SIMULATING STREAMFLOW IN RESPONSE TO CLIMATE CHANGE IN THE UPPER EWASO NGIRO CATCHMENT, KENYA

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ABSTRACT

The study simulated streamflow response under changing climate for Ewaso Ngiro river in Upper Ewaso Ngiro Catchment (UENC), using Soil and Water Assessment Tool (SWAT). Data from National Centre for Meteorological research (CNRM) model of Co-Ordinated Regional Downscaling Experiment (CORDEX) was used to generate climate change scenarios (temperature and rainfall) for representative concentration pathway (RCP) 4.5 and 8.5 from 2021-2080 relative to the baseline 1976-2005. SWAT model was set up using historical daily rainfall and temperature data, soils, Digital Elevation Model and land cover map, and calibrated against observed streamflow. Decreasing trend in historical rainfall and streamflow was observed while increasing trend was observed for temperature. Projections indicated increasing trend in temperature in both RCPs, with RCP 8.5 having higher increase (1.1-2.6°C) than RCP 4.5 (1.0-1.7°C). Rainfall was found to increase from March-November, and decreased in December-February in all scenarios. Change in total annual rainfall ranged from 0.1-18.5% in 2021-2050 and 1.2-18.7% in 2051-2080, which corresponded to increase in streamflow of 20.9-23.6% and 21.2-28.2% respectively. Streamflow in March-May decreased (-26 to -10%) in all scenarios and increased in June-February (9-114%). This was found contrary to streamflow patterns simulated in neighboring catchments where studies indicate increasing streamflow trend in March-May. Streamflow response was found to be sensitive to changes in rainfall, thus emphasis should be put on water conservation and catchment management including protection of headwater forests through agroforestry, afforestation and reforestation.

Key words: Climate change, Streamflow, Simulation, Upper Ewaso Ngiro Catchment

1. INTRODUCTION

Water resources are irregularly distributed in time and space and are under pressure due to human activities and climate change (Cosgrove & Rijsberman, 2014). Availability of fresh water resources is dependent on the prevailing weather and climatic conditions of a region, with negative impacts being felt during extremes of these conditions. Excessive heating of the earth’s surface from global warming results into high evaporation rates leaving the surface dry, thereby increasing intensity and duration of droughts (Trenberth, 2011).

In Ewaso Ngiro, Kenya, annual mean actual evapotranspiration (Eta) increased gradually from 2000 to 2006 at an annual rate of about 15%, with studies indicating that increased evapotranspiration greatly affects fresh water resources (Wu et al., 2012). Previous studies have demonstrated that climate change would influence river’s streamflow (Tao et al., 2014, Kim et al., 2013, Barros et al., 2014, Bates et al., 2008, Dessu & Melesse, 2013).

A study by (Mango et al., 2010) revealed that Upper Mara basin was vulnerable to extremes in projected rainfall changes. They found out that increase in rainfall in the basin was between 5-10% while increase in temperature was between 2.5-3.5° C. Climate change scenarios in Nzoia catchment as stated by (Githui et al., 2009), indicated an increase in rainfall between 2.4-23.2%, increase in temperature of 0-1.7° C and change in streamflow of 6-115%. In larger Mara basin (Dessu & Melesse, 2013) found that annual rainfall increased in 2046-2064 and 2081-2100 with 30-50% increase in March-May season, <10% increase in June-August and over 50% increase in December-February. Annual increase of 2-6% was observed in 2046-2064 while in 2081-2100, -1-11% increase was observed for rainfall. They also observed increase in average temperature between 3° C and 4° C with A1B scenario having the largest decrease and B1 having the least increase.

Negative impacts of reduced water availability become more profound during drought seasons which are characterized by low streamflow levels of river. Upper Ewaso Ngiro Catchment (UENC) experiences these challenges, with studies indicating that streamflow from Ewaso Ngiro River have been declining in the last two decades leading to conflicts between upstream and downstream users (Ericksen et al., 2012, Ngigi et al., 2008). Although human activities contribute to the declining streamflow of Ewaso Ngiro river through abstractions, climate change through increased frequencies of floods and droughts is expected to induce additional risks to the already declining levels of the river, but there is little insight into the effects of climate change on the availability of water in the catchment.

In assessing the impacts of climate change on river flows, hydrological models have proven to be very useful. As stated by (Notter et al., 2007), hydrological models have proven to be useful for investigating the relationship that exists between
climatic parameters, human activities, surface and underground water resources. Many studies have applied hydrological models to investigate the impacts of climate change on runoff and river flows, including (Vörösmarty et al., 2000, Hagemann et al., 2013, Chaplot, 2007, Dessu & Melesse, 2013, Ficklin et al., 2009, Kathumo et al., 2011, Kim et al., 2013, Schneider et al., 2013, Willy Bauwens, 2009).

The overall objective of this study was to simulate streamflow in response to climate change in UENC. The specific objectives were: (1), to determine the trend in historical rainfall, temperature and streamflow in Upper Ewaso Ngiró Catchment (UENC); (2), to determine the future climate change scenarios over UENC and (3), to assess the impacts of climate change on River Ewaso Ngiró’s streamflow.

2. MATERIALS AND METHODS

2.1 Data

Data from CNRM model of CORDEX was used to generate climate change scenarios in terms of rainfall and temperature, and assessed their changes with respect to the baseline (1976-2005), while SWAT model was used in simulating streamflow in response to the climate scenarios generated. Observed daily temperature and rainfall data for Naromoru and Archer’s Post meteorological stations was obtained from the Kenya Meteorological Department (KMD) and covered the period 1976-2005. Daily streamflow data (1987-2010) for Ewaso Ngiró River, at Archer’s Post river gauging station was obtained from Water Resources Management Authority (WARMA). Soil data was obtained as a Digital map of scale 1:1 from International Soil Reference and Information Centre (ISRIC 2016), Digital Elevation Model (DEM) of 100 m resolution from United States Geological Survey (USGS) and land use map of year 2003 from Regional Centre for Mapping and Resource Development (RCMRD).

2.2 Description of the area of study

The catchment (Figure 1) traverses six counties namely; Nyandarua, Laikipia, Samburu, Isiolo, Nyeri and Meru. UENC lies to the north east of Mt. Kenya and the Nyandarua (Aberdares) range between the coordinates 36°0’00” E, 38°0’0” E and 1°0’0” S, 1°30’0” N. It covers an area of approximately 15,000 square kilometers.

The main river originates from the Nyandarua ranges, while the tributaries come from Mt. Kenya and they supply most of the flow in the river (Mati et al., 2008). Some of the tributaries of the river are; Timau, Ontulili, Naro Moru, Teleswani, Burget, Isiolo, Kongoni, Pesi, Sirimon, Nanyuki, Ewaso Narok, Likii and Timau which later converge forming the Ewaso Ngiró river that flows through Archer’s Post.

Temperatures in the upper parts of the catchment range between 9° C -22° C while at lower parts of the catchment temperatures range between 15° C -29° C (Mutiga et al., 2011). High population growth rates have been experienced in the upper parts of the
catchment (4-8%) where the presence of arable land favors agricultural activities (Gichuki, 2004).

Figure 1: Map showing location of Upper Ewaso Ngiro catchment

Highlands receive over 1200 mm of rainfall per year with tri-modal rainfall pattern, with long rains being experienced between April-June whereas short rains experienced between October and December and the third season of rainfall being experienced between July and August. Lowlands receive between 300-600 mm yearly with bimodal rainfall pattern, short rains between October and December being most useful. The Potential Evapotranspiration (PET) in the catchment is between 1200 to 1800 mm per year (Ericksen et al., 2012). Land uses within the catchment comprise of agricultural lands owned by agribusinesses and smallholder farmers, trust lands, private wildlife conservancies and cattle ranches managed by both pastoralists and commercial enterprises. Parks and protected areas are also present and they cover less than 10% of the area with great diversity of wild animals.

2.3 Trend in observed hydro-climatic data

Mann Kendall (MK) trend test at 5% significance level was used in trend detection while Pettit test was used in change point detection i.e. year when shifts in the mean of a particular variable occurred.

2.3.1 Mann Kendall (MK) trend test

MK trend test is a non-parametric trend detection method that was developed by (Mann, 1945, Kendall, 1975) and has widely been applied in several studies. The World Meteorological Organization (WMO) recommended use of MK trend test for assessment and characterization of meteorological data trends. MK has since been considered a robust method over many parametric tests because it is insensitive to missing data and outliers. As stated by (Gocic & Trajkovic, 2013) the test requires raw hydro-meteorological data to detect the possible trends and the method was originally devised by Mann (1954) and later by Kendall (1975). The test assumes existence of one data value at a specific time period, and a median value is used in the case of multiple data points at a time. A data value is compared to subsequent values and MK statistic $S$ is incremented by one each time a value from a later period is higher than the previous value. $S$ is decreased by one if a value is lower than the previous one and the net result is what is presented as MK statistic $S$ in the results. Positive values of $S$ indicate an increasing trend while negative values of $S$ indicate a decreasing trend. The test statistic $S$ is calculated using equation 1:

$$S = \sum_{i=1}^{n-1} \left( \frac{X_{i+1} - X_i}{X_{i+1} + X_i} \right)$$
\[ S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \]  \hspace{1cm} (1)

Where:

- \( x_i \) and \( x_j \) are the data values in the time series,
- \( n \) is the number of data points in the time series,
- \( sgn(x_j - x_i) \) is a sign function such that:

\[
sgn(x_j - x_i) = \begin{cases} 
1 & x_j > x_i \\
0 & x_j = x_i \\
-1 & x_j < x_i 
\end{cases}
\]  \hspace{1cm} (2)

The variance \( S \) is calculated using the following equation when the value of \( n \geq 8 \):

\[
Var(S) = \frac{n(n - 1)(2n + 5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)}{18} 
\]  \hspace{1cm} (3)

In equation (3):

- \( n \) is the number of data points in the data series,
- \( q \) is the number of tied groups (a tied group is a set of data having the same value),
- \( t_p \) is the number of ties of \( p \) extent.

The standard normal test statistic is calculated using the following equation:

\[
Z = \begin{cases} 
\frac{S - 1}{\sqrt{Var(S)}} & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
\frac{S + 1}{\sqrt{Var(S)}} & \text{if } S < 0 
\end{cases} 
\]  \hspace{1cm} (4)

From the above equation, positive values of \( Z \) will indicate an increasing trend while negative values of \( Z \) will indicate decreasing trends.

### 2.3.2 Pettit test

Pettit test is a method of abrupt changes and change point detection developed by (Pettit, 1979) and has been used widely in hydro-meteorological studies including (Mallakpour & Villarini, 2016, Guerreiro et al., 2014, Khisa et al., 2013, Radivojevic et al., 2015). The method tests for a change in the mean of a data series by a non-parametric K-statistic as follows (Equation 5):

\[
K_T = \max|U_{t,T}|, where U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} D_{ij}, D_{ij} = sgn(X_i - X_j), sgn(r) = \begin{cases} 
-1, & r < 0 \\
0, & r = 0 \\
1, & r > 0 
\end{cases} 
\]  \hspace{1cm} (5)

Where:

- \( x_i \) and \( x_j \) are the data values in the time series,
- \( K_T(+) \) indicates an upward shift in the mean of observations,
- \( K_T(-) \) indicates a downward shift in the mean of observations.
- \( t \) is the point of change.

### 2.4 Generation of climate change scenarios

Data from National Centre for Meteorological research (CNRM) model of Coordinated Regional Downscaling Experiment (CORDEX) was used to generate future climate change scenarios for the
catchment from the year 2021-2080, which is a span of 60 years. CORDEX is a climate projection framework with different Regional Climate Model (RCM) simulations including experiments of new simulations of greenhouse gases, carbon cycle and feedback mechanisms (Giorgi et al., 2009). RCMs within CORDEX include; National Centre for Meteorological research (CNRM), Max Plank Institute (MPI) developed by Max Plank Institute of meteorology- Germany, Hadley Center (HadGEM2-ES), Earth System Model of the EC-Earth Consortium, Model for Interdisciplinary Research on Climate (MIROC) jointly developed by the University of Tokyo, NIES and JAMSTEC, National Oceanic and Atmospheric Administration (NOAA), National Climate Centre (NCC) and Canadian Centre for Climate Modelling and Analysis (CCCMA) model developed by Climate Research Division of Environment Canada.

The spatial resolution used by CORDEX is 0.44° which is equivalent to approximately 44 km grid resolution and is based on Representative Concentration Pathways (RCPs) which are stabilization levels of radiative forcing as a result of the concentration of greenhouse gases by the end of 21st century. Four RCPs were selected within CORDEX and they include RCPs 2.6, 4.5, 8.5 and 6.0 which correspond to warming of 2.6, 4.5, 8.5 and 6.0 W/m² respectively. RCPs 4.5 and 8.5 were selected for climate scenarios generation. RCP 4.5 is a stabilization scenario that assumes introduction of emission mitigation policies, although temperature will continue to rise due to inertia in the climate system (Peters et al., 2013), while RCP 8.5 assumes no mitigation measures and temperatures will continue increasing up to 2100 due to continued emission of greenhouse gases (Van Vuuren et al., 2011, Moss et al., 2010).

One RCM model was chosen on the basis of validation between observed climatic data and the model’s historical data. A box plot of all the RCMs together with observed data used to determine which model had a close resemblance to the observed station’s climatic data. From the boxplot, two models (NCC and CNRM) were in close resemblance to the observed data and further statistical tests using correlation coefficient (R²) revealed that CNRM had a higher R² value (0.62) as compared to NCC (0.38). CNRM was therefore selected for use in generating climate change scenarios.

Data from CNRM model was downloaded and used to extract data for UENC. A script for extracting the data was prepared and Grid Analysis and Display System (GRADS) was used to run it in order get the climate change scenarios in UENC.

The period between 2021 and 2050 was referred to as ‘2030s’ while the period between 2051 and 2080 was given the abbreviation ‘2060s’. Mann Kendal (MK) trend test was used to detect trend in rainfall and temperature. Change in climatic parameters (%) was then identified using equation 6 which was
adopted from (Neupane et al., 2015), with a baseline of 1976-2005.

\[
\text{% change} = \frac{\text{Future scenario} - \text{baseline}}{\text{baseline}} \times 100\% \tag{6}
\]

2.5 Implication of climate scenarios on streamflow

Climate change scenarios generated from section 2 was used as input to SWAT model in order to simulate future streamflow of Ewaso Ngiro river. Arc SWAT for ArcGIS 10 interface (of SWAT 2012) was used. Inputs for setting up the model were observed daily precipitation, maximum and minimum temperature, land use map, soil map and digital elevation model (DEM). The model further generated relative humidity, solar radiation, and wind speed with respect to the observed temperature data. SWAT utilizes the basic water balance method for modelling of hydrological responses described using the components below.

**Precipitation** = Change in Soil Water + Evaporation and Transpiration + Percolation on to shallow aquifer + Surface Runoff + Return Flow + Lateral Flow

2.5.1 SWAT model sensitivity analysis, calibration and validation

Sensitivity analysis, calibration and validation was done in order to better parameterize SWAT to the set of local conditions within the catchment, thereby reduced the prediction uncertainty. Automatic calibration was performed in Sequential Uncertainty Fitting (SUFI-2) algorithm of SWAT calibration and uncertainty programs (SWAT-CUP) (Abbaspour et al., 2007) where 500 iterations were performed. Different parameters were changed in each iteration and at the end of the process, the model selected a best match of simulated streamflow to the observed streamflow. This was accompanied by a number of different parameters which were successfully changed, and the new values of these parameters were used in the validation process. Streamflow data for the years 2000 -2005 was used for this purpose.

Validation involved running the model again using the changed parameters from SWAT-CUP in order to determine whether the results of the model can represent real data satisfactorily. Streamflow data for the period 1995-2000 was used for the process. Model evaluation was done using coefficient of variation ($R^2$), Nash-Sutcliffe efficiency (NSE), and ratio of the root mean square error to the standard deviation of measured data (RSR), methods which are recommended by (Moriasi et al., 2007).

2.5.2 Streamflow simulation

The modelled climate change (rainfall, maximum and minimum temperatures) scenarios together with other input requirements for SWAT were used in the already calibrated and validated SWAT model to simulate streamflow response to climate change. Soil and land use maps were first reclassified to meet the required format used by SWAT, and precipitation
and maximum and minimum temperature data were also prepared in a relevant format acceptable by the model. Trend in the simulated streamflow was identified using MK trend test while changes (%) in streamflow with respect to the baseline was carried out using equation 6.

3. RESULTS AND DISCUSSIONS

3.1 Trend in historical hydro-climatic data

Results from MK trend analyses indicated an increasing trend in historical maximum and minimum temperatures at Naromoru and Archer’s Post stations (Figure 2).

![Graph](image)

Figure 2: Trend and change points in annual average maximum temperatures for Naromoru (figure 2a) and Archer’s Post (figure 2b); and annual minimum temperatures for Naromoru (figure2c) and Archer’s Post (figure 2d) in 1976-2005

Temperature trend at Naromoru was statistically significant at 5% significance level while trend at Archer’s Post was not significant. Pettit test also confirmed an increasing trend where the test indicated an upward shift in the mean of minimum and maximum temperatures at Naromoru which occurred in the years 1996 and 1994 respectively and at Archer’s Post which occurred in 1999 and 1997 respectively (Figure 2).
3.2 Climate change scenarios

Rainfall and temperature projections for the period 2021-2050 (2030s) and 2051-2080 (2060s) are presented hereunder.

3.2.1 Temperature changes

The average annual temperature trend at Naromoru and Archer’s Post was found to significantly increase in all the scenarios (Table 1), where the value of Kendall’s statistic $S$ was positive and $p$-values less than significant level alpha indicated that the trend was significant. RCP 8.5 was noted to have high temperature increase than RCP 4.5 since its $S$ values are larger than for RCP 4.5.

**Table 1: Results of Mann Kendall trend test of average annual temperature (2021-2080)**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$S$</th>
<th>2-sided p-value</th>
<th>Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030s Naromoru RCP4.5</td>
<td>0.48</td>
<td>207.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Archer’s post RCP4.5</td>
<td>0.46</td>
<td>199.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Naromoru RCP8.5</td>
<td>0.68</td>
<td>297.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Archer’s post RCP8.5</td>
<td>0.65</td>
<td>283.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2060s Naromoru RCP4.5</td>
<td>0.41</td>
<td>177.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Archer’s post RCP4.5</td>
<td>0.37</td>
<td>161.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Naromoru RCP8.5</td>
<td>0.82</td>
<td>355.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Archer’s post RCP8.5</td>
<td>0.76</td>
<td>329.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The increase in temperature was associated with global warming due to increased greenhouse gases in the atmosphere. Similar results were presented by (Githui et al., 2009, Kim et al., 2013, Rwigi et al., 2016) where RCP 8.5 exhibited higher temperature increases than RCP 4.5.

Figure 3: Trend and change point in rainfall at Naromoru (figure 3a) and Archer’s Post (figure 3b) in 1976-2005

Significant decreasing trend in rainfall was observed at Naromoru during 1976-2005 and this was confirmed by Pettit test conducted where a downward shift in the mean of the total annual rainfall was observed, with a change point in the year 1982 (Figure 2a). Non-significant increasing trend in rainfall was observed at Archer’s Post and Pettit test revealed similar results whereby an upward shift in the mean of the total annual rainfall was observed, with a change point occurring in the year 1985 (Figure 3b). Significant decreasing trend in streamflow was observed with a change point in the year 2002 identified using Pettit test where a downward shift in the mean was observed.
Annual changes in rainfall (%) and temperature (%) with reference to the baseline (1976-2005) are shown in Table 2.

**Table 2: Changes in rainfall and temperature in 2030s and 2060s**

<table>
<thead>
<tr>
<th></th>
<th>Naromoru</th>
<th>Archers Post</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rainfall (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temperature (°C)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCP4.5</td>
<td>14.20</td>
<td>0.10</td>
</tr>
<tr>
<td>RCP8.5</td>
<td>18.50</td>
<td>7.60</td>
</tr>
<tr>
<td>RCP4.5</td>
<td>18.70</td>
<td>10.20</td>
</tr>
<tr>
<td>RCP8.5</td>
<td>14.60</td>
<td>1.20</td>
</tr>
</tbody>
</table>

On average temperature increase at Naromoru in 2030s was found to be 1.00°C and 1.10°C for RCP 4.5 and RCP 8.5 respectively while in 2060s the increase was 1.70°C and 2.50°C for RCP 4.5 and RCP 8.5 respectively. At Archer’s Post, in 2030s average temperature increase was found to be 1.00°C and 1.20°C for RCP 4.5 and RCP 8.5 respectively while in 2060s the increase was 1.70°C and 2.60°C for RCP 4.5 and RCP 8.5 respectively (Table 2).

Seasonal minimum and maximum temperature changes calculated using equation 6 showed that minimum temperatures in March-April-May (MAM), June-July-August (JJA), September-October-November (SON) and December-January-February (DJF) increased in all scenarios (Figure 4). Seasonal maximum temperatures were also found to increase in all scenarios and the results are showed in Figure 5. It was noted that percentage increase in minimum temperatures was higher (between 5 and 38%) than the percentage increase in maximum temperatures in all the seasons (between 3 and 13%), indicating that nights are expected to be warmer in the future.
larger increase than the 2060s as indicated by larger S value.

**Table 3: Mann Kendall trend test results for rainfall at Archers Post and Naromoru (2021-2080).**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Kendall's Tau</th>
<th>Mann Kendall statistic (S)</th>
<th>2-sided p value</th>
<th>Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naromoru</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCP4.5_2030s</td>
<td>0.15</td>
<td>65.00</td>
<td>0.11</td>
<td>0.05</td>
</tr>
<tr>
<td>RCP4.5_2060s</td>
<td>0.25</td>
<td>11.00</td>
<td>0.24</td>
<td>0.05</td>
</tr>
<tr>
<td>RCP8.5_2030s</td>
<td>-0.06</td>
<td>-27.00</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>RCP8.5_2060s</td>
<td>0.01</td>
<td>3.00</td>
<td>0.01</td>
<td>0.05</td>
</tr>
<tr>
<td>Archer's post</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCP4.5_2030s</td>
<td>0.15</td>
<td>67.00</td>
<td>0.23</td>
<td>0.05</td>
</tr>
<tr>
<td>RCP4.5_2060s</td>
<td>-0.11</td>
<td>-46.00</td>
<td>0.41</td>
<td>0.05</td>
</tr>
<tr>
<td>RCP8.5_2030s</td>
<td>-0.06</td>
<td>-25.00</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>RCP8.5_2060s</td>
<td>-0.04</td>
<td>-17.00</td>
<td>0.76</td>
<td>0.05</td>
</tr>
</tbody>
</table>

For RCP 8.5 a decreasing trend was observed in the 2030s, while significant increasing trend was observed in the 2060s. At Archer’s Post, for RCP 4.5, an increasing trend in annual rainfall was observed in the 2030s and a decreasing trend in the 2060s, both trends being insignificant. For RCP 8.5, decreasing trend was observed both in the 2030s and 2060s. Decreasing trend was significant in 2030s and insignificant in 2060s (Table 3). Average increase in rainfall in 2030s at Naromoru was 14.2% and 18.5% for RCP 4.5 and RCP 8.5 respectively. At Archer’s Post, the average increase was 0.3% and 7.6% for RCP 4.5 and RCP 8.5 respectively. Change in mean annual rainfall at Naromoru was found to be 14.2% and 18.5% for RCP 4.5 and RCP 8.5 respectively in the 2030s and 18.7% and 14.6% for RCP 4.5 and RCP 8.5 respectively in the 2060s. At Archer’s Post the change was found to be 0.1% and 7.6% for RCP 4.5 and RCP 8.5 respectively in the 2030s and 10.2%
and 1.2% for RCP 4.5 and RCP 8.5 respectively in the 2060s (Table 2).

Seasonal percentage change with reference to the baseline (1976-2005) was also done and the results are as shown in Figure 6. Increasing rainfall trend was observed in MAM, JJA and SON in the two stations both for RCP4.5 and RCP8.5, except for MAM season in Archers Post for RCP 8.5 in 2060s where decreasing trend was observed. DJF at both stations was found to have a decreasing trend in the seasonal totals as compared to the baseline.

### 3.3 Impact of climate change on streamflow

#### 3.3.1 SWAT model calibration and validation

Sensitivity analysis showed the following parameters were sensitive and had great impact on simulated streamflow; The runoff curve number which affects surface runoff response (\(r_{-CN2}\)), base flow recession factor (ALPHA_BF), groundwater delay (GW_DELAY) and deep percolation (GWQMN). Model performance was evaluated using coefficient of variation (R\(^2\)), Nash-Sutcliffe efficiency (NSE), and ratio of the root mean square error to the standard deviation of measured data (RSR) and the results are shown in Table 4.

**Table 4: SWAT model performance evaluation results**

<table>
<thead>
<tr>
<th></th>
<th>Calibration</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>R(^2)</td>
<td>0.44</td>
<td>0.73</td>
</tr>
<tr>
<td>NSE</td>
<td>0.35</td>
<td>0.53</td>
</tr>
<tr>
<td>RSR</td>
<td>0.81</td>
<td>0.70</td>
</tr>
</tbody>
</table>

From the results in Table 4, the model was considered fit for use in streamflow simulation in the catchment. As stated by (Moriasi et al., 2007) a model is considered to be satisfactory if R\(^2\) > 0.6, 0.50 < NSE \(\leq\) 0.65 and 0.60 < RSR \(\leq\) 0.70.

#### 3.3.2 Simulated streamflow

Trend in simulated streamflow (Table 5) was found to increase in 2030s for RCP 4.5 and in 2060s for RCP 8.5 since the Kendall’s statistic S for the two scenarios are positive (59 and 33).
Table 5: results for Mann Kendall trend test on simulated streamflow

<table>
<thead>
<tr>
<th>scenario</th>
<th>Kendall’s Tau</th>
<th>Mann Kendall statistic (S)</th>
<th>2-sided p value</th>
<th>alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP4.5_2030s</td>
<td>0.14</td>
<td>59.00</td>
<td>0.00</td>
<td>0.05</td>
</tr>
<tr>
<td>RCP4.5_2060s</td>
<td>-0.02</td>
<td>-7.00</td>
<td>0.90</td>
<td>0.05</td>
</tr>
<tr>
<td>RCP8.5_2030s</td>
<td>-0.07</td>
<td>-29.00</td>
<td>0.61</td>
<td>0.05</td>
</tr>
<tr>
<td>RCP8.5_2060s</td>
<td>0.08</td>
<td>33.00</td>
<td>0.56</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The trend in RCP 4.5 was significant while in RCP 8.5 it was insignificant. Streamflow in 2060s for RCP 4.5 and in 2030s for RCP 8.5 was found to be decreasing with no statistical significance (Table 5). Percent changes in seasonal streamflow were analyzed and the results are as shown in Figure 7.

Figure 7: Seasonal percent change of streamflow in 2030s and 2060s with respect to the baseline

As presented in Figure 7, streamflow in MAM season was found to have a decreasing trend in all the scenarios with a greater decrease (-26%) being showed by RCP 8.5 during 2060s and a smaller percent change (-10%) during 2060s of RCP 4.5. All the other seasons were found to have an increasing trend in the streamflow with JJA having a greater percentage increase (90-114%) as compared to the other seasons.

A regression of mean annual streamflow percent changes against mean annual rainfall percent changes at Naromoru showed that change in rainfall in all scenarios would significantly influence streamflow within the catchment. This was due to the fact that the coefficient of variation (R^2) values were more than 0.8, thereby indicating that over 80% of the changes in streamflow can be explained by the changes in rainfall at Naromoru. A regression of changes in rainfall at Archer’s Post and the streamflow produced low R^2 values (<0.4).

Figure 8: a regression of percent change in rainfall (Naromoru) on percent change streamflow

R^2=0.9213

This means that rainfall received at the upper parts of UENC catchment contributes most to the streamflow as indicated by higher R^2 values at Naromoru. Rainfall received at the lower parts of the catchment contributes least to the streamflow since the R^2 values for Archer’s Post were low.
It was also noted that an increase in rainfall in one season resulted to an increase in streamflow in the following season while a reduction of rainfall one season resulted to a decrease in streamflow in the season that follows. This is evident in figures 6 and 7 whereby a decrease in rainfall DJF season resulted to a decrease in streamflow in the MAM season. Similarly, an increase in MAM rainfall resulted to increased streamflow in the JJA season.

4. CONCLUSION
Climate change scenarios over the catchment indicated an increasing trend in temperature, both in RCP4.5 and RCP8.5. The increases were however much higher in RCP8.5 and was associated to the fact that RCP8.5 is a higher greenhouse gas emission scenario with a higher degree of global warming. Similar findings were also presented in (Chaplot, 2007, Field, 2012). Minimum temperatures were also found to increase more than maximum temperatures thus nights are expected to be warmer in future. This led to the conclusion that without mitigation to greenhouse gases, higher temperatures are expected, and therefore low carbon pathways should be enforced.

Variability in seasonal rainfall was observed during 2021-2080. Rainfall increase in MAM season was much lower than rainfall increase in JJA, meaning that activities that used to be carried out in MAM for example agriculture, could perform well in JJA, since enough rainfall is expected during this period. Adaptation measures are therefore encouraged to be adopted in line with results of this study including shifting of agricultural activities to JJA.

Streamflow was found to be affected much by climate change since increase in temperatures are associated to increase in evapotranspiration, thereby reducing the amount of surface water available on land. Variability in rainfall was also found to be contributing much to the variability in streamflow. This was evident when a decrease in rainfall in one season (DJF) led to a decrease in streamflow in the immediate following season (MAM) and over 80% of the changes in streamflow was explained by the changes in rainfall at Naromoru station. Water conservation measures are therefore recommended in order to cater for periods of low rainfall and streamflow amounts.

The study also found out that responses of streamflow to climate change are catchment specific since in Upper Ewaso Ngiro Catchment, streamflow was found to reduce in MAM which is contrary to other neighboring catchments where studies have indicated an increase in streamflow in MAM. Since streamflow response was found to be sensitive to changes in rainfall, emphasis should be put on water conservation and catchment management practices including protection of headwater forests through agroforestry, afforestation and reforestation in order to increase the rate of infiltration and recharge of ground water aquifers.

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