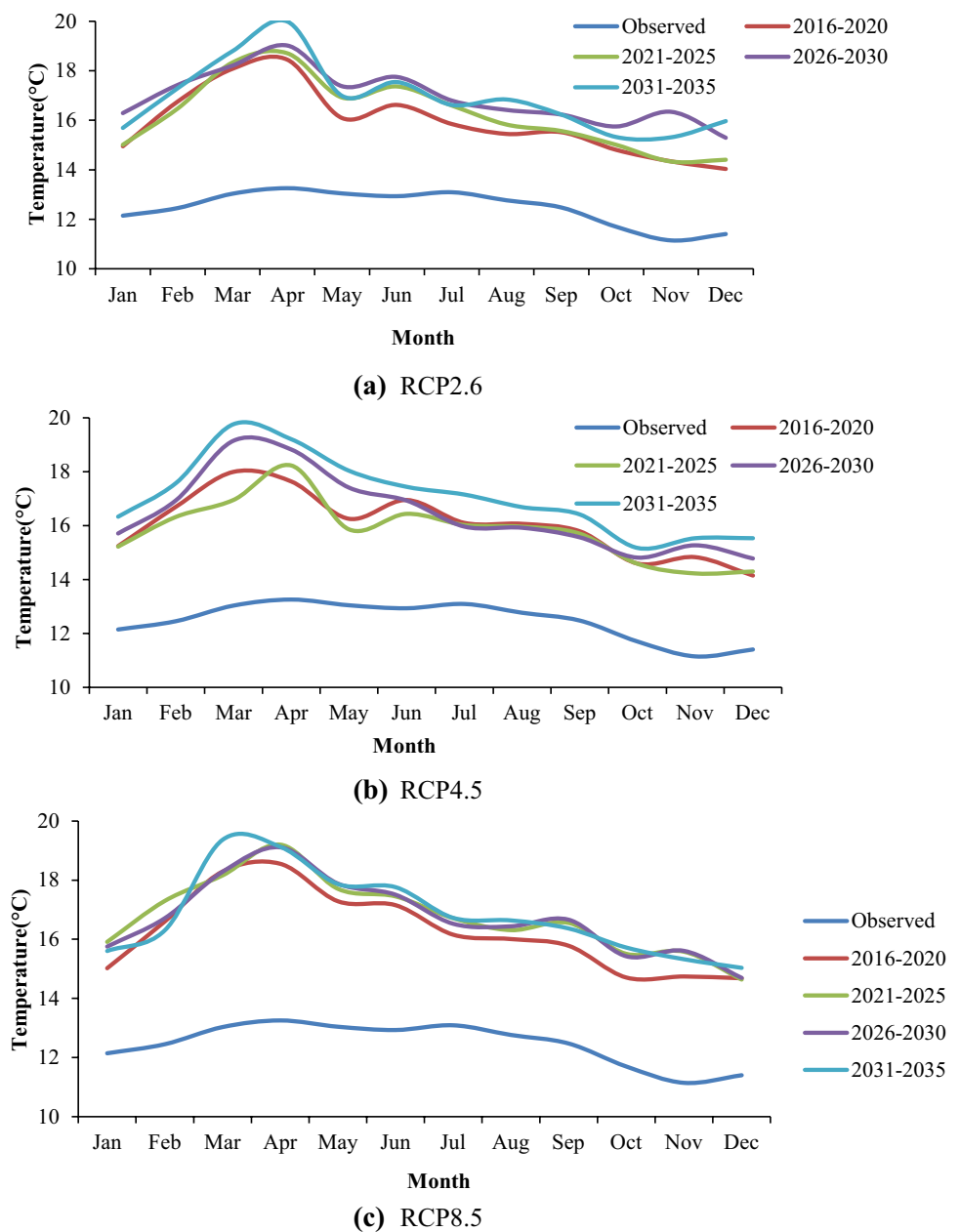
The current account of the water consumption in the model was developed using the demand data of 2015 and simulated streamflow data (Supply) at outlet Bilate at Tena. The basin has three consumptives water demands namely domestic (22.98 MCM), livestock (15.4 MCM) and agriculture (irrigation) (13.11 MCM). These results indicate that the utilization was low compared with a population within the basin. The current total water consumption for the above three consumers within the watershed was estimated to be 51.49 MCM per year. Therefore, the water withdrawal in Bilate watershed can be around 9.03% of the total water available in the basin, which is 570 Mm<sup>3</sup>. The net water demand for each sector was incorporated within the WEAP model simulation (Fig. 18).

Water allocation models must accurately represent the significant features of water resource systems within any basin. Ideally, they should simulate the water availability and demand (Etchells and Malano 2005). In this case, the water demand priority has represented the level of priority for allocation of the available water resources (SEI 2008). For example, the demand that all sites with the highest priority would be supplied first before moving to lower priority sites until all the demands are met or all the available resources are used, whichever comes the first. Priorities for different water demand sites in the basin were established on the basis of water availability in the basin and water demand for the different sectors as well as the environment flow requirement and downstream allocations. These priorities were included the domestic (1), environmental (1), agriculture (2) and livestock (2).

### Reference scenario

In this scenario, the changes can be likely to occur in the future without intervention new policy measures were considered; it only increases in population growth. The annual

**Fig. 12** Monthly minimum temperature change pattern by period for RCP2.5, RCP4.5, and RCP8.5



population growth rate for domestic users and livestock was found to be 3.05 and 3.5%, respectively (Table 2).

**Scenario one**

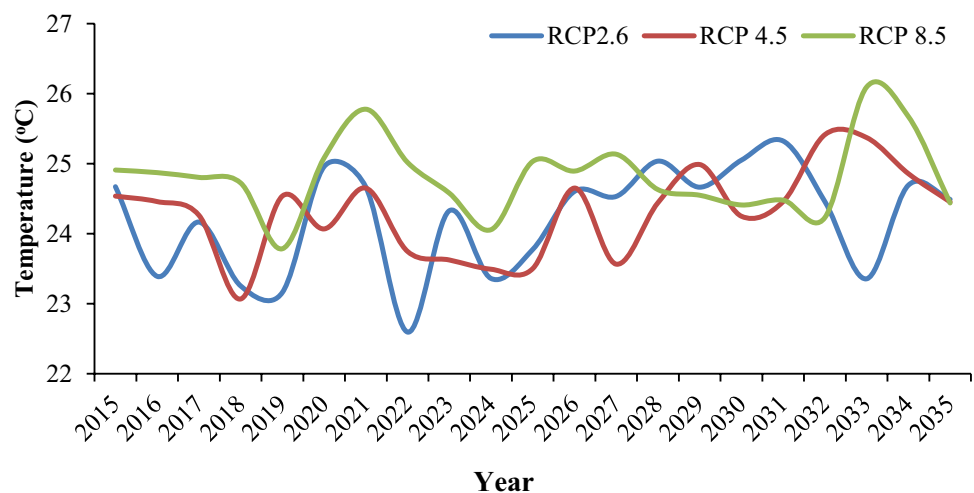
Exploitation of irrigation potential based on pre-identified irrigation development sites. The pre-identified irrigation development sites in the study area are 8000 ha (Awulachew et al. 2012). Therefore, in this scenario, it was assumed that all pre-identified irrigation site may implement with the consideration of annual population growth

rate (3.05%) and livestock (3.5%). The water consumption rate for domestic and livestock remains constant (Table 2).

**Scenario two**

Exploitation of all potential irrigation areas was identified by Awulachew et al. 2012, which brings developed the area to 37,294 ha by the year 2035 (anticipated growth of 2800 ha per year). The population growth rate and livestock were considered as 3.05 and 3%, respectively. The water consumption rate for domestic and livestock remains constant (Table 2).

**Fig. 13** Inter-annual maximum temperature patterns by scenario and year



### Scenario three

Exploitation of all potential irrigation areas was identified by Awulachew et al. 2012, which brings developed the area to 37,294 ha by the year 2035 (anticipated growth of 2800 ha per year). Here, the population growth rate and livestock were considered as 3.05 and 3%, respectively. The water consumption rate for domestic can be increased by double and that of livestock remains constant (Table 2).

### Water requirement for non-consumptive uses

In estimating the availability of water resources, consideration must be given to requirements for environmental flows to maintain the ecosystems of the river, to consider the obligations, and maintain streamflow levels of downstream users. The environmental flow of Bilate watershed in this study was adopted 25% of the river flow to be allocated to the environment needs in order to fulfill the downstream requirement.

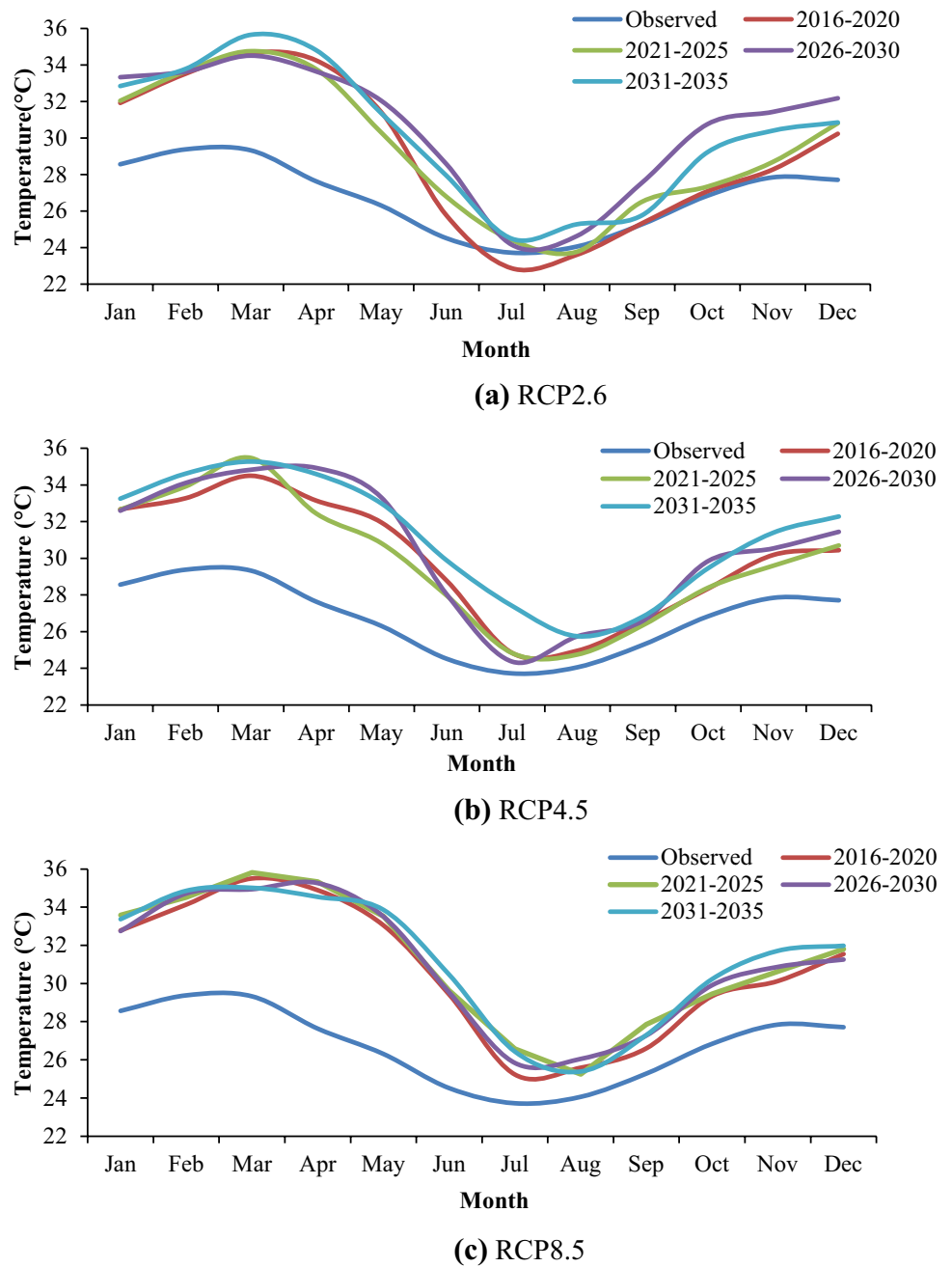
### Conclusions

In this study, the impact of climate change on surface water availability and its allocation was evaluated for Bilate watershed in the Abaya-Chamo sub-basin of Ethiopia. However, this quantification may include uncertainties related to climate change models, downscaling procedures, hydrologic models and lack of good quality and long-term data for the study area. Despite this, efforts were made to simulate future climate change impact on surface water availability and its allocation using SWAT and WEAP model, respectively.

Based on the study, the following conclusions can be drawn:

- The projected inter-annual pattern of rainfall in the Bilate watershed for RCP2.6 scenario did not show the distinct trends. On the other hand, RCP4.5 scenario shows a slight increase and RCP8.5 indicates a more pronounced decrease in annual rainfall. The monthly rainfall pattern for three RCP scenarios clearly indicates that the rainfall can be decreased in the rainy season months (Belg and Kiremt) and increases in the dry months (Bega). The decrease can be more pronounced in Kiremt season. The analysis shows that the seasonal shift can be large in the RCP8.5 scenario.
- In all scenarios, the inter-annual, monthly and seasonal trends show an increase in temperature. The inter-annual pattern of average, minimum and maximum temperature shows an increase more pronounced as scenarios and periods change to the higher order from RCP2.6 to RCP8.5 and from near period (2016–2020) to long period (2031–2035).
- The calibration and validation results were indicated that the SWAT model can simulate the observed streamflow reasonably. The model output shows that there may be an annual decrease in flow up to  $-12.1$  and  $-16.21\%$  for RCP2.6 and RCP8.5 scenarios, respectively.
- Even though the Bilate watershed is having huge surface water resources potential but current utilization of these resources is very limited (only 9.03%) including domestic, livestock and agricultural activities.
- Furthermore, four scenarios were developed based on different sets of assumptions in the basin up to 2035. It was estimated that total annual consumptive water demand may be expected around 14.53, 20.43, 37.47 and 44.46% for the reference scenario, scenario one, scenario two and scenario three, respectively. Also, the study determines

**Fig. 14** Monthly maximum temperature change pattern by period for RCP2.6, RCP4.5, and RCP8.5



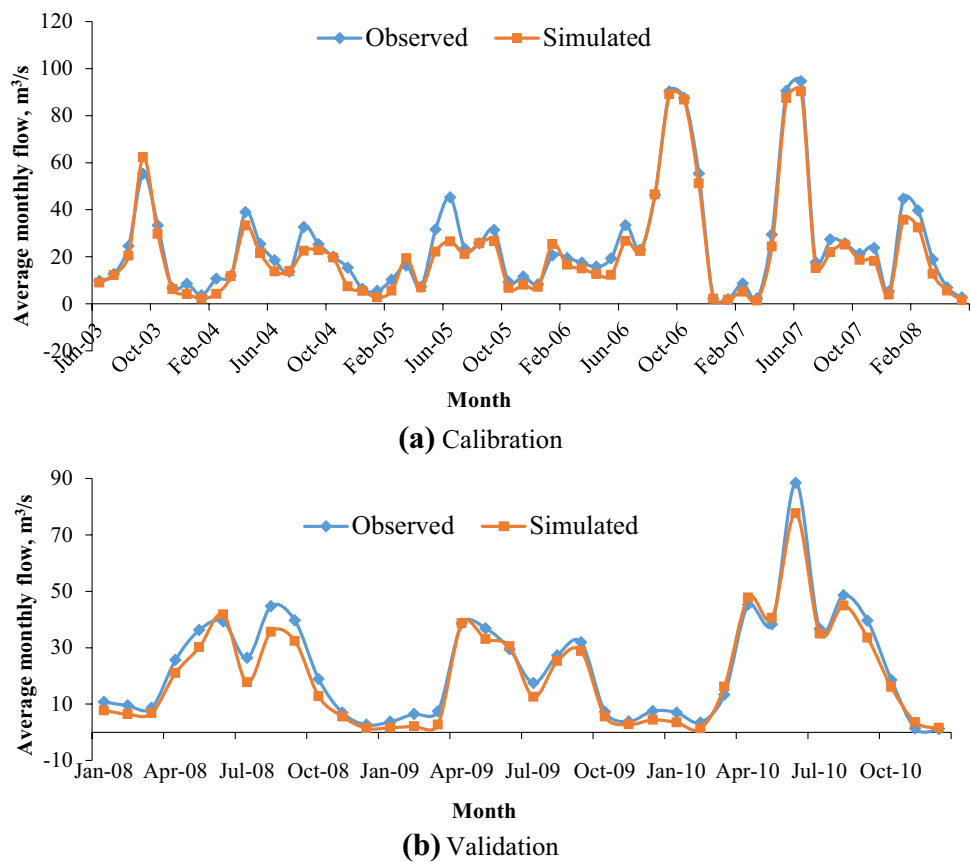
environmental flow requirements (25% of the mean annual flow) to maintain the basic ecological functioning in the basin and regulate flow for downstream uses.

- Finally, this study output can be used for the different stakeholders in the region especially to promote irrigation activities and economic development so that food security can be achieved in the region.

**Table 1** Average annual water balance for both calibration and validation periods

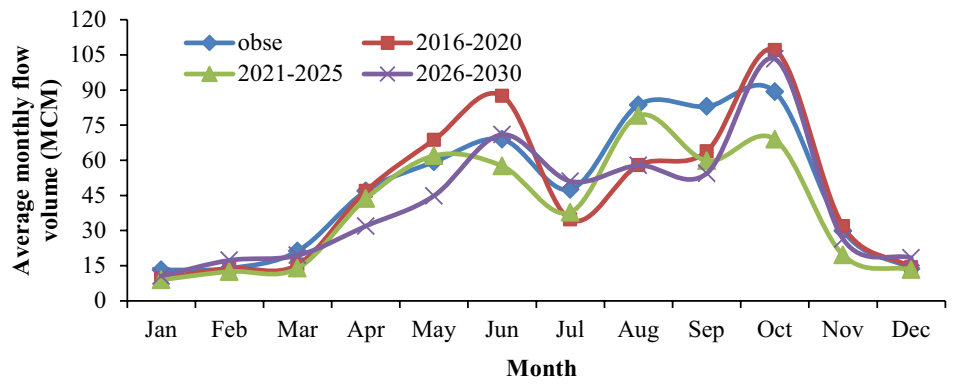
Hydrological parameter	Simulated values (mm)		Weighted average	% annual precipitation
	Calibration	Validation		
Evapotranspiration	772.5	769.6	771.2	77.3
Total AQ recharge	123.7	116.8	120.2	12
Percolation	123.2	117.1	120.1	12
Shallow AQ recharges	105.2	100.5	102.9	10.3
Total water yield	93.8	109	101.4	10.1
Surface runoff	54.7	70.7	62.7	6.2
Base flow	40	40	40	4
Deep AQ recharges	6.2	5.8	6	0.6
Transmission losses	0.9	0.9	0.9	0.16
Groundwater evap	0.8	0.7	0.81	0.07

**Fig. 15** Calibration and validation result of average monthly simulated and gauged flows at the outlet of Bilate watershed

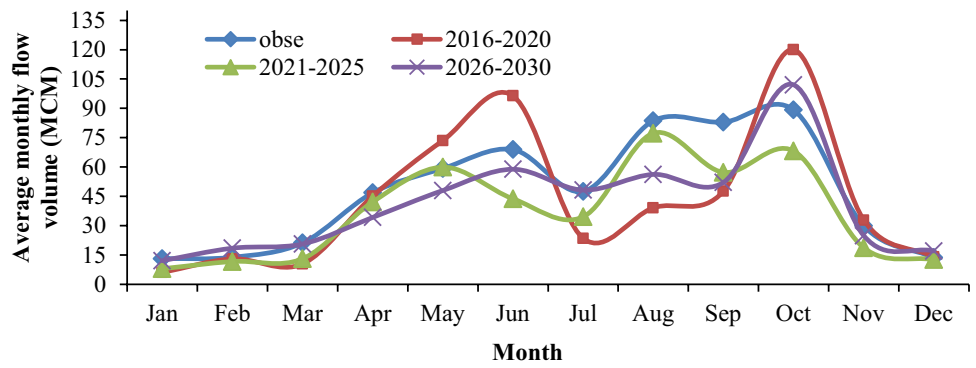




**Fig. 16** Bilate River monthly flow volume at different time horizons under RCP2.6 and RCP8.5 scenario

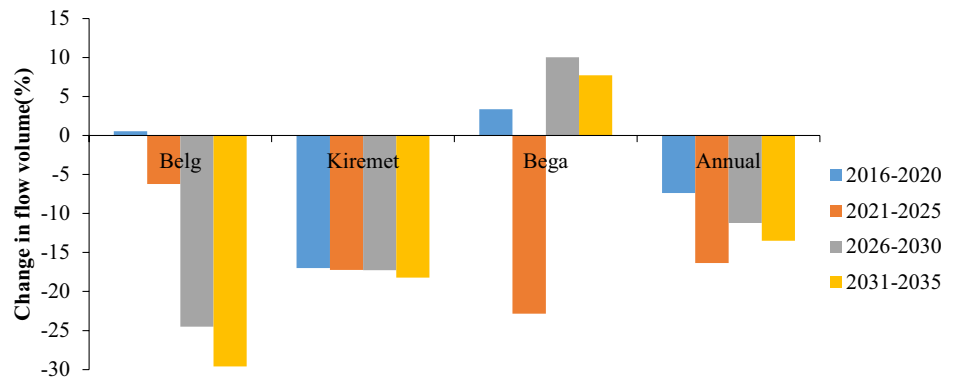


**(a)** RCP2.6

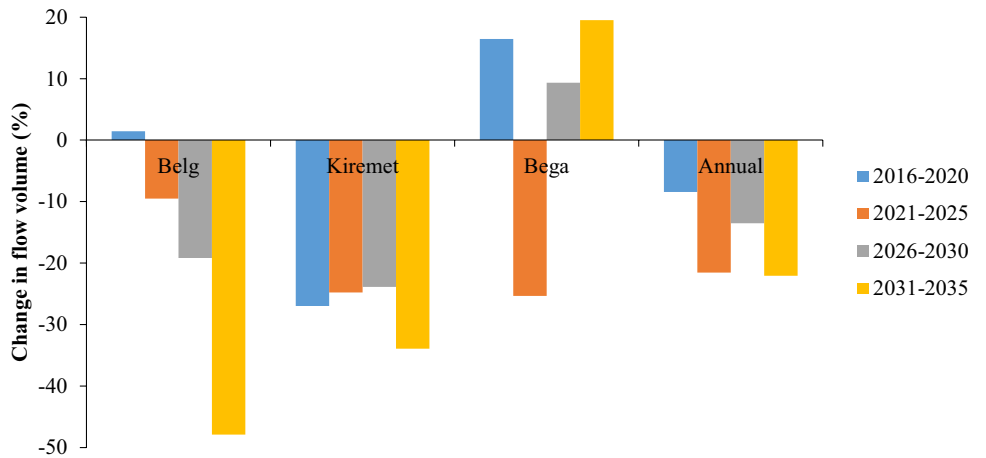


**(b)** RCP8.5

**Fig. 17** Percentage change in seasonal and annual flow volume at Bilate with respect to baseline period for the RCP2.6 and RCP8.5 scenario

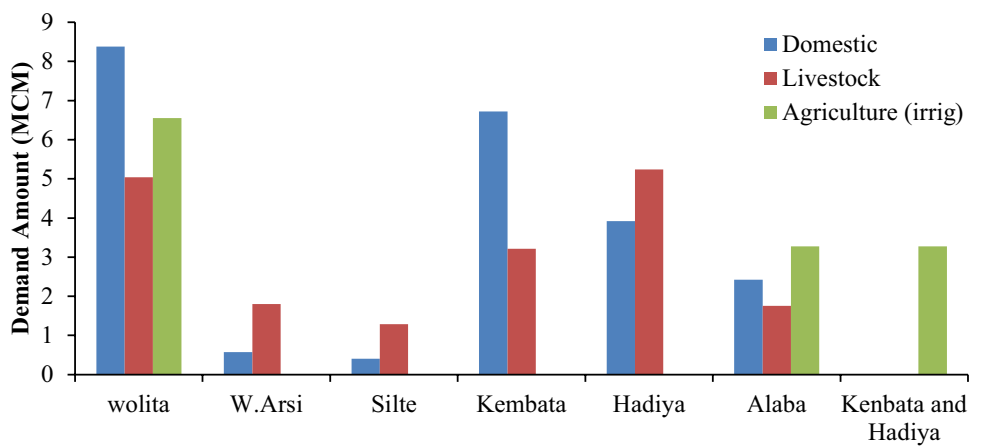


**(a)** RCP2.6



**(b)** RCP8.5

**Fig. 18** The current net demand for each sector incorporated within the WEAP model simulation



**Table 2** Water consumption (MCM) of the reference and scenario one, two and three (2015–2035)

Sector	Reference scenario					Scenario two					Scenario three				
	2015's	2020's	2025's	2030's	2035's	2015's	2020's	2025's	2030's	2035's	2015's	2020's	2025's	2030's	2035's
Domestic	22.42	24.80	30.29	35.19	40.89	22.42	24.80	30.29	35.19	40.89	44.84	49.6	60.58	60.58	81.78
Livestock	15.4	17.85	20.69	23.99	27.81	15.4	17.85	20.69	23.99	27.81	15.4	17.85	20.69	20.69	27.81
Agriculture	13.11	13.11	13.11	13.11	13.11	13.11	13.11	29.91	38.32	46.72	13.11	33.6	54.09	54.09	143.85
Total	51.49	57.66	64.83	73.16	82.83	51.49	66.06	81.63	98.37	116.44	73.35	101.05	135.36	135.36	253.44

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