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ORIGINAL PAPER

Evaluation of impact of climate change on the watershed hydrology, case of Wabe Watershed, Omo Gibe River basin, Ethiopia

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Abstract

Investigating the impact of climate change on watershed hydrology is vital in order to undertake proper mitigation measures and to develop a sustainable climate change adaptation strategy. The objective of this study was the evaluation of the impact of climate change on watershed hydrology, a case study on Wabe watershed, Omo Gibe River basin, Ethiopia. The observed hydro-meteorological data for the baseline period of 1990–2019 was collected from the Ethiopian Ministry of Water, Irrigation and Energy (MoWIE) and the Ethiopian Meteorological Agency (EMA). Three regional climate models (RCMs), i.e., RACMO22T, RCA4, and CCLM4-8-17 derived by one MOHC-HadGEM2-ES Global Climate Model (GCM) were downloaded from CORDEX-Africa. The climate projection of the three RCMs and their ensemble for near-future term (2024–2053) and mid-future term (2054–2083) under RCP4.5 and RCP8.5 climate change scenarios was conducted based on the 1990–2019 baseline data. The climate projection showed that the monthly rainfall will increase by 44.3% in the near-future term under RCP4.5 and by 34.8% and 49% under RCP4.5 and RCP8.5, respectively, in the mid-future term by the CCLM4-8-17 model while a maximum decline of − 45.3% and − 27.1% in rainfall amount was detected by RCA4 in the near- and mid-future terms, respectively, under RCP4.5. The mean monthly maximum temperature rises by 2.55 °C to 3.1 °C while the mean monthly minimum temperature increases by 1.54 °C to 1.89 °C in both time horizons, respectively, under RCP4.5 and RCP8.5. The SWAT model outcome indicated that the stream flow will decline by − 10.67% and − 17.94% under RCP4.5 and RCP8.5, respectively.

Keywords Hydrological process · Regional climate · Hydrologic model · Climate change · Hydrologic response · Wabe watershed

Introduction

Climate change is defined as a change in climate condition that can be determined by changes in the mean and/or variability of its properties (Javadinejad et al. 2021) over time, usually a decade or more. At present, there are several evidences that indicate the existence of climate change across the globe (Hoegh-Guldberg and Bruno 2010; Reihaneh et al. 2016). A tremendous number of researchers have recognized the existence of climate change and its persistence all over the world in the future through their studies (for instance, Shiferaw et al. 2016; Jonas et al. 2018; Alessandro et al. 2018; Wagena et al. 2018). The presence of climate change can be investigated through its impact on various components of the earth's system, especially through the tangible effect on hydrology (Fatahi et al. 2021), water resources, and environments. The extreme climate condition may affect numerous natural resources of the earth's system, but the effect on hydrology and water resource is significant (Wagena et al. 2018; Reihaneh et al. 2016). Amraoui et al. (2019) conducted a study in Sommen river basin (France) in order to investigate the impact of climate change on water resources, and from their finding, they concluded that the groundwater recharge under the climate change scenario was decreased by about 23% across the river basin. Melkamu and Zerihun (2018) carried out a review of the impact of climate change on the watershed hydrology. They concluded that numerous studies have shown increases in the minimum and maximum temperatures and an oscillating precipitation

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pattern. Hartmann et al. (2014) also studied the spatiotemporal impact of climate change on groundwater recharge in the case of Mediterranean karst aquifer. From their work, they concluded that with a small decrease in precipitation, a larger decrease in groundwater recharge was detected. This was mainly due to the fact that some amount of rainfall goes to the atmosphere in the form of evaporation as a result of an increase in land surface temperature. Olarinoye et al. (2020) studied the impact of future climate change and urbanization on groundwater in Arusha, Tanzania. From the integration of satellite imagery, urban growth modeling, groundwater modeling, and hydrological field expedition, they suggested that the groundwater recharge will decrease by 30–44% by 2050 which is mainly due to evaporation. Jonathan et al. (2004) have undertaken a study in order to simulate the impact of climate change on hydrology and water resources in Swaziland. From the study, they investigated that change in climate condition is deteriorating different components of the hydrologic cycle (such as evapotranspiration, precipitation, infiltration rate), and the simulated surface runoff is varied by ±5%. Fikru et al. (2018) have carried out a study on the impact of climate change on the reservoir operation policy, in the case of the Takaze hydropower project. From the outcome of their research, they have concluded that there is a fluctuation in water level due to the extreme dry and/or extreme wet of the weather condition.

Moreover, the global climate pattern is being changed temporally and spatially and also expected to be changed in the future (Parthkumar et al. 2021; Reihaneh et al. 2016; Legese 2017; Wagena et al. 2018; Alessandro et al. 2018). As it was understood from the study conducted by Legese (2017), the global mean surface temperature was increased by 0.8 °C in the past century and by 0.6 °C in the last three decades and will be expected to increase from 1.1 to 6.4 °C in the next 100 years (IPCC 2001; Shiferaw et al. 2016). There are a lot of driving factors behind the accelerating increasing of global warming. Abeyou et al. (2018) suggested that the greenhouse gas emission induced by the industrial revolution and different human activities are one of the driving factors of global warming. The warming up of the system of the globe is leading to a rise in land surface temperature and change in precipitation in the range of ±20% (IPCC 2001; Jonathan et al. 2004; Melkamu and Zerihun 2018). According to Hoegh-Guldberg and Bruno (2010), an increase in greenhouse emission will raise land surface mean temperature by 1.4 to 5.8 °C and disturbs the rainfall pattern. Even if the effect of climate change is concerning all the climate variables and numerous sectors, the effect on temperature and precipitation and thereby on watershed hydrology and water resources sector is substantial (Nguyen et al. 2017). Climate change affects not only the magnitude of rainfall and temperature, but also, it may cause shifting of the rainfall season. Change in rainfall frequency, duration, intensity, and the well-known rainfall season affect the farmers and their production at large, and also leads to the deterioration in the hydrologic processes of certain watersheds (Sang et al. 2019; Hao et al. 2021). Hence, understanding the adverse impact of climate change on watershed hydrology is very crucial for giving direction for the farmers regarding the proper rainfall season for cultivation. On the other hand, climate change can cause extreme precipitation that may result in serious flood hazards together with rapid urbanization (Wang et al. 2015; Nguyen et al. 2018). Likewise, a rise in land surface temperature can cause the removal of a large amount of soil moisture content and a substantial volume of water from the reservoir in the form of evaporation (Talebmorad et al. 2020). This may lead to crop water stress and reduction in water level in the reservoir as a result of which reduction in agricultural and energy production may occur (Shiferaw et al. 2016). Water resources and watershed hydrological response are sensitive to climate change as the inputs to these projects (i.e., inflow and outflow) are climate-dependent variables (Yuzhou et al. 2013; Fikru et al. 2018; Abeyou et al. 2018). The presently noticed change in climate condition is deteriorating several water-related projects all over the world, of which the prominent effect is being perceived on the hydrology of the earth's system (Tesfalem et al. 2018; Parthkumar et al. 2021; Patrick et al. 2021; Marta et al. 2021).The frequently increasing state of global warming due to the current substantial greenhouse gas emission to the atmosphere is one of the prominent drivers of the rise in land surface temperature (Melkamu and Zerihun 2018; Amraoui et al. 2019; Tesfalem et al. 2018), and this on its turn affects different hydrological components of our planet system (Parthkumar et al. 2021; Somsubhra and Manoj 2016; Gabriela et al. 2020; Marta et al. 2021). Numerous scholars have investigated the multiple effect of climate change on the hydrology and water resource system. For instance, effects on crop water use and crop yield (Parthkumar et al. 2021), water resources and its components (Patrick et al. 2021), effect on hydrology (Somsubhra and Manoj 2016; Tesfalem et al. 2018; Marta et al. 2021), groundwater potential and recharge (Amraoui et al. 2019), and stream flow. Furthermore, climate change is upsetting the water balance pattern of the watershed system through affecting the various components of the hydrological cycle such as precipitation, evapotranspiration, infiltration, ground water table, and stream flow (Gabriela et al. 2020).

According to the IPCC findings, even though the impact of climate change is a global issue, its effect is more intensive in developing countries like Ethiopia (Melkamu and Zerihun 2018; Shiferaw et al. 2016) due to the easy vulnerability and weak coordination to combat its effect. Climate change in Ethiopia has been visualized since the last two to three decades with its substantial effects across the country (McSweeney et al. 2008; NMA 2014; Zenebe et al. 2019).

As the studies conducted by Yohe et al. (2006), Springmann et al. (2016), and Mekonnen et al. (2017) confirm, the adverse impact of climate change in Ethiopia is one of the challenging issues behind the hydro-economic development of the country. More than 85% of the Ethiopian economy is leading by agricultural production for which availability of adequate water resource is very important. However, climate change and its state variability are influencing the spatial and temporal water availability of the region, affecting the rainfall pattern and its products (Hailemariam 1999; Melkamu and Zerihun 2018). According to Melkamu and Zerihun (2018), the present-day global warming is causing the land surface temperature to rise and changing the precipitation pattern up to ±20%. The same situation is challenging the Ethiopian water resources and hydrologic system. Many climate change–inducing events such extreme drought, flood, extreme wet and extreme dry, magnitude and seasonal rainfall variation have been occurring across the different regions of the country (Melkamu and Zerihun 2018). As the climate change may cause certain uncertainties in water resource planning and design for different purposes, climate change impact evaluation at the watershed level is very essential (Retinder et al. 2016; Tesfalem et al. 2018). The main target of this study is to investigate the impact of climate change on watershed hydrology, case study on Wabe watershed under three regional climate models (RCMs). In Wabe watershed, there are two competing factors that deteriorate the water resources and hydrologic system. These two governing factors are LULC and climate change (Shiferaw et al. 2016). The study on the impact of LULC change is ongoing, and it is to be sent for publication soon while this paper fully focuses on the impact of climate change on the hydrologic system of the watershed. Wabe watershed is one of the economically important watersheds found in Omo Gibe River basin. It is among the watersheds of the river basin that contributes a huge volume of water to Gibe River along which several hydroelectric power and irrigation projects are being constructed. The watershed encompasses numerous agricultural activities that depend on both irrigation and a rain-fed agricultural system. In Ethiopia, particularly in Wabe watershed, rain-fed agriculture is more common and deviation in rainfall pattern will directly lead to agricultural drought. Therefore, evaluation of climate change impact on watershed hydrology is imperative in order to understand the effect on water resources and water resources–related activities (Ostad-Ali and Shayan 2021). Often, the climate change impact assessment on watershed hydrology and water resources is carried out through the analysis of global climate model (GCM) and regional climate model (RCM) data (Somsubhra and Manoj 2016; Abeyou et al. 2018; Amraoui et al. 2019). Hence, for this study, one GCM known as driving model and the downscaled three RCMs were used in order to investigate the impact of climate change on the hydrology of Wabe watershed. Of course, numerous studies have been conducted and also being undertaken all over the world as well as in Ethiopia against the impact of climate change on the hydrologic system. However, most of these studies were conducted using a station-based approach while this violates the principles of physically based semi-distributed approach. For example, Dibaba et al. (2017) performed performance comparison of different CORDEX RCMs in Didhessa and Fincha Catchment. In such an approach, it may be difficult to compare the observed and RCM data as it is impossible to compare areal coverage of RCMs and actual stations in the study area. To avoid such difficulties, our study was conducted based on the areal-based approach rather than the station-based approach. This is one of the improvements that our study had gotten over some related researches and contributed to scientific communities.

Methodology

Study area

The Omo Gibe River basin is the third largest river basin of Ethiopia next to the Baro Akobo and Blue Nile river basins. It has an area of 79,000 km^2 covering parts of two national regional governments, the Southern Nations and Nationality Peoples Region (SNNPR) and Oromiya regional state government. It generates annual runoff of about 17.90 Bm^3. It consists of several hydropower, irrigation, and water supply projects. Most of these projects were already commissioned (for instance, Gibe-I, Gibe-II, and Gibe-III are hydroelectric projects that were already commissioned) while some of them are under construction, for instance Koysha project. Wabe watershed is one of the watersheds that belong to the Omo Gibe River basin and are contributing huge amounts of annual flow to different reservoirs constructed across the basin. Wabe River is one of the tributaries of the Omo Gibe River that play a vital role in the regular operation of the different projects constructed within this river basin (Shiferaw et al. 2016). Wabe watershed is characterized by the basic climate zone of Ethiopia that is governed by the intertropical climate zone. It is one of the primary watersheds of the river basin that is highly exposed to the effects of climate change. Based on the altitudinal classification of the climate zone, Wabe watershed is categorized under warm to temperate climate zone. Geographically, it is found between 8° 06′ 30″ to 8° 36′ 25″ N latitude and 37° 30′ 05″ to 38° 30′ 30″ E longitude and an average altitude of 2400 m a.m.s.l. to the southwest of Addis Ababa (Fig. 1). It covers an area of about 1943km^2.

Maximum elevation of the watershed is located toward the southeast of the watershed whereas the minimum

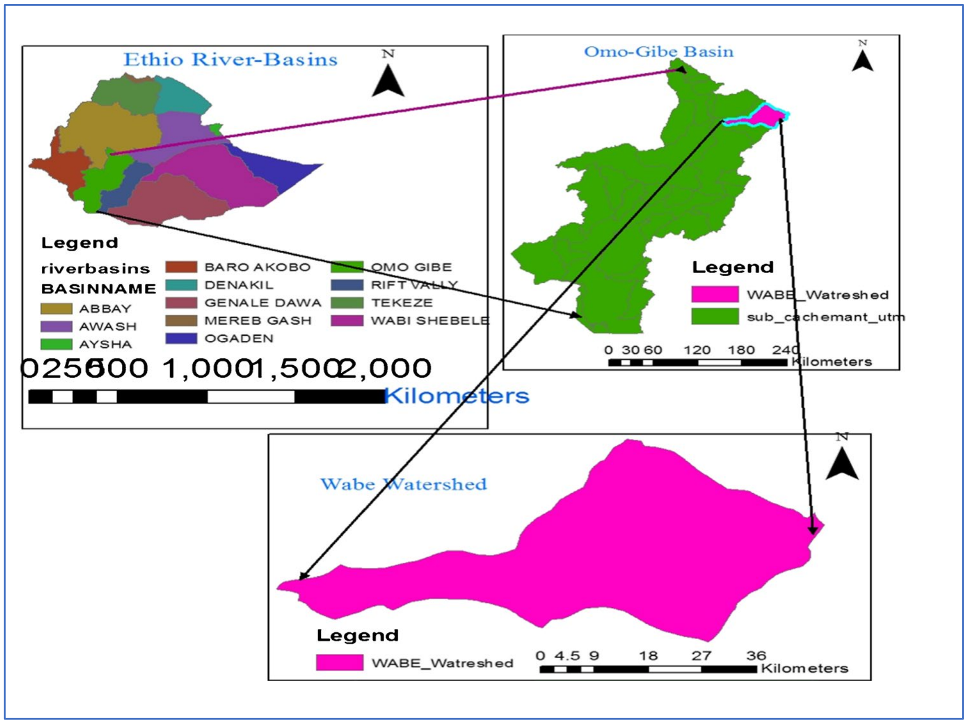

Fig. 1 Location map of Wabe watershed

elevation is found in the southwest part. Therefore, it drains to the southwest and joins the great Omo Gibe River at (347,889.45 m E UTM and 909,169.42 m N UTM). It consists of a lot of meteorological stations of which the synoptic stations such as Kokir meteorological station, Wolkite meteorological station, and Agena Meteorological station were considered for the case of this study. The annual rainfall of the watershed is varying from 1900 mm in the north and 1200 mm in the southeast and < 1200 m toward the southwest and west lowland of the watershed. Also, the mean monthly rainfall of the watershed is dissimilar crosswise the synoptic meteorological stations under consideration. The mean annual minimum and maximum temperatures of the watershed, respectively, are 11.5 °C and 26.3 °C. On the other hand, the mean monthly minimum and maximum temperatures are different across each station. However, across the individual station, there is variation in the minimum and maximum temperatures from 8.5–30 °C. Likewise, the watershed encompasses various land use/land cover and soil types. Among the different land use/land cover (LULC) classifications of the watershed range, brush land constitutes a large portion (about 49.15% of the total areas) whereas corn crop covers a small percentage (Table 1 and Fig. 2B). The watershed comprises four main soil types (Table 2) of which Eutric Vertisols constitute about 45.84% of the total area of the Wabe watershed. This soil type covers the north to northwest and some southwest portion of the watershed (Fig. 2A).

Table 1 LULC classification and areal coverage

SWAT code	Crop name	Area (km^2)	%age of area coverage
NRGD	Range brush land	868.68	49.15
FRDS	Forest deciduous	49.862.82	25
TEFF	Eragrostis Teff	652.71	36.93
FRST	Forest mixed	13.4	7.58
WATR	Water body	33.1	1.87
CORN	Corn	29.04	1.64

Observed data sets

In order to undertake the correct evaluation of climate change impact on watershed hydrology and water resources of the watershed under consideration, different hydro-meteorological data are required. Herein, the daily meteorological data for the synoptic meteorological stations were collected from the Ethiopian Meteorological Agency (EMA). The stream flow data that was used for model calibration and model validation was collected from the Ethiopian Ministry of Water, Irrigation and Energy (MoWIE) office. The land use/land cover (LULC) and soil data for the Wabe watershed were collected from the Ethiopian Mapping Agency (EMA). The high-resolution digital elevation model (12.5 m × 12.5 m) DEM that was mainly utilized for the extraction of different topographic

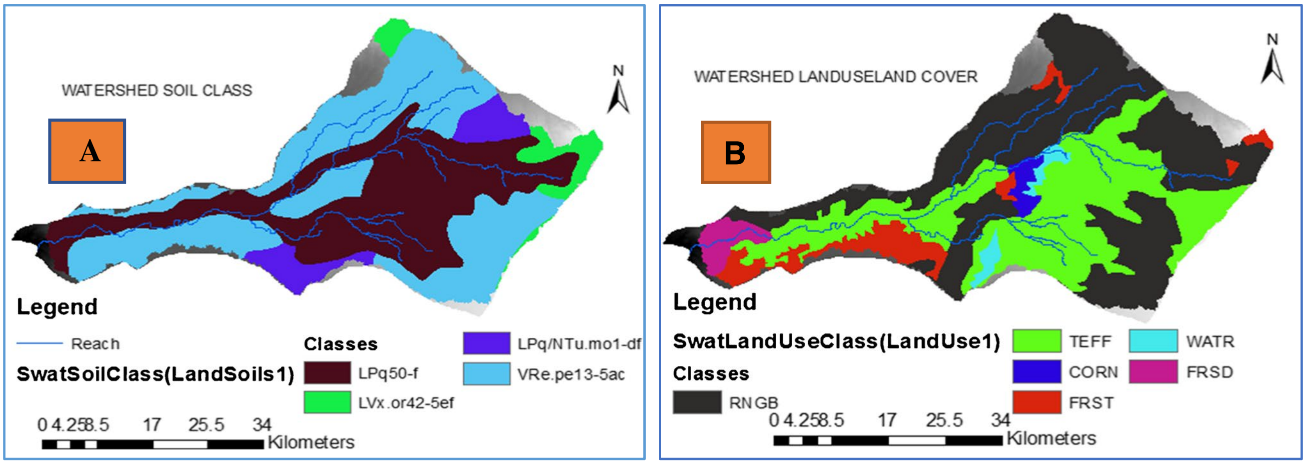

Fig. 2 Soil type (**A**) and LULC (**B**) classification of the Wabe watershed

Table 2 Soil type and their percentage of coverage

Soil name	Symbol	Swat code	Shape area	% coverage
Eutric Vertisols	Vre	Vre.Pe14-5ac	810.17	45.84
Chromic Luvisols	Lvx	Lvx.Or42-5ef	87.8	4.93
Humic Nitisols	Ntu	Lpq/Ntu.Mo11-5d	122.04	6.91
Lithic Leptosols	Lpq	Lpq50-F	747.98	42.32

features and watershed physical parameters of the Wabe watershed was downloaded from Alaska Satellite Facility's website (https://vertex.dac.asf.alska.edu). The observed hydro-meteorological data need further processing before utilizing for the intended purpose. This is because the data may consist of large missing data value, inconsistency, non-stationarity, and/or non-homogeneity. In Wabe watershed, it was observed that the meteorological stations are so dispersed and unevenly scattered. Screening of the daily weather data for every station was undertaken and it was found that some stations were with a large missing data value. Omitting those stations with the largest missing data value, weather data for Kokir station, Agena station, and Wolkite stations for a baseline period of 1990–2019 were considered in this study. The missing data value for each weather data type was filled using XLSTAT statistical software package version 2020.1.1. The data quality test such as data homogeneity and stationarity were also computed using the XLSTAT statistical software package whereas the data consistency test was carried out using double mass curve (DMC). Stream flow data was also undertaken using a similar procedure. RCM data for every grid point covering the watershed was extracted and converted to Microsoft Excel format using RStudio computer programming language.

Climate data sets

For the evaluation of climate change on the hydrology of the specified watershed, the utilization of the GCM and RCM modes is essential (Somsubhra and Manoj 2016; Muhammad et al. 2020). Hence, in our case, three regional climate models, RCM data (i.e., RACMO22T, RCM_RCA4, and CCLM4-8) for one driving model known as Met Office Hadley Centre Earth System-Hadley Centre's Global Environment Model version-2 (MOHC-HadGEM2-ES) under two climate change scenarios that is the Representative Concentration Pathway RCP4.5 and RCP8.5 were downloaded from CORDEX-Africa. Climate model output is mainly important for climate change impact assessment, evaluation, and adaptation strategies. Currently, there are tremendous climate models (GCMs and RCMs) that are most widely applicable for climate change impact assessment in different sectors. This also involves impact evaluation, risk assessment, planning and decision-making, and climate change adaptation strategy setup (Alemseged et al. 2017; Dibaba et al. 2017; Gebrekidan et al. 2018). The main drawback of direct utilization of the GCM model for climate change impact assessment is the uncertainties incorporated due the coarse resolution (250 km × 250 km) of the model. A long time before, this has been one of the challenging issues while applying different climate models for climate for different activities (Alessandro et al. 2018; Abeyou et al. 2018). In order to solve the problem with the GCM model, the World Climate Research Program (WCRP) has developed a worldwide project called Coordinated Regional Climate Downscaling Experiment (CORDEX) (Giorgi et al. 2009; Alemseged et al. 2017; Dibaba et al. 2017). With this project, different GCMs of coarse resolution (250 km × 250 km) were downscaled to different RCMs (50 km × 50 km) based on the dynamic downscaling method. The CORDEX-Africa which was one of the WCRP's projects for African domain was provided for all African regions with about 25 driving model (GCMs) with a bundle of RCMs under each driving model. However, as one pixel size of RCM covers an area of 50 km × 50 km, it is not recommended for a watershed to consist of two meteorological stations far apart more than 50 km. Therefore, areal rainfall needs to be computed and all of the analysis and the computation should be done based on the areal data instead of being limited to a station like in the case of this study. On the other hand, each RCM consists of different climate change scenarios called representative concentration pathways (RCP4.5, 2.6, 6.0, and 8.5) that reveal the rate of greenhouse gas emission (Fikru et al. 2018). Based on this crucial information, one driving model called MOHC-HadGEM2-ES (Met Office Hadley Centre Earth System-Hadley Centre's Global Environment Model version-2) was chosen from CORDEX-RCM (https://esgf-node.llnl.gov/projects/esgf-llnl/) for this study. This driving model contains a different number of RCMs of which RACMO22T, RCA4, and CCLM4-8-17 RCMs were selected and downloaded for the two most widely applicable climate change scenarios (RCP4.5 and RCP8.5). Climate data like precipitation and temperature for every grid point covering the Wabe watershed were extracted from each RCM using RStudio which is a computer programming language and arranged to the form suitable for the analysis.

Bias correction

The easy vulnerability of a watershed hydrology to the erratic climate variables necessitates the projection and evaluation of the impact of climate change on hydrologic cycle and water resources (Claudia and Jan 2012). The most widely applicable means of predicting climate change impact on hydrology is through modeling of different climate variables such as temperature, precipitation, evapotranspiration, etc. in combination with various hydrologic modeling tools (Claudia and Jan 2012). Although this is the case, attention needs to be taken while proceeding with these climatic variables as the RCM can transfer a large information gap from GCM which leads to biases in final outcomes (Christensen et al. 2008; Teutschbein and Seibert 2010; Claudia and Jan 2012). Therefore, one should have to go through different bias correction techniques in order to hand over the expected uncertainties of the model. One of the best and simple solutions recommended by different scientists to reduce such uncertainty of the climate model is to use an ensemble of RCMs (Déqué et al. 2007; Teutschbein and Seibert 2010; Claudia and Jan 2012) in combination with various bias correction methods (Claudia and Jan 2012). For this purpose, there are many bias correction methods that are frequently applied by different scholars across the globe. These are linear scaling, local intensity scaling, power transformation, variable scaling, distribution transfer, and delta change approach. Based on the different recommendations given by numerous scholars concerning the accuracy of the power transformation and scale variance bias correction methods (Leander and Buishand 2007; Leander et al. 2008; Claudia and Jan 2012) and their suitability for our data, we have applied power transformation for precipitation and scale variance for temperature. Here, bias correction for the climate model was done using the observed weather data of the baseline period (1980–2005). CMHyd software package that provided all bias correction techniques was used as an instrument for bias correction execution.

Hydrological model

Hydrological modeling is very essential in order to investigate the watershed hydrological response to the climate change and climate change impact assessment on water resources and hydrologic cycle (Yuzhou et al. 2013; Alemseged et al. 2017; Alessandro et al. 2018). Presently, there are enormous most widely applicable physically based watershed hydrological response modeling tools such as HBV model (Alemseged et al. 2017), HEC-HMS (Yuzhou et al. 2013; Namara et al. 2020) and SWAT (Yuzhou et al. 2013; Shiferaw et al. 2016; Nguyen et al. 2017). Of the listed hydrologic modeling tools, the Soil Water Assessment Tool (SWAT) model is mostly preferred by numerous authors. This is because the SWAT model was developed with various options to insert every watershed physical parameters and climate variables that may upset the good watershed hydrological responses to climate change and watershed physical parameters. This increases the certainty of the SWAT model compared to the other modeling tools. Hence, in order acquire this advantage in our final result, we have used the SWAT model in order to model the Wabe watershed hydrological response to climate change. SWAT is a physically based semi-distributed model that operates on the basis of the daily time series data (Dibaba et al. 2020). It has been applied from the so long time up to date for the long-term continuous stream flow simulation, soil erosion and sediment modeling, and nutrient transport modeling in watersheds of different sizes (Shiferaw et al. 2016). SWAT is an extension of Arc GIS interface works on the principles of the hydrologic response unit (HRU) which is the sub-division of the whole watershed under study into different small sub-watersheds.

It is mainly dependent on the water balance equation expressed by Eq. 1 below.

$$S_{wt} = S_o + \sum_{i=1}^{t} \left(P_d - R - E - w_{seep} - G\right) \quad (1)$$

where S_{wt} is the soil water content (mm), S_o is the initial soil water content (mm), R is the surface runoff (mm), P_d is the daily precipitation (mm), E is evapotranspiration (mm), w_{seep} is soil infiltration (mm), and G is groundwater. Herein, the impact of climate change on the watershed hydrological response was undertaken by simulating the impact on the stream flow of Wabe River near the Wolkite River gauging station. In the SWAT, the hydrological simulation is beginning with watershed delineation. From the watershed delineation of Wabe watershed, about 80 HRU were developed and embedded into the SWAT model together with a weather data from three meteorological stations (Wolkite, Kokir, and Agena). The simulation was conducted based on the Soil Conservation Service Curve Number (SCS-CN) method (Eqs. 2–4).

$$S = \frac{25400}{CN} - 254 \quad (2)$$

where S is the maximum soil retention potential and CN is the curve number.

$$I_a = 0.2S \quad (3)$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (4)$$

where I_a is the initial abstraction (mm), P is the accumulated precipitation, and Q is the surface runoff.

As SWAT is a model that considers numerous watershed physical parameters that may upset the watershed hydrological response, the model parameters need to be calibrated and validated in order to check and reduce their sensitivity. For this, the observed stream flow data taken near the Wolkite River gauging station (1990–2007) was used for calibration (1992–2002) and validation (2003–2007) with a warmup period of 1 year (1990–1991). The parameters' sensitivity against the watershed hydrological response was analyzed using the sequential uncertainty fitting version 2 (SUFI-2) algorithms that were provided in SWAT-CUP (Calibration Uncertainty Program). The other very important procedure in a SWAT model is the model performance evaluation in which the fitness of the model output with respect to the observed data is to be investigated. There are a lot of statistical model performance indicators of which the following are utilized for model performance evaluation against the observed stream flow.

$$NSE = 1 - \frac{\sum \left(Q_s - Q_o\right)^2}{\sum \left(Q_o - \overline{Q_o}\right)^2} \quad (5)$$

Where: NSE is the Nash Sutcliff efficiency, Q_s is the simulated rate of flow (m^3/s), and Q_o is the observed rate of flow (m^3/s), and $\overline{Q_m}$ is the mean observed flow (m^3/s).

$$R^2 = \frac{\sum_{i=1}^{n} \left[Q_{mi} - \overline{Q_m})(Q_{si} - \overline{Q_s}\right]^2}{\sqrt{\sum_{i=1}^{n} \left(Q_{mi} - \overline{Q_m}\right)^2 \sum_{i=1}^{n} \left(Q_{si} - \overline{Q_s}\right)^2}}, 0 \le R^2 \le 1 \quad (6)$$

where R^2 is the coefficient of determination with a standardized value range of $0 \le R^2 \le 1$, Q_m is the measured stream flow, Q_s is the simulated flow, and $\overline{Q_m}$***and***$\overline{Q_s}$ are the means of the measured and simulated flow, respectively.

$$PBias = \frac{\sum \left(Q_m - Q_s\right)}{\sum Q_m} * 100 \quad (7)$$

$$RMSE = \sqrt{\frac{\left(Q_m - Q_s\right)^2}{n}} \quad (8)$$

where n is the total data length (year).

Results and discussion

Climate projection

To demonstrate the variability of climate elements such as temperature and precipitation in the future period along with different RCM models, the climate projection is imperative (Shiferaw et al. 2016; Fikru et al. 2018; Dibaba et al. 2020). Hence, to forecast change in precipitation and temperature over the Wabe watershed and the stream flow, the climate projection of the three RCMs and their mean ensemble for two future periods, i.e., near-future term (2024–2053) and middle-future term (2054–2083), referencing to the baseline period (1990–2019) were made. The projection result depicted that the monthly precipitation of the three RCMs and their ensemble showed an oscillating trend both under RCP4.5 and RCP8.5 scenarios at near- and mid-future terms (Figs. 3 and 4). According to NMA (2014), there is no statistically significant change in average annual rainfall amount between 1951 and 2006, but the IPCC's report indicated that rainfall is increasing by 0.6 to 4.9% and 1.1 to 18.2% for 2030 and 2050 all over the Ethiopian regions. McSweeney (2008) concluded that there is a large rainfall variation in the south part of the country which confirms the result of this study. According to the CCLM4-8-17 RCM model, the

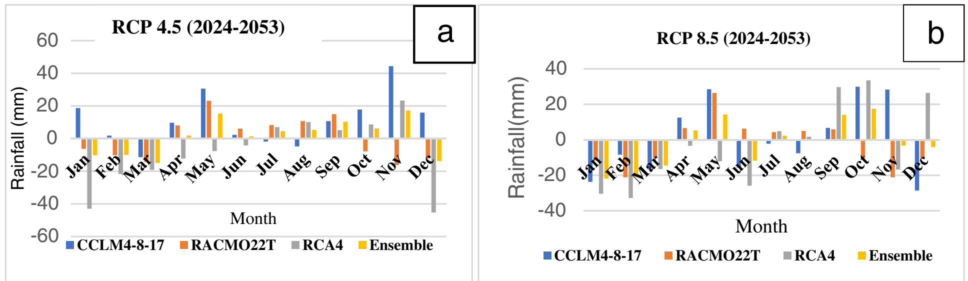

Fig. 3 Variation of mean monthly rainfall at near-future term under RCP4.5 and RCP8.5 climate change scenarios

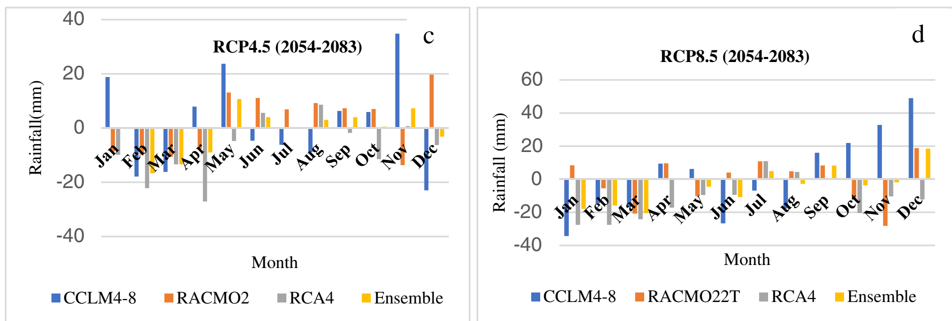

Fig. 4 Variation of mean monthly rainfall at mid-future terms under RCP4.5 and RCP8.5 climate change scenarios

monthly precipitation of the Wabe watershed is increasing throughout the near-future term (2024–2053) except in the months of March, July, and August under RCP4.5 scenarios which increases by 44.36% in November (Fig. 3). Dibaba et al. (2020) obtained decreasing precipitation across the Finchaa catchment in upper Blue Nile basing (Ethiopia) at near- and mid-future terms using the CCLM4-8-17 RCM model but under different driving (GCM) models. This indicates that the response of different RCM models to climate change varies at different river basins and is also governed by GCM. The highest decrease in rainfall amount was detected by the RCA4 RCM model which showed reduction in rainfall amount by − 45.3% in December. It depicted a decline in precipitation from January to June and a rise in precipitation from July to November both under RCP4.5 and RCP8.5 climate change scenarios at the near-future term (Fig. 5). Also, RCA4 showed a decline in precipitation in all mid-future terms under both climate change scenarios (RCP4.5 and RCP8.5) expect in June and August under RCP4.5 and in July–September under the RCP8.5 climate scenario. RACMO22T showed similar trends in the near-future term both under RCP4.5 and RCP8.5 (i.e., decreasing from January to March, increasing from April to September, and declining again from October to December) (Fig. 3a). It also revealed a reduction in rainfall amount from June to April and November and an increment in precipitation amount from May to October and December in the mid-future term under the RCP4.5 climate change scenario and an oscillating trend under RCP8.5 (Fig. 4a, b). The mean ensemble of all the RCM models showed average trends throughout the near- and mid-future terms both under RCP4.5 and RCP8.5 climate change scenarios with small variations.

The CCLM4-8-17 RCM revealed that the rainfall will increase by 34.8% and 49%, respectively, under RCP4.5 and RCP8.5 and decrease − 34.4% under RCP8.5 while the RCA4 RCM showed a decline in rainfall by − 27.1% under the RCP4.5 climate change scenario at the mid future study horizon. Also, seasonal and annual precipitation variation by the three RCM was projected both for near- and mid-future terms under both climate change scenarios. The result of the projection depicted that the individual RCM showed different degrees of variation along the calendars under RCP4.5 and RCP8.5, respectively. Accordingly, the CCLM4-8-17 RCM showed an increase in precipitation in all seasons in the near-future term including the annual rainfall both under RCP4.5 and RCP8.5 except in the summer season under the RCP8.5 climate change scenario while the RCA4 RCM revealed decreasing trends in all seasons and annual rainfall except during the summer season under RCP4.5 (Fig 6).

As per the ensemble mean of all the RCMs, the rainfall increases in all seasons of the near-future term except during the spring under the RCP4.5 and declines in all seasons except during the summer under the RCP8.5 scenario. On the other hand, the RCA4 and RACMO22T showed a large reduction in rainfall (− 16.2 to − 13.4%), respectively, at the near-future term under RCP8.5.

As it is indicated in Fig. 5, the RCA4 RCM depicted a decline in rainfall amount throughout the season of the mid-future term under both climate change scenarios excluding the summer season that showed a rise in rainfall under both

RCP4.5 and RCP8.5 climate scenarios. The mean ensemble of the three RCMs revealed intensification of seasonal and annual rainfall in the mid-future term under the RCP8.5 climate change scenario while it demonstrated an escalation of rainfall amount in the summer and winter seasons and a lessening of rainfall amount during spring and annual basis (Fig. 5).

Temperature projection is also done for all RCMs and their ensemble for both study calendars. The mean monthly maximum temperature will be expected to increase over the Wabe watershed in the near-future terms beginning from the month of July to March by all RCMs. All the RCMs showed a rise in temperature in the near-future term under both climate scenarios excluding April–May under RCP4.5 and May and June under the RCP8.5 climate scenario which showed decreasing temperature by − 1.2 to − 0.7 °C by CCLM4-8-17 under RCP8.5 and by RACMO22T under RCP4.5, respectively (Fig. 7A, B). In the mid-future term, the mean monthly maximum temperature is increasing along

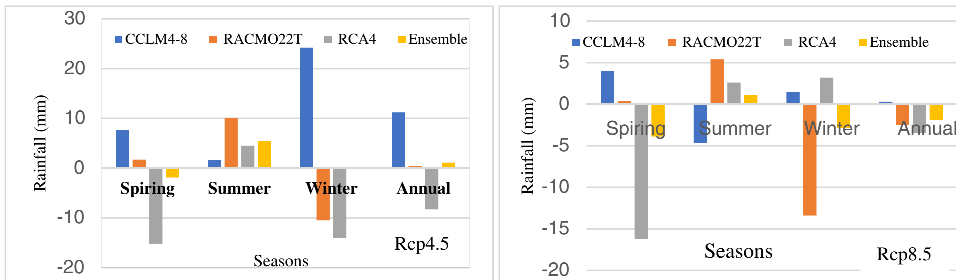

Fig. 5 Seasonal and annual rainfall variation with different RCMs under the two climate change scenarios at mid-future term

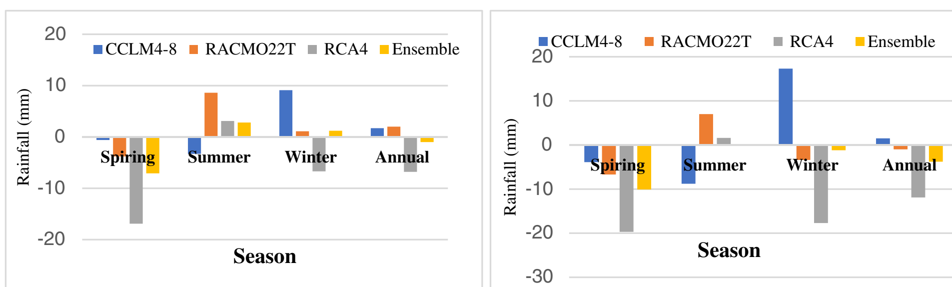

Fig. 6 Seasonal and annual rainfall variations with different RCM under the two climate change scenarios at near-future term

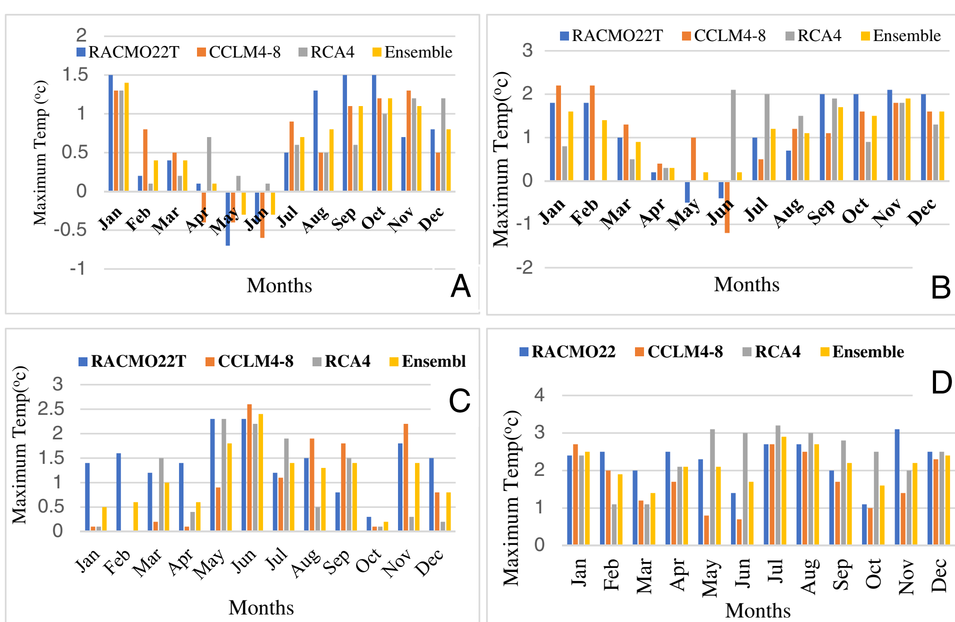

Fig. 7 Mean monthly maximum temperature variation along with different RCMs under RCP4.5 and RCP8.5 at near-future term (**A** and **B**) and RCP4.5 and RCP8.5 at mid-future term (**C** and **D**), respectively

with all RCMs and their mean ensemble under both climate change scenarios with a maximum rising value of 2.55 to 3.1 °C by CCLM4-8-17 and RCA4, respectively (Fig. 7C, D). The minimum mean monthly temperature was projected to increase in both future time horizons under both climate change scenarios with expected rise in temperature of 1.54 to 1.89 °C by CCLM4-8-17 under the RCP4.5 and RCP8.5 climate change scenarios. Maximum decline in temperature (− 0.5 °C) was shown by RACMO22Tin September of the near future-term under the RCP4.5 climate change scenario.

SWAT model simulation

Sensitivity analysis

Parameter sensitivity is one of the main governing factors that deteriorate the positive watershed hydrological responses to different watershed physical factors including the present-day extreme weather conditions. The parameter sensitivity analysis was conducted using SUFI-2 that identified the sensitivity of 9 parameters out of the 18 model parameters. Hence, the model calibration and model validation were undertaken on the basis of the sensitive ranking of these model parameters. The model performance evaluation against all these sensitive parameters was conducted using different statistical performance indicators like NSE, R2, PBias, and RMSE (Table 3). The simulated flow result from the model showed good agreement (Fig. 8 for calibration and Fig. 9 for validation) with the observed flow data as per the three performance indicators except Pbias that depicted poor correlation between the simulated and measured flow data both during calibration and validation.

Table 3 Range of statistical performance indicators during calibration and validation

Performance indicators	Calibration	Validation	Remark
NSE	0.73	0.64	
R2	0.92	0.76	
RMSE	0.54	0.57	
Pbias	− 15.8	− 23.4	

Climate change hydrological impact

The understanding of the impact of climate change on the hydrological processes is very crucial in order for appropriate planning and sustainable utilization of water resources at present and in the future period. One of the most widely applicable ways of investigating the impact of climate change on the watershed hydrological processes is through assessing the impact of climate change on stream flow that is mainly associated with the impact on precipitation and watershed surface temperature. A lot of researchers have been investigating the impact of climate change on the watershed hydrological response through detecting the climate change impact on stream flow. For instance, Dibaba et al. (2020) have investigated the impact of climate change on Fincha'a (Ethiopia) watershed hydrological responses in combination with land use/land cover change, and they found that climate change has a significant effect on stream flow. Shiferaw et al. (2016) also conducted a study on the impact of climate change on the hydrological response of the Omo Gibe River basin (Ethiopia), and they concluded that water resource availability throughout the basin is mainly

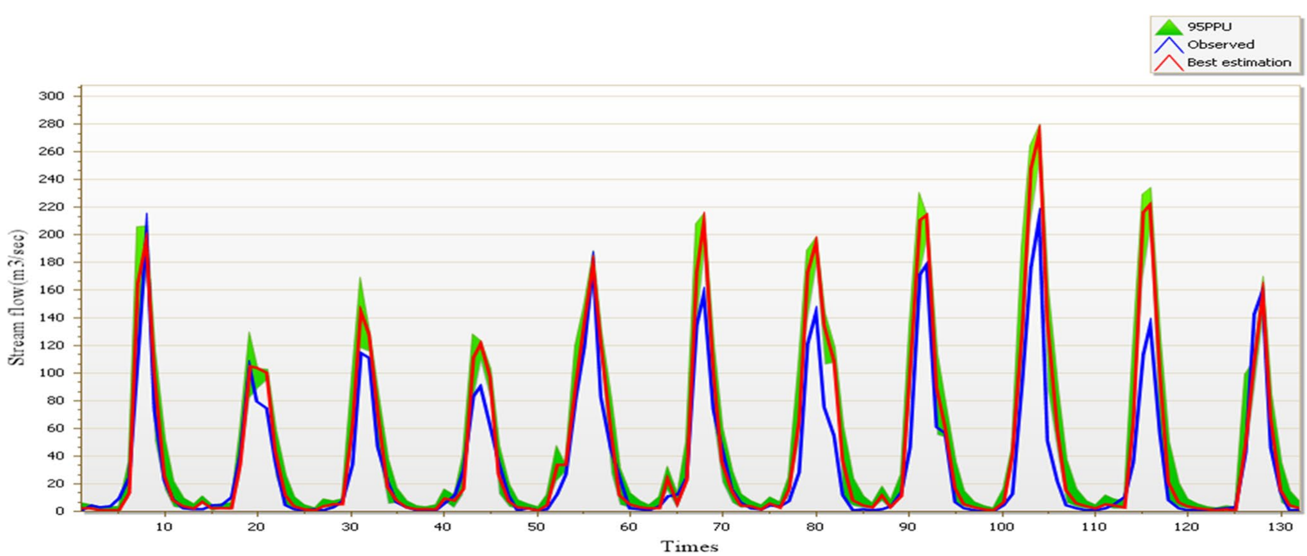

Fig. 8 Model calibration

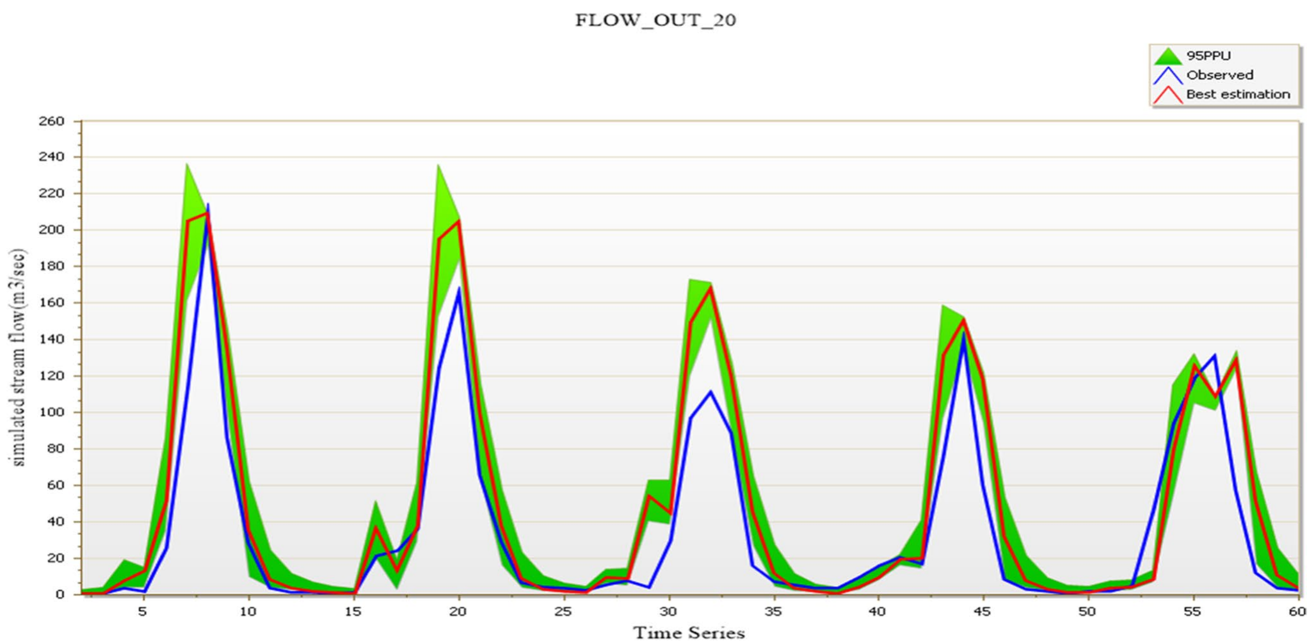

Fig. 9 Model validation

influenced by the erratic climate condition. In a similar sense, this study was focused on investigating the impact of climate change on Wabe watershed by studying the effect of climate change on stream flow for the near- and mid-future term periods using three RCMs and their ensemble under the two most widely applicable climate change scenarios.

The observed stream flow data from 1990 to 2002 was used for calibration and that from 2003 to 2007 for validation. The stream flow simulation for the two future periods (near-future term and mid-future term) based on the three RCMs and their ensemble under the RCP4.5 and RCP8.5 climate change scenarios referencing to the baseline period of 1990–2019 was undertaken. The result of the simulation has shown both an increasing and decreasing trend in stream flow along the time periods under both climate change scenarios on the monthly (Fig. 10),

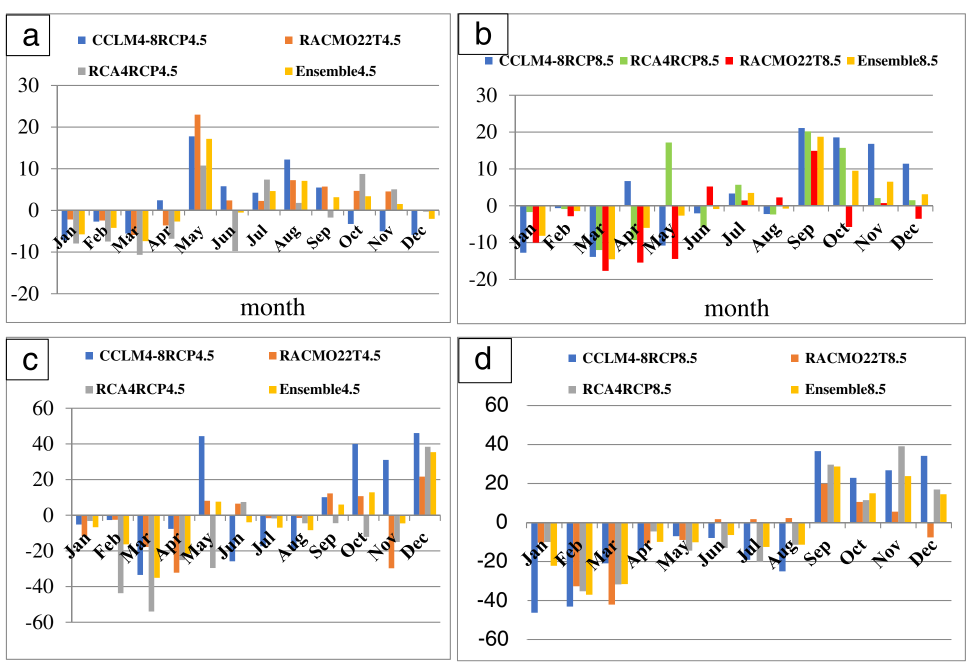

Fig. 10 Mean monthly simulated stream flow variation at near- (**a** and **b**) and mid- (**c** and **d**) future terms under both RCP climate change scenarios of different RCMs and their ensemble

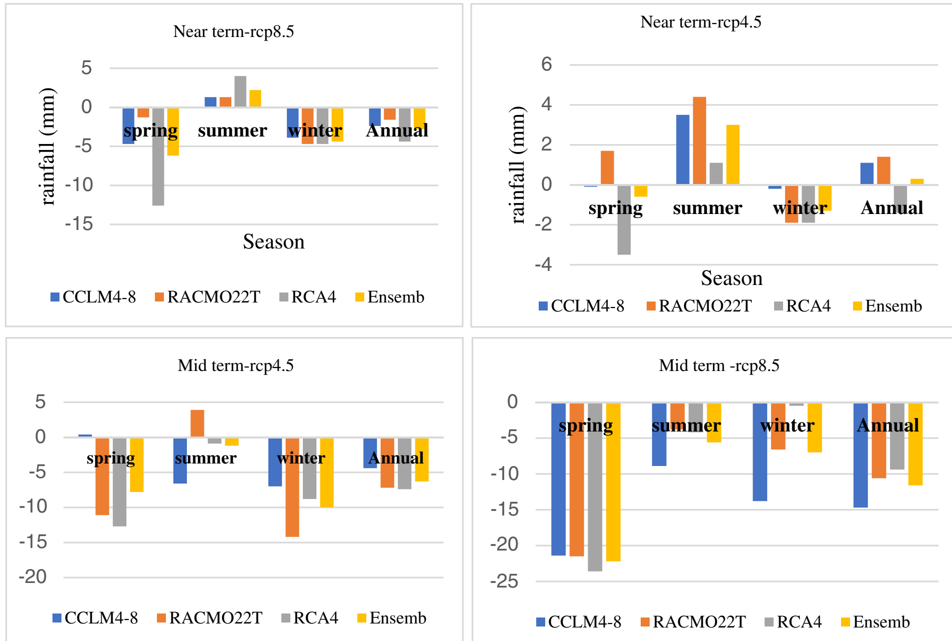

Fig. 11 Annual and seasonal stream flow variation along two future periods

seasonal (Fig. 11), and annual bases. As it can be seen from Fig. 10, the stream flow simulation result from all models and their ensemble depicted large variation in upscaling and downscaling trends comparing to the baseline data. At the near-future term, the stream flow declined by − 2.19 to − 10.67% and by − 0.65 to − 17.94% by all models under both RCP4.5 and RCP8.5 from January to April while it showed an oscillating behavior from May to December. The maximum increasing percentage of + 22.98% was revealed by RACMO22T at the near-future term under the RCP4.5 climate change scenario, by CCLM4-8-17 (+ 20.2%) in the near term and mid-future term under RCP8.5 and RCP4.5, respectively (Fig. 10). In the same study calendar, the mean ensemble of all the models showed an increasing percentage of 17.2% in September under RCP4.5 and 18.73% under RCP8.5, respectively, while it declined by − 7.38% and − 14.53% in the month of March under RCP4.5 and RCP8.5, respectively.

On the other hand, RAC4 and CCLM4-8-17 showed maximum decreasing trends in the midterm under RCP4.5 and RCP8.5, respectively. Furthermore, at the mid-future term, all the models showed decreasing trends from January to August and then increasing behavior from September to December under RCP8.5 except the RACMO22T model that depicted an increasing trend from June to November and then decreasing trends in December (Fig. 10d). The maximum variation in stream flow was shown by RCA4 (− 54 to +39.089%) and CCLM4-8-17 (− 46.29 to + 46.073%) under RCP4.5 and RCP8.5 climate change scenarios, respectively.

A seasonal stream flow also revealed similar patterns with mean monthly stream flow. The influence of climate change on seasonal stream flow along the two study horizons was detected. In near-future term, the spring mean seasonal flow shows an increase with a value of + 1.74% by RACMO22T under RCP4.5 and a decrease with a value of − 3.55% by RCA4 to − 12.6% by RACMO22T under RCP4.5 and RCP8.5, respectively. At the mid-future term, the stream flow in the spring was decreased by − 12.7% under the RCA4 climate model and − 23.64% under RACMO22T under RCP4.5 and RCP8.5, respectively (Fig. 10). The ensemble result also showed a decreasing percentage of − 0.63 to − 6.17% in the near-future term and − 7.82 to − 22.18% in the mid-future term under RCP4.5 and RCP8.5, respectively. Maximum increment was shown in the summer season with an increasing percentage of + 4.4 to + 3.97% by RACMO22T and + 3.03 to + 2.2% by ensemble in the near-future term under RCP4.5 and RCP8.5, respectively. Also, there is maximum variation in stream flow from − 8.86 to + 3.88% by CCLM-4-8-17 and RACMO22T, respectively, under RCP4.5 and RCP8.5 at the mid-future term. The stream flow indicates a sign of decreasing in the winter by − 1.89 to − 4.7% by RCA4 in the near-term period and − 14.2% by RACMO to − 13.8% by CCLM in mid-term period under RCP 4.5 and RCP8.5, respectively.

The mean ensemble shows a decreasing percentage of − 1.3 to − 4.4% in the near-term period and − 9.9 to − 7.0% in the mid-term period under RCP4.5 and RCP8.5, respectively (Fig. 10a–d). The annual stream flow increased by + 1.42% and decreased by − 4.43% under RACMO22T under RCP4.5 in the near-future term and − 7.44 to − 14.68% by RCA4 and CCLM-4-8-17, respectively, under RCP4.5 and RCP8.5 in the mid-future term. The mean ensemble shows stream flow variation from + 0.35 to − 2.8% in the near-future term and − 6.34 to − 11.6% in the mid-future term under RCP4.5 and RCP8.5, respectively (Fig. 11). Depending on the final findings of the study, one can conclude that the study is very important for water resource planners and decision-makers against the effect of climate change. Also, one can recognize that the water resources and hydrologic system of the watershed are under the influence of climate change as some other parts of the country. Therefore, depending on the general result of the study, the authors suggested that sustainable water resource management and proper climate change adaptation strategies need to be developed.

Conclusion

The evaluation of the impact of climate change on Wabe watershed hydrology was conducted using the physically based semi-distributed SWAT model. Three regional climate models (RCMs) under RCP4.5 and RCP8.5 emission scenarios were used for the evaluation. Climate projection for the near-future term (2024–2053) and mid-future term (2054–2083) were conducted referencing to the baseline period (1990–2019) observed data. From the climate projection, it was found that each model and their ensemble showed increasing and decreasing trends for both of the study horizons. However, according to the CCLM4-8-17 RCM model, the rainfall amount in the near-future term under RCP4.5 will increase by 44.36% while it decreases by − 45.3% by the RCA4 RCM model under the same climate change scenario in the same study horizon. The CCLM4-8-17 RCM model revealed that the rainfall will increase by 34.8% and 49%, respectively, under RCP4.5 and RCP8.5 and will decrease by − 34.4% under RCP8.5. The RCA4 RCM showed a decline in rainfall by − 27.1% under the RCP4.5 climate change scenario at the mid-future study horizon. Using the baseline data and ensemble climate projection, the stream was computed using the SWAT model. According to the simulation result, it was found that stream flow will increase in the summer season of the near-future term and decrease in the mid-future term under the entire models and their ensemble. Generally, the extreme wet and extreme dry events were recognized as a result of the impact of climate change in Wabe watershed under both climate change scenarios. Depending on the result of the study, one can recognize that there is high impact of climate change on the water and hydrologic system of the Wabe watershed. Therefore, appropriate mitigation measures such as integrated water resource management (IWRM) strategies need to be undertaken in order to combat the effect of climate change.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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