Analysis of Water Use on a Large River Basin Using MIKE BASIN Model - A Case Study of the Abbay River Basin, Ethiopia

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Abstract

The purpose of this study is to simulate water allocation for major activities (existing and planned) in the Abbay Basin using up-to-date water allocation and simulation models. The model, MIKE BASIN, is used to gain an insight into the potential downstream consequences of the development of physical infrastructure and water abstraction in a number of different future development scenarios. Seventeen irrigation projects covering an area of 220,416 hectares (ha) of land have been selected from different gauged catchments of the subbasin in addition to 4,800 megawatt (MW) hydropower projects on the main stream of the study area (Ethiopian part of Blue Nile). From the analysis, the total water extracted for these irrigation projects was estimated to be 1.624 billion cubic meters (BCM) annually. A reduction in the border flow volume as a result of the implementation of these irrigation projects under the reservoir scenario is 3.04% of the estimated mean annual flow of **50.45** BCM. Similarly, from the analysis, the total power generated due to the development of the major hydropower projects on the main stream, having an installed capacity of 4,800 MW, is 18,432 gigawatt hours (GWh) per year. This implies, while these interventions provide significant opportunities with respect to interventions and energy generations, their impact on downstream water availability is minimal.

Key words: Irrigation and hydropower Development, Blue Nile River Basin, MIKE BASIN Model

Introduction

Pressure on water resources in the Blue Nile basin is likely to increase dramatically in the near future as a result of high population growth in all the riparian states, and increasing development-related water needs in Ethiopia and Sudan. However, in spite of the national and international importance of the region, only a relatively few studies have been conducted and there is only limited understanding of the basin's detailed climatic, hydrological, and topographical and hydraulic characteristics (Johnson & Curtis, 1994; Conway, 1997).

In this paper a water allocation model will be used to ascertain the downstream implications of proposed water resources development in Ethiopia and Sudan. The model will used to gain insight in to the potential downstream consequences of the development of physical infrastructure and water abstraction in a number of different future development scenarios. Each scenario will provide a consistent and plausible description of possible future water demand in the catchment.

Description of the study area

Blue Nile River Basin lies in the western part of Ethiopia between latitudes of 7o 45`N and 12o 46`N; and longitudes of 34o 05'E and 39o 45' E (Figure 1). The basin has an estimated area of 199,812 sq. km. About 46 % of the basin area falls in Amhara State, 32% falls in Oromia and the rest of about 22% in Binishangul-Gumuz States. It covers about 17.5 per cent of Ethiopia's land area BCEOM phase3, part1 (1998). The location of the basin has been shown on figure 1-1 with respect to the other major basins of the country.

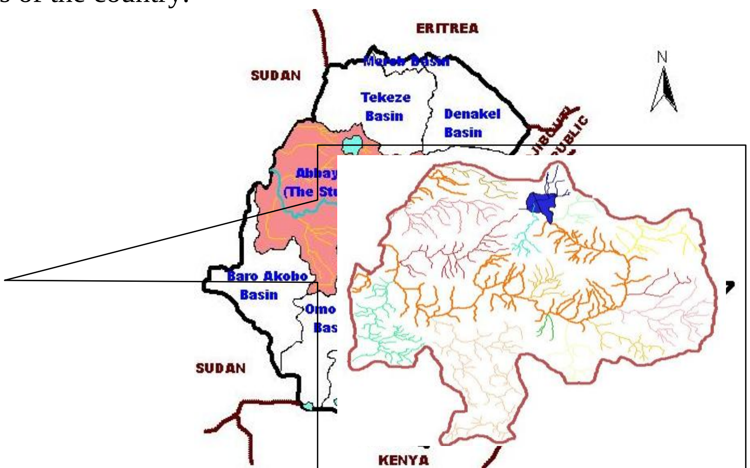


Figure 1: Location Map of the study area with respect to other basins.

Objective of the study and methodology

The main objective of this study is to simulate water allocation for major production activities (existing and planned) in the Abbay basin and to assess the impacts of upstream water allocation on downstream users.

MIKE BASIN is well suited to water resource modeling in the Abbay basins. The model specializes in assessing the potential for water resources development, particularly hydropower and irrigation by determining likely impacts of different water resources development scenarios and optimization of water allocation schemes.

The methodology adopted in the study follows data collection, organization, pre-processing and analysis based on the requirement of MIKE BASIN model.

Data

To achieve the goal of the research most of the data have been collected from the various phase of the Abbay basin master plan document and MOWR.

The data used in the study includes the streamflow data of 3 main river course and 14 tributaries gauges were used to estimate the flow at the project site and computation of Border flow volume.

The other important data includes the demand data for irrigation and hydropower, location of project sites, relevant reservoir data, precipitation and potential evaporation.

Schematization

MIKE BASIN is a network model in which the rivers and their main tributaries are represented by a network of branches and nodes. The river system is represented in the model by a digitized river network that can be generated directly on the computer screen in Arc Map 9.1 (a GIS software package) or for our case by a traced river network that can be delineated from the DEM after calculating the flow direction by the mike basin model as shown in the Figure 2.

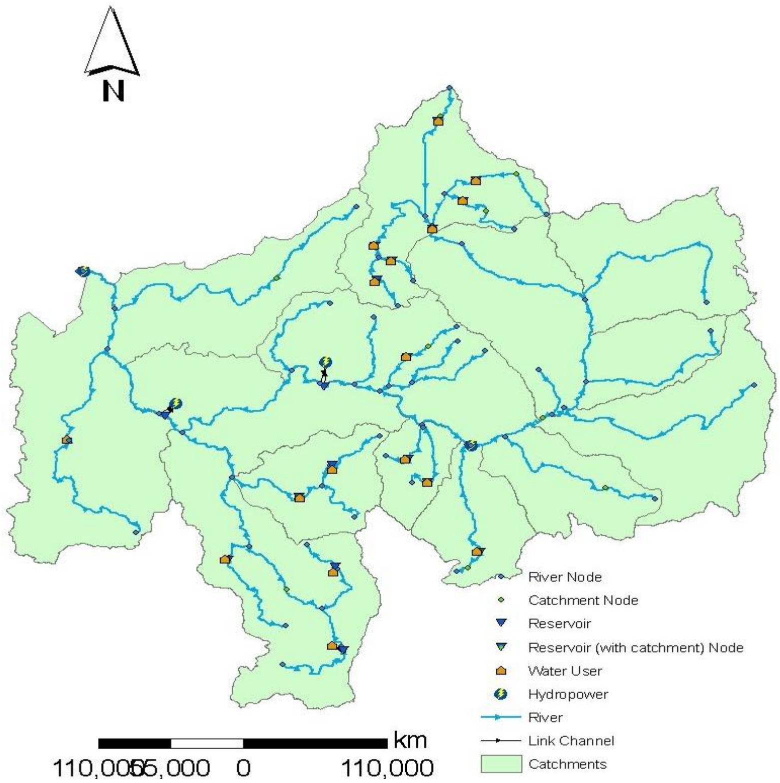


Figure 2: location of different water users and reservoirs

Border flow estimation

The streamflow data of 3 main river course and 14 tributaries gauges were utilized for the computation of border flow volume. The mean monthly flows obtained from the historical records that are converted in to specific discharges for suitability of the model. Bahir Dar, Kessie, and Border and 14 gauged tributaries were utilized. Based on these data, the overall streamflow volume at each gage sites on the mainstream and tributaries was computed by MIKE BASIN. As indicated on Figure 3 below the mean annual flow of Abbay was found to be ***50.45*** BCM at the border and **3.8** BCM at Bahir Dar below the outlet of Lake Tana. The value of border flow obtained from this analysis is almost equal to the one which is estimated on the master plan, which is 50.6BCM.

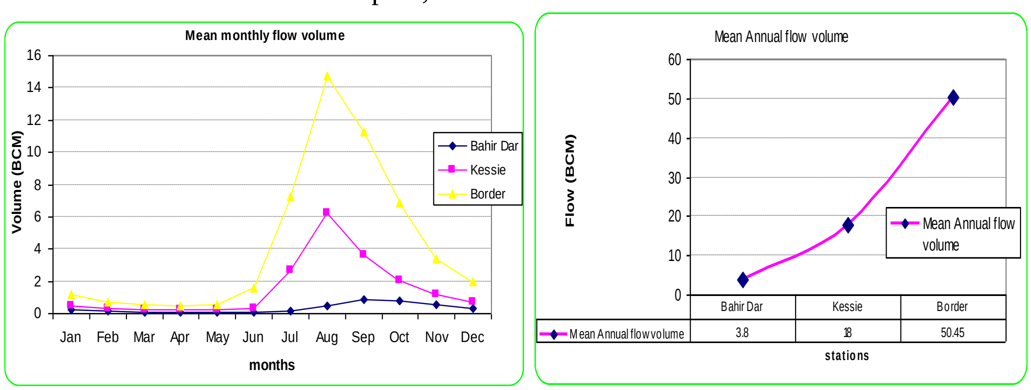


Figure 3: Mean monthly & annual flow volume of Abbay at each gage

Both Graphical and numerical performance measures should be applied in the comparison. The graphical evaluation includes comparison of the simulated and observed hydrograph, and comparison of the simulated and observed accumulated runoff. The numerical performance measures include the overall water balance error (i.e. the difference between the average simulated and observed runoff), and a measure of the overall shape of the hydrograph based on the coefficient of determination or Nash-Sutcliffe coefficient

$$R^2 = 1 - \frac{\sum_{i=1}^{N} [Q_{obs,i} - Q_{sim,i}]^2}{\sum_{i=1}^{N} [Q_{obs,i} - \overline{Q}_{obs}]^2} \quad \text{...1}$$

Where $Q_{sim,I}$ is the simulated discharge at time i, $Q_{obs,I}$ is the corresponding observed discharge, and $\overline{Q}_{obs}$ is the average observed discharge. A perfect match corresponds to R^2=1.

Table 1 Nash-Sutcliffe coefficient at the three main gauging stations

Stations	R^2
Bahir Dar	0.99
Kessie	0.97
Border	0.996

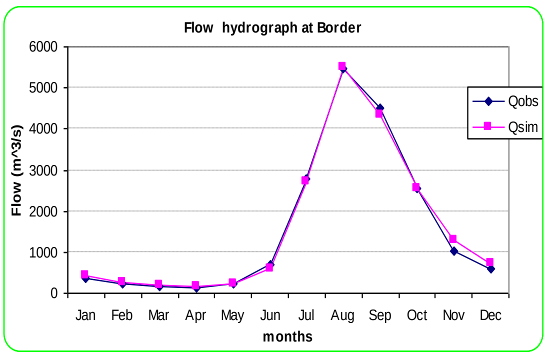


Figure 4: Comparison of Observed and Simulated Flow Hydrographs in m^3/s at Border.

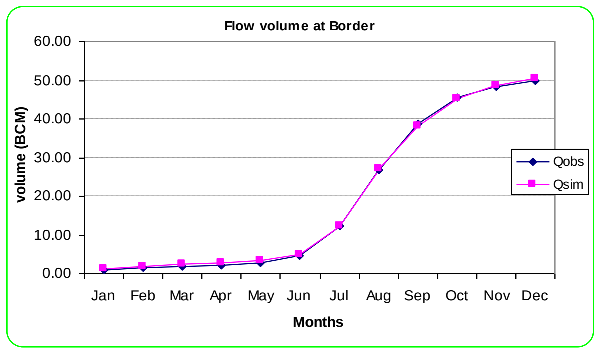


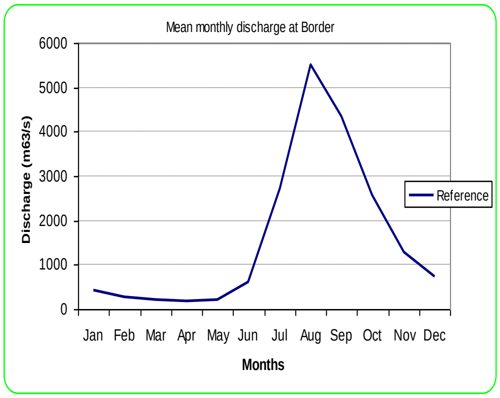
Figure 5: Comparison of accumulated observed & simulated flow volume in BCM at Border

Analysis of scenarios

The results of the analyses of the scenarios are showing the water demand deficits and relative deficits for irrigation. And also show the impact on the Abbay River flow and mainly at the Sudan Border

Reference Scenario

The average monthly discharge and accumulated volume at Sudan Border as computed by MIKE BASIN model for the Reference scenarios it illustrates the tremendous difference between peak flows between 2,500 and 5,500 m^3/s during the period July to October and base flow of less than 500 m^3/s during a prolonged period of 5 months. The average volume flowing out of the Abbay Basin is close to 50.45 BCM; 72% of which flow is the 4 months from July to October included and 6.3% during the 4 months from February to May.



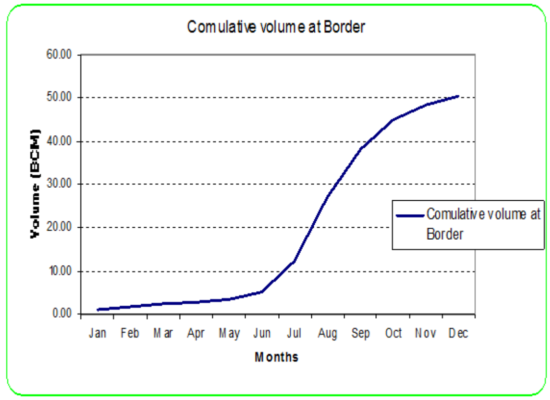


Figure 6: Mean monthly discharge at Sudan Border in m^3/s during reference scenarios

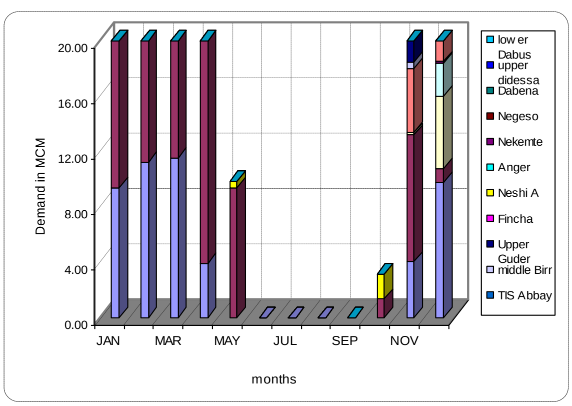
Figure 7: Cumulated Volume at Border during the reference scenario in BCM

A. All identified irrigation projects on the tributary of Abbay River with out reservoir

In this scenario, using the optimized irrigable areas of the Abbay master plan study, we can calculated the water demand of the 17 irrigation projects on the tributary of Abbay River basin. Using this, the water demand deficits of the irrigation projects without reservoir are obtained. The results of the modeling are presented in the graph for irrigation water demand deficits in MCM.

In this simulation there is a project that doesn't get water demand deficits to satisfy the irrigation water demand for the proposed irrigable area. Lower Dabus project as recommended on the Abbay master plan it doesn't require reservoir.

In this Scenario, Finchaa irrigation project having a command area of 6,205 ha has also doesn't need reservoir. But for further expansion (i.e. for irrigating more command area) providing a reservoir is compulsory.



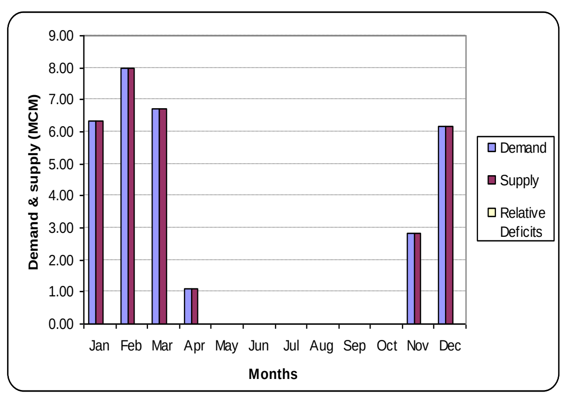


Figure 8: Water demand deficits in MCM On without reservoir scenario for identified irrigation projects

Figure 9: water demand, supply and relative deficits of Lower Dabus in MCM

B. All identified irrigation projects on the tributary of Abbay with reservoir scenario

Based on the analysis of the above simulation (i.e. without reservoir) and recommendation of the Master plans, we simulate the model with reservoirs. The water shortage problem should now be alleviated. About 1.624 BCM of water extracted annually but the total water demand is 1.699 BCM. It doesn't satisfy 0.07452BCM amount of water for all projects under consideration.

As indicated on figure 1-10 in the presence of the proposed reservoirs still there are projects in shortage of water to satisfy their monthly demand. The degree of shortage varies among projects and months. But for water users except Tana basin projects such as Ribb & Jema projects and Negesso &Neshi A, it shows almost no deficit after reservoir as shown in figure 1-10 below. To detect major failures; defined as a monthly failures grater than a threshold that has been set to 25% over a full month. Such failures are considered as able, not only to reduce the yields, but to destroy the irrigated crops completely. A table of values of the relative deficits (irrigation failures) defined by the difference between the discharge required and the discharge delivered, expressed in percent of the requirement is shown above.

Table 2: percentage reliability and number of months below the threshold

Threshold	Koga	M_Bir	Neshi	Jema	Gumera	Megech	Negeso	Rib
>25%	0	0	6	1	0	0	2	1

From the above table Special consideration should be given while implementing Neshi A and Negesso projects.

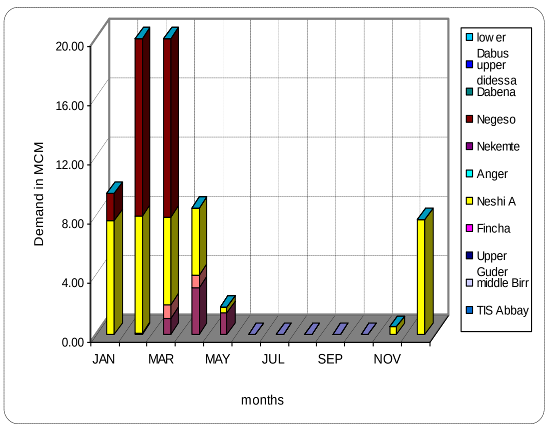


Figure 10: Average monthly demand deficits in MCM

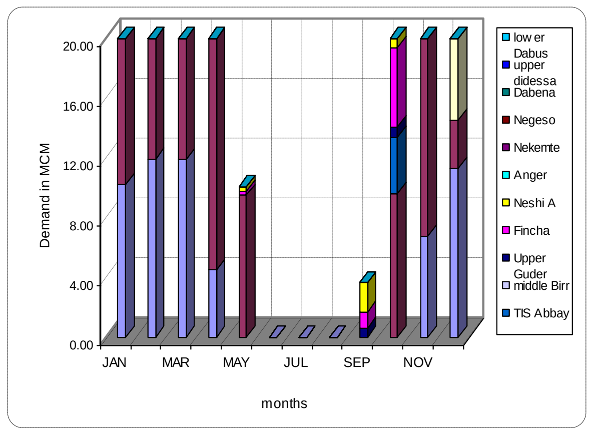


Figure 11: Average monthly water extracted for each water Users in MCM

All identified irrigation projects on the tributary of Abbay with reservoir and Karadobi hydropower projects on the main stream of Abbay. Results of this scenario are presented as follows:

- Installed hydropower and energy production amounts to 1,600MW and 5,644 GWh per year respectively.
- Better Abbay river flow distribution through out the year at Sudan border with 76% of the annual volume being discharged during the period from July to October.
- The hydrograph at the border station is smoothed again with low discharge increased by 14.63% in April and high discharge decreased by 14% in August. This is illustrated by graph below.

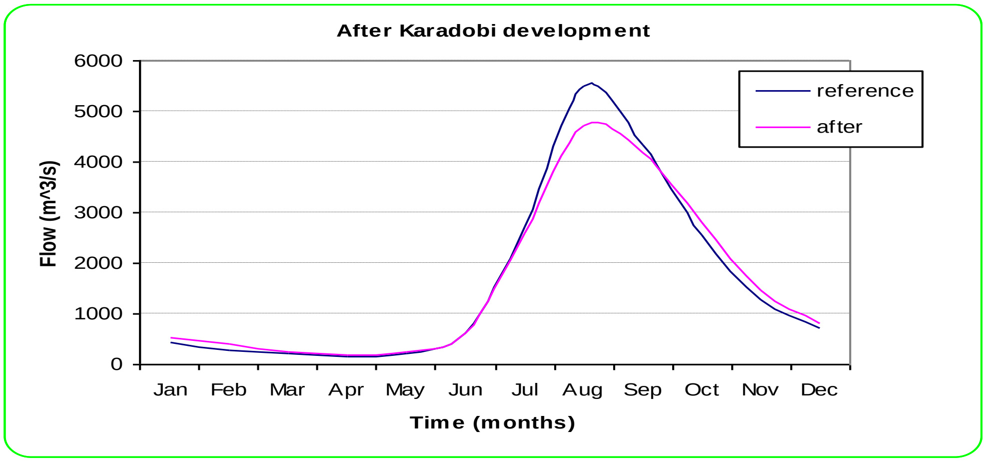


Figure 12: Flow hydrograph at Sudan Border in m^3/s after Karadobi hydropower development

Discharge before and after the project condition on the tributaries

The over all flow condition of the tributaries utilized for irrigation development and that of the main stream used for hydropower development was computed for conditions of before and after project case. The flow after the confluence of a main stream with a tributary is the sum of the upstream flow in the main stream and the flow of the tributary below the withdrawal node.
Based on the above procedure, MIKE BASIN has computed the whole tributaries and main stream flow before and after the implementation of the projects. Based on the results of the model, the following comments are given below.

- The flow in the natural stream becomes zero for a month or consecutive months. The condition needs due consideration for projects of Rib, Neshi A, Negesso, Gumera, Jema, Bir and Megech.
- Unless other downstream tributaries of the above rivers with nil streamflows augment the ecological and down streams water users demand, it will be difficult to implement the proposed irrigation potential.

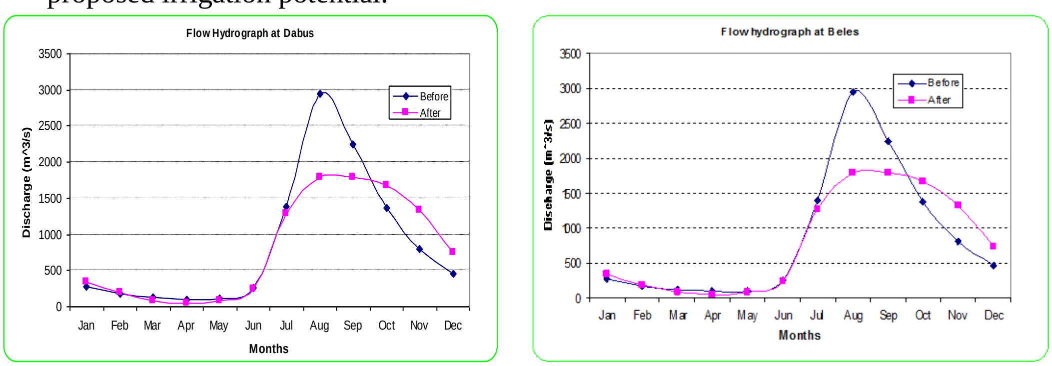


Figure 13: Mean monthly flow of Abbay before and after the projects condition just below Dabus & Beles confluence

Conclusion

From the analysis performed in this study, the total water extracted to irrigate 220,416 ha of land was 1.624BCM per year, inducing for Abbay an average annual flow reduction of about 3.04% at Sudan Border. The over all mean annual flow from the mean monthly data of the main stream gauges was estimated as 50.45 BCM at the Sudan border. As compared to the result of scenario 1 of the master plan to irrigate a command area of 440,804 ha and to generate 9,519 GWh,, the border flow reduction which was 7% as indicated on table 2-4 is compatible with the out put of this study. On the other hand the mean annual flow 50BCM given on the master plan is almost equal to the recent result 50.45BCM.

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