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Full Length Research Article

Development of Water Allocation and Utilization System for Koka Reservoir under Climate Change and Irrigation Development Scenarios: A Case Study of Upper Awash, Ethiopia

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ABSTRACT

The Study was conducted on Upper Awash basin in the Central Rift Valley of Ethiopia, to assess the consequences of climate change and irrigation expansion on current and future water use practices of koka reservoir release for its downstream irrigation water use. Hydrological data were arranged, Meteorological and grid climatic data were correlated with multi-regression and distribution mapping (DM) method separately as an input data source of the WEAP model. The baseline and future irrigation development activities of the area were compared mainly in the two scenarios. First the model calibration, validation and its statistical measures were done. For the climate change scenario, the reservoir evaporation in the baseline period was 404.5Mm3 and for the coming two consecutive 35 years the volume of evaporations is 421.4 m3 and 426.8Mm3 respectively. While compared with the baseline period, the reservoir evaporation increased by 16.9Mm3 and 22.3Mm3 for the coming next two 35 years. In case of irrigation expansions scenario from the total 947.7Mm3 demand of current existing command areas, the supply delivered was 946.7Mm3. The planned irrigation expansions demand is 1659.1Mm3 and the supply will be delivered 1649.3Mm3. From above the unmet will be 711.4 Mm3 and 8.9Mm3 separately. It is concluded from the above finding, unless constructed new projects for additional demand supply the expansion will not meet the demand.

Introduction

Water is not only prejudiced by human activities, but also by natural factors, such as climate change(IPCC, 2007). Hence, the impact of climate change on water resources is the most scenario affecting especially precipitation and temperature, this alters the availability of water flow magnitude, variability and timing of the main flow event are among the most frequently mentioned hydrological issues (Habtom, 2009). According to Intergovernmental Panel on Climate Change (IPCC, 2007d), "Observational evidence from all continents and many natural systems were being affected by regional climate changes, particularly temperature increases and decreasing of precipitation. The developing countries, such as Ethiopia is more vulnerable to climate change because of its economy is extensively dependent on agriculture and natural resources that are sensitive to climate change (Marius, 2009). Water demand is increasing as a result of agricultural expansion and climate change (Ahmed et al, 2015). Awash Basin is one of the country's which highly irrigated and planned to expand in the future (MoWIE, 2014).The koka dam is one of multi-purpose dam for electric power generation and downstream irrigation development uses (OWWDSE, 2014). Therefore, using a decision support system known as the Water Evaluation and Planning (WEAP) Model, quantitative estimates of hydrologic effects of climate change and irrigation expansions are essential for understanding and solving the potential water resource management problems associated with water allocation and planning for irrigation in the coming period. The study was conducted to develop effective water allocation system for Koka reservoir under climate change and downstream irrigation expansion scenarios by considering the following objectives: To evaluate impact of climate change on reservoir water evaporation; To evaluate capacity of reservoir to support downstream irrigation development; To develop effective water allocation techniques under climate change

Materials and methodology

Description of the Study Area

The upper Awash basin lies between longitude *7°52'12" N* and *12°08'24" N*, and latitude *37°56'24" E* and *43°17'24" E*. The Koka reservoir is part of the upper awash sub basin which located at 80 km south east of Addis Ababa between (*8^{o}26'N* and *39^{o}02'E*) at *1590* masl (Zemade, 2011).

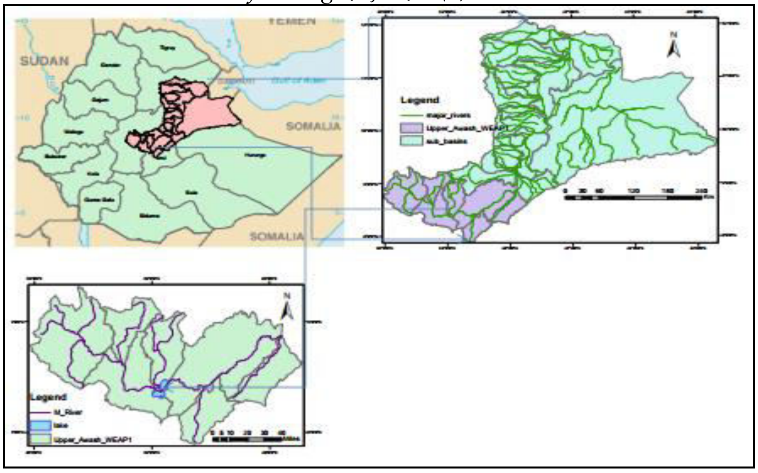
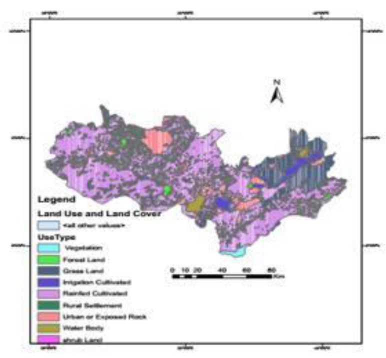


Fig 1:Koka reservoir within upper Awash basin



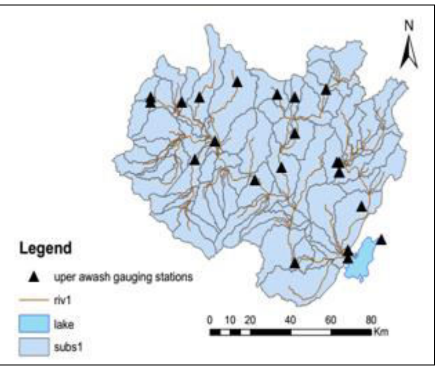


Fig 2: Land use and land cover of upper Awash basin **Fig 3:** Major Metrological stations

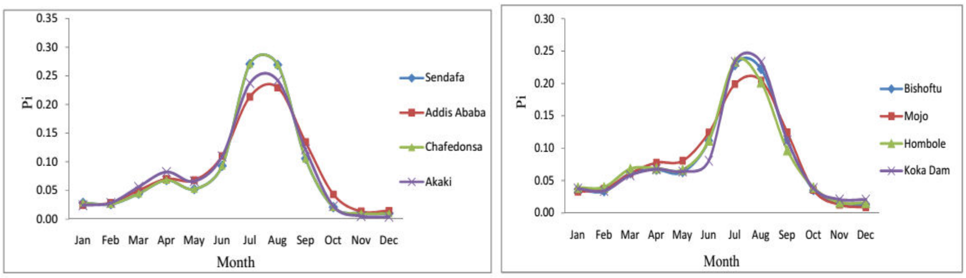
Methodology

The study was conducted starting from November, 21/2015 up to November, 16/2016 for one-year study time. Before starting any model simulation, it is important to check whether the data were homogenous, consistence, sufficient and complete with no missing data, because incorrect data leads to ambiguous results.

Homogeneity test

Homogeneity analysis was used to separate a change in the statistical properties of the time series data. These because of alterations to land use and relocation of the observation gauging station. So, it is carried out by non-dimensional equation:

$P_i = \frac{\overline{P_i}}{P}$ where, Pi is Non dimensional Value of precipitation for the month i, $\overline{P_i}$ is Over years averaged monthly precipitation for the station I, and P is Over year's average yearly precipitation of the station.



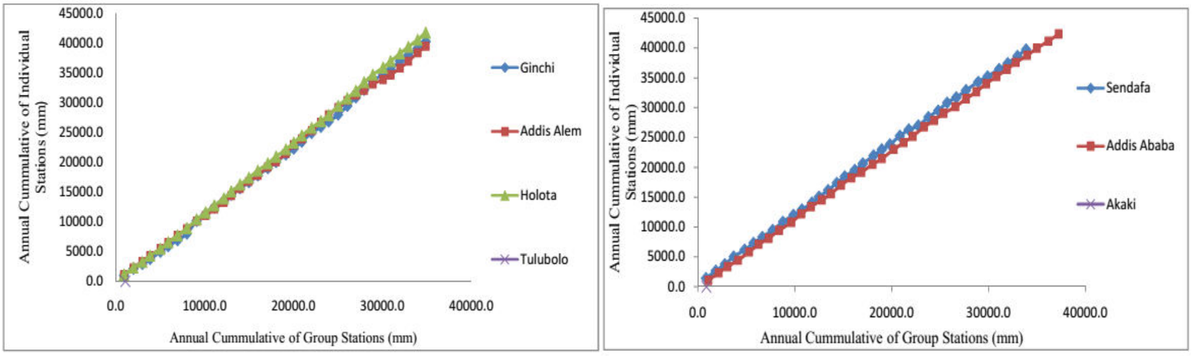
A) Homogeneity test for Sendafa, Addis Ababa, Chafe-donsa and Akaki stations B) Homogeneity test for Bishoftu, Mojo, Hombole and Koka Dam stations

Fig 4: Homogeneity test for selected stations

Consistency test

Consistency of time series data analysed based on theory that a plot of two cumulative quantities that are measured for the same time period should be straight line and their proportionality unchanged, which is represented by slope. Therefore, inconsistency of the record was done by the double-mass curve technique.

$P'_x = P_x \frac{M'}{M}$ Where, Px' is Corrected precipitation at station x, Px is original recorded precipitation at station x, M' is corrected slope of the double mass curve and M is Original slope of the double mass curve.



A) Consistency test for Ginchi, AddisAlem, Holota and Tulubolo stations B) Consistency Test for Sendafa, Addis Ababa, and Akaki stations

Figure 5: Consistency Test for selected stations

Areal rainfall determination

In a given drainage basin rain gauge stations are evenly distributed into sub-basin. The rain is different from station to station in the same catchment. From this idea the average precipitation value is worked out, so as to get the average rain catchments. There are usually three ways of determining the areal precipitation over a catchment from rain gauge measurement. These methods are the Arithmetic means, the Thiessen polygon and the Isohyetal method. TheThiessen polygon was used for this study for its sound theoretical basis and availability of computational tools.

$P_{avg} = \frac{P_1A_1+P_2A_2+P_3A_3+\cdots P_nA_n}{A}$ Where: - P_{avg} is a real precipitation over the sub-basin (mm); P_1, 2…n,is precipitation depth in each station (mm); A_1, 2 …n, is area of each polygon (km^2); A is total watershed area of sub-basin (km^2).

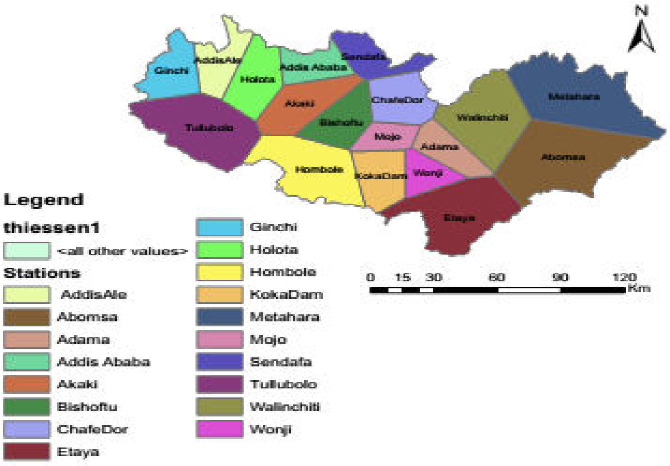


Fig 6: Thiessen polygons for the selected rainfall stations

RCM data correction

Despite of high-resolution climate data provision of regional climate model, first should be corrected by bias correction methods. Thus, the RCM grid data in the upper awash basin were indicated below.

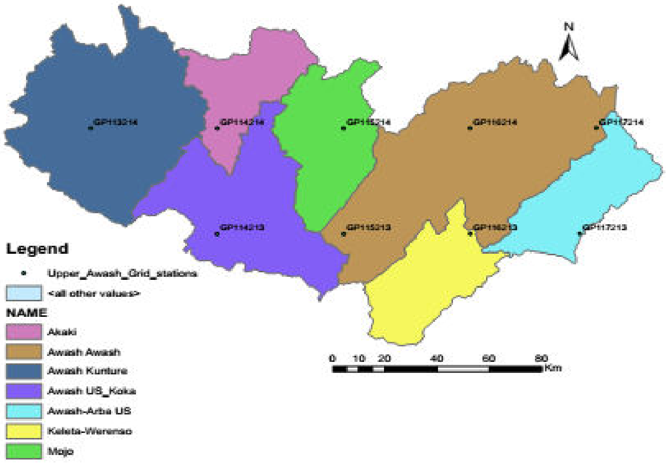


Fig 7: RCM grid data stations in the upper awash basin

The bias corrected was based on the Distribution mapping to match the raw RCM data to that of observation data. It was used to adjust mean, SD and quintiles. The distribution mapping (DM) method considers computing parameters, the Gamma distribution shape parameter (α) and scale parameter (β) often used for precipitation distribution the two parameters were obtained from easy fit software by inputting monthly local intensity scaling corrected and monthly observed data.

$$f_r\left({}^{x}/_{\alpha},\beta\right) = x^{\alpha-1}\frac{1}{\beta^{\alpha}.\ \Gamma(\alpha)}.e^{-x/\beta}; x \geq 0, \alpha, \beta > 0$$

Where,Γ is the Gamma functionSince the raw RCM-simulated precipitation contains a large number of drizzle days, which may substantially distort the raw precipitation distribution, the correction is done on LOCI corrected precipitation $PLOCI_{,m,d}$

$$P_{cor,m,d} = F_r^{-1}\left(F_r\left(P_{LOCI,m,d}/\alpha_{LOCI,m}, \beta_{LOCI,m}\right)/\alpha_{obs,m}, \beta_{obs,m}\right)$$

For temperature, the Gaussian distribution (or normal distribution) with mean μ and SD$\sigma$are usually assumed to fit temperature best.

$$f_N\left({}^{x}/_{\mu}, \sigma\right) = x^{\alpha-1}\frac{1}{\sigma.\sqrt{2\pi}}.e^{-(x-\mu)^2/2\sigma^2}; x \in IR$$

and similarly, the corrected temperature can be expressed as:

$$T_{cor,m,d} = F_N^{-1}\left(F_N\left(T_{raw,m,d}/\mu_{raw,m}, \sigma_{raw,m}\right)/\mu_{obs,m}, \sigma_{obs,m}\right)$$

Where, F_N(.) and F_N^{-1}(.) are Gaussian CDF and its inverse, $\mu_{raw,m}$ and $\mu_{obs,m}$ are observed means for the raw and observed precipitation series at a given month m, and $\sigma_{raw,m}$and $\sigma_{obs,m}$ are the corresponding SDs, respectively.

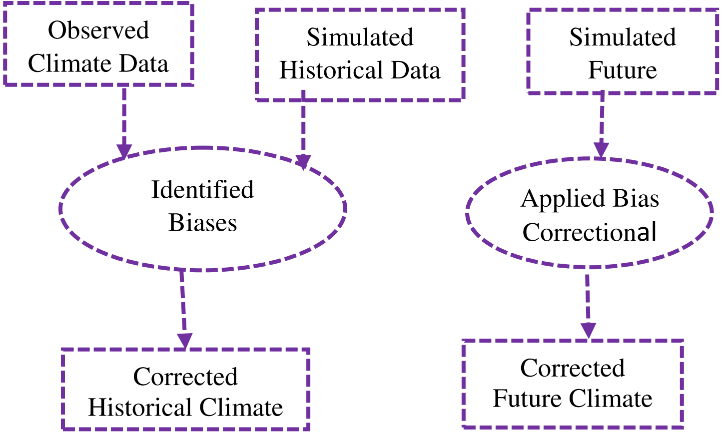


Fig 8: Bias correction framework

RCM data evaluation

The performance evaluation of RCM data corrected against observed precipitation and temperature data. The time series-based metrics include the Nash–Sutcliffe measure of efficiency (NSE), the correlation coefficient (R^2), and the percent of bias (P_{BIAS}) .

$$R^2 = \frac{\sum_{i=n}^{n}\left(P_{obs}^{i}-\bar{P}_{obs}^{i}\right)^2-\sum_{i=n}^{n}\left(P_{sim}^{i}-\bar{P}_{sim}^{i}\right)^2}{\sum_{i=n}^{n}\left(P_{obs}^{i}-\bar{P}_{obs}^{i}\right)^2};$$

$$NSE = 1-\frac{\sum_{i=n}^{n}\left(P_{obs}^{i}-P_{cor}^{i}\right)^2}{\sum_{i=n}^{n}\left(P_{obs}^{i}-P_{obs}^{mean}\right)^2}$$

$$P_{BIAS} = \frac{\sum_{i=n}^{n}\left(P_{obs}^{i}-P_{cor}^{i}\right)*100}{\sum_{i=n}^{n}\left(P_{obs}^{i}\right)}$$

Table 1: Statistical measures of mean monthly corrected RCM precipitations

RCM Grid Data	**NSE**	P_{BAIS}	R^2
GP113214	*0.72*	*9.19*	*0.93*
GP114213	*0.69*	*-1.15*	*0.86*
GP114214	*0.8*	*5.15*	*0.97*
GP115213	*0.81*	*2.97*	*0.95*
GP115214	*0.05*	*-2.16*	*0.9*
GP116213	*0.52*	*-8.5*	*0.85*
GP116214	*0.46*	*16.28*	*0.76*
GP117213	*0.44*	*1.78*	*0.75*
GP117214	*0.5*	*9.81*	*0.76*

The corrected RCM precipitation data time series against observed precipitation as shown blow.

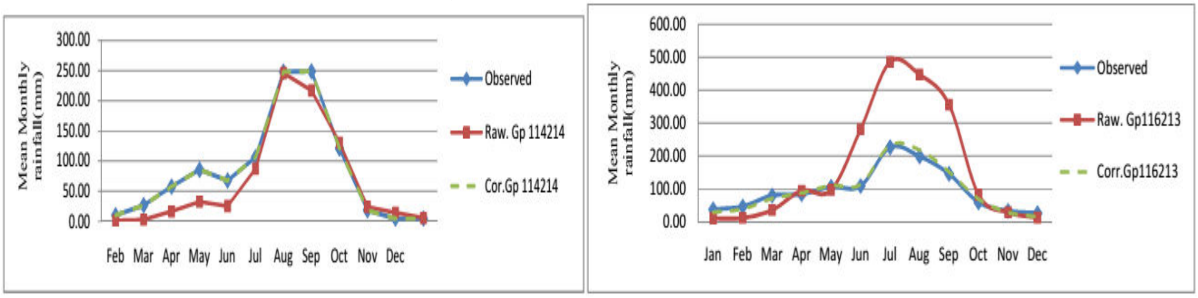


Fig 9: Stations and grid-based comparison of mean monthly rainfall dataset

Steam flow data trend analysis

Due to land use and land cover change on the upper awash basin the stream flow gauging were an overestimated and under estimated stream flow data. Overestimated more indicated on Mojo stream due to rainy season in July and August; in addition to these urbanizations cause high runoff generation like the Akaki gauging station. The second was the under estimation due to land use and land cover change which result in more percolation.

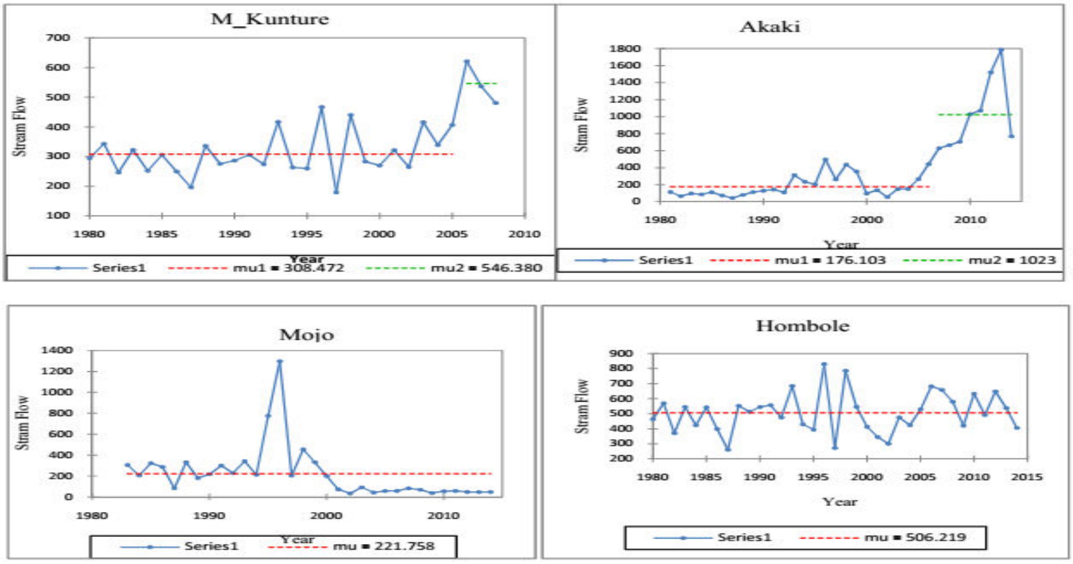


Fig 10: Stream Flow data trend indicator

Configuration of WEAP model

Schematic part of WEAP the boundary of watershed delineated, rivers, demand sites and reservoirs are specified.

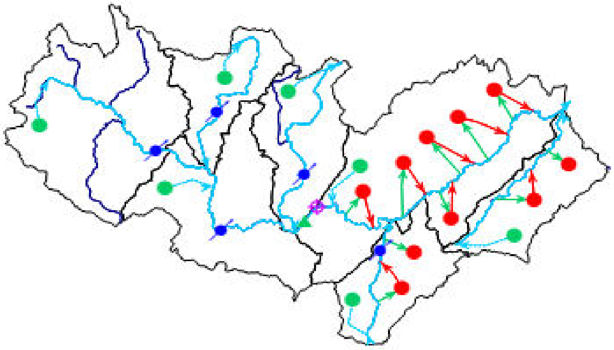


Figure 11: Schematic part of the WEAP model for Upper Awash

Results and discussions

Calibration and Validation results

The graphical and statistical correlation (R^2) and Nash-Sutcliffe (NSE) Coefficient summary comparison of calibration and validation for the major steam stations are shown on Figure *12&13* and in *Table 2* blow.

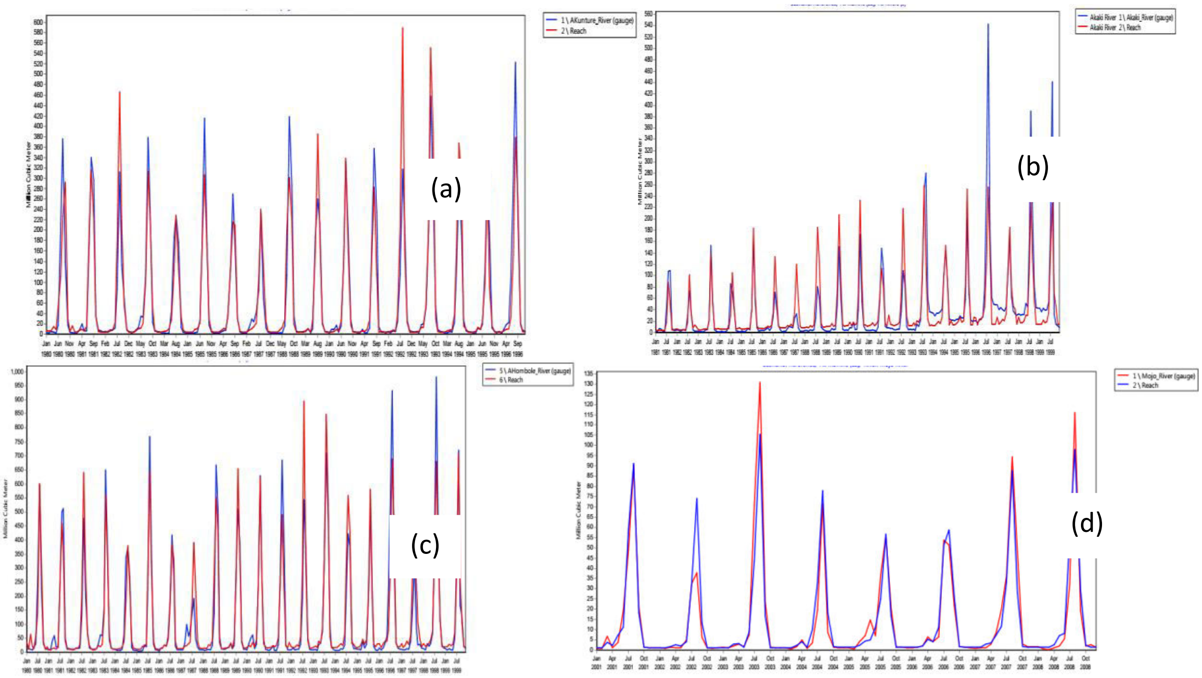


Fig 12: Monthly observed and simulated stream flows for the calibration period at. (a) M/Kunture, (b) Akaki, (c) Hombole, and (d) Mojo stations.

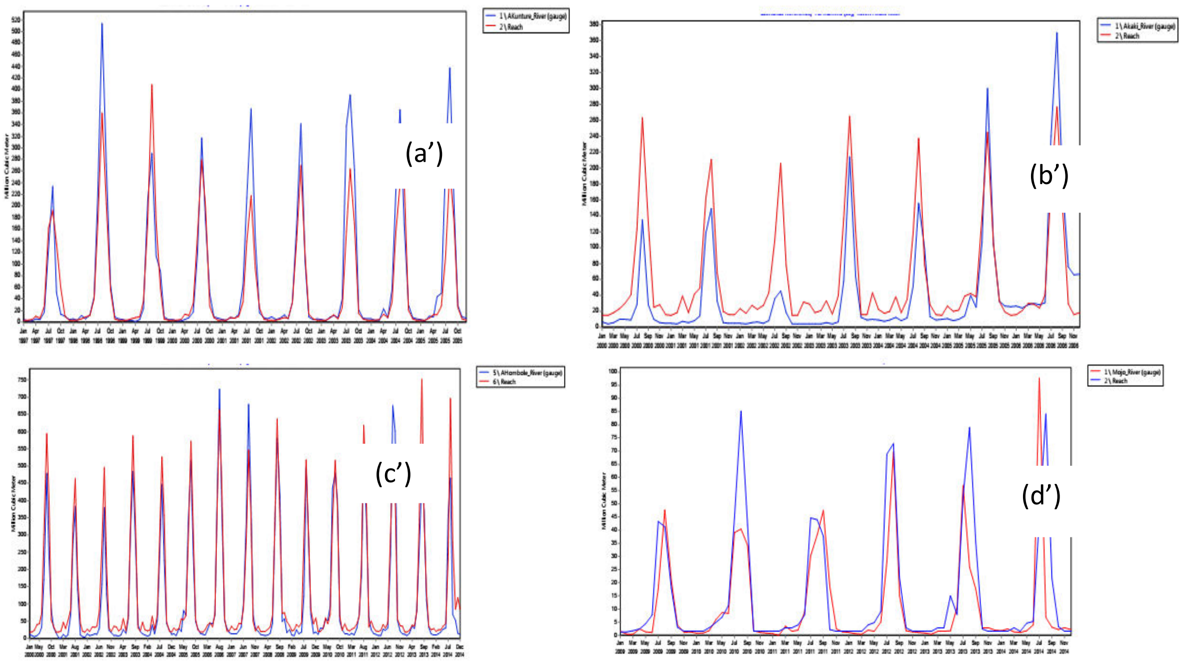


Fig 13: Monthly variation of observed and simulated stream flows for the validation period at; (a’) M/Kunture, (b’) Akaki, (c’) Hombole, and (d’) Mojo.

Table 2: Comparison of calibration and validation of observed and simulated mean monthly Steam flow

Gauging stations	**Calibration Coefficient**		**Validation Coefficient**	
	R^2	**NSE**	**R^2**	**NSE**
M/Kunture	*0.85*	*0.73*	*0.86*	*0.73*
Akaki	*0.73*	*0.65*	*0.63*	*0.50*
Hombole	*0.89*	*0.83*	*0.91*	*0.84*
Mojo	*0.91*	*0.85*	*0.54*	*0.68*

Assessment of steam flow data

The above figures and table, shows that:

The graphical and statistical correlation (R^2) and Nash-Sutcliffe (NSE) Coefficient summary comparison for the major steam stations shows a little difference between M/Kunture, Hombole and Mojo but, Akaki stream flow statistical measure value was less than the other three stations due to land use and land cover change as the result of urbanization. The statistical summary for Nash-Sutcliffe Coefficient (NSE) of calibration and validation period ranges from *0.50* to *0.85* indicating a good agreement between model and observed flows. On the other hand, the Correlation Coefficient ranges from *0.73* to *0.91* and from *0.54* to *0.91* for the calibration and validation period, respectively, showing a very good agreement between simulated and observed data analysis. Larger correlation coefficients exist in the basin stations located, at M/Kunture and Hombolebut, in case of Mojo gauging station the correlation value was much less than the other three stations because of the land use and land cove the of the sub-basin changed after *2000* years which was less amount of runoff generation.

Climate change scenario

Basin temperature

The Figure 14indicated that there will be an increase in average surface temperature of the basin in the future from 18.9^oc to 21.6^oc to24.6^oc consecutive time period. The average monthly basin temperatures are expected to increase more significantly in May.

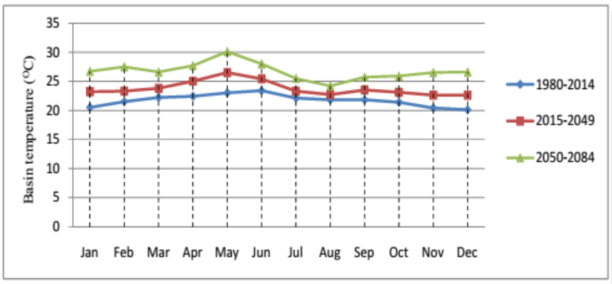


Figure 5. 5Mean Monthly upper basin temperature in deferent time period

Fig 14:Basin temperature

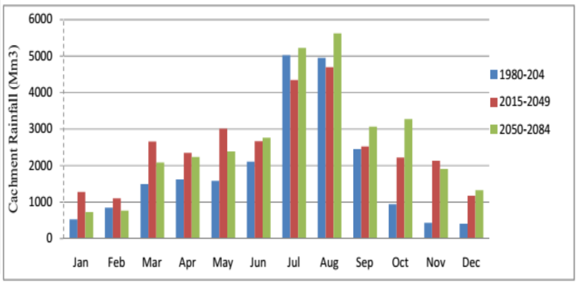


Figure 5. 6 Basin Monthly rainfall variables in deferent time period

Fig 15:Basin rainfall

Basin rainfall

The rainfall over the catchment in the figure *15* above shows a little variation in the baseline year (*1980-2014*) then after great variation for the coming two time period which is for the baseline period was *990.2mm* to*1622.6mm* and *1559.3mm* for the time period of *2015* to *2049* and *2050* to *2084* years respectively. In total there is an increase of rainfall on the watershed in the time.

Evaporation from the reservoir

Table 3: Mean monthly evaporation of koka reservoir (Mm^3)

Period	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
1980-2014	32.0	27.7	36.4	27.6	37.6	38.1	26.1	16.3	38.0	53.8	35.1	35.7	404.5
2015-2049	32.2	28.3	37.0	28.5	38.9	42.6	32.9	17.1	38.6	53.8	35.4	36.1	421.4
2050-2084	32.6	28.5	37.1	29.0	40.1	44.0	33.9	17.7	38.6	53.8	35.4	36.1	426.8

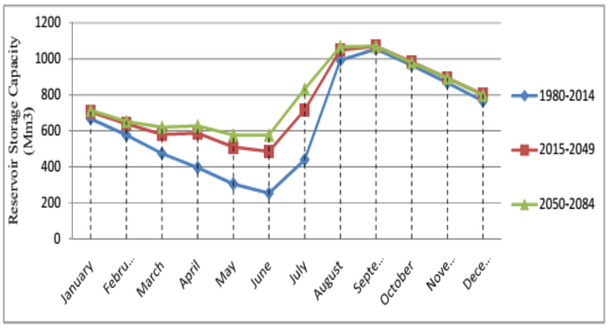
The maximum and minimum net evaporation rate were recorded in Oct and Aug with a value of *53.8* Mm^3 and *16.3*Mm^3 respectively in all of the years and the annual evaporation was *404.5*Mm^3 for (*1980-2014*) years. Similarly, The Koka reservoir monthly evaporation for future time period is shown in the same*table3*above, relative to the baselineperiod will be *16.9*Mm^3*(4.2%)* higher in (*2015-2049*) and *22.3*Mm^3*(5.52 %)* higher in the year of (*2050-2084*). Generally, the reservoir evaporation more in May, June and Oct months of the year this indicates that, the increase in temperature will also increases the average reservoir evaporation.

Reservoir inflows and outflows

Table 4:Monthly inflows and outflows of koka reservoir (Mm^3).

Flow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Sum
Inflow	28.3	21.3	27.5	37.4	34.4	64.8	306.5	656.9	349.2	56.8	28.6	26.7	1638.6
Outflow	84.0	72.6	80.4	77.8	80.1	74.5	80.4	164.8	270.4	80.5	77.8	80.4	1223.5

The inflow of the reservoir maximum at august and minimum at February while the total annual volume of inflow from upstream and the outflow volume to downstream of the reservoir were*1,638.6*Mm^3 and *1,223.5* Mm^3 respectively. In Jan, Feb, Mar, Apr, May, Oct, Nov and Dec there is no rainfall as the result the inflows less than the outflows and the reservoir volume decreased in those months but in Jun, July, Aug, and Sept the inflows greater than the out flows so thereservoir volume become increased. The table 4 above shows the monthly inflows and out flowsof the Koka reservoir in the baseline year. Maximum inflow was in August, but for outflow in September, this is because of concentration time ofrunoff fromremote place of the catchment to rich at outlet of the watershed.



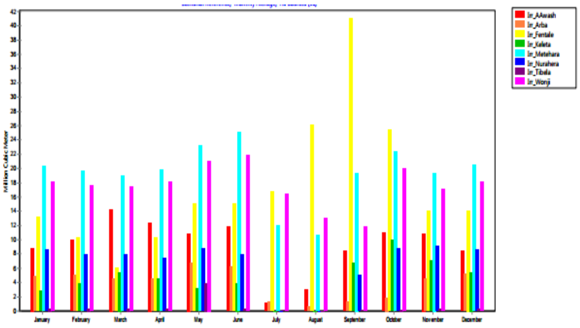


Fig 16: Reservoirs storage capacity Figure 17: Monthly average supplies for all demand sites

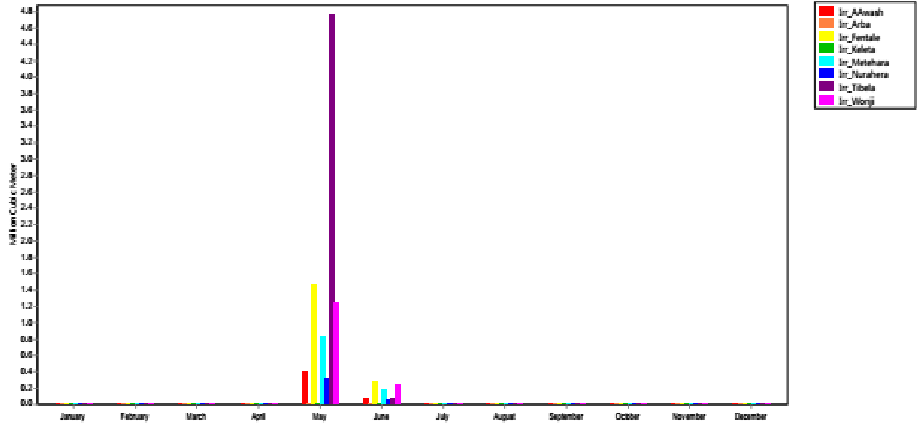


Fig 18: Unmet demand

Reservoir storage capacities

The reservoir storage capacity full, in the rainy months of August, September, and October. The minimum storage was in June while the maximum reservoir storage was in the September. Theannual average koka reservoir capacity under baseline year was *706.6*Mm^3 while, *804.2*Mm^3 and *832.2*Mm^3 in the coming *2015-2049* and *2050-2084* respectively within demand priority given to the reservoirs in the WEAP model was 3. The above result shows that the increments of the storage capacity of the reservoir between top of inactive and top of conservation zone due to temperature and rainfall increment on the catchment. The reservoir can no store beyond the maximum storage elevation of *1590.7 msl.*

Irrigation expansion scenario

Unmet water demand

From total water requirement of the current scenario (*947.7MMC*), *1.0 MMC* (*0.1%*) of the total demandwas unmet. Similarly, in the coming future scenario analysis among the total water requirement (*1659.1 MMC*), the unmet demand observed is *9.8 MMC*. even at present time the keleta Irrigation demand did not met.

Conclusion

The following conclusions has been pinched based on the results obtained in the study.

- The study focused on the major stresses of climate change and irrigation expansion in terms of the water availability at the upper Awash basin.
- The temperature is increase in the coming period as the result of climate change in the region.
- Due to an increase of temperature, there is an incensement of Koka reservoir evaporation in the coming period also when compared to the present baseline.
- Even though the Koka Reservoir water is available, the unmet demand is increased by $8.9Mm^3$ in the coming time period; this is because of the current reservoir flow release is not proportional with irrigation expansion in the future period and the reservoir not store beyond its maximum capacity.
- This study did not take into account the other development; rather than irrigation water allocation at downstream of the reservoir under the two scenarios.

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