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Climate Change Impact on Water Resources in the Awash Basin, Ethiopia

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Abstract: Rapid growth of agriculture, industries and urbanization within the Awash basin, Ethiopia, as well as population growth is placing increasing demands on the basin's water resources. In a basin known for high climate variability involving droughts and floods, climate change will likely intensify the existing challenges. To quantify the potential impact of climate change on water availability of the Awash basin in different seasons we have used three climate models from Coupled Models Inter-comparison Project phase 5 (CMIP5) and for three future periods (2006–2030, 2031–2055, and 2056–2080). The models were selected based on their performance in capturing historical precipitation characteristics. The baseline period used for comparison is 1981–2005. The future water availability was estimated as the difference between precipitation and potential evapotranspiration projections using the representative concentration pathway (RCP8.5) emission scenarios after the climate change signals from the climate models are transferred to the observed data. The projections for the future three periods show an increase in water deficiency in all seasons and for parts of the basin, due to a projected increase in temperature and decrease in precipitation. This decrease in water availability will increase water stress in the basin, further threatening water security for different sectors, which are currently increasing their investments in the basin such as irrigation. This calls for an enhanced water management strategy that is inclusive of all sectors that considers the equity for different users.

Keywords: Awash basin; water availability; climate change; impact assessment; water security

1. Introduction

Climate change and population growth are projected to increase water scarcity concerns. By 2050, an estimated 4.8 to 5.7 billion people will be living in potentially water-scarce areas at least one month per year [1]. At the global scale, projections suggest wetter regions will become wetter and drier regions will get drier according to the United Nations World Water Assessment Programme [1]. However, more specific regional and seasonal projections of climate change impacts are needed. For example, this inference is challenged in the Middle East where climate change signals vary remarkably with seasons without following the "dry gets drier, wet gets wetter" paradigm [2].

Climate change will significantly impact water resources. There is a need to plan how to adapt to these changes, and how to mitigate the changes for water resources. In sub-Saharan Africa, there are many vulnerable river basins. These basins are vulnerable both in terms of the climate system that is highly variable and the potential future changes in climate, but also in terms of management as weak governance and high levels of poverty in the population restrict actions to adapt to climate change [3]. Ethiopia is an example of a country whose river basins are vulnerable to changes in climate, and yet

the country's poverty alleviation and economic growth strategy require effective water resources management for competing sectors and users.

The Awash river basin, Ethiopia, is subject to high climate variability, experiencing frequent floods and droughts. The basin is already subject to water stress, with higher water demand than supply. For instance, a study by [4] estimated an average annual runoff of 4640 MCM (million cubic meter) while the average annual demand is 4670 MCM. The basin is subject to high intra-annual variability, with dry season water shortage recognized as a challenge for various activities such as irrigation and domestic water supply by the Awash Basin Authority [5]. Another study analyzed planned irrigation expansion and demand satisfaction in the basin and showed, with the current 'business-as-usual' case, the dry season faces unmet water demand, with the driest month (January) experiencing approximately 15 MCM of unmet water demand [6]. Water demand is likely to increase with population growth, expansion of agriculture, industries, and urbanization.

Climate variability already has a severe impact on populations and economic productivity in the Awash basin. Severe droughts in the basin have led to a significant depression of crop yields and death of livestock [7], resulting in increases in food insecurity. A modest (5%) decrease in rainfall was estimated to reduce the basin's Growth Domestic Product (GDP) 5%, with a 10% decrease in agricultural productivity [8]. Humanitarian assistance requests are relatively common due to climate shocks, such as the 2015/2016 El Niño events which resulted in a severe drought and a humanitarian response targeting over 10 million people nationally, with many priority '*woredas*' (districts) located in the Awash basin [9,10]. With the potential for climate change to exacerbate these extremes of climate variability in the basin, it is imperative that we develop a better understanding of their potential impact on water resources and how it will impact water supply to meet growing demands.

In Ethiopia, most studies on the impact of climate change on water resources focus on catchments of the Nile basin, for instance [11–14]. In the Awash basin, the number of such studies is limited. Some examples that focused on specific sub-basins are [15,16] that estimated the impact on the stream flow of upper Awash basin and the Keleta watershed runoff within the upper Awash basin, respectively, with divergent results. The study by [16] found increasing runoff projection in the 2050s while the study by [15] found decreasing streamflow projection. These results can be partly attributed to the differences in climate models used in the analysis. Similarly, in the Blue Nile region, in spite of the relatively high number of studies, there is a lack of consistent projections on the impact of water resources. This stems from differences in climate models and their projections, downscaling methods, and hydrological models. The climate models in this geographic area are found to be the major source of uncertainty [17] and selecting models that are better suited for the area under study is essential to deliver robust findings.

The recent simulations done for the Coupled Models Inter-comparison Project phase 5 (CMIP5) made improvements from the previous versions of climate models [18]. The ensemble of these models is commonly used to represent the uncertainty range of the climate models, for example Reference [19]. However, such an approach has limitations when some of the global climate models are not representative of the climatology of the area under study [20]. This can result in little consensus between models on the magnitude or sign of future projections, especially for precipitation change. To avoid including such unrepresentative climate models in impact assessment projections a sub-group of models can be selected based on their performance to capture certain characteristics of the climate of the area of interest. These can provide more plausible results to support adaptation planning.

The aim of this manuscript is to develop better estimates for the impact of climate change on water availability in the Awash basin based on the most regionally representative climate models. The main scientific question to be addressed in this work is whether water availability within the Awash basin will be impacted by changes in precipitation and temperature as a result of climate change. The methods used can be adapted to other basins to help develop more robust estimates for future water availability. The results of this analysis can inform water resources management planning in the basin.

2. Study Area

The Awash river basin (Figure 1) is one of the 12 river basins of Ethiopia. It drains the central and eastern highlands of the country. It has a catchment area of about 110,000 km² [21]. The river starts from Ginichi town west of the capital Addis Ababa. It travels along the Rift Valley and ends in Lake Abe on the border between Ethiopia and Djibouti. Through its journey, the river flows from an altitude of 3000 m above sea level (m.a.s.l.) to 250 m.a.s.l. with a total length of about 1200 km [22]. The average total rainfall ranges from 1600 mm in the highlands to 160 mm in the lowlands [5].
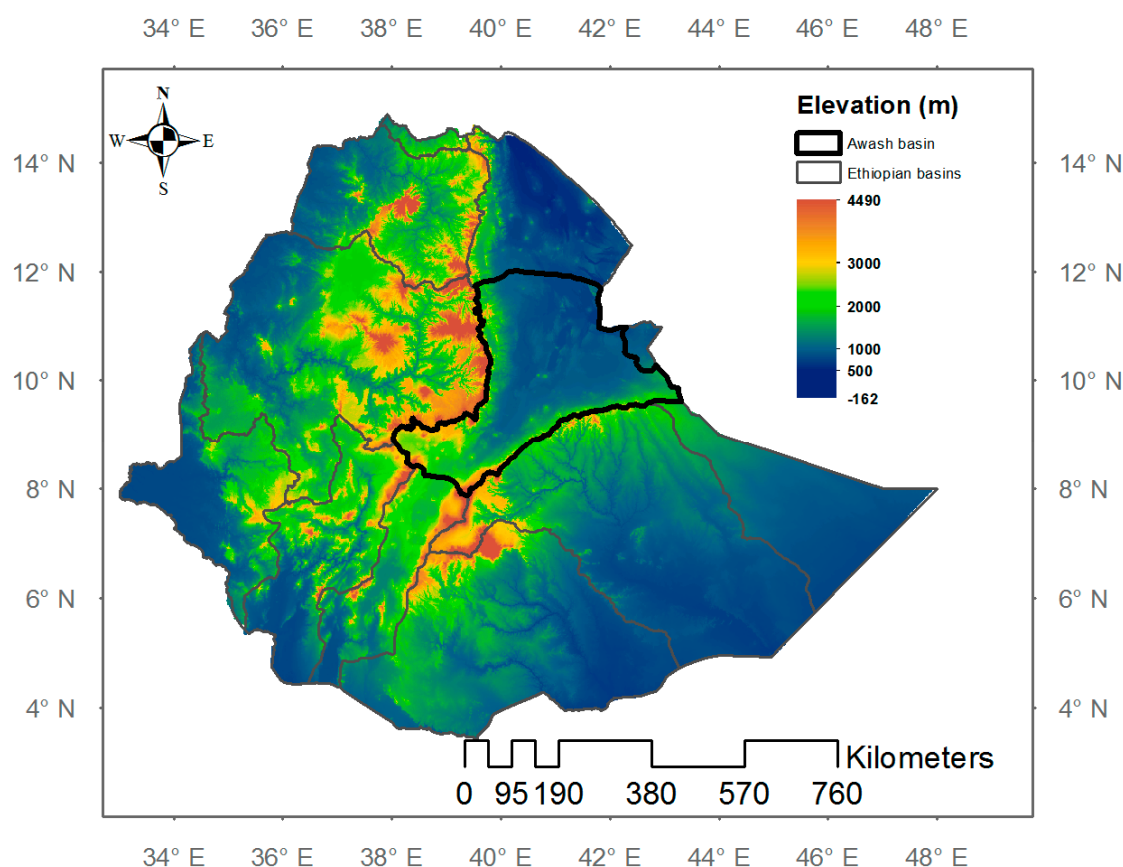

Figure 1. Location and elevation of Awash basin among the Ethiopian river basins.

The Awash basin is divided into three parts upper, middle, and lower basins based on climatological, physical, socio-economic, agricultural, and water resources characteristics [5,21]. The basin hosts an estimated 18.3 million people [5]. Most of this population leads a smallholder farmer and/or pastoralist livelihood [23]. According to the Awash Basin Authority, the total annual water demand by the four sectors is estimated to be 3.4 BCM (Billion Cubic Meter), 0.3 BCM, 0.12 BCM and 0.28 BCM for irrigation, domestic, livestock and industrial uses, respectively [5]. Additionally, most of Ethiopia's large-scale mechanized state and private irrigated farms are located in the basin. Industrial growth in Ethiopia is expanding rapidly, and more than 65% of these industries are currently located in this basin [5]. With these various activities, the basin is economically important for the country for its contribution to the national GDP.

The rainfall pattern in the basin is predominantly unimodal with the main rains occurring from July to September (locally known as *Kirmet*), the rest of the year is mainly dry except small rains during March to May (locally known as *Belg*) (Figure 2). June is a dry and transition month between the *Kirmet* and *Belg* seasons. According to the Awash Basin Authority the months of April to June are critical for irrigators in the basin as it is a peak irrigation period for both small-scale farmers and large-scale

irrigators [5]. Temperature ranges between 19 °C and 23 °C with May and June being the hottest months (Figure 2).
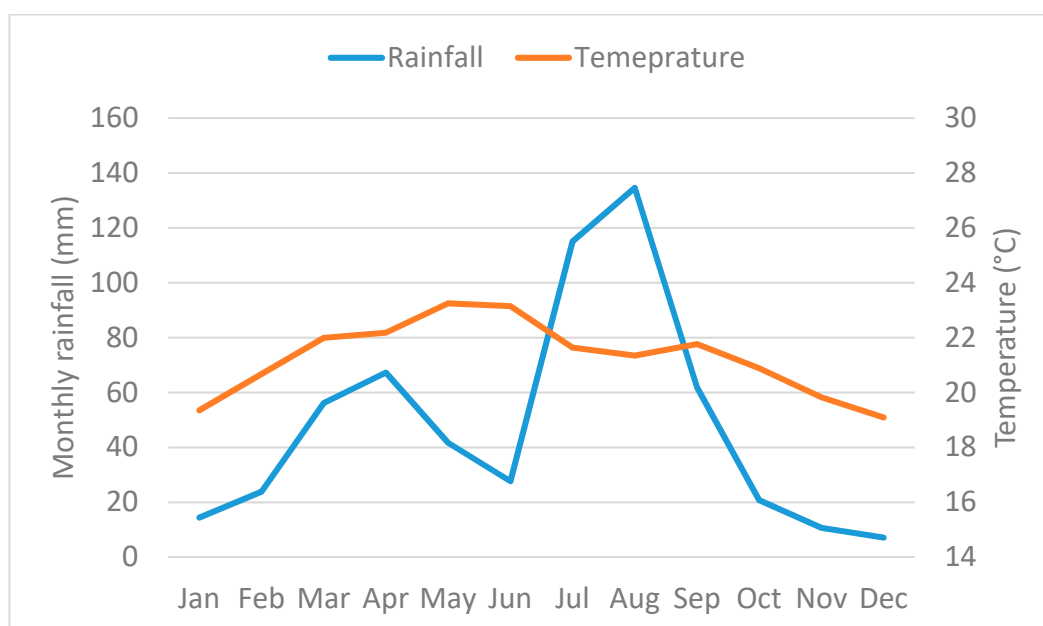

Figure 2. Monthly rainfall distribution and temperature of the Awash basin using CHIRPS and ERA-Interim data, respectively (1981–2005).

3. Data

For rainfall, we used the Climate Hazards Group Infrared Precipitation with Stations v2.0 (CHIRPS), which is a blend of satellite-based rainfall estimates and gauge data [24]. CHIRPS is available at a 0.05° × 0.05° resolution from 1981 to present (see http://chg.geog.ucsb.edu/data/chirps/). It uses a relatively large collection of rain gauge data in East Africa and the accuracy of this data was tested with rain gauges and found to be good for Ethiopia, for example in [25]. The lower Awash lacks a dense network of gauges and this was similar to the tested rainfall products in [25], from which CHIRPS was found to be good. CHIRPS include information from a higher number of gauges (1200) than other precipitation datasets, which makes it preferable for our study area to understand the historical climatology and trends. For historical temperature, the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis [26] is used. This data is available from 1979 to present at 0.75° × 0.75° resolution. ERA-Interim reanalysis shows a fairly good agreement with the ground-based datasets such as the Climate Research Unit (CRU) and therefore taken as a good representation of the temperature of the region.

To estimate the climate change signal, we have used the CMIP5 general circulation models (GCM). One may argue regional climate models (RCM) are better suited for regional impact studies. However, since RCMs are driven by GCMs as their boundary conditions they are influenced by the robustness and accuracy of the GCMs for the specific region under study. Hence, there is a need to understand better suited GCMs for the Awash basin area and subsequent impact studies. Global climate models show a broad range of simulated historical climates for Ethiopia and in the Awash basin in particular (Figure 3). The disparity between ensemble members, not to mention the ensemble mean and observations, requires closer examination of the skill of these models in the region and their ability to make projections of the future in which we have a reasonable level of confidence.
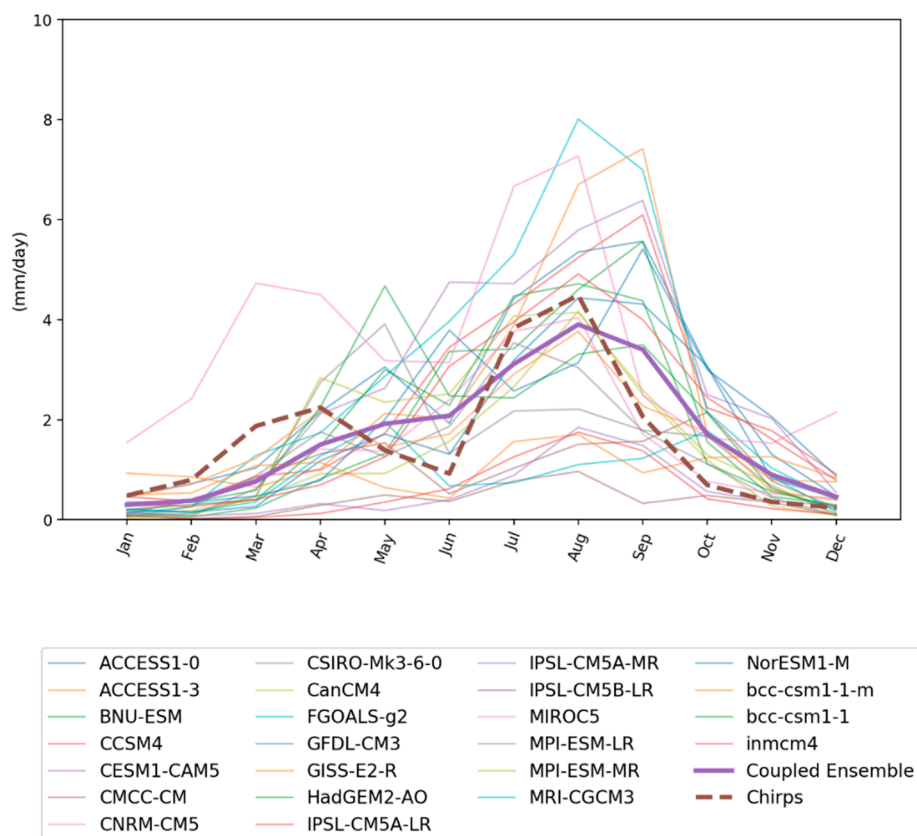
Figure 3. Comparison of Awash basin precipitation observation from CHIRPS (Climate Hazards Group Infrared Precipitation with Stations v2.0) with 24 global climates models historical simulations and their ensemble for the period 1981–2005.

Models were examined in the historical period (1981–2005) for their skill at capturing observed precipitation and temperature. The annual cycle, seasonal biases, variability, and trends of the models were evaluated. The evaluation was done for both the atmosphere-only and coupled versions of the models. The atmosphere-only evaluation was done to evaluate how models perform with observed sea surface temperatures (SSTs) and was, therefore, an evaluation of the model's atmospheric dynamics. Since projections are done with fully coupled models, the coupled model simulations, with interactive SSTs and sea-ice, were also evaluated. Models that performed the best for both types of simulations indicated good underlying atmospheric dynamics and the smallest impacts from SST biases. From the evaluation, three models were highlighted as having a reasonable skill in the region: Geophysical Fluid Dynamics Lab-Climate Model version 3 (GFDL-CM3), Max Planck Institute for Meteorology-Earth System Model-Mixed Resolution (MPI-ESM-MR), and Hadley Centre Global Environment Model version 2—Atmosphere and Ocean (HadGEM2-AO).

Therefore, based on comparing observation data of precipitation from CHRIPS and the historical GCM runs three climate models were selected. The monthly precipitation pattern compared to the observation is given in Figure 4. We will use these same models to estimate the change in temperature and subsequent evapotranspiration with the assumption that temperature projections are better reliable. Table 1 lists the models that performed well in the given metrics with their resolution. For the future climate data, from the Intergovernmental Panel on Climate Change (IPCC) defined Representative Concentration Pathways (RCPs) [18] we have used RCP 8.5 scenario, which represents the highest greenhouse emission level with rising radiative forcing pathway leading to 8.5 W/m^2 in 2100. It is important to note that all datasets were re-gridded to CHIRPS grid spacing (0.05° × 0.05°) using a shapefile for the Awash basin for consistency and comparison of different data sets at the same spatial scale.
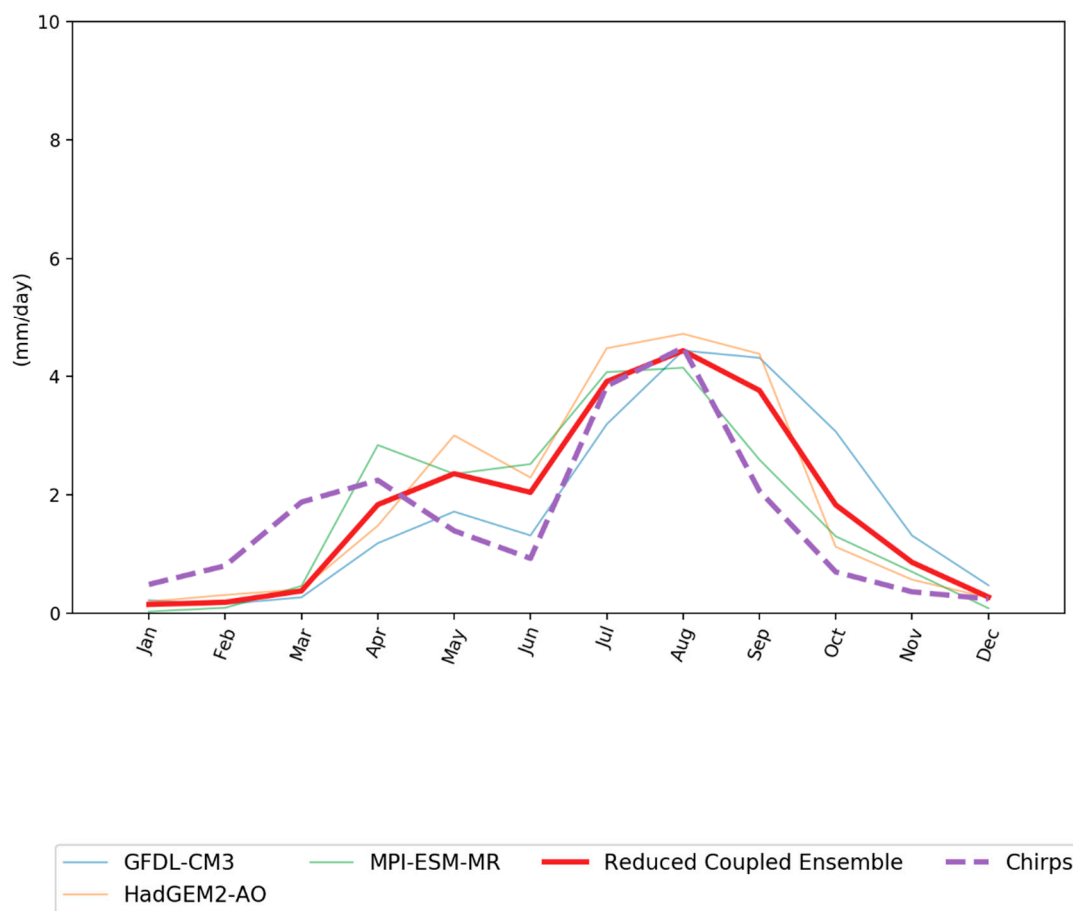
Figure 4. Comparison of Awash basin precipitation observation from CHIRPS with selected three global climate models historical simulations and their ensemble for the period 1981–2005.

Table 1. Selected climate models that met the criteria of capturing characteristics of precipitation over the Awash basin.

No	Model	Resolution
1	GFDL-CM3	$2° \times 2.5°$
2	HadGEM2-A	$1.25° \times 1.875°$
3	MPI-ESM-MR	$1.865° \times 1.875°$

4. Methods

Given that direct use of GCM output to hydrological impact assessment is unadvisable due to the mismatch of spatial resolution between the GCM and what is required for hydrology, the change factor (CF) method is widely used in its various forms, for instance [27–29]. The method is applied to estimate the climate change signal by comparing the given reference historical climatology and a future time horizon with the same length of years. The change signals are estimated by either absolute or relative change factors. Commonly, absolute CFs are estimated for temperature as the difference between the projected and reference values Equation (1) while relative CFs are calculated for precipitation by the ratio of projected values to reference values Equation (2). In this study, the period 1981–2005 is used as the historical reference period and three time slices are used for the future: Near future (2006–2030), mid future (2031–2055) and far future (2056–2080). The CFs are estimated at a monthly time scale and for all the grid points in the Awash river basin.

$$T\_CF_m = T\_fut_m - T\_his_m \tag{1}$$

$$P\_CF_m = \frac{P\_fut_m}{P\_his_m} \tag{2}$$

where: T_CF_m—temperature change factor for a given month, T_fut_m—future temperature values from a climate model for a given month, T_his_m—historical temperature values from a climate model for a given month, P_CF_m—precipitation change factor for a given month, P_fut_m—future precipitation value from a climate model for a given month, P_his_m—historical precipitation value from a climate model for a given month, and m is month from January to December.

The final value of change factors for each month is calculated after obtaining the distribution of change factors based on the approach used in [30]. This approach is dependent on using 20-years out of the reference and future period to calculate change factors. The method produces numerous change factors drawn from all pairs of continuous 20-year blocks from both historical and future periods for each month. The choice of using 20-years as a reference period is based on the adoption of this length in IPCC reports, for example [3]. With this method, one can show the distribution of change factors, unlike the conventional method. The conventional approach gives a single change factor based on a defined historical and future period. This method is dependent on the choice of the fixed periods and associated sampling uncertainty. For instance, in our case, the mean of 25-years historical and future periods would be compared and the change signal is calculated. To avoid such sampling uncertainty, the approach by [30] is more representative of the change and shows the range of uncertainty due to natural variability.

This 20-year sampling method is used for precipitation and temperature change factor calculation of the GCM projections for the Awash basin. Recent studies also used improved change factor method to estimate future water availability, however at daily timescale [2,31]. The future projections are found by mapping the change signals from climate models to observed precipitation and temperature variables. We have selected the median change factor from the 20 years distribution to represent the future projections for the Awash basin. To quantify the potential impact of climate change on water availability of the basin, we estimated effective rainfall by deducting potential evapotranspiration from precipitation. This can be used as a proxy to estimate the amount of water available in the basin Equation (3). For the historical period this is done using the observational data from CHIRPS for precipitation and evapotranspiration estimated using the ERA-Interim temperature data. We have estimated evapotranspiration based on Hargreaves method [32] which has a minimum requirement of temperature and radiation data.

$$WA_m = P_m - ET_m \tag{3}$$

where: WA_m is water availability for a given month, P_m is precipitation for a given month, and ET_m is potential evapotranspiration for a given month.

The future available water is estimated as the difference between future precipitation and potential evapotranspiration. This is estimated by transferring the climate change signal from the climate models to the observed data using Equations (4) and (5). Evapotranspiration is estimated using the Hargreaves method with the projected future temperature. Finally, water availability is estimated using Equation (6).

$$T\_fut(CF)_m = T\_era_m + T\_CF\_median_m \tag{4}$$

$$P\_fut(CF)_m = P\_chirps_m \times P\_CF\_median_m \tag{5}$$

$$WA\_fut_m = P\_fut(CF)_m - ET\_fut(CF)_m \tag{6}$$

where: WA_fut_m is future water availability for a given month, P_chirps_m is observed precipitation for a given month, $P\_fut(CF)_m$ is future precipitation for a given month with change factor mapped into observed data, T_era_m is observed temperature for a given month, $T\_fut(CF)_m$ is future temperature for a given month with change factor mapped into observed data, and $ET\_fut(CF)_m$ is future evapotranspiration for a given month, and m is the month from January to December.

　　　Similar to the previous variables the change signals for water availability are calculated by comparing the future and historical estimates Equation (7).

$$WA\_CF_m = WA\_fut_m - WA\_his_m \tag{7}$$

where: WA_CF_m is the water availability change factor for a given month, WA_fut_m is future water availability for a given month, WA_his_m is historical water availability for a given month, and m is the month from January to December.

5. Results

　　　We have estimated precipitation change factors for each grid cell of the three climate models covering the Awash basin. An example of the distribution of the change factors is shown in Figure 5 for a grid point at middle Awash for the mid-term period using the three climate models. The figure illustrates that change factors vary depending on the choice of periods used for their quantification, especially for the dry season months. After obtaining this distribution of the factors the median factors are used for further analysis. To produce spatial maps, the median change factor value obtained from these three models is mapped for the entire basin, for each month and for the three time periods. To present the results we have divided the seasons crudely into two. The first is between April and September that contains the main rainy season (July–August) or "*Kiremt*" in the local language. The second is the months January-March and October-December in which the dry season months are present and locally called "*Bega*" season.
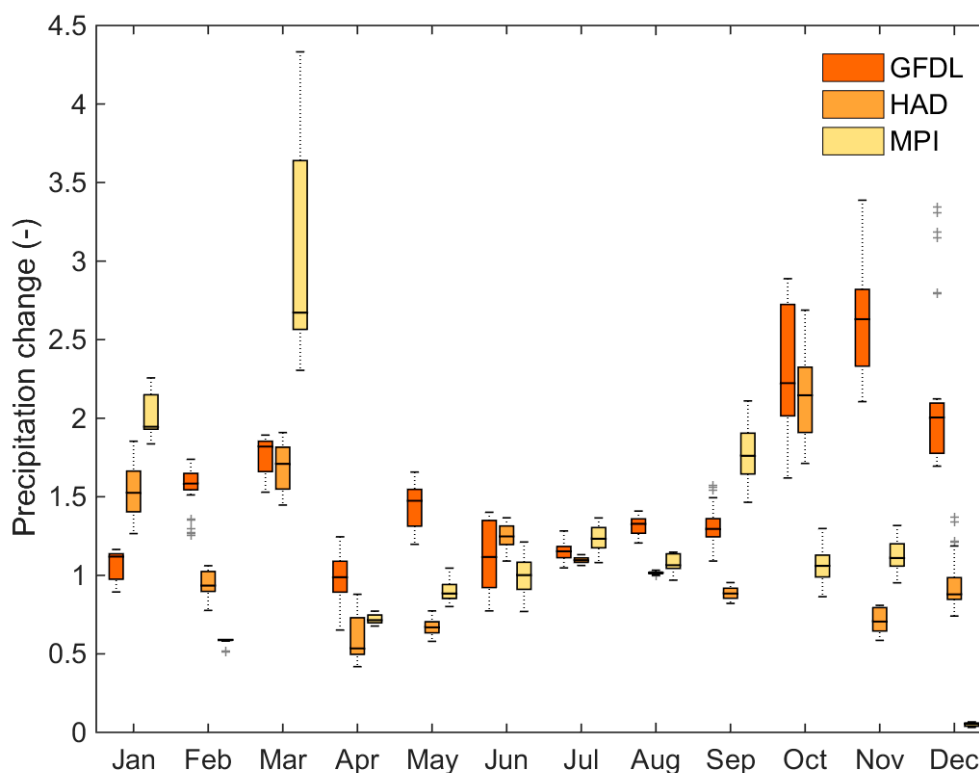

Figure 5. Distribution of change factors (CFs) based on 20-years sampling method at a selected location in middle Awash for the mid-term period (2031–2055) using the three representative models.

　　　The change factors for the months from April to September where the main rains occur in July and August are shown for the three future time periods. In these periods drying conditions are observed for the months April, May, and June at different rates. In the near-term period (2006–2030) the months of April and May are projected to be drier than the rest of the months. This can be up to 30% decrease

in the monthly rainfall at some locations but on average the decrease in rainfall is about 15% (Figure 6). The months of June and July are projected to have a slight increase in precipitation (12%) on average while some areas are projected decreasing precipitation of up to 6%. August, on the contrary, shows a slight increase of 5% throughout the basin while September is showing a slight decrease of 5% on average and a maximum decrease of 16%.
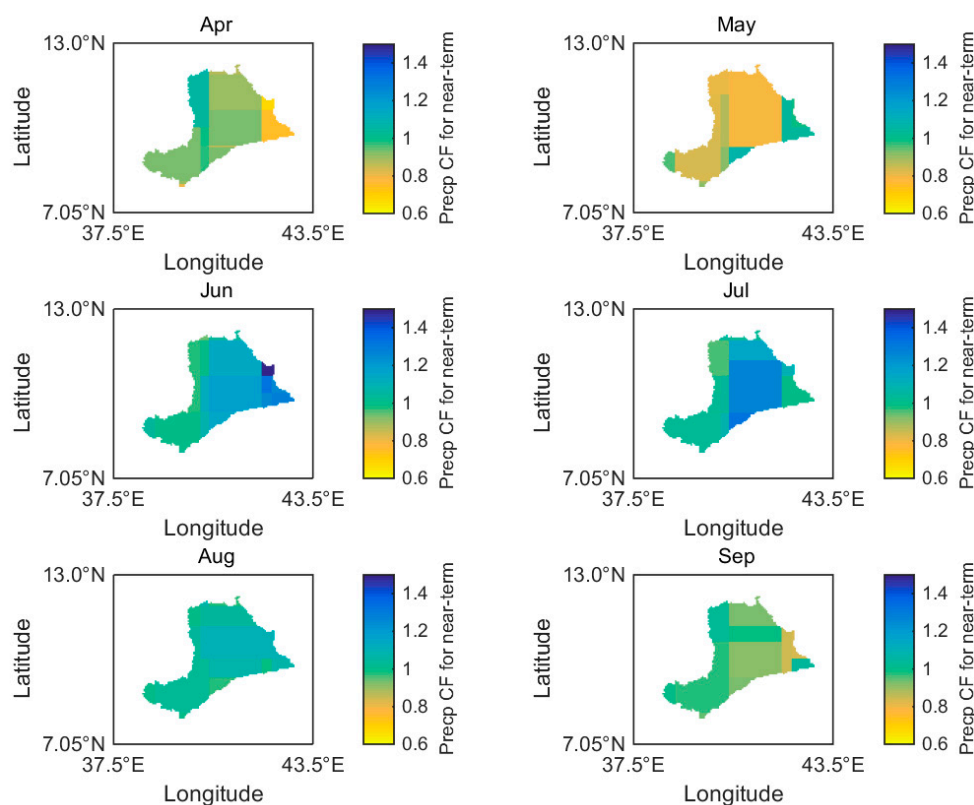

Figure 6. Precipitation change factors for April to September months for the near-term period, 2006–2030 (based on the median of the three models).

During the mid-term (Figure 7) the month of April is drier than the rest of the months with a projected precipitation decrease of 24% on average and a maximum decrease of 29%. May is also projected to be drier than present by 14% on average and a maximum decrease of 25%. The rainy months June to August projected on average increase in precipitation of 4%, 9%, and 6%, respectively. September in the mid-term is projected to have higher precipitation of about 17% on average and that can go to a maximum of more than 30%.

The precipitation projections toward the end of the century are given in Figure 8. In this period the month of June is projected to be drier than the others with precipitation reduction of about 25%. The month of May, on the other hand, is projected to be slightly dry by 5% reduction of precipitation on average while some areas can experience reduction up to 20%. The months April, July and August project increasing precipitation on average (6%, 20% and 11% respectively). The maximum increase in precipitation is in July that can reach up to 40%. September shows mostly decreasing precipitation in the upper and middle Awash by 10% while the lower Awash shows increasing precipitation up to 14%.

From these projections, one can note that the possibility of drought intensification during the April to June months and flooding during July to September months is a likely scenario. Given that historically droughts and floods are frequent in the basin these projections warn the intensifications of such extreme events.
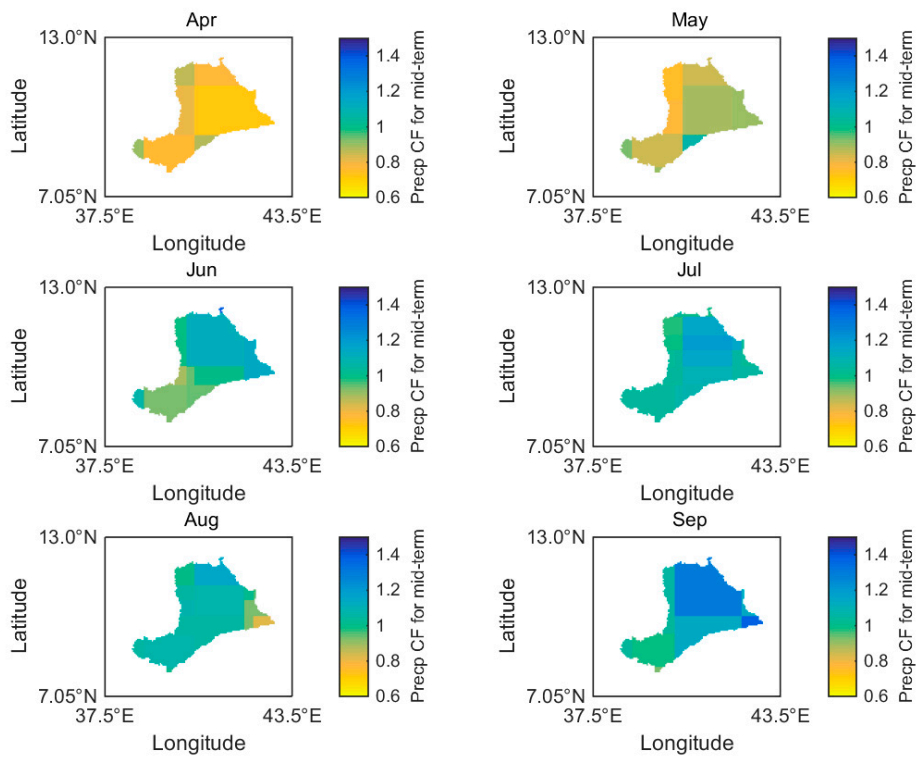
Figure 7. Precipitation change factors for April to September months for the mid-term period, 2031–2055 (based on the median of the three models).
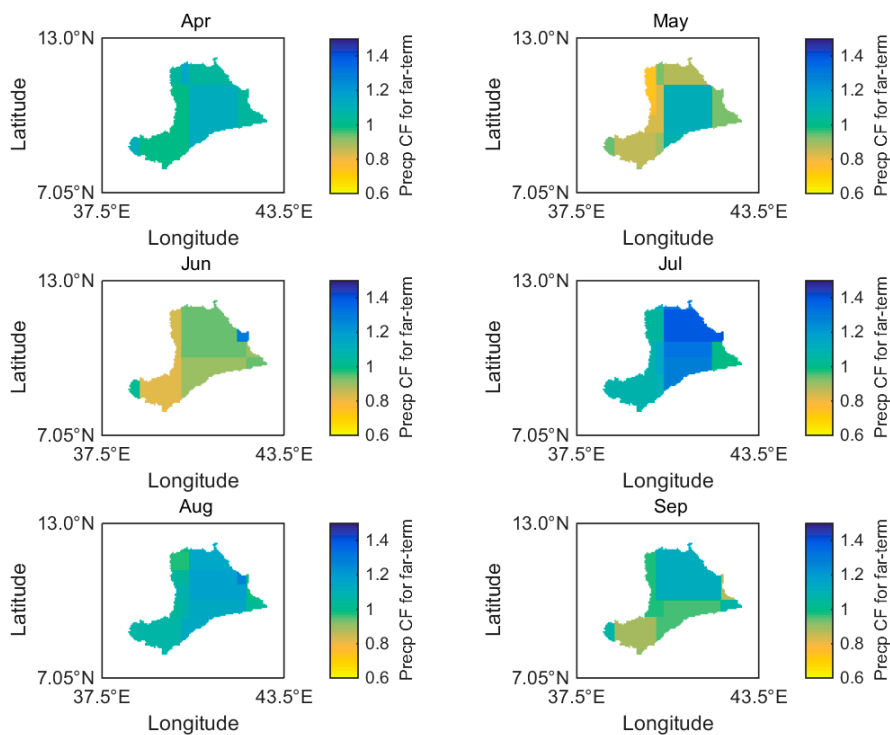

Figure 8. Precipitation change factors for April to September months for the far-term period, 2056–2080 (based on the median of the three models).

While the precipitation projections for the months that include the rainy season is as discussed above the dry months of the Bega season show a distinctive scenario. As an example, the projection for the mid-term period is shown in Figure 9 noting that relatively similar results are obtained for

the other periods. What stands out in this period is the extremely high increase in precipitation. This is particularly the case for March and October months in the mid-term and far-term periods. These projections are more than 70% increase on average. The simulations for these periods must have exceptional inaccuracies to project such extreme cases. Except for the month of February where a decrease in precipitation up to 30% is projected the rest of the months show this extremely high increase in precipitation in parts of the basin. It is hard to trust the simulation results and subsequent change signals from the GCMs for these dry season months due to such an outlier projection.
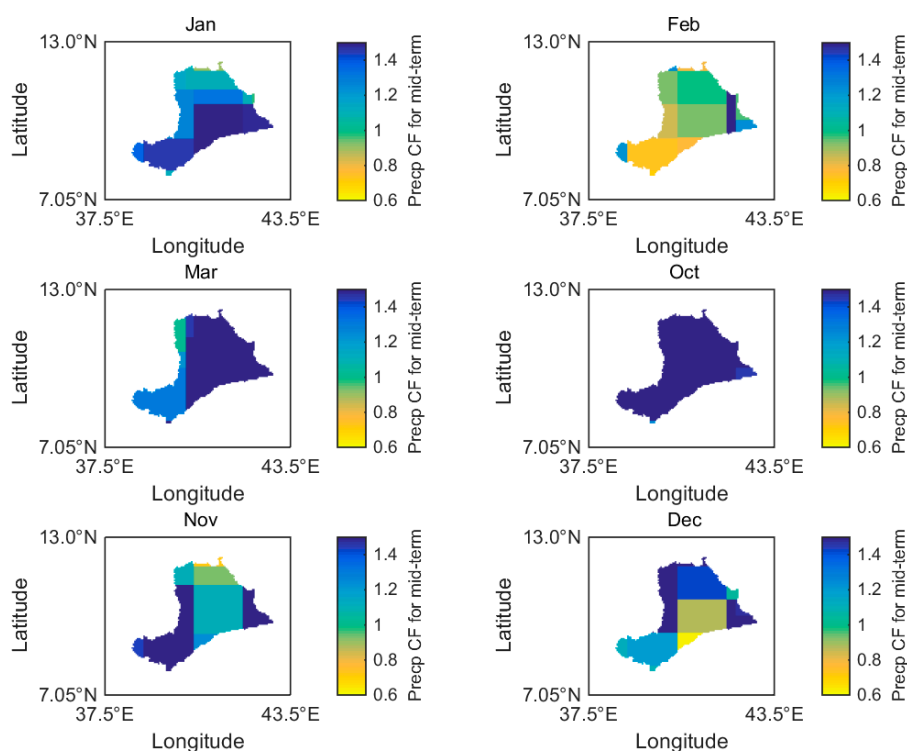

Figure 9. Precipitation change factors for January to March and October to December months for mid-term period, 2031–2055 (based on the median of the three models).

Similar to the precipitation change factor calculation approach, temperature change factors were estimated based on the 20-year sampling method for each grid cell of the three climate models for maximum and minimum temperature variables. An example that shows the distribution of the change factors for maximum temperature at a point in the middle Awash location is given in Figure 10 using the three models for the mid-term period. As can be seen the projections for the future are consistent in indicating an increasing change signal. Clear differences are seen among the models in this temperature projection where GFDL-CM3 model projects a higher maximum temperature than the others for the mid-term period.

The seasonal variation of the average temperature change factors for the entire Awash basin for both maximum and minimum temperature is given in Figure 11. The figure clearly shows as time progresses from near-term to the end of the century the increase in temperature becomes high for both maximum and minimum temperature. This is a constant warming trend of the basin. The dry season period, *Bega*, shows lower increasing signal than the rainy season period, *Kiremt*, for maximum temperature. While for the minimum temperature, both seasons have similar change signal magnitude with only 0.1 °C difference during near and far term periods. The *Kiremt* average change signals are increasing temperature by about 0.8, 2, and 4 °C for near, mid-, and far-term periods, respectively. While that of Bega are 0.7, 1.8, and 3.5 °C for near, mid-, and far-term periods, respectively. The details for maximum and minimum temperature projections is given in Table 2.
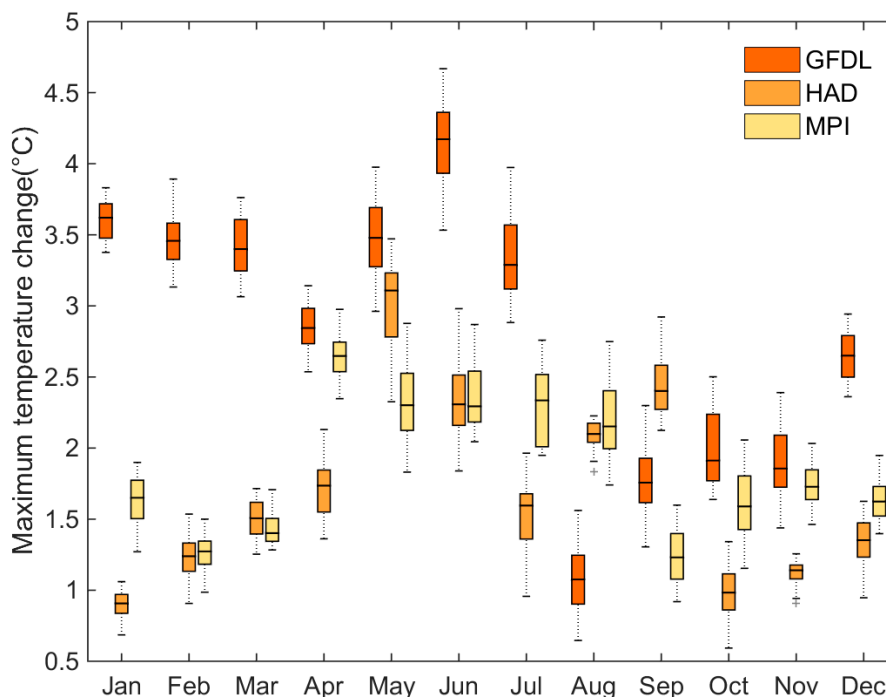
Figure 10. Distribution of maximum temperature CFs based on 20-years sampling method point in middle Awash for mid-term, 2031–2055 using the three models.
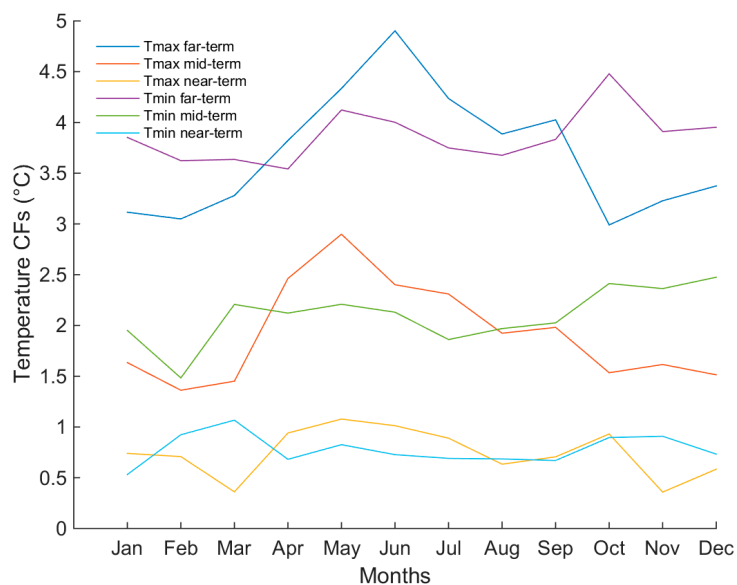

Figure 11. Seasonal variation of average temperature CFs (based on the three models) for the entire Awash basin (Tmax and Tmin maximum and minimum temperature, respectively).

Table 2. Maximum and minimum temperature projections for the entire Awash basin for three periods and two seasons.

Seasons	Near-Term		Mid-Term		Far-Term	
	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
Kiremt	0.9	0.7	2.3	2.1	4.2	3.8
Bega	0.6	0.8	1.5	2.1	3.2	3.9

What we have seen from the above analysis is that there is a consistent trend of increasing temperature projection in the Awash basin while precipitation is projected to be drier for the early months (April, May, and June) before the main rainy season (July–August). From a hydrological perspective, this can cause a decrease in water availability due to low precipitation and high evapotranspiration caused by the increase in temperature. Hence, water availability and the change in the future is computed as described before.

The water availability average change factors for the entire Awash basin and for the three future horizons are shown in Figure 12. The general picture on the projections of water availability in the future is marked by a decrease in water availability for most months except February and March. April to June are projected to face more intense water stress than others. It should be noted that this is a basin average, the spatial distribution varies according to the specific month and the location. The upper Awash basin area and the highlands are better off than the middle and lower Awash basin area during the rainy seasons. This is expected given that the upper basin receives better rainfall amount during the main rainy season than the rest of the basin.
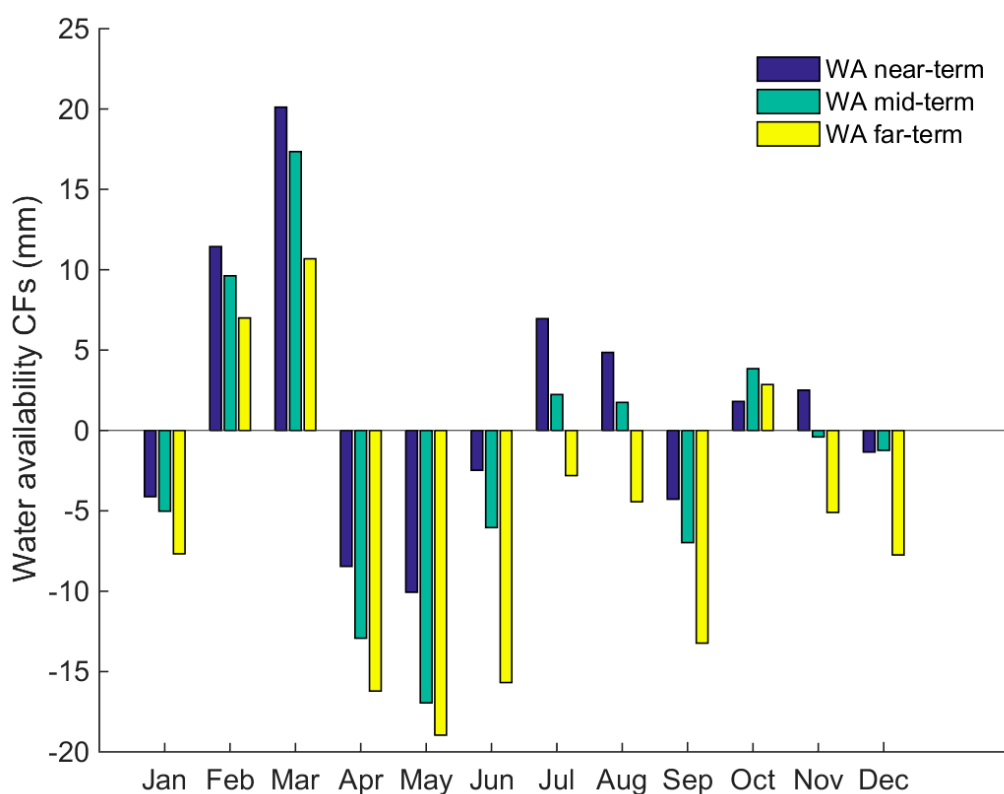

Figure 12. Water availability change factors for the future three periods.

6. Discussion

This study presents the most probable projections for the impact of climate change on the Awash basin hydro-climatic variables, using a methodological approach based on selecting best performing GCMs followed by a change factor method that accounted for sampling uncertainty due to the choice of periods. Our analysis highlighted the spatial differences across the Awash basin, with water deficiency dominant in all areas of the basin except during the wet season in the upper basin, a result consistent with previous findings on seasonal water deficit in the basin [33].

The change in climate as projected by the GCMs shows a clear difference between seasons. During the April-June months decreasing precipitation and increasing temperature led to lower water availability from the present period. These months get drier as the period progress from near-term to far-term. According to the Awash Basin Authority, these months are critical for irrigators in the basin

as it is a peak irrigation period for both small-scale farmers and large scale irrigators. Additionally, water allocation between hydropower needs and irrigators has the potential to increase as a source of conflict in the face of decreased water availability.

From the basin-wide analysis, in the main rainy months of July and August, there is no projection of decrease in water availability until the mid-term period but water stress is likely to be more common towards the end of the century. Although this is the general picture for the basin if we look at the spatial differences the highlands areas are the only parts with water surplus during July and August and the rest of the basin remains under increasing water stress even in these rainy months. June is a hot and dry month separating the two rainy seasons. From the precipitation projections, June will be drier during the far-term period while the near and mid-term projected a slight increase in precipitation. However, since temperature is increasing throughout the future projections, water availability will remain a challenge this month.

A striking extreme increasing precipitation result for months such as March and October are found in this analysis. One possible explanation for the increase in the month of March is "The East African paradox". This term is coined by climate scientists studying the East Africa region and found a decreasing precipitation trend in the region which contrasts to model predictions in the IPCC fifth assessment report that suggest a reversal and project increasing precipitation [34]. This unexplained situation in the climate models can be a simulation inaccuracy that is yet to be investigated. The link with the Awash basin projection can be from the fact that the western part of the Awash basin shares a border with the region characterized by the east African climate system. Therefore, the extreme increases in precipitation, especially for the month of March, might be the responsibility of the "The East African paradox".

Generally, the climate projections showed that the current challenge of the Awash basin in terms of water stress is something that will be intensified under a warming climate. There are some limitations to our analysis. The change signals are merely focused on the magnitude of the change in precipitation and temperature. As our analysis was in monthly timescale we have not considered a change in the frequency of these variables. It is good to note that the change in climate will have implications in changing the frequency of extreme events, which are better captured at daily time-scale. The other limitation is the impact on water resources is estimated without detailed hydrological modelling rather based on effective rainfall as a proxy to water availability. This approach provides information mainly on the surface water resource.

7. Conclusions

Hydro-climatological variability is one of the main challenges facing the Awash basin's water resources management. Our study has shown that climate change will have major implications for water availability in this basin. Based on selected climate models that best captured the historical characteristics of the basin's climate, intensified water stress is projected for three future periods. This is due to an increase in temperature and subsequent intensification of evapotranspiration which is consistent across the climate models. Decreasing precipitation in the April–June months is a major concern for the irrigation sector and for the basin authority on water allocation among various users. Historically the middle and lower parts of the basin are water deficient in all seasons and this is projected to intensify.

The projected decrease in water availability throughout the future periods signal increased water stress in the basin and the risk of water security for the different sectors, which are currently increasing their investments in the basin. Likewise, it is imperative to recognize that factors such as population growth and land use change may play prominent roles in risking water security for the people of the basin. This emphasises the need for an enhanced water management strategy that is inclusive of all sectors and considers equity in water allocation strategies.

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