Modeling the Impact of Climate Change on Flood and Drought: Case Study Awash River Basin, Ethiopia

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1. Introduction

**What is.....?**

**Climate?**
- Is the weather in some location/place averaged over some long period of time (Long-term average of weather condition)

**Climate Change?**
- The change in climate variable that occurs over a longer period of time typically over decades and centuries and may not return to its former state unless significant measures are taken place.

**Climate Variability?**
- The change that occurs within smaller/shorter time frame such as a month, a season or a year and may return to its former state.
1. Introduction

**Consequence of Climate Change**

- Sea level rise
- Change in Temperature
- Change in Precipitation
- Extreme events (flood and drought)

**Agriculture and food security**
(crop yields, irrigation demand, …)

**Forest**
(composition, health and productivity, …)

**Water resources**
(water supply, water quality, …)

**Coastal areas**
(erosion, inundation, cost of prevention, …)

**Species and natural areas**
(biodiversity, modification of ecosystems, …)

**Human health**
(infectious diseases, human settlements, …)

► Sea level rise
► Change in Temperature
► Change in Precipitation
► Extreme events (flood and drought)
1. Introduction

Basic Observation of Climate Change in IPCC 5th Assessment Report

According to IPCC AR-5

- Increased surface temperature
- Increased GHG concentration in the atmosphere
- Unexpected hazards such as drought, flooding, global warming, rise of ocean and lake levels.
1. Introduction

Basic Observation of Climate Change in IPCC 5th Assessment Report

Temperature Change
► The global average combined land and ocean surface temperature shows a warming of 0.85 (0.65 to 1.06) ºC.
► Each of the last three decades has been successively warmer at the Earth’s surface than any preceding decade since 1850.

Greenhouse Gas Emission
► Anthropogenic greenhouse gas (carbon dioxide, methane, and nitrous oxide) emissions have increased since the preindustrial era, driven largely by economic and population growth, and are now higher than ever.

Sea Level Rise
► Over the period 1901 to 2010, the global mean sea level rose by 0.19 (0.17 to 0.21) m.
► The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia.
1. Introduction

Climate change could intensify hydrological extremes, changing not just the magnitude but also the timing of flood and drought events (Lavers et al., 2015).

Ethiopia

- High potential for extreme events (floods and droughts), wet seasons can be wetter and warm seasons can also be warmer, (NAPA, 2007).
- Ethiopia is subject to high climate variability and change (IPCC, 2007), experiencing frequent floods and droughts, particularly in the Awash River Basin.
- The current scenario indicates that flood and drought are the recurrent common phenomena of Awash Basin, with devastating effects on environmental, social, and economic loss.

1.1. Objective

To assess the impacts of climate change on hydrological extreme events (flood and drought) under current and future climate change scenarios
2. Study area

Where is our research site?

- Conducted in the middle and lower Awash River Basin, Ethiopia
- Geographical location, north-eastern part of Ethiopia, 8°49' to 14°30'N latitude and 39°34' to 42°28'E longitude.
- Arid and semi-arid climate with low and erratic rainfall.

Middle Awash Valley
- Between Awash station and the Mille river.
- The altitude varies from 500m to 1000m a.s.l.

Lower Awash Valley
- An altitude between 250m and 500 m with the mean annual rain fall of less than 200mm.
This study mainly focused on assessing the potential impacts of climate change on hydrological extremes (flood and drought) with the application of a physically based hydrological model HEC-HMS, Standardized Precipitation Indices (SPI) and RCM model output for future climate projection in the basin.
Data Collection

1. Climate Data
   → Observed/station data
   → Three RCM model output (MIROC5-RCA4, CSIRO-RCA4, and CNRM-RCA4)

2. Hydrological Data
   → River flow data

3. Spatial Data
   → DEM, Digital Stream Network, Soil map, and LULC
3. Methodology and Analysis

Table. Summary of input dataset, including data-type and their sources.

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Climate</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed data</td>
<td>Ethiopia national meteorology agency</td>
<td>Daily maximum and minimum temperatures and precipitation (historical and future period)</td>
</tr>
<tr>
<td>RCM model data</td>
<td>CORDEX Africa</td>
<td></td>
</tr>
<tr>
<td><strong>Soil map</strong></td>
<td>Digital Soil Map of the World (DSMW)</td>
<td>Soil classification and properties</td>
</tr>
<tr>
<td><strong>DEM</strong></td>
<td>ASTER (<a href="https://earthdata.nasa.gov/">https://earthdata.nasa.gov/</a>)</td>
<td>Elevation, overland, channel slopes, boundary</td>
</tr>
</tbody>
</table>

Figure. Input spatial data for HEC-HMS model for the Awash River Basin
Climate Change Scenario and RCM output

- The future climate variables were projected using the RCM model based on two RCP scenarios.

  → RCM models: MIROC5-RCA4, CSIRO-RCA4, and CNRM-RCA4
  → Scenario Generation: RCP scenarios (RCP4.5 and RCP8.5)

  Bias Correction Method
  - Linear-scaling approach: due to its suitability and simplicity for bias correction on a daily basis of precipitation and temperature data.

- The future scenarios were developed by dividing the future time series into two periods:
  → 2030s (2011-2050) and 2090s (2051-2100).
The HEC-HMS model was used to simulate runoff events (floods) under different climate change scenarios.

For the model build-up five steps were followed including delineation of the watershed, selecting or specifying the sub-basin from the total sub-basin.

Model calibrations and validation
The model's performance was evaluated through the calibration and validation process and then the calibrated model was then applied to various climate scenarios.

- The model ran for 19 years (1996-2015) using available observed data.
- Warm-up period (1996-1998) for normalization of the model.
- The model calibration (1999-2011) and model validation (2012-2015).
3. Methodology and Analysis

Drought Analysis Based on Drought Indices

- The standardized precipitation index (SPI) was used to assess the meteorological drought in terms of severity and duration.
- The SPI is the most widely used drought index which is recommended by organizations like WMO and NOAA.
- The SPI is estimated based on long-term precipitation records that are fitted to a probability distribution.
- SPI uses only precipitation data for its calculation.

<table>
<thead>
<tr>
<th>SPI value</th>
<th>Drought category</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0+</td>
<td>Extremely wet</td>
</tr>
<tr>
<td>1.5 to 1.99</td>
<td>Very wet</td>
</tr>
<tr>
<td>1.0 to 1.49</td>
<td>Moderately wet</td>
</tr>
<tr>
<td>-0.99 to 0.99</td>
<td>Near normal</td>
</tr>
<tr>
<td>-1.0 to -1.49</td>
<td>Moderately dry</td>
</tr>
<tr>
<td>-1.5 to -1.99</td>
<td>Severely dry</td>
</tr>
<tr>
<td>-2 and less</td>
<td>Extremely dry</td>
</tr>
</tbody>
</table>
The performance of the HEC-HMS model was evaluated through a calibration and validation process using observed streamflow data over a period of 1996-2015 (Sisay et al., 2017).

The model performed well for our study area with reasonable accuracy as shown in Table both Nash-Sutcliffe Efficiency (NSE) and coefficient of determination ($R^2$) > 0.7 for both the calibration and validation periods (1999-2011 and 2015-2015).

### Table. Summary of model performance criteria for calibration and validation

<table>
<thead>
<tr>
<th>Period</th>
<th>Middle Awash</th>
<th>Lower Awash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R2</td>
<td>NSE</td>
</tr>
<tr>
<td>Calibration (1999-2011)</td>
<td>0.78</td>
<td>0.8</td>
</tr>
<tr>
<td>Validation (2012-2015)</td>
<td>0.82</td>
<td>0.73</td>
</tr>
</tbody>
</table>
4. Results and discussion

Drought Analysis Results

- The drought indices for the 6- and 12-month time scales (SPI-6 and SPI-12) were selected for the study of drought characteristics.
- A drought event occurred when the drought index (SPI) values were less than -1.0 (Table).
- The overall categories of drought are considered (mild drought and above), areas in the Middle and Lower Awash Basin are most frequently hit by droughts.

Figure. Six-monthly and 12-monthly SPI values for historical and future climate change scenarios.
4. Results and discussion

Flood Analysis Results

Table. Changes in flood magnitudes between the current; and the 2030s and 2090s time periods.

<table>
<thead>
<tr>
<th>Return periods</th>
<th>5</th>
<th>10</th>
<th>25</th>
<th>50</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030s</td>
<td>8.7</td>
<td>4.2</td>
<td>1.5</td>
<td>-2.6</td>
<td>-5.5</td>
</tr>
<tr>
<td>2090s</td>
<td>10.5</td>
<td>8.9</td>
<td>8</td>
<td>7.3</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Figure. Flood frequency curve for Awash River based on future scenario simulation.

Figure. Changes in flood magnitudes between the current and the 2030s, 2090s the time period corresponding to the return period.

- Figure and table, present the percentage increase in peak flow of river corresponding to different return periods (5, 10, 25, 50, 100) by the 2030s and 2090s.
- These results indicate an average increase in flood events.
- Moreover, the analysis indicates that the overall increasing trend in the frequency of flood events is not linear.
→ This study addresses climate change impact assessment on the hydrological extremes (drought and flood)

→ For hydrological simulation, we used the HEC-HMS model
  ▪ calibrated and validated in daily and monthly time steps.
  ▪ the model performed well with reasonable accuracy (NSE and R^2 > 0.7).

→ Moreover, drought analysis indicates that the overall categories of drought are considered (mild drought and above), and the basin is most frequently hit by droughts.

→ Furthermore, the maximum river flows in the future will be higher and more variable in terms of magnitude, and irregular occurrence, than at present. It is observed that climate change has a significant impact on the high flow condition of the Awash River.

To investigate the robustness of the results, further research on future extreme events is required by considering multi-model ensemble climate scenarios and socio-economic changes (land use land cover change).
References


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Thank you for your attention!!