Climate Change Impact on Water Resources Availability of Finchaa-Amerti-Neshe Multipurpose Cascaded Reservoirs

Sisay Simachew[1]*, Hatiye, Samuel Dagalo[2]

[1]Faculty of Water Resources and Irrigation Engineering, Arba Minch Water Technology (AWTi), Arba Minch University, Arba Minch, Ethiopia, P.O. Box 21. [1]sisaysimachew@gmail.com; [2]samueldagalo@gmail.com
*Corresponding author

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Abstract

The most profound effect of climatic change may be alterations in the regional hydrologic cycle and changes in regional water availability. Besides the increasing water scarcity, climate change threatens to exacerbate the current supply-demand imbalance. In this study, the impact of climate change on water availability and reliability to satisfy the increasing demand under changing the climate on Finchaa sub-basin has been evaluated using the Water Evaluation and Planning (WEAP) model. WEAP package was utilized to simulate the future water availability using the runoff generated by the Hydrologiska Byråns Vattenbalansavdelning (HBV) model as an input. The performance of the model was assessed using statistical tools such as Nash and Sutcliffe efficiency criteria (R^2) and the Relative Volume Error (RVE) during model calibration and validation steps. R^2 values were greater than 0.8 and RVE values were near 0 for all the three sub-catchments showing the better performance of the model. The prediction for future climate variables, on the other hand, showed an increasing trend for both maximum and minimum temperature values. However, for precipitation, it doesn't manifest any systematic increasing or decreasing trend in the next three decades. Consequently, the total water availability in the study area is expected to decrease by 11.88% in the next thirty years. Compared to the base scenario, the simulated future inflow to Finchaa and Neshe reservoirs has shown a slight increment at the end of 2025 and a small decrease at the end of 2040. However, the simulated future inflow volume to Amerti reservoir has shown a likelihood of small and considerable decrease at the end of 2025 and 2040, respectively. Considering the future expansion in the study area, all future and existing demand sites in the study area may be fully satisfied with 100% demand site coverage and 98.89% demand site reliability under changing the climate. Finally, it can be concluded that even though the demand in the sub-basin is increasing greatly, the available water resources is expected to be satisfactory under changing climate conditions for the next thirty years.

Keywords: Climate Change, Water Availability, Finchaa sub-basin, WEAP and HBV models, Reliability

1. Introduction

Climate change is the result of variations in components of the climatic systems. Processes in the atmosphere interact strongly with those on land, on and in the oceans, as well as with the cryosphere and biosphere. In this respect, increases of atmospheric concentrations of trace gasses such as carbon dioxide, methane, nitrous oxide, tropospheric ozone, and others due to human activities enhance the earth's natural greenhouse effect and lead to global warming. As the temperature of the atmosphere rises, in response to global warming, the saturation deficit increases, and therefore the warmer atmosphere can contain more moisture. Therefore, the main greenhouse gasses and water vapor will increase and will result in a positive feedback on global warming. Moreover, according to scenarios developed in the IPCC special report on the emission scenarios (SRES), the globally averaged surface air temperature is projected to rise by 1.4^{o}C to 5.8^{o}C by 2100 relative to 1990. It has been recognized that the atmospheric changes are due to both natural fluctuations in climate and anthropogenic activities from the human impact.

The IPCC's (2007) findings indicate that developing countries, such as Ethiopia, will be more vulnerable to climate change. It may have far-reaching implications to Ethiopia for various reasons, mainly because the economy of the country largely depends on agriculture. Climate change and its impacts are, therefore, a case of concern to Ethiopia. Hence, assessing water resources vulnerability to climate change and preparing adaptation options as part of the entire development program is very crucial for the country (NMSA 2001). Observational records in Africa show that the regional climate has been warming in the 20th century at the rate of about 0.05^{o}C per decade (IPCC 2001). While the exact nature of the changes in temperature or precipitation, and extreme events are not known, there is a general agreement that extreme events will get worse, and trends in most variables will change in response to warming. By 2025, it is assumed that 22 countries will experience a water-stress situation due to rapid population growth, expanding urbanization, increased economic development, and climate change. Ethiopia is not exceptional to this and will be experiencing water stress situation in the future. At the mesoscale, climate change is likely to affect the local water planning especially in the river basins where water resources are stressed under different demands and competing sectors. Finchaa sub-basin is one of the basins facing this kind of problem.

Finchaa sub-basin is naturally endowed with land features that are characterized by large upstream water potential sites, intensive downstream irrigable lands and a high head hydropower plant at the foot of almost vertical canyons. In the sub-basin, there is a project called Finchaa-Amerti-Neshe multipurpose project. The project comprises big irrigation and hydropower projects including the community water supply. The main sources of water for this all activities are the three reservoirs (i.e. the Finchaa, Amerti, and Neshe reservoirs). Finchaa and Amerti reservoirs are the earliest in the Blue Nile (Abbay) basin (constructed in 1968 and 1984 respectively), whereas the construction of Neshe reservoir was completed in the year 2011. Since the construction of the dams, downstream irrigation in the area has been expanding from time to time. As a result, there is an increasing demand for water which leads to competition for water among different sectors. Sometimes upstream users are releasing inadequate water for downstream users which often leads to conflict between upstream and downstream water users (Aboma 2010; Daniel 2007). There is an ever-increasing demand for water in the basin which makes the water management tense since balancing between demand and supply requires adequate information about the availability of the water in time and space. Figure 1 below shows historical and future plan of the irrigable area in the study area depicting an ever-increasing demand for irrigation water.

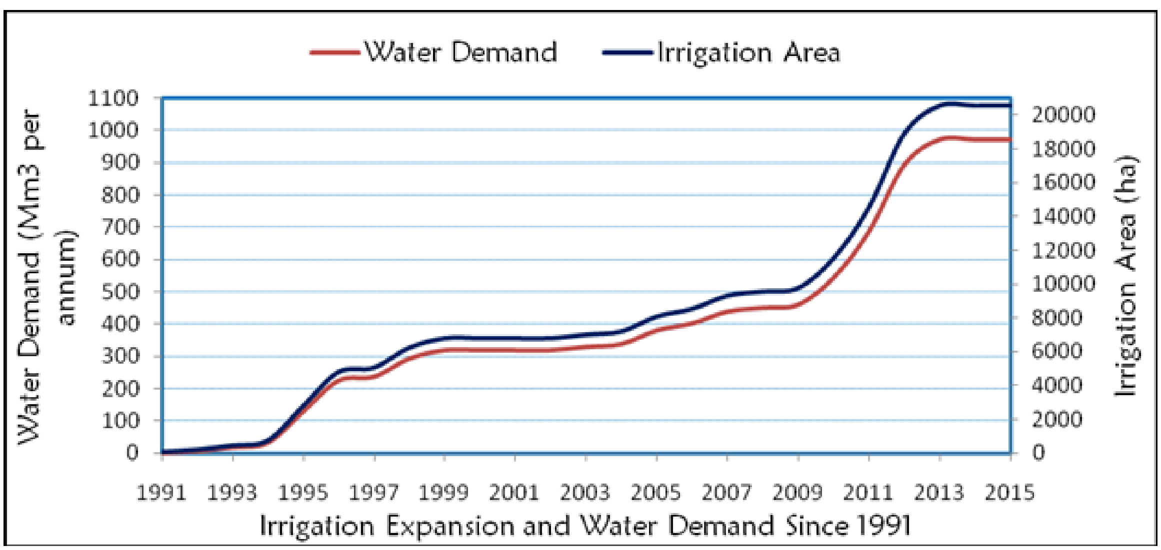


Figure 1. Historical and future irrigation and water demand in Finchaa sub-basin (1991 to 2015)

There were few studies conducted so far in the study area related to climate change and reservoir operation rules (Daniel 2007; Kebede 2010; Zeray 2010). These studies indicated that there will be likely changes in future climate variables in the particular sub-basin. Kebede (2010) has analyzed the upstream-downstream interaction and impacts of climate change on water storage interventions in the Abbay river basin, Ethiopia while Zeray (2010) has evaluated potential water storage options to cope up with climate change and variability in the basin with a focus on Finchaa and Tana sub-basins. In fact, none of these studies have focused on the problem of water availability and reliability issues in such chaotic water demanding environment under future changing climate conditions. There are several models available to assess water demand and allocation in a given basin. The Water Evaluation and Planning (WEAP) model is one of these among others which is used in this study.

The WEAP model has been applied along with the other hydrological model to assess the impact of water availability under climate change in many river basins to simulate current and future water demand in many development projects of Ethiopia (Engidaw K., 2016; Fufa T., 2016; World Bank, 2006). The WEAP model was applied to simulate current and future water demand in the Blue Nile of the country (World Bank, 2006). The model was also used to study the effect of climate change on the reservoir and the downstream irrigation development which depends on the water release of Koka reservoir. The model statistical measures have shown that it is a very good model which can simulate the current and future scenarios well (Fufa 2016). WEAP model was also used along with the SWAT hydrological model for prediction of demands of Wabishebele River and its surface water potential (Engidaw 2016). However , the application of WEAP model was not tested for the Finchaa-Amerti-Neshe multipurpose cascaded reservoirs and under such varying demands and supply conditions in Ethiopia. Therefore, the aim of the particular study is to (i) evaluate climate change impact on water resources availability and its reliability on Finchaa-Amerti-Neshe multipurpose cascaded reservoirs the WEAP model, (ii) check the reliability of the available resources (demand coverage and reliability) and (iii) quantify climate change impact on hydropower production of the Finchaa and Neshe hydropower stations employing the WEAP and HBV hydrological model.

2. Materials and Methods

2.1. Description of the study area

Finchaa sub-basin is part of the Blue Nile (Abbay River) basin which contains three sub-basins (Finchaa, Amerti, and Neshe). The sub-basin has an area of 4089 km^2. Finchaa and Amerti dams and reservoirs are the earliest in the Blue Nile basin whereas the construction of Neshe dam and hydropower system was started recently in 2008. Finchaa sub-basin lies between 9°10' to 10°00' N latitude and 37°00' to 37°30' E longitude. The sub-basin is located around 315 km northwest of Addis Ababa. Figure 2 provides the location map of the area. Topographically, Finchaa sub-basin is dominated by rugged and swampy terrain. The altitude in this sub-basin ranges approximately between 869 m a.m.s.l and 3,205 m a.m.s.l. The topography of the lower valley is slightly rolling with a slope of 2% towards the river and around 12% towards the lateral drainage way. The hydro-metrological gauging stations in and around the sub-basin used in this study are shown in Figure 3.

Major infrastructure development of the area started in the late 1960's, with the design and construction of the Finchaa hydropower project. The installed capacity of the hydropower project was 100 MW and it came into operation in 1972. The Finchaa hydropower system was expanded in 1980 by diverting Amerti flows into the Finchaa reservoir by constructing a 20 m high composite embankment (earth and rock fill) dam on Amerti River and a 1.57 km long diversion tunnel. As a result, the capacity was upgraded to 134 MW. Additional turbine units were installed to provide the capacity. Finchaa sugar plantation and its processing facility were developed in late 1990's and the factory was commissioned in 1999. The plantation is located downstream of the Finchaa power plant and takes advantage of regulated flows provided by Finchaa reservoirs. The factory has an annual production of 1 million quintals of white sugar and 7 million liters of ethanol from an irrigation area of 14,500 ha. Further, the government plan is planning to expand the capacity of the factory to produce 2.7 million quintals of white sugar and 21 million liters of ethanol when the maximum expansion reaches 20,567 ha of land from which 5,000 ha of land is to be irrigated using the flow regulated by Neshe reservoir (Finchaa Project Implementation Master Plan 2011). The Neshe hydropower capacity is 100 MW.

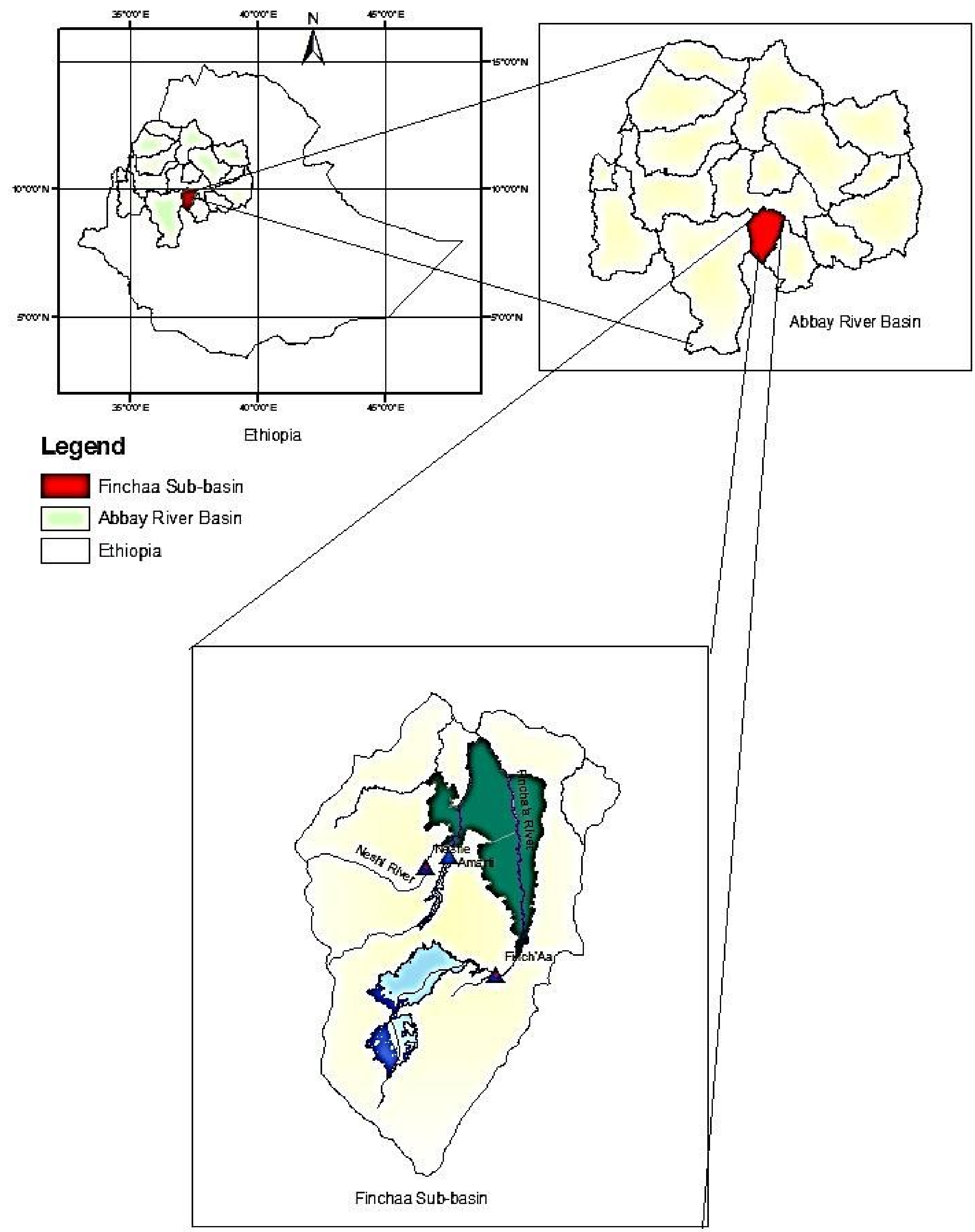


Figure 2. Location and description of the study area

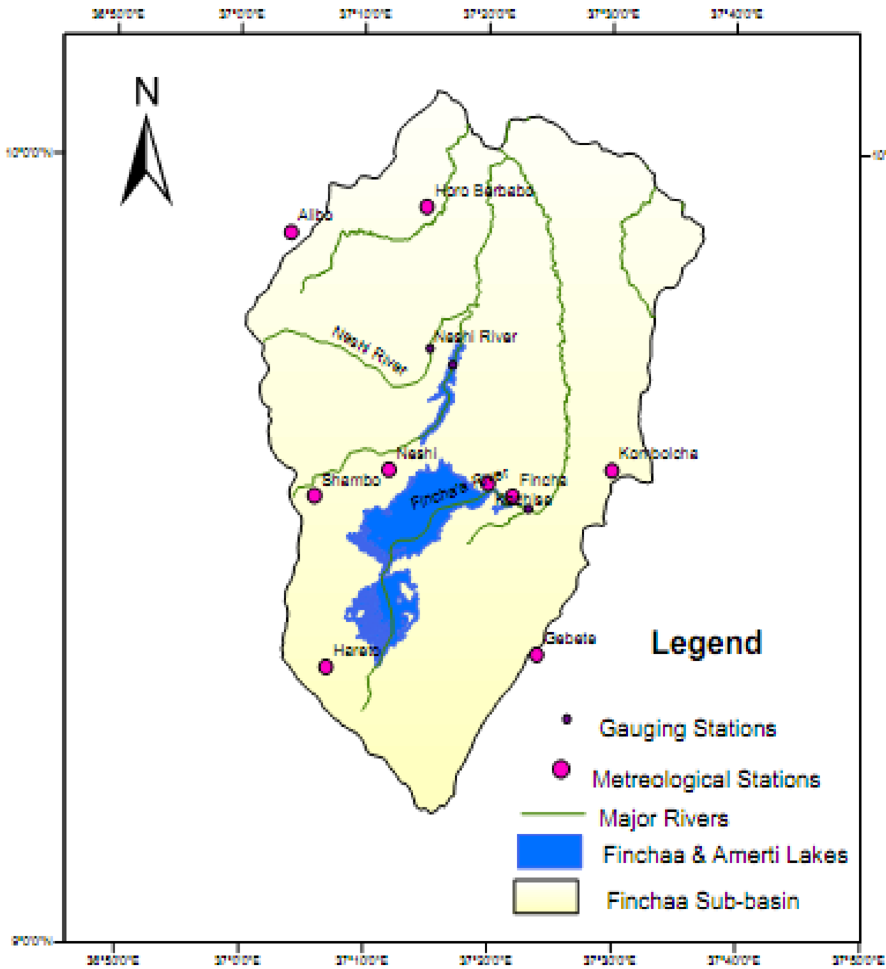


Figure 3. Finchaa sub-basin hydro-metrological stations

2.2.Climatic Data analysis

A field visit was made to understand the water resources systems of the sub-basin and to have a general understanding of water resources development activities in the sub-basin. Meteorological, hydrological, and water resources data relevant to the study were collected. Climatic, stream flow, water demand, irrigation, and hydropower scheme data were collected from Ministry of water resources, Ethiopian Meteorological Agency, Finchaa Sugar Estate and the previous studies. Downscaled future climate data was collected from International Water Management Institute (IWMI). Eight rain gauge stations were used for climatic data analysis.

2.3.Rainfall Data Analysis

A number of methods are being proposed for estimating missing rainfall data including station average, normal ratio, and isohyetal methods. Normal ratio method is adopted in this study since the average annual catch differs by more than 10% (Richard, 1998) which is given as:

$$P_x = \frac{N_x}{n}\left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + ...\frac{P_n}{N_n}\right) \quad (1)$$

where the P_x= missing value of precipitation to be computed; N_x = average value of rainfall for the station in question for recording period; N_1 = average value of rainfall for the neighboring station; P_1... P_n = rainfall of neighboring station during the missing period and n = number of stations used in the computation. Time series of hydrological data has been checked for inconsistency and non-homogeneity.

2.4.Flow Data Analysis

The streamflow data collected from Finchaa, Amerti and Neshe gauging stations have some missing values, although sufficient period of record exists for the Neshe station. A method suggested by Gordon et al. (1992) was used to screen the discharge data by a quick visual scan of the time series data to detect gross errors such as erroneous peak flow, missed recordings, and flows of constant rate. Missing flow data records for the sub-basin were filled by correlation equations earlier developed by Aboma (2010). The correlation equations used for the Finchaa and Amerti gauging stations in terms of Neshe gauging are expressed below. The R^2 values for this relation were 0.89 and 0.96, respectively, for Finchaa and Amerti stations (Aboma 2010).

$$Q_F(t) = 2.12 + 0.88Q_N(t) + 1..03Q_N(t-1) \quad (2)$$

$$Q_A(t) = 0.893Q_N(t) \quad (3)$$

where Q_F *(t)* = flow at Finchaa gauging station at time t; Q_N *(t)* = flow at Neshe gauging station at time t; Q_N *(t-1)* = Flow at Neshe gauging station at time t-1; Q_A *(t)* = flow at Amerti gauging station at time t.

2.5.Potential Evapotranspiration and Open Water Evaporation

For this study Penman-Monteith method was used to calculate the daily potential evapotranspiration and open water evaporation as suggested by FAO (Allen et al. 1998).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (4)$$

where ET_o = reference evapotranspiration [mm day^{-1}]; R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}]; G = soil heat flux density [MJ m^{-2} day^{-1}]; T = mean daily air temperature at 2m height [^{o}C]; U_2 = wind speed at 2m height [ms^{-1}]; e_s = saturation vapour pressure [KPa]; e_a = actual vapour pressure [KPa] ; e_s-e_a = saturation vapour pressure deficit [KPa]; Δ = slope of vapour pressure curve [kPa°C^{-1}]; γ = psychrometric constant [kPa°C^{-1}].

2.6.Catchment Data Analysis

Due to its semi-distributed nature, HBV model needs sub-division of the basin into different elevation zones. Each elevation zone of the sub-basin was divided into different vegetation cover (forested and non-forested) areas (IHMS, 2006). The study sub-basin was also processed and further divided into different zones using the land use and land cover data of the study area. Figures 4(a) and 4(b) show Finchaa sub-basin land use and land cover maps.

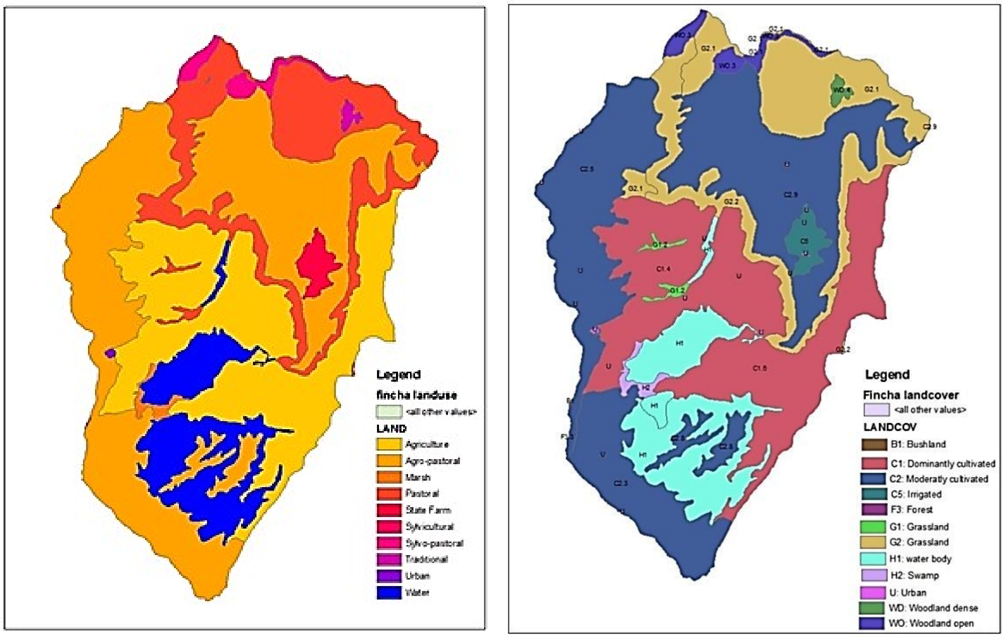


Figure 4. Finchaa sub-basin land use (a) and Finchaa sub-basin land cover (b)

2.7. Materials

Tools including Instat+v3.36, FAO ET_o calculator, ArcView GIS 9.1, HBV-96 and Water Evaluation and Planning (WEAP) have mainly been used in this study to achieve the intended objectives of the study. Downscaled local climate scenarios (RegCM3 forced by ECHAM5 with A1B emission scenario) were collected from IWMI. ArcView GIS 9.1 was applied for spatial data analysis and the HBV-96 hydrological model was used for runoff generation.

WEAP is an analytical framework developed for the evaluation of climate change and other drivers that water managers commonly confront (Yates et al. 2006). In addition to its main function of the improved water allocation, the WEAP model was applied in this study to study the effect of climate on water availability using the runoff generated by the HBV hydrological model as an input. Monthly data on reservoir operation, hydropower, river head flow, water use at demand sites and environmental flow requirements were provided to the WEAP modeling environment.

2.8. Calibration and Validation

Statistical indices including Nash and Sutcliffe efficiency criteria (R^2) and the Relative Volume Error (RV_E) were used in this study, which are commonly used in hydrological modeling. The Nash and

Sutcliffe coefficient (R^2) is a measure of efficiency that relates the goodness-of-fit of the model to the variance of measured data. R^2 can range from -∞ to 1 and an efficiency of 1 indicates a perfect match between observed and simulated discharges. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas efficiency less than zero occur when the observed mean is a better predictor than the model (Legates and McCabe 1999).

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Q_{sim(i)} - Q_{obs(i)}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs(i)} - \overline{Q_{obs(i)}}\right)^2} \quad (5)$$

$$RV_E = \left[\frac{\sum_{i=1}^{n}\left(Q_{sim(i)} - Q_{obs(i)}\right)}{\sum_{i=1}^{n}\left(Q_{obs(i)}\right)}\right] \times 100\% \quad (6)$$

where: $Q_{obs(i)}$= observed flow at time step i; $Q_{sim(i)}$ = simulated flow at time step i; $\bar{Q}_{sim(i)}$ = average observed flow.

2.9.Water Demand Analysis

Competing demand sites and catchments, the filling of reservoirs, and flow requirements were allocated water according to their demand priorities. The demand priority is related to the demand site, catchment, the reservoir (priority for filling), or flow requirement. Priorities can range from 1 to 99, with 1 being the highest priority and 99 the lowest. Reservoir priority default value is 99 since reservoir is filled only if water remains after satisfying all the other demands.

Generally, the water in the sub-basin is used for various purposes including irrigation by large, followed by water supply and hydropower production. Irrigation demands were calculated by simulating demand node and FAO CROPWAT 8.0 model used to simulate the observed seasonal pattern of irrigation with different cropping seasons in the basin. The current water demand is summarized in Table 1. The water supply for the domestic purposes was computed based on the existing population and individual requirements. The hydropower demand was assessed using the installed capacities of the power plants.

Table 1. Current water demand

Sr. No.	Name	Size	Description	Water Use per annum
1	Finchaa Irrigation Scheme	12,700 ha	For sugarcane plantation	589.50 Mm^3
2	Nedi Irrigation Scheme	5,200 ha	For sugarcane plantation	239.70 Mm^3
3	Finchaa Hydropower Plant	134 MW	For power generation	936.30 Mm^3
4	Neshe Hydropower Plant	100MW	For power generation	618.10 Mm^3
5	Main Town Water Demand	21,875 (No.of population)	For Community water supply	12.61 Mm^3
6	Village Water Demand	6,968 (No.of population)	For Community water supply	11.67 Mm^3
7	Factory Water Demand	-	For Factory use	10.09 Mm^3

The government long-term plan at the area is to further expand the existing capacity of irrigation project as the revenue from the sugar factory is promising which in turn results in increases in the demand for water. The number of population is also increasing, and hence community water supply at large is increasing from time to time. All the consequences of expansion were included in the analysis. Accordingly, the irrigation water demand during the maximum expansion expected to rise to 956.68 Mm^3 per annum (i.e., in 2015). On the other hand, the total community water demand and the factory water demand is expected to increase to 95 Mm^3 at the end of 2015.

2.10. Scenario Development

Three independent scenarios were simulated based on development plans of the basin and the likelihood of short and long-term development interventions. The model was first configured to simulate a baseline period between 1996-2010. Scenario-1 was carried out for the period between 2011-2025 and scenario-2 was conducted for the period between 2026-2040. Figure 5 shows the overall procedure of the conceptual framework for this study.

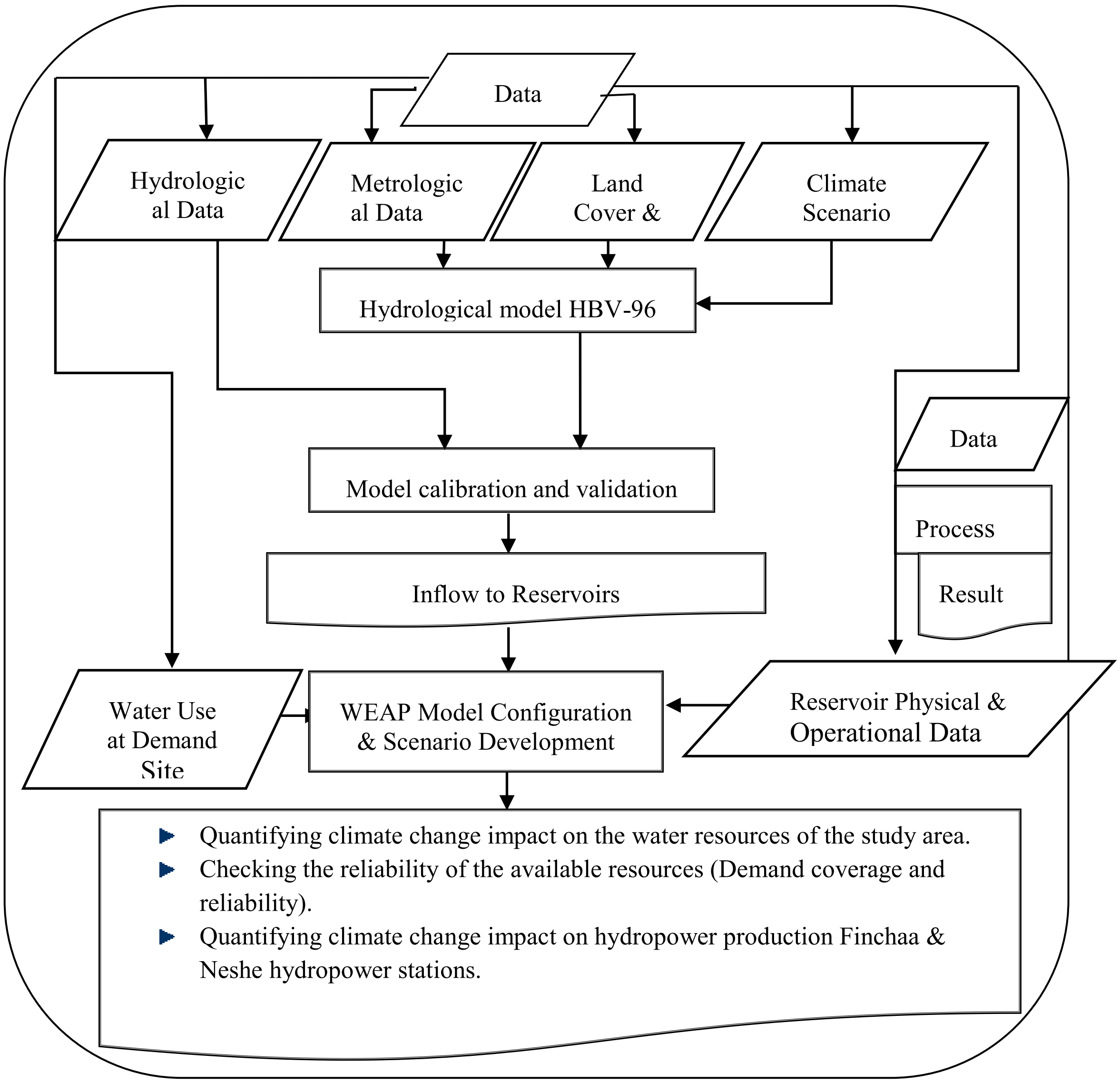


Figure 5. Conceptual framework of the study

3. Results and Discussions

3.1. Climate Variables

Water availability is directly affected by temperature and precipitation changes as well as evapotranspiration in the study area. Both predicted maximum and minimum temperature values show an increasing trend in the future climate. The projected maximum temperature showed an increasing trend for all time horizons for the next century (1981-2100). A relatively larger absolute monthly difference from the baseline temperature is found in the months of February to

March in scenario-1 and January to April in scenario-2. Consecutively, the mean annual temperature changes also confirmed the average increasing trend of maximum temperature. Absolute changes in the mean annual maximum temperature values are expected to be +0.41 ^{o}C in scenario-1 and +0.52 ^{o}C in Scenario-2. The mean monthly absolute change in maximum temperature is shown in Figure 6. The generated minimum temperature also showed an increasing trend in the next century (1981-2100). Comparatively, the minimum temperature trend for the next century shows a higher rate of increase than that of the maximum temperature. The mean annual absolute change in minimum temperature is nearly +0.68 ^{o}C and +0.97 ^{o}C in scenario-1 and scenario-2, respectively. Figures 6 (a) and 6(b) shows the trend of the maximum and minimum temperatures in sub-basin in the next century. The results from this study also agree with the latest IPCC (2007) report in which the global temperature will be expected to rise by 0.6 ^{o}C – 1.4 ^{o}C in the next temperature.

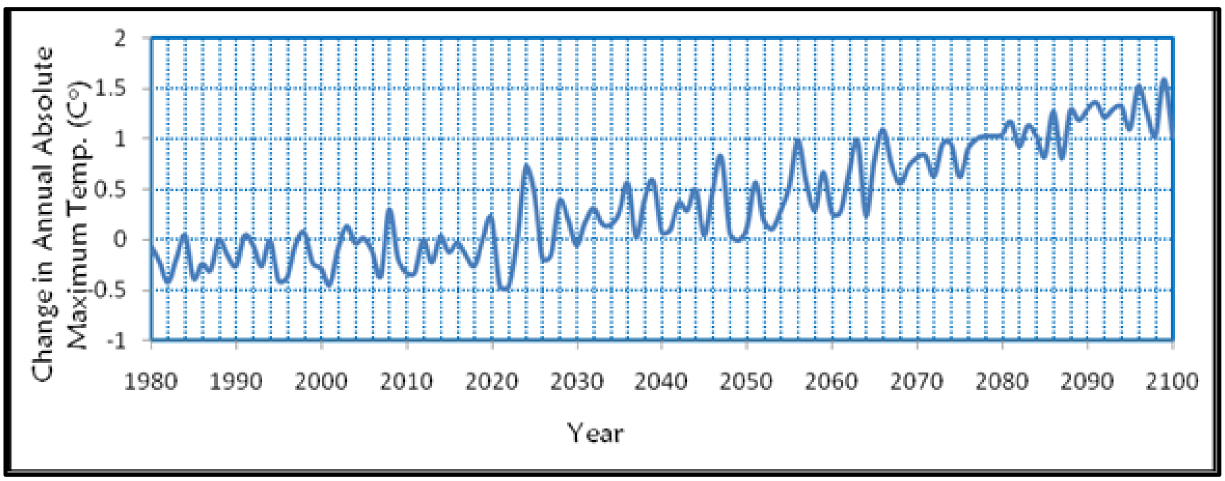


Figure 6(a). The trend of absolute maximum temperature change for the next century (1981-2100)

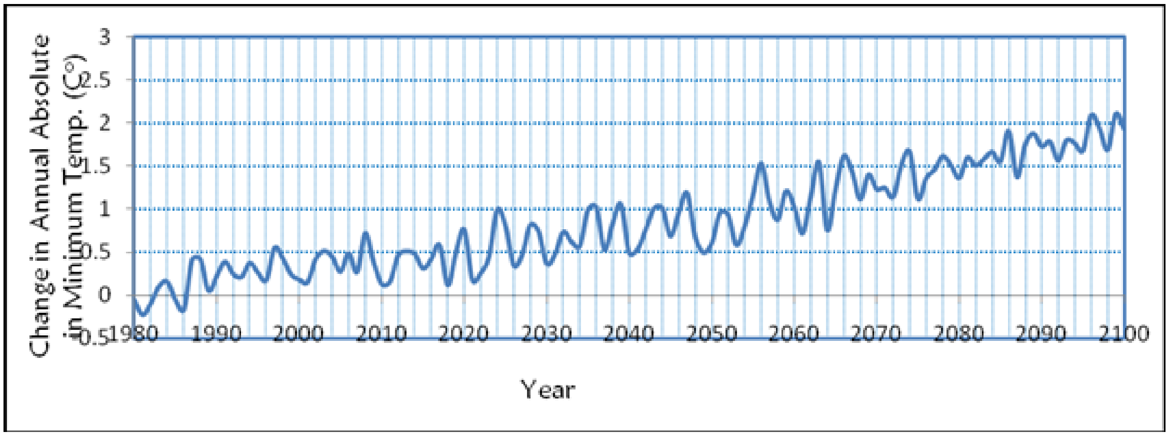


Figure 6(b). The trend of absolute minimum temperature change for the next century (1981-2100)

Unlike the temperature, the projected precipitation does not reveal a systematic increasing or decreasing trend for the next century. This may be attributed to the complicated nature of precipitation processes and its distribution in space and time. However, for the period between 2080-2100, it shows a slight decrease in rainfall trend. The precipitation, in general, in the area experiences a mean monthly increase amount by 6.07% in scenario-1 and a mean monthly decrease in an amount of 0.25% in scenario-2. Generally, for both scenarios, the precipitation showed an increasing trend for the months of July, August, and September. Figure 7 depicts the mean monthly precipitation for all scenarios.

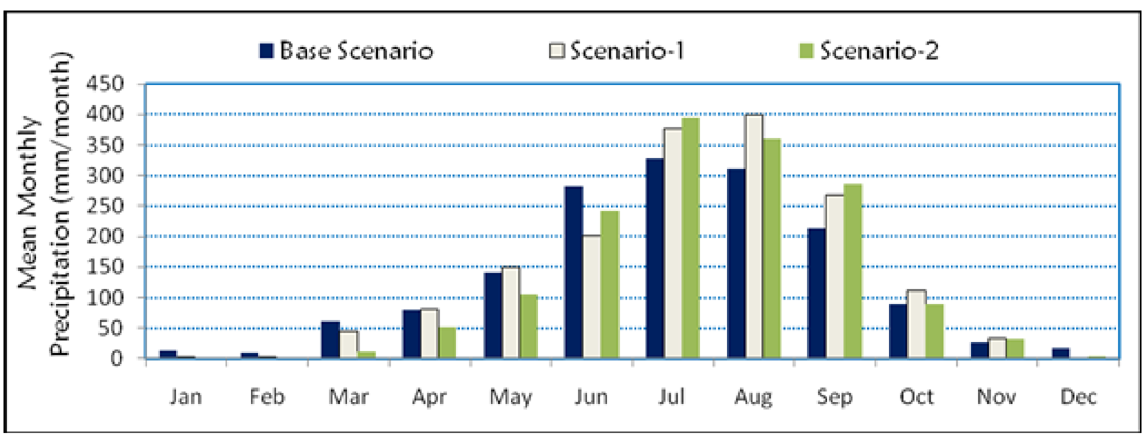


Figure 7. Mean monthly precipitation for all scenarios

The total annual open water evaporation also showed an increase in an amount by 7.43% in scenario-2 and almost no change in scenario-1. Changes in evaporation are mainly explained by the climatic variables including temperature. The rate of monthly open water evaporation is found to increase relatively at a higher rate during the months of March, April, and May in scenario-2. The two scenarios have shown a slight decrease in the months of June to September (during the rainy season). Except in the months of February and March, open water evaporation in scenario-1 has shown a small decrease. Figure 8 shows the mean monthly open evaporation for all scenarios.

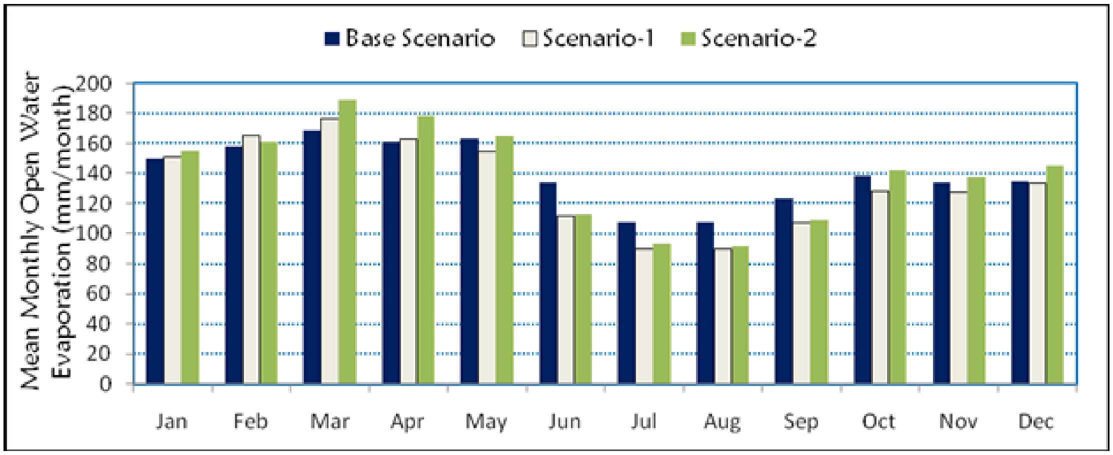


Figure 8. Mean monthly open evaporation in mm/month for all Scenarios

3.2. Model Calibration and Validation

Calibration is aimed at the water balance and overall shape agreement of the observed discharge using RV_E (relative volume error) and R^2 (Nash and Sutcliffe coefficient). The model is calibrated for eight years (1994-2001) for the three reservoirs. The parameters were manually calibrated by iterating the parameter values till the best value of R^2 and RV_E were obtained. After calibration, the model was validated for four years (2001-2005) (Table 2).

Table 2. Calibrated model parameters for Finchaa sub-basin with their recommended range of values and validated for four years (2002 to 2005)

Parameters	Calibrated Values			Range of values
	Finchaa	Amerti	Neshe	
α	0.6	0.6	1.1	0.5 - 1.1
β	1	1.5	1.25	1 - 4
FC	600	600	600	100 - 1500
K_4	0.001	0.0075	0.001	0.001 – 0.1
KHQ	0.042	0.05	0.025	0.005 – 0.2
L_P	0.4	1	0.85	<=1
Maxbaz	1	1	1	1 - 5
Perc	0.9	0.3	0.175	0.01 - 6

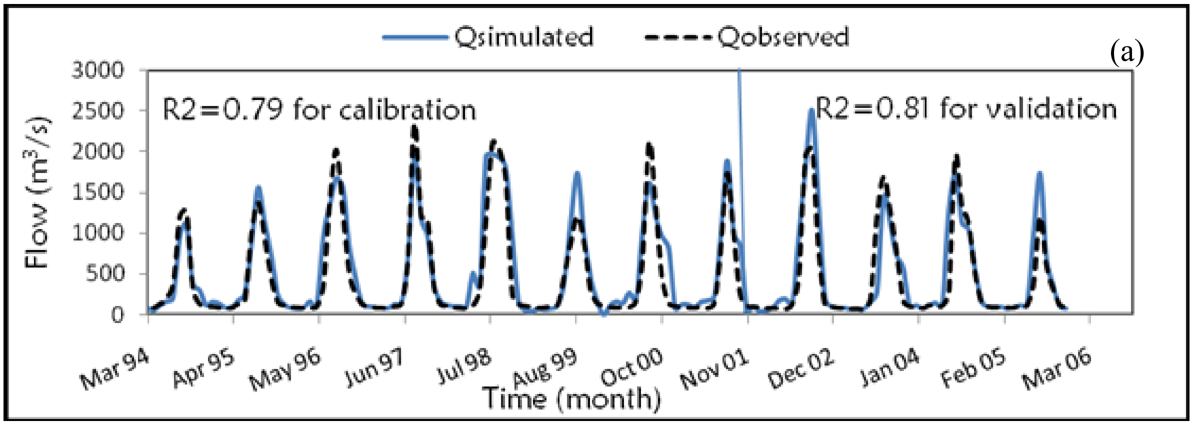
Alfa (α) is a measure of non-linearity of the upper reservoir to transfer excess water from the soil zone as quick flow. Similar values of α have been computed for Fincha and Amerti reservoirs. Comparatively, a large value of α for the Neshe reservoir shows flow complexity between the reservoirs. Neshe is located downstream of the Fincha and Amerti reservoirs and has significant differences in the watershed area, drainage density, and length. Beta (β) is the exponent in the equation for discharge from the zone of soil water. Field capacity (FC) is the maximum soil moisture storage capacity in the model [mm] which is related to soil properties. Larger FC values indicate relatively fine-textured soils which promote delayed runoff generation than coarse textured soils. KHQ is the recession coefficient for the upper response box when the discharge is HQ. K_4 is the recession coefficient for lower response box, describes the recession of the base flow. L_p is limit for potential evaporation. Maxbaz is the number of days in the transformation routine. Perc describes the percolation from the upper to lower response box [mm/day].

Model calibration and validation results are also shown graphically in Figures 9 (a)-9(c) for all the stations. Table 3 shows the statistical indices for both model calibration and validation periods.

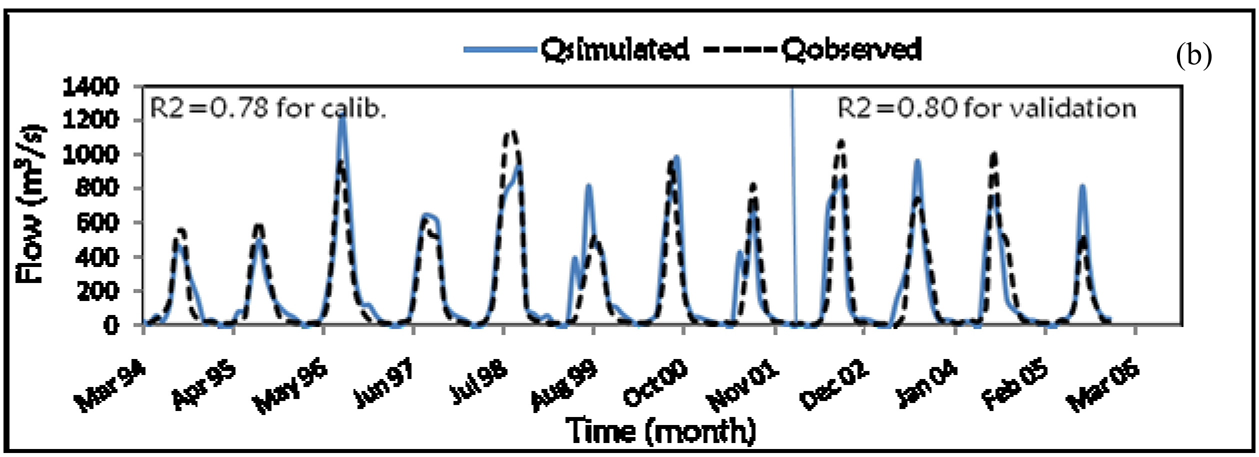
Table 3. Statistical values for model calibration and validation

Catchments	Calibration			Validation		
	Finchaa	Amerti	Neshe	Finchaa	Amerti	Neshe
R^2	0.79	0.78	0.81	0.81	0.80	0.83
RV_E	-8.43%	12.78%	8.74%	-9.70%	9.82%	4.50%

Model calibration and validation results indicate that the model performance for Finchaa and Amerti reservoirs is satisfactory while that of Neshe is very good.



(a)



(b)

(c)

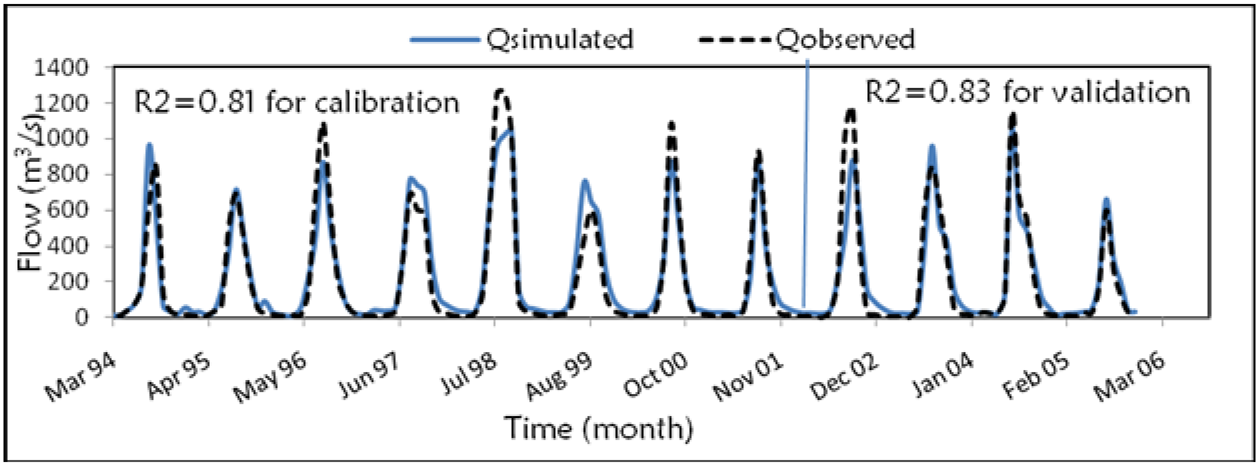


Figure 9. Simulated and observed hydrograph for calibration and validation for Fincha (a) Amerti (b) and Neshe (c) sub-watersheds

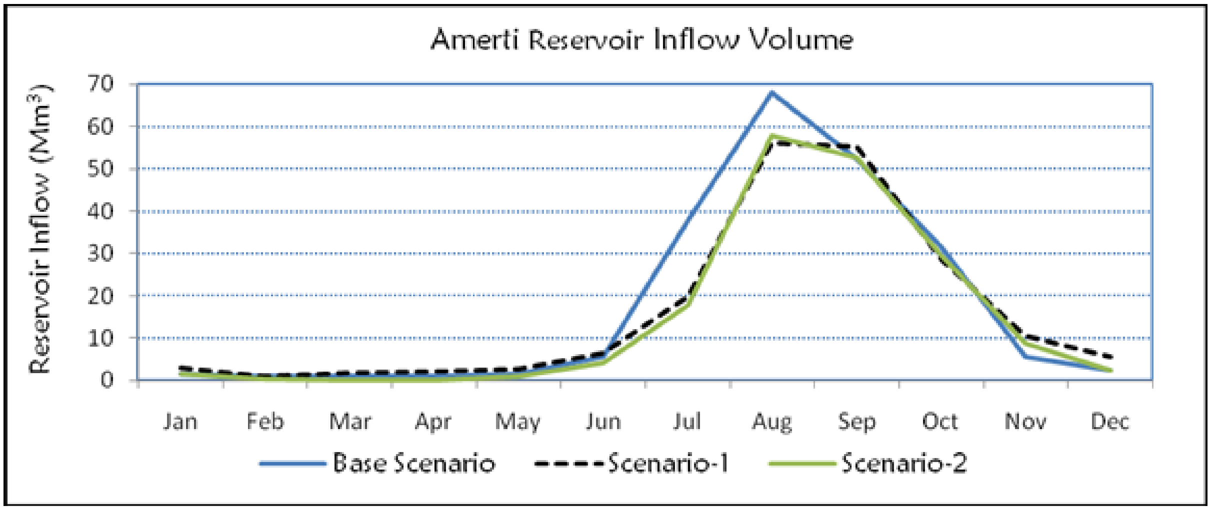
3.3.Climate Change Impact

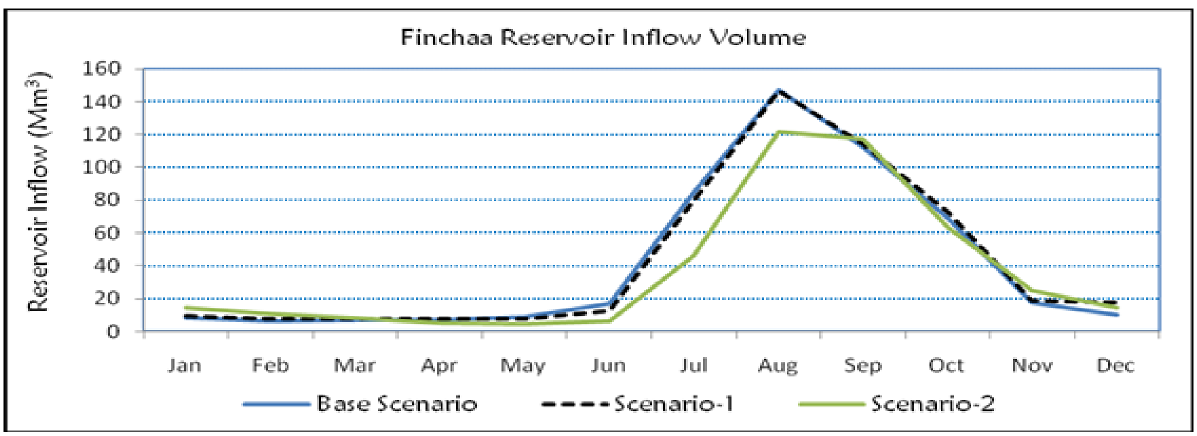
3.3.1. Impact on Streamflow

For comparison purpose, the generated inflow volume to the three reservoirs was compared with the base scenarios (1996-2010) mean monthly flow. Relative to the base scenario, the simulated future inflow to Finchaa and Neshe have shown an average slight increment in volume for scenario-1 and a small decrease in scenario-2. But, simulated future inflow volume to Amerti reservoir has shown a likely small and considerable decrease in scenario-1 and scenario-2 respectively. The results are presented in Table 4 and Figure 10.

Table 4. Change in inflow volume over the period of 2011-2040 for the three reservoirs

Reservoirs	Scenarios	Inflow Volume (Mm^3)	difference (Mm^3)
Finchaa Reservoir	Base scenario	494.00	-
	Scenario-1	502.00	+8.05 (+1.63%)
	Scenario-2	437.63	-16.41 (-11.41%)
Amerti Reservoir	Base scenario	209.36	-
	Scenario-1	192.57	-16.75 (8%)
	Scenario-2	176.14	-33.22 (-15.87%)
Neshe Reservoir	Base scenario	234.08	-
	Scenario-1	238.07	+3.98 (+1.70%)
	Scenario-2	217.05	-17.04 (-7.28%)


Amerti Reservoir Inflow Volume
Reservoir Inflow (Mm3)
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Base Scenario
Scenario-1
Scenario-2


Finchaa Reservoir Inflow Volume
Reservoir Inflow (Mm3)
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Base Scenario
Scenario-1
Scenario-2

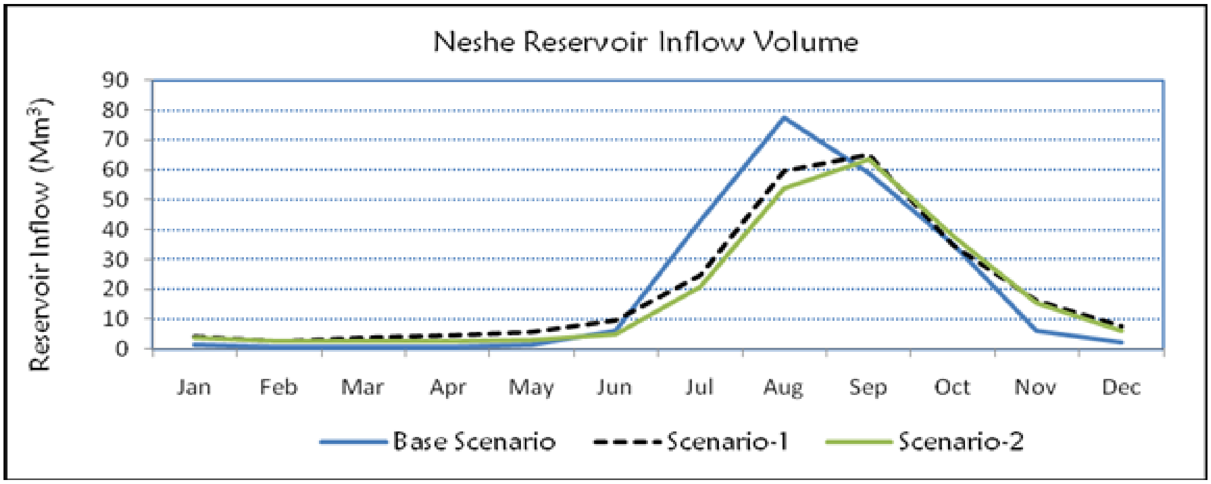


Figure 10. Finchaa, Amerti and Neshe mean monthly reservoirs inflow volume (Mm^3) for different scenarios, respectively.

3.3.2. Impact on Reservoir Storages

The storage of the three cascade reservoirs fluctuates between its top of inactive and top of conservation levels in order to fulfill the demand from multiple users within the sub-basin. In both scenarios, the storage volume in all reservoirs fluctuates by far less than the base scenario. This is not only because of the climate change impact but also because of the increase of the demands from year to year. The storage volumes of all reservoirs are significantly more in the months of August to October (rainy season) but decrease very much after supplied water is delivered to downstream uses from December to May (dry season). Table 5 shows mean monthly storage volume of the three reservoirs under different scenarios.

Table 5. Change in the mean monthly storage volume of the three reservoirs under different scenarios

Reservoirs/Scenarios		Storage Volume (Mm^3)	Difference (Mm^3)
Finchaa Reservoir	Base scenario	10,363.70	-
	Scenario-1	9,364.70	-998.99 (-9.64%)
	Scenario-2	9,091.63	-1,272.06 (-12.27%)
Amerti Reservoir	Base scenario	947.14	-
	Scenario-1	942.11	-5.03 (-0.53%)
	Scenario-2	924.15	-22.98 (-2.43%)
Neshe Reservoir	Base scenario	2,189.42	-
	Scenario-1	2,115.34	-74.08 (-3.38%)
	Scenario-2	1,921.47	-267.95 (-12.2%)

3.3.3. Impact on Reservoir Inflow, Outflow and Hydropower Generation

Inflows and outflows of water for reservoir node and link in the system include calculating withdrawals from supply sources to meet the power, irrigation and water supply demands. This model attempts to optimize coverage of demand site and in-stream flow requirements, subject to demand priorities, supply preferences, mass balance and other constraints. Because the inflow to the reservoirs and storage of reservoirs are impacted due to the changing climate and increasing downstream demand, the inflow and outflow of the three reservoirs in the two scenarios are also affected.

The potential of a given hydropower station to generate power is limited by storage and turbine capacity. The sensitivity of climate to hydropower production is related to the storage of the reservoirs. In addition, turbine capacity (installed capacity) can also limit the ability of schemes to produce hydropower. In this study, it has been investigated that the monthly power generation has shown almost no change during scenario-1 and has shown a slight decrease of 5.9% (-76.25 Gigawatt-Hour) for Finchaa hydropower in scenario-2. However, for Neshe hydropower station, the result has shown no significant deviation when compared with the base scenario.

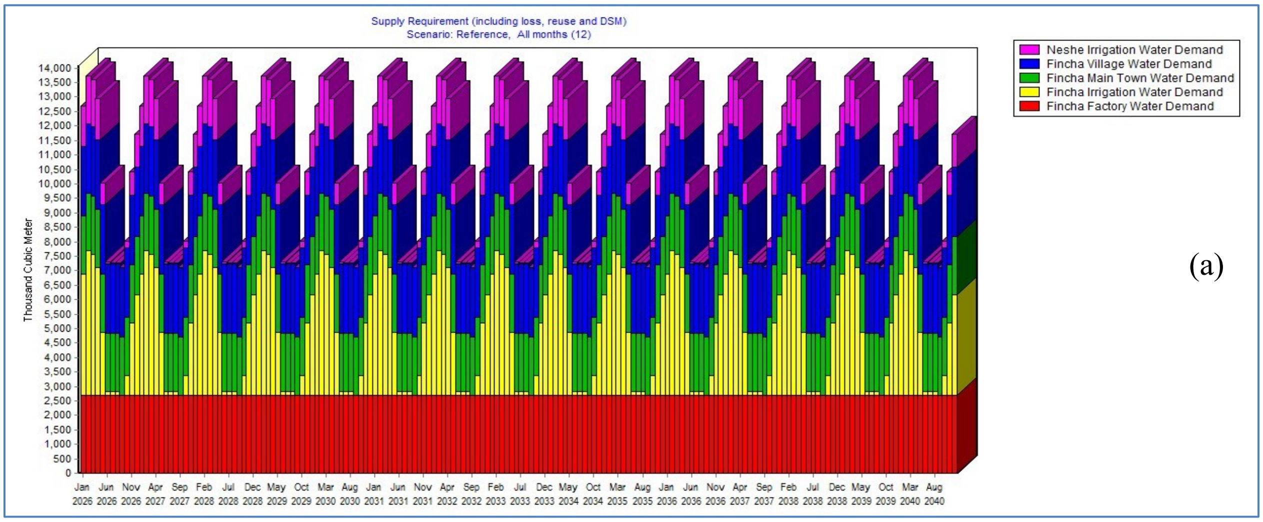
3.3.4. Impact on Demand Coverage and Reliability

Demand coverage is the percent of each demand site's requirement (adjusting for demand site losses, reuse and demand-side management savings) that is met from 0% (no water delivered) to 100% (delivery of full requirement). On the other hand, reliability is the percent of the time steps in which a demand site's demand is fully satisfied. The model results showed that all demand sites in the study area were satisfied with 100% demand site coverage and 98.89% demand site reliability.

Hydropower demands for both Finchaa and Neshe hydropower generations were also satisfied with a 100% hydropower coverage and 92.22% and 100% hydropower reliability for Finchaa and Neshe, respectively. The results obtained are summarized in Table 6. Further, the WEAP model result of supply requirement for various demands/purposes for three scenarios has been worked out. The supply requirement for scenario-1 and scenario-2 has been shown for domestic water supply; irrigation and industrial water demand are shown in Figure 11.

Table 6. Summary of demand site coverage and reliability in the study area

Demands Sites/Parameters	Demand Site Coverage (%)	Demand Site Reliability (%)
Finchaa Irrigation	100	98.89
Finchaa Sugar Factory	100	98.89
Finchaa Main Town	100	98.89
Finchaa Village	100	98.89
Neshe Irrigation	100	98.89
Finchaa Hydropower	100	92.22
Neshe Hydropower	100	100



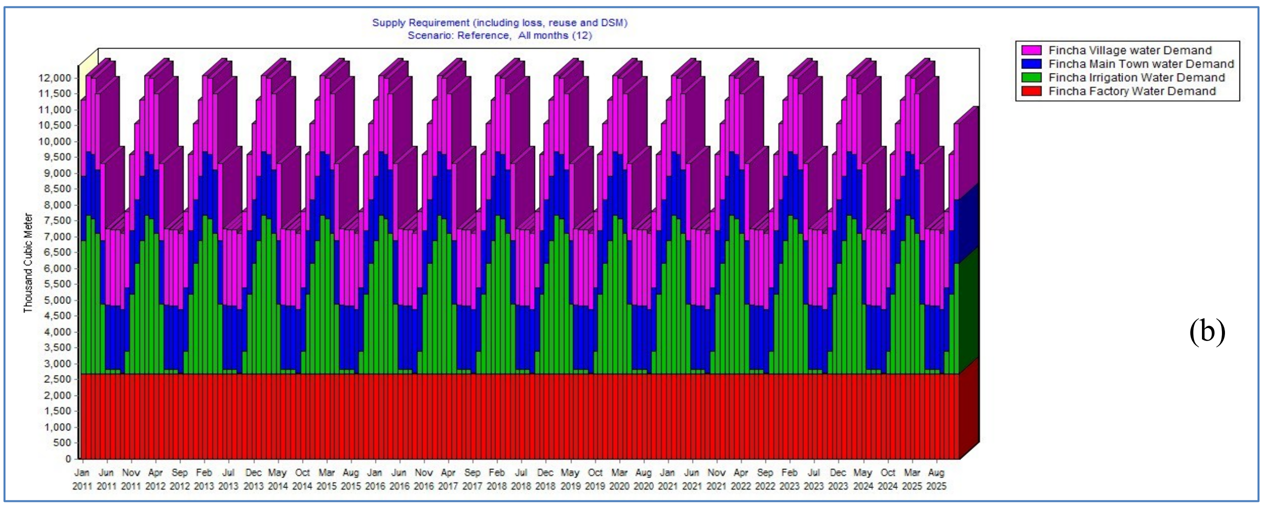


Figure 11**.** Supply requirement in the study area for scenario-2(a) and scenario-1(b)

The demand site coverage and reliability in the study area is analyzed considering the maximum future demand that is expected in both scenarios and the result has shown that almost the water resources fully satisfied the maximum demand with full coverage and reliability. Finally, the study concluded that the fear stated under section problem statement is baseless and unreasonable. The study confirmed that the water resources in the study area are adequate to satisfy the increasing future demand including the government's future development plan. Therefore, it can be believed that the Finchaa Sugar Factory can produce 2.7 million quintals of white sugar as per the plan without a shortage of water under changing climate.

4.Conclusions

In this study, the WEAP model was applied to evaluate the impact of climate change on water availability under the highly increasing future demand conditions. Two future time scenarios were studied consisting of the time period of 15 years each: 2011-2025 and 2026-2040 besides the base period (1996 to 2010) which is mainly used for the purpose of comparison in this study.

Both HBV and WEAP models were calibrated and validated for the study area using the statistical parameters. The results of calibration and validation showed that the HBV model can be used for further simulation of river flows in the study area. The WEAP model which uses the outputs of HBV model has been used to quantify the water availability in the study area. The projected maximum and minimum temperature showed an increasing trend for the next century, but the precipitation doesn't show a significant difference from the current condition. The projected temperature values are within the limits of the earlier projection carried by the IPCC, (2007).

The total water available in the study area was compared with the base period. Mean monthly flow values were used for the purpose of evaluation. It has been observed that the total water availability in the study area is expected to decrease by 1,670.57 Mm^3 (11%) over the period of thirteen years in the study area. From the study, relative to the base scenario, the simulated future inflows to Finchaa and Neshe have shown an average slight increment for scenario-1 and a small decrease in scenario-2. However, simulated future inflow volume to Amerti reservoir is likely to show a small decrease for scenario-1 and considerable decrease during scenario-2.

In both scenarios, the storage volumes in the three reservoirs fluctuate by far less than the base Scenario. This is not only because of the climate change impact but also due to the increase in demands for water from year to year. The storage volumes of all reservoirs are getting increased during the months of August to October (rainy season) but often decrease very much after supplying water to users from December to May (dry season). Similar to the other demands, the water demand for both Finchaa and Neshe hydropower productions are also satisfied in the study area. Therefore, even though the demand is increasing from time to time, the study confirmed that the available water resource is enough to satisfy the increasing demand. The result was simulated using the WEAP model considering the future maximum expansion in the study area and all demand sites in the study area can be fully satisfied.

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