Arjo Didessa Reservoir Water Evaluation and Application System, Ethiopia

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ABSTRACT
The Abay basin is one of the Ethiopian basins endowed with abundant surface water and groundwater resources that require proper management and to be wisely utilized in a sustainable manner. Didessa River is one of the tributary of Abay basin. Currently Arjo Didessa earthen dam is the reservoir found in the Upper Didessa River being utilized for irrigation uses and other purpose from the same source. For this reason it needs evaluation and planning of the Didessa river water at different scenario. To address water resources fairly to all users requires technical issues and specialized tools to obtain hydrological and physical parameters and spatial information, Global Mapper to manipulate the DEM data in line with the shape files of the river basin and model to assess the consequences of climate change and irrigation expansion on current and future water use scenario. Records of hydrology and meteorological data have been statistically tested and arranged as an input data source to fit the model. This study analyzed the model calibration, validation and its statistical measure were seen and the result shows that it is very good and the model can simulate the current and the future scenarios. After all of this done, the results revealed that unless the minimum flow requirements are maintained, the future irrigation demands are unmet in more or less. Due to the climate change the volume of reservoir evaporation was increased by the time.

Introduction
Ethiopia has begun to effectively water resources development plan since few years ago. Though the development activities encompass all major river basins of the country, the huge agricultural and hydroelectric power potentials in the Upper Blue Nile Basin have attracted considerable attention. Didessa River is also one of the tributary of upper Nile sub basin: Hence, there are currently a number of water resources development projects in the construction and planning phases in Didessa River of the Abay Basin.

Arjo Didessa reservoir is upper Blue Nile basin reservoirs located in the southern Nile Basin West Ethiopia with an estimated drainage area of 3400km². Didessa river is fed by four major tributaries all of them rising in the highlands surrounding the basin.

Reservoir of Arjo Didessa water storage nearly satisfy the full current demand, but there is possibility of larger water shortages in the future due to irrigation expansion, climate change and population growth rate. Then providing evaluation and allocating water is very crucial. Water is influenced by human activities and also by natural factors, such as climate change. Hence, the impact of climate change on water resources is the most crucial research agenda in worldwide level today (IPCC, Technical paper VI Climate change and Water., 2007). This change affecting certain components of the hydrological cycle, especially precipitation and temperature, this alters the spatial and temporal availability of water resources. It can change flow magnitude; variability and timing of the main flow event are among the most frequently mentioned hydrological issues (Habtom, 2009).

To address this need, the study assessed the impact of climate change and irrigation expansion and population growth on available water resources of Arjo reservoir in the upper sub-basin of the Didessa catchment using a decision support system known as the Water Evaluation and Planning (WEAP) Model. WEAP is a systematic framework developed for the evaluation of climate change and other drivers that water managers commonly challenging (Azman, Azman, B. (2007).

The main aim of this thesis is to evaluate adequacy Arjo Didessa reservoir water balancing demands and supplement in current and future scenario, to predict future water demands and allocation based on different development scenarios and to
analyses water required for irrigation, drinking and livestock at
deferent scenario to ensure the sustainable development in
Didessa watershed

Statement of problem
The recently conducted Arjo Didessa Integrated Master Plan
Project studies by oromia water work and design enterprise has
indicated that the Didessa reservoir have a potential to store
water for 56000ha land area. Even though there issurplus water
in storage there is an irrigational expansion and population
growth and climate change within the basin. This also indicates
that in future the development of all users competes for the same
resource from upper Didessa sub basin. Moreover, different
irrigation projects, sugarcane plantation and water supply are on
plan to be expanded. Due to climate change and expansion of
users continue in reduction of water resource capacity and
scarcity of the water will occur. Therefore the water management
of the reservoir is becoming very important.

Materials and methods
Description of study area
This thesis emphasize on the Arjo Didessa reservoir water
management system which is located in Ethiopia specifically
located in East and West Welega zone, Illubabor zone, Jimma
(special zone of Oromiya region) and some part in Kamashi zone
of Benishangul-Gumuz region.

Geographical Location
Geographically the sub-basin is located between 07°40’- 10°0’N
and 35°32’-37°15’E latitude and longitude respectively in
western part of Ethiopia. The general elevation in the basin
ranges between 653 meter a.s.l. and 3144meter a.s.l.

Methods
The method used in this thesis fulfillment include, the study of
literature review, collecting relevant information or data of the
study area, discusses the types and source of data required for the
study, applying different methods and techniques to estimate the
runoff in to the reservoir. The reservoir operation will be
performed applying simulation techniques.

Watershed delineation
Prior to data collection the boundary of the study area was
delineated. The Digital Elevation
Model (DEM) following drainage boundaries of Didessa basin
coverage was shown blow.

![Digital Elevation Model (DEM)](image)

**Fig 1.** The Digital Elevation Model (DEM)

Material Used
The materials used for this research depending on the objective
were Arc view GIS tool to obtain hydrological and physical
parameters and spatial information of the study area, DEM data
used as an input data for ARC-GIS software for catchment
delineation and estimation of catchment characteristic,
Hydrological and meteorological data, WEAP model for basin
simulation and Microsoft EXCEL to analyze WEAP outputs.

Data Analysis
Before starting hydrological and Metrological data analysis; it is
important to check whether the data are homogeneous, correct,
sufficient and complete with no missing data, it is because
erroneous data resulting from lack of appropriate recording,
shifting of station location and processing are serious as they lead
to inconsistency and ambiguous results that may contradict to the
actual situation

Result and Discussion
The results of the incremental calibration for the Didessa at Arjo
are summarized in Figure and table below implies overall there is
good agreement between simulated and observed Monthly flows.
The seasonal variation shows a fairly good agreement between
high flows and low flows but the rise of the hydrograph appears
to be a bit delayed and the corresponding fall. WEAP includes a
linkage to a parameter estimation tool (PEST) that allows the
user to automate the process of comparing WEAP outputs to historical observations and modifying model parameters to improve its accuracy. I use Excel to calibrate one or more variables in WEAP model, which can be particularly useful when using the Soil Moisture method of catchment hydrology and I get the result as below.

![Graph showing observed and simulated monthly average flows for Didessa at Arjo reservoir.]

**Fig 2.** Observed and simulated monthly average flows for Didessa at Arjo reservoir

**Model performance evaluation**

The Nash-Sutcliffe Efficiency (Nash and Sutcliffe 1970) is a dimensionless, normalized statistical value and expresses the noise to information ratio (equation 1). It shows how well the plot of observed versus simulated data fits the 1:1 line. Its usage is recommended from ASCE (1993).

\[
NSE = \frac{(Q_m-Q_i)^2}{(Q_s-Q_{av})^2} = 0.86
\]

Where,
- \(Q_im\) = observed discharge at time step i
- \(Q_is\) = Simulated discharge at time step i
- \(Q_m\) = mean of observed discharge

The range of NSE goes from -1 to 1. NSE < 1 indicates that the model's prediction is worse than the mean observed discharge and NSE = 1 signifies an optimal fit of observed and simulated values. For values between 0 and 1 the performance is generally seen as acceptable (Nash, 1970).

![Graph showing model performance evaluation.]

The validation results for the period (2000-2015) for the Didessa at Arjo are summarized in Figure 5.3 and Figure 5.4 below. Overall, the simulated flows for the validation period compare well with the observed flows but there is some variation which is evident in the seasonal plot and the standardized residuals plot.

- Observed and simulated monthly flows at Didessa at Arjo for the validation period (2010-2015).

For values of NSE is 0.5 which is between 0 and 1 the performance is generally seen as acceptable.

![Graph showing observed and simulated monthly flows.]

**Fig 3.** Observed and simulated monthly flows for Didessa at Arjo reservoir

**Discussion**

A key scenarios describing possible future irrigation situation in the Upper Didessa sub Basin have been defined. The starting point for the scenarios is an assumption that in line with the new Water Resources Management Strategy, the overriding policy is to prioritize the development of irrigation areas to their full potential (Awulachew, Loiskandl, & Alamirew, 2007). From this assumption, the Didessa reservoir dam in the basin has been simulated for irrigation water supply in downstream Irrigation Schemes. Design capacity of the Reservoir has an average annual...
volume of 706.6MCM. Before climate change and irrigation expansion the area of Arjo is 56000ha. The Scenario shows the utilization of the full irrigation potential with the Didesessareservoir capacity for different uses. The model result gives the monthly average water demand and annual summation

demand for downstream Irrigation Scheme. The total net amount of water required to meet the irrigation demands of all the sites from current scenario (2000 – 2015) was as bell.

Table 1. Current scenario water balance

<table>
<thead>
<tr>
<th>Reference(annual)</th>
<th>Supply Delivered(m$^3$)</th>
<th>Supply Requirement(m$^3$)</th>
<th>unmet(m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic use</td>
<td>14022203.62</td>
<td>14022203.62</td>
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<tr>
<td>Livestock use</td>
<td>2289365.15</td>
<td>2289365.15</td>
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<tr>
<td>Local irrigational use</td>
<td>26824.34567</td>
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<tr>
<td>Governmental irrigation use</td>
<td>189205458.4</td>
<td>189205458.4</td>
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</tbody>
</table>

Climate change scenario (2016-2030)
The runoff over the catchment is fluctuating pattern but a little variation in the baseline year (2000-2015) after then a great variation for the future time period due to climate change. In total there is a decrease of runoff on the watershed in the coming two consequent years when it is related to the current year however it is enough to satisfy water required by users.

Table 2. Climate change scenario (2016-2030)

<table>
<thead>
<tr>
<th>Scenario (2016-2030)</th>
<th>Supply Delivered(m$^3$)</th>
<th>Supply Requirement(m$^3$)</th>
<th>unmet(M$^3$)</th>
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</thead>
<tbody>
<tr>
<td>Domestic use</td>
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<td>government irrigation</td>
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</table>

Climate change scenario (2031-2050)
Even though there is change in water runoff volume due to climate change there is no risk of water required in the (2031 - 2050) and 2051-2080 years when it is compared with the (2016 - 2030) period. This means still there is enough water for different users.

Table 3. Climate change scenario (2031-2050)

<table>
<thead>
<tr>
<th>Scenario (2031-2050)</th>
<th>Supply Delivered(m$^3$)</th>
<th>Supply Requirement(m$^3$)</th>
<th>unmet(M$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic use</td>
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<tr>
<td>Livestock use</td>
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<tr>
<td>Local irrigation use</td>
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<td>Schematic irrigation</td>
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Table 4. Climate change scenario (2051-2080)

<table>
<thead>
<tr>
<th>Climate change (2051-2080) scenario</th>
<th>Supply delivered(m$^3$)</th>
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<td>government irrigation</td>
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</table>

Irrigation expansion scenarios
Irrigation expansion scenarios describing possible future irrigation situation in the Upper Didessa sub Basin have prioritize the development of irrigation areas to their full potential. Working from this assumption, the Didessa reservoir dam in the basin have been selected for simulation of irrigation water supply in downstream Irrigation Schemes. The future climate change and irrigation expansion coverage was 56000ha while forecast potential downstream of Didessa, giving a total irrigable potential of 80000ha (from Arjo Didessa document).

Table 5. Irrigation expansion scenarios

<table>
<thead>
<tr>
<th>Irrigation expansion scenarios</th>
<th>Supply Delivered(m$^3$)</th>
<th>Supply Requirement(m$^3$)</th>
<th>unmet(m$^3$)</th>
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</thead>
<tbody>
<tr>
<td>Domestic use</td>
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<td>Livestock use</td>
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<td>government irrigation</td>
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</table>

Conclusion
This research analysed the effects of climate change and irrigation expansion scenarios based on current and future development by considering the return flow in operation and other development are insignificant on Arjo Didessa reservoir
using simulated and observed stream flow data. The performance evaluation of the model confirmed that the statistical measure parameters were very good and the model can be used to simulate future stream flow with the climate change and irrigation expansion effect in the basin. For the climate change scenario, the volume of reservoir evaporation in the (2016-2030) period was increased by 13.1%, 2031-2050 periods was increased by 21.3%, and 2051-2080 period was increased by 23.4% when comparing with the current scenario. While compared with the baseline period, the first 15 years the reservoir evaporation will increase. The Arjo Didessa Reservoir water has nearly full supplement yet there is not much unmet demand in all irrigation areas in the coming different future time period. This implies the current reservoir flow is enough with irrigation expansion in the future even though there is flow decrement due to climate change. At the end the Water Evaluation and Planning System (WEAP) Model has been found to be useful as an Integrated Water Resources Management tool for balancing water supply and demand for current and future scenarios in a priority ways of allocation.

References