JOURNAL OF WATER AND LAND DEVELOPMENT
e-ISSN 2083-4535

Polish Academy of Sciences (PAN), Committee on Agronomic Sciences
Institute of Technology and Life Sciences (ITP)

JOURNAL OF WATER AND LAND DEVELOPMENT
2021, No. 48 (I–III): 215–224; https://doi.org/10.24425/jwld.2021.136164

Available (PDF): https://www.itp.edu.pl/JWLD; http://journals.pan.pl/jwld

Received 19.07.2020
Reviewed 16.10.2020
Accepted 18.10.2020

Water resource modelling for the Lake Tana sub-basin using the Mike Basin model for current and future water resource development scenarios

Asegdew G. MULAT ✉

Bahir Dar University, Bahir Dar Institute of Technology, Faculty of Civil and Water Resource Engineering, P.O. Box. 26, Bahir Dar, Ethiopia

For citation: Mulat A.G. 2021. Water resource modelling for the Lake Tana sub-basin using the Mike Basin model for current and future water resource development scenarios. Journal of Water and Land Development. No. 48 (I–III) p. 215–224. DOI 10.24425/jwld.2021.136164.

Abstract

Rainfall in the Lake Tana basin is highly seasonal and the base flow contribution is also low resulting in the need for reservoirs to meet the agricultural demand during the dry season. Water demand competition is increasing because of intense agricultural production. The objective of this study is to develop water balance models. The Mike Basin model has been selected for water allocation modelling and identifying potential changes needed to the existing water allocation scheme to reduce the stress due to increased water demand. The study considers baseline and future development scenarios. The construction of new dams results in two competing effects with respect to evaporation loss. The first effect is increased evaporation from new reservoirs, while the other is reduced evaporation from the Lake Tana as a result of a decreased surface area of the lake and reduced inflow of water to the lake. Once a dam is built, there will be an additional free water surface area and more evaporation loss. In dry months from January to May, the irrigation water demand deficit is up to 16 Mm^3. It is caused by reservoirs built in the basin, which reduce the inflow to the Lake Tana. The inflow varies between wet and dry months, and there is more water flow in wet months (July, August and September) and reduced flow in dry months because of the regulatory effects produced by the reservoirs.

Key words: *development scenarios, Lake Tana sub-basin, Mike Basin model, modelling, reservoir operation, water resource*

INTRODUCTION

The water resource management has been increasingly dealing with competing demands for limited or diminishing resources. Thus, the allocation and monitoring of water consumption between competing users, including the environmental use, play a critical role. The scarcity of water resources and increasing demands require effective, reasonable, and sustainable water allocation policies. It is going to be a serious challenge for water resources managers to match supply and demand in the future.

A water balance model includes equations intended to represent parameters and variables of the hydrological system subject to the hydrologic cycle. Depending on the purpose and data availability, modelling can have different levels of complexity. Regardless its complexity, a model provides an overview of the physical world. According to WALKER and ZHANG [2001], it is important to know that an increasing model complexity does not necessarily improve accuracy.

The Lake Tana sub-basin is considered to be an essential resource for the economic development of the country. The maximum estimated irrigation potential is about 346,089 ha [MACDONALD 2004]. An estimated cultivated area is around 121,704.2 ha (around 35% of the total) [ADSWE, LUPESP 2015]. The water supply for projects planned is either from storage reservoirs or from pump schemes that will abstract water from the lake.

Due to high population growth and degradation of the watershed in the basin, water scarcity will become a more serious issue in the future. The rainfall distribution is erratic and highly seasonal and the base flow contribution is insufficient to satisfy the agricultural water demand in the dry season. Therefore, the construction of a dam is important for water storage and regulation to meet the agricultural water demand during dry seasons and utilize the resource potential. EL-RAEY *et al*. [1995] identified water resources as one of the three sectors most vulnerable to climate change in the region.

There are several water user sectors in the region. These include agricultural production, environment, domestic use and hydropower. Water users depend on the huge proportion of the catchment mean annual runoff. The intense agricultural production and the absence of rational and basin-wide water resources management have led to an increase in competing water demands in the region.

The Ethiopian government along with the regional government have planned a number of irrigation projects in the Lake Tana sub-basin. These projects are at different development levels, some (like Koga irrigation projects) are already operational, and some (Rib and Megech) are under construction, whereas the others focus on studies and designing. There has been little systematic analysis of alternatives from a regional perspective to provide for more flexible water allocation and integrated water resources management.

The main objective of this study is to develop water balance models (based on investigation of stream flow and water demand data) and schematize the Lake Tana sub-basin to determine the basic water balance according to information available and provide hydrologic input for planning and management of the Lake Tana sub-basin. The purpose is to provide a formal quantitative analysis of the integrated water resources management for the Tana Basin by considering the current water use and future development strategies. The Mike Basin has been selected for water allocation modelling and identifying potential changes needed to the existing water allocation scheme to reduce the stress due to increased water demand and climate changes.

MATERIALS AND METHODS

STUDY AREA

Lake Tana is the largest fresh water lake in Ethiopia located north of the Abbay River Basin (upper Blue Nile River). It is also the source of water for the Abbay River / the Blue Nile River. The sub-basin covers an area of 15,123 km^2 and is fed by four perennial rivers (Gilgil Abbay, Megech, Ribb, and Gumera) and about 60 seasonal streams [Studio Pietrangli 1990]. As indicated by SMEC [2008], Lake Tana covers about 20% of the Tana Basin and it is 78 km long by 67 km wide. The storage capacity of Lake Tana is nearly 28 Bm^3 and it is shallow with a mean depth of 9.53 m.

Gilgel Abbay (4517 km^2) in the southern part of the Tana Basin, whereas Ribb (2156 km^2) and Gumara (1604 km^2), both in the eastern part of the Tana Basin, are the rivers that flow to the Lake (Fig. 1). The mean elevation of the Tana Basin is 2025 m a.s.l., with the highest elevation of 4100 m a.s.l. in the Simien Mountains, in the north--eastern part of the basin. At the outflow of the basin into the Abbay at Bahr Dar, the elevation is about 1786 m a.s.l. To the east of the basin boundary, the topography is dominated by the presence of two large shield volcanoes, Mountains Choke and Guna, while to the west it drops sharply to the adjacent Beles and Dinder basins across the West Tana escarpment. There are large flood plains around Lake Tana with obstructed drainage conditions. During the rainy season, large parts of floodplains are swamped. During the recession of floodwater, farmers start cultivating the area, with rice production becoming increasingly popular.

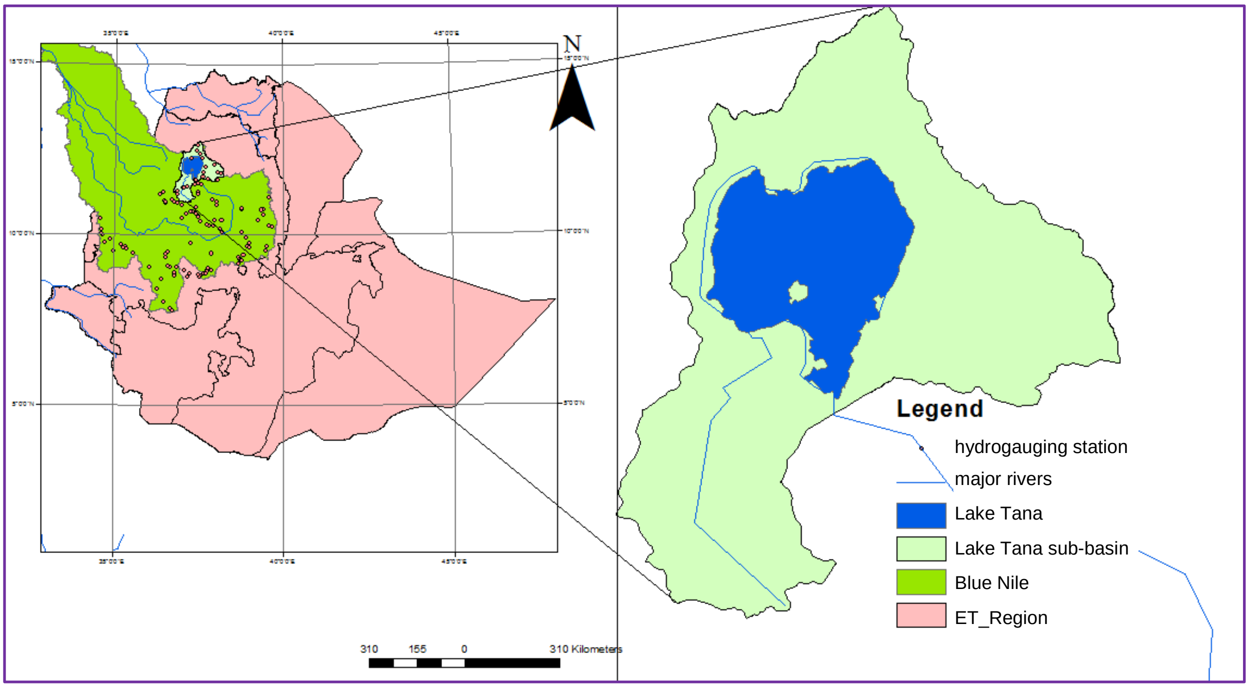

Fig. 1. Lake Tana sub-basin; source: own elaboration based on GIS

According to SETEGN *et al*. [2008] and SMEC [2008], the mean annual rainfall and mean annual actual evapotranspiration are 1280 mm and 773 mm respectively. The climate of the region is "tropical highland monsoon" with main rainy season between June and September. The air temperature shows large diurnal but small seasonal changes with an annual average of 20°C.

The basin has been identified by the government as a growth pole area due to its high potential for irrigation, hydropower development, high value crops and livestock production, and ecotourism. According to the SMEC study [SMEC 2008], the long term (1964–2003) average lake water level is estimated at 1786.10 m a.s.l. The average annual inflow contributed by Gilgel Abbay to the Lake Tana reservoir is 1.8 Bm^3, the Rib and the Gumara contribute 0.68 Bm^3 and 0.83 Bm^3 respectively, whereas Magic 0.45 Bm^3. The outflow volume from Lake Tana at the Bahir Dar gauging station is about of 4 Bm^3 [KEBEDE *et al*. 2006; SMEC 2008; WALE 2008; YOHANNES 2007].

In 1995–1996, the Chara Chara weir at the outlet of Lake Tana at Bahir Dar was put in operation for hydropower production (Tis-Abbay HPP I & II with 77 MW installed capacity). The weir controls a volume of 9.1 Bm^3 in the lake (2.4 × average annual outflow) between 1784 and 1788 m a.s.l. Currently, the weir is also used to divert water from the lake to the Tana-Beles system. At present, in the Gilgel Abbay basin, the Koga irrigation system occupies a gross command area of 7,000 ha.

DATA USED

Although data are collected from different sources (from Ministry of Water and Energy, Abbay authority, Amhara region bureau of agriculture and water resource development, etc.), their proper processing remains a challenge. In such cases, pre-processing of collected data is required to use them as input for the modelling process. The following variables and parameters have been included in input data (time series input data) to the Mike Basin model:

– rivers represented by river reaches and nodes,
– catchment area,
– reservoirs characteristics and operation rules,
– water users, including irrigation, represent all users that abstract or consume water,
– water returns to surface and/or groundwater,
– hydrologic information at different catchments, viz. stream flow, rainfall, and reservoir.

Stream flow data. The catchment runoff represents locations in the model where water is introduced directly to the stream system. The hydrological analysis that will be undertaken during the study requires the collecting and reviewing of hydrometric and stream flow data associated with the Tana Basin. Time series data from ten inflow locations into Lake Tana include: Gilgel Abbay, Megech, Ribb, Gumara, Koga, Gemero, Garno, Dima, Gedla and Tana Ungaged Inflow.

Water users data. The most common water use in the Tana Basin is agriculture (irrigation). It is defined as a water user and added to the model as a water user node. There is variation of water demand due to seasonal changes and the variations are described by a time series file for each water user node. The time series of return flow, which also varies depending on the water demand, is the part of water that is supposed not to be consumed at the water user node and can be conveyed back to more river nodes. Figure 2 shows the location of irrigation projects in the Lake Tana basin.

In the current situation, the water system under this study is based on the assumption that water requirements are met, including the Koga reservoir irrigation. For the future scenario, it includes all proposed and under construction projects. Table 1 shows the future monthly irrigation demand related to irrigation projects in the Lake Tana basin.

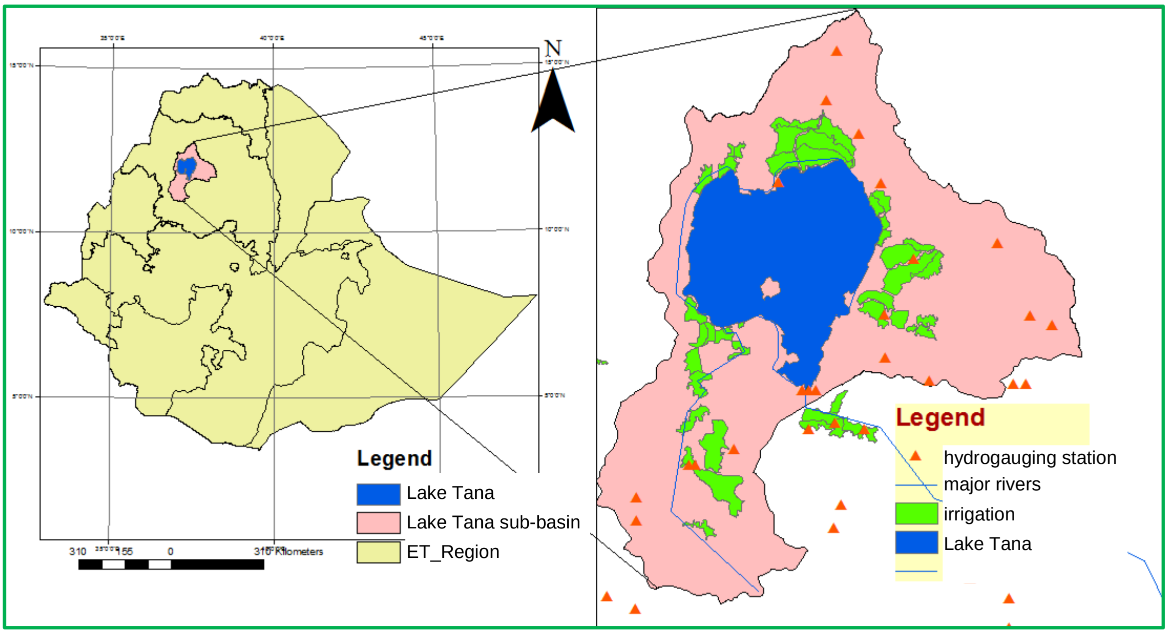

Fig. 2. Location of irrigation and dam sites in the Lake Tana sub-basin; source: MoWR [2009]

Table 1. Irrigation water requirements in the Lake Tana basin at full development level ($m^3 \cdot s^{-1}$)

Site	Water requirement in month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
Megech	8.13	9.53	10.60	10.08	5.47	0.00	0.00	0.00	0.00	2.64	6.39	7.39	5.02
Gumara	5.69	6.67	7.42	7.05	3.83	0.00	0.00	0.00	0.00	1.85	4.47	5.17	3.51
Ribb	5.69	6.67	7.42	7.05	3.83	0.00	0.00	0.00	0.00	1.85	4.47	5.17	3.51
Lake Tana	7.03	8.25	9.17	8.72	4.73	0.00	0.00	0.00	0.00	2.29	5.53	6.39	4.34
Jema	3.25	3.81	4.24	4.03	2.19	0.00	0.00	0.00	0.00	1.06	2.56	2.95	2.01
Gilgel Abbay	5.49	6.43	7.15	6.80	3.69	0.00	0.00	0.00	0.00	1.78	4.31	4.98	3.39
Koga	2.66	3.10	3.47	3.14	0.97	0.00	0.00	0.00	0.00	0.36	2.27	2.55	1.54

Source: MoWR [2009].

Reservoirs data. Individual reservoirs can simulate the performance of specific operating policies using relevant operating rule curves. These define desired storage volumes, water levels and releases at any time as a function of the existing water level, time of the year, demand for water, and expected inflows. All reservoir data originate from design documents and study reports at different levels.

MODELING OF THE LAKE TANA SUB-BASIN

The Mike Basin network model has been selected for the Lake Tana sub-basin modelling. In the model, rivers and their main tributaries are represented by a network of branches and nodes. The river system is represented as a digitized river network. It can be generated directly on the computer screen using GIS software.

The natural river system of the Tana Basin is schematized and represented displayed as a node-branch structure. This schematization consists of a network of connected nodes. These nodes represent surface water reservoirs, dams, weirs, pumps, hydropower stations, water users, inflows, man-made and natural bifurcations, intake structures, natural lakes, etc. Branches represent the river and its main tributaries, off take points were selected on the main river and/or tributaries to release water to cover downstream irrigation and hydropower water demands. The simulation considered only two major water demand sectors: irrigation and hydropower.

In the modelling processes, the model represents watershed runoff given as input data, linear reservoir approach, and complete water balances for reservoirs including rainfall/evaporation on Lake and reservoirs surface. The model reflects a simple water accounting process for each node and between nodes while taking into account possible routing mechanisms. The schematization of the river basin is such that the availability of water at major control structures and major water extraction points (users) are appropriately represented.

A set of successive activities has been followed to set up an operational water balance model. At first, schematization of the model has been performed by describing boundary conditions, watersheds, and time and space input variables. Secondly, the simulation methods have been defined such as surface runoff, water demand for irrigation and loss due to evapotranspiration based on hydrological characteristics and data availability of the basins.

The major irrigation system in the basin is based on the gravity flow from reservoirs. The schemes were then distributed to the nearby nodes according to their demand, and return flows that are not used by the schemes were directed to immediate downstream nodes. The schematization is made as follows:

- two flow series are considered in the schematization, representing the input to the potential reservoir and flows to the water demand (irrigated) area;
- small scale irrigation, scattered over each of sub-basins, has been taken into account as a single aggregated irrigation area; the irrigation area is the sum total of all constituent irrigation areas and it is characterized by an average cropping pattern and irrigation amount.

The total river basin is subdivided into a number of sub-basins. Sub-basins have their hydrological entities and represent various small water users in a sub-basin. The study has provided a relevant evaluation of water availability for major users, as well as water control structures and water balance of each basin. Small water users are provided with water by the local runoff and for them water may be diverted from the basin network. Sub-basins interact with the basin network by the diversion of water towards the sub-basin and drainage from the sub-basin.

The preparation of the network included a list of typical nodes and link types. The river basin network schematization of nodes and links represent existing and potential (inactive) infrastructure and water users. The network schematization link source priority lists with characteristics of all nodes and operation rules and water allocation priorities. Figure 3 shows the schematization of the Tana basin for baseline and future development scenarios.

SCENARIOS

Scenarios are alternatives used to compare different cases and provide an organized approach to the possible future water resource development and management options, opportunities and risks, and interaction between them. Results are useful for decision making and consensus building. During this study, an investigation has been conducted to assess future probable changes in inputs to the water balance model, which may have impact on the spatial and temporal distribution of water availability in the basin. Endogenous scenarios have been developed based on probable changes in water management inputs to the model.

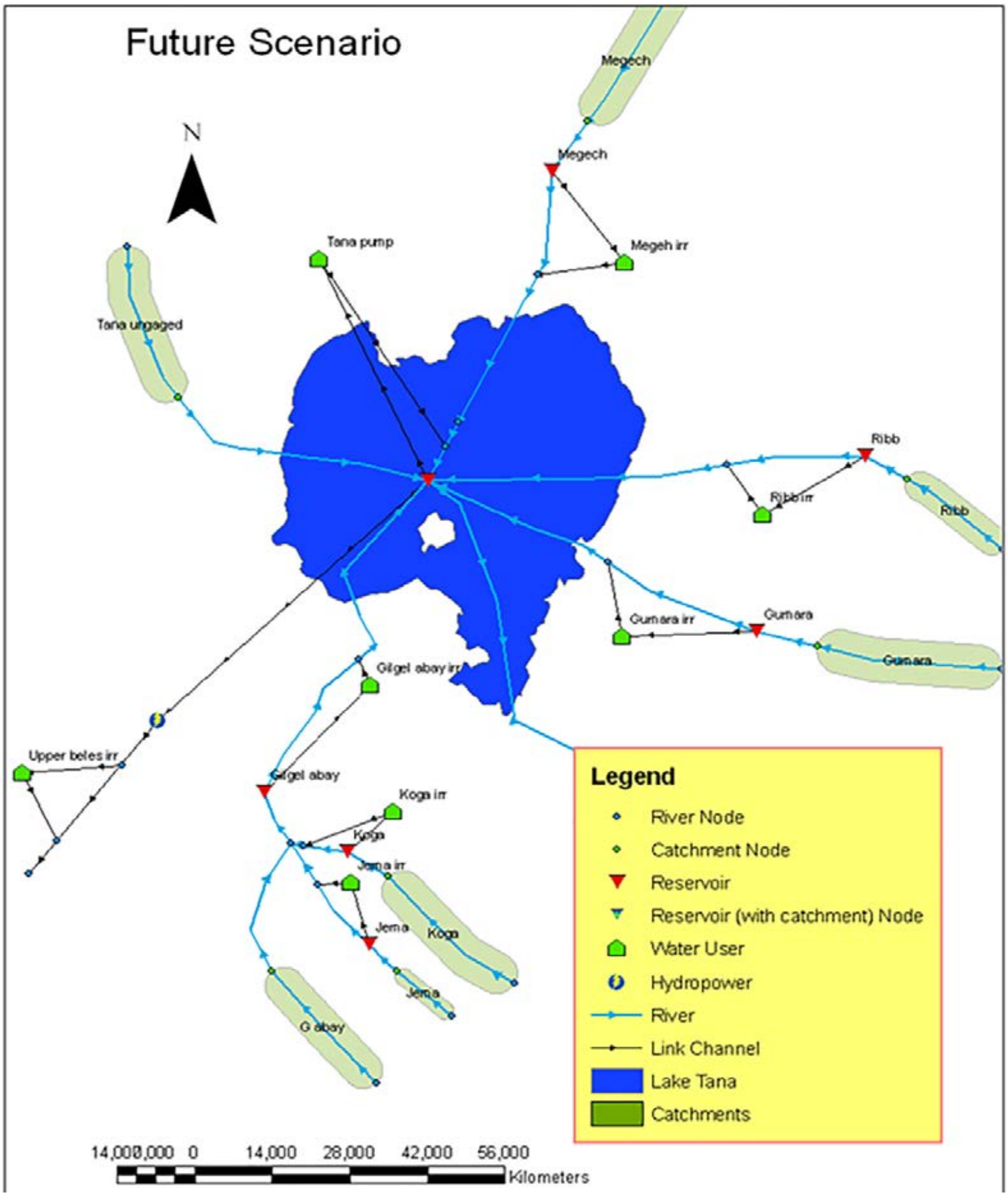

Fig. 3. Schematization of the Lake Tana basin for future scenarios from Mike Basin modelling; source: own elaboration

The study has defined endogenous scenarios which mainly focus on future water resource management options to improve water availability for agricultural demand and hydropower production supporting the well-being of the society. Finally, the hydrological model has been set up for different scenarios and impacts on the spatial and temporal distribution of water availability simulated for the Lake Tana sub-basin. These included baseline (current situation) and future development scenarios.

RESULTS

MODEL PERFORMANCE

The reliability of the model depends on model simulated results and whether model results match the observed values from stream flow measurements. This translates into greater confidence among users. To facilitate the evaluation of the model quality, a visual comparison has been done between observed and simulated hydrographs; additionally, statistical analyses have been applied towards the end of the process, e.g. the use of the Nash–Sutcliffe efficiency (*NSE*), coefficient of determination (R^2), mean relative bias (*MRB*) and root mean square error (*RMSE*).

The Nash–Sutcliffe efficiency (*NSE*) includes normalized statistics. The comparison of the relative magnitude of the residual variance (noise) and the measured data variance (information) has been determined by the *NSE* [NASH, SUTCLIFFE 1970]. The *NSE* indicates how well the plot of observed versus simulated data fits the 1:1 line [MORIASI *et al*. 2007]. The *NSE* value of 1 indicates a perfect situation.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_i - \hat{Q}_i)^2}{\sum_{i=1}^{n}(Q_i - \overline{Q})^2} \quad (1)$$

Where: Q_i = the measured value (stream discharge); $\hat{Q}_i$ = the simulated value; $\overline{Q}$ = the average measured value; *n* = the number of data points.

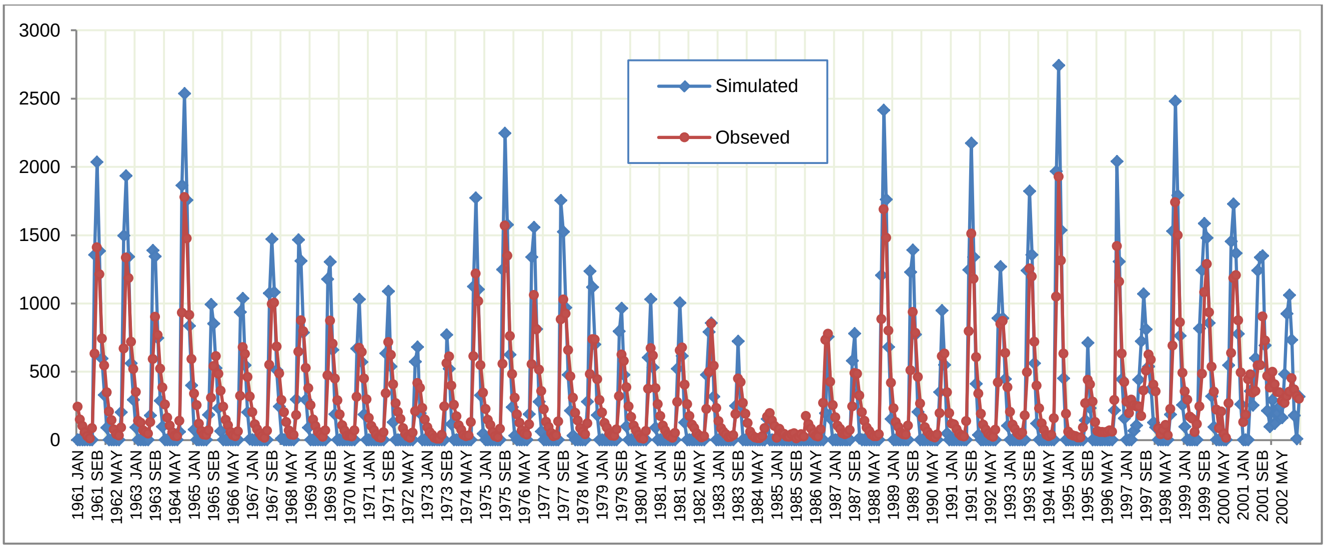

Fig. 4. Graphic comparison of simulated and observed monthly time series; source: own study

If R^2 is equal to 1, the relation between simulated and observed time-series is a perfect linear relationship. If R^2 is equal to –1, the relation between simulated and observed time-series is perfectly anti-correlated. Finally, if R^2 is equal to 0, both series are uncorrelated. Like for the *NSE*, the closer the R^2 is to 1, the more accurate the model is.

The graphical model evaluation technique is used to show a visual comparison of simulated and measured data and to provide the first overview of model performance [ASCE 1993; LEGATES, MCCABE 1999]. In this study both graphical techniques and quantitative statistics have been used in the model evaluation. Figure 4 shows monthly time series data and annual flow data of observed (collected from Ministry of water Resource) and simulation flow results of the Mike Basin modelling. Both *NSE* and R^2 values are 0.93, which indicates good performance of the model.

SIMULATIONS RESULTS

Simulation results represent to performance of reservoirs, irrigation units and water balance at user nodes and river flows at each river node. Simulations have been based on monthly flows in specific series of years considered as representative for a possible future scenario. Simulations are provided for all reservoirs in future conditions based on monthly flows from January 1961 to December 2002.

The model was used to simulate selected future scenarios. A baseline scenario foresees the continuation of the current situation and the other scenario considers a full development of the Tana basin, in other words, all proposed and designed reservoirs will be in operation. The scenarios were developed using the 2020–2061 demand data and 1961–2002 simulated stream flow data based on the assumption that a similar stream trend will exist in the future. Agricultural demand and hydrological condition are assumed as unchanged with no restriction to meet water demand in the future.

The primary goal of the baseline development phase is to generate a model that accurately reflects actual current conditions and potential future conditions using currently established infrastructure. The baseline model is similar to the calibration model, since it uses a general model framework developed in the first phase, but model inputs and structure are modified to simulate future conditions. The primary input to the baseline model includes assumed future hydrologic inflows, demands, and reservoirs in the Lake Tana sub-basin. Due to the uncertain nature of these projected inputs, the outputs are naturally subject to larger degree of uncertainty and any application of the model must recognize these limitations.

The current baseline model has been developed based on historical hydrological inflows. Although this provides a sound justification for estimated future inflows, this method assumes a stationary situation and does not consider hydrologic conditions that have not been historically recorded. In the development of the Lake Tana sub-basin model using the Mike Basin, historical hydrologic inflows are used for the baseline model and future planning scenarios. However, the model is configured to readily accept alternative hydrologic inputs as they develop in the future.

Demands used in the current baseline model are monthly average consumption data available from the different source (ENTRO, Ministry of Water and Energy) model. No increases or decreases in the total annual consumptive use are currently assumed, but they can be easily integrated into the model as improved demand projections are developed.

The baseline model has assumed initial conditions in reservoirs. Since no precise data for current reservoir levels were known, all reservoirs were considered at their full capacity or targeted January elevations on the starting time step with the exception of the Lake Tana, which assumed an initial starting elevation of 1786 m a.s.l. Due to the current application of this model for the purpose of long-term comparative studies or proposed infrastructure, this assumption was deemed reasonable.

In the third phase of the Mike Basin model development, proposed reservoirs were added to the model. Proposed reservoirs were incorporated into the model with their sufficient physical properties, including storage, characteristics, evaporation and rainfall, area-elevation-capacity curve and operation rules.

Water loss from reservoirs. Water loss occurs due evaporation from water surfaces. As the water level increases, there will be more free water surface area and the evaporation loss will increase accordingly. The evaporation loss (mm·day^{-1}) upstream of the basin is less as compared to the downstream. As a dam is constructed, there will be additional free water surface area and more evaporation loss. The mean annual loss for Lake Tana will be 1.3 Bm^3 and the loss from all other reservoirs will be less, which is 12 Mm^3 for Koga and Gilgel Abbay. However, for Megech, Gumara, Rib and Jemma it is not more than 4 Mm^3 (Fig. 5).

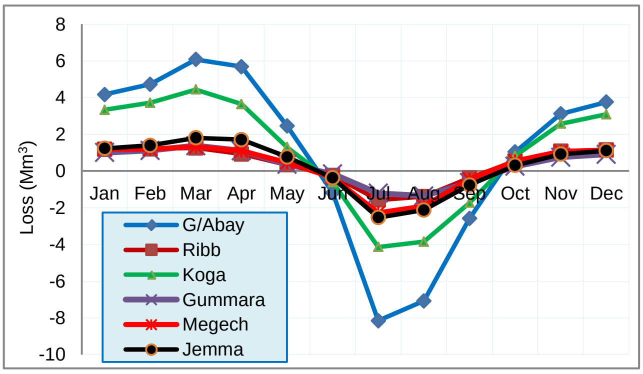

Fig. 5. Simulation results of mean monthly water loss from reservoirs (Mm^3); source: own study

As shown in the Figure 5, the water loss from reservoirs is lower (negative value) in rainy months. In the rainy month mostly from July to October, this indicates that the gain (rainfall) is more than the loss (evaporation loss rate).

Irrigation water demand deficit. The ability to meet water supply requirements for irrigation was analysed in the Mike Basin model given the assumed monthly depletions. In the baseline model, essentially all demands were met. However in the scenario models, it was clear that the initial period of filling the reservoirs might produce shortages for water users unless otherwise managed. Each of the five (Koga, Megech, Ribb, Tana pump and Gummara) represented water users on the Lake Tana sub-basin indicated shortages. Their cumulative effect is shown in Table 2.

There is maximum irrigation water demand deficit in the dry months (January–May) and the rest of the season will include small number of months with an irrigation water deficit. Table 2 shows the number of months, total water deficit in the simulation period and the event based reliability. In all cases, the water deficit is insignificant, whereas event-based reliability is more than 80% for all filling options. This is assumed to be acceptable [HASHIMOTO *et al*. 1982; JHA, GUPTA 2003].

$$NS = \frac{NNF}{TNM}100 \qquad (2)$$

Where: NS = event-based reliability (%); NNF = total number of non-failure months (480-months with deficit); NTM = number of total months (480 months).

Figure 6 shows cumulative irrigation water deficit for the whole basin in hypothetical flow scenarios (20% flow reduction, 20% flow increment and normal flow). The simulation result shows that in all cases irrigation performance is very good with more than 92% event-based reliability.

Inflow to reservoirs. The construction of reservoirs in the upper part of the basin produces advantages and disadvantages for downstream reservoirs. The amount of water flowing to reservoirs will be more regulated and constant due to upstream cascades.

Figure 7 shows the mean monthly inflow hydrographs for the reservoirs in the Lake Tana basin. As shown in the figure, Lake Tana has a stronger regulating effect, since the outflow from the lake is more uniform than the inflow to the lake. There is small reduction of the inflow to Lake Tana due to reservoirs built in the basin. Moreover, the inflow varies for wet and dry months. There is a higher

Table 2. Number of months with water deficit, total deficit (Mm^3) and event based event based reliability (from simulation result)

Month	Koga		Ribb		Gummara		Tana Pump		Megech	
	monthly deficit (MCM)	No. of month with deficit	monthly deficit (MCM)	No. of month with deficit	monthly deficit (MCM)	No. of month with deficit	monthly deficit (MCM)	No. of month with deficit	monthly deficit (MCM)	No. of month with deficit
Jan	0.29	1	2.13	6	0.00	0	4.37	4	0.91	1
Feb	1.13	5	2.34	5	2.00	2	5.70	5	0.55	1
Mar	1.55	7	3.19	6	3.00	4	8.54	9	0.71	1
Apr	1.60	7	5.15	8	13.69	8	9.69	8	1.04	1
May	0.96	5	5.68	6	16.69	7	5.87	7	0.28	1
Jun	0.00	0	0.00	0	8.00	0	0.00	0	0.00	0
Jul	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Aug	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Sep	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Oct	0.00	0	0.00	0	0.00	0	0.71	2	0.00	0
Nov	0.30	0	0.84	3	0.00	0	2.72	0	0.00	0
Dec	0.64	0	1.32	0	0.00	0	3.64	2	0.00	0
Annual (Mm^3)	6.47		20.65		43.38		41.24		3.49	
Total month		25		34		21		37		5
NS (%)		95		93		96		92		99

Source: own study.

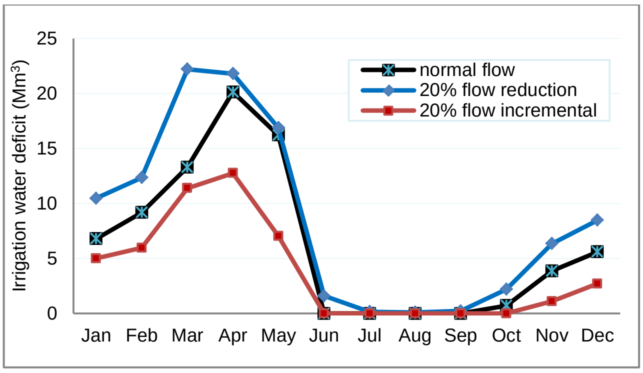

Fig. 6. Simulation results of cumulative irrigation water deficit in the basin for 20% flow reduction, 20% flow increment and for normal flow (Mm^3); source: own study

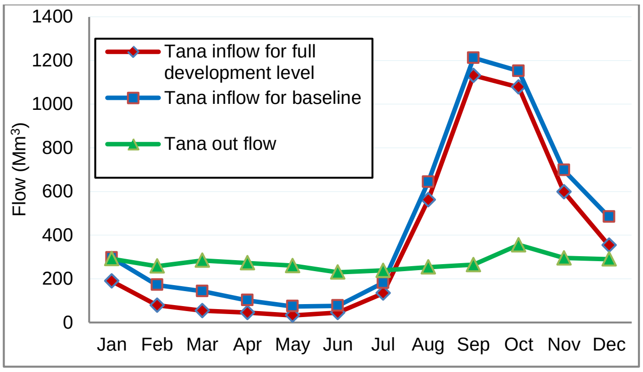

Fig. 7. Simulation results for mean monthly inflow to Lake Tana (Mm^3); source: own study

water inflow in wet months (July, August and September) and a lower inflow in dry months.

Figure 8 shows the mean monthly pool level of Lake Tana for different flow and development situations. As shown in the figure, the full level development will highly affect the water level in the lake, which is less than the historical minimum mean level.

According to PASTOR *et al.* [2014], more water is needed for environmental flows during low-flow periods (46–71% of average low-flows) compared to high-flow periods (17–45% of average high-flows). The calculated global annual environmental flow requirements (*EFRs*) for fair ecological conditions represent between 25% and 46% of the mean annual flow (*MAF*). The deduction of flows from the upstream rivers results in the reduction of inflow to the lake by 7–62% (Tab. 3). In dry months, the available flow ranges from 38% to 73% of the mean annual flow, which is 53% on average. During the wet season, the mean available water is 87% of the mean annual flow.

Outflow from reservoirs. The outflow from reservoirs could be distributed to cater for water demand projects. Figure 9 shows the mean monthly outflow from reservoirs. More water will be spilled water during wet months and the water abstraction during dry months will be significant. The inflow and outflow have a large impact on the reservoirs to be constructed because more water will be consumed in irrigation sites. The inflow and outflow show different trends, and the inflow and outflow hydrograph will change as a result of the upper reservoir regulation effect.

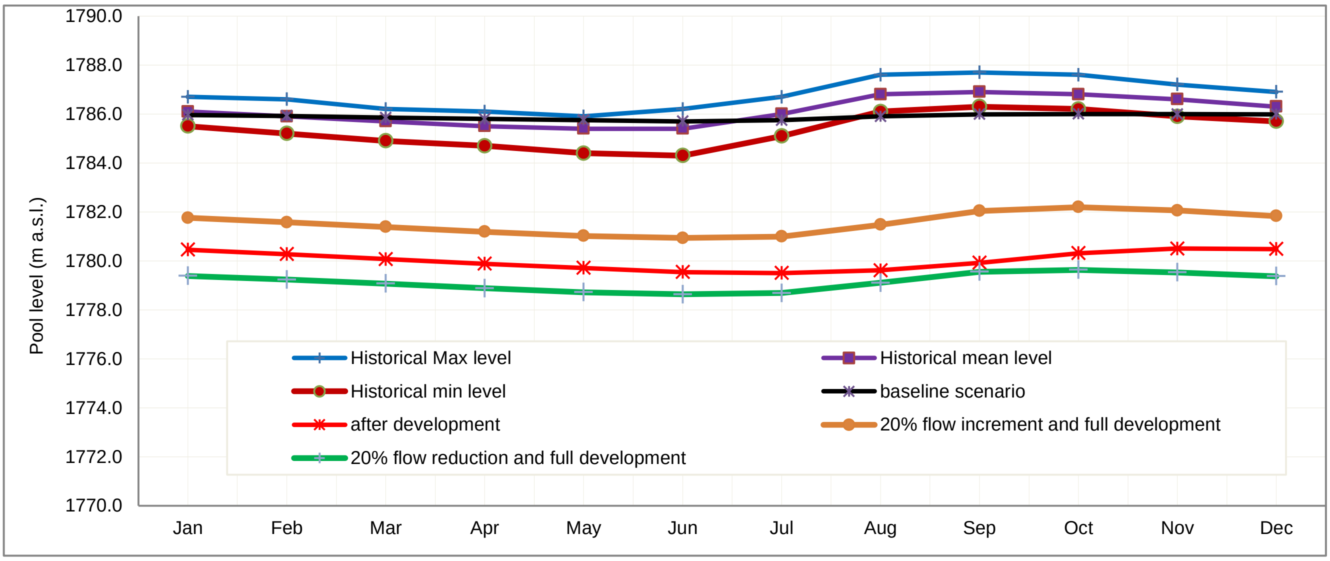

Fig. 8. Simulation results of pool level (m a.s.l.) in Lake Tana for different flow and development scenarios; source: own study

Table 3. Inflows to Lake Tana for baseline and full development level (Mm^3) from simulation result

Specification	Value in month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
Mean baseline (MCM)	296	172	144	102	74	77	181	643	1 211	1 151	697	484	5 233
With full development (MCM)	190	79	54	45	33	46	134	561	1 131	1 077	598	353	4 302
Difference (MCM)	107	93	89	56	41	31	47	82	80	74	99	131	931
Percentage	36	54	62	55	56	40	26	13	7	6	14	27	18

Source: own elaboration.

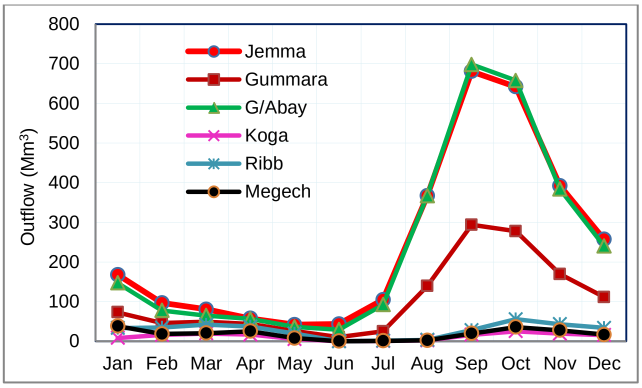

Fig. 9. Simulation results of mean monthly outflow from reservoir (Mm^3); source: own study

CONCLUSIONS

There is a need for better management of water resources in the area. A decision needs to be made on water allocation and development. All studies agree that the system analysis using a mathematical model provides a suitable methodology to analyse various aspects of the water resource system. A mathematical model ultimately supports the decision-making process by selecting the best alternative policies, subject to all pertinent constraints and various optimization techniques.

An effort has been made to collect and utilize all available public data describing physical characteristics of the basin and the current and proposed reservoir operations. Datasets of hydrologic inflows and consumptive uses were extracted from different sources and incorporated into the Mike Basin model. The application of outputs from these efforts has allowed to develop the Mike Basin model, focus on developing of operational rules for the reservoirs, and to simulate actual management practices. These practices are presumed to achieve multiple objectives, such as meeting irrigation water demand and meeting environmental criteria.

The proposed infrastructure incorporated into the model represents some of the major developments under consideration. The model has been configured to allow the user to consider the combination of proposed reservoirs. More importantly, the model allows for modifications to be readily made, including the addition of new infrastructure, modification of operational rules or improvement of input data.

Hydrographs for the basin will be changed due to the construction of new dams on the tributaries of the Lake Tana basin. Irrigation deficits can be expected in dry months, unless other irrigation method, e.g. pressurized irrigation, is introduced. As the water level increases, there will be more free water surface area and the evaporation loss will increase accordingly.

Negative impacts on river ecosystems due to construction and operation of dams can be minimized by careful planning and operation. Development objectives that protect biodiversity and ecosystem service should be the basis for planning and decision-making.

REFERENCES

ADSWE, LUPESP 2015. Hydrology and water resource assessment in Tana sub basin [online]. Vol. 3. Bahir Dar, Ethiopia. Amhara National Regional State, BoEFPLAU. [Access 23.11.2015]. Available at: https://mahiderzewdie.files.wordpress.com/2015/08/livestock-final-draft.pdf

ASCE 1993. Criteria for evaluation of watershed models. American Society of Civil Engineering. Journal of Irrigation and Drainage Engineering. Vol. 119(3) p. 429–442. DOI 10.1061/(ASCE)0733-9437(1993)119:3(429).

EL-RAEY M., EL-QUOSY D.H., EL-SHAER M., EL-KHOLY O.A., SOLIMAN A. 1995. Egypt: Inventory and mitigation options, and vulnerability and adaptation assessment. CSP Interim Report – Egypt, U.S. Country Studies Program.

HASHIMOTO T., STENDINGER J.R., LOUCKS D.P. 1982. Reliability, resiliency, and vulnerability criteria for water resources system performance evaluation. Water Resources Research. Vol. 18. No. 1 p. 14–20.

JHA M.K., GUPTA A.D. 2003. Application of Mike Basin for water management strategies in a watershed. Water International. Vol. 28. No. 1 p. 27–35. DOI 10.1080/02508060308691662.

KEBEDE S., TRAVI Y., ALEMAYEHU T., MARC V. 2006. Water balance of Lake Tana and its sensitivity to fluctuations in rainfall, Blue Nile basin, Ethiopia. Journal of Hydrology. Vol. 316 p. 233–247.

LEGATES D.R., MCCABE G.J. Jr. 1999. Evaluating the use of “goodness-of-fit” measures in hydrologic and hydroclimatic model validation. Water Resources Resources. Vol. 35(1) p. 233–241. DOI 10.1029/1998WR900018.

MACDONALD M. 2004. Koga irrigation project interim report. Addis Ababa, Ethiopia. Ministry of Water Resource.

MORIASI D.N., ARNOD J.G., VAN LIEW M.W., BINGNER R.L., HARME R.D., VEITH T.L. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE. Vol. 50(3) p. 885−900.

MoWR 2009. Growth corridor for Tana and Beles Sub-Basin: Endowment, potential and constraints. Vol. I. Main Text. Addis Ababa. Ministry of Water Resource.

NASH J.E., SUTCLIFFE J.V. 1970. River flow forecasting through conceptual models. Part 1. A discussion of principles. Journal of Hydrology. Vol. 10(3) p. 282–290.

PASTOR A.V., LUDWIG F., BIEMANS H., HOFF H, KABAT P. 2014. Accounting for environmental flow requirements in global water assessments. Hydrology and Earth System Sciences. Vol. 18 p. 5041–5059. DOI 10.5194/hess-18-5041-2014.

SETEGN S.G., SRINVASAN R., DARGAHI B. 2008. Hydrological modelling in the Lake Tana Basin, Ethiopia using SWAT model. The Open Hydrology Journal. Vol. 2 p. 49–62.

SMEC 2008. Hydrological study of the Tana-Beles Sub-Basin main Report. Addis Ababa, Ethiopia. Ministry of Water Resources. Melbourne, Australia. SMEC (Snowy Mountains Engineering Corporation) pp. 110.

Studio Pietrangli 1990. Tana Beles project. Part 2. Chara Chara Weir General Report. Addis Ababa, Ethiopia.

WALE A. 2008. Hydrological Balance of Lake Tana, Upper Blue Nile basin, Ethiopia [online]. MSc thesis. Enschede. ITC, Netherlands. [Access 23.11.2015]. Available at: https://webapps.itc.utwente.nl/librarywww/papers_2008/msc/wrem/wale.pdf

WALKER G.R., ZHANG L. 2001. Plot-scale models and their application to recharge studies. In: Studies in catchment hydrology: The basics of recharge and discharge. Eds. L. Zhang, G.R. Walker. Melbourne. CSIRO Publishing. DOI 10.1071/9780643105423.

YOHANNES D. 2007. Remote sensing based assessment of water resource potential for Lake Tana [online]. MSc Thesis. Addis Ababa University Civil Engineering. [Access 23.11.2015]. Available at: http://etd.aau.edu.et/handle/123456789/2719