

EVALUATION OF CLIMATE CHANGE IMPACT ON BLUE NILE BASIN CASCADE RESERVOIR OPERATION

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ABSTRACT

This study mainly deals with evaluation of climate change impact on Blue Nile basin cascade reservoir operation in particular to Beko-Abo, Mandaya and Border reservoirs, which are proposed cascade hydropower development on main stream of Abbay river basin. To evaluate the impact of climate change, climate change scenario of evapotranspiration & precipitation were developed for three period using output of ECHAM5 with RCM for A1B emission scenario was used to develop the future climate change scenario. A hydrological model, HEC HMS, was used in order to simulate the current and future inflow volume to the reservoirs. The performances of the model was assessed through calibration and validation process and resulted NSE from 0.74 to 0.88 during calibration and from 0.71 to 0.84 during validation at the four gauge stations. The projected future climate variable shows an increasing trend for both maximum and minimum temperature and evapotranspiration but precipitation shows fluctuating trend in the next century. Relative to the current condition, the average annual open water evaporation for Beko-Abo reservoir might increase by 4.02% and 5.934%, for Mandaya reservoir it might also increase by 8.11% and 10.23% and for Border reservoir also shows an increase of 8.68% and 17.05% in 2011-2026 and 2026-2041 scenarios respectively. Comparison to the base period and the future period average annual inflow volume shows an increase of 9.05% and 6.04% at Beko-Abo and an increase of 7.17% and 4.39% at Mandaya during 2011 2026 and 2026 2041 periods respectively and at Border reservoir a decrease of 12.29% during 2011 2026 and 14.55% during 2026 2041 periods. The average annual power generation using HEC ReSim might increase by 1.53% and 1.11% at Beko Abo and might also increase by 2.56% and 1.47% at Mandaya hydropower station during 2011 2026 and 2026-2041 periods respectively. For Border hydropower station, the average annual power generation might decrease by 0.95% and 2.91% for both periods in comparison to the base period.

On average the time based and volumetric reliability of the reservoirs estimated to be more than 90%. The resilience of the reservoirs is below 50% and their vulnerability is less than 50%. Therefore, these performance indices reveals good performance of the reservoirs except the speed of recovery of the reservoir from failure because the reservoir will not able to recover rapidly from failure to safe state.

KEYWORDS: Climate Change, RCM, CLM, Reliability, Resilience, Vulnerability, Blue Nile, Beko-Abo, Mandaya, Border, HEC-HMS, HEC-Ressim, Reservoir Operation

INTRODUCTION

The impact of climate change on water resources are becoming a critical issue for many countries in the developed and developing world. Climate change is likely to alter the hydrologic cycle in many ways that may cause substantial impacts on water resource availability and changes in water quality (Schindler, 1997).

The study area, Abbay River Basin, which is found in the northwestern part of Ethiopia between $7^{\circ}45'$ and $12^{\circ}45'N$ latitude, and $34^{\circ}05'$ and $39^{\circ}45'E$ longitude. It covers an area of approximately $199,812\text{km}^2$ with a total perimeter of 2440km . The annual rainfall varies between about 800mm to $2,220\text{mm}$ with a mean of about 1420mm . The rainfall pattern is almost uni-modal (BCEOM, 1999).

The aim of this paper is to evaluate the impact of climate change on selected Blue Nile Basin cascade reservoirs operation under climate change scenarios on inflow volume or stream flow, open water evaporation loss, operation rule, hydropower production capabilities of the each reservoirs and thereby examine the reservoirs capability to meet the target demand in the future climate condition.

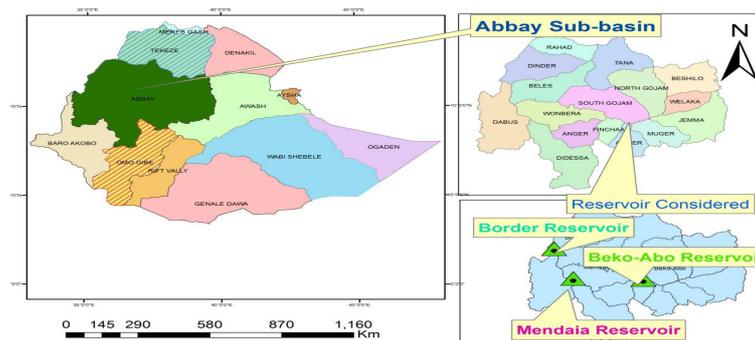


Figure 1: Location and Basin Map of the Study Area

OBJECTIVE OF THE STUDY

The general objective of the study is to evaluate the impact of climate change on selected Blue Nile Basin cascade reservoirs operation under climate change scenarios.

The Specific objectives are:-

- To evaluate climate change scenarios using Regional Climate Model.
- To estimate current and future inflow volume in to each reservoir by employing a hydrological model.
- To evaluate the rate of change in open water evaporation losses from Cascaded reservoirs with future climate change.
- To assess the impact of climate change on the hydropower production capabilities of the each reservoirs and thereby examine the reservoirs capability to meet the target demand in the future climate condition.
- To develop current and future reservoir operation rule curve for cascaded reservoirs using HEC-ResSim model.

MATERIALS AND METHODS

2.1 Model Description

For climate change downscaling purpose dynamical downscaling model, Climate Local Models (CLM) which is designed to downscale climate was utilized as to get future trend and scenarios. Arc-GIS for spatial data analysis and making connection with Arc-Hydro and HEC-GeoHMS were used to estimate initial parameter and to prepare basin and

meteorological model for HEC-HMS hydrologic modeling for runoff generation and HEC-ResSim model for reservoir operation are the models used for this study. The performance of the reservoirs was evaluated using RRV-Criteria.

2.2 Physiographical Data

Hydrological, DEM of 90mx 90m resolution, Land use/land cover, Soil and geology shape file data for the study area taken from Ministry of water and Energy. The meteorological data have been collected from National Meteorological Agency (NMA).

The predicted future climate change parameter on daily basis for a period of 30 years (2011 to 2041) was collected from International Water Management Institute (IWMI). For this specific study Penman-Monteith method is adopted to calculate the daily potential evaporation

2.3 Hydrological Modeling & Hec-Hms Model Performance

The model performance in simulating observed discharge was evaluated during calibration and validation by inspecting simulated and observed hydrograph visually and by calculating Nash and Sutcliffe efficiency criteria (NSE), coefficient of determination (R^2), and Percent difference /Relative Volume Error (D) were used using the following selected methods.

Method	Loss Method	Transform Method	Base flow	Calibration & Validation	Objective Function	Optimization algorithm
Selected	Deficit and Constant	Clark unit hydrograph	Monthly Constant	Automated & Manual	PWRMSE	Nealder & Mead(NM)

RESULTS AND DISCUSSIONS

The climate scenario was generated (RCM forced by ECHAM5 with A1B emission scenario) for the sub basins for 30 years period from 2011-2041. The projected future climate change scenario shows an increasing trend for both maximum and minimum temperature and evapotranspiration but precipitation shows fluctuating trend in the next century.

3.1 HEC-HMS Hydrological Model Result

For all gauging station daily and monthly data for the sub-basin from 1996-2001 was used for calibration and from 2002-2005 for validation and 1995 was used for warm up the model (warm up period).

3.1.1 Calibration and Validation Result Based on NSE

Table 1

S.No	Catchment	Calibration		Validation	
		Daily	Monthly	Daily	Monthly
1	Kessie	0.64	0.82	0.60	0.80
2	Border	0.75	0.88	0.72	0.84
3	Didessa	0.63	0.80	0.63	0.79
4	Beles	0.52	0.74	0.51	0.71

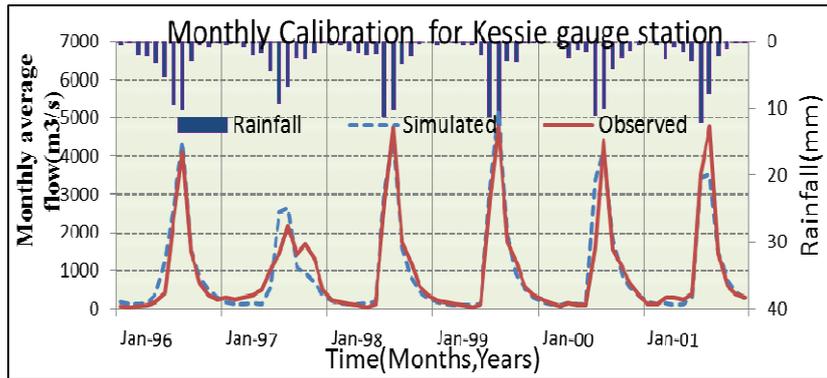


Figure 1

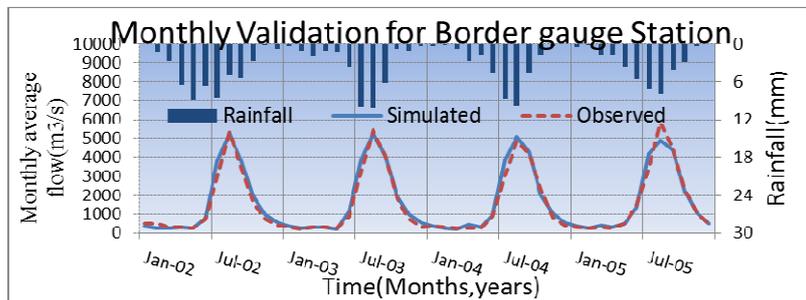


Figure 2

3.2 Reservoir Inflow Volume

For comparison purpose the generated inflow is compared with the baseline (1996-2011) mean monthly flow. Comparison to the base period and the future period average annual inflow volume shows an increase of 9.05% and 6.04% at Beko-Abo and an increase of 7.17% and 4.39% at Mandaya during 2011-2026 and 2026-2041 periods respectively and at Border reservoir a decrease of 12.29% during 2011-2026 and 14.55% during 2026-2041 periods

3.3 Reservoirs Evaporation

The future reservoir evaporation shows an increasing trend for all three reservoirs. Relative to the current condition, the average annual open water evaporation for Beko-Abo reservoir might increase by 4.02% and 5.934%, for Mandaya reservoir it might also increase by 8.11% and 10.23% and for Border reservoir also shows an increase of 8.68% and 17.05% in 2011-2026 and 2026-2041 scenarios respectively.

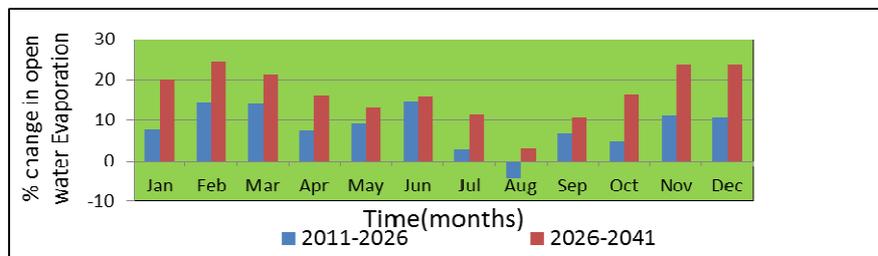


Figure 3 1: Border Reservoir Projected Monthly Percentage Change in Open Water Evaporation

3.5 Evaluating of The Performance Indices Of Reservoirs

From reservoir performance indices, on average the time based and volumetric reliability of the reservoirs estimated to be more than 90% .The resilience of the reservoirs is below 50% and their vulnerability is less than 50%. Therefore, these performance indices reveals good performance of the reservoirs except the speed of recovery of the reservoir from failure because the reservoir will not able to recover rapidly from failure to safe state, instead reservoir translate to safe state after continuous failure state.

Generally all three reservoirs have good ability to meet the target demand for the simulation period and from volume point of view or no shortage of flow to meet the demand but the three reservoirs require somewhat a longer period to meet the demand once the failure to meet the target demand is occurred.

3.6 Reservoir Hydropower Generation

A reservoir simulation model, HEC-ResSim, was used to simulate the hydropower potential of the reservoirs and to determine the reservoirs operation rule curve.The averageannual power generation might i ncrease by 1.53% and 1.11% at Beko-Abo and might alsoincrease by 2.56% and 1.47% at Mandaya hydropower station du ring 2011-2026 and 2026-2041 periods respectively. For Border hydropower station, the average annual power generation might decrease by 0.95% and 2.91% for both periods in comparison to the base period. The reservoirs cascade operation using tandem rule for two upstream and a release rule for downstream reservoir shows insignificant variation of water level for future condition in comparison to the base period.

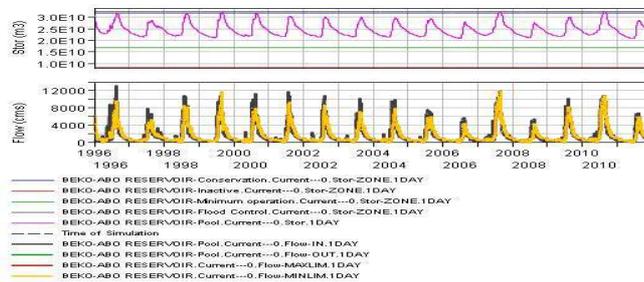


Figure 3 2: Beko-Abo Reservoir Storage For Current(1996-2011) Scenerio

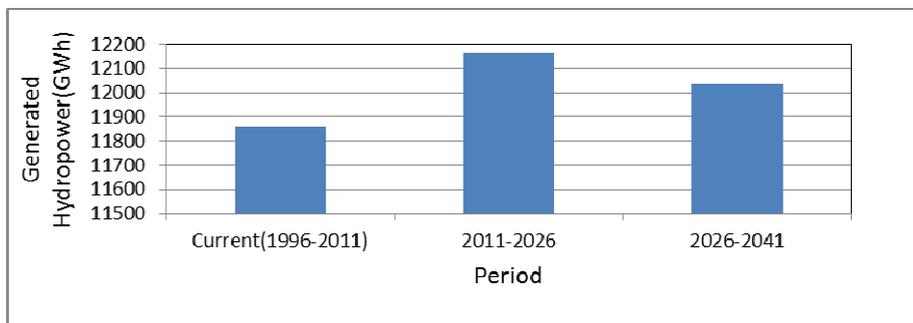


Figure 3 3: Average Annual Hydropower Generated At Mandaya Hydropower Station

CONCLUSIONS

- The projected future climate change scenario shows an increasing trend for both Tmax & Tmin and ETO but PCP shows fluctuating trend in the next century.
- The average annual open water evaporation in all reservoirs shows an increasing trend in future climatic condition.
- The HEC-HMS hydrological model which is calibrated and validated, simulate the observed discharge in reasonably well manner. Hence, it is concluded that the HEC-HMS model is an acceptable hydrological model in order to generate inflow for such type of studies.
- From reservoir operation (HEC-ResSim), the average annual power generation shows an increasing in Beko-Abo and Mandaya where as a decreasing in Border reservoir.
- For all reservoirs the increasing or decreasing of power generation was in proportion with the increasing or decreasing of the inflow in to the reservoir.
- Under the current design of the reservoir and the hydropower stations, the future climate change under A1B emission scenarios might not impose any consequence in the power generation capability, performance of the reservoirs in meeting the target demand, Rule curve of the reservoirs with the consideration of described research limitations.

RECOMMENDATIONS

- Climate is not static and assumptions made about the future based on the climate of the past may be inappropriate. Assumptions about the probability, frequency, and severity of extreme events used for planning should be carefully re-evaluated.
- Further studies which incorporate the impact of climate change with land use and land cover change, plus sediment inflow to the reservoirs should be undertaken using a physically distributed hydrological modeling.
- The HEC-ResSim optimal result is based on a successive trial and error procedure that is not fully assured for the optimal value. Hence, further study should undertake other optimization method for reservoir operation by including “**Grand Ethiopian Renaissance Dam**” (5250MW).

REFERENCES

1. Abeyou, w. (2008). *Hydrological balance of Lake Tana, Upper Blue Nile Basin, Ethiopia*, M.Sc. thesis, International Institute for Geo-information science and Earth observation, Netherlands.
2. Arnell, N.W. (2006a): *Global impacts of abrupt climate change: an initial assessment*. Working Paper 99, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, 37.
3. BCEOM.(1999). *Abbay River Basin Integrated Development Master Plan Project and Associates* .(1999). Abbay Basin Integrated Development Master Plan Project; Phase 2, Section II, Vol. III: Water Resources: Part 1 – Climatology and Part 2 - Hydrology.

4. Genet,E. (2008).“*Reservoirs water balance analysis, Joint operation and optimal operation rules for system performance.*” A case proposed reservoirs on the main Blue Nile River, Ethiopia, MSc thesis, Arba-Minch University, AMU.
5. Hailay,Z .(2010). *Assessment of Potential Surface Water Storage Options to Cope Up With Climate Change and Variability in Abbay River Basin: The Case of Tana and Fincha Sub-basins.* MSc thesis, Arba-Minch University,AMU.
6. Hashimoto,S.J.R., Loucks, D.P.T.(1982).*Reliability, resiliency and vulnerability crireria for water resource system performance evaluation.* WaterResources Research 18 , 14–20.
7. Muluneh,B. (2008). *Evaluation of Impact of Climate Change on Water Resource Availability in the Catchments of Blue Nile Basin,* MSc thesis, Arba-Minch University, AMU.

