Evaluating the Effect of Historical Climate Change on Extreme Stream Flow Cases of Gumara Watershed, Upper Blue Nile Basin, Ethiopia

Gashaw Gismu Chakilu
College of Agriculture, Wolaita Sodo, University, PO box 138, Wolaita Sodo, Ethiopia

Abstract
Climate and land cover change are very important issues in terms of global context and their responses to environmental and socio-economic drivers. The dynamic of these two factors is currently affecting the environment in unbalanced way including watershed hydrology. The change of observed steam flow is the effect of the combined change of climate and land use land cover of the catchment. In this paper the impact of climate change on stream flow specifically on extreme flow events were evaluated through application of Soil and Water Assessment Tool (SWAT) model in Gumara watershed, Upper Blue Nile basin Ethiopia. The trend of regional climate, like temperature, rainfall and evapotranspiration of the past 40 years in the study area were tested and then the extent of changes has also been evaluated in terms of monthly bases by using two decadal time periods. The period between1973-1982 was taken as baseline and 2004-2013 was used as change study. The efficiency of the model was determined by Nash-Sutcliffe (NS) and Relative Volume error (RVe) and their values were 0.66 and 0.72% for calibration and 0.64 and 1.23% for validation respectively. Both the high and low flows of the catchment have been taken from the simulated stream flow. The high flow has been identified using Annual Maximum (AM) method and the low flow was also identified by using Seven Day Sustained (SDS) minimum annual flow of the river. The impact of climate change was more significant on high stream flow than low flow of the catchment. Due to climate change, when the high flow was increasing by 17.08%, the low flow was decreasing by 6%. The overall results of the study indicated that Climate change is more responsible for stream flow during wet season than dry season.
Keywords: Climate, High flow, Low Flow, SWAT, Gumara, Blue Nile.

1. Introduction

Climate and land cover change and associated impacts on water resources are being the hot issues in recent years (Yanhu He et al, 2013). This is due to the direct or indirect impacts brought by climate and land use change both have contributed to some water problems, such as water shortage, flooding, and water logging to different extent. According to (Dibike et al., 2012) changes in rainfall and temperature would have consequences on the evapotranspiration conditions and water balance of a given catchment. Temperature, precipitation and evapotranspiration conditions are the determining factors of watershed hydrological systems. Changes may increase or decrease runoff trends and also annual water supply.

Climate change is believed to have significant impacts on local hydrological regimes, such as in stream flows which support aquatic ecosystem, navigation, hydropower, irrigation system, etc. Besides to the possible changes in total volume of flow, there may also be significant changes in frequency and severity of floods and droughts. Hence hydrological models provide a framework to conceptualize and investigate the relationship between climate and water resource (XU, 1999).

Understanding the hydrologic response of watersheds to physical and climatic (rainfall and air temperature) change is an important component of water resource planning and management (Vorosmarty et al., 2000). Observed climatic changes in Africa include warming of 0.7^{O}C over the 20th century, 0.05^{O}C warming per decade and increased precipitation for East Africa (FAO, 2010).

In Ethiopian, on the head of Blue Nile and in Lake Tana basin, over the past few decades the physical characteristics including the stream flow have been adversely changed. Moreover, the hydrological dynamics has been strongly modified. This has a direct impact on the lake and the flow condition of upper Blue Nile as well. Therefore, it is very important to understand the functioning of the lake catchments and their hydrological response under historical climate change scenario conditions and the water resources development of the basin requires a judicious planning for the protection of the fragile ecosystem. This study has been designed to evaluate the trend and change of historical climate over the past four decades and assess the response of stream flow particularly on the high and low flow cases of the watershed.

2. Materials and Methods

2.1. Description of the Study area

Gumara watershed is located to the east direction of Lake Tana basin; it is found between latitude of 11^{o}35' and 11^{o}55' N and longitude of 37^{o}40' and 38^{o}10' E. It has a total drainage area of 1277.51 km^2 up to the gauging station (near Woreta) ahead of 25 km^2 before it joins the lake. The total main stream length from its origin (near mountain Guna) is approximately 132.5 km, before the river joins Lake Tana.

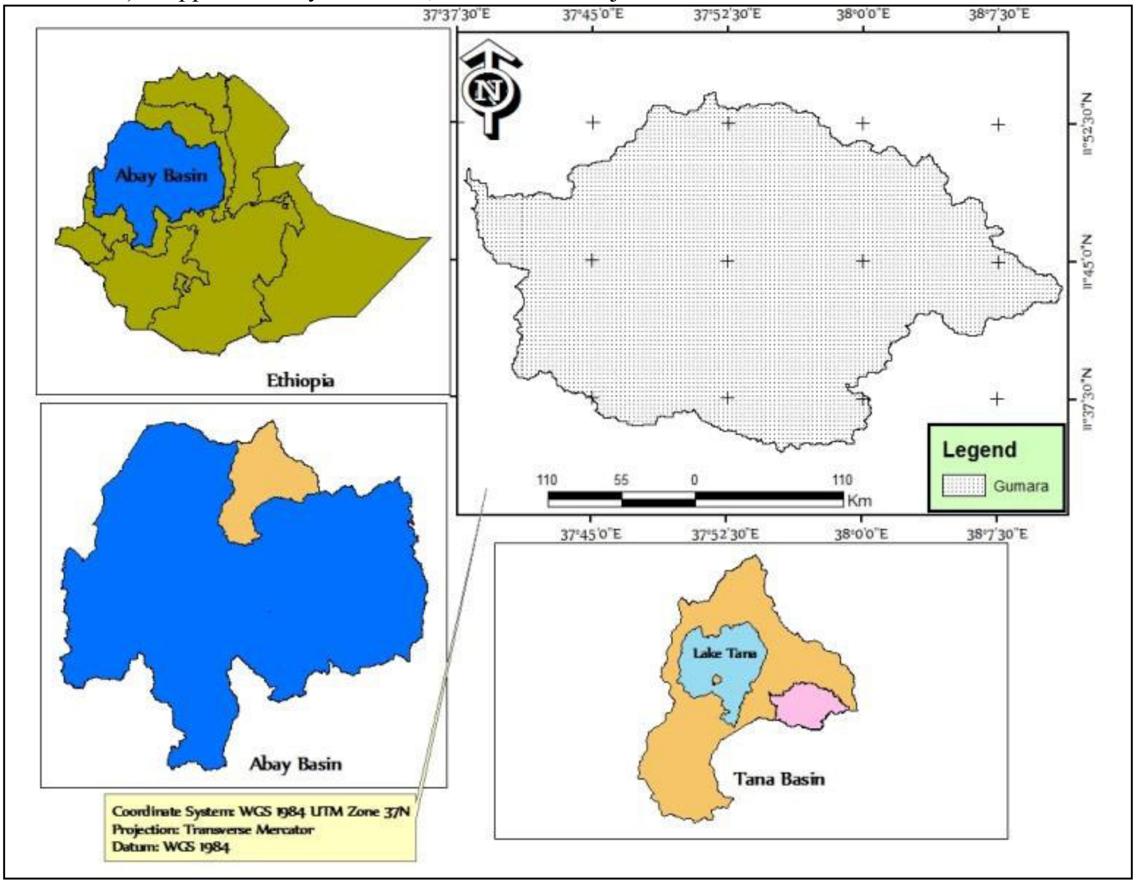

Figure 1: **The map of geographical location of the study area.**

2.2. SWAT model description

The Soil and Water Assessment Tool (SWAT) is a versatile, physically distributed model with spatial and temporal variability consideration, for simulating runoff and sediment transportation of small and large watersheds. The model is a physical based, semi-distributed and operating on daily time step (Neitsch et al., 2005). As a physical based model, SWAT create Hydrological Response Units (HRUs) to represent spatial heterogeneity based on the specified threshold percentage of the watershed land use, soil types and slope.

The model provides two methods of surface runoff calculation: one is the runoff curve number method developed by the Soil Conservation Service (SCS) of the United States Department of Agriculture (USDA, 1986) and the other is through the Green–Ampt infiltration method (Green and Ampt, 1911). Runoff is generated from given watersheds that are become saturated or during a storm period. Infiltration as initial abstraction measurement and plot studies in the Ethiopian highlands watersheds has shown that infiltration rate on hillsides with dominant sand and gravel cover can be higher than the greatest rainfall intensity with the same magnitude (McHugh, 2006).

The hydrologic water balance and cycle simulated by SWAT model is based on the following water balance equation: $SW_t = SW_o + (R_{day} – Q_{surf} – E_a – W_{seep} – Q_{gw})$

Where: SWt is the final soil water content (mm), SW_o is the Initial Soil water content on daily bases (mm), t is the time in days, R is the amount of rainfall in daily bases (mm), Q_i is the surface runoff on day (mm), Ea is the amount of evapotranspiration in daily bases (mm), W_{seep} is the amount the Vadose zone from soil profile on day (mm) and Q_{gw} is the amount of return flow on daily bases.

SWAT 2012 of Arc SWAT, extension of ArcGIS is used for watershed delineation, develop hydrological response unit (HRU), edit input data, calibrating the model and run the model. The overall steps and procedure that will be applied in SWAT modeling is described in figure 8. Arc SWAT interface is used because Arc GIS have the ability to analysis table and summarizing statistical component of the model.

2.3. Data collection and analysis

2.3.1. Trend test analysis of climate and observed stream flow data

The need for this analysis is to determine whether there is the trend of climate and stream flow data within the past

40 years. This is the first point to be known before the change was quantified and the impact was evaluated. Mann-Kendall trend test was applied to evaluate the trend of climate and observed stream flow data of the study area. The trend of rainfall, both maximum and minimum temperature and observed stream flow were done and the result has been interpreted and illustrated by graphs and tables.

2.4. Model calibration and validation

The model has been calibrated to determine the representative value of parameters on the study area through changing the values of selected parameters until the maximum efficiency was obtained. The model calibration efficiency has been evaluated by the NSE and R^2 Relative Volume Error (RVE). All those three objective functions compared the simulated and observed value of the model with different statistical formula. For many numbers of iterations, the manual calibration is better than automatic one in a way that it takes in to account the consideration of the real physical characteristics of the catchment. Every parameter has been iterated 2000 times by changing their values with respect to their maximum and minimum limits.

After the model has been calibrated and the optimum values of important parameters have been determined, those values were verified by using different climate and land use land cover data. This verification has validated the consistency of selected parameters.

2.5. SWAT Model Structure

To simulate stream flow, SWAT model was constructed starting from watershed delineation. Digital elevation model (DEM) with 30*30m resolution is the basic and primary ground for watershed delineation and it was used as an input to compute the slope of the catchment. After the watershed had been delineated, other hydrological response units like, slope, soil and land use characteristics of the model were masked and overlaid with respect to delineated watershed. The model was classified the catchment in to 24 sub basins. On the other side, climate data was used as another input in SWAT model for simulation of stream flow. Daily maximum and minimum temperature, daily rainfall and whether generator were used as an input, the others like solar radiation, relative humidity and wind speed data which are designed to compute the evapotranspiration of the catchment by the model itself were generated on the whether generator. Then after the process of defining HRUs and importing whether station data, set up of SWAT model was arranged and it had simulated stream flow by default parameters. To fit the simulated flow with observed flow of the catchment, important parameters were selected by the processes of sensitivity analysis and by those parameters the model was calibrated by using automatic calibration (SWAT CUP 2012) until the maximum value of model efficiency was obtained.

2.6. Impact of climate change on stream flow dynamics

After the trend of climate, land use land cover and observed stream flow of the catchment have been tested, the impacts of climate change and land use land cover change on stream flow of Gumara watershed was evaluated by comparing the simulated flow generated by climate data between 1973-1982 and 2004-2013 and land use / cover data between 1973 and 2013.

Once the model was calibrated by 11 most important parameters and validated the values of these parameters, SWAT model has simulated stream flow two times to evaluate the impacts of these two variables separately and in combined manner. The values of those 11 parameters were constant for all simulation processes. First stream flow was simulated by using 1973 land use land cover data and 1973-1982 climate data which was considered as the base line for change study. Secondly, flow was generated by 1973 land use land cover data and 2004-2013 climate data. The effects of climate change were evaluated in such a way that comparing the flow result of simulation one and simulation two.

3. Result and Discussion

3.1. Climate change result

Before the magnitude of changes in temperature and rainfall has been assessed and the impact on stream flow was evaluated, the Mann-Kendall trend test was applied. The result showed that there is the increasing trend of the observed rainfall, and temperature of the catchment with in the past 40 years. The trend test result graph is shown on figure (2).

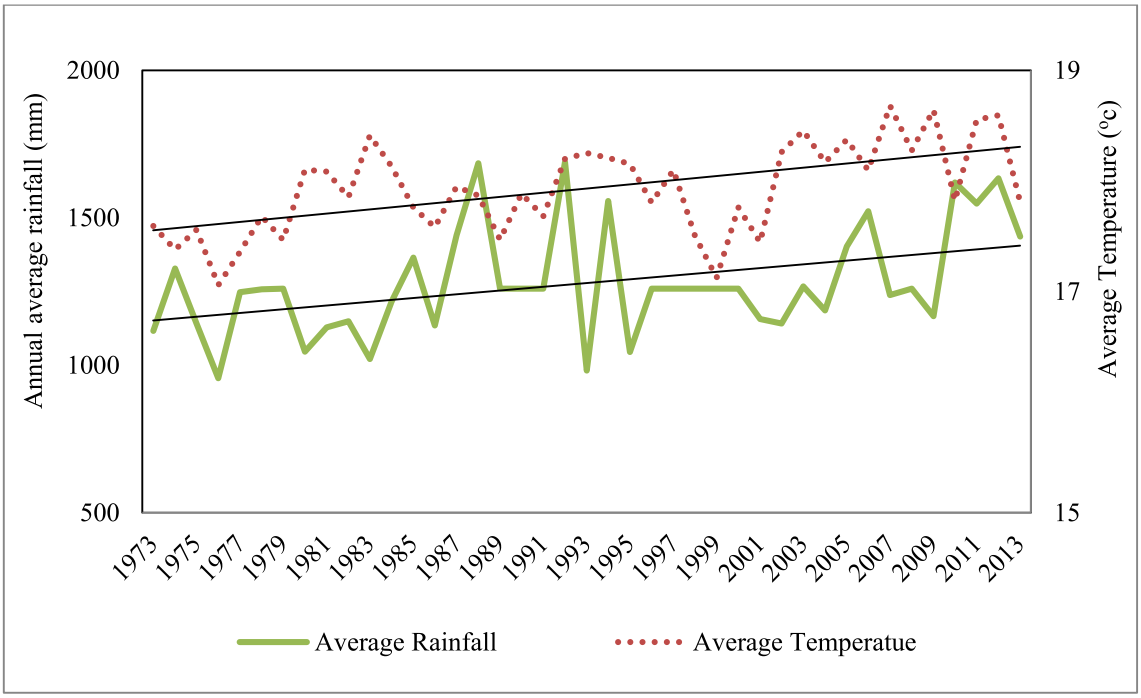

Figure 2: Trend test line graph of average rainfall and temperature

After the trends of observed rain fall and temperature data were determined, the change between (1973-1982 and 2004-2013) was evaluated. The change has been evaluated based on monthly, annually and total bases with in the two decades. Based on the result, the rainfall of Gumara watershed has been increased and the change is showing by 10.13% within the past 40 years (table 1).

Table 1: change of rainfall between the first and the last decades of the past 40 years.

Rainfall	1970s	2010s	Change	% of change
Monthly Average (mm)	114.25	128.36	14.11	10.13
Annual Average (mm)	1370.99	1540.33	169.35	
Total (mm)	13709.90	15403.32	1693.45	

Both the maximum and minimum temperature of Gumara watershed has shown the increasing trend (fig.3). Then, after the trend is determined, the change between these two decades is also evaluated in terms of average basis. Maximum and minimum temperatures are increasing by 0.36°c and 0.43°c respectively. Averagely the temperature of the catchment has been increasing by 0.4°c which is by (see table 2).

Table 2: Change of average maximum, minimum and mean temperature

Temperature	1973-1982	2004-2013	Change
Tmax.	26.06	26.42	0.36
Tmin.	10.17	10.60	0.43
Tmean	18.11	18.51	0.4

A. Effect of climate change on stream flow of the catchment.

After the flow of the base line period had been determined, the effect of climate change was evaluated by changing only the climate data set of 2004-2013. The land use / cover data was not changed; the model had simulated stream flow by 1973 land use / cover and 2004-2013 climate data. The result had also been analyzed in terms of monthly average, average annual and total values of the flow and compared with the base line stream flow (table 3).

Table 3: Effect of climate change on stream flow

No.	Flow time scale	1970s	2010s	Change	% of change
1	Daily average (m^3/s)	31.31	36.69	5.28	16.86
2	Annual average (Mm^3/y)	988.09	1157.97	169.87	
3	Total (Mm^3/y)	9880.9	11579.66	1698.76	

Therefore, the result of the study showed that the steam flow of the study area has been increasing by 16.86% because of 40 years of regional climate change. The change is due to the increment of rainfall within those 40 years of time set. Even if the temperature and/or potential evapotranspiration has also been increasing, it has not significant effect on flow of the catchment.

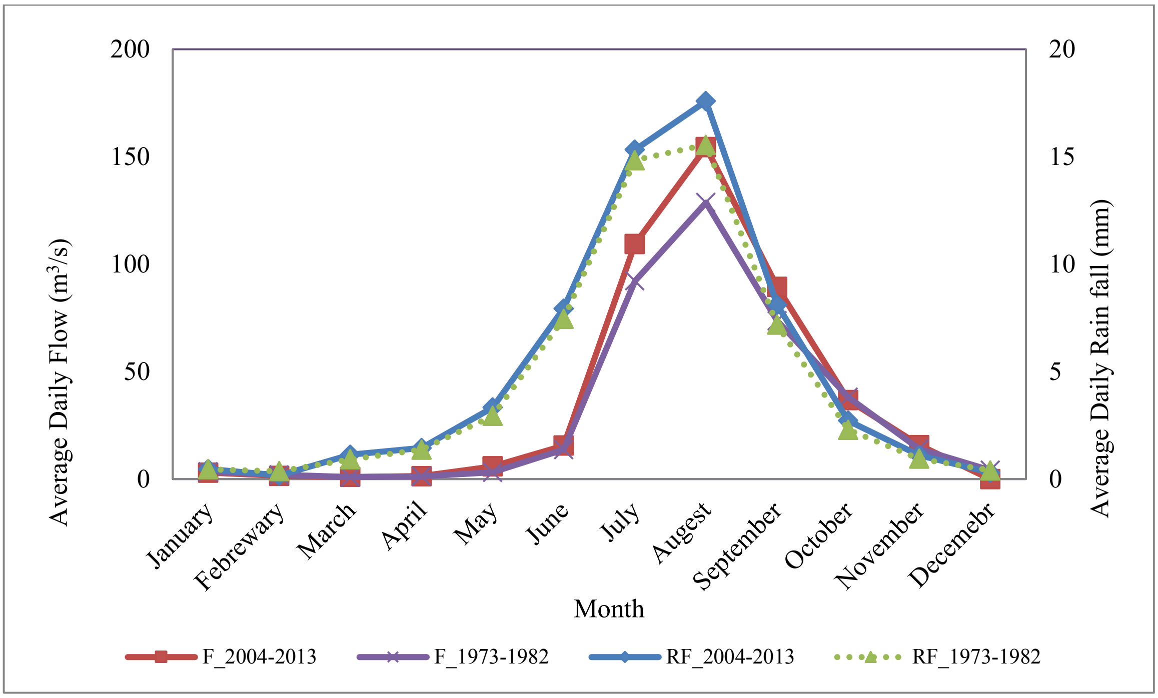

Figure 3: Rainfall and stream flow line graphs

The above graph is figured to show the change of rainfalls and flows between these two decades in daily average basis of each month. And it also showed that the relationship between rainfall and flow with respect to seasonal variation.

3.2. The Impact of Regional Climate Change on High Flow

Besides to the normal and average flow, the impact of climate change on high flow of the catchment has also been evaluated. This assessment is really necessary to know the effect of climate change especially change in rainfall on the occurrence of flood on the study area with in the last 40 years.

After simulating the stream flow using SWAT model, we evaluated the trend of maximum stream flow. Annual Maximum (AM) series model had been used to extract the high stream flow. The period of analysis was from 1973 to 2013. The annual pick value of flow for the two decades had been identified and the change has also been evaluated. The results from this analysis have indicated that there was an increasing trend of high stream flow from the river. This is likely driven by the dynamics in climate change in the watershed. Based on the result of the study, climate change has a significant effect on the trend of maximum flow of the catchment (figure 4).

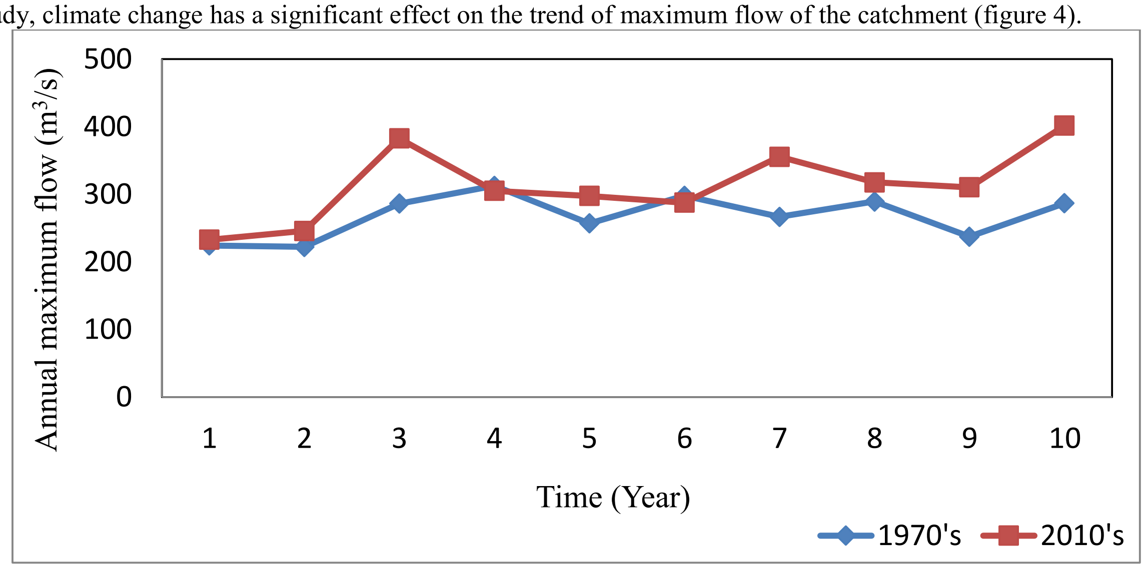

Figure 4: Effect of climate change on high flow showing chart.

Based on figure 4, the result showed that there is change in maximum flow in decadal time periods. The change of maximum rain fall has played the primary role for the increment of maximum flow of the catchment.

When comparison is done between the above two graphs, they have similar trends and it indicates that the maximum flow variation between these two time periods is the result of variation of maximum rainfall on the corresponding flow records. For the sake of evaluating the degree that how much the change of maximum rain fall has been affecting the trend of high flow; the number values of maximum rainfall and the corresponding maximum flow of the catchment had also been presented.

The result is showing that the average annual maximum rain fall of the base line period is 54.47 mm, but by increasing 8.35 mm, the maximum rainfall of 2004-2013 is 62.82mm; the change is 15.46%. On the other side the average annual maximum flow values of 1973-1982 and 2004-2013 are 268.01m^3/s and 313.79m^3/s respectively; increased by 17.08% (table 4).

Table 4: Annual maximum rain fall and corresponding high flow of Gumara watershed

Year	1973-1982 Annual maximum		2004-2013 Annual Maximum	
	Rain fall (mm)	Flow (m^3/s)	Rain fall (mm)	Flow (m^3/s)
1	48	224.26	54	232.853
2	42.6	222.1918	47.25	245.867
3	60.5	286.195	70.05	382.758
4	63.8	312.524	55.5	305.248
5	59.5	256.875	63.4	297.648
6	62	297.864	60.7	287.758
7	48.4	266.574	67.6	355.674
8	54.7	289.478	60.2	317.854
9	45.8	237.41	65.2	310.486
10	59.4	286.752	84.3	401.758
Average	54.47	268.0124	62.82	313.790

In addition, it was also necessary to identify the maximum of maximum annual rainfall values which are the highest two values for these two decades. The highest values for the base line and change study periods (1970's and 2010's) are 63.8mm and 84.3mm respectively; the change is 20.5mm which was increased by 32%.

Due to the change of the two decadal maximum rain fall values, the pick of the maximum flow of these two decades has also shown a significant value change which is also 312.52m^3/s and 401.76m^3/s respectively. There is 89.24m^3/s flow difference between these two pick values; which showed the increment by 29%. Therefore it is possible to conclude that the regional climate change of Gumara watershed has an effect on the trend of high flow of the catchment.

3.3. Impact of Climate Change on Low Flow of Gumara Watershed

The low flow of any catchment has usually been recorded during dry seasons mostly in our country Ethiopia; it is from February up to April in a given year. In this study area the annual minimum flow for both ten years of periods was identified and the flow variation because of climate change has also been evaluated. Seven day sustained low flow in a given year from the lowest flows was selected to represent the low flow in each year. The result showed that effect of climate change on the low flow is not that much significant.

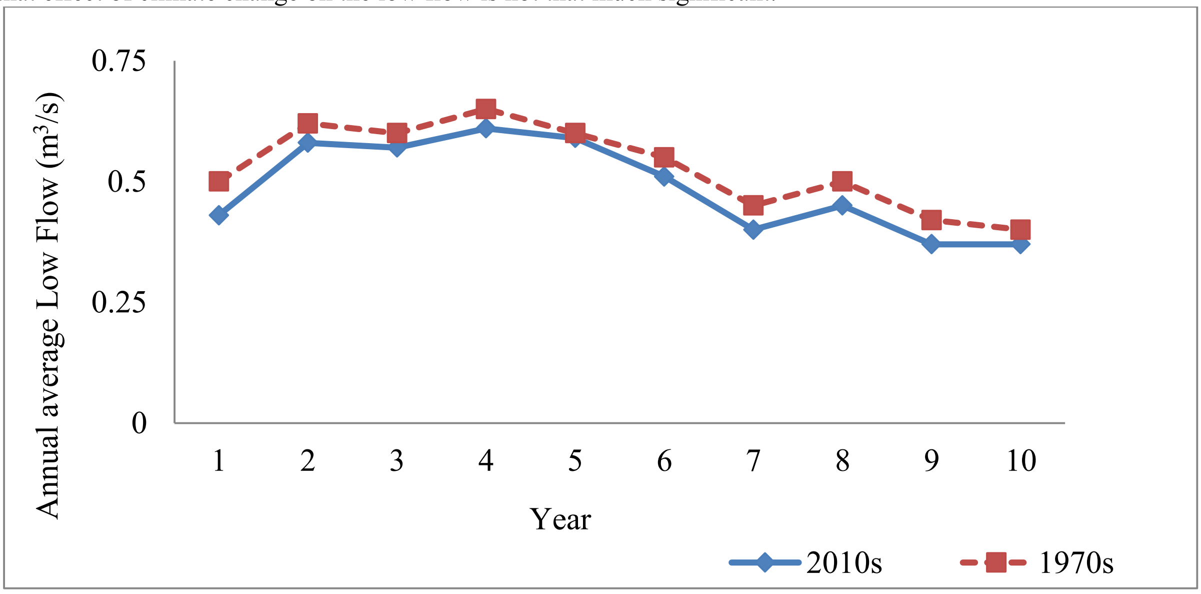

Figure 5: Effect of climate change on low flow

Generally the variation in low flow (figure 5) is the result of increasing temperature trend and consequent change of potential evapotranspiration of the catchment. In addition even though it has not been done in this study, application of small scale irrigation on the upper catchment of Gumara watershed which has increased since 1995 would likely have impact for the reduction of base flow or low flow of the catchment.

The change in mean value of annual minimum flow has indicated a reduction of 0.03m^3/s which is 6%. When it is necessary to compare the most minimum value of (1970s and 2010s) values of these two time periods, the minimum value of annual minimum flow in the base line period is 0.4m^3/s but in the second or change study period, the most minimum flow value was 0.37m^3/s, it is reduced by 7.5%.

Table 5: The effect of climate change on low flow of Gumara watershed

Year	Annual minimum flow between 1973-1982 climate data (m^3/s)	Annual minimum flow between 2004-20013 climate data (m^3/s)
1	0.5	0.45
2	0.62	0.6
3	0.6	0.58
4	0.65	0.61
5	0.6	0.6
6	0.55	0.53
7	0.45	0.42
8	0.5	0.47
9	0.42	0.4
10	0.4	0.37
Average	0.53	0.50

4. Conclusion

Before the climate change was evaluated, the trend of the mean values of rainfall, both maximum and minimum temperature, collected from three metrological stations, computed potential evapotranspiration and observed stream flow of the catchment was done by using Mann-Kendall trend test. Based on this test all variables are found in increasing trend. Then after, the changes of these variables are quantified by comparing the first and last decades of the past 40 years of time series data, which are (1973-1982) and (2004-2013). Based on this method of change study, the rainfall was increased by 14.11mm in terms of monthly average value, maximum temperature has also been increasing by 0.36^{o}c, minimum temperature is by 0.43^{o}c, and potential evapotranspiration was increased by 4.94mm/day in monthly average basis. Generally in terms of percentage values those variables have been increasing by 10.13%, 1.38%, 4.23% and 9% respectively.

The study revealed that climate change was having significant effect on the stream flow dynamics of the catchment. The average stream flow was 31.31m^3/s in the base line period and it was increased by 5.38m^3/s (16.35%) due to change of regional climate of the study area. Climate change has been more affecting the high flow than the low flow of the catchment. Based on the result of the study, when the high flow is increasing by 17.08%, the low is decreasing by 6% because of climate change. Even though, both rainfall and temperature have been increased with in the past 40 years, the above extent of change of flow was caused by rainfall change.

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