Impacts of Climate and Land Use Change on Hydrological Response in Gumara Watershed, Ethiopia

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Abstract

Climate and land-use change affect the hydrologic cycle by altering streamflow (SF), surface runoff (SR), base-flow (BF), and evapotranspiration (ET). The Lake Tana basin has experienced both land-use and climate change over the past 40 years, and this change can continue in the future. Several studies have addressed the separate impacts of either land-use or climate change on the watershed's hydrology, but few have explored the combined impacts. In this study, the SWAT model was applied to evaluate the combined impacts of land-use and climate change on hydrological responses in Gumara watershed. This study examined four land-use scenarios that include the present (2015) and projected (2050) land-use based on the business-as-usual trend (BAU), expansion of irrigation crop (EIC), and expansion of forestland (EFL). The climate variables were simulated using Weather Research and Forecasting (WRF) model for the baseline (2005-2015) and projected period (2045-2055) under RCP4.5 and RCP8.5 scenarios. The result showed that SR increase by 5.1% under BAU scenario while BF decrease by 6.5% without altering SF and ET noticeably. On the contrary, SF decrease by 12.5% and 5.2% respectively under EIC and EFL scenarios, while ET increase by 4.8% and 8.9% respectively under EIC and EFL scenarios. The simulated SF, SR, and ET under RCP8.5 may increase significantly by 34.3%, 51.8%, and 12.2%, respectively. Similarly, the simulated SF, SR and ET may increase significantly under the combination of all three land-use and RCP8.5 scenarios. The findings suggested that climate change will have a greater effect on hydrologic responses than land-use change. The expansion of agriculture and the wetter climate would exacerbate flooding, while the expansion of irrigation and forest offset SF increases. The results of this study can be useful to decision-makers and planners in the design of adaptive measures to climate and land-use change.

Impacts of Climate and Land Use Change on Hydrological Response in Gumara Watershed, Ethiopia

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Abstract

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Keywords: hydrological response; land-use change; climate change; SWAT; WRF

1 Introduction

Both climate and land-use change affect the spatial and temporal variability of the watershed hydrology through modifying streamflow, surface runoff, base-flow and evapotranspiration (Rahman *et al.* , 2015; Liu *et al.* , 2017). According to the Intergovernmental Panel on Climate Change report (IPCC, 2014), global average temperatures and frequency of heavy precipitation events are expected to increase in the mid-21st century. These changes will affect the hydrologic cycle through enhanced evaporation, peak flow, and flooding. Furthermore, land-use change seriously affects water resources mainly through partitioning of the rainfall amount into interception, evapotranspiration, infiltration, and soil moisture storage, thereby affecting the availability of watershed hydrology (Mishra *et al.* , 2010; Mango *et al.* , 2011). Human activities especially agricultural land expansion at the expense of forest cover have been the primary reason for the land-use change (Mottet *et al.* , 2006). The impact assessment study showed that interactions between land-use and climate could create serious challenges for water quantity and quality. Therefore, understanding the combined effects of land-use and climate change can be a basis for improved water resources management.

In recent years, many studies examined the combined impact of land-use and climate change on hydrologic processes (Koch *et al.* , 2015; Hyandye *et al.* , 2018; Aboelnour *et al.* , 2019). The findings from these studies consistently highlight the water balance components including streamflow, surface runoff, groundwater, and evapotranspiration are likely to be impacted by future land-use and climatic changes. However, the relative impacts of land-use and climate change may vary from place to place due to the rate and extent of changes in climate and land-use. For example, some studies have found that the hydrological processes are impacted more by climate change than land-use change (Mekonnen *et al.* , 2018; Aboelnour *et al.* , 2019), and other studies have indicated that the impacts of land-use change are more significant as compared to the impacts of climate change (Mwangi *et al.* , 2016; Yin *et al.* , 2017). The interaction between climate change and land-use change is non-linear (Jung *et al.* , 2011). For example, some studies reported that the increase in streamflow due to land-use change was amplified by wetting climate scenarios (Marhaento *et al.* , 2018), and other studies found that climate change could substantially offset runoff increment due to urbanization (Sunde *et al.* , 2018). This highlights the importance of considering the combination of scenarios to understand the impact of environmental changes in the future availability of water resources. Therefore, investigating the effects of changes in climate and land-use on watershed hydrology has a great practical significance; especially in the tropical region like Ethiopia, where climate and land-use change rapidly (Berihun *et al.* , 2019; Chimdessa *et al.* , 2019).

In Ethiopia, during the past four decades, there has been extensive land-use changes and intensification of climate change. The land-use studies across different parts of Ethiopia have shown that the coverage of cropland has been expanded extensively (Teferi *et al.* , 2013; Jemberie *et al.* , 2016; Gebremicael *et al.* , 2019). This land-use dynamic has resulted in a change in the fluxes of the hydrological cycle (Teklay *et al.* , 2018), which caused an increase in surface runoff and a decrease in soil moisture and evapotranspiration (Woldesenbet *et al.* , 2017; Gebremicael*et al.* , 2019). Climate change may further intensify this process through alteration of the hydrological cycle (Bekele *et al.* , 2019). According to World Bank (2019), climate projections for Ethiopia indicate an overall increase in temperature and precipitation for all months, especially during the wet season. The changes in both temperature and precipitation exhibit remarkable regional variability as evident from the Lake Tana basin predict to experience a warmer and wetter climate in the future (Ayele *et al.* , 2016; Nigatu *et al.* , 2016).

Although the water resources in the Lake Tana basin is highly vulnerable to both land-use and climate change (Woldesenbet *et al.* , 2018), several studies have investigated the impact of either land-use change (Andualem and Gebremariam, 2015; Gumindoga *et al.* , 2015; Woldesenbet *et al.* , 2017; Gashaw *et al.* , 2018) or climate change (Abdo *et al.* , 2009; Dile *et al.* , 2013; Enyew*et al.* , 2014; Taye *et al.* , 2015; Ayele *et al.* , 2016) on the hydrological responses. Very few studies investigated the combined effect of land-use and climate change on water resources in the basin (McCartney and Girma, 2012; Woldesenbet *et al.* , 2018). Moreover, most of the studies which examined the impact of climate change on water resources have assumed that land-use remains static. On the other hand, studies that investigated the impact of land-use change rarely considered climate dynamics. However, land-use and climate in the future will change intensively due to urbanization, population growth, economic development, and global warming (McCartney and Girma, 2012). The expansion of cropland and deforestation accompanied by climate change may impose an unprecedented impact on watershed hydrology, whereas afforestation and water harvesting structure may modify the negative impact of climate change (McCartney and Girma, 2012). Gumara river is one of the tributaries in Lake Tana basin where small and large scale irrigation projects are planned to improve the livelihood of the community. However, there is inadequate information about land management practices in modifying the impact of climate change on water resources in the watershed level.

Therefore, this research is designed to investigate the combined and individual impact of land-use and climate change on the hydrological responses in Gumara watershed, Ethiopia. In this study, four land-use and three climate change scenarios were used for hydrological simulations using the SWAT model for the projected period and the reference period.

2 Materials and Methods

2.1 Study area

Gumara watershed is located in the northwestern part of Ethiopia between 37.63°-38.18° longitude and 11.57°-11.90° latitude. Gumara river originates from a small spring located near Guna Mountain and drains to the eastern part of Lake Tana (Figure 1). The catchment area of the Gumara river is 1269 km^2. Gumara river is one of the main streams on the east side, flowing into Lake Tana. Elevation of Gumara watershed varies from 1794 and 3704 meter above sea level, with a mean elevation of 2272 m. From the slope map, around 60% of the catchment area falls in the slope range from 0 to 15% and 32% of the area falls in the slope range of 15–30%. The remaining 8% of the area has slopes steeper than 30%.

The watershed has a tropical humid climate with distinct dry and wet seasons. The mean annual rainfall is 1387 mm, of which about 70–90% falls from June to September rainy season while less than 10% during April and May. The long term average daily minimum and maximum temperatures are 9 °C and 28.5 °C, respectively. The majority of the watershed area is covered by cultivated land (92%), and the remaining area is covered by shrubs (3%), grassland (4%), and forest (1%). The most dominant soil type is Haplic Luvisols (64%) which is found in the midstream parts of the watershed. The second dominant soil is Eutric Vertisols which is found in the downstream parts. Chromic Luvisols mainly extends to downstream and upstream parts of the watershed. Eutric Fluvisols is the least common soil type ($< 1\%$) in the watershed.

Figure 1

2.2 Data availability

Spatial and non-spatial data were collected for the hydrological model evaluation and future land-use modeling. Land-use maps of 30-m spatial resolution for the years 1985, 1995 and 2015 were available for Gumara watershed from Teklay *et al.* (2018). The soil map, streamflow and Gumara Irrigation Project plan were collected from the Ministry of Water, Irrigation and Electricity of Ethiopia (MoWIE, 1998, 2008). DEM data with a spatial resolution of 90 m was obtained from the Shuttle Radar Topographic Mission (SRTM). The meteorological dataset was collected from the National Meteorological Agency (NMA) of Ethiopia from five stations (Figure 1). The spatial road network and town map were available from Ethiopia Mapping Agency. The population size and agricultural management practices such as major crops, planting, harvesting and killing, tillage, and fertilize application data for the watershed were obtained from the Central Statistical Agency of Ethiopia and South Gondar Zone Agriculture Office (CSA, 2007; SGZOA, 2016).

2.3 Hydrological model

The Soil and Water Assessment Tool (SWAT) is a physically-based, computationally efficient, semi-distributed model to simulate and predict the impacts of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land-use, and management conditions over long periods (Neitsch*et al.* , 2011). The model has been widely used in different watersheds across the world and proved to be an effective tool to examine hydrological responses to land-use and climate changes (Kumar*et al.* , 2017; Pandey *et al.* , 2017; Polanco *et al.* , 2017; Lee *et al.* , 2018). In the SWAT model, the target watershed is divided into sub-basins linked by the channel network, each sub-basin is further subdivided into several hydrological response units (HRUs) of homogeneous land-use, slope and soil characteristics. Hydrological components, nutrients and sediment yield are simulated at the HRU level and then aggregated for each sub-basin. The detailed model description is found in Neitsch *et al.* (2011).

The suitability of the SWAT model to estimate hydrologic processes to land-use change in Gumara watershed was assessed by Teklay *et al.*(2018). In this study, the SWAT model set-up followed the same settings as in the previous chapter. Therefore, this study presented only a summary of the model set-up and evaluation results. The watershed area was discretized into 22 sub-basins. These sub-basins were further discretized into HRUs by setting zero percent threshold level for land-use, slope, and soil. The Penman-Monteith method was chosen to calculate reference evapotranspiration (Gebre and Ludwig, 2015). The Soil Conservation Service Curve Number and the variable storage method were used to calculate surface runoff and flow routing, respectively.

Based on the previous studies in the region and literature survey (Setegn *et al.* , 2008; Gebremicael *et al.* , 2013; Dile*et al.* , 2016), eighteen SWAT parameters were calibrated using the Sequential Uncertainty Fitting version 2 (SUFI-2) in the SWAT-Calibration and Uncertainty Procedure (SWAT-CUP) package (Arnold*et al.* , 2012). The model was calibrated using monthly streamflow data for a period of fifteen years from 1990 to 2004. The calibration was performed through a "trial and error" process by manually adjusting the parameter ranges based on published literature (Van Griensven *et al.* , 2012; Dile *et al.* , 2016; Fentaw *et al.* , 2018). After calibration, the model was validated using streamflow data from 2005 to 2015. The performance of the SWAT model was assessed using two qualitative statistics recommended by Moriasi *et al.*(2007): Nash-Sutcliffe Efficiency (NSE) value and Percent Bias (PBIAS). The results of the model calibration show that the simulated mean monthly streamflow in the calibration period agrees well with the observed records, with NSE and PBIAS values of 0.89 and 10.7%, respectively. For the validation period, the NSE and PBIAS model performance of the SWAT model was 0.85 and 8.7%, respectively. These findings are in agreement with previous studies in the region (Setegn*et al.* , 2008; Dile *et al.* , 2016; Teklay *et al.* , 2018).

2.4 Land-use scenario

A scenario-based land-use change simulation can help to assess the potential impacts of land-use change on water resources in an uncertain future (Cao *et al.* , 2019). To examine the impact of land-use changes on the hydrological response in Gumara watershed, three future land-use scenarios for the year 2050 were developed. These scenarios were made to include the ongoing trends of land-use change within the study area, the future water resource development plan, and the idealized afforestation program. The land-use scenarios included:

i. Business-as-usual (BAU) scenario

In this scenario, the past land-use change trends were extrapolated into the future by assuming the past trends of land-use change will continue in the future. The BAU land-use scenario was simulated using a Module for Land-use Change Evaluation (MOLUSCE) component of QGIS. The module simulated land use land cover map based on a Monte Carlo Cellular-automata modeling approach. In recent years, this module has been widely used to simulate land-use changes (Rahman *et al.* , 2017; Ashaolu *et al.* , 2019). MOLUSCE is designed to analyze land-use changes and predict the future direction of change by using spatial change variables. The spatial variables including elevation, slope, and population density, as well as the distance to town and roads, were considered. These biophysical and socio-economic variables are widely used to analyze the change patterns and to extract effective information about the effects of human activities on land-use change (Doğan and Buğday, 2018). ArcGIS 10.1 software was used to prepare a raster spatial map. In this study, Artificial Neural Networks was used to model LULC transition potential between 1985 and 1995. The land-use map for 2015 was predicted based on the change transition area matrix. Then, both the present and predicted images of the year 2015 were compared for validation of the model. The classified land-use map of 2015 had a high overall accuracy of 86.4% and a kappa coefficient of 0.82. Finally, the land-use for 2050 was predicted using a fitted model and transition matrix generated between 1995 and 2015 land-use maps.

ii. Expansion of Irrigation Crop (EIC) scenario

The future water resource development plan was considered in the EIC scenario. Gumara Irrigation Project map was scanned from the feasibility study document from the Ministry of Water, Irrigation and Electricity of Ethiopia (MoWIE, 2008). The scanned map was converted into a digital map using the Geo-referencing tool in ArcGIS. A dam is planned on the Gumara River at the midstream part of the watershed which covers a 3.51 km^2 area at the full reservoir level. The stored water will then irrigate about 14.0 km^2 land at the downstream side of the watershed. The EIC scenario was developed by replacing the present land-use pixels with irrigated cropland and reservoir pixels. Tomato, onion, and maize are the most widely cultivated crop types in the watershed (SGZOA, 2016). In the SWAT modeling, the whole irrigation farm was seeded to grain the three crops with equal proportion. The planting data started on January 1 of every simulation year.

iii. Expansion of Forestland (EFL) scenario

Expansion of forestland (EFL) scenario is an idealized land-use condition for the 2050 period. The EFL scenario was developed by assuming that the forest area will expand in the future especially on sloppy areas. The agriculture and shrub-land area on a slope greater than 15% are replaced by forest land-use. In this scenario, only the grassland and urban area were preserved.

2.5 Climate scenario

The baseline and future climate variables used in this study were simulation output from the Weather Research and Forecasting (WRF) model as presented in the previous chapter. GCMs data has too low spatial resolution for hydrological applications (Hurkmans *et al.* , 2010). Thus they were dynamically downscaled using the WRF model in three steps. First, the WRF output with a resolution of 36 km was obtained from the outer domain, which was reduced to 12 km (intermediate domain) and 4 km (inner domain) (Teklay *et al.* , 2019). In this study climatic data (rainfall and temperature) from the simulation of the internal domain were considered in the hydrological modeling processes.

The future scenarios were based on Representative Concentration Pathways (RCPs) radiative forcing as defined by the IPCC (2014). This study used RCP4.5 and RCP8.5 emission scenarios. The RCPs are named according to radiative forcing target level for 2100. The radiative forcing estimates are based on the forcing of greenhouse gases and other forcing agents. The RCP4.5 is a stabilization scenario without an overshoot pathway to 4.5 W/m^2 after 2100. The total radiative forcing under RCP4.5 is stabilized before 2100 by the employment of a range of technologies and strategies for reducing GHG emissions. The RCP8.5 refers to high GHGs concentration levels and characterized by increasing GHG emissions over time, leading to a radiative forcing of 8.5 W/m^2 at the end of the century.

Compared to observations, the baseline climate dataset had some errors. This model bias need to be corrected by using observation climate data. For this purpose, five observation stations within and around Gumara watershed were used. The biases in rainfall simulation were corrected by power transformation (PT) method, whereas biases in temperature were corrected by variance scaling (VS). The bias correction was employed separately at each meteorological station. To evaluate the bias correction performance, the average daily observation and WRF simulation (before and after bias correction) were compared using statistical measures such as correlation coefficient (r) and root mean square error (RMSE). While bias correction improved overall performances of the WRF model in simulating rainfall and temperature; there were differences in model evaluation statistics (Figure A1 and Table A1). For temperature, bias-corrected mean values were very close to the observed. After bias correction, the RMSE was significantly reduced from 2.99 ^{o}C to 1.53 ^{o}C and 2.69 ^{o}C to 1.37 ^{o}C for maximum and minimum temperature, respectively, whereas RMSE was slightly decreased from 7.86 to 7.05 mm/day for rainfall. The bias-corrected data also showed a good agreement with observed data, especially for temperature. The correlation coefficients between observed and simulated data were significantly improved from 0.72 to 0.85 for maximum temperature and from 0.68 to 0.82 for minimum temperature, while it did not show significant improvement for precipitation correction. These results suggested that bias-corrected output was acceptable and consistent with previous studies (Sisay *et al.* , 2017; Goshime *et al.* , 2019).

2.6 Combined land-use and climate change scenario

The combination of four land-use scenarios (present, BAU, EIC, and EFL) and three climate scenarios (baseline, RCP4.5, and RCP8.5) leads to 12 (1 reference + 11 future) scenarios, for which hydrologic responses were simulated using the calibrated SWAT model. For the reference period (2005-2015), the SWAT model used bias-corrected baseline climate data and present land-use of 2015. Table 1 shows the 12 scenarios that implemented in the study by categorizing the impacts of land use land cover change alone (LULCC), climate change alone (CC), and combined land use land cover and climate change (LULCC_CC) scenarios on hydrological responses. For each scenario, four water balance components, namely streamflow (SF), surface runoff (SR), base-flow (BF) and evapotranspiration (ET) were analyzed and compared to the reference conditions. A Student's t-test at a 95% confidence level was employed to assess the significance of the difference between the reference and scenario simulations.

Table 1

3 Results

3.1 Land-use change

The most commonly distributed land-use type in 2050 under BAU is agriculture (Table 2). Compared to the present land-use (2015), BAU scenario grassland, shrub-land and forestland decreased by 1.6%, 2.6% and 0.3%, respectively, while agriculture and urban increased by 4.3% and 0.2%, respectively (Table 2). In the downstream and upstream parts of the watershed, grassland and shrub-land areas were mainly converted into agriculture (Figure 2). The results of agriculture and urban land expansion in the BAU scenario agrees with Gashaw *et al.* (2018) study in the Upper Blue Nile basin.

Under EIC, land-use in 2050 is predominantly agriculture, followed by irrigation crops, shrub-land, grassland, water, forestland, and urban. Compared to the present land-use, agriculture, grassland and shrub-land decreased by 9.2%, 1.0% and 0.2%, respectively, while the new land-use, such as irrigation crop and water, covered the watershed area by 9.3% and 0.9%, respectively. However, forestland and urban land coverage remain static in the future. Figure 2 shows that, under EIC, the irrigation command area was located in the downstream part and the reservoir was found in the midstream part of the watershed.

Table 1

Under EFL, land-use in 2050 is mainly agriculture, followed by forestland, grassland, shrub-land, and urban. Compared to the present land-use, agriculture and shrub-land decreased by 36.1% and 3.1%, respectively, while forestland coverage significantly increased by 39.2%. Figure 2 shows that, under EFL, reduction of shrub-land found in the midstream part of the watershed, while the expansion of forest and reduction of agriculture occurred in the entire watershed.

Figure 2

3.2 Climate change

The projected monthly rainfall shows inconsistent directions and magnitude of change between RCP4.5 and RCP8.5 scenarios. However, as shown in Figure 3a, the mean monthly rainfall may increase during the dry season (February and April) while it may decrease in August and November under RCP4.5 and RCP8.5 scenarios. The mean annual rainfall in the study watershed is projected to increase by 73.7 mm (5%) under RCP4.5 and 376.5 mm (25.7%) under RCP8.5 (Figure 3a). Under RCP8.5, rainfall increase may occur in most months of the year. In RCP4.5, rainfall may decrease during the rainy months (June to September) and the dry months (October and November). On the contrary, rainfall increase under RCP8.5 mainly concentrated in the rainy months (June and July). In spring, rainfall is projected to increase by 320.6 mm (172.5%) and 84.5 mm (45.5%) under RCP4.5 and RCP8.5 scenarios, respectively. However, rainfall under RCP4.5 may decrease by 176.2 mm (17.4%) and 86.3 mm (34.6%) in summer and autumn season, respectively.

Figure 3

The simulated minimum temperature shows a consistent increase in all months under both RCP4.5 and RCP8.5 scenarios (Figure 3b). The mean annual minimum temperature is projected to increase by 1.5 °C and 2.0 °C under RCP4.5 and RCP8.5, respectively. The monthly minimum temperature increases under RCP4.5 is between 0.3 °C and 3.5 °C with the maximum increase in December, while minimum temperature increases under RCP8.5 ranged from 1.1 °C to 2.8 °C with the maximum increase in March. Unlike minimum temperature, the simulated maximum temperature shows a distinct direction of changes between RCP4.5 and

RCP8.5 scenarios in some months. Figure 3c shows an increase of the simulated maximum temperature in all months under RCP8.5, whereas maximum temperature under RCP4.5 may decrease in January, February and April. Under RCP4.5, the monthly maximum temperature may increase by 0.9 °C to 3.2 °C, and decrease by 0.5 °C to 1.1 °C. Under RCP8.5, the magnitude of increase in maximum temperature varies between 0.6 °C and 3.7 °C. The mean annual maximum temperature is expected to increase by 1.7 °C and 2.6 °C under RCP4.5 and RCP8.5 scenarios, respectively. It is noted that the increase in maximum temperature is higher than the increase in minimum temperature. The increase in mean annual minimum/maximum temperature under RCP8.5 is larger than that under RCP4.5 because the RCP8.5 scenario represents a higher radiative force (Wulong *et al.* , 2018). These results are in agreement with results from previous studies in the Gumara watershed (Gebre and Ludwig, 2015; Ayele *et al.* , 2016; Melke and Abegaz, 2017).

3.3 The impact of land-use change on hydrologic response

To evaluate the impacts of land-use change, hydrological processes were simulated using the calibrated SWAT model under four land-use (PER in 2015 and BAU, EFL, and EIC in 2050) scenarios with baseline climate. The relative change between the present and future land-use in streamflow (SF), surface runoff (SR), base-flow (BF), and evapotranspiration (ET) are shown in Table 3 and Figure 4. Compared to the REF simulation, BAU scenario show marginal increase in mean annual SF (0.4%), while a decrease in SF is predicted under EFL (5.2%) and EIC (12.5%). Similarly, the mean annual SR under EFL and EIC scenario is predicted to decrease by 10% and 7.9%, respectively, whereas SR under BAU is expected to increase by 5.1%. The mean annual BF under EFL is slightly higher than that of under present land-use. However, agriculture practices in both rain-fed and irrigation under EIC scenario can significantly decrease the mean annual BF as high as 19%. In BAU and EIC scenarios, BF contribution to SF is 38%, which is lower than BF contribution under present land-use. The mean annual ET under EFL and EIC is likely to increase by 8.9% and 4.9%, respectively, while BAU scenario yields a marginal decrease (0.5%) in ET. The mean annual ET account for 37%, 41% and 39% of the mean annual rainfall, respectively, under BAU, EFL and EIC scenarios. Both EFL and EIC scenarios have a slightly higher tendency on the rainfall partitioned into ET, whereas BAU scenario has a slightly lower tendency compared to the present land-use.

Table 3

On monthly scale, the simulated SF under BAU scenario is slightly higher (up to 3 mm) than the REF simulation during the main rainy season (June to August) and similar to the REF simulation during the dry season (Figure 4a). SF under EFL may decrease from May to September, with the largest decrease of 15.8 mm in July. Under EIC scenario, SF is projected to decrease significantly from July to October. Regarding other hydrological processes, the increase of agriculture by the expense of shrub and grassland under BAU depict a trend of increasing SR and decreasing BF and ET from May to September. Under EFL, BF is projected to increase during the end of summer (August) and late-autumn (September). However, ET under EFL may increase consistently in most months, with the largest increase of 10.6 mm in September (Figure 4d). Under EIC, BF may decrease by up to 56.6 mm during the rainy months (July to September) and late-rainy month (October), while ET may increase in most months. However, ET increases in January and February are significantly higher than that in other months, which may relate to the crop growth stage.

Figure 4

3.4 The impact of climate change on hydrologic response

To assess the impacts of climate change, hydrological processes were simulated using the calibrated SWAT model under three climate scenarios (Baseline, RCP4.5 and RCP8.5) with the PRE land-use. The simulated hydrological components for the projected period under RCP4.5 and RCP8.5 scenarios were compared to the corresponding values in the baseline period. Overall, an average of about 74 mm and 377 mm more rainfall per year was estimated to fall in the watershed in the future under RCP4.5 and RCP8.5 scenarios, respectively (Table 4). From the total annual rainfall, 99% contributed to SF and ET in both the reference

(REF) and future simulation (RCP4.5 and RCP8.5). The remaining 1% contributed to groundwater recharge. Under RCP4.5, about 81% of the rainfall increase contribute to ET increase (60 mm). The remaining 19% contributed to SF (13 mm) and groundwater recharge (1 mm). On the contrary, 81% of the rainfall increase under RCP8.5 contribute to SF increase (308 mm) and 18% of the rainfall increase contribute to ET increase (67 mm). The remaining 1% contribute to groundwater recharge increase (2 mm). The simulated SR under RCP4.5 and RCP8.5 scenarios is greater than the reference simulation. However, SR under RCP8.5 (51.8%) is significantly higher than the reference simulation. The mean annual BF under RCP4.5 may decrease by 6.8%, whereas BF under RCP8.5 may increase by 9.2%. In RCP4.5 and RCP8.5 simulations, BF contribution to the watershed SF is 38% and 33%, respectively.

Table 4

As can be seen in Figure 5, the peak flow under RCP4.5 is projected to decrease, while a higher and earlier peak flow (shifting from August to July in the future) is simulated under RCP8.5. This may be due to the future rainfall decreases under RCP4.5 and increases under RCP8.5 during the main rain months (June and July). The simulated SF under RCP4.5 is likely to increase from February to May with the largest increase of 85.9 mm in April (Figure 5a). However, SF may decrease by up to 81.5 mm during the rainy months (July to September) and up to 14.9 mm during the dry period (October to January). Under RCP8.5, SF is expected to increase from February to July with the largest increase of 265 mm in July, while SF decreases are projected to occur during the dry period (November to January) and rainy month (August). With the exception of magnitude, the direction of monthly changes in SR is closely mirrored the changes simulated for SF (Figure 5b). Under RCP4.5, BF contribution to SF may increase during the dry months (March to May), while the contribution may decrease from July to September (Figure 5c). However, under RCP8.5, the highest BF increase and decrease may occur during the rainy months (July and August), which corresponds to the rainfall changes during rainy months. The simulated ET under both scenarios is larger than the reference simulation in most months (Figure 5d). Under RCP4.5, the largest increase in ET is projected to occur in April (48.1 mm) while the largest decrease may occur in November (18.2 mm). Under RCP8.5, a maximum increase in ET is predicted in March (33.4 mm), whereas the highest decrease in ET will occur in December (6.1 mm).

Figure 5

3.5 The combined impact of land-use and climate change on hydrologic response

To assess the combined impacts of land-use and climate change on hydrological processes, six simulations were carried out by using a combination of three land-use and two climate change scenarios. The changes in hydrological processes were profound in the combined land-use and climate scenarios (Table 5 and Figure 6). The mean annual SF is projected to increase under BAU4.5, BAU8.5, EFL8.5 and EIC8.5 scenarios. The largest increase in SF may occur under BAU8.5 (34.9%). Conversely, SF is projected to decrease under EFL4.5 and EIC4.5 scenarios, with the largest decrease of 11.9% under EIC4.5. The combination of land-use and climate scenario will have an additive effect on SF simulation. For example, SF increase under BAU8.5 (34.9%) is the simple addition of SF increase under BAU land-use scenario alone (0.4%, Table 3) and RCP8.5 climate scenario alone (34.3%, Table 4). The RCP8.5 climate scenario in combination with land-use scenarios has a considerable influence on SR. Overall, SR under BAU8.5, EFL8.5 and EIC8.5 are significantly larger than the reference simulation. Such increases in SR are mainly derived by RCP8.5 rainfall increases. The expansion of irrigated cropland (EIC) combined with climate change scenarios may substantially decrease BF. Similarly, the combination of BAU and RCP4.5 will yield significantly lower BF compared to the reference simulation. The EFL8.5 scenario produce the largest increase in BF (12.2%), while the EIC4.5 scenario yield the largest decreases in BF (26.8%).

Table 5

The result shows that all the combined scenarios increase mean annual ET, with the largest increase of 21.1% under EFL8.5 and the smallest increase of 10.1% under BAU4.5. The increases in mean annual ET under the combined land-use and climate change scenarios is more pronounced than that under land-use and climate scenario alone. For example, the increases in ET under EFL (49 mm) alone (Table 3) and RCP4.5 (60 mm) alone (Table 4) are not significant, but the combination of the two scenarios (EFL4.5) may produce a significantly larger mean change (116 mm). The result also shows that the combined impacts of land-use and climate change are additive to the separate impacts. For example, ET decrease of 3 mm under BAU alone (Table 3) and ET increase of 67 mm under RCP8.5 alone (Table 4) result in an increase of 64 mm under BAU8.5 (Table 5). However, the combined land-use and climate change impacts is slightly greater than the sum of the separate changes under EFL4.5 and EIC4.5 scenarios.

The changes in SF show increases in most months under the combined land-use and RCP8.5 scenarios (Figure 6a). The greatest increase will occur in July (267 mm) under BAU8.5. However, in July, SF under the combination of RCP4.5 and land-use scenarios may decrease due to rainfall decrease under RCP4.5 (Figure 3a). Moreover, in August, SF under all the combined scenarios are substantially lower than the reference simulation, which corresponds to monthly rainfall distribution under both climate scenarios. This indicate that the direction of monthly SF changes is mainly driven by climate change scenarios. In most months, SF change between land-use scenarios are very small compared to changes between emission scenario (Figure 6a). The change in monthly SR follow similar pattern as for SF; the mean increase of up to 227 mm and decrease of up to 46 mm may occur in July under BAU8.5 and EFL4.5 scenarios, respectively (Figure 6b). BF under all the combined scenarios are projected to increase during the dry months from March to May, whereas it may decrease substantially during August (Figure 6c). The directions of change in the monthly BF under different scenarios are similar to those under the climate change scenario alone. ET under all the combined scenarios show increases in most months. However, the increases in March and April are substantially higher than other months. From February to May, ET under all the combined scenarios is larger than that under the reference simulation. This is similar to what is found with the climate simulations alone. The direction and magnitude of changes in ET are mainly driven by the climate change scenarios. However, during June to September, the direction of change in ET follows similar patterns to those under EFL land-use scenario. For example, ET under EFL4.5 is slightly larger (1.2 mm) than the reference simulation in June, which result from the counterbalance between ET increase under EFL alone (6.6 mm) and a decrease under RCP4.5 alone (7.2 mm).

Figure 6

4 Discussion

4.1 The impact of land-use change on hydrological response

The BAU scenario had less forest and shrub-land area than the PRE land-use, and its total agriculture area increase by 4.4%. As a result of this, the simulated SR may increase and BF may decrease in the future under BAU scenario. Agriculture areas have been positively correlated to SR. For example, in the Upper Blue Nile basin, Woldesenbet *et al.*(2017) found a strong positive correlation between the area of agriculture and mean annual runoff. This result is consistent with previous studies where the increase of agriculture coverage resulted in SR increase owing to reduced percolation and evaporation (Gashaw*et al.* , 2018; Teklay *et al.* , 2018; Berihun *et al.* , 2019). The expansion of agriculture (BAU) increase the contribution of SR to SF (Table 3). The cultivation practices could form soil crusting, which result in low infiltration and BF (Rahbeh *et al.* , 2013).

The SF decrease under EFL can be attributed to lower SR due to increasing forestland which improve the water holding capacity of the soil, infiltration and recharge. This result is in agreement with findings that show forestland expansion reduce SF and SR (Guzha *et al.* , 2018; Gebremicael *et al.* , 2019). A decrease in SF and SR are also attributed to the increase of water retained in the watershed and increase of ET as forest cover increase. These results are comparable with those from Woldesenbet *et al.* (2018) in the Upper Blue Nile basin, Ethiopia and Bossa *et al.* (2014) in the West Africa region. The increase in ET due to forest expansion has been reported by Hyandye *et al.* (2018), wherein they found that forest expansion (+7%) in Ndembera watershed located in Tanzania increased ET by approximately 8%.

The introduction of irrigated cropland and water reservoir under EIC may decrease SF during the main rainy season (Figure 4a). This is due to the diversion of SF into the reservoir to stores water for the dry season irrigation demand. Evaporation from the reservoir may contribute to ET increase. Besides, ET increase under the expansion of irrigation crops may result from the high leaf area index and transpiration demand for irrigation crops. This result agrees well with the study by Hyandye*et al.* (2018) and who reported that ET would increase by 30 mm due to the expansion of irrigated onion and rice farms by 10%.

Overall, most of the water balance component changes between the present and future land-use scenarios were insignificant ($p>0.05$, Table 3), since the converted land-use areas were smaller than the threshold level which cause significant change on hydrological processes. These results agree with Li *et al.* (2007) study in the West African basins. They simulated the hydrological impact of land-use change and found that deforestation below 50% has no significant impact on streamflow and water yield; however, the water yield was dramatically increased when land-cover change exceeds this threshold. In other regions, Eckhardt *et al.* (2003) also quantified the minimum proportion of a watershed that has to undergo a land-use change to detect apparent water balance differences. They found that the mean surface runoff amount was changed when approximately 20% of the watershed area was changed.

4.2 The impact of climate change on hydrological response

The future climate simulations show increases in mean annual rainfall by about 74 mm under RCP4.5 and 377 mm under RCP8.5, yet some simulation may decrease from June to November under RCP4.5 and from November to January, and in May and August under RCP8.5. The mean annual SF is simulated to increase mainly due to the increase of mean annual rainfall. However, the relationship between rainfall and SF is complicated and non-linear. The projected rainfall change can be amplified in the SF hydrograph (Figure 5a). This amplification may occur when the projected rainfall increases concentrate on rainy months of June and July (Figure 3a) when soil moisture is relatively high in the study watersheds. The increase in streamflow due to rainfall increment was also discussed by Pandey *et al.* (2017); they revealed that a 28% increase in annual rainfall resulted in streamflow increase by approximately 49% from their study in the Armor watershed in Godavari river basin, India. Besides, the temporal distribution of rainfall also affects peak flow and SF change. SF change under RCP4.5 is very small, owing to the rainfall decline in the main rainy months (June to September). However, rainfall increase under RCP4.5 concentrate in the dry season (March and April), which leads to an increase in rainfall partitions to percolation. As a consequence, ET is projected to increase mainly attributed to the soil moisture evaporation (Figure 5d). This indicate that warmer temperature shifted rainfall increase into ET increase, which is consistent with the findings of Mango *et al.*(2011) in the East African watershed. They found that the modest increases in precipitation are partitioned largely to increase ET. The monthly ET changes are almost similar pattern with monthly rainfall changes. This result agrees with Marhaento *et al.* (2018) study in Indonesia, who found that ET simulation highly influenced by rainfall change compared to temperature change. However, Hyandye *et al.*(2018) found different results from this study. They found that changes in ET mainly associated with changes in temperature.

4.3 The combined impact of land-use and climate change on hydrological response

The results show that the combined land-use and climate change have a more noticeable effect on SF and SR. The significant increase in rainfall and expansion of agriculture will have an additive impact on SF and SR (Legesse *et al.* , 2010; Mango *et al.* , 2011). Moreover, the highest SF increase during the main rainy months may cause flooding in the future. Afforestation in the steep slope area is recommended to reduce SR which is the major cause of flooding and soil erosion (Nyssen *et al.* , 2004). The forest expansion in the sloppy areas improve rainfall partitioned into infiltration, subsequently reduce SR (Table 5). The results related to forest expansion effect on water balance components are consistent with the findings of Woldesenbet*et al.* (2018) in the Upper Blue Nile basin and Marhaento *et al.* (2018) in the Samin catchment. Besides, conserving the rainy season excess water for the dry season irrigation play a substantial role in reducing SF (Table 5). However, irrigation practice may increase SR during the dry season (Figure 6b) and will cause soil erosion. Therefore, different water management practices must be implemented to reduce SR.

The expansion of forest and irrigation along with climate change may increase ET significantly (Table 5). The slight increase of rainfall alone (RCP4.5) does not show significant ET change, whereas both climate and land-use change have a significant impact on ET (Table 5). The combination of climate change and land-use (BAU) have additive impacts on ET. However, ET increase under forest and irrigation expansion (EFL and EIC) is amplified by projected future climate (RCP4.5), which result from plant transpiration and evaporation from soil moisture and canopy interception. This result is consistent with the findings of Marhaento*et al.* (2018). However, the climate change signal had a dominant effect on simulated water balance components. Similar conclusions have been reported in the Upper Blue Nile basin (Mekonnen *et al.* , 2018). The combined impacts of climate and land-use change show a non-linear effect on water balance components, which is consistent with results found for climate and land-use change impacts on hydrological responses in Hinkson Creek Watershed in central Missouri (Sunde *et al.* , 2018).

5 Conclusions

This study presented an integrated modeling approach for assessing the separate and combined effects of land-use and climatic changes on hydrologic processes in Gumara watershed. The study used Weather Research and Forecasting (WRF) model to downscale GCM output from the latest generation of climate models (CMIP5), Land-use Change Evaluation (MOLUSCE) module to generate future land-use scenarios, and a process-based watershed hydrologic model (SWAT). In this study, four land-use and three climate scenarios were developed and used as input for the SWAT model to determine the relative and the interaction impacts of the two changes.

The results suggest that most of the combined scenarios have a pronounced effect on streamflow and surface runoff. However, climatic changes could have a larger impact than land-use change on streamflow and surface runoff. When the expansion of agriculture scenario (BAU) is replaced by the expansion of forest scenario (EFL), the mean annual surface runoff may decrease by 14.7% and 10.8% under RCP4.5 and RCP8.5 scenarios, respectively, while the mean annual base-flow may increase by about 9.3% and 10.1% under RCP4.5 and RCP8.5, respectively. The monthly changes in streamflow are mainly driven by climate change scenarios. Moreover, the influence of the combined effect on streamflow does not vary directionally in most months. The largest uncertainty in streamflow simulation (-99.3 mm to 267 mm) may occur in July which can be attributed to the uncertainty of rainfall prediction (-102.3 mm to 235.5 mm). The result also indicates that the effect of climate change on the mean annual evapotranspiration is extremely larger than the effect of land-use change. The increases of evapotranspiration under climate change scenarios are augmented by increases under the expansion of forest and irrigation scenarios, while the marginal decrease in evapotranspiration under the expansion of agriculture scenario is offset by increases under climate change scenarios. Similarly, the magnitude and direction of monthly changes in evapotranspiration are mainly driven by climate change scenarios, but the forest expansion effect is most influential from June to September.

In general, the results were not conclusive but provide insight into the future hydrologic scenario of Gumara watershed. Projections of future availability of water resources contain a large number of uncertainties, and this work demonstrates that the relative and the combined effect of land-use and climate change on water balance components. Moreover, the model output can provide useful information about the contribution of each land-use to water balance components as well as to water balance dynamics due to climate change. The results suggest that water resources in the Gumara watershed may increase or decrease in the mid-21st century as a consequence of climate and land-use changes, it is a great difficulty to ascertain an accurate magnitude of change.

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Data Availability

Data used to support our findings are available from the corresponding author upon request.

Appendix A

Figure A1

Table A1

6. References

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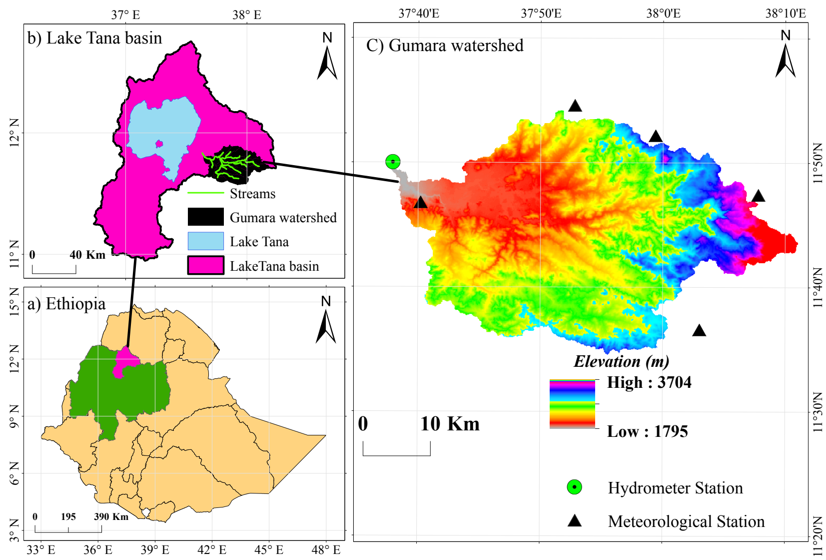

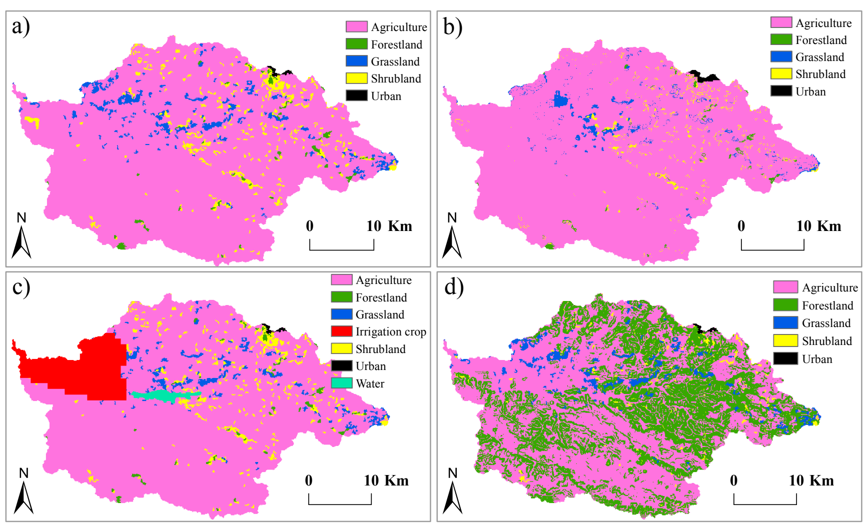

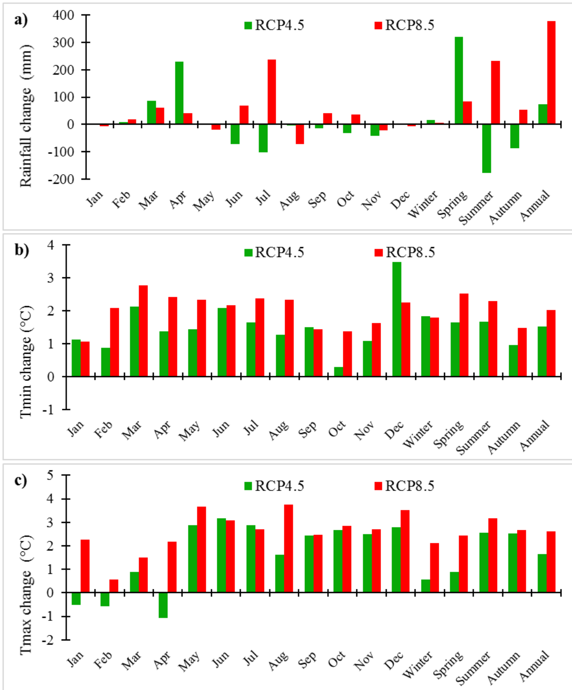
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Rainfall change (mm)
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100
0
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Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Winter Spring Summer Autumn Annual
b)
RCP4.5
RCP8.5
Tmin change (°C)
4
3
2
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0
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Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Winter Spring Summer Autumn Annual
c)
RCP4.5
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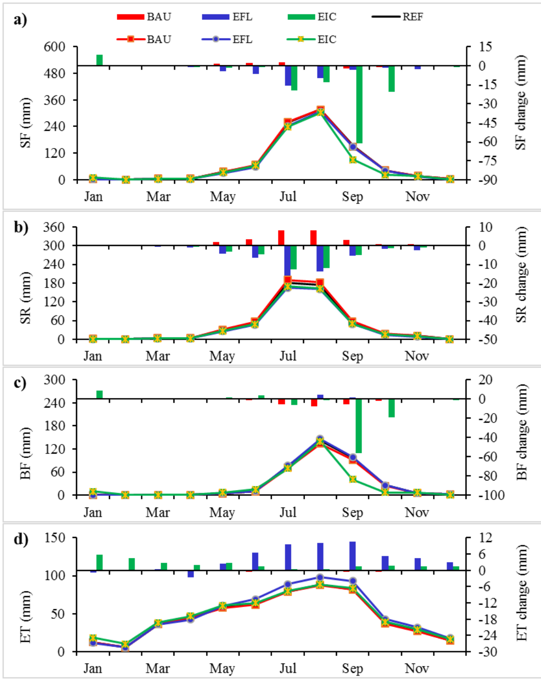
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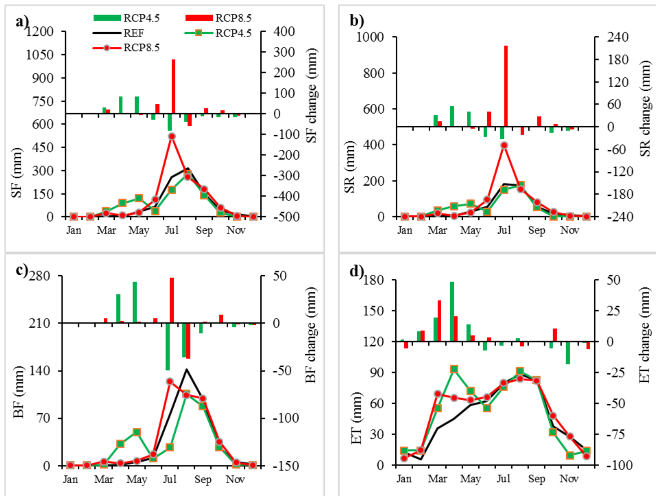
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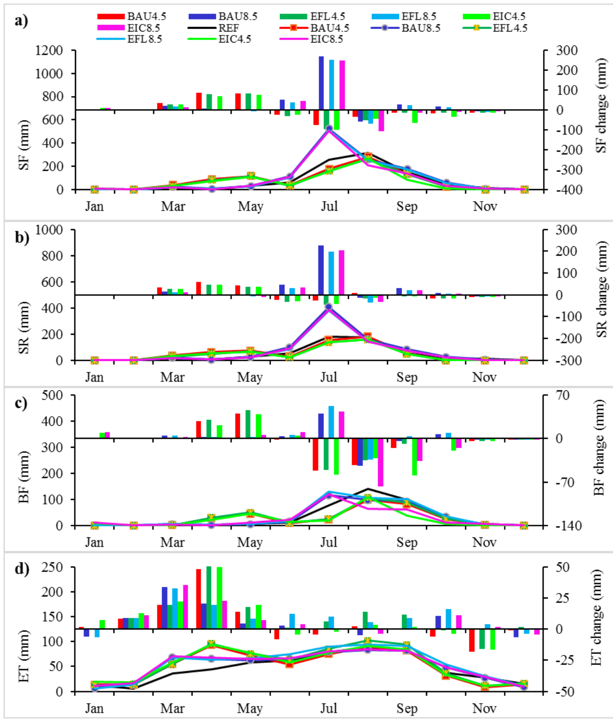
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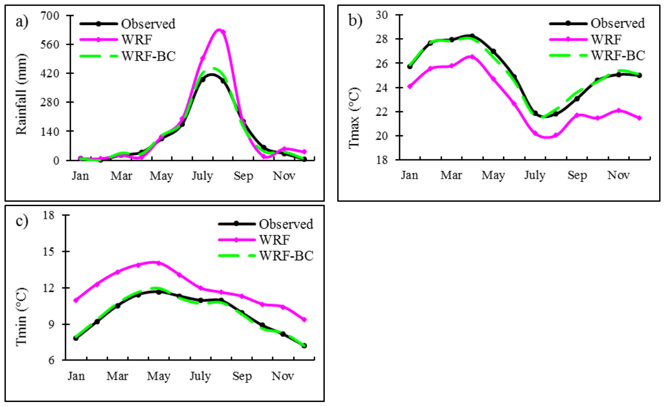

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