Investigation of Climate and Land Use Change Impacts on Stream Flow of Guder Catchment, Ethiopia

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Abstract

Climate change (CC) and land use/cover change (LUCC) are the main drivers of streamflow change. In this paper, we investigate the impact of climate and LULC change impact on stream flow of Guder catchment by using Soil and Water Assessment model (SWAT). The scenarios were designed in a way that LULC was changed while climate conditions remain constant; LULC was then held constant under a changing climate and combined effect of both. The result shows that, the combined impacts of climate change and LULC dynamics can be rather different from the effects that follow-on from LULC or climate change alone. Streamflow would be more sensitive to climate change than to the LULC changes scenario, even though changes in LULC have far-reaching influences on streamflow in the study region. A comprehensive strategy of low impact developments, smart growth, and open space is critical to handle future changes to streamflow systems.

Introduction

Climate and land use and land cover (LULC) change are considered the main two drivers affecting water quantity in watersheds and waterways (Kharel, G.; Zheng, H.; Kirilenko 2016). Due to this, effective planning and management of water resources require better understanding of climate and land use/land cover change effects on watershed hydrology , which is critical in supporting ecosystem services and food security (S. G. Tekleab and Kassew 2019)

Over the last century, climate observations at regional and global scales revealed the more frequent extreme events characterized by changes in temperature and precipitation with direct impacts on local and regional water resources (IPCC, 2013). The concentration increased to over 400 ppm in 2015 and it is expected to reach 463–623 ppm by 2060 and 470–1099 ppm by 2100. With continuation of the above emissions trajectory, the global mean surface temperatures would likely increase by 2.0^{o}C by mid-century and 3.7^{o}C by the end of the 21st century (IPCC, 2014). Fortunately, this global climate changes especially on the Nile Basin are gain particular concern due to their geopolitical and socioeconomic implications (Niang *et al.,* 2014).

Upper Blue Nile is expected to have a lower streamflow by the end of the 21st century because of declining precipitation and increasing use of water for irrigation and hydropower(Mccartney et al. 2012). (Fikru et al. 2018) studied impact of climate change on water resource on Guder catchment of upper Blue Nile Basin in Ethiopia using SWAT Hydrological model. SDMS was used to project climate variable at local scale from coupled model inter-comparison project 3 (CMIP3) data set and found that an increments of mean annual and seasonal in flow volume for both A2a and B2a emission scenario in three benchmark period in the future.

In addition to climate change issues, changes in land use have also been a major driving factor of hydrologic alterations (Ficklin et al. 2009). Numerous studies have investigated hydrological impacts of land use change at watershed scales(Dwarakish and Ganasri 2015).

Some of the study are; increased transpiration(Hardanto, A., Meijide, A., Kohler, M., Hendrayanto, Holscher 2015), increased evapotranspiration (Hardanto, A., Meijide, A., Kohler, M., Hendrayanto, Holscher 2015), decreased infiltration, reduced minimum discharge and water quality(Darma et al. 2016). All these changes potentially increase streamflow fluctuation in a river basin. For example,(Schilling et al. 2008) found that average annual ET decreased with increasing corn acreage in the Raccoon River watershed in Iowa.

The effect of changes in forest and other land use patterns on the flow regime needs monitoring, especially in areas such as the Upper Blue Nile basin, where streamflow during the dry season is an important factor for food security and the development potential of the region(Dile, Berndtsson, and Setegn 2013). The recent study done by (Kidane et al. 2019) reveal that LU/LC change increased the wet season flow by 14.5% while decreasing by 9.65% in dry season. In wet season the flow increased by 4.5% while decreased by 3.3% in dry season because of change in climate and seasonal variability. The study showed the increase in streamflows can be directly attributed to the expansion of cultivated lands at a cost of the forested vegetation.

1.2 Statement of the Problem

This study provides a different perspective review of possible climate and land use change impacts on annual river flow from a large world in different part of watershed. Given that both climate and land use change can play different roles in affecting stream flow different hydro climatic conditions there is a need to evaluate their relative impacts at regional scales. Despite the climate and land use are dynamic factors that greatly influence stream, integrate impacts of climate and LULC change on stream flow are not yet well understood.

As the principal supplier to the Nile flow, the Guder catchment response to environmental change LULC and climate change is vital for the Nile River flow in general, and the catchments in particular. Moreover, combined study of climate change and LULC can provide information about watersheds that will be useful for making decisions regarding the development and management of water and land resources(Randhir, T. O. and Tsvetkova 2011). This reveals that, separate studies of LULC or climate changes do not completely answer the questions as to the resulting influences on streamflow.

An adequate amount of research has been conducted on the potential impacts of LULC change on stream (Rientjes et al. 2011), (S. Tekleab 2020) (Welde and Gebremariam 2017). Similarly some research is done on future climate change on stream flow (Fikru et al. 2018) (Beyene, Lettenmaier, and Kabat 2010) (Alemseged and Tom 2015) (Welde and Gebremariam 2017)). Having separate studies of LULC or climate changes does not completely answer the questions as to the resulting influences on streamflow. It is, therefore, crucial to consider both climate change and LULC dynamics and to evaluate their relative influence to stream flow change.

The common traits of these studies is the use of historical climate and land use data as well as potential land use and climate change scenarios obtained from appropriate projection models. This study followed a similar approach; but nuanced it with the use of complimentary climate and land use scenarios to highlight their individual and combined roles in streamflow variations, which is not very common

1.3. Objectives of the Study

1.3.1. General objective

The general objective of the study was to investigate response of streamflow under changing climate and LULC in Guder catchment of Upper Blue Nile Basin in Ethiopia.

1.3.2. Specific objectives

In order to achieve the general objective of the study, the following specific objectives are set to:

1. Selection of appropriate Regional climate models output that fits the study area.
2. Determine future Temperature and Precipitation scenario for the study area using dynamically downscaled climate model.
3. Quantify impact of future climate change on Streamflow.
4. Quantify the impact of future LULC on Streamflow.
5. Analyze both LULC and climate change implication on future streamflow on Guder catchment.

Material And Method

2.1 Description of the study area

The Guder Catchment is located in the central highlands of Ethiopia. It stretches between latitudes of 9056’0” and 80 41’0”N and longitudes of 370 22’0” and 37013’0”E (Fig 1), and it is part of Blue Nile basin. The watershed area is 662,767 ha; an average of 93% of which is used for agricultural practices. The watershed contains Guder River, which is a tributary of Abay rivers network, which drains to southwest. The river flows from the south to the north and has its outlet to the Abbay River. The Guder catchment borders with the Muger sub-basin to the east, the Awash Basin to the south and the Fincha sub-Basin to the west. The topography of Guder catchment is complex mountainous areas and elevation ranging from 1500-3000m with altitude ranges from 498 up to 4261 masl. The main rainfall season which accounts for about 80–90% of the annual rainfall occurs from June to September, while small rains also occur during December to March. The mean daily temperature of the watershed ranges between 17.30 and 23.40 C. Lower annual rainfall less than 1600 mm in the major sub basin and higher rainfall greater than 1600 mm in same high lands of catchment (Alemseged and Tom 2015).

2.2 Metrological and Hydrological Data Collection

The basic data needed for the investigations in this paper consists of six main parts, including. (1) Digital Elevation Model (DEM) data, which was obtained from the topographical data at the scale of 1:250,000-pixel resolution of a 30m by 30m resolution ASTER Global Digital Elevation Model was obtained from the Ministry of Water Irrigation and Electricity of Ethiopia (MOWIE). (Fig 2) (2) Soil data was extracted from Abay basin master plan developed by Ministry of Water Resource in 2011 with a resolution of 1:250,000. The study watershed contains thirteen soil types across the area at different coverage (Fig 3). (3) LULC maps, which were extracted from the satellite remote sensing image data of Landsat TM with a scale of 1:100,000-pixel resolution of 30 m x 30 m provided by the Company of Geographical Information Monitoring Cloud Platform, 30 m x 30 m (Fig 4). Basic meteorological data such as precipitation, temperature, wind speed, solar radiation and relative humidity was obtained from National Metrology agency. The weather data used were represented from five stations (Asgori, Gedo, Kachis, Shambu and Tikur Inchini) in and around the catchment. (5) Monthly streamflow from the period of 1999–2001 was obtained from (MOWIE) department of Hydrology. (6) RCMs simulations from Coordinated Regional Climate Downscaling Experiment Program (CORDEX) driven by RCA-4 are obtained from CORDEX Project under the Africa Domain with a spatial resolution of˜50 km (0.44˚).

2.3 Climate Change Scenario

Endris et al., (2013) indicated that, the RCMs rainfall simulation varies along the regions, performing good in some and poorly in others. This inconsistency of the performance across regions and seasons indicates the need for evaluation of sensitivity of regions to the choice of RCMs. This could be achieved through proper performance evaluations of the RCMs.

In this study, the best performing RCM was adopted from (Alemseged and Tom 2015). The author dynamically downscaled simulations of eight GCMs, which were part of the Coupled Model Intercomparison Project Phase 5 (CMIP5). The downscaling was accomplished by the recent version of the Rossby Centre using the Regional Climate Model—RCA4 (http://www.smhi.se/en/). After evaluating the performance of eight Regional Climate Models (RCMs) in Coordinated Regional Climate Downscaling Experiment (CORDEX) Africa, MPI-ESM-LR RCMs showing a better performance were selected for this study.

Selection of emission scenario is less significant for the near term climate projections (Praskievics, S and Chang 2014) (Roosmalen, Sonnenborg, and Jensen 2014) meaning that the choice among RCP2.6, RCP4.5, RCP6.0 and RCP8.5 concentration pathways is not vital for short-term projected climate data (2021–2040). Fortunately, this study is interested to understanding the implication RCP 4.5 on global warming under 20 C for Guder Catchment. For the simulation of temperature and precipitation, we applied the changes in climate variables derived from the outputs of four climate CMIP5 models under moderate (RCP 4.5). The years 2021–2040 served as future scenario periods and the period from 1986 to 2017 as a historical baseline to evaluate the climate changes. By 2100, the radiative forcing level reached a value of 4.5 W/m2 and the CO2 concentration increased to 650 ppm (parts per million by volume) under scenario RCP 4.5.

2.4 Bias Correction

The climate model data for hydrological modeling (CMhyd) (Rathjens et al., 2020), obtained from https://swat.tamu.edu/software/, was used to process the precipitation and temperature bias correction. (Teutschbein and Seibert 2013) have provided a full review of the bias correction techniques. According to (Teutschbein and Seibert 2013), all the bias correction techniques have improved the simulation of precipitation and temperature. The study by used CMhyd for extraction of CORDEX-NetCDF, and bias correction of minimum and maximum temperature to predict climate change-induced temperature changes in upper blue nile catchment. Accordingly, we select CMhyd for bias correction of GCM data of the study area.

2.5 LULC change scenarios

For providing food and energy security, the Ethiopian government has been building smaller to mega dams in the Upper Blue Nile basin. However, erosion and sedimentation are considered as two of the factors leading to siltation of reservoirs. The erosion rates were higher from cropland than the averages for all lands in the study region (Ebabu et al. 2019) due to cultivation on steep slopes. There is a strong commitment from the government to tackling erosion and sedimentation, as well as rehabilitating degraded lands. One of the plausible measures for the future LULC map could be converting cultivation land on steep slopes higher than 10% to forest land in the Guder Catchment based on 2015 historical LULC maps. In addition, existing and planned irrigation schemes, including reservoirs, could be incorporated in the future land-use and land-cover scenario. Forest and woodland expansion can also be used for fuel wood and carbon sequestration. The final LULC map was used as an input in a calibrated and validated SWAT model to simulate the future streamflow.

2.6 The hydrological SWAT model

The SWAT model is a basin-scale, semi-distributed and continuous-time model developed by the Agricultural Research Service of the US Department of Agriculture (Neitsch and Al. 2014). It is linked to ArcGIS and capable of analysing large datasets on various geographical scales . The hydrology sub-model is based on the water balance equation, which includes daily precipitation, evapotranspiration, percolation, runoff, and return flow components. In using the SWAT model, the catchment was divided into multiple sub-watersheds, and then discretized into a series of hydrological response units (HRUs), which included unique land uses, soil characteristics, and slopes. The SCS (Soil Conservation Service) curve number method, which is based on the local land cover, soil type and antecedent moisture conditions, was used to estimate surface runoff. Depending on data availability, the model provides various methods for estimating potential evapotranspiration, including the Penman-Monteith, Priestley Taylor, and Hargreaves methods. In this study, we used the Hargreaves method (Neitsch and Al. 2014) and ArcSWAT v. 2012.10.3.18 in ArcGIS (v. 10.3).

$$SWt = SWo + \sum_{i=1}^{t} (Rday - Qsurf - Ea - Wseep - Qgw) \ldots\ldots\ldots (1)$$

2.7 Model inputs and model set-up

A DEM having a resolution of 30 m was extracted from the Aster Global DEM. Soil data was extracted from Abay basin master plan developed by Ministry of Water Irrigation and Electricity of Ethiopia (MOWIE) in 2011 with a resolution of 1:250,000. The Landsat satellite imageries were obtained from Ethiopian Mapping Agency to identify the LULC of the watershed during three period of 2015. The LULC classes generated for the study area were (1) Moderately cultivated land, (2) grass land, (3) shrub land, (4) settlement and (5) forest land. Daily temperature and precipitation data were recorded from Five station (Kachis, Gedo, Tikur, Asgori and Shambu), located within and near the watershed; these data were collected by the Ethiopia Metrological Agency (EMA) for the period 1987–2016. River daily discharge data for the outlet of the basin for the period 1990–2001 were obtained from (MOWIE); these data were used for calibration and validation. The basin was automatically delineated using a threshold value of 3000 ha, which resulted in delineation of 31 subbasins. We used threshold values of 0, 10, and 10% for land cover, soil, and slope, respectively, in producing the HRUs.

The zero thresholds set for the land cover was to retain very small patches and to better understand the impact of land cover on discharge.

2.8 Sensitivity Analysis, calibration and validation

Owing to a large number of flow parameters in SWAT, identifying the most sensitive parameters is necessary to improve the calibration of the hydrological model. Through the sensitivity analysis, the most sensitive parameters that strongly influence the flow process will be identified. The Sequential Uncertainty Fitting (SUFI-2) embedded in the SWAT-CUP (Calibration and Uncertainty Program) was used to achieve the sensitivity analysis, calibration and validation(Abbaspour et al. 2015). To compare the measured and simulated monthly discharge, values were calculated using the Nash-Sutcliffe efficiency paramet ((Nash and Sutcliffe 2013) and the coefficient of determination (R2). The simulation periods for calibration and validation were 1990-1997 and 1998–2001, respectively

The model performance ratings were based on the statistics recommended by (D. N. Moriasi et al. 2007) R2 varies between 0 and 1, where higher value shows less error. NSE ranges from negative infinity to 1 (best). PBIAS close to 0 shows best the simulation, a negative value indicates overestimation and a positive value indicates under simulation of the model. RSR varies from zero to a large positive number. The lower RSR shows a better simulation of the model. These statistics are calculated using Equations (2) to (5):

$$R^2 \frac{\left[\sum_{i=1}^{n}[Q_{obs} - Q_{obs,m}]\,[Q_{sim} - Q_{sim,m}]\right]^2}{\left[\sum_{i=1}^{n}(Q_{obs} - Q_{obs,m})^2 \sum_{i=1}^{i}(Q_{sim} - Q_{sim,m})\right]^2} \dots\dots\dots (2)$$

$$E_{NS}= \frac{\left[\sum_{i=1}^{n}(Q_{sim} - Q_{obs,m})\right]^2}{\left[\sum_{i=1}^{n}(Q_{obs} - Q_{obs,m})\right]^2} \dots\dots\dots (3)$$

$$\text{PBIAS}\ \% = \frac{\sum_{i=1}^{n}(Q_{sim} - Q_{obsOi})}{\sum_{i}^{n} Q_{sbd}} \dots\dots\dots (4)$$

2.9 Model and simulations

GCMs are main sources of projected climatic data used to evaluate precipitation shift, temperature increase, or changes in meteorological events. Even though the modeled changes in watershed hydrology may be small, the choice of short-term scenarios avoids too important uncertainties in climate change: human behavior and policy choices. It is difficult to develop realistic land use and world market scenarios for a period of N 20 to 30 years (Roosmalen, Sonnenborg, and Jensen 2014). For this reason, short-term scenarios from 2021-2040 were considered in this study. Simulations based on altering LULC for the same climatic condition was applied to evaluate the impact of LULC on streamflow.

On the other hand, the impact of climate change on streamflow was assessed without altering LULC. Differences between the outcomes from these runs and a control run revealed the effect of changes in either the LULC or climate on streamflow. The control run was a simulation using 2015 LULC and historical climate data. Results of changes in both LULC and climate from those used in the control run described the combined influences of both climate and LULC changes on catchment streamflow.

Following the calibration, all the model parameters were held constant for modeling future conditions. However, future climate and LULC changes may possibly alter the model parameters(Vaze et al. 2010). The responses of catchment streamflow to LULC and climate changes were evaluated using the SWAT and the impacts of a single factor, i.e. LULC or climate change, on streamflow regime was distinguished according to(Giorgi, Jones, and Asrar 2017) . In this study, three simulations were carried out to assess three different scenarios, i.e. the impacts of future climate change alone future climate change, future LULC change only LULC change and future climate and LULC changes combined future LULC change and future climate change.

Result And Discussion

3.1. SWAT model calibration and uncertainty

We used SUFI-2 to calibrate and verify monthly measured discharges at the outlet of the basin relative to predicted. The major model parameters and their best values in the monthly calibration procedure are shown in (Tab 1) and (Tab 2) shows the Nash-Sutcliffe (NSE) and the R2 values. Twelve key parameters in controlling the hydrology of the Guder catchment were adjusted from the model default values. These parameters were selected based on sensitivity analysis. The results show that the NSE values for the calibration and validation periods were 0.83 and 0.8, respectively; the recommended value for good model performance is 0.65–0.75 (Moriasi et al. 2007). The NSE value in the validation period was higher than that in the calibration period. (Fig 5) shows good agreement between observed and best simulated according to goodness scale of (D. N. Moriasi et al. 2007). Consequently, the performance of the SWAT was considered sufficient to assess the effect of future land cover and climate changes on streamflow.

3.2. Future temperature and precipitation changes

The projected climate change for the period 2021–2040 under the RCP4.5 scenario is shown in Figure 4. During seasonal change, there would be more precipitation in JJAS (June, July, April and September) as compared to MAM (March, April and May) and ONDJF (October, November, December, January and February). The major rainfall moths (June and July did not show a consistent trends. Studies(Beyene, Lettenmaier, and Kabat 2010) (Dile, Berndtsson, and Setegn 2013) show a similar trend of rainfall in the Upper Blue Nile River basins in the future period. Projection using RCP 4.5 scenarios predicted an increment from the base line time horizon, which showed an increment of Annual maximum temperature of 1.4 0C with 2020’s scenarios. Unlike maximum temperature, projection of minimum temperatures showed reduction in minimum temperature by the months of July (0.411 0C) and August (0.6 0C). The temperature change projection for Guder catchment is in line with the range produced in by other researcher over the UBNR (Forecasting, Gebre, and Ludwig 2015) (Tegegne, Park, and Kim 2017).

3.3. Land use/land covers change and prediction

One of the plausible measures for the future LULC map could be converting cultivation land on steep slopes higher than 10% to forestland (Haregeweyn et al., 2006). According to Girmachew, (2016) Guder catchment is supposed to be one of the major irrigation potential sites of the Abay basin. Once Land use scenario was prepared by using different conservation assumption, historical LULC was modified to future scenario by using Land use update (LUP) (Fig 6 and Tab 3). Final LULC scenario was used to simulate the stream flow by the help of edit SWAT input.

3.4. Impact of future Climate change on streamflow.

(Fig 7a) shows the simulated Streamflow under future climate change compared with the baseline period (1986–2017) and constant land cover conditions. The highest decrease in stream flow is observed during December, which could be a result of 22% decrease in precipitation by 2040. A significant increase in stream flow is expected to occur between Junes to September because of the 41% increase in precipitation in 2040. (Mishra and Lilhare 2016) were found similar stream projection flow during the wet season. They reveal that, the in dry season (Jun-September) stream projection was increased in the majority of the sub-continental river basin.

3.5. Impact of future Land use/land covers change on streamflow.

(Fig 7b) showed that Stream flow simulation based on projected land use change indicates decrease in annual stream flow by 13% due to land use change compared to that in the baseline period in the Guder catchment. Based on future projections, cultivated land use would cover less than 40% in 2040 of the watershed. This reduction in cultivated land use would lead to decrease in annual stream flow compared to the baseline scenario. The result shows that the mean stream flow in wet season, small rain season and dry season was 10%, 3% and -4% respectively. This result is supported by past studies in Upper Blue Nile basin at different temporal and spatial context (Temesgen Gashaw a and ⁎, Taffa Tulu a, Mekuria Argaw a 2016).

3.6. Impacts of future climate and Land use/land cover changes on stream flow

Climate change simulations combined with land use/land cover for 2040 demonstrated an annual increase of 18 % for the RCP4, based on the inter-model average. Seasonal and annual stream flows at the Guder catchment outlet might be offset under concurrent effects of future land use /land cover and climate change compared to sole future climate change scenario (Fig. 7c). . Stream flow would be more sensitive to climate change than to the LULC changes scenario, even though changes in land use have far-reaching influences on stream flow in the study region. In a similar climate and land use change impact study, (Tavernia et al. 2013) reported that projected water stress (i.e. water demand/water supply) would be more sensitive to climate change than land use change in the Northeast and Midwest, United States.

Conclusion

We have Investigate the separate and combined impacts of projected future changes in land use and climate on the water balance components in the Guder catchment. The simulation due to climate impact shows that, the highest decrease in stream flow observed during December (22%) and the large flow of mean month observed on August (36%) by 2040 with RCP 4.5 scenario. The change in annual flow due to impact of climate change was 31 %. This shows that climate change is very sensitive factor for stream flow of Guder catchment.

Stream flow simulation based on projected Land use/land cover change indicates increase in annual stream flow by 16.5%. Expansion of forest cover after reverting cultivation lands on steep slopes to forest might increase streamflow in the rainy season and decrease it in the dry period, thus maintain extreme hydrological regime. On the other hand, loss of forests would increase flood potential, and also intensify drought impact. Furthermore, forest loss on steep slope might increase surface runoff, which in turn implies accelerated land degradation. Overall, the sensitivity of water resources for land use/land cover and climate change over Guder catchment shows the effect of land use/land cover change is stunned by the effects of climate change. Consequently, climate change is found to be predominant over the effects of LULC change.

The analysis of combined effect of land use and climate change impacts demonstrate that, the total increases in mean annual streamflow was 18.5%. The combined impacts of climate change and LULC dynamics can be rather different from the effects that follow-on from LULC or climate change alone. The important inference from these findings is that it could be possible to alleviate intense floods or droughts due to future climate change by planning LULCs to attain particular hydrological effects on land cover in the basin. Stream flow would be more sensitive to climate change than to the LULC changes scenario, even though changes in land use have far-reaching influences on stream flow in the study region.

The LULC change scenario was set up based on the assumption of more conservation practices in the future in order to reduce erosion and sedimentation. Furthermore, limited availability and quality of hydro-climatic data in the region need urgent attention to improve our understanding of the change in existing and future climate and LULCCs. These shortcomings may possibly increase the uncertainty of the model outcomes.

The findings and approach of this study still have significance for natural resources management in the future for the Guder catchment, as well as other regions encountering similar pressures from climate change and LULC dynamics. As land development and change in climate would continue, integrated land and water use planning should be executed to deal with the potential changes of hydrological regime and land degradation. In general, the result highlights the need for regional developments and cooperation to urge strong climate-resilient management strategies and to counteract the rapid climate changes in the catchment.

Declaration

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Conflicts of Interest Statement

Manuscript title: **Investigation of Climate and Land Use/Land Cover Change Impacts on Stream Flow of Guder Catchment in Upper Blue Nile in , Ethiopia**

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Availability of data and Material (The CMIP6 data was used for the study and downloaded from http://esgf-node.llnl.gov that was freely available for users.**)**

Code Availability (All code for data cleaning and analysis associated with the current submission is available at the local authorities in Ethiopia**)**

Author Contribution

Bekam Bekele, Boja Mekonnen and Abdulkerim Bedewi conceived and designed the model and simulations; Bekam Bekele collected and analyzed the data; Boja Mekonnen and Abdulkerim Bedewi made editing corrections and improvements to the manuscript; Bekam Bekele wrote the paper. All authors have read and approved the final manuscript.

Ethics Approves (We confirm that the manuscript has been read and approved by all named authors. We further confirm and understand that the corresponding author is the sole contact for the editorial process)

Consent of Participation (For this type of study formal consent is not required**)**

Consent of publication (For this type of study consent for publication is not required**)**

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Tables

Tab 1 Model parameters and their best values used for SUFI-2

Parameters	Range used in calibration	Fitted /Calibrated
r_CN2.mgt	0.3 to 0.59	0.34
r_OV_N.hru	-0.2 to 0.08	0.02
r_SOL_K.sol	-0.1 to 0.4	0.1
r_SOL_AWC.sol	0.2 to 0.46	0.35
v_CH_K2.rte	123 to 194	156
v_REVAPMN.gw	0 to 500	48.3
a_GWQMN.gw	0.83 to 2.4	1.6
v_ALPHA_BNK.rte	0.004 to -0.48	-0.39
v_CANMX.hru	0 to 10	0.01
v_SURLAG.bsn	0 to 0.2	0.15
r_GW_REVAP.gw	0.02 to 0.1	0.07
v_CH_N2.rte	0.15 to 0.29	0.29

Tab 2 Model calibration and validation performance

Criteria	Calibration	Validation
Coefficient of determination (R^2)	0.84	0.85
Nash–Sutcliffe efficiency (NS)	0.83	0.8
% BIAS	8.3	2.3

Tab 3 Proportional extent of current and future LULC in Guder Catchment

Name of LULC	LULC in 2015 (%)	LULC in 2040 (%)
AGRR	76.33	56.44
RGNE	2.04	1.95
BERM	5.5	5.46
FRST	0.22	14.12
WATR	1.16	0.63
URBN	0.12	0.12
AGRL	14.70	14.08
CRIR	-	7.20

Figures

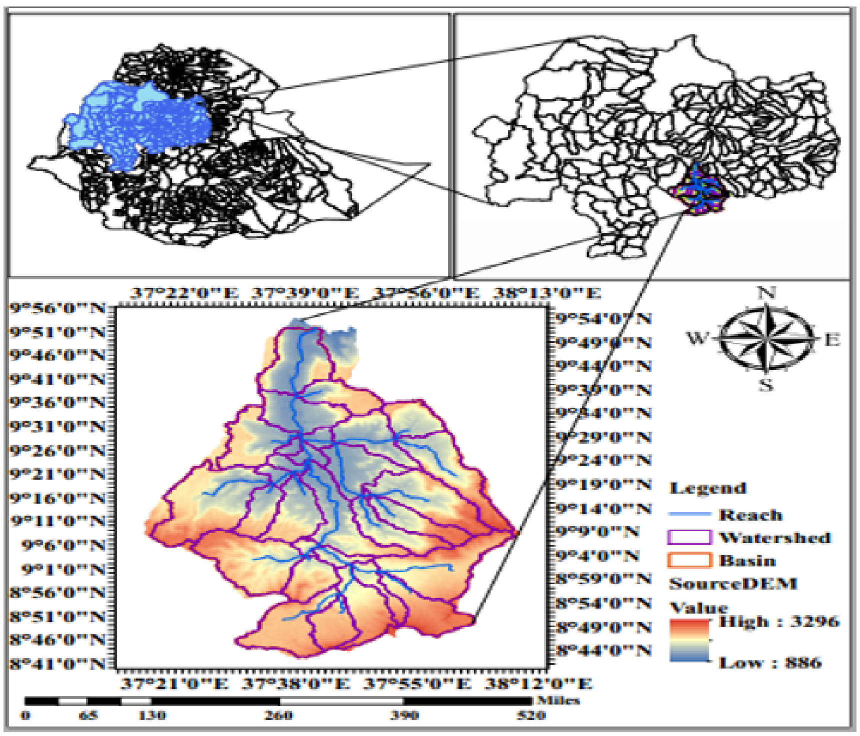

Figure 1

Location map of study area

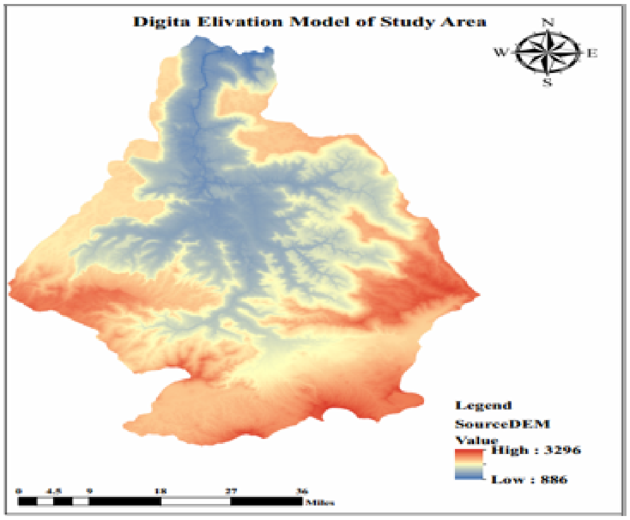

Figure 2

Digital Elevation Model of Guder Catchment. Source: MOWIE, (2015)

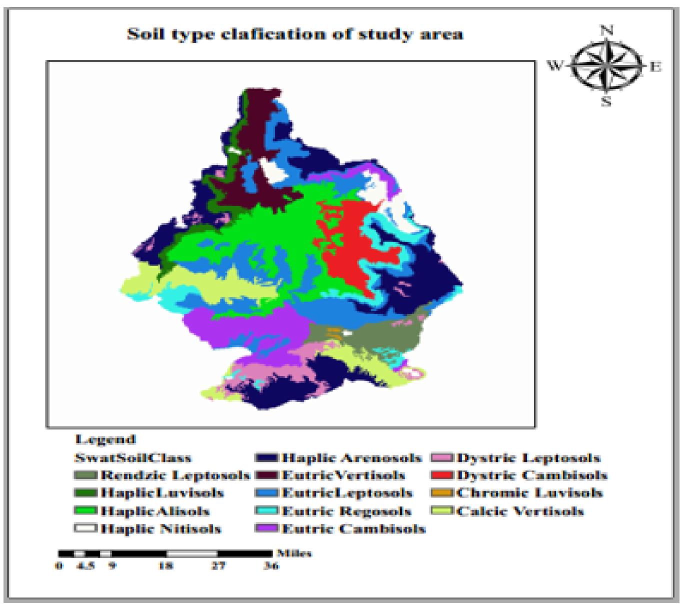

Figure 3

Map of the soil types of Guder Catchment. Source: MOWIE, (2015)

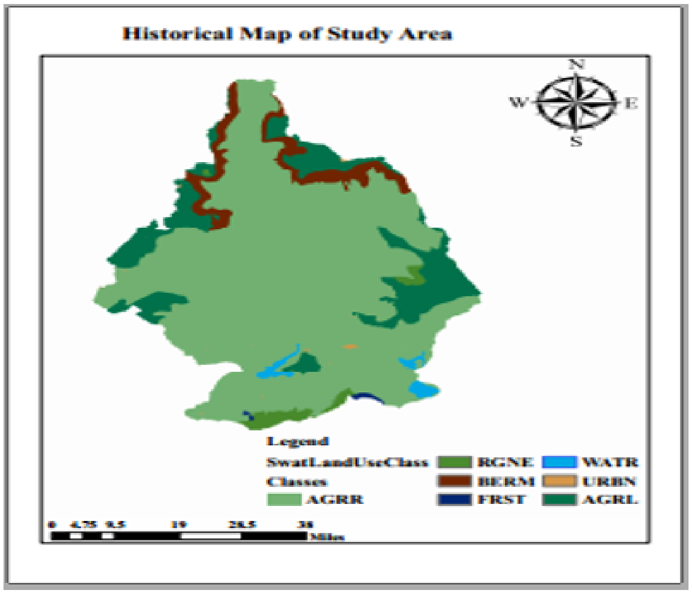

Figure 4

Guder Catchment Land use Land cover. Source; MoWIE, (2015)

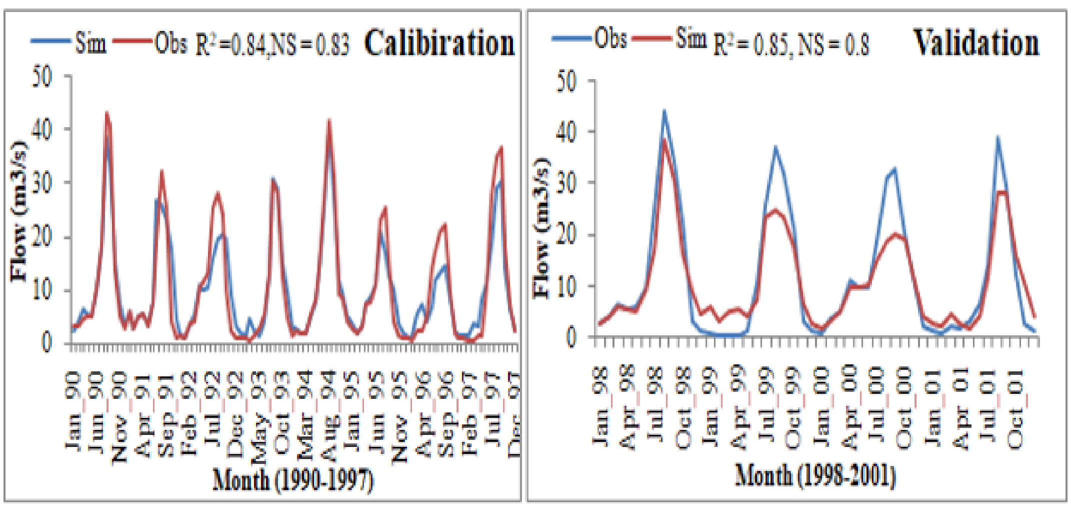

Figure 5

Model parameters and their best values used for SUFI-2

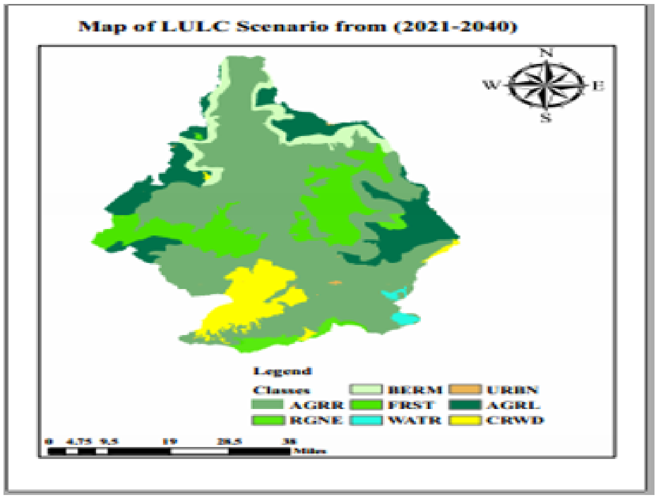

Figure 6

Land use and Land cover change of Guder Scenario

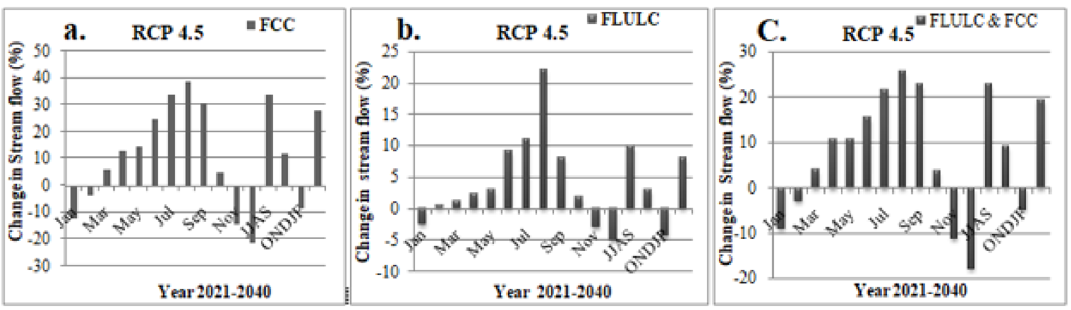

Figure 7

Stream flow response to climate change (a), Land use/land covers change (b) and combined impact of both climate and land use/land cover change (c).