# Evaluation of the climate change impact on Legedadi and Dire reservoirs using R-R-V-criteria

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# Abstract

This study mainly deals with evaluation of the climate change impact on Legedadi and Dire reservoirs which is found in north-east Awash River Basin, Ethiopia. Projection of the future climate variables is done by using Max Planck Institute for Meteorology – Earth System Model (MPI-ESM). In the present study, future rainfall MPI-ESM product corrected by using $BF_{TV}$ (Bias factor time variance).

The 1996-2016 was taken as baseline period against which comparison was made. A hydrological model, HEC-HMS was utilized to simulate Runoff in the study area. The performance of the model was assessed through calibration and validation process and resulted NSE=0.87 and PEV=7.5% during calibration and NSE=0.84 and PEV=7.85% during validation. The projected future climate variables has two future time series 2040s and 2080s, for both future time series an increasing trend evaporation from the open water surface of reservoirs when the projected average maximum and Minimum temperatures increase from the baseline period and precipitation shows a fluctuation event. Evaluation to the base and the future period average annual inflow volume shows an increase of 2.44% and decrease 0.99% at Dire reservoir and an increase of 5.15% and decrease 1.15% at Legedadi reservoir during 2040s and 2080s periods respectively.

In general analysis of the reservoirs with current and future climate change output indicates that the reliability and resilience of the reservoirs is sensitive to precipitation change than change in temperature on differing dimensionless vulnerability of the reservoirs doesn't demonstration extraordinary difference for both the change in precipitation and temperature.


# 1. Introduction

Earth's average temperature has risen by $1.5^0$C over the past century, and is projected to rise another 0.5 to $8.6^0$C over the next hundred years. Small changes in the average temperature of the planet can translate to large and potentially dangerous shifts in climate and weather. [1].climate change includes major changes in temperature, precipitation, or wind patterns and among other effects that occur over several decades or longer[2]. The interaction of increased temperature; increased sediment, nutrient and pollutant loadings from heavy rainfall; increased concentrations of pollutants during droughts; and disruption of treatment facilities during floods will reduce raw water quality and pose risks to drinking water quality [3].

As indicated by Bisrat Kifle in 2017 The climate change projections result under RCP 4.5 and RCP 8.5 scenarios on surface water supply shows that the level of reservoirs volume both at Legedadi/Dire and Gefersa reservoirs will be reduced in the projected years between the years 2023 and 2039 [4]. The natural stream of Legedai River water potential is reduce time to time due to climate change, high urbanization and degradation that decrease the water potential of the river
from the previous amount and it changes the land cover of the areas.

Legedadi and Dire catchment area is the largest of the other water supply source of Addis Ababa city. The Legedadi dam was commissioned in 1970 and Dire dam was commissioned in 1999, both situated about 32Km east of Addis Ababa, have a capacity of 63 MCM and 19MCM and the catchments is 91.2 $Km^2$ and 77.9$Km^2$ respectively. Upstream of the respective dams location are located to the east of Addis Ababa. They are both sub-catchment of Legedadi river basin locally known as Mutincha which flows in northeast-southwest direction and is part of the drainage system that flows the northwest corner of the Awash River basin. The average annual surface water potential of the two catchment is estimated by the year of 2000 master plan study to be 86MCM for the Legedadi catchment and 50MCM for the dire catchment [5].

The reservoirs is exist in Oromia region state, Ethiopia under the administration of Addis Abeba water and sanitation office. The Legedadi and Dire catchments is founded between latitude $9.00^0$ N-$9^0$ 9’ 24” N and longitude $39.00^0$E-$39^0$ 12’E. The region is characterized by arrange of volcanic mountains rising to elevation from 1917 to 2560 m.a.s.l.

# 2. Material And Method

## 2.1 Data Collection

### 2.1.1 Data Sources

The general methodology were collecting metrological data from NMA (National Meteorological Agency), hydrological data from MoWIE (Minster of Water, Irrigation and Energy), topographic data from Ethiopian Map agency, GCM data (CMIP5) RCP4.5 from international water management institute and (CMIP6) RCP4.5 downloaded from KNMI Climate Explorer (https://climexp.knmi.nl/selectfield_cmip6.cgi?id=someone@somewhere).

The data quality was checked by using data quality tests and missing data also filled using different method which is appropriate for the data.

## 2.2 Description of selected climate model

The focus of this study is evaluating climate change impact on Legedadi and Dire reservoirs using the CMIP6 current Max Planck Institute for Meteorology (MPI-M) running: experiment ssp245 using the MPI-ESM1-2-LR model and CMIP5 ESM (earth system model) version of the Max Planck Institute for Meteorology (MPI-ESM) Rcp 4.5 output to simulate land surface water with $0.44^0 * 0.44^0$ spatial resolution. CMIP6 MPI-ESM1-2-LR was extracted from KNMI Climate Explorer and CMIP5 received from IWMI (International Water Management Institute) and then bias in rainfall and temperature products was assessed and corrected before satellite rainfall and temperature products can be used in hydrologic applications.

## 2.3 HEC-HMS model description

HEC-HMS is a comprehensive hydrologic model developed by Hydrologic Engineering Centre (HEC) of United States Army Corps of Engineers (USACE). It is designed to simulate the rainfall runoff processes of dendrite watershed systems. HEC-HMS model works as semi-distributed model, the catchments area can be divided into different sub-basins and the sub-basins further be divided into different elevation and vegetation zones.

The DEM 30 by 30 and land use land cover data of Awash basin was received from Ministry of Water, Irrigation and Electricity of Ethiopia was used to delineate the study area by using ARC-GIS software. The HEC-HMS model requires daily rainfall as input. Hence rainfall data for the period of twenty one years (1996-2016) was prepared for four meteorological stations for the catchments area. Aerial rainfall in the model is computed by multiplying the rainfall by the weight of each station for the sub basin considered in the analysis. The weight of each meteorological station was computed by the Thiessen polygon method. Future Potential Evapotranspiration is calculated using the Hargreves potential evapo-transpiration with future CMIP temperature. Fortunately the average monthly values of current PET of Legedadi and Dire is already done by A.A.W.S.O (Addis Abeba water and sanitation office).

In this study, Hec-Geo HMS is used to derive river network of the basin and to delineate sub basins of the basin from the digital elevation model (DEM) of the basin and exporting the file to HEC-HMS. Hec-Geo HMS is a geospatial hydrology toolkit for engineers with limited GIS experience [6]. It is an extension package used in ArcView software.

# 3. Result And Discussions

The corrected CMIP5 and CMIP6 MPI-ESM precipitation projection exhibited an increase in annual mean precipitation in the 2040s but decrease in 2080s time periods. When comparing the historical climatic variables and generated future climate trends, it is generally observed that the future trends of maximum and minimum temperature follows the same increasing behaviors.

## 3.1 Evaporation from the reservoir

The average annual open water evaporation shows increases in amount by 0.027% in 2040s and0.08% increase is projected in 2080s under CMIP6 (MPI-M) MPI-ESM1-2LR and 0.12 % in 2040s and 0.15 % increase is projected in 2080s for CMIP5 (MPI-M) MPI-ESM-LR in the catchment. In the reservoirs doesn't show significant change in open water evaporation, the rate of monthly open water evaporation is found to increase relatively at higher rate during the month October to April in 2040s and 2080s for both scenarios.

## 3.2 HEC-HMS Hydrological Model Results

### 3.2.1 Calibration and validation

The calibration and validation of HEC-HMS for this particular study area was carried out using twenty one years from 1996-2016 daily rainfall and daily stream flow data of Legedadi River at Mutincha station.

### 3.2.2 Calibration and validation result

The HEC-HMS model is calibrated and validate for the observed period of twenty one year (1996-2016) and the best-fit parameters sets are using PEV (percentage error volume) and NSE (Nash and Sutcliffe coefficient). In simulation of the runoff, the observed period is divided in to two zones, the first is to calibrate (1996-2008) and the last is to validation (2009-2016) and found PEV = 7.5% and NSE = 0.87 for calibration and PEV = 7.85% and NSE= 0.84 for validation. Therefore the model can reasonably be used for the intended purpose.

### 3.3 Reservoir inflow volume

The generated inflow is compared with the current (1996-2016) the simulated future inflow shows an average annual increase in volume by 5.15% in 2040s and decrease 1.15% in 2080s for Legedadi reservoir and increase in volume by 2.44% in 2040s and decrease 0.99% in 2080s for Dire reservoir. Generally, the changes in the reservoir inflow are observed higher during June to October (wet-period).

## 3.4 Evaluating of the performance indices of reservoir

When relating the Legedadi and Dire reservoirs the maximum draw down in water level is exhibited during 2080s under CMIP5 and CMIP6 (MPI-M) where the projected inflow is minimum in this case Legedadi reservoir is good for implemented than the Dire reservoir in runoff during long period of time exceedence of the storage capacity of a reservoir that provides a steady supply of current and under future annual volume with a desired performance.

### 4. Conclusion

The projected maximum and minimum temperature shows an increasing trend for the next century, but the precipitation could not able to replicate the historical (observed) data this is due to complicated nature of precipitation processes distribution in space and time and its uncertainty. The HEC-HMS model used for generating the inflow and shows well manner for model performance. It was generally observed that the reliability index of the Legedadi reservoir for current and future MPI-ESM RCM output reveals above 80% and above 73% for Dire reservoir, hence it is concluded that the Legedadi reservoir has high capability to meet the required target demand than Dire reservoir in all time horizons.

### Declarations

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. The manuscript was done by the aid of Bahir Dar University only for buy climate data from National meteorology of Ethiopia.

We confirm that the manuscript has been read and approved by our named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved between us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property.

In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property. We understand that the Corresponding Author is the sole contact for the Editorial process. Surafel Alebel is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author.

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# Figures

### Figure 1

Figure 1-1 Map of Ethiopia regions and study area

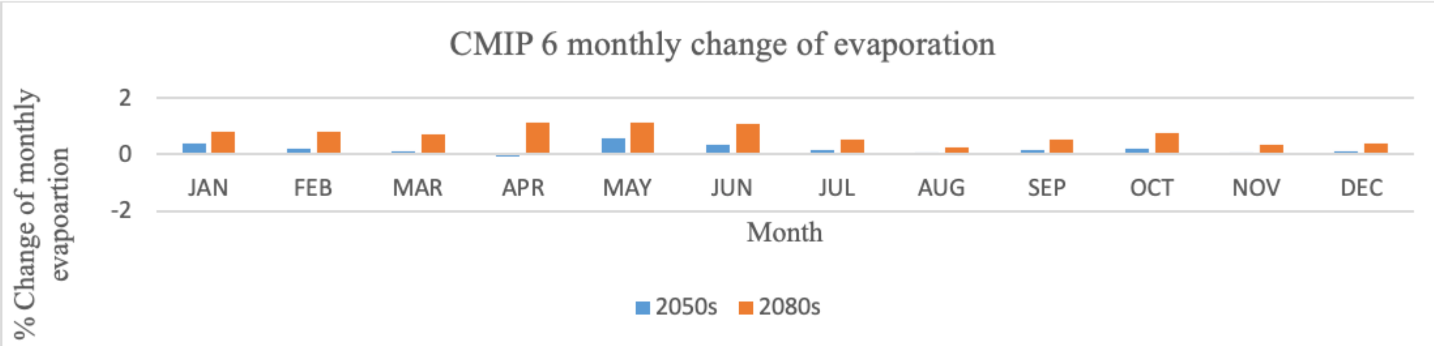


Figure 2

Figure 3-1 Projected monthly CMIP6 (MPI-M) percentage change in open water evaporation

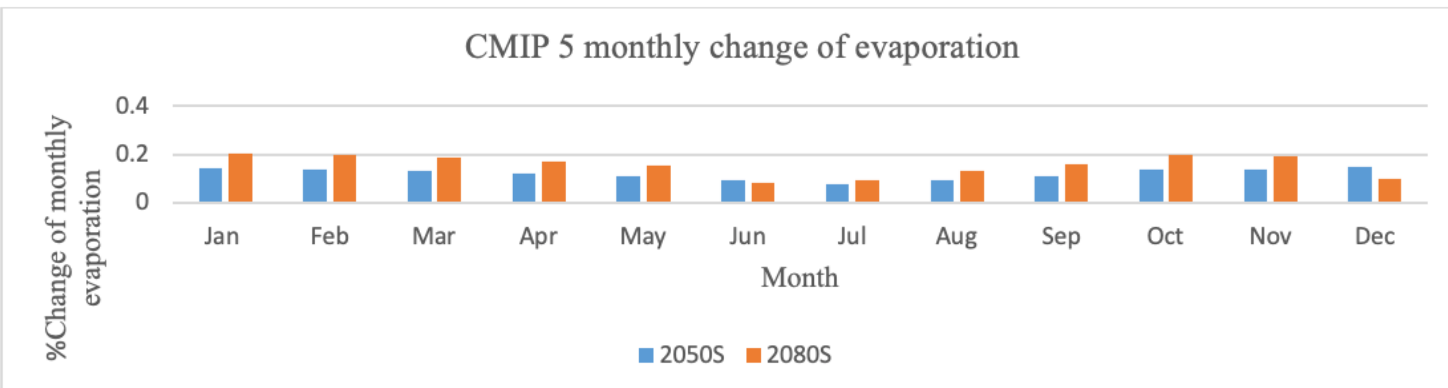


Figure 3

Figure 3-2 Projected monthly CMIP5 (MPI-M) percentage change in open water evaporation

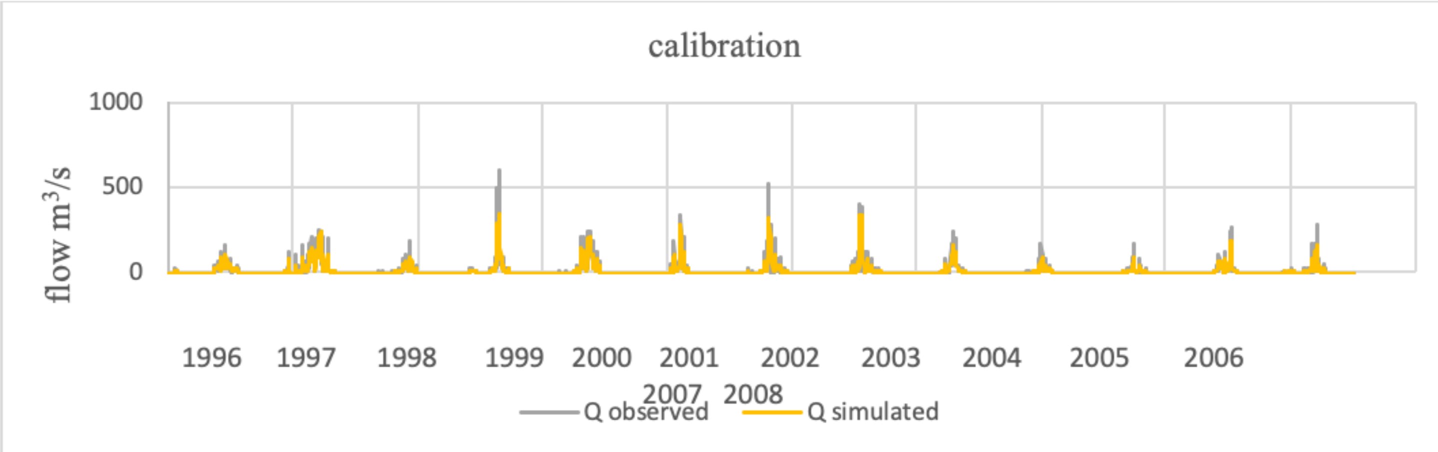


Figure 4

Figure 3-3 Simulated and observed hydrograph for calibration period daily time scale

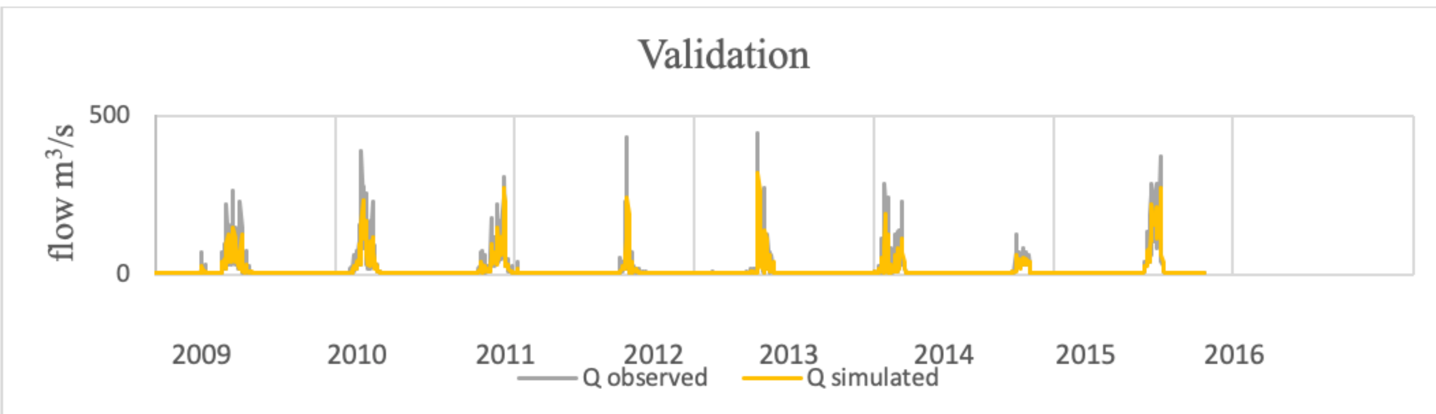


Figure 5

Figure 3-4 Simulated and observed hydrograph for validation period daily time scale