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Research Article

Impacts of Climate Change on Streamflow on Dawa Sub-watershed, Genale-Dawa River Basin, Southern Ethiopia

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Abstract

Climate change is statistical variations over an extended period in the features of the climate system, such as variations in global temperatures and precipitation, caused by human and natural sources. In this study aimed to measure and examine how streamflow in the Dawa sub-basin, Genale Dawa River basin was affected by climate change. It used the average of five regional climate models from the Coordinated Regional Climate Downscaling Experiment (CORDEX) Africa, under two different scenarios of Representative Concentration Pathways: RCP4.5 and RCP8.5. The baseline scenario was based on the data from 1975 to 2005, while the future scenarios were based on the data from 2020s (2025–2054) and 2050s (2055–2084). The HBV hydrological model used to assess the impact on streamflow. The HBV model showed good statistical performance in simulating the impact of climate change on streamflow, with a coefficient of determination (R^2) of 0.88 and Nash-Sutcliffe Efficiency (NSE) of 0.77 for monthly calibration, and R^2 of 0.86 and NSE of 0.83 for monthly validation. The impacts quantified using the mean monthly changes in precipitation, maximum and minimum temperatures. The bias-corrected precipitation and temperature showed a reasonable increase in both future periods for both RCP 4.5 and RCP 8.5 scenarios. These changes in climate variables resulted in a decrease in mean annual streamflow by 1.6 and 3.5% for RCP 4.5 and by 4.6 and 4.9% for RCP 8.5 scenarios of the 2020s and 2050s, respectively. Based on the analysis that predicted a drop in precipitation during the months, and seasons and an increase in precipitation during the *Belg* season, with a corresponding decrease and rise in stream flow throughout the watershed. So to offset the variation in the watershed, community should adopt various; Soil and water conservation technologies, Using drought-tolerant crops, Implementing various trees and appropriate design and applying a water harvesting structure like in-situ, internal or micro catchment, external or macro catchment water harvesting and Surface runoff harvesting. This result offers useful information for current and future water resource management in the basin and similar other watershed in the country.

Keywords

Climate Change, CMhyd, Cordex, Ethiopia, HBV, Streamflow

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1. Introduction

Climate change is statistical variations over an extended period in the features of the climate system, such as variations in global temperatures and precipitation, caused by human and natural sources. The world climate changes mainly influence rainfall distribution and availability of water on the earth's surface due to rainfall is the main source of water in a river basin [1]. The amount of precipitation that falls within a river basin directly correlates with the volume of water bodies inside it [24, 17]. River basin function is expected to significantly impact by climate change, with changes expected to the frequency and amount of rainfall events [39, 19] and relative humidity [39]. In sub-Saharan Africa, freshwater availability is essential for both social and economic advancement. Water is essential for many important economic and social processes, including agriculture, industry, urban growth, hydropower production, inland fisheries, transportation, and leisure. These operations create jobs and bring in money to keep the economy afloat. In addition to its economic significance, fresh water is crucial for tackling issues of hunger, poverty, and health, as the Millennium Development Goals acknowledge [38].

Environmental change influences are usually evaluated on two different scales: the worldwide or mainland scale takes into consideration a general perspective on the bigger setting and examples, while provincial examinations center on subtleties, for instance flood or dry spell hazards. By contrasting environmental change influences between variant districts, benefits of the two methodologies can be combined. This way of bridging these two scales is probably going to give new insights into the attributes of environmental change in the genuine locales, yet in addition past [28].

The global mean surface temperature has been rising since the late nineteenth century, according to historical temperature data, with the last three decades being consistently higher than any of the preceding decades [14]. The global warming trend has the potential drastically change global precipitation patterns and water supply. Numerous parts of Africa, including the Sahel in the north, the Greater Horn of Africa, and western and southern Africa, have experienced catastrophic droughts in the past few decades and millennia and are susceptible to the adverse effects of climate change [13]. Global warming is happening, according to a thorough analysis of the vast amount of data the Intergovernmental Panel on Climate Change (IPCC) has collected about many aspects of the climate system [15, 16]. Hydrological research has made the effects of climate change on hydrological systems a top goal [7]. Different regions of the world have indicated how streamflow conditions affected by climate change [23, 20]. Where the environment grows drier, these effects will be especially severe [25].

Assessments of how climate change affects streamflow have conducted all around the world. (E.g. in China, in Ethiopia, in India or on the global scale [22, 14, 21, 2]. Numerous studies have demonstrated climate and streamflow changes for different basins throughout the world (e.g. [3-5, 11, 12, 18]. These studies show that climate changes have continued and will continue to influence streamflow discharge. Trend-based climate change scenarios of the 2030s will increase the average annual streamflow by 5.2% [18]. This significantly affects soil erosion and streamflow compared to other scenario conditions by using the GCM model [10] analyzed several climate factor trends and concluded that the Gilgal Abay catchment will be approximately 2 ℃ warmer by (2011–2025), leading to increases in evapotranspiration and subsequent streamflow changes. In this study, out of four alternative emission scenarios of RCP 2, RCP 4.5, RCP 6 and RCP 8.5, Regional climate model (RCM) data from the ensemble of CORDEX Africa have run under RCP 4.5 and 8.5. These incorporated into the calibrated and validated using the HBV hydrological model. The RCP 4.5 scenario describes the stabilization without overshoot pathway to the radiative forcing trajectory, which goes to a peak level of 4.5 W/m^2 [8]. The RCP 8.5 corresponds to the rising radiative forcing pathway leading to 8.5 W/m^2 by 2100. The purpose of this study was to produce impact-specific, scientifically grounded data that will directly assist in the development of Ethiopia's local and national climate change response plans. The particular goals were to use the semi-distributed hydrological model HBV to simulate the hydrology of the chosen Dawa River sub-basins, estimate the effects of climate change on hydrology and river flows, and suggest adaptation strategies for the sustainable management of water resources in the face of climate change.

2. Materials and Methods

2.1. Description of the Study Area

The location of the Dawa River watershed is 38^{0}2'48' to 41^{0}2'34"E and 4^{0}5'8" to 6^{0}27'18"N (Figure 1) It makes up a portion of Ethiopia's southeast highlands and is located 567 kilometers southwest of Addis Ababa. The Dawa River Sub-watershed is located in East Africa, covering an area of 235765 ha and flows through three major countries: Kenya, Ethiopia, and Somalia, with 81% falling into Ethiopian territory. The Dawa River Sub-watershed has a maximum and minimum elevation of 2345 and 1149 meters above sea level, respectively, and the inclination of the basin is toward the southeast. With steep slopes at the upper river parts and undulating terrain and mild slopes at the downriver parts, it is characterized by mountainous and severely dissected areas of land The Dawa River encompasses a cool zone, a temperate zone, and hot lowlands, which are the three major climatic zones of the country.

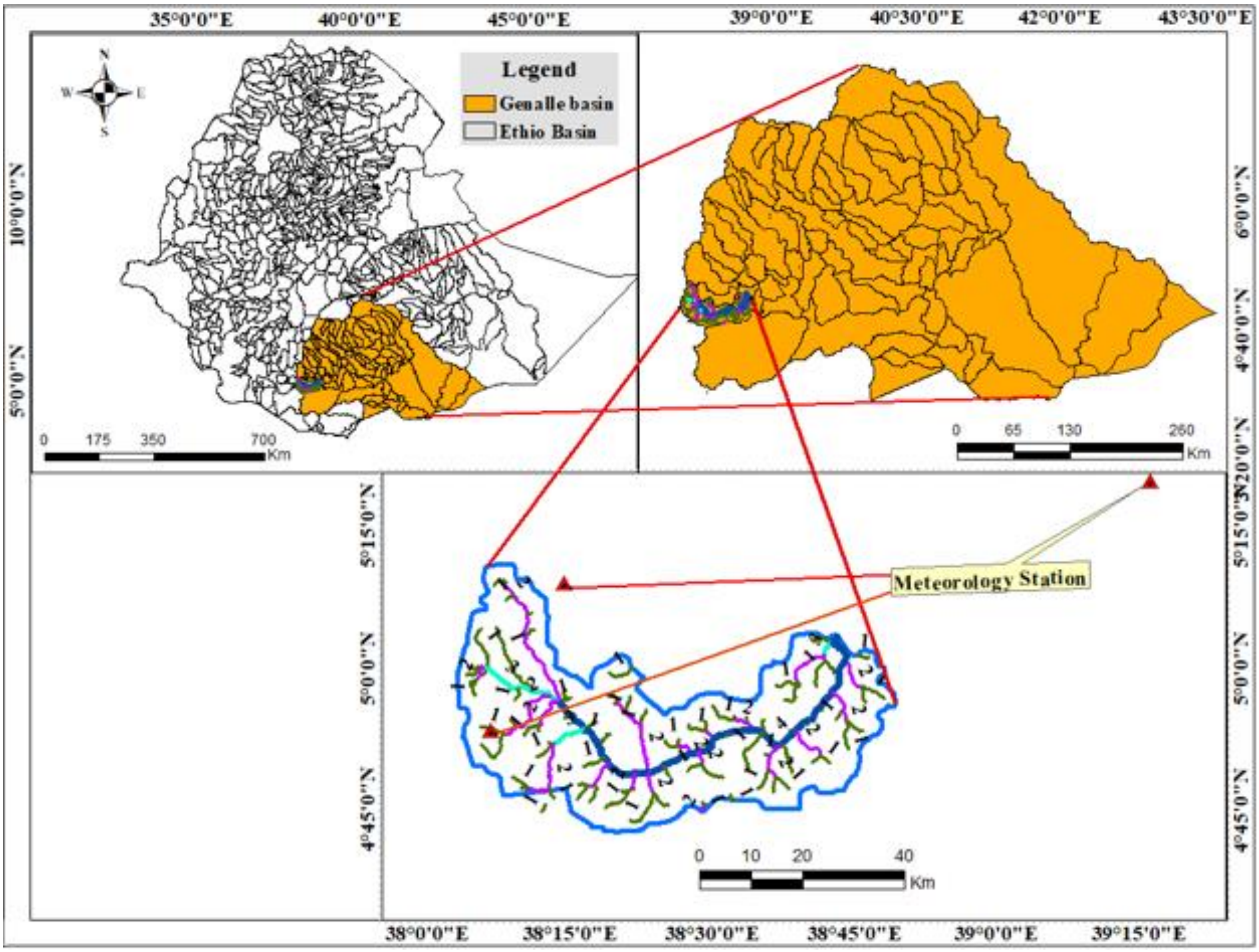


Figure 1. *Location Map of the Study area (Source: Ethiopian Geospatial Map, 2016).*

2.2. Climate Data and Scenarios Generation

Daily baseline data was taken from the Ethiopian Nation Metrological Agency (for the stations Yabello, Hageremariam, Kibre Mengist, Negalle, Oda Shakiso and Mega). The baseline period from 1975 to 2005 was used for the analysis of the baseline scenario, while the periods 2020s (2025–2054) and 2050s (2055–2084) were used for future scenario analysis.

A set of simulations (historical and future scenario) was conducted with an ensemble mean of five regional climate model runs (Table 2) from the Coupled Model Intercomparison Project phase fifth (CMIP5). At the boundaries of models, an ensemble mean was taken from the CORDEX Africa [29] regional climate models, with a spatial resolution of 0.44° following the RCP4.5 and RCP8.5 emission scenario pathways. Ensemble mean data are available in the context of the Coordinated Regional Climate Downscaling Experiment [30] over Africa at 0.44°resolution for the period 1950–2100, and it has already been used over Africa [31, 33-35]. The data analyses focus on the periods (1975–2005) as a reference period and future period (2020–2080). As precipitation and temperature are the key drivers for the hydrological regime of climate change [29], its main impact through changes in these variables was bias-corrected following the method of [41]. To make the baseline data (1975–2005) amenable to further analyses, the missing values were packed using the arithmetic mean method [42], and the consistency and homogeneity of rainfall were checked by the double mass curve technique [43] and Standard Normal Homogeneity test using XLSTAT (version 2019.1) software, respectively. Four stations of rainfall within or approximately the boundary of the catchment was used for annual rainfall estimation. Finally, the bias-corrected and uncorrected data processes were evaluated using the standard deviation (SD) and mean absolute error (MAE), where the latter is a quantity used to measure how close simulated forecasts are to the observed data [40]. In addition, trends and patterns of baseline climate were examined using statistical descriptors like mean, coefficient of variance (CV) and standard deviation to permit assessment of future climate change scenarios.

***Table 1.** Statistical summary of data (1975–2005) for Streamflow, Rainfall, T_{max} and T_{min}.*

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
RF (mm)	17.1	24.7	74.8	147.2	109.2	22.6	14.0	15.7	37.6	119.6	61.1	0.7	644.2
Tmax (℃)	27.7	28.4	27.6	24.7	24.4	23.2	23.0	23.9	25.3	24.7	32.6	27.0	26.0
Tmin (^{o}C)	12.9	14.2	14.9	15.5	14.9	14.0	13.9	13.9	14.2	14.7	13.8	12.7	14.1
Flow (M^3/s)	9.7	8.1	8.7	18.4	33.5	26.9	20.3	22.1	26	34.7	32.7	17.5	24.1

***Table 2.** Summary of the Regional Climate Models and their driving Global Climate Models used.*

Institution	GCM	RCM	Resolution (Lat & Log)
Canadian Centre for Climate Modelling and Analysis	CCCmaa-CanESM2	SMHI-RCA4	2.8*2.8
National Institute for Environmental Studies and Japan Agency for Marine-earth Science and Technology, Japan	MIROC-MIROC5	SMHI-RCA4	1.4*1.4
Met Office Hadley Centre, UK	HadGEM2-ES	SMHI-RCA4	1.25*1.25
CSIRO-QCCCE-CSIRO-MK3-0	CSIRO-MK3-6-0	SMHI-RCA4	1.9*1.9
Max Planck Institute for Meteorology, Germany	MPI-M-MPI-ESM-LR	SMHI-RCA4	1*1

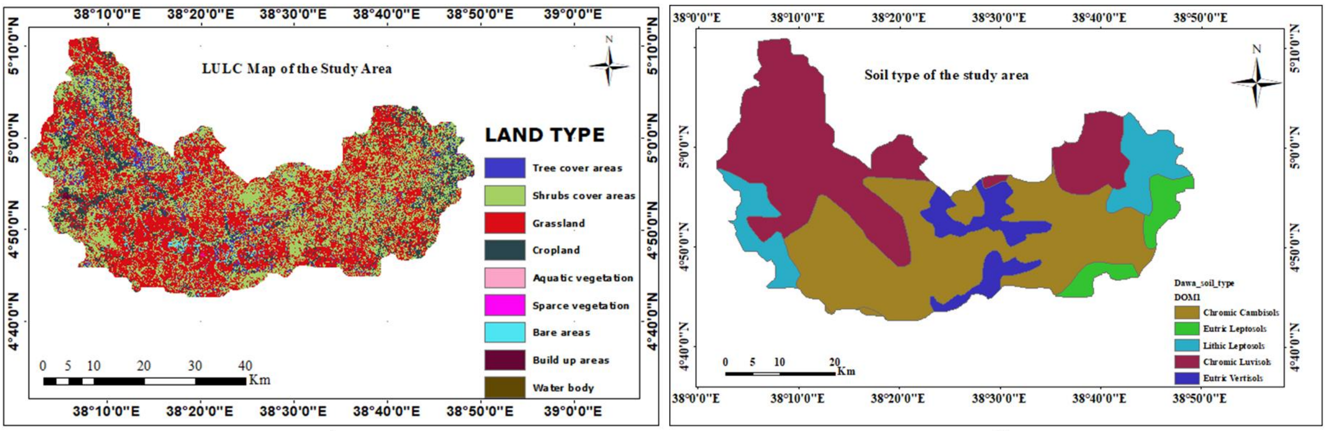


***Figure 2.** A. Land use land cover (2016) and B. Soil type.*

2.3. Hydrological and Spatial Data

The streamflow data utilized to validate and calibrate the simulation of the HBV model. The Ministry of Water and Energy (MoWE) provided daily streamflow data for the Dawa sub-basin at Melka Guba station. (Table 4) Land use land cover images used for this study were obtained from the FAO 2016 and soil data were collected from the Harmonized World Soil Database (HWSD) [9] (Figure 2).

2.4. HBV Model Description

Table 3. Spatial coverage of different LULC classes, Soil types and slope classes of the study area.

LULC class 2016	Proportional area (%)	Soil type	Proportional area (%)	Slope classes (%)	Proportional area (%)
Tree cover areas	4.29	Chromic Cambisols	41.5	0 - 4.9	47.58
Shrubs cover areas	36.71	Chromic Luvisols	36.3	4.9 - 10.8	46.28
Grassland	46.85	Lithic Leptosols	10.4	10.8 - 20.1	4.7
Cropland	10.55	Eutric Vertisols	7.4	20.1 - 33.3	1.4
Flooded	0.002	Eutric Leptosols	4.4	>33.3	0.03
Sparse vegetation	0.03				
Bare areas	1.49				
Build up areas	0.09				
Waterbody	0.013				

Table 4. Applied datasets, their resolution and the required parameters in this study.

Data Set	Resolution	Parameters
DEM	12.5m	Topographical data
Soil map	1Km	Soil class
Land use map	12.5m	Lad cover and use
Climate	Daily (0.44^0)	Precipitation and Temperature
Discharge	Daily	Stream flow data

Table 5. Performance indicators of model streamflow simulations.

Name of indicator perfect	Formula	Simulation value
Coefficient of determination	$R^2 = 0.88$	0.86
Nash-Sutcliffe Efficiency	NSE = 0.77	0.83

3. Results and Discussions

3.1. Baseline Change in Rainfall and Temperature

Rainfall varies greatly on a yearly and monthly basis, with six months mean January, February, June, July, August, and December out of the twelve months receiving less than 20 mm per month on average from 1991-2020. On the other side, April, followed by October, is the month with the highest mean rainfall (147.2 mm), during the same period (119.6 mm). The trend and inter-annual variability of rainfall, maximum and minimum temperature for the baseline period 1975– 2005 (observed and Historical climate model output) are shown in Figures 3, 4 and 5. In addition to the mean (X) and the standard deviation (SD), and coefficient of variance (CV) was used to classify the degree of variability as less rainfall variability (CV < 20), moderate rainfall variability (20 < CV < 30), high rainfall variability (CV > 30), very high rainfall variability (CV > 40%) and extremely high rainfall variability (CV > 70%) [6, 26].

Rainfall in Yabello is highly variable, as indicated by the computed CV value of 34.45%, while the coefficient of variation for all months spans between 49.4 to 387.5%. Particularly, the CV values that exceed 100% for the research area's months of January, February, March, June, July, August, and December show that rainfall has an exceptionally high inter-annual variability due to CV>70% (Table 6). These findings are consistent results with those reported by [26].

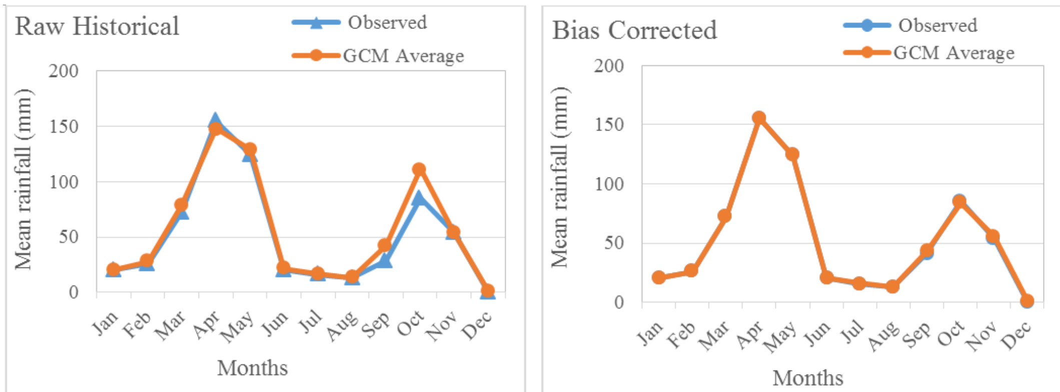


***Figure 3.** A comparison of the simulated and observed mean monthly rainfall before and after bias adjustment can be seen on the left and right.*

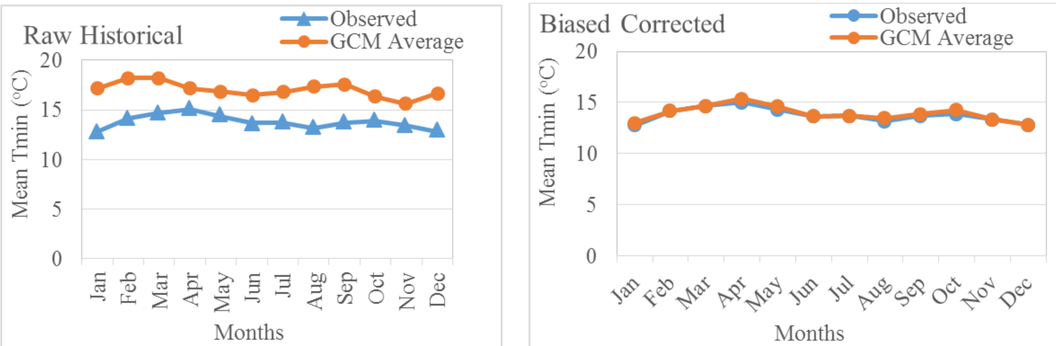


***Figure 4.** Comparison of bias-corrected mean monthly T_{min} before (left side) and after (right side) simulation and observation.*

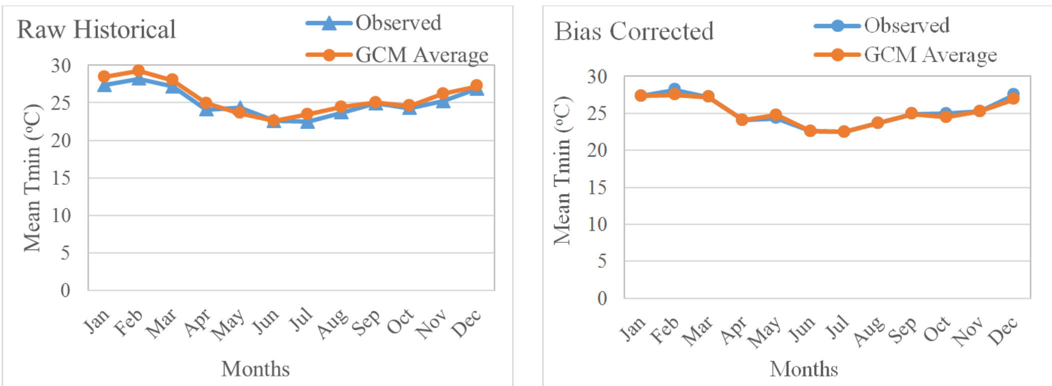


***Figure 5.** Comparison of bias-corrected simulated and observed mean monthly T_{max} before (left side) and after (right side).*

During March, October, and November, the rainfall trend significantly increased (P-value > 0.05) Table 6 and Figure 6. The slope estimations for March, October, and November showed 0.46, 0.3, and 0.46 respectively. These months show the largest changes in magnitude. For the remaining months over the research years, there is no monotonic trend (P_{value} > 0.05) except for January, February August and October. This discovery is consistent with those that have been reported by

[27]. The seasonal distribution of rainfall reveals that *Birra/Belg* (February to May), which recorded a mean precipitation of 355.9 mm, is followed by *Bona* (October to January), which experienced a mean record of 198.4 mm. However, *Ganna* (June to September) was the period for the lowest with 89.9mm.

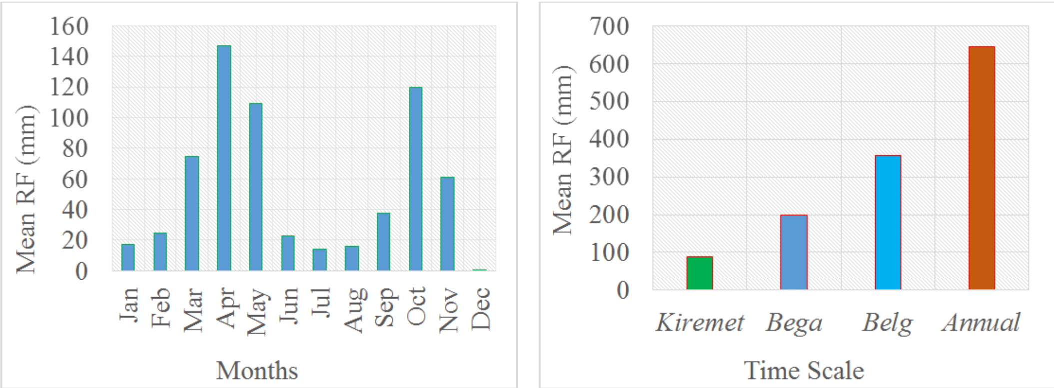


Figure 6. *Baseline period areal rainfall observed period.*

Table 6. *Descriptive statistics and test results of monthly Observed precipitation (1991–2020).*

Time	Mean	SD	CV	Z	P	SS
Jan	17.1	23.3	136.4	-0.04	0.68	
Feb	24.7	34.3	139.3	-0.04	0.68	
Mar	74.8	79.6	106.4	0.01	0.34	0.46
Apr	147.2	72.7	49.4	-0.13	0.23	
May	109.2	74.1	67.8	-0.28	0.01	
Jun	22.6	26.8	118.9	-0.13	0.20	
Jul	14.0	14.8	105.4	-0.27	0.01	
Aug	15.7	21.5	136.9	-0.05	0.61	
Sep	37.6	33.7	89.6	-0.28	0.01	
Oct	119.6	87.7	73.3	0.04	0.69	0.30
Nov	61.1	51.5	84.3	0.11	0.30	0.46
Dec	0.7	2.7	387.5	-0.41	0.00	
Kiremt	89.9	55.3	61.4	-0.19	0.07	
Bega	198.4	121.5	61.2	0.08	0.02	
Belg	355.9	151.9	42.7	-0.25	0.33	
Annual	644.2	222.2	34.5	-0.1	0.33	

3.2. Hydrological Model Calibration and Validation

Dawa sub-basin streamflow gauged near Melka Guba used to calibrate the hydrological model for a period of January 1, 1991, to December 31, 2020, using the HBV calibration technique. For the model setup, this study followed the calibration procedure. The model calibration and validation results for monthly flow (Figures 9 and 10) indicated generally a good fit between measured and simulated output results.

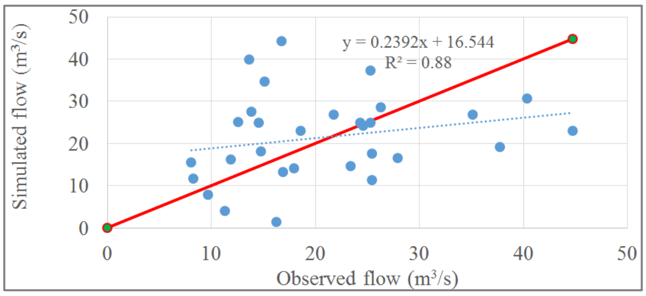


Figure 7. *Scatter plot of simulated versus observed flow monthly during the calibration period.*

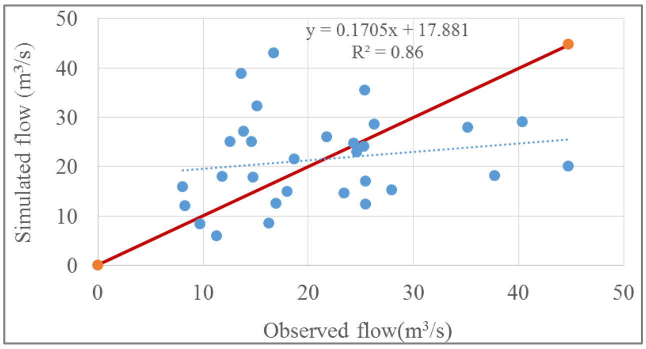


Figure 8. *Scatter plot of simulated versus observed flow monthly during the validation period.*

The model calibration and validation results for monthly flow (Figures 9 and 10) indicated generally a good fit between observed and simulated output results.

3.3. Potential Changes of Streamflow Under Climate Change

There is a developing interest from an extensive variety of chiefs for environmental change data on territorial to neighborhood scales and at high spatial goal [32]. Time series data for the 2020s and 2050s were obtained by utilizing the changes in bias-corrected climate variables (absolute difference for temperature and percentage difference for precipitation) from the baseline climate. To estimate the potential influence of climate change on streamflow, an HBV simulation was conducted for the baseline, 2020s, and 2050s using continuously calibrated soil, land use/cover, and slope parameters. The streamflow simulation findings for the 2020s and 2050s were compared to the simulation for the baseline era.

The Nash Sutcliffe efficiency and coefficient of determination were taken into consideration as part of the parameters sensitivity test, which involved adjusting one parameter at a time while maintaining the other values constant.

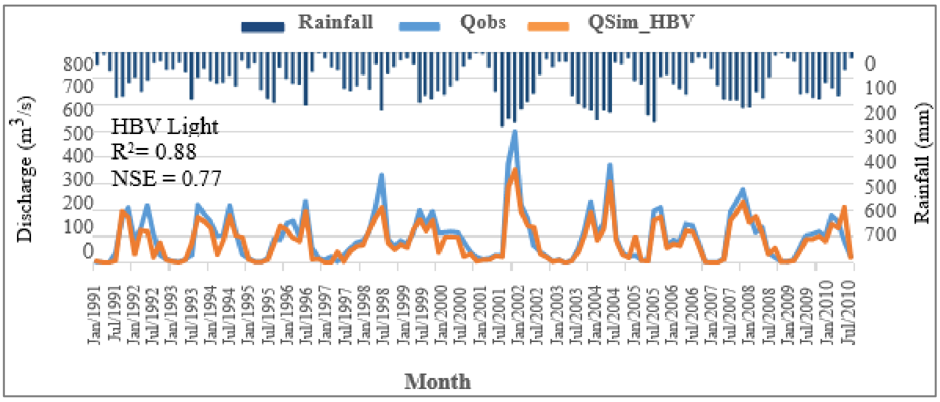


Figure 9. *Monthly observed vs. simulated discharge hydrograph for Dawa sub-watershed of calibration period.*

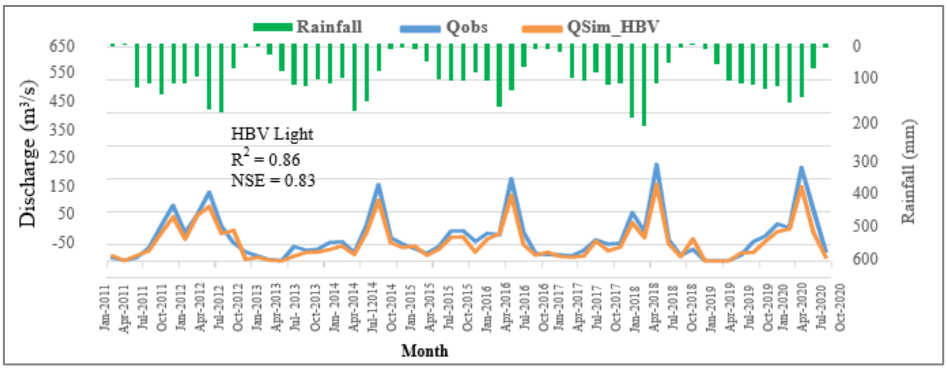


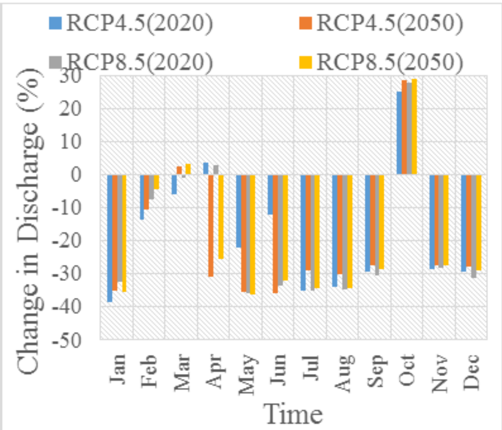
Figure 10. *Hydrograph of Dawa sub-watershed monthly observed vs. predicted discharge of validation period.*

3.4. Impact of Climate Change on Stream Flow Under Future Scenarios

Ethiopia is powerless against effects of environmental change given the nation has encountered some of the most awful dry spell occasions in beyond a very long while [37]. The river flow data was used as the baseline flow for the analysis of the effects of climate change in comparison to the projected flows for the 2020s (2025–2054) and 2050s (2055–2084). Based on this, the HBV light analysis of the hydrological impact of the Dawa sub-watershed was conducted utilizing data from two future time series spanning 30 years for RCP 4.5 and RCP 8.5. The HBV light model's output proved useful in determining the potential trend of the simulated river flow.

For the RCP 4.5 scenario, the HBV light shows a percentage decline in the total average annual flow volume of between -1.6% (2025-2054) and -3.5% (2055-2084), whereas, for the RCP 8.5 scenario, the decline is between -4.6% (2025-2054) and -4.9% (2055-2084). For both the RCP4.5 and RCP8.5 scenarios, monthly, the model shows decreasing trends in January, February, March, May to September, November, and December; and increasing trends in March, April, and October over the two subsequent time horizons (Figure 11 left). Seasonally, the model predicts an increasing trend in the *Belg* season (February to May) and a decreasing trend in the *Kiremt* season (June to September) and *Bega* season (October to January) compared to the base period. For simulation using the HBV model in the *Kiremt* season, the percentage change varies between -30.5% to -31% and -32.5% to -35% RCP4.5 and RCP8.5, respectively. Additionally, the percentage decreases for the *Bega* season were -21.4% to -25.2% in RCP4.5 and RCP8.5, respectively, and -29.2% to -26.9%. The increments for the Belg season were, respectively, +39.3% to +40% and +39.2% to +38.5% RCP4.5 and RCP8.5. According to Figure 11 right, the HBV light represents a percentage reduction in the total average annual flow volume of between 1.6% and 3.5% in the RCP4.5 scenario and between 4.6% and 4.9% in the RCP 8.5 scenario. During scenario developments, a fall in mean annual precipitation at times when a fall in average total annual flow volume seen.

Furthermore, under the future RCP4.5 (2020) and RCP 8.5 (2020) scenario, the model predicts the lowest percentage decline in March and the biggest percentage decrease in January. On the other side, the model predicts that for both scenarios, October was the biggest percentage increase, and March and April saw the lowest percentage increase in RCP4.5 (2050) and RCP8.5 (2050) respectively. This is due to the precipitation increase having the corresponding lowest and highest percentage increases. This result is consistent with that of [36].



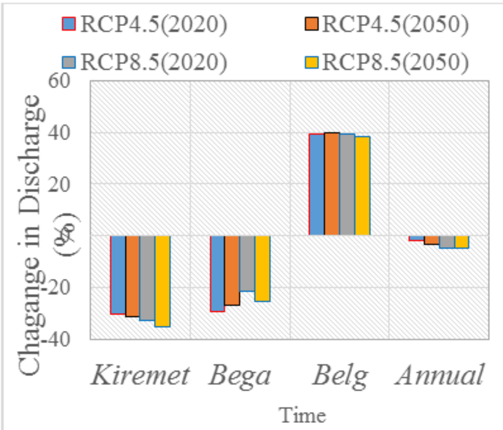


Figure 11. *Projected change of mean monthly and seasonal discharge in 2020 and 2050 from the baseline period.*

The results showed that the mean annual streamflow was predicted to fall by 1.6% and 3.5% for the RCP 4.5 scenario in 2020s and 2050s and by 4.5% and 4.95% for the RCP 8.5% scenario in 2020s and 2050s, respectively. Similar to the moderate scenario (RCP4.5), it is evident that the sub-basin streamflow is probably going to decline. The months of April, May, and October are when the research area has the most rainfall. Understanding the hydrological effects of climate change will require an understanding of future changes in streamflow for these months.

4. Conclusions

In this study, the effects of climate change on streamflow in the Dawa sub-basin of Genale Dawa River basin, Ethiopia, was examined. The results of bias-corrected temperature and precipitation showed a logical increase in all future periods under both RCP 4.5 and RCP 8.5 scenarios. The study also confirmed that HBV is a useful tool for assessing the effects of climate change on the hydrological cycle in the sub-basin.

When the climate change simulations for the 2020s and 2050s are compared to the baseline (1975–2005), the RCP 4.5 emission scenario leads to greater annual precipitation and temperature than the RCP 8.5 emission scenario, which in turn causes differences in the flow of streams in the catchment areas. Future period mean annual stream flow projections indicate that the 2020s and 2050s RCP 8.5 scenarios anticipated seeing a reduction of 4.5% and 4.95%, respectively, and 1.6% and 3.5%, respectively, for RCP 4.5 scenarios. As with the moderate scenario (RCP4.5), it is clear that the streamflow in the sub-basin was most likely decrease. October's high-flow months have a significant impact on both the RCP 4.5 and RCP 8.5 scenarios. To reduce poverty and food insecurity in the watershed, both on and off-site water harvesting structures, micro-dams for flood control, and the conservation of home and agricultural water consumption are necessary. Water must use, especially in October, the month with the highest flow. The HBV hydrological model calibration has as many unknowns as the absence of land use change. This study is still helpful, though, since it sheds light on how sensitive the Dawa sub-basins streamflow is to climatic variations. Therefore, it is recommended that further research be done in the future, particularly on model uncertainty analysis, the use of various climate models. Based on the analysis that predicted a drop in precipitation during the months, and seasons and an increase in precipitation during the *Belg* season, with a corresponding decrease and rise in stream flow throughout the watershed. So to offset this variation in the Dawa watershed, the community should adopt various; Soil and water conservation technologies, Using drought-tolerant crops in the watershed, Implementing various trees (afforestation and re-afforestation) and Appropriately designing and applying a water harvesting structure like in-situ, internal or micro catchment, external or macro catchment water harvesting and Surface runoff harvesting in the watershed.

Abbreviations

CORDEX	Coordinated Regional Climate Downscaling Experiment
RCP	Representative Concentration Pathways
R^2	Coefficient of Determination
NSE	Nash-Sutcliffe Efficiency
HBV	Hydrologiska Byråns Vattenbalansavdelning
CMhyd	Climate Model for Hydrology
HWSD	Harmonized World Soil Database
MoWE	Ministry of Water and Energy

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Author Contributions

Ayana Bulti: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing – original draft, Writing – review & editing

Fentaw Abegaz: Formal Analysis, Methodology, Project administration, Supervision, Validation, Visualization

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Data Availability Statement

The author's want to express our utmost gratitude to the Ethiopia National Meteorological Agency for providing all required Meteorological data and Ministry of Water and Energy of Ethiopia for providing essential Stream flow data for my work.

Conflicts of Interest

The authors declare no conflicts of interest.

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