



# Evaluation of multi-storage hydropower development in the upper Blue Nile River (Ethiopia): regional perspective

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## ARTICLE INFO

### Keywords:

Eastern Nile  
Water resource modeling  
Blue Nile cascades  
Renaissance Dam

## ABSTRACT

*Study region:* Eastern Nile River Basin (Ethiopia, Sudan and Egypt).

*Study focus:* This study aims to understand the future water development perspective in the Eastern Nile region by considering the current water use situation and proposed reservoirs in the upper Blue Nile (Abbay) River basin in Ethiopia using a simulation approach. The study was carried out by using a monthly time step and historical ensemble time series data as representative of possible near future scenarios. Series of existing and proposed cascaded water development projects in the upper Blue Nile were considered in the study.

*New hydrological insights for the region:* The results indicated an overall energy gain in the Eastern Nile region increases by 258%. The upstream country Ethiopia can generate as much as 38200 GWh/year of Energy while the energy production in Sudan increases by 39%. The cascaded developments integrated with existing water resources systems have a performance efficiency of above 92%. This study was an indicative analysis of the potential benefit of upstream Nile development without significantly affecting existing development in the Nile Basin. Further scientific analysis in this direction would help the Nile countries to reach a water use agreement.

## 1. Introduction

There is huge hydro power development potential in the Eastern Nile Basin (Waterbury, 2002; Swain, 2002). The greatest development potential, about 58% of the total in the Nile Basin, is located in Ethiopia; this is because of the great differences in altitude (Ethiopia, 2000). There are a number of water resource development projects in Ethiopia specifically in the Abbay River Basin. The projects are at different stage of development, some are in operational stage, some are under construction and the other are in the studying and design phases. Due to the high variability in annual rainfall, conservation of water and irrigated agriculture has been considered as a way to mitigate the effects of drought.

According to the master plan study of Abbay river basin (BCEOM, 1999) the total potential for hydropower generation in the basin is about 13,000 MW. This is many times as much as the existing installed capacity. The Abbay basin master plan in Ethiopia and other regional projects, for instance the Joint Multipurpose Projects (JMP), has identified three hydropower dams upstream of the Grand Ethiopian Renaissance Dam (GERD).

An evaluation of the impacts and benefits of the Grand Ethiopian Renaissance Dam (GERD) during the impounding phase on downstream structures, especially on High Aswan Dam (HAD), was conducted by considering different flow scenarios (Mulat and Moges, 2014). The study concluded that under normal and wet flow scenarios of the 6 years filling period, GERD has no significant

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<https://doi.org/10.1016/j.ejrh.2018.02.006>

Received 30 May 2017; Received in revised form 16 February 2018; Accepted 19 February 2018

Available online 07 March 2018

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impact on downstream water uses. The agricultural water requirement from HAD which is a concern in Egypt could not be affected under these scenarios. The reduction in the storage volume of HAD never reached its minimum operation level. While the regional energy increases by about 63% due to early start of energy production at GERD. If the worst scenario of 6 years consecutive drought such as in 1980s (18% of the longer term mean) would occur, or if the flow is reduced by 10% or more from the long term mean annual flow, then the planned 6 years filling of GERD is insufficient to fill the reservoir without affecting downstream water uses.

The objective of this study was therefore to provide quantitative analysis of water resources management for the Eastern Nile region by considering the current irrigation water use and proposed reservoirs in the Abbay-Blue Nile River basin. The simulation starts after the end of the GERD filling stages. This analysis was then used for assessing the impacts and benefits of the upper cascades on downstream structures and the basin as a whole during its filling and full operation. In addition, the study tested the utility of hydropower development on the Abbay-Blue Nile River by evaluating different development or dam scenarios.

## 2. The Eastern Nile

There are two major basins within the Nile basin. These are the Eastern Nile which includes Abbay-Blue Nile, Tekeze (Atbara), Baro Akobo (Sobat), and the Nile Equatorial Lake including mainly Lake Victoria basin and Equatorial Lakes. The Blue Nile is the most important tributary of the Nile. It contributes about 60% of the total annual Nile flow (Sutcliffe and Park, 1999). More than 70% of the flow of the Blue Nile is generated by the four months (June–September) wet season rainfall in Ethiopia. Annual average rainfall over the Blue Nile basin is  $400 \times 10^9 \text{ m}^3/\text{yr}$  where 62.5% falls on the Ethiopian plateau (Mageed, 1994). As the Blue Nile drops into the lowlands and into southern Sudan, rainfall decreases and evaporation increases, resulting in a significant net loss. Temperatures also increase in variability, and reach substantially higher levels than at Lake Tana. The Sennar region, located in the southeastern part of Sudan, experiences evaporation rates of 2500 mm/yr and receives 500 mm/yr of rainfall with mean daily temperature of 30 °C (Sutcliffe and Park, 1999).

The Blue Nile basin (BNB) is characterized by highly rugged topography and considerable variation in altitude. Total area of the basin is 311,437 km<sup>2</sup>, of which approximately 63% is in Ethiopia and 37% is in Sudan. The elevation of the basin varies greatly from over 4000 m in the headwaters of some tributaries to 700 m at the foot of the plateau. The highest point in Lake Tana is about 1800 m and the river enters Sudan at an elevation of 490 m at the border of the two countries, i.e., with a gradient of approximately 1.5 m/km. This gives the Blue Nile its unique feature of huge potential energy opportunity to develop hydropower.

## 3. Existing and proposed water resources developments

The physical characteristics for the High Aswan Dam and Lake Nasser/Lake Nubia were extracted from the Power Toolkit provided by ENTRO. The information contains descriptions of the turbine characteristics including explicit relationships between operating head, turbine releases and power generation. Several water resources development projects in the eastern Nile basin are categorised as under operation (existing), under construction and proposed to be developed. Most of the operational reservoirs are in Sudan and Egypt. The under construction Grand Ethiopian Renaissance Dam (GERD) and the other three cascades under design and study phases are located in Ethiopia (Fig. 1 and Table 1).

### 3.1. Existing developments

#### 3.1.1. Tana Beles project

Lake Tana is a natural reservoir that controls the Tana sub-basin flows. The Lake is fed by the Gilgel Abbay, Megech, Ribb and Gumara rivers; and its surface area ranges from 3000 to 3500 km<sup>2</sup> depending on season and the amount of rainfall. The lake level has been regulated since the construction of the control “Chara Chara” weir where the lake discharges into the Blue Nile. This controls the flow to the Blue Nile Falls (Tis Abbay) and hydro-power station, which now the hydropower production is left in favor of the Tana Beles plant. The Tana-Beles hydropower project was completed in May 2010 and the project diverts water directly from Lake Tana and is represented as such in the models. The relationship between the diverted flow and intake elevation for the diversion is defined in the Beles Multipurpose Level 1 Design Report from the Ethiopian Electric Power Corporation (EEPCO, 2006). Water diverted through the Tana-Beles project is returned entirely to the headwaters of the Beles which flows into the Blue Nile upstream of the border between Sudan and Ethiopia.

#### 3.1.2. Roseires Dam

Roseires Dam was completed in 1966 with an initial capacity of  $3.024 \times 10^9 \text{ m}^3$  at level 480 m level. The main objective to supply irrigation demands as first priority, and hydropower generation is the second priority. During its lifetime, the reservoir suffered from serious sedimentation which reduced its storage capacity to less than  $2.0 \times 10^9 \text{ m}^3$ . The deep sluices with sill levels of 435.5m.a.s.l are used to pass the main volume of the flood, and to flush the sediment. Due to the large seasonal fluctuation, relatively small storage volume, and high amount of sediment accumulating in Roseires, the operational criteria is specified to draw down the reservoir starting in mid-January and maintain a minimum elevation until the peak flow has passed in September. Therefore, meeting target elevation criteria is the primary guiding principle of the operation of Roseires Dam as it was indicated in the ENTRO power tool kit.

#### 3.1.3. Sennar Dam

The Sennar Dam was built in 1925 on the Blue Nile near the town of Sennar, Sudan. The dam is 3025 m long, with a maximum

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