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Trend ofLake Evaporation Considering Climate Change, the Case of Lake Hawasa, Ethiopia

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Abstract: ***Nowadays, the sign of climate change and its impact is enlightening on different natural and manmade systems one of the physical system is lake. This study mainly deals with Trend of Lake Evaporation Considering Climate Change on Lake Hawassa, which is found in Rift Valley of Ethiopian. Projection of the future climate variables is done by using General Circulation Model (GCM) which is used for estimating the future climatic condition. Statistical DownScaling Model (SDSM) is applied in order to downscale the climate variables for the study area. The projected future climate variable shows significant increasing trend for both maximum and minimum temperature in A2a and B2a emission scenarios. The study reveal that the evaporation from the open water surface of Lake Hawassa will be expected to increase by 1.65 % and 2.65% under A2a emission scenario in 2020sand 2050s respectively. The open water evaporation might rise by 1 % in 2020s and y 2.47 % in2050s for B2a emission scenario respectively.***

Keywords: Climate Change, Lake Evaporation, GCM, SDSM, Hawasa.

1. Introduction

Weather is the state of the atmosphere at a given time whilst climate is the average weather over a period of time (Thorpe, 2005). Even though the annual periodicity in weather patterns, the Earth's climate has changed many times during the planet's history, with events ranging from ice ages to long periods of warmth (Yehun, 2009).

Human activities, primarily the burning of fossil fuels and changes in land cover and use, are nowadays believed to be increasing the atmospheric concentrations of greenhouse gases. This changes energy balances and tends to warm the atmosphere which will result in climate change. IPCC reports indicate that mean annual global surface temperature has increased by about 0.3 - 0.6 o C since the late 19th century and it is expected to further increase by 1–3.5°C over the next 100 years (IPCC , 2007).

The change on temperature and precipitation components of the can have a direct consequence on the quality and quantity of lake evaporation and of the runoff component therefore, the spatial and temporal water balance, can be significantly affected (Zeray, 2006). Therefore, it is very important to assess the expected impact on the lake evaporation due to expected climate changes. In this study we specifically estimated future Lake Evaporation with respect to base period so, the main objectivewas to quantify the Trend of Lake Evaporation Considering Climate Change.

2. Research Methodology

2.1 Description of Lake Hawasa

This study was conducted in southern nation Nationalities Regional state, Ethiopia.Lake Hawasa is the lake which is found in rift valley of Ethiopia covering an area of 100 km^2, which is located at (6^{0}70'-7^{0}00' N and 38^0 22' – 38^0 29' E) (Halcrow, 2008) .

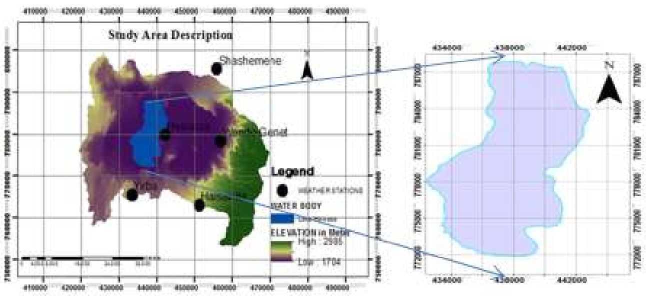


Figure 1: General descriptions of the Lake Hawasa

Lake Hawasa is a closed and situated in a calderal depression. The nested Hawasa-Korbetti Caldera complex forms a giant elliptical depression 30-40 km wide on the rift floor (Woldegabriel, 1987). The Eastern wall (Wondogent escarpment) of the caldera which is about 500 meters high overlaps the eastern rift valley margin.

2.2 Downscaling of Global Climate Models to Watershed Level

The coarse spatial resolution of the GCM led to apply a downscaling model so as to downscale its outputs to suit the study area, Hawasa watershed. The Statistical DownScaling Model (SDSM) version 4.2.9 that is a windows-based decision support tool for regional and local scale climate change impact assessments was selected for this purpose (Wilby *and Dawson,* 2007).

The SDSM rely on empirical relationships between local-scale (predictands) and regional-scale (predictors) to downscale GCM scenarios. Compared to other downscaling methods, the statistical method is computationally inexpensive, relatively easy to use and provides station-scale climate information from GCM-scale output, which can be most needed in many climate change impact studies. Among the different GCMs, the HadCM3 that couples Atmosphere–Ocean General Circulation Model was selected in this study for the prediction and rate of change of future climate. It is selected due to the availability and ease of a downscaling model with sufficient details on predictor files (A2a and B2a) representing the study area. After selecting the scenarios, the future time scales from the year 2011 until 2070 were divided into two periods of 30 years considered (2011-2041 and 2041-70) and their respective changes were determined as deltas for temperature and as percentages for precipitation from the base period values.

Statistical DownScaling Model (SDSM 4.2) developed by Wilby and Dawson (2007) was downloaded freely from http://www.sdsm.org.uk. Downscaling climate data was done by using Statistical DownScaling Model (SDSM 4.2.9). The HadCM3 was employed for A2 and B2 emission scenarios. A2 is medium-low emission scenario; B2 is Medium-High emission scenario (IPCC, 2012).

2.3 Impact of Climate Change on LakeEvaporation

Water balance approach, Mass transfer approach, Energy balance approach, or Penman combination approach and pan evaporation approach are some to estimate evaporation from open water. Due to its demand of usually an available data from most of meteorological stations like surface water temperature, most of the approaches are less applicable to data scarce areas (Dingman, 2002).

Penman (combination) is an approach which does not require surface water temperature and is recommended for estimating free water evaporation (Maidment, 1993).Monthly evaporation over the Lake has been estimated using Penman method based on Hawasa station data (temperature ,precipitation ,wind speed, relative humidity and sunshine hours) for periods of baseline (1978-2000) and future (2020s and 2050s). When estimating evaporation of future (2020s and 2050s), other climate variables as wind speed, solar radiation, and relative humidity were assumed to be constant throughout the future simulation periods.

The Penman or combination equation for estimating open-water evaporation is defined as:

$$\mathbf{E_{open}} = \frac{\Delta}{\Delta+\gamma} * (\mathbf{R_n} + \mathbf{A_h}) + \frac{\gamma}{\Delta+\gamma} * \frac{6.43*(1+0.53U_2)*(e_s-e_s)}{0.1555\lambda} \quad (1)$$

Where $E_{open=}$ open-water evaporation (mm day-1),

R_n = net radiation at the water surface (MJ m-2day-1),

e_s - e_a=vapor pressure deficit (kPa)

Δ is the slope of the vapor pressure curve (kPa °C-1) at air temperature,

γ is the psychrometric constant (kPa °C-1), and

λ is the latent heat of vaporization (MJ kg-1).

A_h= energy advected to the water body, (mm day-1)

In estimating R_n an appropriate value of albedo (α) should be used, which depends on the evaporating surface for open-water α = 0.08. In the Penman equation, it is assumed there is no change in heat neither storage nor heat exchange with the ground, and no advected energy and, hence, the actual evaporation does not affect the over passing air (Dingman, 1992). Data required to apply the equation includes solar radiation (or sunshine hours or cloudiness), wind speed, air temperature and relative humidity, all averaged over the time-step adopted.

In this study Statistical downscaling model were applied in order to meet the objective of this research. The overall step to study the impact of climate change was described by this simple conceptual framework Figure 2.

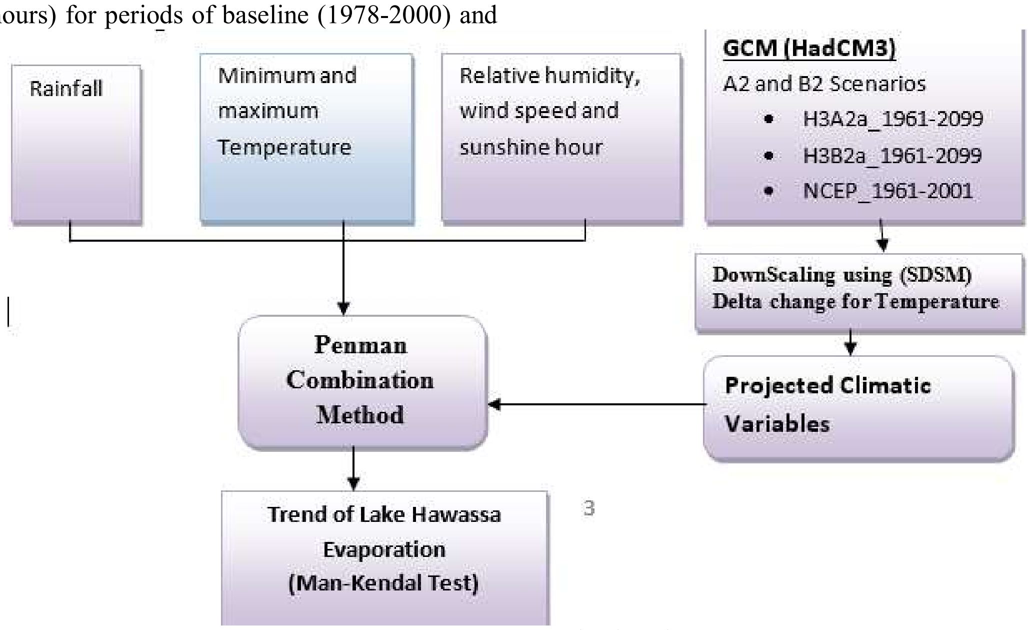


Figure 2: Frame work of study

The model output of HadCM3 was used in this study to simulate the climatic effect of increased atmospheric concentration of greenhouse gases and the climate model output was downscaled to catchment scale using Statistical Downscaling Model (SDSM).

2.4 Trend Analysis

Mann-Kendall test was performed on the monthly and annual Lake Hawasa evaporation to detect the trends in the time series. The test was based upon the null hypothesis of no trend, H_o, i.e. the observations are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing trend. In this study projected mean monthly precipitation, temperature and Lake Evaporation were used. The Mann-Kendall test is applicable in cases when the data values x_i of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i \quad (2)$$

Where $f(t_i)$ is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time.

To test the null hypothesis of no trend, H_o, i.e. the observations x_i are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. In the computation of this statistical test Man Kendall exploits both the so called S statistics given in Gilbert (1987) and the normal approximation (Z statistics). For time with 10 or more data points the normal approximation is used. If n is at least 10 or more the normal approximation test is used. First the variance of S is computed by the following equation which takes into account that ties may be present:

$$VAR(s) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p\text{-}1)(2t_p\text{+}5)] \quad (3)$$

Here q is the number of tied groups and t_p is the number of data values in the p_{th} group. The values of S and VAR(S) are used to compute the test statistic Z Equation 3.

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} \; if \; S < 0 \end{cases} \quad (4)$$

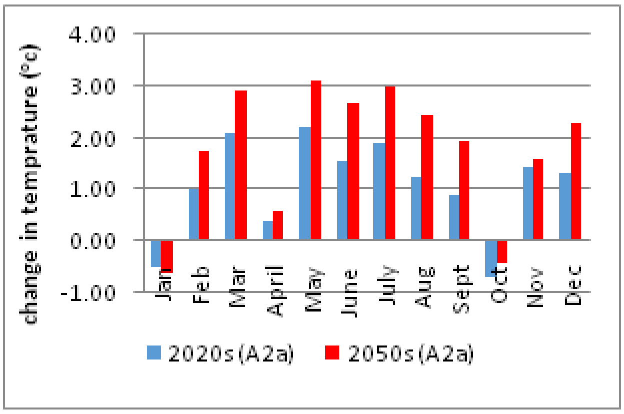
3. Result and Discussions

3.1 Projected Scenarios Developed for Hawasa Station

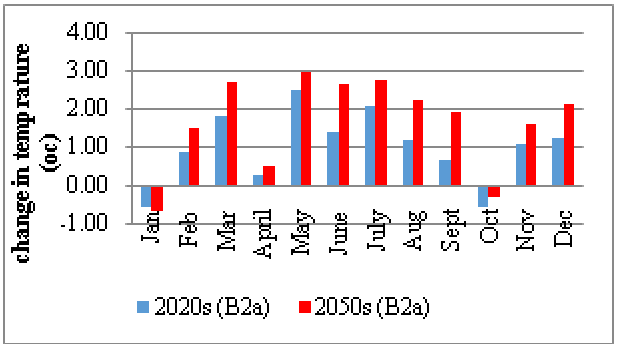
After the calibration and validation of SDSM model carried out, the daily future climate variables are projected (scenarios generated) for the 2011-2070 period using the Had CM3 Global Circulation Model. The projection generates 20 ensembles of daily climate variables, which are equally plausible hence; these ensembles are average dout in order to consider the characteristic so fall those20 ensembles.

3.2 Projected Maximum Temperature

Figure 3 depicts that the projected maximum temperature in 2020s indicated that maximum temperature might rise by 1.07 C^0 and 0.98 C^0 A2a and B2a. Whereas, in 2050s the increment might be 1.8 C^0 and 1.6 C^0 for A2a and B2a scenarios, respectively. This shows that the projected period will experience increasing trend in maximum temperature for both A2a and B2a scenarios. However, the increments will be less for B2a scenario relative to A2a scenario. This is due to the fact that A2a represents medium high scenario which produces more CO2 as compared to B2a scenario which is medium low scenario.



(a) *Maximum temperature A2a scenario*

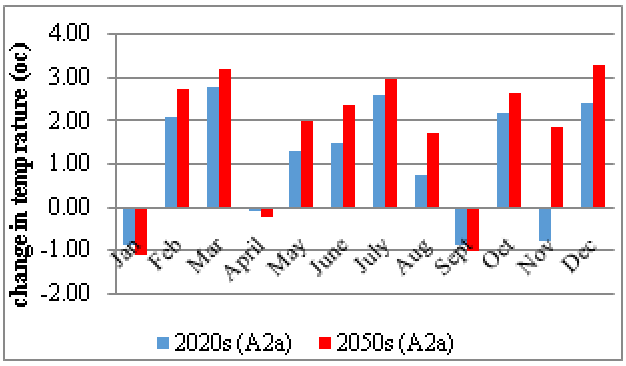


(b) *Maximum temperature B2a scenario*

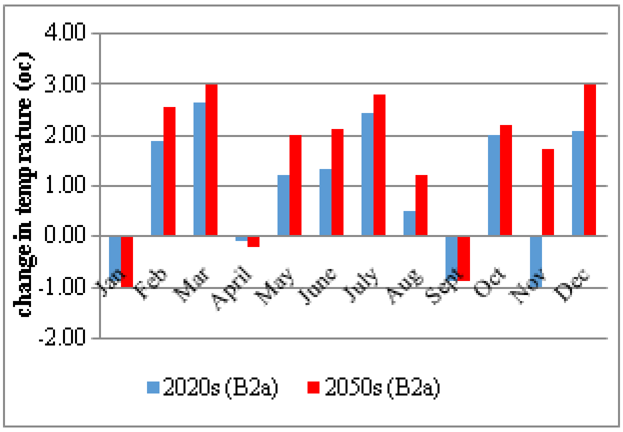
Figure 3: Projected change in mean monthly maximum temperature (delta values)

3.3 Projected Minimum Temperature

As shown in Figure 4 like case of projected average monthly maximum temperature, minimum temperature also reflects increasing trend in future climate periods. The projected minimum temperature for future periods for A2a and B2a scenarios are shown in Figure 3.4. As change of minimum temperature for Hawasa station shows an increment except January, September and November. Additionally, it shows the highest maximum projected minimum temperature will occur during months of February, December and January, July for both A2a and B2a scenarios. The downscaled minimum temperature in 2020s indicated that the minimum temperature will rise by 1.1 C^0 and 0.94 C^0 for both A2a and B2 scenarios. For 2050s the increment will be 1.71 C^0 for A2a and 1.54 C^0 for B2a scenarios respectively.



(a) minimum temperature A2a scenario



(b) minimum temperature B2a scenario

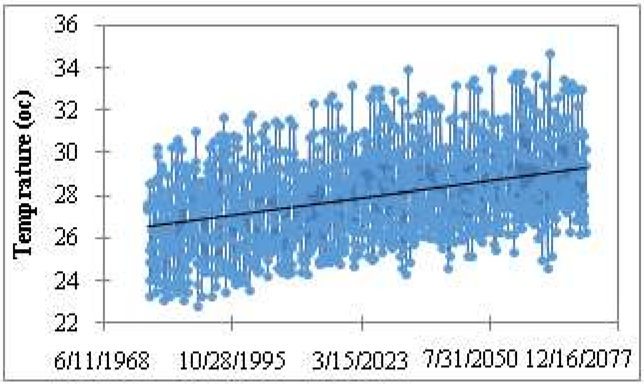
Figure 4: Change in average monthly minimum temperature (delta values)

4. Trend of Projected Temperature and Precipitation

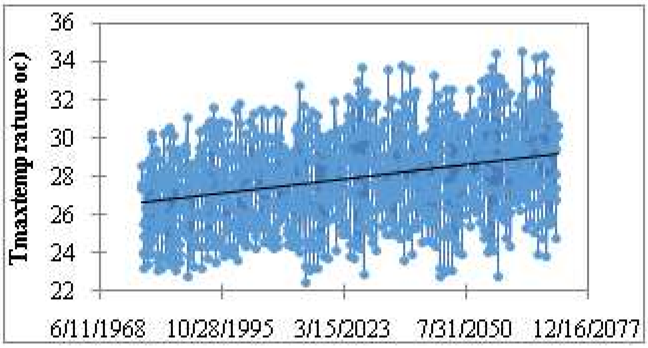
Man Kendall was applied to test trend of monthly average precipitation the result show that the computed p-value is greater than the significance level alpha=0.05, the null hypothesis H_0 cannot be rejected (Table 1).

Table 1: Mann-Kendall trend test of projected climate variables

Variable	Max. Temperature (A2a)	Max. Temperature (B2a)	Minimum Temperature (A2a)	Minimum Temperature (B2a)
Kendall's tau	0.232	0.205	0.233	0.215
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001
alpha	0.05	0.05	0.05	0.05



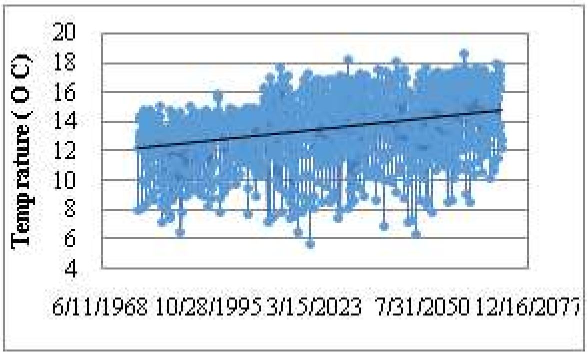
(a) Maximum temperature A2a



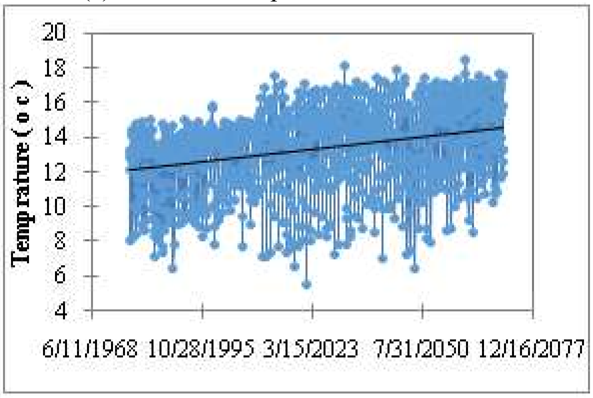
(b) Maximum temperature B2a

Figure 5: Projected t*rends of Monthly average maximum temperature at Hawasa Station (1978-2070)*

The trend test of monthly average maximum and minimum temperature for both A2a and B2a scenarios was performed using Man-Kendall method and the result reveals that the computed p-value is lower than the significance level =0.05,the null hypothesis H_0 rejected, and the alternative hypothesis Ha was accepted (see Figure 5 and 6;Table 1). So, there is a significant increasing trend in monthly average minimum temperature and maximum temperature.



(a) Minimum temperature A2a scenario



(b) Minimum temperature B2a scenario

Figure 6: *Projected trends of monthly average minimum temperature at Hawasa Station (1978-2070)*

Generally, generated future scenarios for the two predictand variables (maximum temperature, and minimum temperature) generally shows significant increasing trend with respect to the base period.

5. Impact of Climate Change on Lake Evaporation

Figure 7 indicates the estimation of Evaporation of January generally decreases at 2020s and 2050s of both A2a and B2a scenarios but, except January in all months shows relative increase at 2020s and 2050s of both A2a and B2a scenarios.

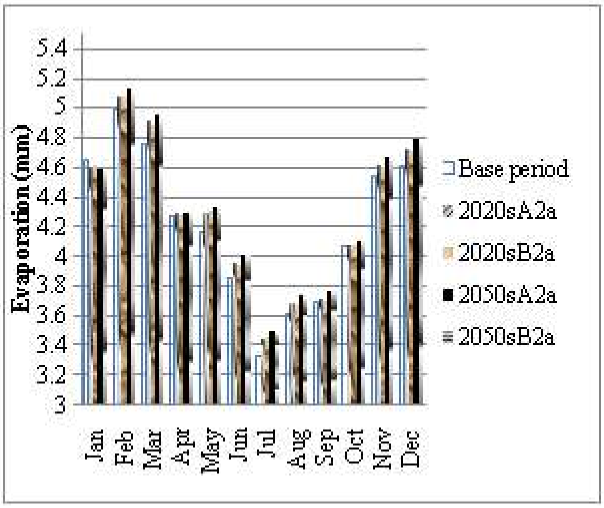


Figure 7: Monthly Average evaporation

In 2011-2040 (2020s) period, the annual Evaporation over the Lake Hawasa might increase by 1.65% and 1.5% for A2a and B2a scenarios relative to base period, respectively and in the 2041-2070 (2050s) period; the annual Evaporation over the Lake Hawasa might increase by 2.65% and 2.47% for A2a and B2a scenarios, respectively.

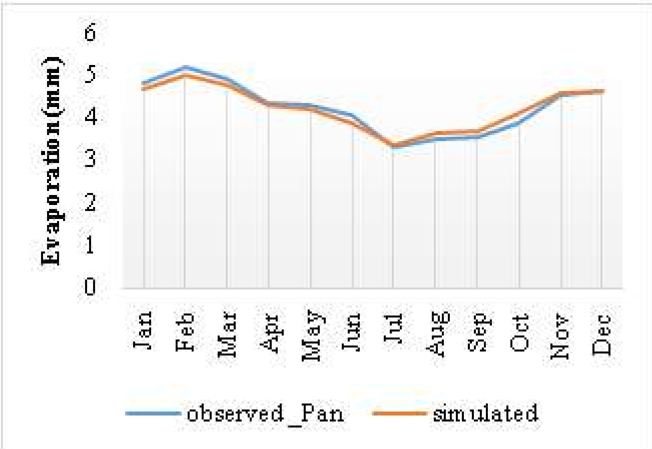


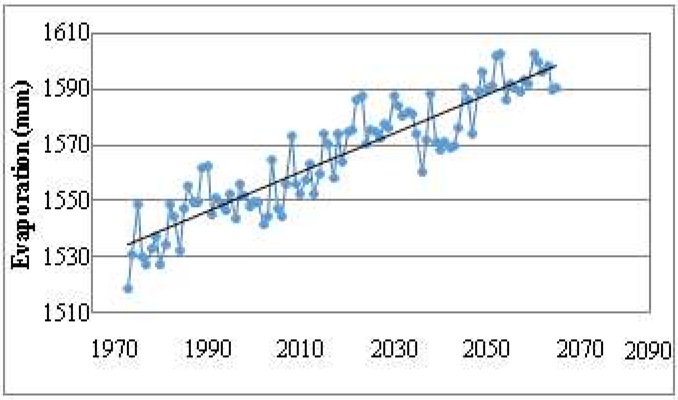
Figure 8: Monthly average observed (Pan Evaporation)

The adjusted pan evaporation based on pan coefficients which is collected from Hawasa meteorological station has relatively good correlation (R^2=0.81) with simulated over lake evaporation, therefore is possible to simulate projected (impacted) lake evaporation.

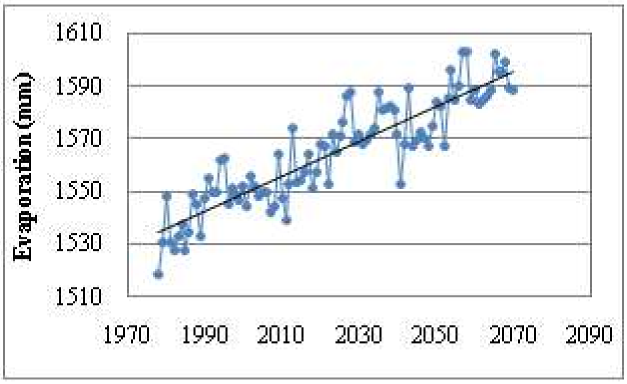
Table 2: Man Kendall Test statistics of Lake Evaporation

Variable	Evaporation (A2a)	Evaporation (B2a)
Kendall's tau	0.741	0.721
p-value	< 0.0001	< 0.0001
alpha	0.05	0.05

The trend of lake evaporation was performed using Man Kendall method and similar test interpretation (hypothesis) was used with temperature the result show as shown in Table 2 and Figure 9 the result show that the computed p-value is lower than the significance level alpha=0.05 so there is a significant increasing trend in annual lake evaporation for both A2a and B2a scenarios.



(a) Evaporation of A2a scenario



(b) Evaporation of B2a scenario

Figure 9: Lake Evaporation of A2a and B2a scenarios (1978-2070)

6. Conclusions

In this studyopen water evaporation was simulated in response to the A2a and B2a emission scenarios. The Statistical Downscaling Model was used to downscale finer and estimate of climatic variables using predictors obtained from the HadCM3 experiment for both A2a and B2a Scenarios and Penman combination was applied to simulate lake evaporation. The study confirmed that the Statistical DownScaling Model (SDSM) is able to simulate all except the extreme climatic events. The average monthly and annually maximum temperature might rise up to 3 °C and 1.8 °C; and the average minimum temperature up to 2.5°C and 1.34°C monthly and annually, respectively. Trend test confirms that the climate change scenarios developed for the years 1978-2070 using the outputs of HadCM3 maximum temperature, minimum temperature, and Lake Evaporation has significant increasing trend.

This study should be extended by considering combined changes in wind speed, relative humidity, solar radiation and etc. in addition to the changes in climate (i.e. precipitation and temperature).

The GCMs was downscaled to catchment scale using the Statistical DownScaling Model (SDSM) which is a regression based model. There also other downscaling methods such as stochastic weather generators and regional should be used other than SDSM.

The output of models depend on the quality of the input data, Lack of reliable climate data was one of the challenges in this study. Hence, responsible bodies (i.e. National meteorology agency) should give due care to the acquisition and recording of consistent data.

Watershed based integrated water resources management approach should be a central part of the whole climate change adaptation option and ensure sustainability, intersectoral collaboration is essential. Different stakeholders need to participate at all levels of the water resources development and management activities in protecting Lake Hawasa. Each stakeholder or users shouldinvolve in the process has different functionsfrom water law and policy making, regulation, technical assistance and coordination, up to monitoring and evaluation, awareness creation and participation.

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