International Journal of Computers & Technology
Volume 4 No. 2, March-April, 2013, ISSN 2277-3061

Evaluation of Operation of Lake Tana Reservoir Future Water Use under Emerging Scenario with and without climate Change Impacts, Upper Blue Nile

Getachew Tegegne[1], Dr. Ing.Dereje Hailu[2], Prof.Dr.S.Moses Aranganathan[3]

[1]Department of Civil Engineering, Adama Science and Technology University, Adama, Po.box-1888, Ethiopia, email: getfix@rocketmail.com

[2]Department of Civil Engineering, Addis Ababa University, Addis Ababa, Po.box- 32490,Ethiopia,email:dhasfaw@gmail.com

[2]Department of Civil Engineering, Adama Science & technology University, Adama, Po.box- 1888,Ethiopia,email:ermoses1954@yahoo.co.ln

Abstract - This paper presents simulation of Lake Tana reservoir future water use under emerging scenario with and without climate change impacts.

Two different development and climate change scenarios were developed to simulate Lake Tana water level i.e., i) Base line scenario (1991-2000) ,ii) Future development scenario on short term periods(2031-2040) , and ii) Future development scenario on long term periods (2091-2100). River head flow estimated by Soil and Water Assessment Tool (SWAT) was used as an input to Water Evaluation And Planning (WEAP) model to simulate the Lake level for each scenario.

Based on WEAP model simulation results, demand coverage and reliability of 100% was observed in all scenarios for Tana-Beles hydropower project. For scenarios without climate change impacts, there are longer periods of time when mean monthly lake levels are below 1785 masl (i.e., the minimum lake level required for shipping). Under natural conditions (lake level without project), they exceed this level in 100%.under current conditions (Base line scenario, BLS), they exceed this level in 89% of the months. In the full development scenario (FDSC′), this will decrease to 83%. For all scenarios with climate change impacts, Lake water Level will not significantly be affected by climate change impacts.

Key Words: SWAT, WEAP, Lake Level, Lake Tana, Climate Change, Reliability.

I.INTRODUCTION

The increased demand of water for agriculture, industries, domestic, and power generation in Lake Tana sub-basin requires proper planning and management of water resources in the basin. The basin has more than 40 rivers inflow in to Lake Tana and about 93% of the inflow is coming from the four major rivers Gilgel Abbay, Gummera, Rib and Megech [3].

II.STUDY AREA DESCRIPTION

The purpose of this study is therefore applying a physically based semi distributed model called Soil and water assessment tool (SWAT), to understand the hydrology of the basin, to know the water resource potential as a whole from gauged and un-gauged catchments as well as water evaluation and planning (WEAP) model[6] were used to asses upstream catchment development and climate change impact on Lake Tana water level and to assess the sustainability of Tana –belles Hydropower plant on the basis of adjusting the operation rule of Lake Tana reservoir.

The analysis presented in this paper is the first of its kind which was done using actual data in Lake Tana sub-basin. The study addresses; The assessment of water resources potential of Lake Tana basin, Assessment of Impact of upstream irrigation development on Lake Tana water level and Tana-belles Hydropower plant, Assessment of impact of climate change on Lake Tana and Beles hydro power plant with and without emerging upstream irrigation project, and assessment of the sustainability of Tana-Beles development on the basis of adjusting the operation rule of the Lake.

The output of this study can be used as an input for decision support for water resources planning, development, and management of water resources in the basin.

Lake Tana Basin is part of the Blue Nile basin, which lies in a natural drainage basin of about 15114 Km^2 as per this research work using SWAT delineation. Among which about 20.47% is covered by the Lake Tana. Lake Tana basin is found in North West part of Ethiopia and it extends between 10.95^0N to 12.78^oN latitude and from 36.89^oE to 38.25^oE longitude (highlighted in fig.1).

Topography is generally uniform and quite well adapted to irrigation development surrounding Lake Tana [5, 9]. The elevation ranges between 914 m to 4096 m +MSL, which is extracted from DEM (90*90m) resolution. There are two seasons rainy and dry. The rainy season has two periods, the little rains, during April and May, and the big rains, which last from mid- June to mid-September. The rainfall distribution in the basin is found to be a mono-modal pattern i.e. one peak value observed during rainy season especially in July, and August.
Considering the rainfall stations in the basin for a period of 1996-2006 the mean annual rainfall amount ranges between 813 mm in Yifag and 2328 mm in Enjibara. Similarly the mean annual minimum and maximum temperature ranges between 9.3 ^oC in Dangila and 29.6 ^oC in Gorgora respectively.

Land use of study area was classified based on Abay river master plan study conducted by BCEOM, in 1996-1999[2], about 51.37 % of the watershed area was covered by Agriculture, 21.94 % by Agro-pastoral, 20.41 % by Lake Tana, 0.39 % by Agro-Sylvicultural, 0.13 % by wetland, 5.47 % by Pastoral, 0.15 % by Sylvicultural, 0.03 % by sylvo-pastoral and 0.11 % by Urban.

The soil classification for the study area is also adopted from Abay river master plan study in 1996-1999 conducted by BCEOM [2]. Based on the classification Halpic luvisol which covers about 20.68 % of the watershed area is considered to be the major dominant soil in the study area.

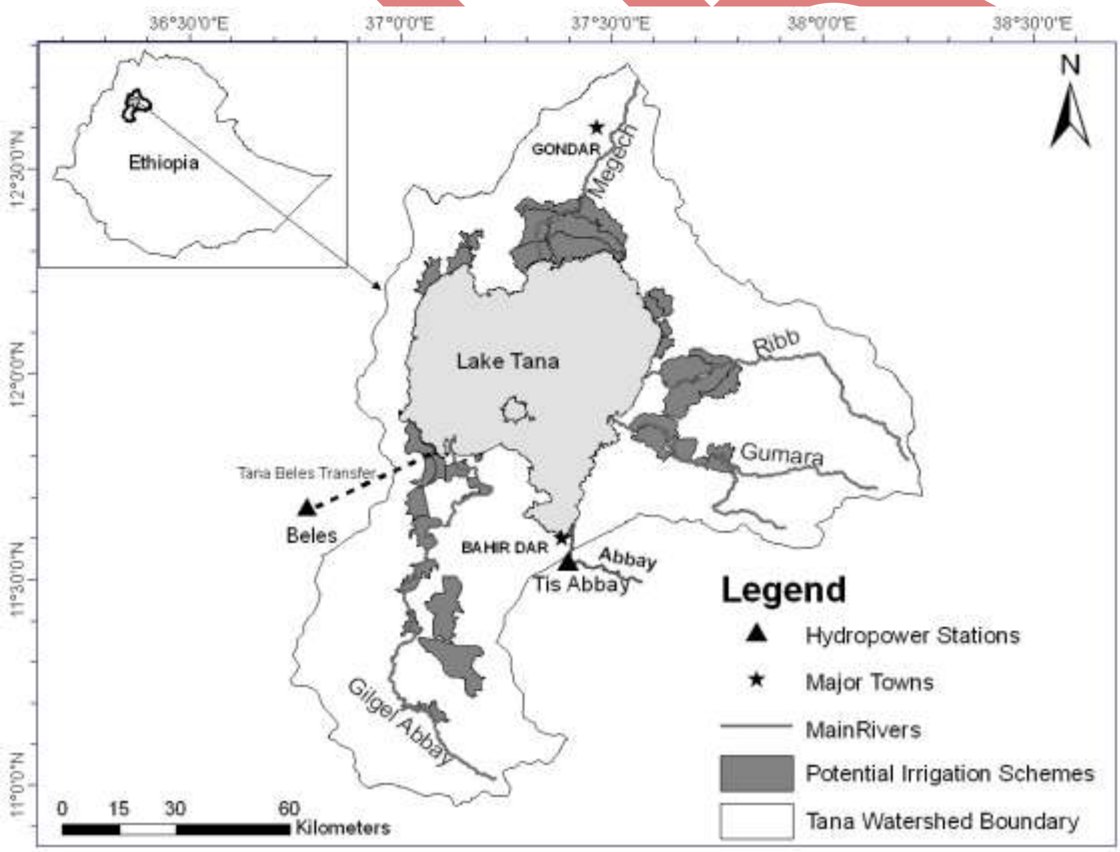

Figure 1: Location Map of Lake Tana Basin

III.METHODOLOGY

The following flow chart indicates the overall framework of the methodology to be followed throughout the study.

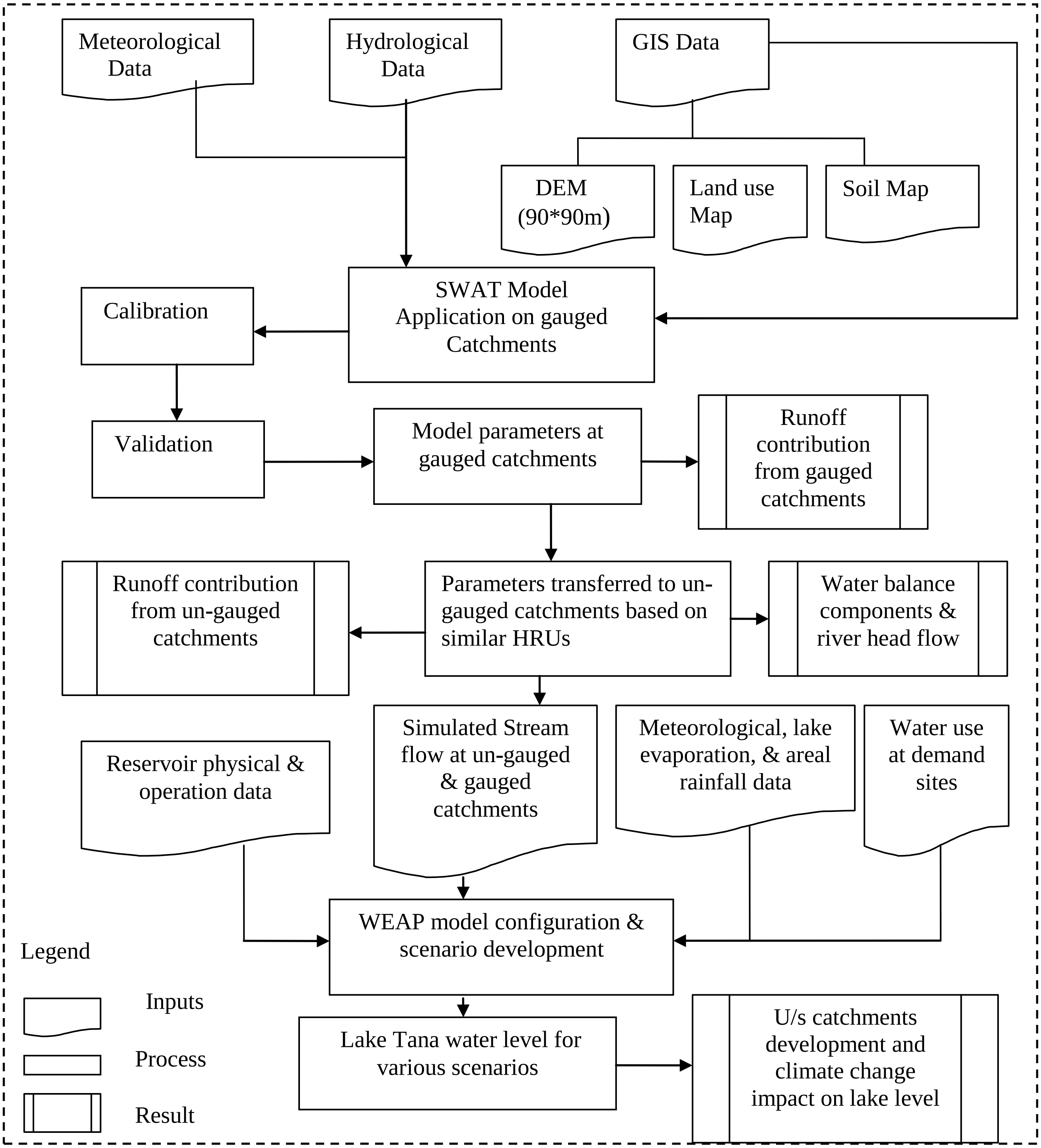

Figure 2: General frame work adopted for the study

International Journal of Computers & Technology
Volume 4 No. 2, March-April, 2013, ISSN 2277-3061

IV.SCENARIO DEVELOPMENT

In this study the model was set-up to simulate two scenarios based on development plans of the basin. The model is first configured to simulate a base line scenario, for which the water availability and demands can be confidently determined. It is then used to simulate for future development scenarios to assess the impact of development and climate change on the hydrology and water resources.

a) Scenario BLS: Base line scenario(1991-2000),
b) Scenario FDSC′: Future development scenario (future water demand without climate change);
c) Scenario $FDSC_1$: Future development scenario under climate change on short term basis (2031-2040),and
d) Scenario $FDSC_2$: Future development scenario under climate change on long term basis (2091-2100).

Interventions in the water sector in Abbay basin fall in to three main areas: irrigation, hydropower, and water supply. However, water supply requirements are small relative to those for irrigation and hydropower [2]. Projects, like water supply and sanitation, that do not significantly influence the results of water availability in the basin was not also be considered.

A. Scenario BLS

This Scenario represents the existing development in the basin. Relative to the basin water resource potential; development activities achieved yet is insignificant. Koga irrigation, Tis Issat fall and Tana Beles Hydropower schemes was considered for the base line scenario. When Tana Beles transfer become operational Tiss Abbay I and II hydropower stations will be used as standby stations, only to operate as a backup system when problems in the National grid may require [2,7]. Hence they are not considered in this scenario.

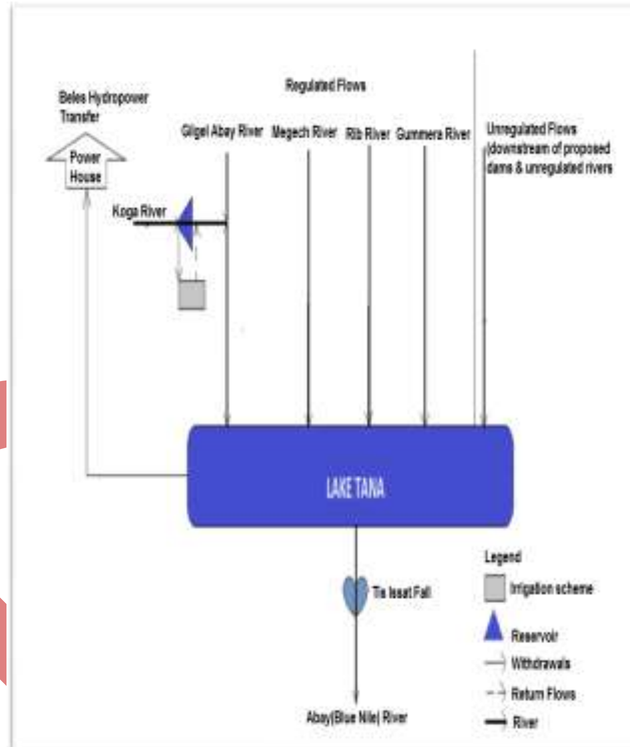

Figure 3: Schematic of the model configuration for the Current situation Scenario

B. Scenario FDSC′

This Scenario represents full development activities in the basin which are expected to be operational in future period of time. The analysis includes projects which are currently operational, ongoing development, and likely development activities. The scenario not considers the impact of climate change on hydrology and water resources in the basin.

C. Scenario $FDSC_1$ & $FDSC_2$

This Scenario represents full development activities which are expected to be operational in the long period of time in the future. Scenario $FDSC_1$ represents future development scenario with climate change for time periods of 2031-2040 and scenario $FDSC_2$ represents future development scenario with climate change for time periods of 2091-2100.The analysis includes projects which are currently operational, ongoing development, and likely development activities. The scenario considers the impact of climate change on hydrology and water resources in the basin. i.e., the climate variables are under the influence of climate change in the future.

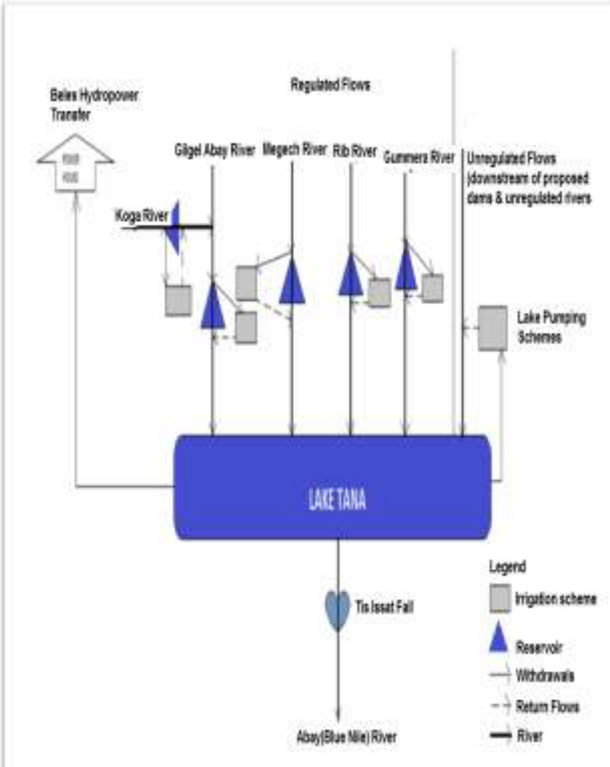

Figure 4: Schematic of the model configuration for the future development Scenario.

V.RESULTS AND DISCUSION

A. Evaporation and rainfall over the lake

From the Thissen polygon analysis, the annual average areal rainfall over the Lake for the simulation periods of (1991-2000), (2031-2040), and (2091-2100) found to be 1291mm/year, 1737.693mm/year, and 1690.104 mm/year respectively. From CROPWAT model the average annual evaporation over the Lake for the simulation periods of (1991-2000), (2031-2040), and (2091-2100) found to be 1618 mm/year, 1767 mm/year, and 1909 mm/year respectively.

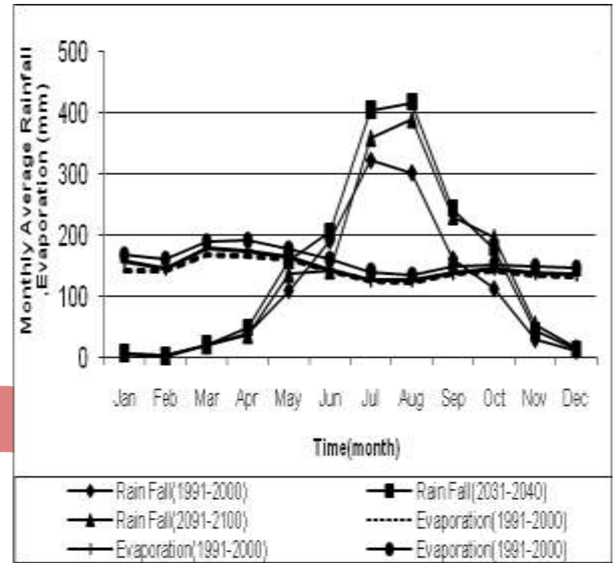

Figure 5: Monthly average rainfall and evaporation over Lake Tana.

B.Modeling of Gauged Catchments

Historical observed stream flow of Gilgel Abay at Merawi, Gummera at Bahirdar, Rib at Addiszemen and Megech at Azezo were calibrated from a period of 1996-2002 and validated from a period of 2003- 2005 .

Table 1: Calibration & validation statistics of observed and simulated stream flow

Average monthly flow (m^3/sec.)		R^2	NSE
Observed	Simulated		
Gilgel Abay River (Calibration period 1996-2002)			
57.26	58.21	0.91	0.91
Gilgel Abay River (Validation period 2003-2005)			
34.64	32.95	0.93	0.92
Gummera River (Calibration period 1996-2002)			
37.74	38.8	0.70	0.70
Gummera River (Validation period 2003-2005)			
34.06	27.69	0.91	0.90
Rib River (Calibration period 1996-2002)			
14.93	15.82	0.82	0.82
Rib River (Validation period 2003-2005)			
13.88	13.28	0.84	0.83
Megech River (Calibration period 1996-2002)			
7.18	7.04	0.8	0.76
Megech River (Validation period 2003-2005)			
8.06	4.53	0.92	0.91

C.The inflow hydrograph from gauged and ungauged catchments

Once the model is calibrated and verified at the gauged location the model output during that period were quantified and taken as simulated inflow series. Later this inflow series will be used for water balance analysis.

Similarly, the inflow series for ungauged catchments were done by transferring calibrated parameters having the same HRUs as gauged catchments. The total inflow in to the Lake mouth was determined after having the inflow from gauged catchments and inflow from ungauged catchments separately and later the total inflow was taken as the aggregate of inflow series from gauged and ungauged catchments.

From the model result total inflow from gauged catchments was found 2850.727MCM, 3595.137MCM, and 3311.873MCM for time period (1991-2000), (2031-2040), and (2091-2100) respectively. Total inflow from ungauged catchments was found 3759.228MCM, 5382.034MCM, and5006.76MCM for time periods of (1991-2000), (2031-2040), and (2091-2100) respectively.

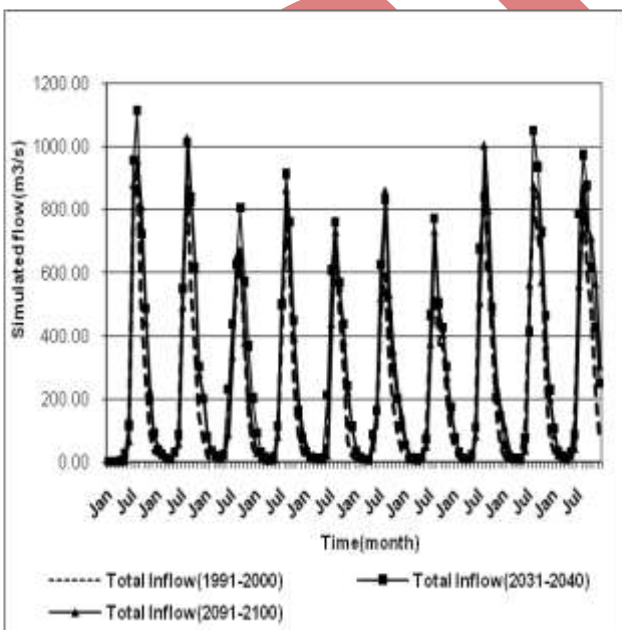

Figure 6: Total Inflow Hydrograph from gauged and ungauged catchment for all scenarios.

D.Elevation Area Volume Relation ship

The elevation Area Volume relation ship of Lake Tana reservoir was calculated for the calibration period (1996-2002).The polynomial fitted bathymetry by Pietrangeli and Abeyou [1, 8] used in this research work is as follows: Elevation-Volume-Area relation ship as per Pietrangeli and Abeyou

Table 2: Elevation Volume Area relation ship

Pietrangeli	$E = 1.08*10^{-9}(V)^2+3.88*10^{-4}(V)+1775.58$ $A = 6.20*10^{-8}(V)^2+1.72*10^{-2}(V)+2516.3$
Abeyou	$E = 1.21*10^{-13}(V)^3-1.02*10^{-8}(V)^2+6.20*10^{-4}(V)+1774.63$, $A = 7.93*10^{-11}(V)^3-5.81*10^{-6}(V)^2+1.65*10^{-1}(V)+1147.51$

Where E= Lake level elevation, m. +MSL
A= Surface area of the Lake, Km^2
V= Lake volume, MCM

The basic equation used in the water balance:

$$S_t = S_{t-1} + I(t) + P(t) - O(t) - E(t) + G_{in} - G_{out} - \Delta s \quad (1)$$

Where:
S_t = Lake storage volume at the end of current month,
S_{t-1} =Lake storage volume at the end of previous month,
I(t) =Simulated inflow volume from gauged and un-gauged catchments at current month,
O(t) = Outflow volume at the Lake outlet,
P(t)=Areal rainfall volume on the Lake surface,
E(t)=Evaporation volume on the Lake surface,
G_{in} (t) = Ground water inflow in to the Lake at the end of current month,
G_{out} (t)= Ground water outflow from the Lake at the end of current month.
Δs = other losses.

The water balance terms were computed using EXCEL spread sheet model and the monthly water balance result obtained by using the relation ship developed by Abeyou, (2008) has been best fitted than Pietrangeli, (1990).

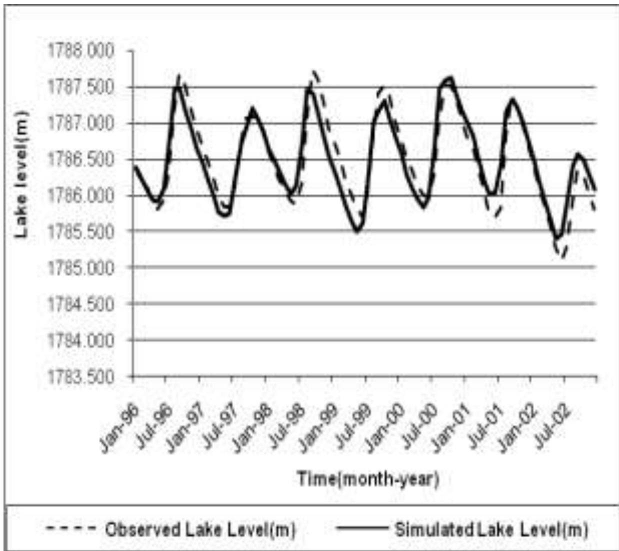

Figure 7: Observed and Simulated Lake Level with out project for the period 1996-2002.

Table 3: Lake Tana Annual water balance components simulated from 1996-2002

Water balance components	mm/year
Lake areal rainfall	+1291
Gauged River inflow	+822
Un-gauged river inflow	+1297
Lake Evaporation	-1618
River outflow	-1725
Change in storage	67

E.Upstream Catchment Development Impact on Lake Tana Water Level

Figure 8 presents a comparison of the time series of simulated lake levels with project and without project for all scenarios. The results indicate the decline in mean annual lake levels, and consequently lake area, as water resources development in the catchment increases. As water resources development increases there are longer periods of time when mean monthly lake levels are below 1785 masl (i.e., the minimum lake level required for shipping) [4]. Under natural conditions (lake level without project), they exceed this level in 100%.under current conditions (Base line scenario, BLS), they exceed this level in 89% of the months. In the full development scenario (FDSC′), this will decrease to 83%.

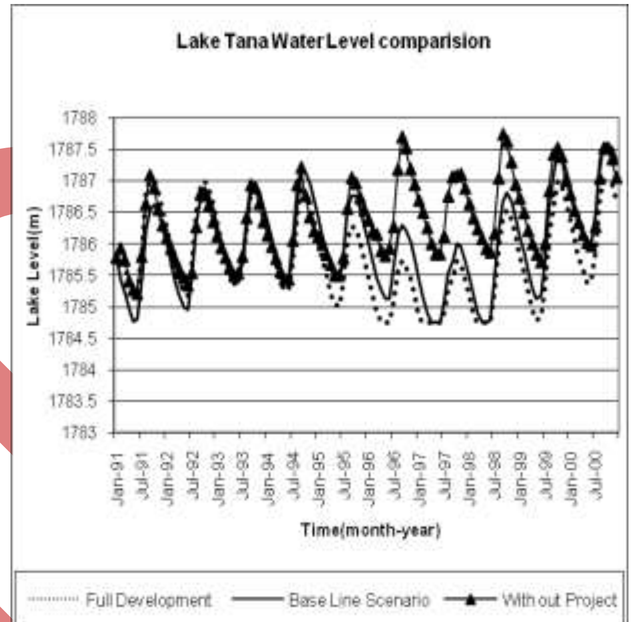

Figure 8: Comparison of simulated lake level with project and without project (1991-2000)

F.Upstream Catchment Development Impact on Tana-Beles Hydropower Plant

Table 4 and 5 presents annual unmet demand in million cubic meter for base line scenario and full development scenario respectively. From the result, 100 percent reliability of Tana-Beles hydropower project was observed for base line scenario and full development scenario.

Table 4: Yearly unmet demands (MCM) for BLS scenario (1991-2000)

Scheme	1991*	1992*	1993	1994	1995	1996	1997	1998	1999	2000	Sum
Tana Beles Hydropower	0	0	0	0	0	0	0	0	0	0	0
Koga Irrigation	47.4446	0.00407	0	0	0	0	0	0	0	0	47.44
Sum	47.4446	0.00407	0	0	0	0	0	0	0	0	47.44

1991* 1992* shows the "warm up" period for reservoirs filling and not considered for analysis

Table 5: Yearly unmet demands (MCM) for FDSC′ scenario (1991-2000)

International Journal of Computers & Technology
Volume 4 No. 2, March-April, 2013, ISSN 2277-3061

Scheme	1991*	1992*	1993*	1994	1995	1996	1997	1998	1999	2000	Sum
Tana Beles Hydropower	0	0	0	0	0	0	0	0	0	0	0
Gilgel Abay Irrigation	91.37	46.72	34.31		0	0	0	0	0	0	172.40
Gumera Irrigation	26.01	0	0	0	0	0	0	0	0	0	26.01
Koga Irrigation	48.300	33.21	0	0	0	0	0	0	0	0	81.51
Megech Irrigation	39.639	29.15	13.61	0	0	0	0	0	0	0	82.41
Rib Irrigation	166.94	42.64	19.86		0	0	0	0	0	0	229.44
Tana Pump Irrigation	0	0	0	0	0	0	0	0	0	0	0
Sum	372.26	151.73	67.79	0	0	0	0	0	0	0	591.79

1991* 1992* 1993* shows the "warm up" period for reservoirs filling and not considered for analysis.

G.Climate Change Impacts on Lake Tana Water Level

Currently, there is great uncertainty about the likely impacts of climate change in the Abay Basin. Results from Global climate models (GCMs) are contradictory; some show increases in rainfall whilst others show decreases. A recent study of 17 GCMs indicated that precipitation changes between -15% and +14% which, compounded by the high climatic sensitivity of the basin [4].

Generally there is an increasing trend in both precipitation and runoff in the basin for the time period of 2031-2040 and 2091-2100. PET and reservoir evaporation shows an increasing trend for all future scenarios. The cumulative impacts of these hydrologic parameters on Lake water Level were checked using WEAP simulation model.

The results of the WEAP model simulation shows that Lake water Level will not significantly be affected by climate change impacts for all future scenarios. Figure 9 and 10 presents a comparison of the time series of simulated lake levels for all future scenarios with and without project.

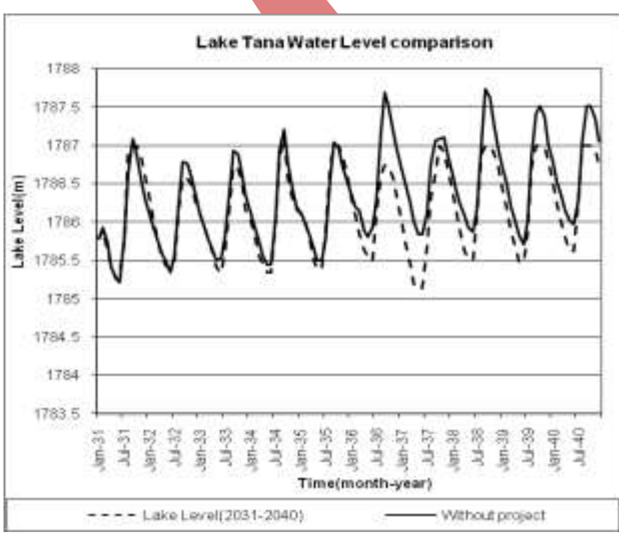

Figure 9: Comparison of simulated Lake Levels with and without project (2031-2040)

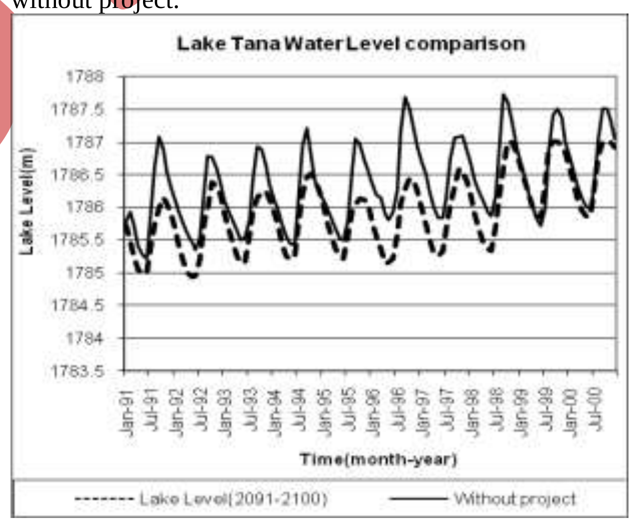

Figure 10: Comparison of simulated Lake Levels with and without project (2091-2100)

H.Climate Change Impacts on Tana-Beles Hydropower Project

The result shows climate change impacts are not significant in the basin and hence, there is no problem of water shortage for proposed development activities due to climate change impacts. By giving higher priority for hydropower schemes than irrigation schemes, the demand coverage and reliability of 100 percent was observed for Tana– Beles hydropower project

Table 6: Yearly unmet demands (MCM) for $FDSC_1$ scenario (2031-2040

Scheme	2031*	2032*	2033	2034	2035	2036	2037	2038	2039	2040	Sum
Tana Beles Hydropower	0	0	0	0	0	0	0	0	0	0	0
Gilgel Abay Irrigation	97.63	0.002	0	0	0	0	0	0	0	0	97.63
Gummera Irrigation	25.42	0	0	0	0	0	0	0	0	0	25.42
Koga Irrigation	48.14	0.004	0	0	0	0	0	0	0	0	48.14
Megech Irrigation	39.44	0.01	0	0	0	0	0	0	0	0	39.45
Rib Irrigation	164.12	0.99	0	0	0	0	0	0	0	0	165.11
Tana Pump Irrigation	0	0	0	0	0	0	0	0	0	0	0
Sum	374.77	1.01	0	0	0	0	0	0	0	0	377.7

2031* 2032* shows the "warm up" period for reservoirs filling and not considered for analysis

Table 7: Yearly unmet demands (MCM) for $FDSC_2$ scenario (2091-2100)

Scheme	2091*	2092*	2093*	2094	2095	2096	2097	2098	2099	2100	Sum
Tana Beles Hydropower	0	0	0	0	0	0	0	0	0	0	0
Gilgel Abay Irrigation	106.71	0.006	0	0	0	0	0	0	0	0	106.71
Gummera Irrigation	26.14	0.01	0	0	0	0	0	0	0	0	26.15
Koga Irrigation	48.30	0	0	0	0	0	0	0	0	0	48.31
Megech Irrigation	39.64	30.41	15.74	0	0	0	0	0	0	0	85.80
Rib Irrigation	167.93	19.27		0	0	0	0	0	0	0	187.20
Tana Pump Irrigation	0	0	0	0	0	0	0	0	0	0	0
Sum	388.72	49.70	15.74	0	0	0	0	0	0	0	454.18

2091* 2092* 2093* shows the "warm up" period for reservoirs filling and not considered for analysis

VI.SUMMARY AND CONCLUSION

A cascade of two models was used in this study. The SWAT model was setup from January 1985 - December 2006.Calibration and validation was done for seven years monthly time step (1996-2002) and three years monthly time step (2003-2005) respectively. After modeling the gauged watershed, calibrated parameters were transferred to ungauged watershed by lumping the parameters having the same hydrologic response unit (HRUs). The model output indicates that, the total annual inflow volume from gauged and ungauged catchments estimated to be 6229.115 MCM for calibration period. From the Thissen polygon analysis, the annual average areal rainfall over the Lake for the simulation periods of (1991-2000), (2031-2040), and (2091-2100) found to be 1291mm/year, 1737.693mm/year, and 1690.104 mm/year respectively. From CROPWAT model the average annual evaporation over the Lake for the simulation periods of (1991-2000), (2031-2040), and (2091-2100) found to be 1618 mm/year, 1767 mm/year, and 1909 mm/year respectively.

Water demand analysis were done by using WEAP Simulation Model for entire projects in the basin for three different development scenarios, which will assist the water experts and decision makers in making a realistic estimate of water availability and allocation.

The WEAP model simulation results indicate the decline in mean annual lake levels, and consequently lake area, as water resources development in the catchment increases. As water resources development increases there are longer periods of time when mean monthly lake levels are below 1785 masl (i.e., the minimum lake level required for shipping). Under natural conditions (lake level without project), they exceed this level in 100%. Under current conditions (Base line scenario, BLS), they exceed this level in 89% of the months. In the full development scenario (FDSC′), this will decrease to 83%. The results of the WEAP model simulation shows that Lake water Level will not significantly be affected by climate change impacts for all future scenarios. By giving higher priority for hydropower schemes than irrigation schemes, the demand coverage and reliability of 100 percent was observed for Tana – Beles hydropower project under all scenarios with and without climate change.

REFERENCES

[1] Abeyou W., (2008). Hydrological balance of Lake Tana, Upper Blue Nile Basin, Ethiopia, a M.Sc. thesis, International Institute for Geo-information science and Earth observation, Netherlands.

[2] BCEOM (1999): Abbay River Basin Integrated Development Master Plan Project and Associates (1999).

[3] 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 316: 233-247.

[4] McCartney; Alemayehu; Shiferaw; Awulachew, S.B. (2010). Evaluation of Current and Future Water Resources Development in the Lake Tana basin, Ethiopia. Colombo, Srilanka: International Water Management Institute.39p. (IWMI Research Report 134).

[5] MoWR (Ministry of Water Resources) (1998). Abbay River Basin Integrated Development Mater Plan Project: Phase 2, vol. VI, Water Resources Development, part 2, Large Irrigation and Hydropower Dams. Report, Addis Ababa, Ethiopia.

[6] SEI (Stockholm Environment Institute).(2007). WEAP: Water Evaluation and Planning System user guide. Boston, Stockholm Environment Institute.

[7] SMEC (Snowy Mountains Engineering Corporation). (2008): Hydrological Study of the Tana – Beles Sub-basins, main report. Addis Ababa, Ethiopia: Ministry of Water Resources.

[8] Studio Pietrangeli, (1990). Tana Beles Project studies document.

[9] WWDSE (Water Works Design and Supervision Enterprise) and TAHAL Consulting Engineers Ltd. (2008). Lake Tana sub-basin four dams project, final feasibility report for Megech Irrigation Project, Vol. III: hydrological report. Addis Ababa, Ethiopia.