

# Land Use and Climate Change Impacts on the Hydrology of the Bago River Basin, Myanmar

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**Abstract** Assessment of land use and climate change impacts on the hydrological cycle is important for basin scale water resources management. This study aims to investigate the potential impacts of land use and climate change on the hydrology of the Bago River Basin in Myanmar. Two scenarios from the representative concentration pathways (RCPs): RCP4.5 and RCP8.5 recommended by the Intergovernmental Panel on Climate Change, Fifth Assessment Report (IPCC AR5) were used to project the future climate of 2020s, 2050s, and 2080s. Six general circulation models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) were selected to project the future climate in the basin. An increase of average temperature in the range of 0.7 to 1.5 °C and 0.9 to 2.7 °C was observed under RCP 4.5 and RCP 8.5, respectively, in future periods. Similarly, average annual precipitation shows a distinct increase in all three periods with the highest increase in 2050s. A well calibrated and validated Soil and Water Assessment Tool (SWAT) was used to simulate the land use and climate change impacts on future stream flows in the basin. It is observed that the impact of climate change on stream flow is higher than the land use change in the near future. The combined impacts of land use and climate change can increase the annual stream flow up to 68 % in the near future. The findings of this study would be beneficial to improve land and water management decisions and in formulating adaptation strategies to reduce the negative impacts, and

harness the positive impacts of land use and climate change in the Bago River Basin.

**Keywords** Climate change · Land use change · Stream flows · RCPs · Bago River Basin

## 1 Introduction

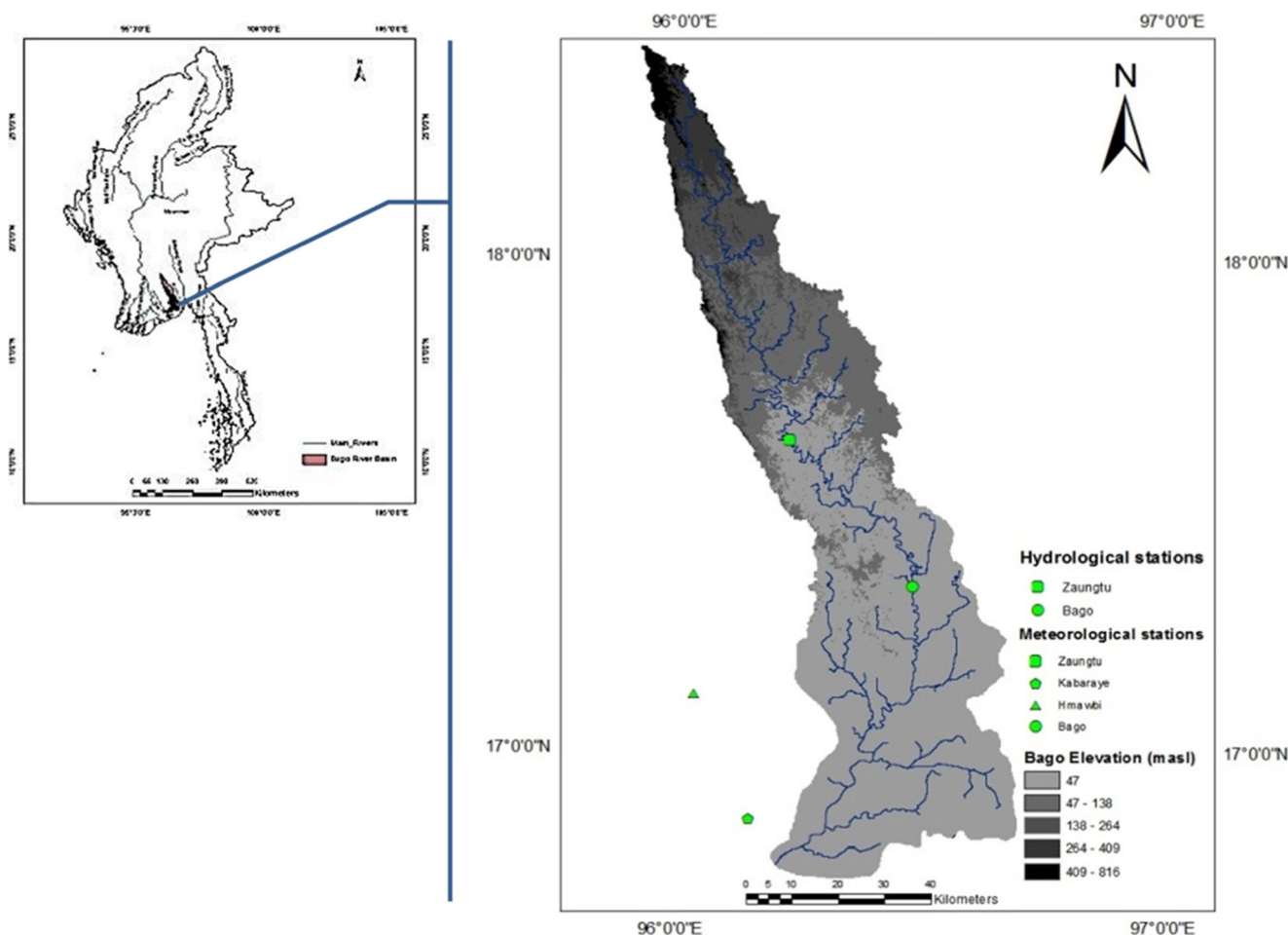
Climate change combined with land use and land cover change can alter the basin hydrological cycles by affecting evaporation, evapotranspiration, soil infiltration and surface and subsurface regimes [9]. The hydrological cycle has been substantially influenced by climate change and human activities. It is, therefore, very important to analyse the impacts of climate change on hydrology, particularly on a regional scale, in order to understand the potential changes in water resources and water-related disasters, and provide support for regional water management [35, 36]. Cherkauer and Sinha [8] pointed out that changes in meteorological parameters impact on water quality and quantity, thus influencing the water supply system, hydropower generation, ecosystem services, and livelihoods. Most of the Asian countries have been experiencing more frequent floods and droughts over the past decades as a consequence of climate change and human activities [6]. Although climate change is a global phenomena, the impact is mostly experienced by regional communities who heavily depend on climate-sensitive sectors like agriculture, water resources, and forestry for their livelihoods. Similarly, there has been an increase in extreme weather events and a rise in sea level due to global warming affecting the water resources of coastal areas [2].

The effects of land use change are directly linked to changes in the hydrological components of watersheds as reported in several studies related to hydrologic changes in land surface

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**Fig. 1** Location map of the Bago River Basin with hydro-climatic stations

[19]. Wang et al. [34] stated that the distinguishing effects of land use changes due to concurrent climate variability poses a particular challenge. Although the impact of land use change on the annual water balance is relatively small at a large catchment scale [21], land use change with climate change can undoubtedly affect the water resource system [28]. Temporally, the short-term impacts of land use change and climate variation can often be seen on the peak runoff, while the long-term impacts are more apparent on the average annual runoff [37]. For example, the effects of land use change on

river flows are more evident in the arid climates, where the low river flows are more sensitive to land use change [29].

Basin scale water resources planning, development, and management, calls for an increased understanding of the stream flow changes caused by both the combined and separate impacts of future climate and land use changes on hydrology and water resources [17]. Lorencova et al. [18] and Xu et al. [35, 36] reported that these two driving forces, climate change and land use change, affect the water resource availability at various temporal and spatial scales in the basins.

**Table 1** Statistics of hydro-meteorological parameters at four stations in the Bago River Basin

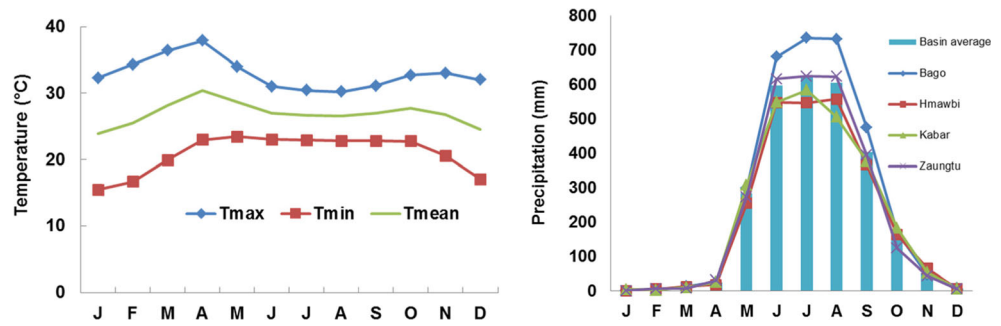
Station	Avg annual precipitation (mm)	Mean $T_{max}$ (°C)	Mean $T_{min}$ (°C)	$T_{mean}$ (°C)	Avg annual stream flow (m <sup>3</sup> /s)	Lat_N (°)	Lon_E (°)	Elevation (masl)
Bago	3185	32.6	20.6	26.6	1597.9	17.3	96.5	19
Kabaraye	2607	33.1	21.2	27.2	–	16.9	96.2	31
Zaungtu	2746	33.0	20.1	26.6	1412.8	17.6	96.2	37
Hmawbi	2541	33.1	21.7	27.4	–	17.1	96.0	22

$T_{mean}$  mean temperature,  $T_{max}$  maximum temperature,  $T_{min}$  minimum temperature

Meteorological parameters:1975–2009

Hydrological parameters:1990–2009

**Fig. 2** Distribution of average monthly  $T_{max}$ ,  $T_{min}$ ,  $T_{mean}$ , and precipitation in the Bago River Basin during 1975–2005



Many studies reported that climate change contributions are higher towards stream flow change compared to land surface change. However, the impact differs from one location to another because of the differences in climate and watershed characteristics.

Climate change, together with land use change, is threatening the socio-economic development of Myanmar. The Bago River Basin has been experiencing several floods and droughts in recent years because of climate change impacts. Consequently, floods and droughts have caused the degradation of natural water resources [15]. It has been reported that annual rainfall has decreased and seasonal stream flows are reduced, particularly during the summer season. In summer, many areas of the Bago River Basin are known for their scanty rainfall, very high rates of evaporation, and reduced water storage capacity. Water yields declined at the basin outlet during the summer and winter but increase during the rainy season. The outflow from this basin is insufficient for agricultural production in the downstream area. On the other hand, there are also serious floods in the Bago River Basin when cyclones pass through the coastal area. During the rainy season, a rapid flow occurs when there is a large amount of water in the river. In the dry period, especially in March when there is less water in the river, the flow of the river reduces to a velocity ranging from 6–40 cm/s. In the rainy season, a greater quantity of water in the river at the flood level of 860 cm causes the river to regain its flowing rate of 137 m<sup>3</sup>/s, and as the flood level becomes higher to the point of 900 cm, the flow rate increases up to 200 m<sup>3</sup>/s [16].

The major objective of this study is to project future climate change and land use change and assess its impact on hydrology and water resources in the Bago River Basin. This study

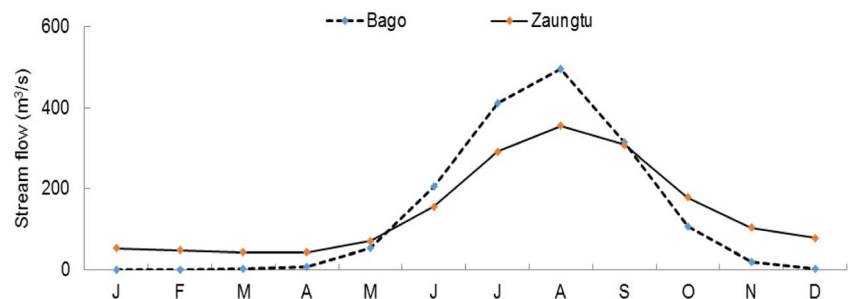
envisions capturing the benefits of the new emission scenarios called the representative concentration pathways (RCPs) and use of multiple general circulation models (GCMs) to project the future climate of the basin.

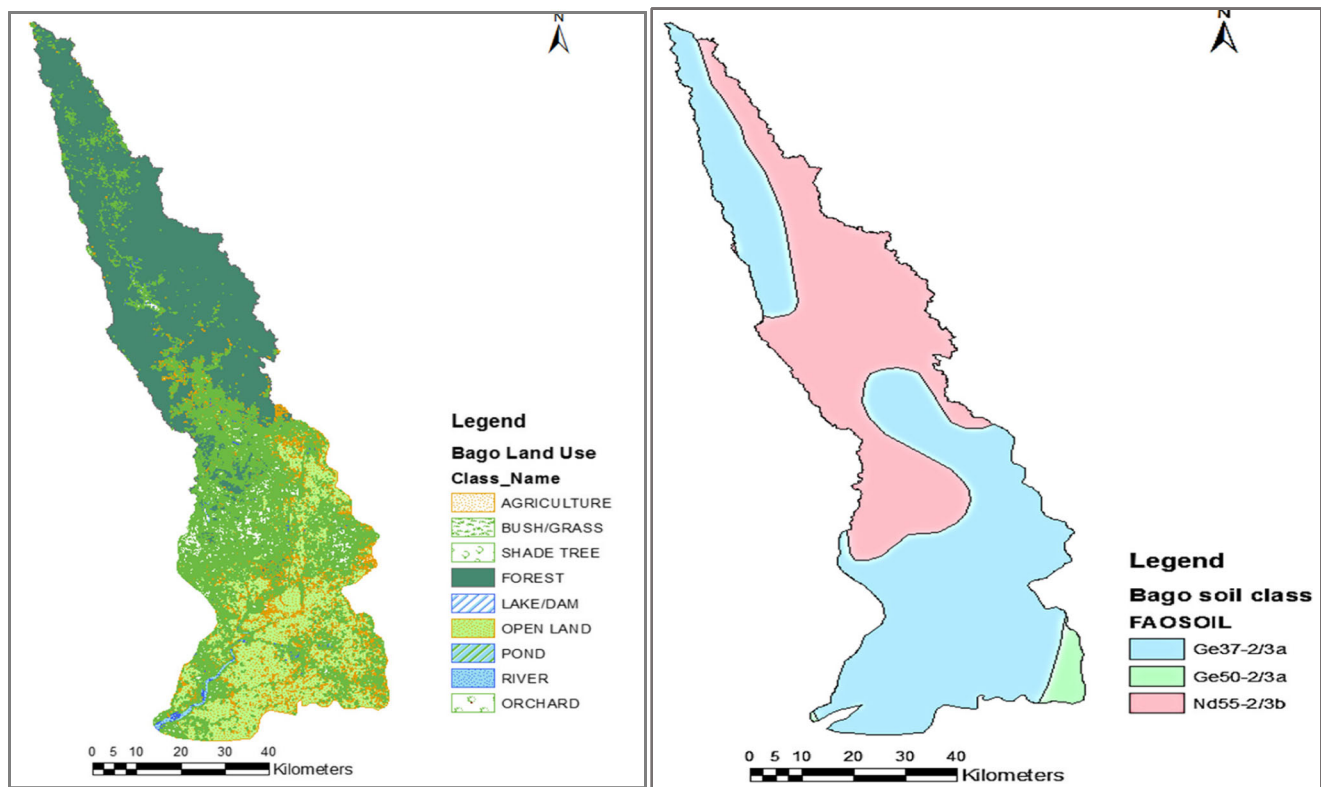
## 2 Data and Methods

### 2.1 Study Area

The Bago River Basin is one of the strategic river basins of Myanmar, covering approximately 91 % of the Bago district with an area of 4, 883.1 km<sup>2</sup>. The basin lies within latitudes 16° 40' 30" and 18° 25' 48" N, and longitudes 95° 54' 39.6" and 96° 44' 38.4" E. The Bago River is the source of water for hydropower generation, irrigation, fisheries, and navigation. In the Bago River Basin, a hydropower dam for electricity generation, and a diversion weir for irrigation use were constructed near Zaungtu village in 1996 and 1998, respectively. Three earthen dams namely Kodukwe, Salu, and Shwelaung were constructed in 2011 and opened in May, 2012 for the purposes of flood control during the rainy season, irrigation water use for summer paddy cultivation, and the water supply for green projects around the Yangon area during the dry season. A flood diversion channel from Zaungtu weir to Moeyongyi lake was also completed in 2012 [27]. The majority of the area in the basin falls under 47 m above mean sea level (masl). The study area has four meteorological stations namely Bago, Zaungtu, Kabaraye, and Hmawbi and two hydrological stations: Bago at the outlet of the basin and Zaungtu at the middle stream (Fig. 1).

**Fig. 3** Distribution of average monthly stream flow of the Bago and Zaungtu stations in the Bago River for 1990–2009





(a) Land use map

(b) Soil map

**Fig. 4** Land use and soil maps of the Bago River Basin for the year 2010. **a** Land use map. **b** Soil map

**2.2 Hydro-climatic Condition of the Basin**

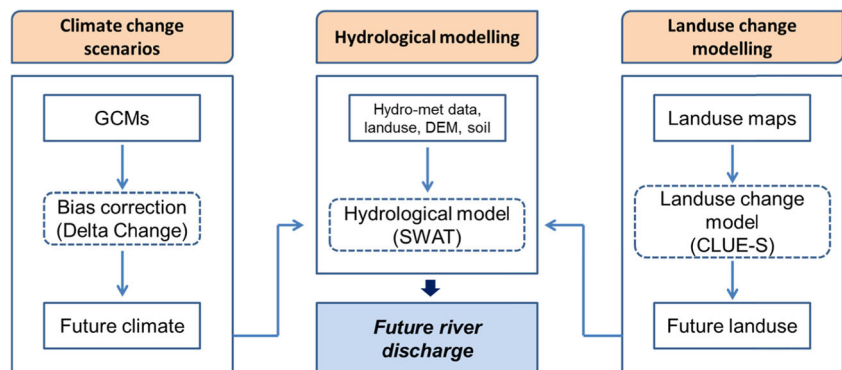
The climate of the Bago River Basin is tropical monsoon with a heavy seasonal rainfall, high temperature, and distinct wet and dry seasons [15]. The hydro-meteorological data from 1975–2005 was obtained from the Department of Meteorology and Hydrology, Myanmar. The basin scale average annual values for maximum temperature, minimum temperature, and mean temperature are 33, 21, and 27 °C, respectively (Table 1). According to the meteorological records, January and December are the coldest months, whereas April is the hottest month (Fig. 2). The stream flow is generally higher in the Bago station (downstream) during the

monsoon season, whereas it is higher in Zaungtu (upstream) during the winter season (Fig. 3).

**2.3 Spatial Data and Its Characterization**

The spatial data used for this study are digital elevation model (DEM), land use, and soil map. The DEM of the basin was created from topographic maps and channel survey maps provided by the Directorate of Water Resources and Improvement of River Systems, Myanmar. The Bago River Basin is divided into five major elevation ranges in this study: <47, 47–138, 138–264, 264–409, and 409–816 masl. A large

**Fig. 5** Research methodology framework used in this study



**Table 2** List of the GCMs used in this study and their characteristics

Model	Resolution (long by lat)	Scenarios	Origin
BCC-CSM1.1	2.815° × 2.815°	RCP4.5 RCP8.5	Beijing Climate Center, China
CCSM4	1.25° × 0.9°	RCP4.5 RCP8.5	National Center for Atmospheric Research, USA
MIROC5	1.40° × 1.40°	RCP4.5 RCP8.5	Atmosphere and Ocean Research Institute, Japan
MRI-CGCM3	1.125° × 1.125°	RCP4.5 RCP8.5	Meteorological Research Institute, Japan
BNU-ESM	0.75° × 0.75°	RCP4.5 RCP8.5	College of Global Change and Earth System Science, China
FGOALS-g2	1.9° × 1.9°	RCP4.5 RCP8.5	Chinese Academy of Sciences

part of the basin, almost 60 %, is below 47 masl followed by the elevation range of 47–138 masl.

In this study, a land use map of 2010 with 30-m resolution was obtained from USGS (<http://landcover.usgs.gov/>) (Fig. 4a). It is observed that grassland is the most dominant land use type, contributing to more than 32 % of the total area, whereas open land is about 28 %. The other land use types in the basin are agriculture and forest. A soil map of 1: 5,000,000 was downloaded from the Digital Soil Map of the World (<http://www.fao.org/>) (Fig. 4b). The dominant soil types in the basin are eutric gleysols (Ge37-2/3a), eutric gleysols (Ge50-2/3a), and nitosols (Nd55-2/3b).

### 3 Methodology

The methodology of this study consists of projection of future climate, hydrological modelling, and land use change modelling (Fig. 5). Delta change method of bias correction was used in projection of future climate, a distributed hydrological model, Soil and Water Assessment Tool (SWAT) was used to simulate the hydrology and CLUE-S model was used to project the future land use change scenarios in the Bago River Basin. The details are described in the section below.

**Table 3** Area under different land use types in the Bago River Basin

Land use	Area (km <sup>2</sup> )		
	2001	2005	2010
Agriculture	493.2	664.1	879.0
Grassland	2000.6	1313.6	1753.0
Forest	1128.0	1040.1	507.8
Open land	499.5	1148.4	1368.0
Orchard	639.7	614.4	282.5
Waterbody	122.1	102.5	92.8

### 3.1 Climate Change Scenarios

The climate change scenarios of the 2020s (2010–2039), 2050s (2040–2069), and 2080s (2070–2099) were constructed using outputs of six GCMs downloaded from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (<http://cmip-pcmdi.llnl.gov/cmip5/>). These GCMs cover different resolutions, varying from 0.75° × 0.75° to 2.815° × 2.815°. The characteristics of GCMs are provided in Table 2.

In this study, a delta change method was used to correct the bias in climate data of GCMs. The underlying idea of the widely used delta change method (Andréasson et al. 2004; Bosshard et al. 2011; Gellens and Roulin 1998; Graham et al. 2007a, 2007b; Middelkoop et al. 2001; Moore et al. 2008; Shabalova et al. 2003) is to use the GCM-simulated future change (anomalies) for a perturbation of observed data rather than to use the GCM simulations of future conditions directly. The control run, also known as baseline climatology, corresponds therefore, by definition, to the observed climate and can, thus, not be used for a proper evaluation. For the future scenario, the GCM-simulated anomalies between control and scenario runs are superimposed upon the observational time series. This is usually done on a monthly basis. A multiplicative correction is used for

**Table 4** Land use classes and driving factors evaluated for the Bago River Basin for the 2020s

Land use class	Driving factors (location)
Forest	Altitude (mm)
Grass	Slope
Orchid	Aspect
Agriculture	Distance to town
Shade tree and open land	Distance to stream
	Distance to road
	Erosion vulnerability
	Geology
	Population density (neighbourhood 5 × 5)

**Table 5** Beta values for regression results on the spatial distribution of land use in the Bago River Basin in 2020s

Driver	Forest		Orchard		Grass		Agriculture	
	Beta	Exp(B)	Beta	Exp(B)	Beta	Exp(B)	Beta	Exp(B)
Constant	-1.98		0.58		-0.75		-1.63	
Geology								
Rock	2.71	14.99	-0.69	0.50	-3.26	0.04		
Sediment	2.05	7.78			-0.89	0.41		
Erosion								
Moderate erosion	-1.82	0.16	1.01	2.73	1.27	3.58		
No erosion	-1.18	0.31	-0.51	0.60				
Elevation	0.01	1.00	-0.01	0.99	-0.01	0.99	-0.03	-0.98
Slope			0.04	1.04	0.02	1.02	-0.12	0.88
Aspect	0.01	1.00	-0.01	0.99				
Distance to road			-0.01	0.99	-0.02	0.98	0.01	1.00
Distance to town	0.01	1.00	-0.01	0.99	0.01	0.99		
Distance to stream					-0.01	0.99		
Population density	-0.01	0.99	0.01	1.00	-0.01	0.99	0.01	1.00
ROC value	0.94		0.92		0.82		0.91	

precipitation (Eqs. (1) and (2)), whereas an additive correction is used to adjust temperature (Eqs. (3) and (4)):

$$P^*_{\text{contr}}(d) = P_{\text{obs}}(d) \quad (1)$$

$$P^*_{\text{scen}}(d) = P_{\text{obs}}(d) * \left[ \frac{\mu m [P_{\text{scen}}(d)]}{\mu m [P_{\text{contr}}(d)]} \right] \quad (2)$$

$$T^*_{\text{contr}}(d) = T_{\text{obs}}(d) \quad (3)$$

$$T^*_{\text{scen}}(d) = T_{\text{obs}}(d) + \mu m (T_{\text{scen}}(d)) - \mu m (T_{\text{contr}}(d)) \quad (4)$$

### 3.2 Land Use Change Assessment

In this study, the land use change in the basin was analysed using data and information obtained from USGS Earth Explorer (<http://earthexplorer.usgs.gov/>). The total area under each land use class of 2001, 2005, and 2010 is presented in Table 3. It can be observed that the area under

**Table 6** Future seasonal and annual changes in Tmax and Tmin relative to the baseline period (1975–2005) under RCP4.5 and RCP8.5 in the Bago River Basin

Period	RCPs	Annual		Summer		Rainy		Winter	
		T <sub>max</sub>	T <sub>min</sub>	T <sub>max</sub>	T <sub>min</sub>	T <sub>max</sub>	T <sub>min</sub>	T <sub>max</sub>	T <sub>min</sub>
2020s	RCP4.5	0.7	0.7	-0.2	-0.3	1.2	0.6	1.2	1.8
	RCP8.5	1.1	0.6	0.1	-0.5	1.8	0.6	1.4	1.7
2050s	RCP4.5	1.3	1.0	0.5	0.2	1.7	0.8	1.7	2.0
	RCP8.5	1.8	1.5	1.0	0.9	2.3	1.4	2.2	2.3
2080s	RCP4.5	1.7	1.3	1.6	1.7	1.6	0.9	1.8	1.2
	RCP8.5	2.9	2.5	2.9	2.9	3.0	2.2	2.7	2.3

grassland, forest, and orchard has decreased, whereas agriculture and open land areas have increased from 2001 to 2010.

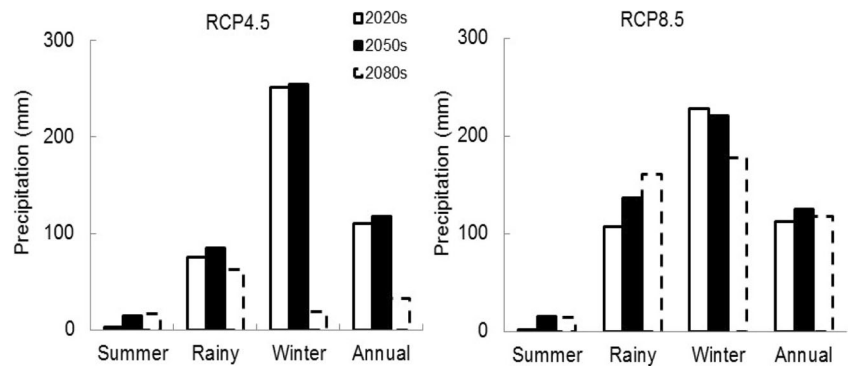
### 3.3 Land Use Change Projection Using the CLUE-S Model

In this study, the CLUE-S (Conversion of Land Use Change and its Effects at Small Regional Extent) modelling approach was used for dynamic modelling of land use change. The CLUE-S is specifically developed for the spatially explicit simulation of land use change based on an empirical analysis of location suitability combined with the dynamic simulation of competition and interactions between the spatial and temporal dynamics of land use systems [31–33]. The model is a multi-scale land use change model used for understanding and predicting the impact of biophysical and socio-economic forces that drive land use change [31]. It is especially useful for the assessment of changes in complex spatial patterns of land use due to the explicit attention given to linkages between the temporal and spatial dynamics of land use change [31].

The methodology for the development of land use change scenarios is based on the extrapolation of the spatial relationship between the current pattern and a set of explanatory or location factors. The CLUE-S model can be divided into two modules: a non-spatial demand module and a spatially explicit allocation module, operating at the respective regional and pixel levels. The model was calibrated using historical data describing the land use patterns from 2001–2009 and validated using a 2010 land use map of the Bago River Basin.

In this study, the logistic regression method was used to evaluate the relationship between land use and its driving factors to indicate the probability of a certain grid cell being

**Fig. 6** Future average annual and seasonal changes in precipitation relative to the baseline period (1975–2005) under RCP4.5 and RCP8.5 in the Bago River Basin



devoted to a land use type given a set of driving factors as follows:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \dots + \beta_n X_{n,i} \quad (5)$$

where  $p_i$  = probability of a grid cell for the occurrence of the considered land use type and  $X_s$  = driving factors.

The land use classes analysed in the Bago River Basin and the driving variables that were assumed to represent the driving factors are presented in Table 4.

For each land use class, a logistic regression was run. Table 5 presents the results of these regressions. The spatial distribution of all land use classes could well be explained by the selected driving variables, as indicated by the high receiver operating characteristic (ROC) test statistics (scale 0.5–1).

#### 4 Climate Change and Land Use Change Impact on Hydrology

##### 4.1 Hydrological Modelling Using the Soil and Water Assessment Tool (SWAT)

In this study, the SWAT model was used to analyse the climate change and land use change impacts on the hydrology. Setegn et al. [25] proved that SWAT does not require much

calibration, and thus can be used in ungauged catchments or in large and varied catchments. SWAT is a watershed scale, physically based, distributed hydrological model developed to predict the impact of land management practices on the hydrologic and water quality responses of complex watersheds with heterogeneous soils and land use conditions [3]. The model partitions a watershed into subwatersheds and organises input information for each subwatershed into the following categories: climate, hydrologic response units, ponds/wetlands, groundwater, and the main stream reach draining each subwatershed. As a process-based model, SWAT can be extrapolated into a broad range of conditions that may have limited observations, and therefore, it is widely used to study the impacts of environmental change (e.g. [5, 7, 10, 24]).

##### 4.2 SWAT Model Performance Evaluation

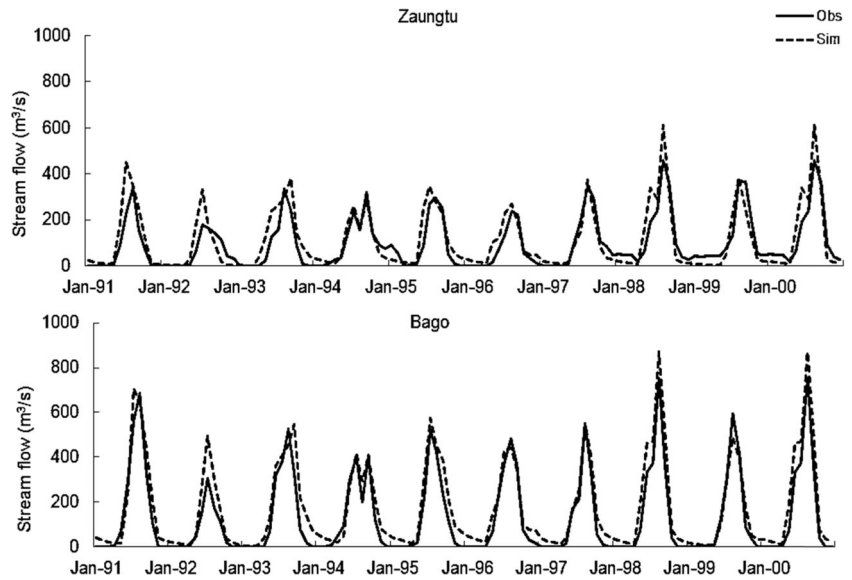
In this study, the performance of the model was evaluated using the coefficient of determination ( $R^2$ ), Nash-Sutcliffe (NS) efficiency, and percent bias (PBIAS). Zhang et al. 2014 stated that NSE and  $R^2$  values greater than 0.6 means a perfect match. On the other hand, PBIAS should be less than 15 % for good predicted efficiency [11].  $R^2$  is calculated as:

$$R^2 = \frac{\left[\sum_i (Q_i^{obs} - Q_i^{obs}) - (\sum_i (Q_i^{obs} - Q_i^{sim}))\right]^2}{\sum_i (Q_i^{obs} - Q_i^{obs}) - \sum_i (Q_i^{obs} - Q_i^{sim})^2} \quad (6)$$

**Table 7** Sensitive parameters of SWAT modelling for stream flow simulation in the Bago River Basin

Parameters	Description and units	Fitted parameter value
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mmH <sub>2</sub> O)	0
GW_REVAP	Groundwater ‘revap’ coefficient	0.2
SHALLST	Initial depth of water in the shallow aquifer (mmH <sub>2</sub> O)	500
REVAPMN	Threshold depth of water in the shallow aquifer for ‘revap’ or percolation to the deep aquifer to occur (mmH <sub>2</sub> O)	500
ESCO	Soil evaporation compensation factor	0.5
CHK2	Channel effective hydraulic conductivity (mm/h)	100
CN2	Curve number	70
CANMX	Canopy storage (mm)	100

**Fig. 7** Comparison between observed and simulated monthly stream flow at the Zaungtu and Bago stations for the calibration period 1991–2000



NS is defined by:

$$NS = 1 - \frac{\sum_{i=1}^n [(Q_i^{obs} - Q_i^{sim})^2]}{\sum_{i=1}^n (Q_i^{obs} - Q_i^{mean})^2} \tag{7}$$

PBIAS is derived using the following equation:

$$PBIAS(\%) = \frac{\sum_{i=1}^n (Q_i^{obs} - Q_i^{sim}) \times 100}{\sum_{i=1}^n Q_i^{obs}} \tag{8}$$

Where  $Q_i^{obs}$  is the measured daily stream flow,  $Q_i^{sim}$  is the computed daily stream flow of the given year and  $Q_i^{mean}$  is

average daily stream flow for the simulation period and  $n$  is the number of daily stream flow values.

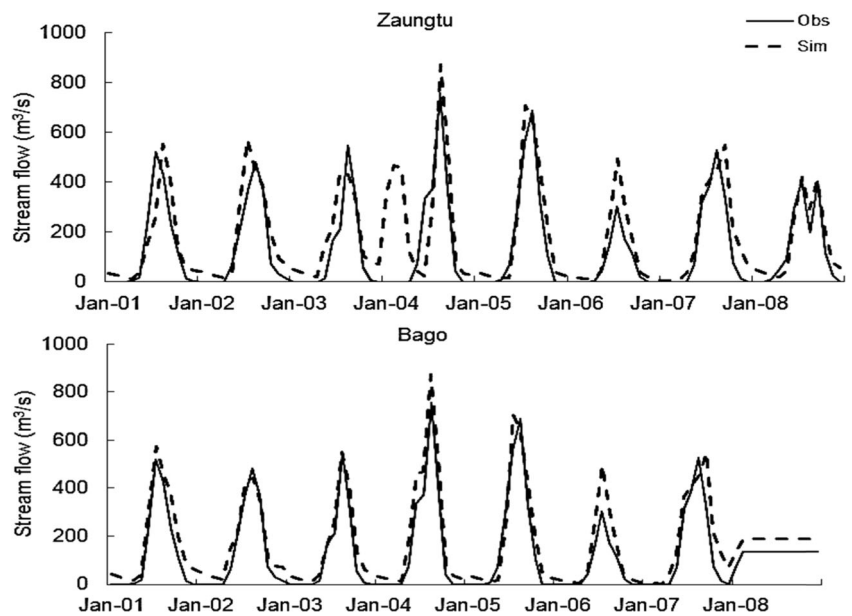
## 5 Results and Discussion

### 5.1 Climate Change Scenarios

#### 5.1.1 Future Temperature

The projected changes in maximum temperature ( $T_{max}$ ) and minimum temperature ( $T_{min}$ ) are analysed for three periods: 2020s (2010–2039), 2050s (2040–2069), and 2080s (2070–2099) relative to the baseline period of 1975–2005 under the

**Fig. 8** Comparison between observed and simulated monthly stream flow at the Zaungtu and Bago stations for the validation period 2001–2008





**Table 8** Performance of the SWAT model to simulate stream flow using daily and monthly data

Station	Data	Calibration (1991–2000)			Validation (2001–2008)		
		$R^2$	NS	PBIAS (%)	$R^2$	NS	PBIAS (%)
Zaungtu	Daily	0.73	0.71	-21	0.73	0.71	-19
	Monthly	0.81	0.82	-15	0.82	0.81	-18
Bago	Daily	0.79	0.73	-24	0.71	0.70	-22
	Monthly	0.93	0.86	-16	0.93	0.81	-14

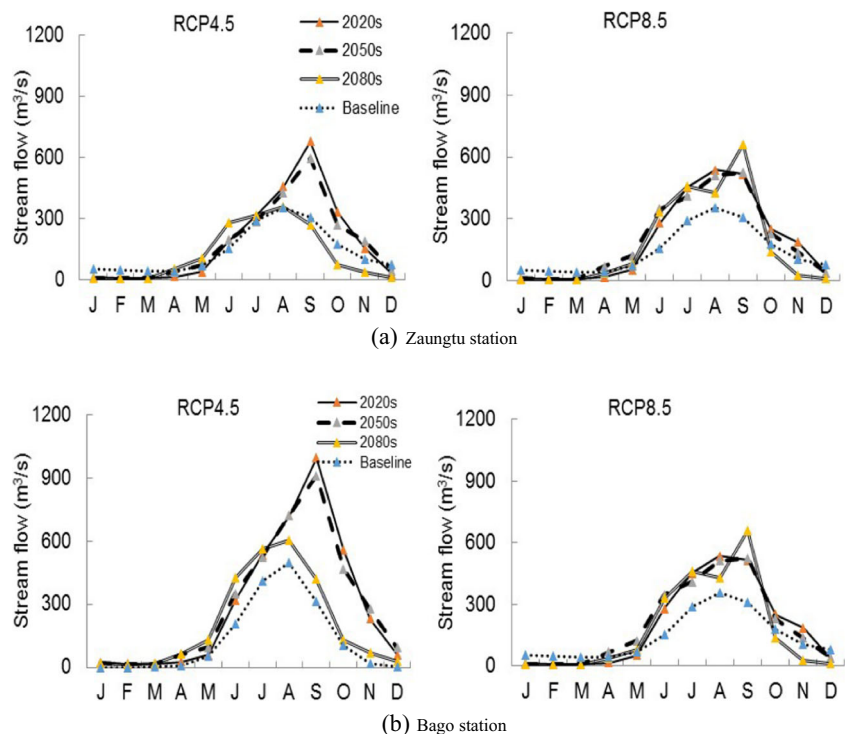
RCP4.5 and RCP8.5 scenarios. Table 6 shows average annual and seasonal  $T_{max}$  and  $T_{min}$  changes under RCP4.5 and RCP 8.5 scenarios for all periods. The seasonal results are based on three clearly distinguishable seasons in Myanmar: summer (JFMA), rainy (MJJA), and winter (SOND). All GCMs under both RCP scenarios indicate an increase in  $T_{max}$  and  $T_{min}$  for seasonal as well as annual projections. Average annual  $T_{max}$  is projected to increase by 0.7 to 1.7 °C and 1.1 to 2.9 °C under RCP4.5 and 8.5 respectively. Similarly, all seasons show an increasing temperature under both scenarios in all three periods except the summer of 2020s for RCP4.5. Under the RCP8.5 scenario, all seasonal and annual changes in  $T_{max}$  are projected to increase by 2.7 °C or higher in the 2080s. Similar future changes in  $T_{max}$  are projected under RCP4.5 but of much smaller magnitude. Average annual  $T_{min}$  is projected to rise by 1.3 and 2.5 °C under RCP4.5 and 8.5, respectively. In the case of seasonal changes, the winter of

the 2050s is affected the most under RCP4.5 while it is the summer for the 2080s for RCP8.5. Future changes in  $T_{min}$  are projected to be larger in magnitude under RCP8.5 than RCP4.5.

5.1.2 Future Precipitation

The projection of average precipitation under RCP4.5 and 8.5 scenarios are compared with the baseline period of the whole basin as shown in Fig. 6. The peak of precipitation changes for RCP4.5 is greater than those of RCP8.5. Figure 6 depicts the changes in average annual and seasonal precipitation for the whole basin under both scenarios. Average annual precipitation is estimated to increase by 30–120 mm under RCP4.5 and by 110–125 mm under RCP8.5. As for seasonal changes, all seasons are likely to receive more precipitation in the future with respect to the baseline values. The winters of the 2020s and 2050s show a definite increase in precipitation by about 225 mm under RCP8.5 and 250 mm under RCP4.5. However, the increase in precipitation for the summer in the 2020s under both scenarios is relatively smaller. RCP4.5 projects a greater increase in winter precipitation compared to RCP8.5. Both scenarios show similar changes in annual precipitation for the first two periods. On reaching 2080s, RCP8.5 still projects a continuous increase of precipitation, while in RCP4.5, the change is subsiding. Therefore, as per the projection, the future climate in the Bago River Basin is expected to

**Fig. 9** Simulated average monthly stream flow at the a Zaungtu and b Bago stations during the baseline period and the three future periods using the multi-model mean of projections under RCP4.5 and 8.5 scenarios



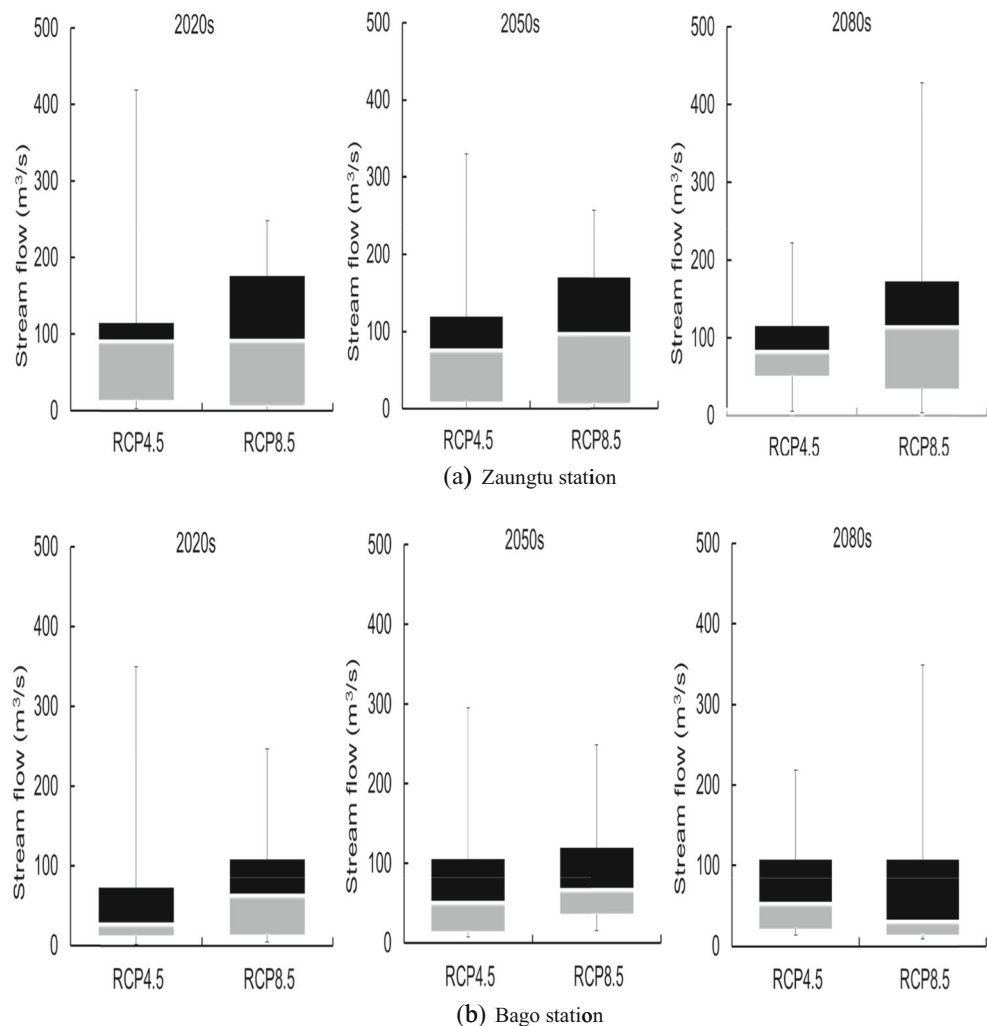
be wetter than baseline period. The winter season is highly affected under both RCPs.

## 5.2 Simulation of Stream Flows

### 5.2.1 Sensitivity Analysis of the SWAT Model

Twenty seven hydrological parameters were tested to identify sensitive parameters for the simulation of stream flow using the Automated Latin Hypercube One-factor-At-a-Time (LH-OAT) global sensitivity analysis procedure [30]. The eight most sensitive parameters (Table 7) were chosen for calibration of the model. These parameters were baseflow alpha factor (ALPHA BF), threshold water depth in the shallow aquifer for flow (GWQMN), soil evaporation compensation factor (ESCO), channel effective hydraulic conductivity (CH K2), initial curve number (II) value (CN2), available water capacity (SOL AWC), and maximum canopy storage (CANMX). This also includes water uptake directly from the shallow aquifer by deep tree and shrub roots (GW REVAP) and (REVAPMN) [23].

**Fig. 10** Changes in annual average stream flow for the 2020s, 2050s, and 2080s relative to the baseline period (1990–2009) at the **a** Zaungtu station and **b** Bago station



### 5.2.2 Calibration and Validation of the SWAT Model

Figures 7 and 8 illustrate the observed and simulated hydrograph during calibration and validation of the SWAT model in both the stations Zaungtu and Bago, respectively. These figures show that the model reproduces the historical records of discharge reasonably well. The coefficient of determination ( $R^2$ ), Nash-Sutcliffe (NS) efficiency coefficients, and percent bias (PBIAS) calculations are shown in Table 8. For the Zaungtu station, the hydrological model simulates the monthly discharge quite reasonably. The  $R^2$  values are 0.81 and 0.82 and the NS values are 0.82 and 0.81 for the calibration and validation, respectively. The PBIASs are  $-15$  and  $-18$  %, respectively.

For the Bago station the  $R^2$  values are 0.93 and 0.93, and the NS values are 0.86 and 0.81 for calibration and validation, respectively. The PBIASs are  $-16$  and  $-14$  % respectively. The overall performance is better than for the Zaungtu station. In general, the hydrological model shows satisfactory performance in simulating monthly river flows in the Bago River Basin.

5.2.3 Future Stream Flow Simulation

The mean monthly stream flow at the Zaungtu and Bago stations for the baseline period and three future periods under two scenarios are depicted in Fig. 9. It is observed that the stream flow within June to October is projected to increase at both stations. The peak of the stream flow is observed in September (the beginning of the winter season) under both scenarios in all periods at the two stations although the baseflow peaks in August. The summer season flow (January to April) is projected to remain with the same variation as the baseline period at the Bago station for all periods. However, at the Zaungtu station, the baseline stream flow is higher than the projected flow under both scenarios in the summer season. In the winter season, the projected seasonal flow is higher than the baseline at the Bago station, but the Zaungtu station has a different variation (lower than the baseline) in the month of December. In 2080s, three months (October, November, and December) will witness lower stream flow at the Zaungtu station. During August, the projected stream flow is higher than the baseline period under both RCP4.5 and 8.5; however, variability is observed in September. The projected peak streamflow under RCP4.5 is higher than that of RCP8.5 in September of early and mid future at both stations.

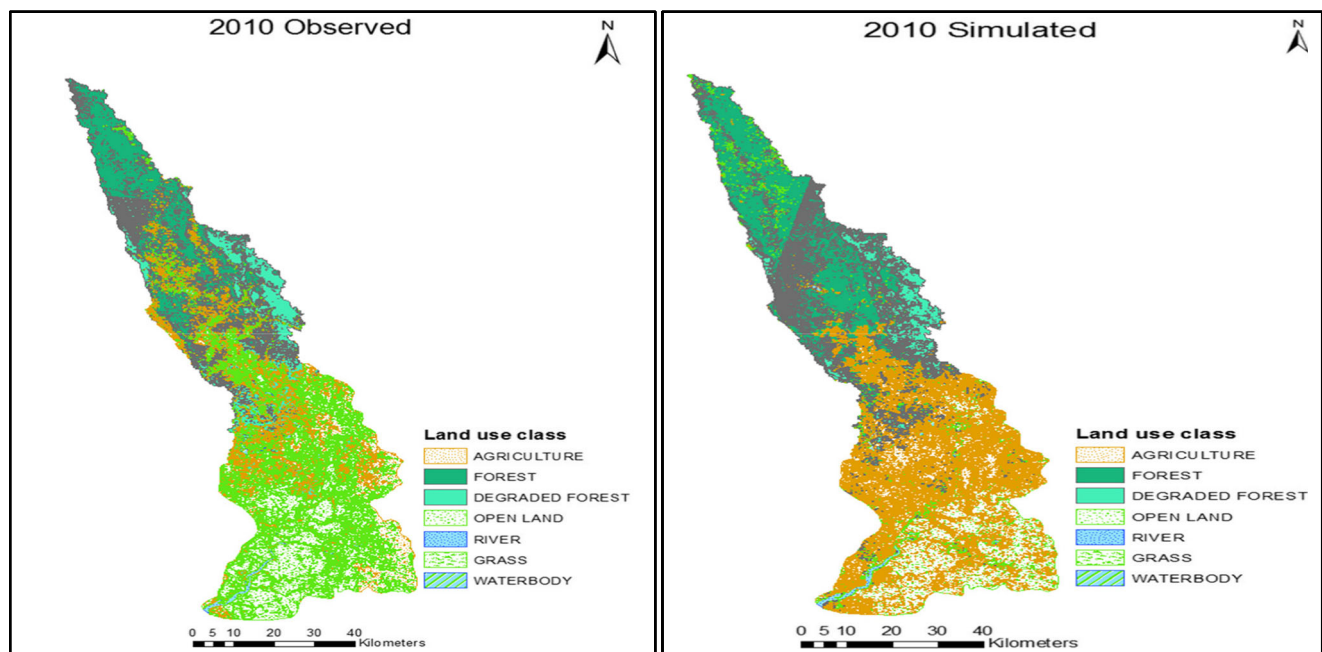
The change in annual stream flow under RCP4.5 and 8.5 relative to the baseline period at the Zaungtu station is shown in Fig. 10a. The annual stream flow is projected to change in both scenarios. The median value indicates an

**Table 9** Comparison between observed and simulated land use for 2010

Land use	Area (km <sup>2</sup> )		Relative error (%)
	Observed	Simulated	
Agriculture	879	1000	-13.77
Grassland	1753	1630	7.00
Forest	507.8	562	-10.67
Open land	1368	1262	7.75
Orchard	282.5	324	-14.69
Waterbody	92.8	105	-13.15

increase in all periods under both RCP4.5 and 8.5 scenarios. At the Zaungtu station, changes in annual flow under RCP8.5 is greater than RCP4.5, showing 30 m<sup>3</sup>/s in the 2020s, 41 m<sup>3</sup>/s in the 2050s, and 34 m<sup>3</sup>/s in the 2080s respectively. Therefore, higher changes in annual stream flow are expected for the Zaungtu station compared to Bago. During the 2020s in Zaungtu, the flow is projected to increase to 420 m<sup>3</sup>/s under the RCP4.5 scenario. Under RCP8.5, the stream flow will increase to 440 m<sup>3</sup>/s in the 2080s.

The changes in annual stream flow in future periods with respect to the baseline period at Bago is shown in Fig. 10b. In all periods, the projected stream flow is greater under the RCP8.5 scenario. Results indicate that the stream flow can increase to 350 m<sup>3</sup>/s in the 2020s period under the RCP4.5 scenario and the same level in the 2080s under RCP8.5.



**Fig. 11** Observed and simulated land use in the Bago River Basin for 2010

**Table 10** Projected change in land use in the Bago River Basin during the 2020s

Land use	Area (km <sup>2</sup> )		Change (km <sup>2</sup> )
	2010	2020s	
Agriculture	879.0	1767.7	888.7
Grassland	1753.0	908.3	-844.7
Forest	507.8	590.9	83.1
Open land	1368.0	1113.3	-254.7
Orchard	282.5	407.2	124.7
Waterbody	92.8	95.7	2.9

### 5.3 Simulation of the Combined Impact of Land Use and Climate Change on Hydrology

#### 5.3.1 Projection of Land Use Change in 2020s

The land use for 2010 was projected using the CLUE-S model and compared to the actual land use map of 2010 (Fig. 11). It was found that the model simulated land use map of 2010 is very much similar with the observed land use map of 2010 (Table 9). The relative error for simulation of each land use category is less than 15 % and is considered as acceptable for the study.

The model simulated land use changes for six land use types in the basin. Agriculture, grassland, open land, and forest are the most important land use types in this area. Due to the dominance of urbanisation in this area, a number of driving factors related to this process have been included, such as the accessibility of the area by different agriculture types. Validation methods for this type of study include the calculation of the kappa statistic [38]. The resultant kappa index was 0.7998, showing the total accuracy of the land use simulation to be reliable, and hence the CLUE-S model was used to simulate land use changes of the Bago River Basin in 2020s. This study used the multiple resolution procedure, quantifying the degree of matching or similarity between complex spatial patterns. The multiple resolution method indicates whether the pattern is relatively well matched.

Table 10 depicts the projected land use area of the Bago River Basin during the 2020s. The area under agriculture is projected to increase from 18 to 36 % due to the assumption of modernisation in the economy, and cultivation of rice and paddy in the basin. The area under waterbody shows very small changes. On the other hand, grassland decreased from 36 to 19 %, whereas the orchard area increased by 6 and 8 % in 2010 and 2020s, respectively.

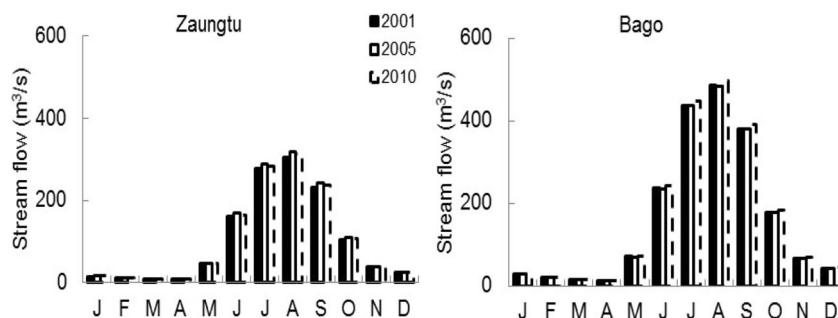
#### 5.3.2 Impacts of Climate Change and Land Use Changes on Hydrology

The land use maps for 2001, 2005, and 2010 were used to analyse the impacts of past land use change on stream flow at the Zaungtu and Bago stations. The effects of land use change on stream flows at the two stations are shown in Fig. 12. It is observed that there is no significant impact of land use change on stream flow at either station. Furthermore the impacts of land use change on stream flow at the Zaungtu and Bago stations are within 2.8 % during 2001 and 2005 compared to 2010.

In order to analyse the combined impact of climate change and land use change, the simulated stream flows under the land use change scenario and RCP4.5 and 8.5 climate change scenarios for the future period (2010–2039) are compared to the corresponding current conditions i.e. baseline period (1990–2009). To estimate the impact of climate change on stream flow, the future climate of the 2020s was used with current land use maps. Similarly, to estimate the impact of land use change on stream flow, the future land use map for the 2020s was used with the current climate. The future climate of the 2020s and land use maps for the 2020s were used to estimate the combined impact of climate change and land use change on stream flow in the Bago River. The annual and seasonal changes in stream flow are outlined in Table 11, whereas monthly changes in stream flow under RCP 4.5 and RCP 8.5 scenarios for both stations are depicted in Fig. 13.

The results show that the hydrology of the basin is more impacted by climate change compared to land use change in the near future (2020s) (Table 11). The average annual flow is projected to increase by 31–37 % and 56–58 % in Zaungtu

**Fig. 12** Average monthly stream flow in the Zaungtu and Bago stations of the Bago River Basin simulated using land use maps of 2001, 2005, and 2010



**Table 11** Changes in average stream flows under future climate change (CC), land use change (LU), and combined impact of climate change and land use change (CC + LU) scenarios for the 2020s at the Zaungtu and Bago stations

Period	Baseline stream flow (m <sup>3</sup> /s)	CC (m <sup>3</sup> /s)		% change from CC		LU (m <sup>3</sup> /s)		% change from LU		CC + LU (m <sup>3</sup> /s)		% changes from CC + LU	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Station: Zaungtu													
Annual	143	187	196	31	37	157	159	10	11	212	234	48	64
Summer	46	12	11	-74	-76	45	44	-2	-4	13	12	-71	-73
Rainy	218	251	330	15	52	229	242	5	11	284	390	30	79
Winter	167	299	247	79	48	197	191	18	14	338	298	102	78
Station: Bago													
Annual	134	211	213	56	58	151	152	12	13	222	226	65	68
Summer	2	3	3.2	74	85	3	3	74	74	3	3	74	74
Rainy	292	313	357	7	22	311	311	7	7	341	387	17	33
Winter	111	304	267	174	141	141	141	27	27	311	274	181	147

and Bago stations, respectively, under climate change scenarios. Whereas the average annual flow is projected to increase by 10–11 % and 12–13 % Zaungtu and Bago stations, respectively, under land use change scenarios.

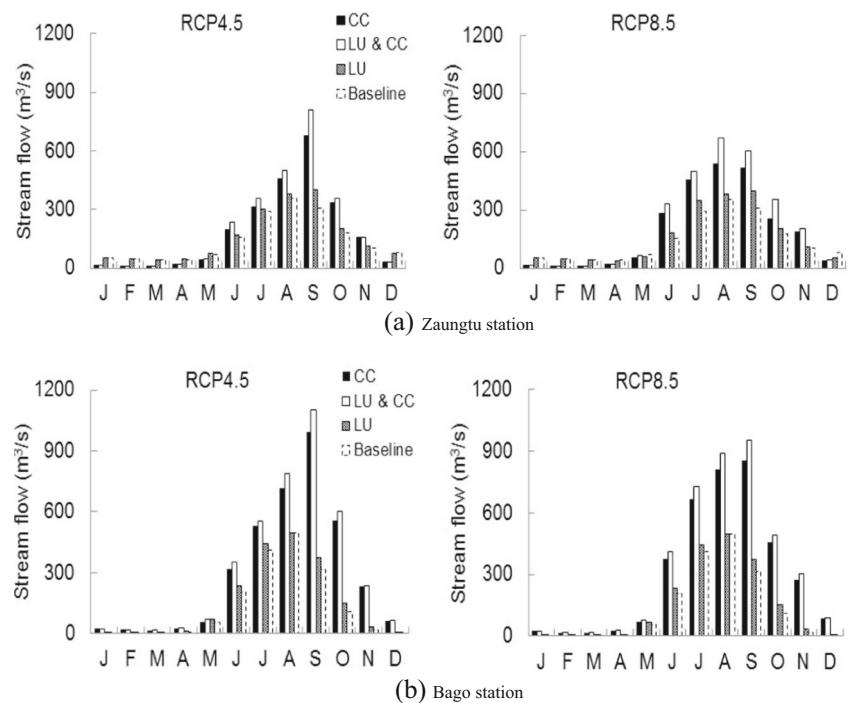
The projected stream flows under the combined land use and climate change impacts in the late rainy and early winter months (July, August, September, and October) show greater increase compared to the individual climate change and land use change impacts. The decrease in streamflow is projected in the summer season in the Zaungtu station, whereas it is increased in the Bago station. The decrease in streamflow is similar to the impacts from climate change only in the

Zaungtu station. In both of the stations the winter season streamflow is highly affected by combined impact of climate change and land use change. This result indicates that climate change and land development alter the seasonal distributions of the stream flows rather than the change in the average annual stream flow.

### 6 Conclusions

This study used an integrated modelling approach to examine the land use change and climate change impacts on the

**Fig. 13** Simulated average stream flows under future climate change and land use change scenarios for the 2020s at the **a** Zaungtu and **b** Bago stations



hydrology of the Bago River Basin in Myanmar. Bias corrected outputs of six GCMs were used to construct future climate change scenarios in the basin. The results of climate change analysis showed an increase in average temperature under both RCP scenarios in the future. An increase of temperature in the range of 0.7 to 1.5 °C and 0.9 to 2.7 °C was observed under RCP 4.5 and RCP 8.5, respectively, by 2100. In general, an increase in precipitation was observed in the future, subject to monthly variations.

The Conversion of Land Use and its Effects at Small Regional Extent (CLUE-S) model was used to simulate the land use conditions for 2020s. The future climate scenarios and land use change scenarios were fed into a well calibrated and validated hydrological model, SWAT, to examine the impacts of climate change and land use change on the hydrology. The results show that the hydrology of the basin is more impacted by climate change compared to land use change in near future. Furthermore, the projected stream flows under the combined land use and climate change impacts show greater increase compared to the individual climate change and land use change impacts. The winter season streamflow is expected to be highly affected by separate as well as combined impacts of climate change and land use change in the basin.

This study is the first of its kind in Myanmar and the results can be useful to understand the potential impact of climate change on hydrology and water resources in the Bago River Basin. Policy maker and planners would be benefited by this study to formulate adaptation strategies to offset the negative and harness the positive impacts of climate change and land use change in the basin.

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