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


International Conference on Regional Climate, ICRC-CORDEX 2023.

Ermias Sisay Brhane[1] and Koji Dairaku[2]

1. Degree program in System and Information Engineering, University of Tsukuba, Tsukuba, Ibaraki, Japan
2. Graduate School of Systems and Information Engineering, University of Tsukuba, Tsukuba, Ibaraki, Japan

# 1. Introduction

筑波大学 University of Tsukuba

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 it former state unless significant measures are taken place.

**Climate Variability?**

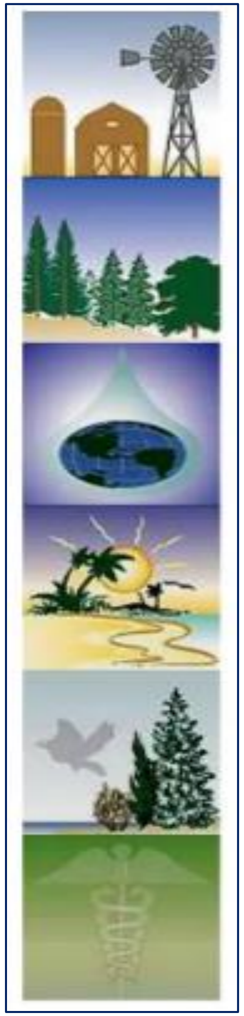
- The change that occurs within smaller/shorter time frame such as a month, a season or a year and may return to its former state.

# 1. Introduction

筑波大学
University of Tsukuba

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,…)

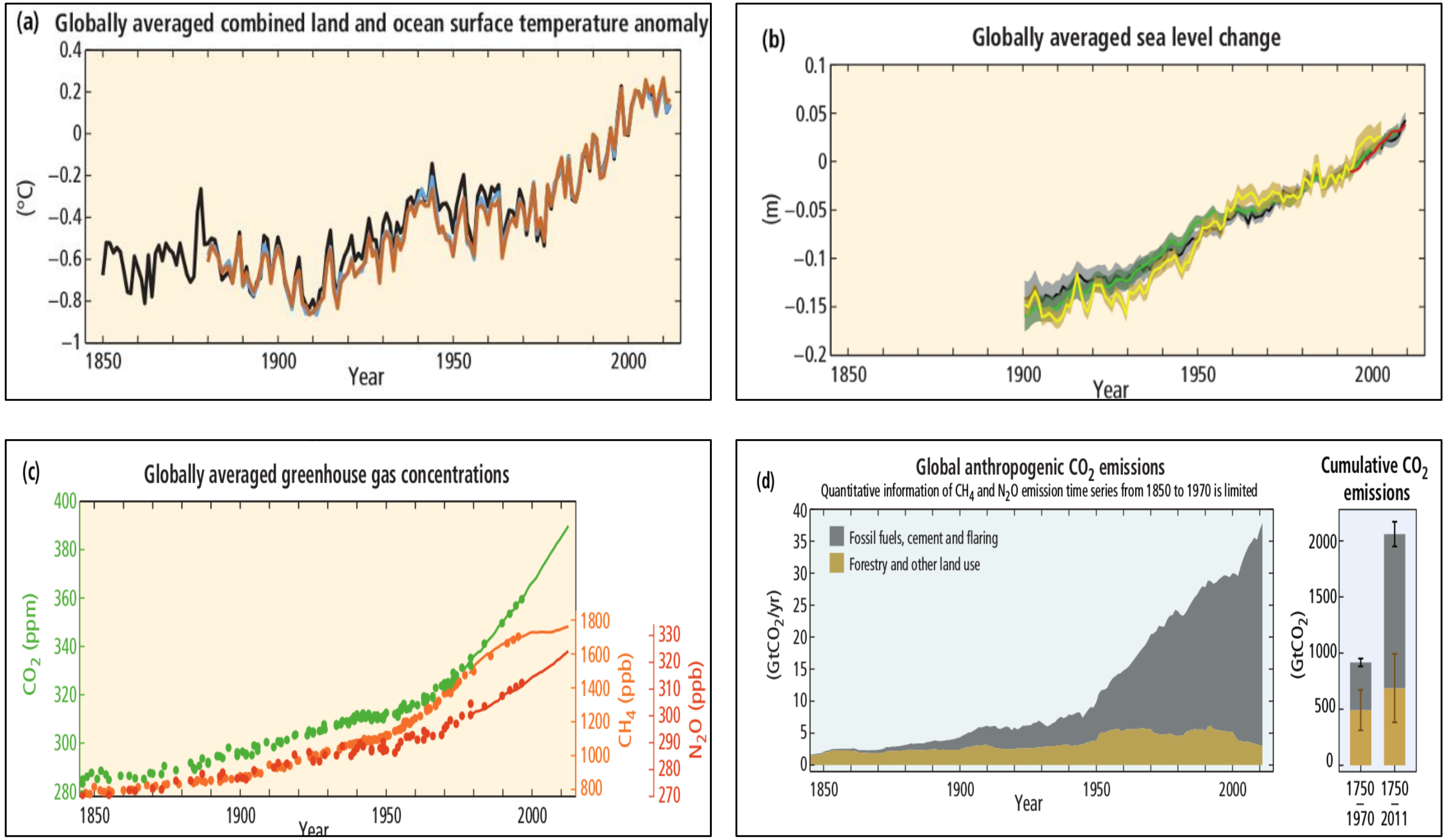
**Species and natural areas**
(biodiversity, modification of ecosystems….)

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

# 1. Introduction

筑波大学
University of Tsukuba

## 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

筑波大学 University of Tsukuba

## 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) $^{0}$C.
- 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

筑波大学 University of Tsukuba

- ▶ 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

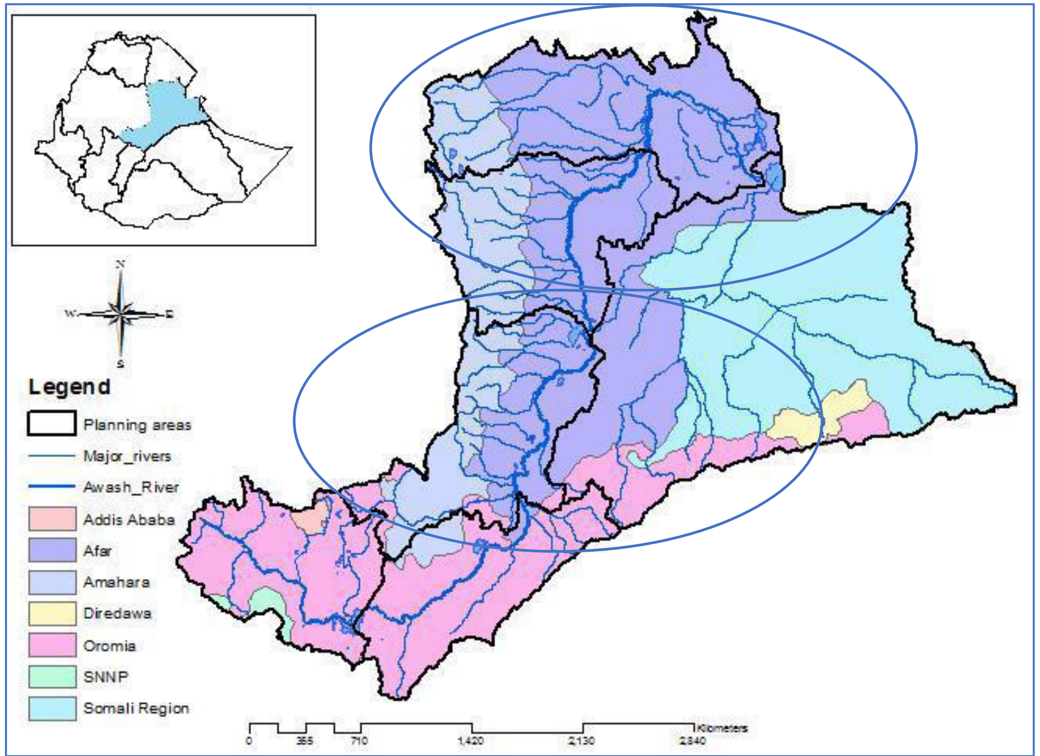
→ To assess the impacts of climate change on hydrological extreme events (flood and drought) under current and future climate change scenarios

# 2. Study area

筑波大学
University of Tsukuba

## 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 to1000m a.s.l.

### Lower Awash Valley

→ An altitude between 250m and 500 m with the mean annual rain fall of less than 200mm.

# 3. Methodology and Analysis

筑波大学
University of Tsukuba

**What have we tried to do?**

- 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.

# 3. Methodology and Analysis

筑波大学
University of Tsukuba

## 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

筑波大学
University of Tsukuba

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

| Data | Source | Description |
|---|---|---|
| Climate | | |
| Observed data | Ethiopia national meteorology agency | Daily maximum and minimum temperatures and |
| RCM model data | CORDEX Africa | precipitation (historical and future period) |
| Hydrological data | Minster of Water Resource (MoWR) | Daily streamflow (1996–2015) |
| Soil map | Digital Soil Map of the World (DSMW) | Soil classification and properties |
| Land use | ESA-CCI land use (http://esa-landcover-cci.org/) | Land use classification – cropland, forest, etc. |
| DEM | ASTER (https://earthdata.nasa.gov/) | Elevation, overland, channel slopes, boundary |

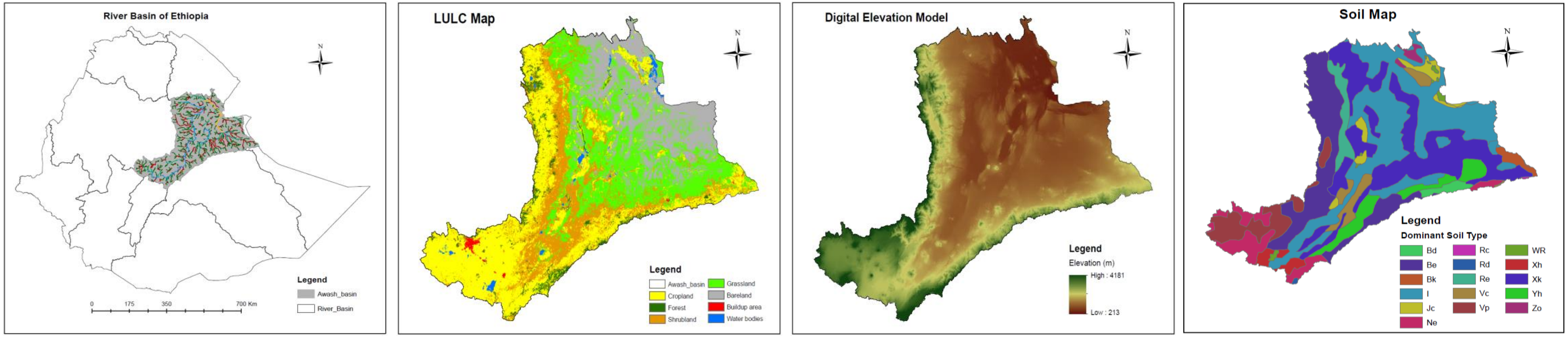



**Figure.** Input spatial data for HEC-HMS model for the Awash River Basin

# 3. Methodology and Analysis

筑波大学 University of Tsukuba

## 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).

# 3. Methodology and Analysis

筑波大学
University of Tsukuba

## HEC-HMS and Model Setup

- 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 Setup

**Sensitivity Analysis**
↓
**Model calibration and Validation**
↓
**Model Performance Evaluation**
↓
**Coefficient of Determination ($R^2$) and NSE**
↓
**Model Efficiency Test**

## 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

筑波大学 University of Tsukuba

## 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.** Classification of drought events based on SPI value (McKee et al., 1993)

| SPI value | Drought category |
|---|---|
| 2.0+ | Extremely wet |
| 1.5 to 1.99 | Very wet |
| 1.0 to 1.49 | Moderately wet |
| -0.99 to 0.99 | Near normal |
| -1.0 to -1.49 | Moderately dry |
| -1.5 to -1.99 | Severely dry |
| -2 and less | Extremely dry |

# 4. Results and Discussion

筑波大学 University of Tsukuba

## Model Calibration and Validation Results

- 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

| | Middle Awash | | Lower Awash | |
|---|---|---|---|---|
| Period | R2 | NSE | R2 | NSE |
| Calibration (1999-2011) | 0.78 | 0.8 | 0.86 | 0.79 |
| Validation (2012-2015) | 0.82 | 0.73 | 0.83 | 0.71 |

# 4. Results and discussion

筑波大学 University of Tsukuba

## 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.

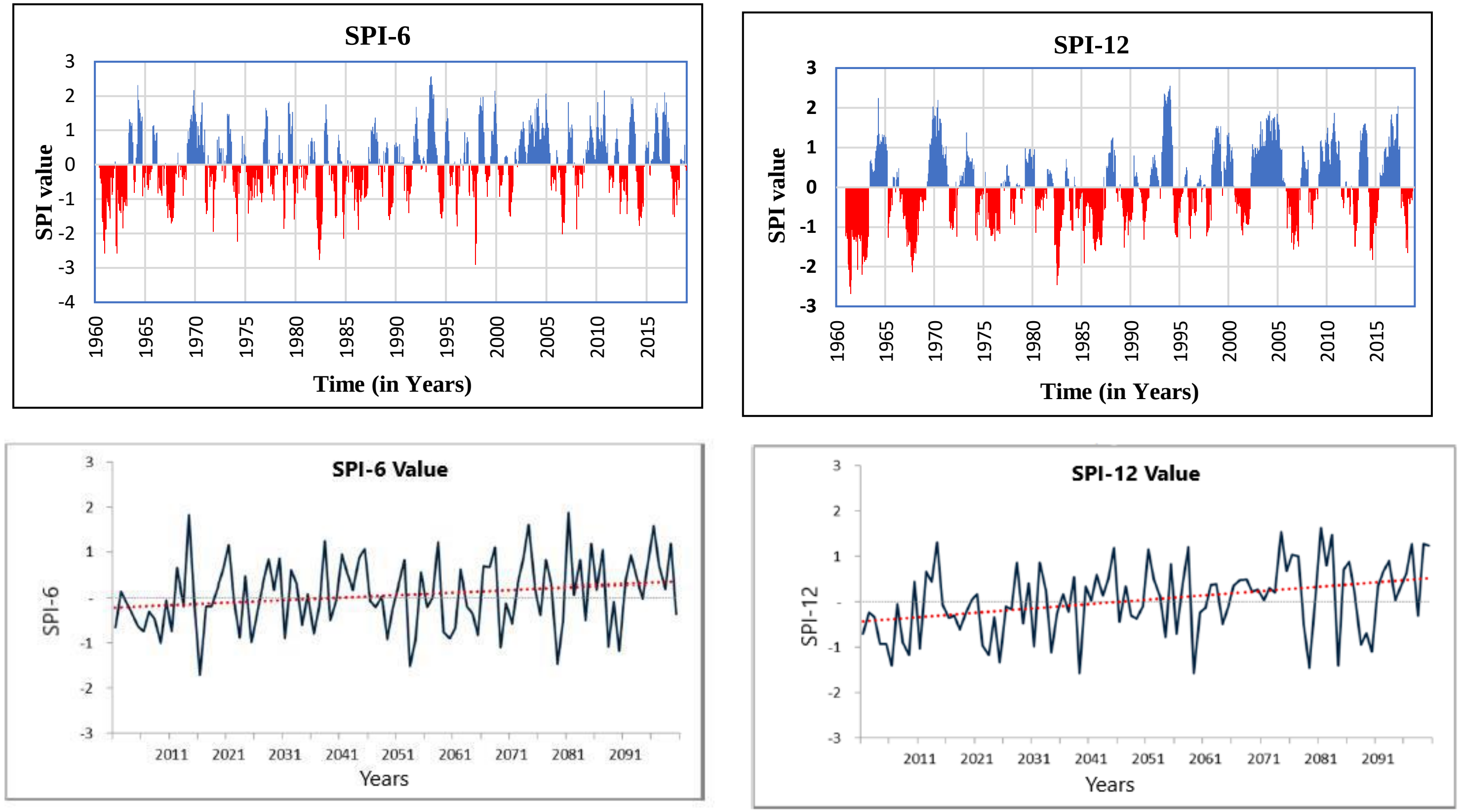



**Figure.** Six-monthly and 12-monthly SPI values for historical and future climate change scenarios.

# 4. Results and discussion

筑波大学 University of Tsukuba

## Flood Analysis Results

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

| Return periods | | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|
| | | Percentage (%) | | | | |
| Periods | 2030s | 8.7 | 4.2 | 1.5 | -2.6 | -5.5 |
| | 2090s | 10.5 | 8.9 | 8 | 7.3 | 7.2 |

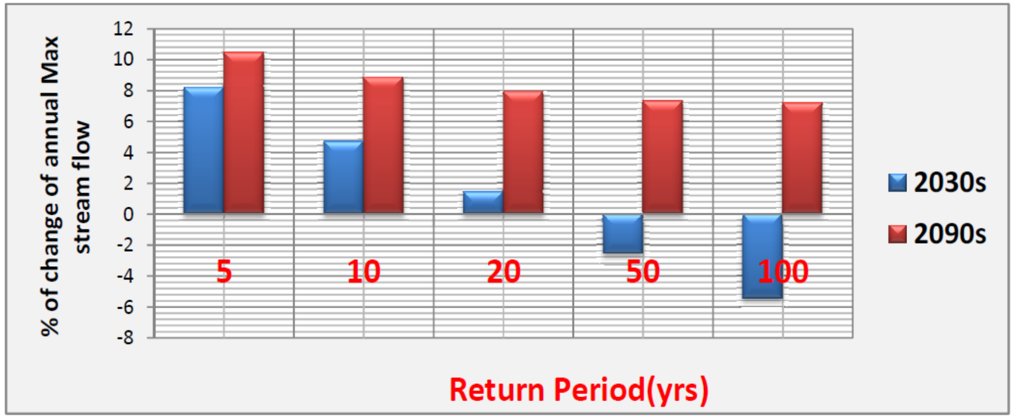



**Figure.** Changes in flood magnitudes between the current and the 2030s, 2090s the time period corresponding to the return period

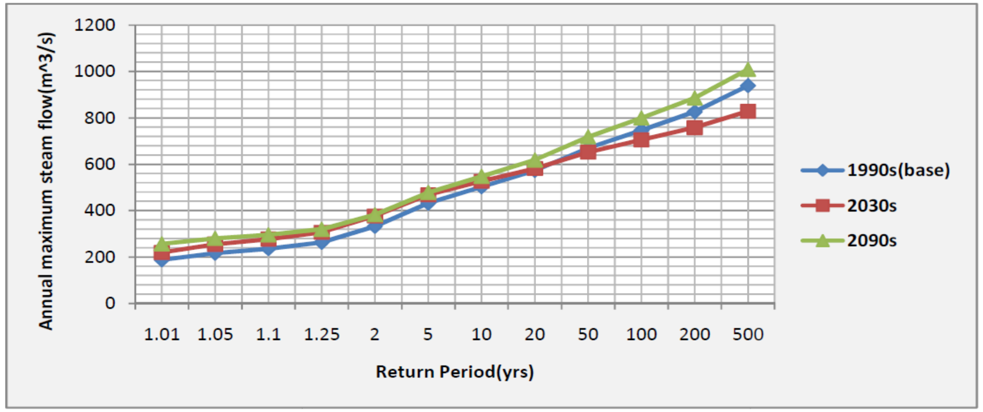



**Figure.** Flood frequency curve for Awash River based on future scenario simulation.

- 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.

# 5. Conclusion

筑波大学 University of Tsukuba

→ 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 $R2>0.7$).

→ 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


- De Luis, M., Gonzalez-Hidalgo, J.C., Brunetti, M. and Longares, L.A. (2011). Precipitation concentration changes in Spain 1946–2005. Nat. Hazards Earth Syst. Sci. 11,1259–1265.
- Fay, M., Block, R.I. and Ebinger, J. (2010). Adapting to Climate Change in Eastern Europe and Central Asia, Vol. 52862. World Bank Group,180.
- Hare, W. (2003). Assessment of Knowledge on Impacts of Climate Change, Contribution to the Specification of Art, 2 of the UNFCCC. WBGU
- Lavers, D. A., Ralph, F. M., Waliser, D. E., Gershunov, A., and Dettinger, M. D. (2015). Climate change intensification of horizontal water vapor transport in CMIP5. Geophys. Res. Lett. 42, 5617–5625.
- McKee, T.B., Doesken, N.J. and Kleist, J. (1993). The relationship of drought frequency and duration to time scales. AMS 8th Conference on Applied Climatology, (January), 179–184.
- Oliver, J.E. (1980). Monthly precipitation distribution: a comparative index. The Professional Geographer. 1980; 32(3):300–309.
- Sisay, E., Halefom, A., Khare, D., Singh, L. and Worku, T. (2017). Hydrological modelling of ungauged urban watershed using SWAT model. Modeling Earth Systems and Environment, 3(2), pp.693-702.


# Acknowledgment


This study is supported by the Ministry of Education, Culture, Sports, Science and Technology, Japan, under the Japanese Government MEXT: Monbukagakusho Scholarship program.

Thank you for your attention!!