American Journal of Water Resources, 2019, Vol. 7, No. 1, 23-29
Available online at http://pubs.sciepub.com/ajwr/7/1/4
Published by Science and Education Publishing
DOI:10.12691/ajwr-7-1-4

Comparative Assessment of the Effect of Climate Change and Human Activities on Streamflow Regimes in Central Rift Valley Basin, Ethiopia

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Received December 20, 2018; Revised January 23, 2019; Accepted February 01, 2019

Abstract Climate change and anthropogenic activities are the main driving factors for changes in hydrological processes of a given watershed. This research was conducted to assess the relative contribution of climate change and human activities to streamflow change. The ensemble mean of five regional climate models (RCMs) in the coordinated regional climate downscaling experiment (CORDEX)-Africa was considered for the purpose of this study. Two emission scenarios, the Representative Concentration Pathways, RCP4.5 and RCP8.5, were considered for the future scenario period (2041–2070). Streamflow change due to climate change and human activities was assessed using coefficient of elasticity method and SWAT hydrological model. A change due to climate change was further split into change due to precipitation and evapotranspiration. Climate change contributed 46.7% while human activities contributed 53.3% to changes in streamflow. It was found that a 10% decrease in precipitation caused a reduction of 25.1% in streamflow, while 10% increase in potential evapotranspiration caused a reduction of 15.5% in streamflow. The results from ensemble mean of Regional Climate Models (RCMs) show that the average projected precipitation will decrease by 7.97% and 2.55% under RCP4.5 and RCP8.5 respectively. On average, temperature will increase by 1.9°C and 2.7°C under RCP4.5 and RCP8.5 respectively. This corresponds to 4.89% and 6.59% increase in potential evapotranspiration under RCP4.5 and RCP8.5 respectively. Using coefficient of elasticity method, the estimated values of streamflow change were – 26.9% and – 15.8% under RCP4.5 and RCP8.5 respectively. The results of this study show that the reduction in streamflow due to human activities was higher than the reduction due to climate change. The streamflow change induced by anthropogenic factors can be associated with factors such as water abstraction, land use change, ground water abstraction, and the other catchment properties. Hence, further research is recommended to separate changes from these factors.

Keywords: *climate change, human activity, streamflow, precipitation, evapotranspiration*

Cite This Article: Takele Gadissa, Maurice Nyadawa, Benedict Mutua, and Fiseha Behulu, "Comparative Assessment of the Effect of Climate Change and Human Activities on Streamflow Regimes in Central Rift Valley Basin, Ethiopia." *American Journal of Water Resources*, vol. 7, no. 1 (2019): 23-29. doi: 10.12691/ajwr-7-1-4.

1. Introduction

Climate variability and human activities are the main driving factors for the changes in watershed hydrology [1,2]. Climate change includes changes in precipitation and temperature. Change in temperature is most commonly related to evapotranspiration. The changing patterns in rainfall and temperature will significantly affect East African society [3]. For instance, there has been an increase of 1.5°C of the maximum daily temperature in the Central Rift Valley Basin over a period of 37 years according to [4]. It is expected that the associated evapotranspiration will also increase in the range of 3-4%. This will cause water shortage in the basin and the effect will further be significant if the temperature continues to increase. On the other hand, human activities can also alter streamflow directly or indirectly by affecting hydrological processes or disturbing climate variables [1].

Among climate variables, precipitation is the main driver of variability in the water balance over space and time, and changes in precipitation have very important implications on streamflow change. In addition, direct human activities which include land use and land cover change, water withdrawal for irrigation and domestic supply, dam construction and reservoir operation can impact negatively on water resources [5,6,7]. In this regard, several scholars [8,9,10,11] emphasized on the need to investigate the effects of climate change and human activities on streamflow change in different regions of the world.

This paper presents a study that was conducted in the Central Rift Valley Basin (CRVB), Ethiopia. The Central Rift Valley is part of Greater African Rift and comprises a chain of Lakes (Ziway, Langano, Abiyata and Shala), streams and wetlands. The Central Rift Valley Basin is a closed basin and is environmentally very most vulnerable [12]. Recently, there has been an increasing water demand in the basin [13]. As the rate of water abstraction continues, the water levels in Lake Ziway will also continue to decline. The water resource in the basin is particularly overused mainly for irrigation and the situation is unsustainable. Hence, the flow from Lake Ziway to Lake Abiyata through Bulbula River will be in steady decline. As a result, Lake Ziway will become endorheic like others in the basin leading to the rise in its salinity according to [12,14].

The annual streamflow records from different gauges for Ziway sub-basin in Central Rift Valley Basin (CRVB) show a decreasing trend in the historical period (1966 – 2010). This might be associated with a decrease in precipitation and an increase in evapotranspiration in the basin. Deforestation and intensive cultivation have also affected streamflow in the Central Rift Valley Basin [15,16]. Hence, it is important to separate and quantify the streamflow change due to the impact of climate change from that of human factors. The change due to climate change should further be dissociated into change caused by precipitation and evapotranspiration.

Several studies have been conducted to study water resources in Central Rift Valley Lakes Basin [13,17,18,19]. However, only a few studies tried to assess the effects of climate change and human activities on streamflow change using hydrological models [20,21,22,23]. Application of hydrological models involves a number of procedures and complex parameter setting with various uncertainties. In the contrary, Budyko hypothesis [24] is a simple water energy balance model which is described in terms of precipitation and evapotranspiration. The elasticity-based method of Budyko hypothesis has more advantages than the hydrological modeling approach in assessing environmental change on streamflow because it does not require detailed spatial input data [25].

Therefore, it is crucial to conduct this study to have a better understanding of future water resources under changing climatic conditions, which is of great importance for planning, operation and management of hydrological systems for decision making in the Central Rift Valley Lakes Basin. The objectives of this study are to: (i) investigate the relative contribution of climate change and human activities on streamflow change (ii) further identify contribution of precipitation and evaporation to climate change in changing streamflow (iii) predict future streamflow change in the Central Rift Valley Basin (CRVB) based on projected climate variables from Regional Climate Models (RCMs).

2. Materials and Methods

2.1. Description of the Study Area

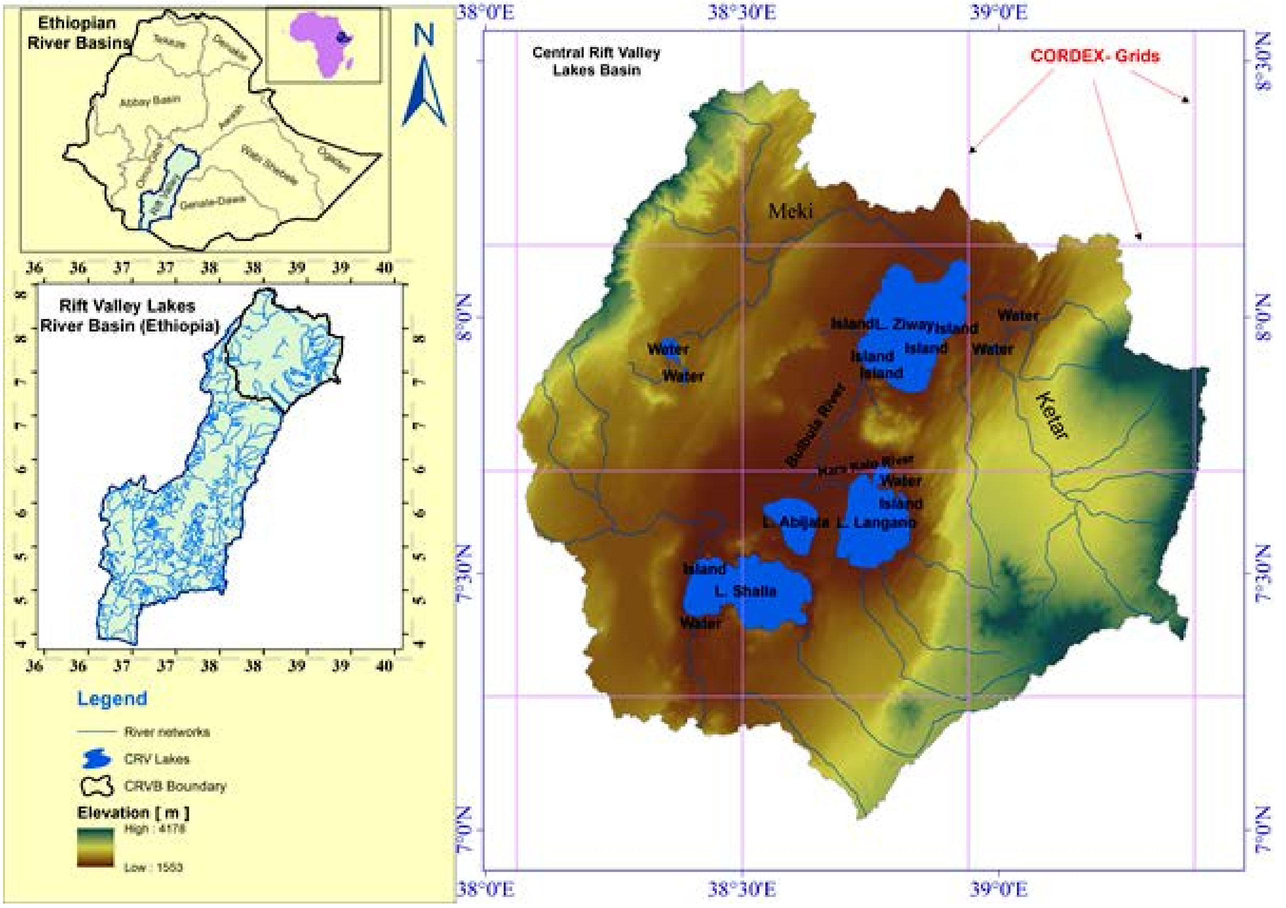

Figure 1. Location map of the study area with lakes, river networks, and grid points

The Central Rift Valley Basin (CRVB) is located between 38°15′ E and 39°30′ E longitude and 7°10′ N and 8°30′ N latitude, as indicated in Figure 1. It covers an area of approximately 14,477 km^2. Locally, the Central Rift Valley Basin is situated in two adjoining regions namely; the administrative regions of Oromia, the Southern Nations Nationalities and Peoples Region (SNNPR). The mean annual rainfall of the study area varies between 600 mm near the lakes and 1200 mm in the highlands or mountainous areas. The average minimum temperature is 10.5°C, while the average maximum temperature is 24.3°C. The basin contains four major lakes namely; Ziway, Shala, Abiyata, and Langano. It also has perennial rivers, which include: Meki, Ketar, Bulbula and Horakelo. Lake Abiyata is connected to both the Ziway and Langano lakes through the Bulbula and Horakelo Rivers, respectively. However, Lake Abiyata is more sensitive to the reduced flows of the Bulbula River compared to those of the Horakelo River. Within the same basin, the lakes have different characteristics. Lake Shala which a closed lake is the deepest, and is highly alkaline, making its water unusable for irrigation purpose [12]. Lake Langano has a relatively stable water level as compared to other lakes in the basin. Among all of the lakes, only Lake Ziway is a freshwater lake. Hence, this study focused more on this lake in the Central Rift Valley Basin.

Lake Ziway has a catchment of about 7300 km^2, a lake surface area of 440 km^2, a lake volume of 1.5 mcm, and a maximum depth of 9m. The Meki and Ketar Rivers are the two major rivers, contributing an annual streamflow of about 276 mcm and 464 mcm respectively. According to data obtained from Ministry of Water, Irrigation and Electricity (MWIE), the rate of sediment entering the lake through Meki River is higher than that of the Ketar River.

2.2. Data Requirements

Different data sets were used in the study. The data included; digital elevation model (DEM), hydrological, meteorological, soil and land use/cover data, and amount of abstraction in the basin. The study used daily meteorological data for the period from 1966 to 2010. The data included rainfall, minimum temperature and maximum temperature and daily streamflow data. All of the required data were obtained from the National Meteorological Agency of Ethiopia, the Ministry of Water, Irrigation, and Electricity, the Oromia Bureau of Water and Energy, the Oromia Water Works Design and Supervision Enterprise (OWWDSE), the Oromia Irrigation Development Authority (OIDA), and the Rift Valley Lakes Basin Authority (RVLBA).

The hydrological and meteorological data collected were checked for their homogeneity, correctness, sufficiency, and completeness. The missing data values were filled using the inverse distance weighing (IDW) method, and then finally used as inputs to the climate and hydrological models. Within the study area, the most dominant land use is agriculture (72.64%) followed by range land (14.65%). The soil types are predominantly Haplic Luvisols (40%), Vitric Andosols (13%) and Calcaric Fluvisols (0.25%) of the total area under study. More than 50% of the study area has slope ranging from 0-8% with about 39% of the study area having a slope range of 3–8%, while 20% of the area under study having a slope range of 0–3%.

2.3. Evapotranspiration

Evapotranspiration is not usually measured directly, but in most cases estimated by some methods based on other measured parameters. In order to calculate evapotranspiration, at least the data of daily temperature is necessary. Blaney-Criddle Method [26], which is the simplest empirical equation, was applied to estimate evapotranspiration.

$$E_o = P\left(0.46T_a + 8\right). \tag{1}$$

Where, E_o is potential evapotranspiration, p is monthly percentage of daytime hours of the year (depends on latitude) and T_a is mean temperature. P for the study area ranges from 0.27 to 0.28. Thus, the average value of 0.275 was used for the purpose of this study.

The temperature is relatively constant throughout the year in Ziway with an average value of 20.5°C; the daily maximum range is from 25°C to 29°C and the daily minimum temperature between 11.7°C and 15.6°C. The temperatures decline to the west as the elevation increases.

2.4. Trend Analysis

Mann-Kendall test was used for trend analysis. It is a non-parametric test and has been widely used to detect time series trends in the field of hydrology [19,27]. The Mann-Kendall test statistics S is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_i - x_j) \tag{2}$$

Where x_i and x_j are the annual data values in years i and j, i> j respectively

$$\operatorname{sgn}\left(x_i - x_j\right) = \begin{Bmatrix} 1 \ \ if \ \ x_i - x_j > 0 \\ 0 \ \ if \ \ x_i - x_j = 0 \\ -1 \ if \ \ x_i - x_j < 0 \end{Bmatrix}. \tag{3}$$

The concept is that each data value is compared with the subsequent value and if the subsequent value is higher than the previous value, S is assumed to be +1. If the value is lower, S is assumed to -1 and if there is no value difference S is assumed to be 0. The variance for this this test can be computed as:

$$Var\left(S\right) = \frac{\left[n\left(n-1\right)\left(2n+5\right) - \sum_{i=1}^{m} t_i\left(t_i - 1\right)\left(2t_i + 5\right)\right]}{18} \tag{4}$$

Where n is the number of time series data, m is the number of tied groups, t_i is the number of data points in the i^{th} group. The standard test statistics can be computed as:

$$Z = \begin{Bmatrix} \dfrac{S-1}{\sqrt{Var\left(S\right)}} & if \ \ S > 0 \\ 0 & if \ \ S = 0 \\ \dfrac{S+1}{\sqrt{Var\left(S\right)}} & if \ \ S < 0 \end{Bmatrix}. \tag{5}$$

Positive values of Z indicate the increasing trends, while negative values of Z show decreasing trends. The null hypothesis is rejected when the absolute value of Z is greater than $Z_{1-\alpha/2}$ at significance level of α. A significance level of 5% was used for the purpose of this study.

2.5. The Budyko Framework

According to [24], the Budyko hypothesis is a simplified water balance model that partitions precipitations into evapotranspiration and streamflow using the Budyko curve [9]. Budyko equation in a generalized form according to Choudhury [28] is given as:

$$E_a = \frac{P\,E_o}{\left(P^n + E_o{}^n\right)^{1/n}} \tag{6}$$

Where, E_a is actual evapotranspiration, P is precipitation, E_o is potential evapotranspiration, and n is catchment specific parameter (dimensionless).

According to [2,8,10], the change in streamflow is further expressed as:

$$\Delta Q = \left(1 - \frac{\partial E_a}{\partial P}\right)\Delta P - \frac{\partial E_a}{\partial E_o}\Delta E_o - \frac{\partial E_a}{\partial n}\Delta n \tag{7}$$

Where, ΔQ is change in streamflow, ΔP is change in precipitation, ΔE_o is change in potential evapotranspiration, and Δn is change in catchment specific parameter.

$$\frac{\partial E_a}{\partial P} = \frac{E_a}{P}\left(\frac{E_o{}^n}{P^n + E_o{}^n}\right) \tag{8}$$

$$\frac{\partial E_a}{\partial E_o} = \frac{E_a}{E_o}\left(\frac{P^n}{P^n + E_o{}^n}\right). \tag{9}$$

The change in streamflow was divided into change induced by climate change and catchment properties. The change induced by climate change was further classified as change due to precipitation and potential evapotranspiration change, which is expressed as follows:

$$\Delta Q_C = \left(1 - \frac{\partial E}{\partial P}\right)\Delta P - \frac{\partial E_a}{\partial E_o}\Delta E_o. \tag{10}$$

The difference between the observed streamflow and the streamflow caused by climate change is referred as residual change. This is generally caused by change in catchment properties and other human induced factors. According to [2,9], residual change is estimated using the equation given as:

$$\Delta Q_R = \Delta Q_o - \Delta Q_c. \tag{11}$$

Finally, the following equation was developed for Lake Ziway basin, which was further be related to lake level change as a result of streamflow change.

$$\frac{\Delta Q}{Q} = 2.51\frac{\Delta P}{P} - 1.51\frac{\Delta E_o}{E_o}. \tag{12}$$

2.6. SWAT and Regional Climate Models (RCMs)

The SWAT model and the ensemble mean of five Regional Climate Models (RCMs) were applied for the purpose of this study [23,29]. The two major rivers, Meki and Ketar, were considerd for this study. Five regional climate models namely; CCLM4-8-17, HIRHAM5, RACMO22T, RCA4 and REMO2009 from CORDEX-Africa under two scenarios; RCP4.5 and RCP 8.5 were selected for this study. The climate outputs of these models were bias corrected using linear scaling, power transformation and distribution mapping methods [30-34]. In order to study the impact of climate change on water availability in Central Rift Valley basin, the SWAT model was calibrated and validated yielding the regression coefficient (R^2) values of 0.6 and 0.55 respectively.

The bias corrected ensemble mean of RCMs outputs in the scenario period was used as input to the SWAT model for monthly stream flow simulation.

Table 1. Change in Climate Data in Scenario Period as Compared to the Historical Period [23]

Grid	P (%)		Max.T		Min.T	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
1	−11.71	−7.04	+1.81	+2.44	+2.21	+3.15
2	−13.64	−8.33	+1.91	+2.57	+2.77	+3.94
3	−4.24	0.73	+1.79	+2.44	+2.33	+3.25
4	−5.54	0.21	+1.71	+2.34	+1.92	+2.73
5	−9.33	−1.69	+1.62	+2.19	+2.02	+2.84
6	−4.27	1.70	+1.67	+2.27	+2.14	+2.99
7	−6.35	−3.13	+1.74	+2.41	+1.91	+2.77
8	−7.14	−1.11	+1.61	+2.21	+2.00	+2.86
Aver	−7.78	−2.33	+1.73	+2.36	+2.16	+3.07

3. Results and Discussion

3.1. Trend Analysis

Mann-Kendall test was used to assess trends in streamflow for the study period from 1966 to 2010. During the period under study, it was noted that there was no sufficient recorded data for evapotranspiration. Hence, Blanney-Criddle formula which uses maximum and minimum temperature was applied to assess evapotranspiration. The Mann-Kendall trend analysis showed that there was a statistically significant decrease in streamflow at 5% level of significance. The abrupt change in streamflow occurred after 1983 (Figure 2). This could have been contributed by the drought period between 1984 and 1985 that was experienced in Ethiopia. Hence, the study period was split into a base period (1966 – 1983) and change period (1984 – 2010).

Precipitation (Figure 3) and evapotranspiration data were also split into two based on streamflow data. Although it is not significant, precipitation showed a decreasing trend while evapotranspiration showed an increasing trend after the change point.

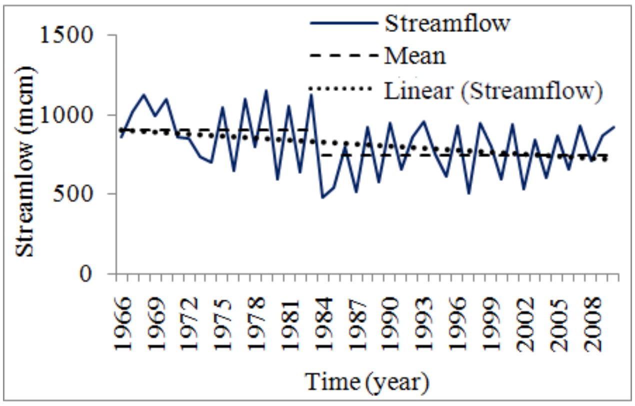

Figure 2. Trend of streamflow from base period (1966 – 1983) to change period (1984 – 2010)

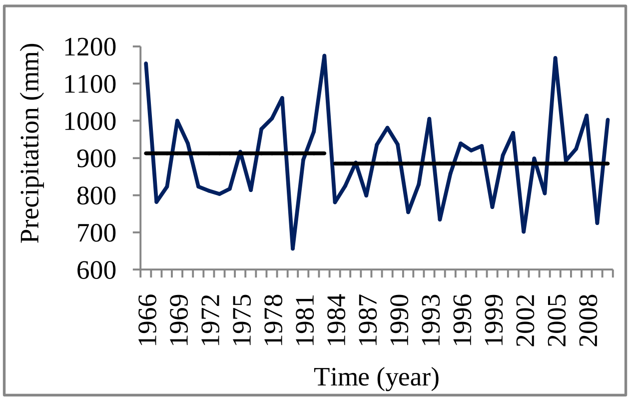

Figure 3. Precipitation after and before change point in the study period (1966 – 2010)

3.2. Streamflow Sensitivity to Climate Change

The equation developed (equation 12) for Lake Ziway basin predicts the relative change in streamflow as a result of change in precipitation and potential evapotranspiration. The predicted results show that a 10% increase in precipitation will increase streamflow in the basin by about 25.1% while a 10% increase in potential evapotranspiration gives a decrease in streamflow by about 15.1%. The results from this study are in agreement with the findings of similar studies in different areas. For example, [20] applied the physically based distributed Precipitation Runoff Modelling System (PRMS) to study hydrological response of a catchment to climate and land use changes in Ketar River catchment of Central Rift Valley Basin in Ethiopia. The result showed that a 10% decrease in rainfall produced a 30% reduction on the simulated discharge, while a 1.5^{o}C increase in air temperature caused a decrease of the simulated discharge by about 15%. The results of a study by [21] also indicated similar results for streamflow under RCP4.5. From the results of this study, it is evident that the average annual stream flow into Lake Ziway will significantly decline from 19.47% to 20.43% under different old emission scenarios (SRES). This is further in agreement with research results by [35] in the basin that also indicated the decreasing trend of surface and base flows. A study by [36] also indicated that inflow into Gibe cascade reservoirs will slightly decrease under future climate prediction. The results of a research by [37] indicated the decrease in precipitation between 3% to 6% with a corresponding decrease in average discharge of 5% in the period 2001-2050 compared to 1961-2000 for Volta basin in West Africa.

3.3. Separating Contribution of Climate Change and Human Activities to Streamflow Change

From the long-term observed change in streamflow, precipitation, potential evapotranspiration and actual evapotranspiration (Table 2), it was possible to separate contribution by climate change and that due to land use/land cover. Accordingly, a decrease in precipitation caused a decrease of about 39.5% in streamflow while an increase in potential evapotranspiration caused a decrease of about 7.2% in streamflow (equation 12). This implies that the climate change has a net contribution of about 46.7% while the contribution by land use/cover change contributing to about 53.3%. This shows that the reduction in streamflow due to human activities (53.3%) is higher than the reduction due to climate change (46.7%).

Table 2. Annual Mean Values of Water Balance Components for the Study Period

Climate Variable	Period (1966-1983)	Period (1984-2010)	Period (1966-2010)
P(mm)	912.55	884.97	896.00
E_p(mm)	1755.04	1771.38	1762.58
Q(mm)	128.85	106.28	115.31
E_a (P-Q)	783.70	778.69	780.69
n	1.78	1.88	1.84

Generally, there are two types of human activities affecting streamflow change [38]. The first category is land use change which includes deforestation while the second category is water abstraction for irrigation purpose. During field visits, it was observed that both categories are the main characteristics of the study area. Most studies also show that human activities are the highest contributing factors to streamflow change. For example, a research conducted by [2] demonstrated that the change in runoff was more sensitive to land use change (97.5%) than climate change (2.5%) in the upper Mara River in Kenya. These authors further stated that a 10% increase in precipitation contributed to a 20.7% increase of runoff and a 10% increase in evapotranspiration contributed to a 10.8% decrease of runoff.

Research scholars [6] identified that direct human activities have greater impacts on the decreasing streamflow trends as compared to climate change in Weihe River Basin in Northwest China. In another study conducted by [9] in Upper Hanjiang River Basin (UHRB) in China, the results showed that the spatial variability of climate change contribution to streamflow change ranged from 46% - 83%. In an addition, researchers [39] reported that the streamflow change due to human activities in the water source area of Baiyangdian Lake in China ranged from 60% – 62%. This shows that similar to the current study, most studies indicated that human activities impacted more on the streamflow change as compared to the impact by climate change.

Similar to this study, sensitivity analysis of climate change and human activities to streamflow change using hydrological models and elasticity coefficient method give similar results. For instance, the response of runoff to climate change and human activities for a typical basin in the Northern Taihang Mountain of China [40] was assessed using SWAT model and elasticity coefficient method. The contribution of climate change and human activities to streamflow change was 38.64 and 61.36% respectively using SWAT model while it was 36.31 and 63.69% respectively using elasticity coefficient method. Hence, it can be noted that equation (12) adopted for Central Rift Valley Basin based on Budyko elasticity coefficient can predict climate change impact on streamflow change.

3.4. Climate Change Impact on Streamflow Using SWAT Model

The mean of the monthly stream flow was compared with the mean monthly flow in the historical period to see the impact of climate change (Table 3). The results indicate that the stream flow of both Meki and Ketar Rivers,, will decrease under both the RCP 4.5 and RCP 8.5 scenarios . The decrease in discharge may be due to decrease in rainfall during that period. The overall average results show that there will be a change in streamflow by -17.9% and -4.6 % under RCP4.5 and RCP8.5 respectively.

Table 3. Climate Change Impact on a Streamflow Using SWAT Model

	Historical	RCP4.5	RCP8.5
Inflow (mcm)	810.6	665.3	773.4
dQ (%)		-17.9	-4.6

3.5. Climate Change Impact under RCP4.5 and RCP8.5

The projected Regional Climate Models (RCMs) outputs (Table 1) were used for the prediction of streamflow change using equation 12. Blaney-Criddle method (equation 1) was used to estimate evapotranspiration from the projected maximum and minimum temperature. Hence, potential evapotranspiration was found to be 1762.6mm, 1848.7mm and 1878.7mm under historical, RCP4.5 and RCP8.5 respectively. From the developed equation (12), the estimated values of streamflow change were – 26.9% and – 15.8% under RCP4.5 and RCP8.5 respectively. The developed model relatively overestimates streamflow change as compared to SWAT model (Table 3). However, it can fairly estimate the streamflow change due to climate change and human activities.

4. Conclusions

Elasticity coefficient method and SWAT hydrological model were used to explore relative contribution of climate change and human activities to streamflow change. The results show that human activities caused a streamflow change of 53.3% while climate change caused 46.7%. A Simple streamflow sensitive equation was developed for the study area. From the equation, it was found that climate change a 10% decrease in precipitation caused 25.1% reduction in streamflow while a 10% increase in evapotranspiration caused 15.1% reduction in streamflow. The climate data outputs from Regional Climate Models (RCMs) were also applied in the developed equation from coefficient of elasticity method to estimate streamflow change due to climate change in future scenario period (2041 – 2070). The result was compared with the streamflow change estimated using SWAT model. It was found out that the equation developed for the basin can estimate change in streamflow due to climate change under two emission scenarios, RCP4.5 and RCP8.5.

Hence, it can be concluded that anthropogenic factors have a higher impact on streamflow change than that by climate change. The equation developed from coefficient of elasticity method based on Budyko hypothesis can predict streamflow change under projected climate change. The streamflow change induced by anthropogenic factors can be associated with factors such as water abstraction, land use change, ground water abstraction, and the other catchment properties. Hence, further research is recommended to separate changes from these factors.

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