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Assessment Of the Impacts of Climate and Land Use/Land Cover Changes on Water Runoff in Ca River Basin in Vietnam

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Abstract

In recent years, rapid socio-economic development and human behaviors have led to significant changes in land cover in Ca river basin, Vietnam. Coverage changes breakdown inflows and water levels of rivers and streams, affecting hydrological factors and water resources. In addition, impacts of climate change has been increasingly evident, causing negative changes in precipitation and temperature. These problems greatly affect the water resources of the North Central region in general and the Ca river basin in particular. Therefore, this study aims to assess the simultaneous impact of land cover and climate change on the water resources of the Ca river basin. The impacts were assessed quantitatively using the future climate and land cover scenarios. These scenarios are included in the simulation with the SWAT model, which has been calibrated and tested suitable for the Ca river basin, reaching 0.73-0.85 and 0.87-0.95 with Nash – Sutcliffe (NSE) and R^2, respectively. Simulation results show that in the Ca river basin during the rainy season, there is an increase in flood flow, and a decrease in flow in the dry season, making the flood situation in the downstream area are prone to more serious and make salinity penetrate deeper into the river in the dry season.

Keywords: Impacts of Climate Change; Land Use/Land Cover; Markov - Cellular Automata simulation; Ca River Basin; Landsat Images.

1. Introduction

The North Central region in recent years has experienced rapid socio-economic development, resulting in impacts on the land surface: the decline in forest cover, the increasing area of agricultural land and the rate of urbanization make the basins here also face drastic changes [1], [2]. Changes in land cover can have both positive and negative impacts on water resources in both space and time.

In addition, rapid increase in temperature, decrease in dry season rainfall, increase in flood season rainfall, and increase in the frequency of extreme weather events rate and often difficult to predict. Those changes, especially in temperature and rainfall, will directly affect the water resources of the North Central region in general and the Ca river basin in particular.

Besides, in Vietnam, it can be seen that most of the studies either stop at the construction of the cover changes, have not provided the cover scenarios, or only evaluate the effects of the change of cover on water resources, or only assessing the impact of climate change on water resources [3],[4],[5],[6],[7],[8], there has not been any research evaluating how the change of the two above factors affects water resources. Internationally, studies abroad have solved this problem theoretically, but in terms of practical application, to be able to build a simulation model, it depends on the understanding ability of each individual study group for each specific basin.

Therefore, the goal of the article towards assessing the impact of the change of cover on the water resources of the Ca river basin in the context of climate change is a very necessary issue to serve the assessment of water resources, helping the managers to manage water resources and make strategic decisions to overcome droughts, floods, and develop socio-economic more effectively.

2. Materials and methodology

2.1. Study Area

The Ca river system stretches from 18°15’50” to 20°10’30” north latitude and 103°45'20' to 105°15'20'' east longitude. The outlet of the basin is located at 18°45'27" north latitude and 105°46'40"east longitude. The starting point of the basin in the territory of Vietnam is at 19°24'59'' North latitude and 104°04'12' East longitude [9]. Ca river basin is the second largest basin of the North Central region, extends from the Xieng - Khuang plateau of the Lao People's Democratic Republic to Nghe An province and a part of Thanh Hoa and Ha Tinh provinces.

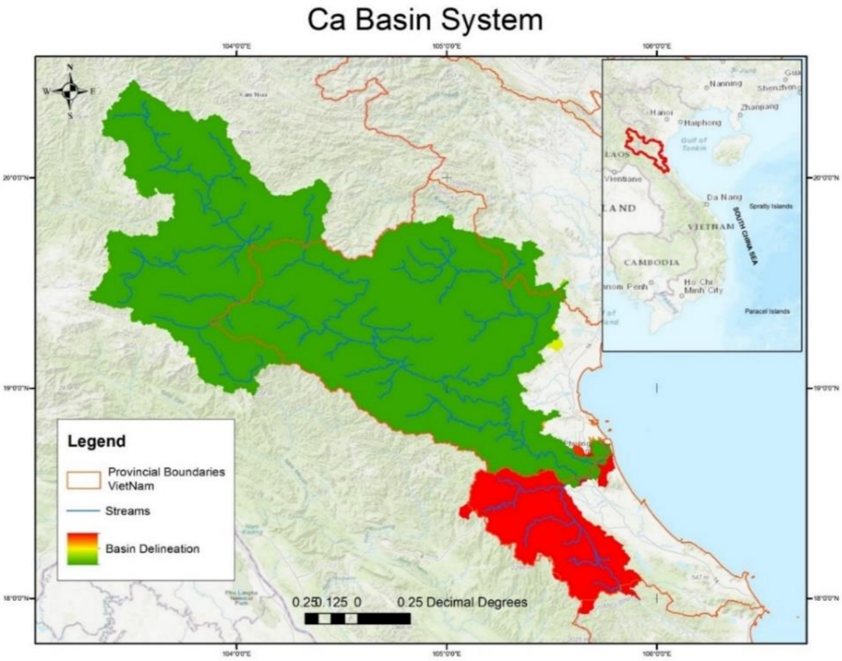


Figure 1. Ca River Basin System

The mainstream of the Ca river system has a length of approximately 513 km, of which 361 km are within the Vietnam territory [10]. The area of the Ca river basin in the territory of Vietnam is 17,730 km^2, out of a total of 27,200 km^2 of the whole basin [11]. Annually, the basin receives an average of 1100 ÷ 2500 mm of rainfall. In areas receiving heavy rainfall such as the upper reaches of Hieu and La rivers, the average amount of rain received can be up to 2000 ÷ 2400 mm. Coverage on the basin includes 44% forest, 16% wet rice, 2% vegetables and crops, and 38% other land types [12].

2.2. Research data

2.2.1. Spatial data

Terrain data

Figure 2 shows the topographic data of the Ca river basin as grid plots. Data were collected from the United States Geological Survey (USGS) [13] as a digital elevation model (DEM) with spatial resolution of 30m and fed into the SWAT model to simulate the flow network of the basin. Before being included in the SWAT model, the DEM data were calibrated to the UTM WGS84 coordinate system.

Soil data

Soil map data on the territory of Vietnam is the data of the material cover on the surface, which is referenced to the WGS 84 coordinate system. The data includes attributes such as: The soil type code is divided by FAO and soil type. The data are referenced to the FAO World Soil Classification.

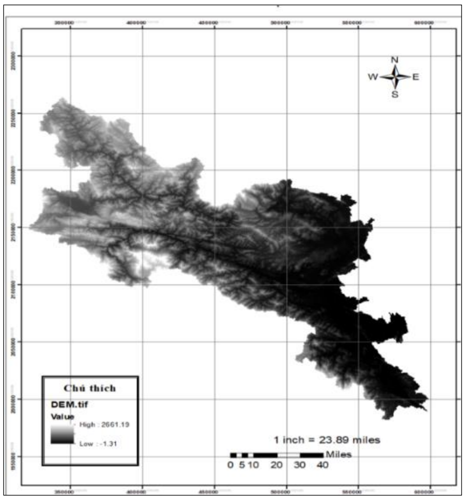


Figure 2. DEM of Ca river basin

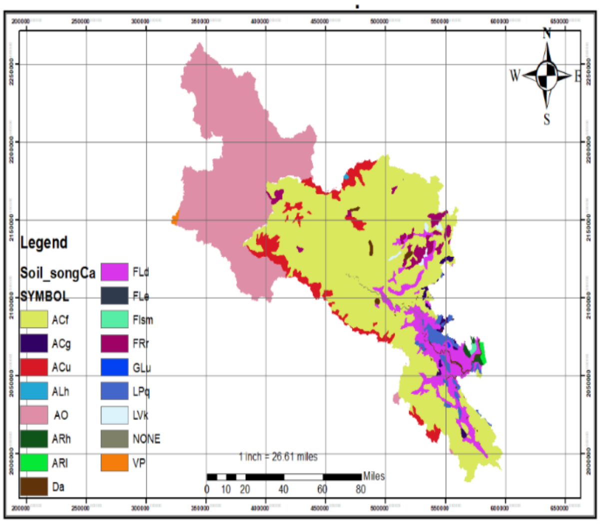


Figure 3. Soil type map of Ca river basin

Table 1. Main soil types in Ca river basin

No.	FAOSOIL	Name	Area (ha)
1	Ao90-2/3c	Degraded gray soil on sedimentary and metamorphic rocks	8184
2	I-Lc-Bk-c	Rocky land soil	892
3	Af60-1/2ab	Red-brown silver gray soil	2063
4	Gd29-3a	Peat clay	2614
5	Ag17-1/2ab	Shale-colored gray soil	1209
6	Ao107-2bc	Gray soil on the rocks	13175

According to Table 1, there are mainly 6 types of soil in the study area, of which gray soil on rocks occupies the largest area, accounting for nearly 48% of the total basin area. In addition, degraded gray soil on sedimentary and metamorphic rocks also accounts for 29% of the total basin area. The rest are other types of soil such as rocky land soil, peat clay, red-brown silver-gray soil, and shale-colored gray soil.

Land use data

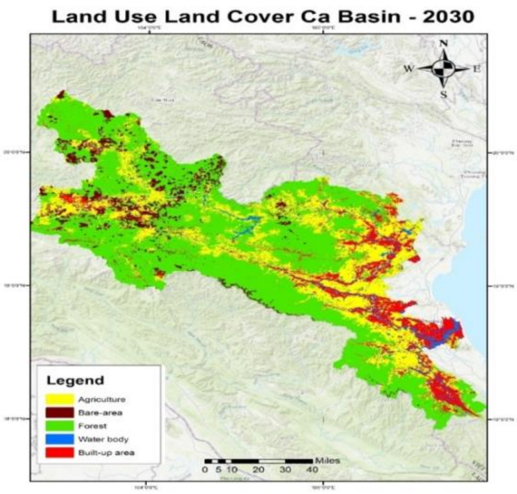


Figure 4. Land use map of Ca river basin in 2030

The 2030 river land use data was established by the Markov - Cellular Automata simulation method with input data of Landsat 5 TM, Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images. of the years 2005, 2010 and 2015. The simulation model Markov - Cellular Automata has also been calibrated and tested under the conditions of the Ca river basin. The simulation model results are verified with the 2015 cover map and the Kappa coefficients are: K_{no} = 0,95, $K_{location}$ = 0,91, $K_{locationStrata}$ = 0,91, $K_{standard}$ = 0,91 [14].

The land use map of the Ca river basin with 5 different types of land is divided according to the land-use code table under Table 2:

Table 2. Types of land use in Ca river basin in 2030

No.	Names according to SWAT	Short form	Area (ha)	Area (%)
1	Water	WATR	85.163	3,13
2	Agricultural Land- Generic	AGRL	693.484	25,52
3	Forest - Mixed	FRST	1.502.803	55,31
4	Residential	URMD	269.172	9,91
5	Barren	BARR	166.518	6,13

2.2.2. Attribute data

Weather data

The climate of the basin provides energy, moisture and determines the relative importance of components in the hydrological cycle. Weather data required for SWAT includes daily rainfall, maximum and minimum daily air temperature; solar radiation, wind speed and relative humidity.

- Rainfall data: rainfall on 16 stations: Dua, Do Luong, Nam Dan, Cho Trang, Muong Xen, Quy Chau, Nghia Khanh, Hoa Duyet, Linh Cam, Son Diem, Cua Hoi, Kim Cuong, Huong Khe, Vinh, Quy Hop, Tay Hieu, Tuong Duong.

- Temperature data: maximum and minimum air temperature during the day at 7 stations: Quy Chau, Quy Hop, Tay Hieu, Tuong Duong, Vinh, Huong Khe, and Do Luong.

Meteorological data are taken from the Center for Hydrometeorological and Environmental Monitoring, Viet Nam Meteorological and Hydrological Administration, including daily rainfall data and average daily water flow data from 2010 to 2015.

Actual flow data

Actual flow data are provided by the Center for Hydrometeorological and Environmental Monitoring, Viet Nam Meteorological and Hydrological Administration, and are used to evaluate the simulation results of the SWAT model.

Hydrological data includes daily water flow of Quy Chau, Nghia Khanh, Son Diem, Hoa Duyet stations.

Climate change scenario data

Future rainfall and temperature are taken from the 2016 climate change scenario: RCP4.5 and RCP 8.5 [15], specifically as follows:

About temperature:

According to the RCP 4.5 scenario, the average annual temperature in the first periods of the 21st century will increase from 0.3 to 1,1^{o}C; according to the RCP 8.5 scenario, the average annual temperature of this periods increases by 0.6 to 1,5^{o}C [15]. Based on the input data of the SWAT model, the minimum and maximum temperature in the statical calculation topic of changes in 2 temperature characteristics are in Tables 3.4 and 3.5. From 2020 through 2039, there is a tendency for temperature increase at all stations in all scenarios, but not evenly between months. Particularly in the RCP 4.5

scenario of May, the temperature at most stations will decrease. According to the RCP 8.5 scenario, the largest temperature increase at Tuong Duong station is 1.6°C in April. The annual temperature increase at stations on the Ca river basin is shown in Tables 3 and 4.

Table 3. Change of monthly mean minimum temperature at meteorological stations in the period 2020 - 2039 compared to the baseline period (°C)

Month	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
RCP4.5												
Con Cuong	0,7	0,7	1,1	0,9	-0,1	0,8	0,8	0,8	0,7	0,6	0,6	0,9
Do Luong	0,7	0,7	1,1	0,9	-0,1	0,8	0,8	0,8	0,8	0,6	0,6	0,9
Huong Khe	0,8	0,7	1,1	0,9	-0,2	0,7	0,8	0,7	0,7	0,5	0,6	0,8
Quy Chau	0,7	0,7	1,2	1,0	-0,1	0,9	1,0	0,9	0,8	0,7	0,7	0,9
Quy Hop	0,7	0,8	1,1	0,9	0,0	0,8	0,9	0,8	0,8	0,7	0,6	0,9
Tay Hieu	0,8	0,8	1,3	1,0	-0,5	1,0	1,1	1,0	0,8	0,6	0,7	1,0
Tuong Duong	0,7	0,7	1,1	0,9	-0,1	0,8	0,8	0,8	0,7	0,6	0,6	0,9
Vinh	0,7	0,7	1,1	0,9	-0,2	0,8	0,9	0,8	0,8	0,6	0,6	0,8
RCP8.5												
Con Cuong	1,0	1,0	1,2	1,1	1,0	1,0	1,0	0,9	0,9	1,0	0,8	1,0
Do Luong	1,0	1,0	1,3	1,1	1,1	1,0	1,0	1,0	0,9	1,0	0,8	1,0
Huong Khe	1,0	1,0	1,2	1,1	1,0	1,1	1,0	0,9	0,8	0,9	0,8	1,0
Quy Chau	1,0	1,1	1,3	1,1	1,1	1,2	1,1	1,1	1,0	1,1	0,8	1,0
Quy Hop	1,0	1,0	1,2	1,1	1,0	1,0	1,0	1,0	0,9	1,0	0,8	1,1
Tay Hieu	1,1	1,1	1,3	1,2	1,2	1,3	1,3	1,2	1,1	1,1	0,9	1,1
Tuong Duong	1,0	1,0	1,3	1,1	1,0	1,0	1,0	0,9	0,9	1,0	0,7	1,0
Vinh	1,0	1,0	1,2	1,1	1,0	1,1	1,0	1,0	0,9	1,0	0,8	1,0

Table 4. Change of monthly mean maximum temperature at meteorological stations in the period 2020 - 2039 compared to the baseline period (°C)

Month	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
RCP4.5												
Con Cuong	0.7	0.6	0.8	0.9	-0.2	0.8	1.0	0.9	0.8	0.8	0.7	0.7
Do Luong	0.7	0.6	0.9	0.9	-0.1	0.7	1.0	0.9	0.8	0.7	0.6	0.7
Huong Khe	0.6	0.5	0.8	0.8	-0.2	0.7	1.0	0.9	0.7	0.6	0.5	0.7
Quy Chau	0.7	0.6	0.8	0.8	0.7	0.8	1.0	1.0	0.9	0.8	0.7	0.8
Quy Hop	0.7	0.6	0.8	0.8	-0.1	0.8	1.0	1.0	0.8	0.8	0.7	0.7
Tay Hieu	0.7	0.6	0.8	0.8	-0.2	0.8	1.0	0.9	0.8	0.8	0.7	0.7
Tuong Duong	0.8	0.8	0.9	1.0	-0.2	0.8	1.0	0.9	0.8	0.9	0.8	0.8
Vinh	0.6	0.6	0.8	0.8	-0.2	0.7	1.0	0.9	0.8	0.6	0.6	0.7
RCP8.5												
Con Cuong	1.2	1.1	1.2	1.4	1.3	1.2	1.3	1.3	1.4	1.2	1.1	1.1
Do Luong	1.2	1.1	1.3	1.4	1.3	1.2	1.2	1.2	1.4	1.1	1.0	1.1
Huong Khe	1.0	1.0	1.1	1.3	1.2	1.2	1.3	1.2	1.3	1.0	0.8	1.0
Quy Chau	1.3	1.1	1.3	1.4	1.3	1.3	1.3	1.3	1.5	1.2	1.1	1.1
Quy Hop	1.3	1.2	1.3	1.4	1.3	1.2	1.3	1.3	1.5	1.2	1.1	1.2

Tay Hieu	1.2	1.1	1.3	1.4	1.2	1.2	1.2	1.3	1.5	1.1	1.1	1.1
Tuong Duong	1.4	1.4	1.4	1.6	1.3	1.2	1.3	1.3	1.5	1.3	1.2	1.2
Vinh	1.1	1.0	1.2	1.3	1.2	1.2	1.2	1.2	1.3	0.9	0.9	1.0

About rainfall:

As temperature changes, the trend of rainfall change at stations in the Ca river basin during the study period increased compared to the baseline scenario in both RCP4.5 and RCP 8.5 scenarios but the rainfall trend change during this time does not differ too much between the two scenarios [15]. The monthly rainfall variation rates of each climate change scenario compared to the baseline are summarized in Tables 5 and 6.

Table 5. Change in average monthly rainfall at meteorological stations according to RCP4.5 scenario for the period 2020 – 2039 compared to the baseline period

Station	Unit	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Con Cuong	mm	0.4	0.7	2.7	-8.4	3.4	2.8	4.3	24.4	33.8	36.7	3.7
	%	1.4	1.7	6.1	-11.1	1.6	2.2	2.8	10.2	11.7	14.5	5.5
Do Luong	mm	0.2	1.2	2.7	-7.9	-2.3	22.9	23.6	18.6	13.6	38.1	6.5
	%	0.8	3.5	6.6	-11.2	-1.3	17.6	14.2	7.7	4.0	11.8	7.9
Huong Khe	mm	5.4	2.4	3.4	-0.2	-4.5	21.2	3.0	36.6	32.1	-17.9	43.9
	%	13.8	5.3	5.3	-0.2	-2.0	14.6	2.0	13.2	7.6	-3.4	25.9
Quy Chau	mm	-1.0	-0.8	3.8	-4.1	9.2	2.4	5.3	10.8	25.4	24.9	1.1
	%	-9.1	-6.1	13.9	-4.9	3.7	1.3	2.8	4.1	10.0	14.4	2.8
Quy Hop	mm	-1.0	0.3	3.3	-3.6	11.9	18.4	9.8	21.0	25.5	32.0	2.0
	%	-7.2	1.4	10.0	-4.6	5.8	10.9	5.6	7.9	9.7	16.0	5.0
Tay Hieu	mm	0.7	-0.9	2.3	-3.0	0.3	19.8	15.8	10.2	19.1	47.6	2.4
	%	5.1	-4.6	7.8	-5.2	0.2	13.7	9.3	4.0	7.0	22.8	4.9
Tuong Duong	mm	-0.9	0.1	5.0	-7.3	20.4	-10.4	-1.7	32.7	15.0	21.7	0.5
	%	-14.9	0.6	17.4	-11.1	12.4	-7.6	-1.0	14.5	8.0	16.5	1.4
Vinh	mm	2.8	0.5	1.9	-6.0	5.8	23.9	0.5	25.8	27.6	46.4	24.2
	%	5.0	1.4	3.1	-10.9	3.5	28.6	0.5	11.0	7.2	8.8	20.9

Table 6. Change in average monthly rainfall at meteorological stations according to RCP8.5 scenario in the period of 2020 – 2039 compared to the background period

Station	Unit	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Con Cuong	mm	2.2	0.3	1.3	-15.9	32.6	13.2	37.7	69.0	14.4	20.1	39.9	3.0
	%	7.8	0.7	2.9	-20.9	15.7	10.5	24.7	28.8	5.0	7.9	59.3	9.0
Do Luong	mm	1.2	1.3	-0.5	-16.6	12.3	23.3	47.5	57.0	-21.4	40.6	61.5	0.4
	%	4.5	3.7	-1.2	-23.5	7.1	17.9	28.6	23.6	-6.2	12.5	75.0	1.1
Huong Khe	mm	5.0	3.5	0.1	-20.6	-5.9	4.1	33.6	93.9	-14.4	27.2	106.5	2.3
	%	12.8	7.7	0.2	-23.8	-2.6	2.8	22.7	34.0	-3.4	5.1	62.8	3.3
Quy Chau	mm	0.3	-0.7	2.5	-13.5	10.5	3.8	37.4	50.6	12.9	11.7	18.3	0.2
	%	2.7	-5.3	9.1	-16.3	4.2	2.1	19.5	19.0	5.1	6.8	46.5	1.2
Quy Hop	mm	0.6	0.3	1.9	-12.9	22.0	9.4	38.0	54.7	20.6	25.2	22.4	0.3
	%	4.3	1.4	5.8	-16.5	10.7	5.6	21.7	20.7	7.8	12.6	56.2	1.4
	mm	1.3	-0.4	1.6	-13.0	7.1	6.6	44.1	53.2	11.0	46.2	36.2	0.9

Tay Hieu	%	9.4	-2.1	5.4	-22.3	4.4	4.6	26.0	21.0	4.0	22.2	74.4	3.9
Tuong Duong	mm	1.4	0.2	3.2	-10.6	36.4	6.1	26.0	59.5	23.2	9.6	12.8	1.5
	%	23.2	1.2	11.1	-16.1	22.2	4.4	15.8	26.4	12.4	7.3	37.1	11.4
Vinh	mm	3.8	0.9	0.7	-15.0	23.4	25.5	26.4	70.4	-11.3	42.8	83.9	2.8
	%	6.8	2.6	1.1	-27.2	14.0	30.6	27.8	30.1	-3.0	8.1	72.5	4.2

2.3. Methodology

2.3.1. Theoretical background

To model precipitation–runoff processes, many methods can be used. These methods can be used to solve different hydrological objectives, such as operational hydrology, flooding, drought or sediment transmission modeling. One of the first steps to solving the problem is to select a model that is appropriate for a particular hydrological objective.

The Soil and Water Assessment Tools (SWAT) model developed by the United States Department of Agriculture (USDA) has been shown to be an effective tool for water resource assessment with large catchments. The SWAT model was developed to assess the impact of land use, erosion and agricultural chemical use on a river basin system. The model is built on a physical basis, besides incorporating regression equations describing the relationship between input and output variables. The model requires information about weather, soil properties, topographical data, land cover and land use in the catchment. The physical processes related to water movement, sediment movement, farming process, nutrient cycle, etc. are all described directly in the SWAT model using this input data.

In terms of the whole basin, the SWAT model is a distribution model. This model divides the flow into three phases: ground phase, subsurface phase (close to surface, underground) and river phase. The description of hydrological processes is divided into two main parts described below:

Soil phase in the hydrological cycle

The soil phase in the hydrological cycle is modeled based on the following water balance equation [16]:

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

where:

- SW_t: the total amount of water at the end of the calculation period (mm);
- SW_0: the total initial water volume at day i (mm);
- t: time (day);
- R_{day}: the total amount of precipitation at day i (mm);
- Q_{surf}: total surface water volume of the day i (mm);
- E_a: the amount of evaporation at day i (mm);
- w_{seep}: the amount of water entering the underground at day i (mm);
- Q_{gw}: the amount of water regressing at day i (mm).

The division of the study basin into sub-basins allows the model to demonstrate the differences in evapotranspiration for different crops and soil types. Runoff is simulated separately for each hydrostatic release unit (HRU) and flood transmission to obtain the total surface runoff for the entire basin. This increases the accuracy of the model and better represents the water balance equation physically.

Water phase in the hydrological cycle

The water phase in the hydrological cycle uses the SCS curve number method [17] and the Green - Ampt (1911) infiltration equation [18] to calculate the surface runoff. The numerical curve method requires only daily rainfall, while the Green Ampt method requires hourly precipitation. Therefore, to fit the existing data in this topic, only the numerical curve method is mentioned.

The SCS flow equation is an empirical equation commonly used to evaluate the total runoff for different land-use types and soil properties. In the SCS curve method, the curve index value varies non-linearly with soil moisture. The value of the curve number decreases when the soil moisture is close to that of wilting plants and increases close to 100 when the soil moisture reaches a value close to the saturation moisture. SCS curve index equation [17]:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{R_{day} - I_a + S}$$

where:

- Q_{surf}: The effective amount of surface runoff or precipitation (mm);
- R_{day}: daily rainfall (mm);
- I_a: initial water capacity (mm);
- S: storage parameter (mm).

Storage parameters vary spatially according to changes in soil properties, land use, and management, slope, and time. This parameter is defined as follows:

$$S = 25.4(\frac{1000}{CN} - 10) \quad (a)$$

where: CN is the curve index.

Normally I_a = 0,2S and equation (a) is written as:

$$Q_{surf} = \frac{(R_{day} - 0.2.S)^2}{(R_{day} - 0.8.S)}$$

Model testing

The effectiveness of the model is evaluated by comparing the results of running the model with real data measuring annual, monthly and daily flow.

The mean, standard deviation, coefficient of determination (R^2) [19] and the Nash-Sutcliffe efficiency (NSE) [20] were used to evaluate the accuracy of the SWAT model. The formula for calculating R^2 and NSE is shown in the following two formulas (1) and (2), respectively:

$$\boldsymbol{R^2} = \left(\frac{\sum_{i=1}^{n}(Oi - \bar{O}i)(Pi - \bar{P}i)}{\sqrt{\sum_{i=1}^{n}(Oi - \bar{O}i)^2}\sqrt{\sum_{i=1}^{n}(Pi - \bar{P}i)^2}} \right)^2 \quad (1)$$

$$\textbf{NSE} = 1 - \frac{\sum_{i=1}^{n}(Oi - Pi)^2}{\sum_{i=1}^{n}(Oi - \bar{O}i)^2} \quad (2)$$

Where O_i is the actual measured value (m^3/s), $\bar{O}_i$ is the average measured real value (m^3/s), $\bar{P}_i$ is the simulated value (m^3/s), n is the number of calculated values.

The R^2 value ranges from 0 to 1, representing the correlation between the actual measured value and the simulated value. R^2 values > 0.5 are considered acceptable with R^2 approaching 1 shows a high correlation [17]. Meanwhile, the NSE index runs from -∞ to 1, measuring the conformity between the actual measured value and the simulated value on a 1:1 straight line. NSE values > 0.5 are considered acceptable. With NSE > 0.65 showing high concordance and NSE in the range 0.54 < NSE < 0.65 showing relatively high concordance [21], [17].

If R^2, NSE is under or close to 0, then the result is considered unacceptable or unreliable. Conversely, if these values are equal to 1, then the simulation result of the model is perfect. However, no uniform rules have been identified in the evaluation of simulation results from these statistical parameters [17].

Table 7. Simulation level of the model corresponding to the R^2 index

R^2	0,9 – 1	0,7 – 0,9	0,5- 0,7	0,3 – 0,5
NSE	0,8-1,0	0,65-0,8	0,5-0,65	0,5 >
Simulation scale	Good	Fair	Average	Poor

2.3.2. Proposed methodology

Using GIS and SWAT module to solve the problem of simulating the flow of the Ca river basin. The approach is simulated as shown in the diagram below:

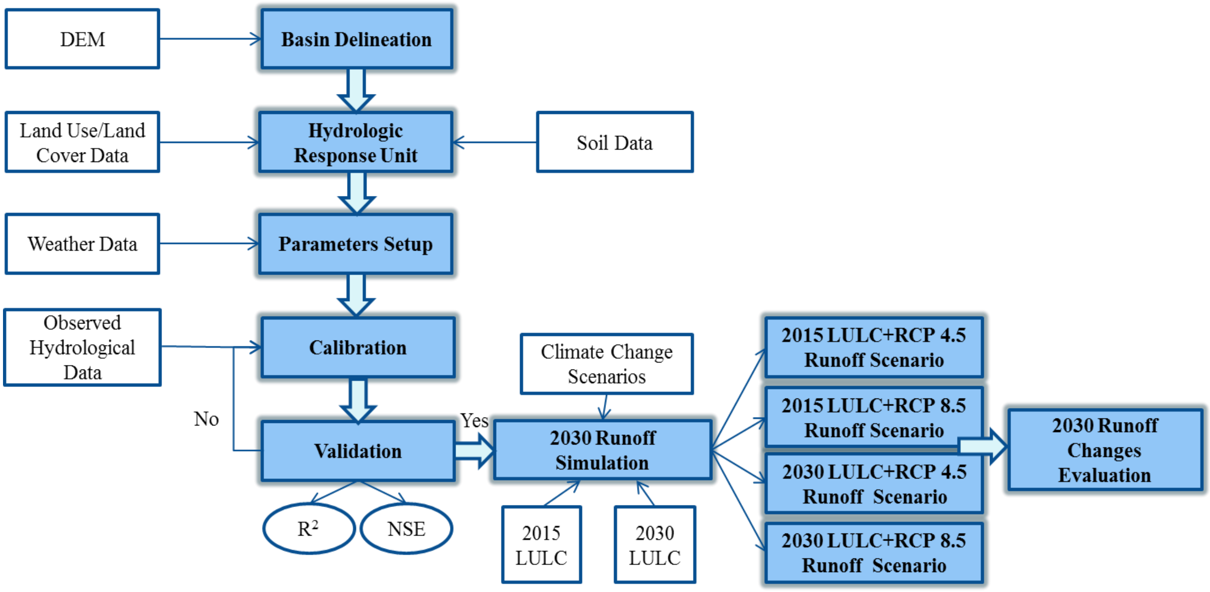


Figure 5. Research workflow

The process of simulating the flow of the Ca river basin is carried out step by step as shown in Figure 5 and is divided into two main stages. Phase 1 serves to calibrate, verify and determine the optimal set of parameters for the SWAT model, the input data is weather data for the 2010 - 2015 period and corresponds to land use data 2015. Phase 2 serves to simulate river basin flows in the year 2030, the input data is replaced by rainfall and heat data for the period 2020-2039 from the climate change scenario and 2030 land use data of the river basin area.

3. Result and discussion

3.1. Sub-basin division

The process of basin delimitation is necessary to define the river network. The research uses a method of generating DEM digital elevation maps, then determining the flow direction and accumulating flow to determine the river network and basin boundaries. Following is determining the critical area for defining the water source of the river. The smaller this limited area, the more detailed the river network that the model automatically generates. The result of basin delineation is to divide the basin into 34 sub-basins.

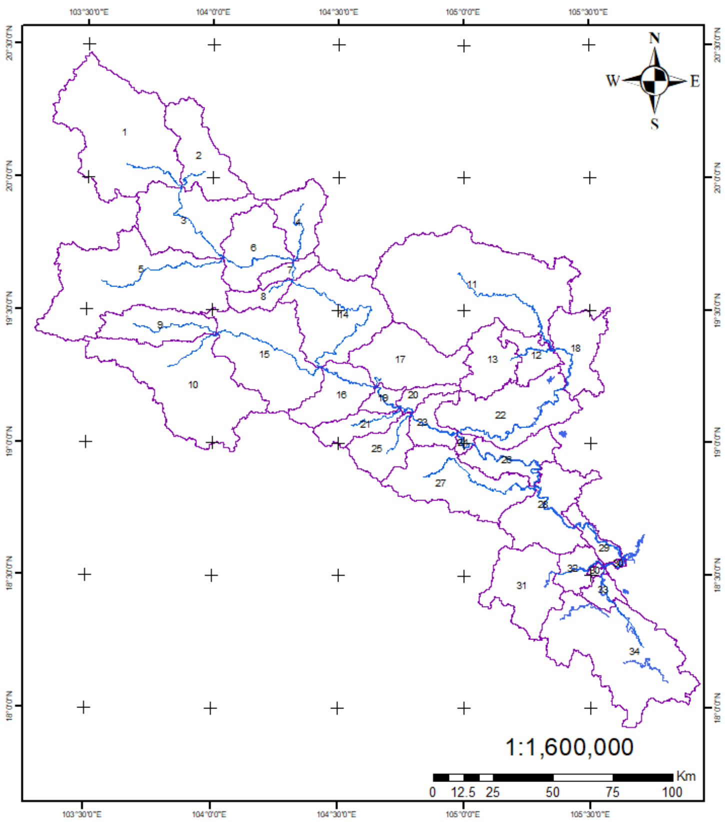
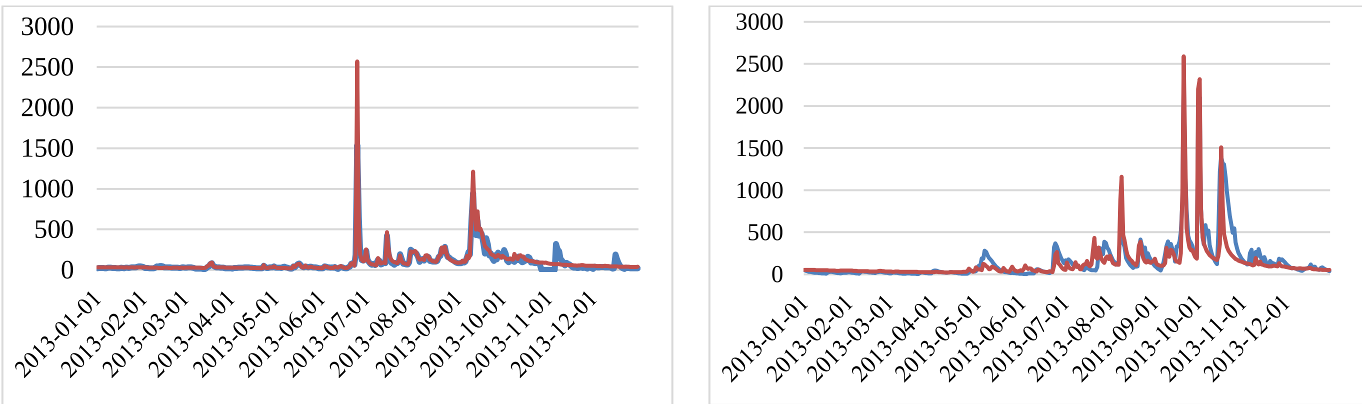


Figure 6. Division of Ca River sub-basin

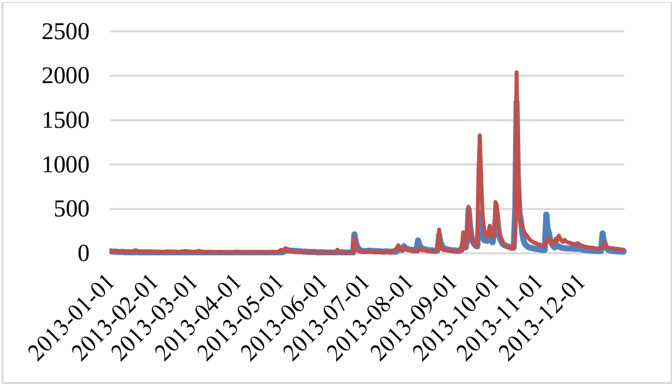
3.2. Calibration, validation and determination of parameters set

3.2.1. Test correction results

The model has set up a flow simulation for the entire Ca river basin. The simulated flow was evaluated at hydrological stations: Quy Chau, Nghia Khanh, Son Diem and Hoa Duyet. The article selects 2 years 2013 and 2015 to calibrate and validate the results. The results of the simulation model calibration for the sub-basins are shown in Figure 7.



a) b)



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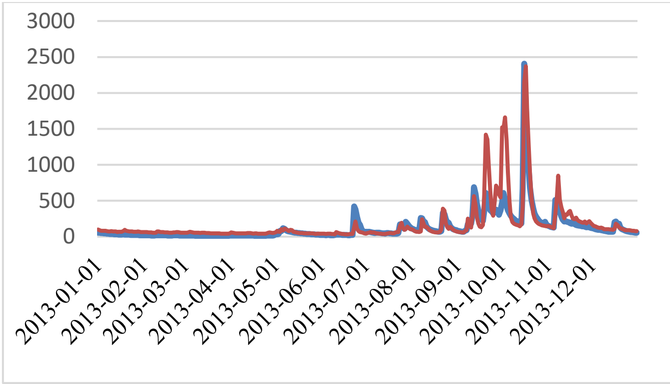
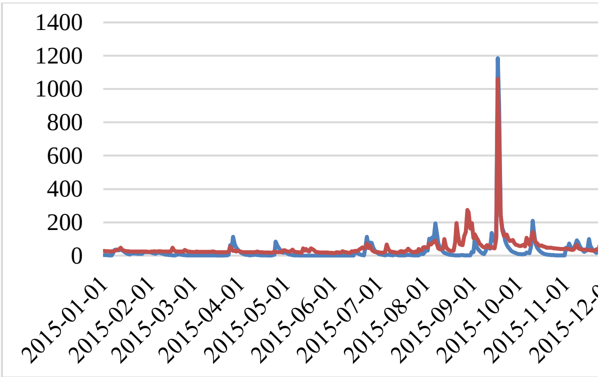


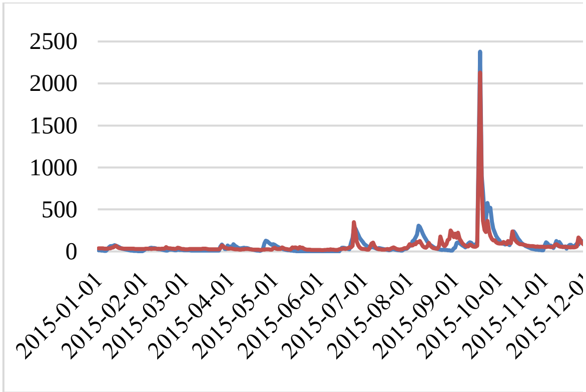
d)

Figure 7. The daily mean runoff (m^3/s) simulated and observed in 2013 at stations: a) Quy Chau, b) Nghia Khanh, c) Son Diem, d) Hoa Duyet

After keeping the same set of parameters, test the suitability of the parameters for each sub-basin with the 2015 data. The results are shown in Figure 8.



a)



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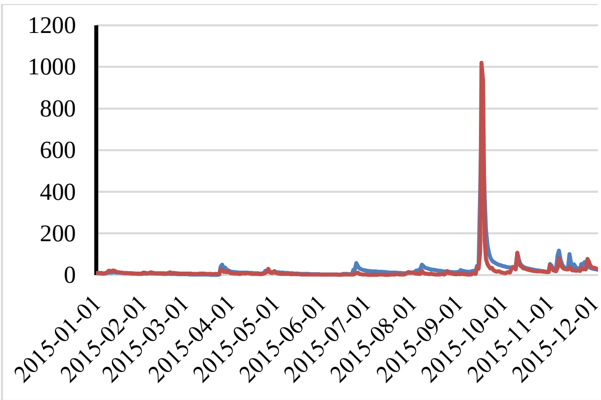

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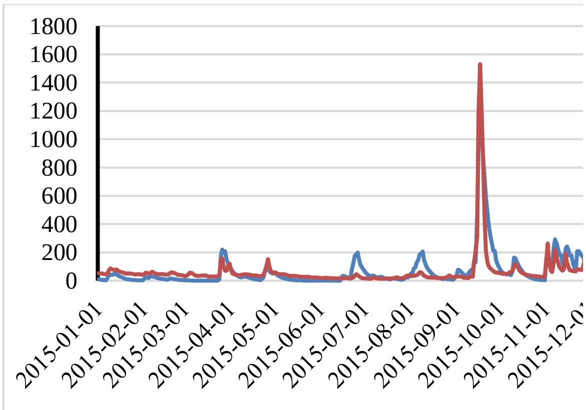


d)

Figure 8. The daily mean runoff (m^3/s) simulated and observed in 2015 at stations: a) Quy Chau, b) Nghia Khanh, c) Son Diem, d) Hoa Duyet

The article evaluates simulation results based on NSE and R^2 index. The results of the evaluation of the indicators are as follows:

Table 8. Index of calibration and validation results

Station	Calibration		Verification	
	NSE	R^2	NSE	R^2
Quy Chau	0,858	0,948	0,658	0,893
Nghia Khanh	0,773	0,899	0,807	0,94
Son Diem	0,782	0,906	0,792	0,898
Hoa Duyet	0,725	0,874	0,754	0,879

From the calculation results shown in the figure, it is shown that the simulated and observed runoff process curves have a relatively good agreement. In general, the model is capable of simulating the time variation of the flow of both seasons: the flood season and the dry season on the river, but for flood peaks, the accuracy of peak discharge is still different from each other. As small flood peaks, the simulated flow tends to be larger than measured, while for large flood peaks, simulation tends to be smaller than measured. For the evaluation results according to the NSE criteria, the results are quite good, and the R^2 criterion between simulation and real measurement has a good correlation.

Through the process of calibrating and validation, the SWAT model taking into account 4 hydrological stations Quy Chau, Nghia Khanh, Hoa Duyet and Son Diem with a series of daily flow data, the results proved SWAT model quite suitable with the correlation between the calculated and real-time flow process curves of day and month is quite good.

3.2.2. SWAT model parameter set after calibration

Evaluation of the results of calibration and model verification is quite good, the optimal set of parameters of the SWAT model for the Ca river basin is determined as shown in Table 9:

Table 9. Result of parameter set detection in SWAT model

No.	Parameter	Meaning	Value Threshold	Value
1. Surface flow parameters				
1	CN2	CN2 index corresponds to humid conditions II	35÷98	75 (forest) 80 (other lands)
2	OV_N	Manning's "n" value for overland flow.	0,01÷30	0,03÷0,05
3	SOL_K	Saturated hydraulic conductivity (mm/ hour)	0÷2000	SOL_K1:100 SOL_K2:120 SOL_K3:150
4	SOL_BD	The soil bulk density	0,9÷2,5	1,38
5	CH_K(1)	Effective hydraulic conductivity in main channel alluvium.	0÷300	0,01
6	CH_N(1)	Channel roughness coefficient (mm/hour)	0,01÷30	0,01
7	SOL_AWC	Available water capacity of the soil layer	0÷1	0,2÷0,35
8	ESCO	Soil evaporation compensation factor	0÷1	0,5

No.	Parameter	Meaning	Value Threshold	Value
9	EPCO	Plant uptake compensation factor	0÷1	0,56
10	SURLAG	Surface runoff lag coefficient	0÷24	0,1÷1
2. Flow parameters in the river				
11	CH_K(2)	The hydraulic conductivity of the river	-0,01÷500	0,01
12	CH_N(2)	River roughness coefficient (mm/hour)	-0,01÷30	0,01
3. Underground flow parameters				
13	ALPHA_BF	Baseflow alpha factor	0÷1	0,01
14	GW_DELAY	Groundwater delay time	0÷500	80÷100
15	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	0÷5000	500
16	GW_REVAP	Groundwater "revap" coefficient	0,02÷0,2	0,1
17	REVAPMN	Threshold depth of water in the shallow aquifer for. “revap” or percolation to the deep aquifer to occur	0÷1000	100

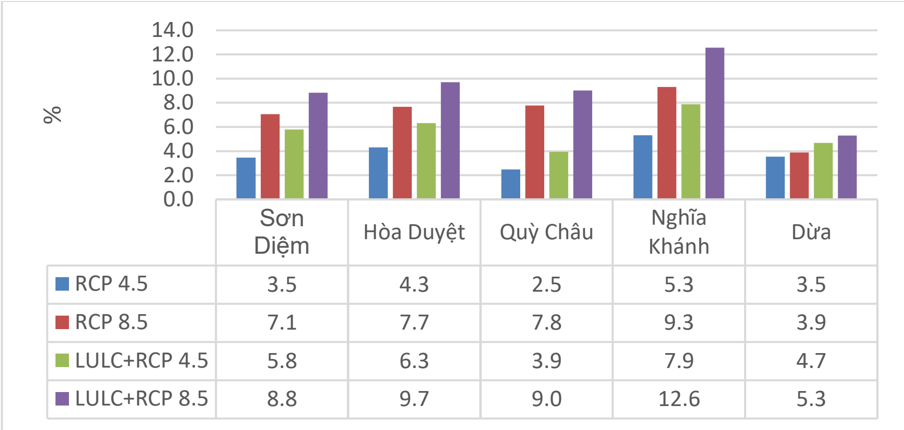
3.3. Simulation of runoff changes in the basin

After calibration and testing, the model's parameter set is used to calculate the flow for the future period from 2020 - 2039. The input data of the model including future daily rainfall and temperature at meteorological stations is taken from the day-to-day climate change scenario up to 2039 and the land-use change in the basin by the year 2030.

To assess the effects of climate change and land-use change on the Ca river basin. The research simulated flow with 4 scenarios: Climate change scenario RCP 4.5; Climate change scenario RCP 8.5; Land use change + climate change scenario RCP 4.5 and Land use change + climate change scenario RCP 8.5.

3.3.1. Annual runoff

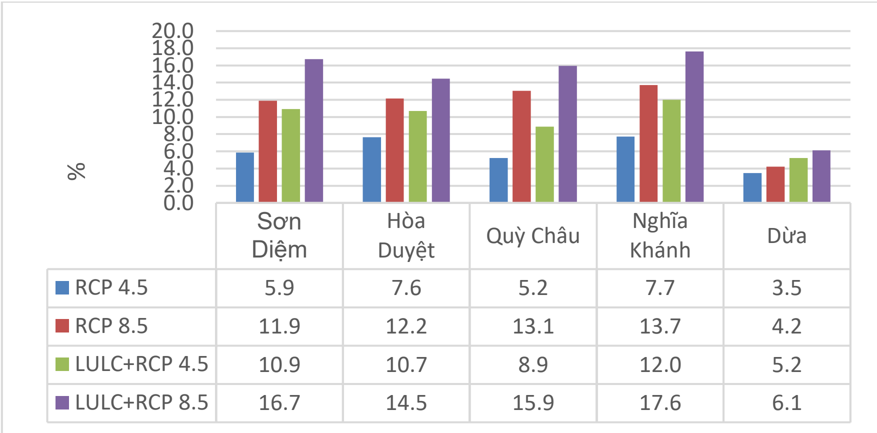
According to the 4 scenarios, the annual water flow in the whole basin tends to increase compared to the baseline period (1986-2005). The uptrend is most evident in the land-use change scenario combined with the RCP 8.5 climate change scenario with a marked increase in annual flow in the period of 2020 to 2039, the largest increase at Nghia Khanh station is 12.6% compared to the baseline period. The trend of increasing annual flow is the least at most stations in the RCP 4.5 scenario, Quy Chau station has an increase of only 2.5% in annual flow compared to the baseline period. In case the flow is affected by climate change combined with land-use change, the annual flow volume will increase more than the scenario affected by climate change. At the stations that change annual flow according to the scenarios, there is a difference but not much (less than 10%), especially at Dua station, the difference in annual flow variation of the scenarios compared to the background period is very little.



	Sơn Diệm	Hòa Duyệt	Quỳ Châu	Nghĩa Khánh	Dừa
RCP 4.5	3.5	4.3	2.5	5.3	3.5
RCP 8.5	7.1	7.7	7.8	9.3	3.9
LULC+RCP 4.5	5.8	6.3	3.9	7.9	4.7
LULC+RCP 8.5	8.8	9.7	9.0	12.6	5.3

Figure 9. Annual flow variation at stations compared to baseline at stations on Ca river basin

3.3.2. Flood season runoff



	Sơn Diệm	Hòa Duyệt	Quỳ Châu	Nghĩa Khánh	Dừa
RCP 4.5	5.9	7.6	5.2	7.7	3.5
RCP 8.5	11.9	12.2	13.1	13.7	4.2
LULC+RCP 4.5	10.9	10.7	8.9	12.0	5.2
LULC+RCP 8.5	16.7	14.5	15.9	17.6	6.1

Figure 10. Flood runoff variation at stations compared to baseline at stations in Ca river basin

As shown in Figure 10, the water flow in the months of the flood season has increased significantly compared to the baseline scenario. The largest increase in flow rate is at Nghia Khanh station at 16.7% (the average flow rate in flood season increases by 178 m^3/s). Due to the largest control area, the average flow in the flood season at Dua station increases the most. Under the scenario of climate change RCP 8.5 and land-use change, the increase in average discharge in flood season at Dua station is 211 m^3/s. However, considering the average flow rate of the flood season, the Dua station changes the least. According to the climate change scenario RCP 4.5, the result of calculating the flow rate increase at Dua station is the least (3.5%) compared to all scenarios at the stations.

The scenario of land-use change combined with climate change significantly increases the flow volume during the flood season. According to the climate change scenario RCP 8.5 and land-use change at all stations, the flow rate in flood season increases the most by more than 10%, except for Dua station, the flow rate increases only 6.1%. The dike system in the sub-basins and the process of socio-economic development have greatly changed the land use purpose, leading to the change in the area of natural forest due to the conversion of agroforestry land into urban and arid. This is one of the main reasons for the significant increase in flood season flow in the basin.

3.3.3. Dry season runoff

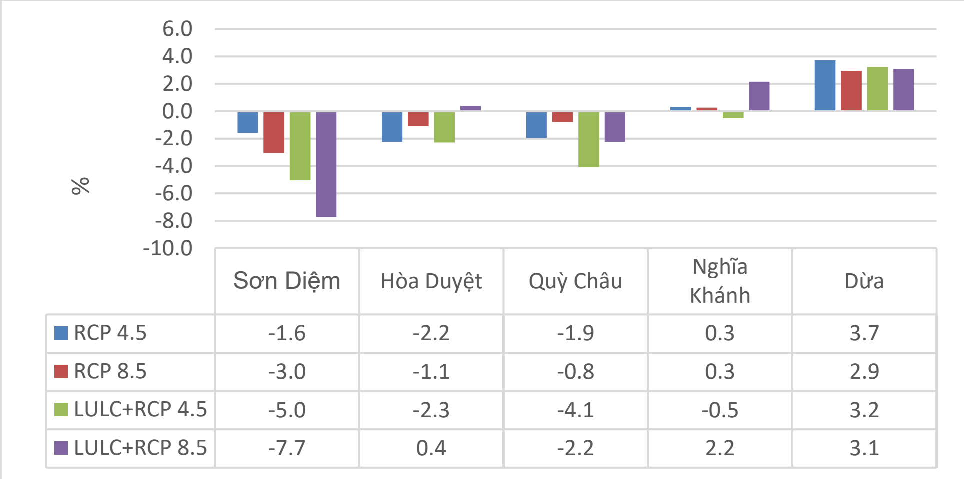


Figure 11. Variation of shallow flow at stations compared with baseline at stations on Ca river basin

Compared with the flood season, from December to June of the following year, the amount of flow in the dry season at the stations is much less in both quantity and rate. In the scenarios, most of the flows at stations tend to decrease compared to the background period, except for Dua station, which tends to increase slightly from 2-4%. This may be due to the large catchment area up to the Dua station. In this area, the rainfall varies widely between regions. The dry season flows at Son Diem station decrease the most, especially in the scenario RCP 8.5 combined with land-use change.

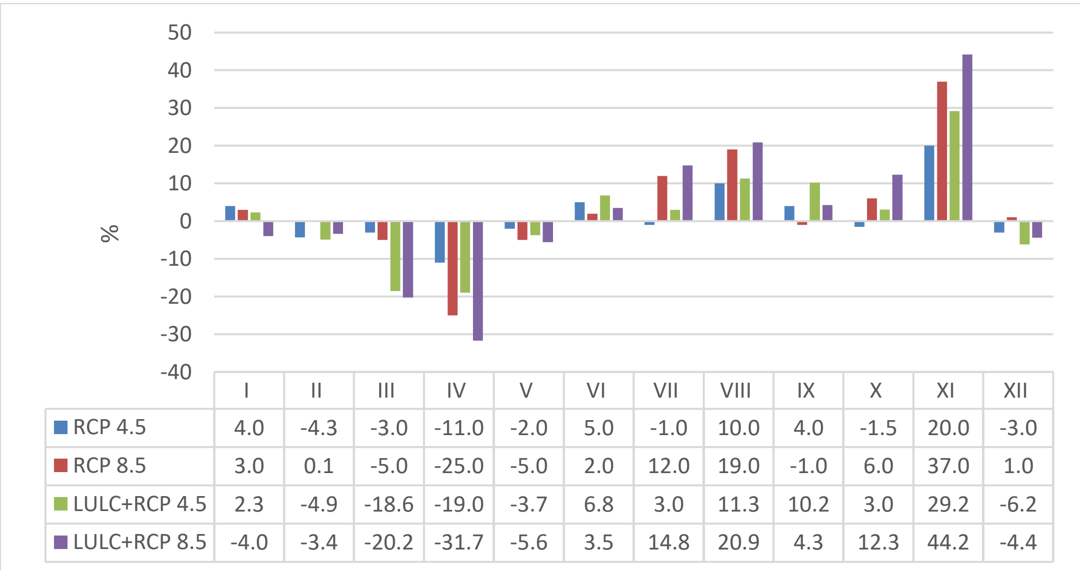
Table 10. Statistical table of changes in annual, flood and dry runoffs for the period 2020-2039 of the scenarios compared to the baseline period

Scenario	Annual runoff			Flood Season Runoff			Dry Season Runoff		
	Q (m3/s)	ΔQ (m3/s)	ΔQ (%)	Q (m3/s)	ΔQ (m3/s)	ΔQ (%)	Q (m3/s)	ΔQ (m3/s)	ΔQ (%)
Son Diem									
RCP 4.5	529.0	17.7	3.5	366.8	20.3	5.9	162.2	-2.6	-1.6
RCP 8.5	547.4	36.1	7.1	387.6	41.1	11.9	159.8	-5.0	-3.0
LULC+RCP 4.5	540.8	29.5	5.8	384.3	37.8	10.9	156.5	-8.3	-5.0
LULC+RCP 8.5	556.4	45.2	8.8	404.3	57.9	16.7	152.1	-12.7	-7.7
Hoa Duyet									
RCP 4.5	1144.0	47.1	4.3	781.3	55.4	7.6	362.7	-8.3	-2.2
RCP 8.5	1181.1	84.2	7.7	814.1	88.2	12.2	367.0	-4.0	-1.1
LULC+RCP 4.5	1166.3	69.4	6.3	803.7	77.8	10.7	362.6	-8.4	-2.3
LULC+RCP 8.5	1203.4	106.5	9.7	830.9	105.0	14.5	372.5	1.5	0.4
Quy Chau									
RCP 4.5	1042.5	25.2	2.5	662.0	32.8	5.2	380.4	-7.5	-1.9
RCP 8.5	1096.4	79.2	7.8	711.4	82.2	13.1	385.0	-3.0	-0.8

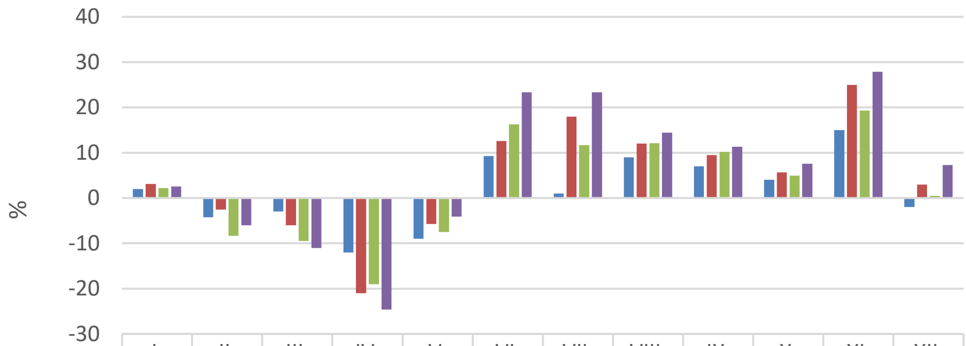
Scenario	**Annual runoff**			**Flood Season Runoff**			**Dry Season Runoff**		
	Q (m3/s)	**ΔQ (m3/s)**	**ΔQ (%)**	**Q (m3/s)**	**ΔQ (m3/s)**	**ΔQ (%)**	**Q (m3/s)**	**ΔQ (m3/s)**	**ΔQ (%)**
LULC+RCP 4.5	1057.4	40.2	3.9	685.2	56.0	8.9	372.2	-15.8	-4.1
LULC+RCP 8.5	1108.9	91.6	9.0	729.6	100.3	15.9	379.3	-8.7	-2.2
Nghia Khanh									
RCP 4.5	1579.5	79.5	5.3	1085.7	77.9	7.7	493.9	1.6	0.3
RCP 8.5	1639.5	139.5	9.3	1145.9	138.2	13.7	493.6	1.3	0.3
LULC+RCP 4.5	1618.4	118.4	7.9	1128.6	120.9	12.0	489.8	-2.5	-0.5
LULC+RCP 8.5	1688.3	188.3	12.6	1185.4	177.7	17.6	502.9	10.6	2.2
Dua									
RCP 4.5	4913.8	167.8	3.5	3575.8	119.8	3.5	1338.0	48.0	3.7
RCP 8.5	4930.4	184.4	3.9	3602.4	146.4	4.2	1328.0	38.0	2.9
LULC+RCP 4.5	4968.1	222.1	4.7	3636.3	180.3	5.2	1331.8	41.8	3.2
LULC+RCP 8.5	4997.3	251.3	5.3	3667.3	211.3	6.1	1330.0	40.0	3.1

3.3.4. Monthly runoff

Considering the period of flow variation between months at the stations, the difference is clearly shown in Figure 12. Statistical results of monthly flow according to the scenarios at the stations are shown. statistics in Table 11.

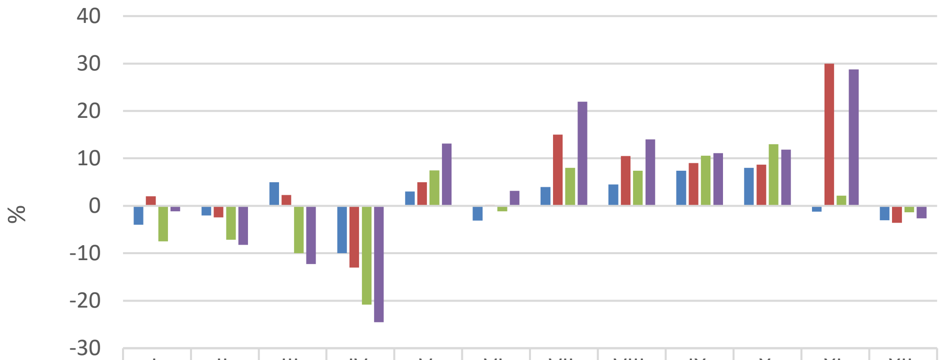


a)



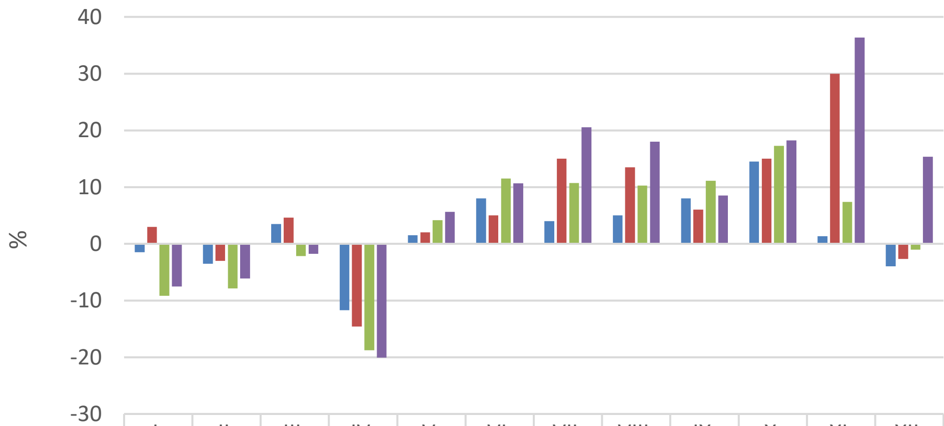
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
RCP 4.5	2.0	-4.3	-3.0	-12.0	-9.0	9.3	1.0	9.0	7.0	4.0	15.0	-2.0
RCP 8.5	3.1	-2.5	-6.0	-21.0	-5.7	12.6	18.0	12.0	9.5	5.6	25.0	3.0
LULC+RCP 4.5	2.2	-8.4	-9.5	-19.0	-7.5	16.3	11.7	12.1	10.2	4.9	19.3	0.5
LULC+RCP 8.5	2.5	-6.0	-11.0	-24.6	-4.1	23.4	23.3	14.4	11.3	7.5	27.9	7.3

b)



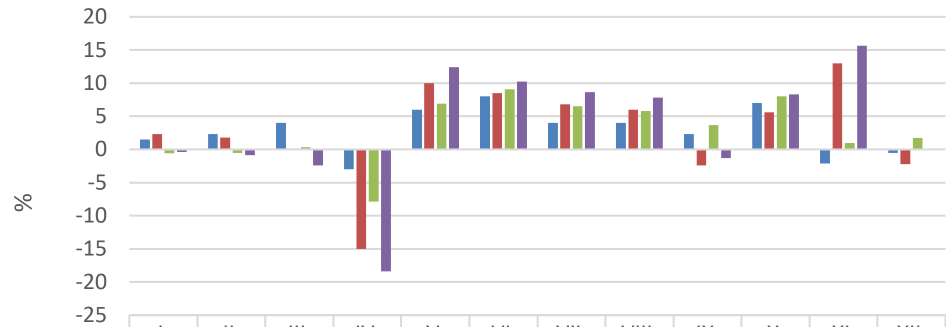
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
RCP 4.5	-4.0	-2.0	5.0	-10.0	3.0	-3.1	4.0	4.5	7.4	8.0	-1.2	-3.0
RCP 8.5	2.0	-2.4	2.3	-13.0	5.0	0.2	15.0	10.5	9.0	8.7	30.0	-3.6
LULC+RCP 4.5	-7.5	-7.1	-9.9	-20.8	7.4	-1.2	8.0	7.4	10.6	13.0	2.2	-1.4
LULC+RCP 8.5	-1.2	-8.2	-12.3	-24.5	13.1	3.2	21.9	14.0	11.1	11.9	28.8	-2.6

c)



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
RCP 4.5	-1.5	-3.5	3.5	-11.7	1.5	8.0	4.0	5.0	8.0	14.5	1.3	-4.0
RCP 8.5	3.0	-3.0	4.6	-14.6	2.0	5.0	15.0	13.5	6.0	15.0	30.0	-2.7
LULC+RCP 4.5	-9.2	-7.9	-2.2	-18.8	4.1	11.5	10.7	10.3	11.1	17.3	7.4	-1.0
LULC+RCP 8.5	-7.5	-6.1	-1.8	-20.1	5.6	10.7	20.6	18.0	8.5	18.2	36.3	15.3

d)



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
RCP 4.5	1.5	2.3	4.0	-3.0	6.0	8.0	4.0	4.0	2.3	7.0	-2.1	-0.5
RCP 8.5	2.3	1.8	0.1	-15.0	10.0	8.5	6.8	6.0	-2.4	5.6	13.0	-2.2
LULC+RCP 4.5	-0.6	-0.6	0.3	-7.9	6.9	9.1	6.5	5.8	3.7	8.0	0.9	1.7
LULC+RCP 8.5	-0.4	-0.9	-2.4	-18.4	12.4	10.2	8.7	7.8	-1.3	8.3	15.6	0.1

e)

Figure 12. Monthly runoff variation of the scenarios compared with the baseline period at stations: a) Son Diem, b) Hoa Duyet, c) Quy Chau, d) Nghia Khanh, e) Dua

At Son Diem station, the water flow in the months of the flood season is mostly increased, the months in the dry season are decreased except for June (this is the transition month between the dry season and the flood season). November is the month with the highest increase in water flow (more than 40%) and June is the month with the lowest decrease in water flow (30%) according to the land-use change scenario and RCP8.5.

At Hoa Duyet station, the water flow in the months of the flood season is mostly increased, the months in the middle of the dry season have decreased, only increasing in the first two months of the dry season and the last month of the dry season. November is the month with the highest increase in water flow (nearly 30%) and April is the month with the lowest decrease in water flow (more than 20%) according to the scenario of land-use change and RCP8.5.

At Quy Chau station, every month during the flood season, the flow increases by about 10-20%, especially in November, according to the RCP4.5 scenario, the flow increases by 30%. April has the largest flow reduction in all scenarios, ranging from 10-25%. September under the scenario RCP 8.5 also has the largest increase in water flow (30%).

At Nghia Khanh station, the water flow in the months of the flood season increases, October and November are the two months with the most uptrend. November under the scenario RCP 8.5 and land-use change have the largest increase in water flow (over 35%). In the first and middle months of the dry season, the monthly flow of the scenarios mainly decreases or increases very little, only increases at the end of the dry season (May, June) and April is the month with the most decrease in water flow (10-20%).

At Dua station, the trend of monthly flow variation is slightly different from the above stations. The monthly flow mainly tends to increase in both the flood season and the dry season. In the months of the flood season, the flow increases a lot. November under the scenario RCP 8.5 and land-use change have the largest increase in water flow (more than 15%). In the dry season months, the flow increases very little, only April has the largest decrease in water flow up to 18.1% in the scenario RCP 8.5 and land-use change.

Table 11. Average monthly flow by scenarios

Sub-basin	Scenario	Flow (m3/s)											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Son Diem	Baseline	22.2	19.9	18.0	17.5	26.5	27.5	38.9	68.7	107.4	77.7	53.6	33.3
	RCP 4.5	23.1	19.0	17.5	15.6	25.9	28.9	38.6	75.6	112	76.6	64.3	32.3
	RCP 8.5	22.9	19.9	17.1	13.1	25.2	28.1	43.6	81.8	106	82.4	73.4	33.6
	LULC+RCP 4.5	22.7	18.9	14.7	14.2	25.5	29.4	40.1	76.5	118	80.1	69.2	31.2
	LULC+RCP 8.5	21.3	19.2	14.4	11.9	25.0	28.5	44.7	83.1	112	87.3	77.2	31.8
Hoa Duyet	Baseline	50.2	45.3	38.9	40.0	61.3	60.4	35.5	83.2	235.2	224.6	147.4	74.8
	RCP 4.5	51.2	43.4	37.8	35.2	55.8	66.0	35.9	90.6	252	234	170	73.3
	RCP 8.5	51.8	44.2	36.6	31.6	57.8	68.0	41.9	93.1	258	237	184	77.1
	LULC+RCP 4.5	51.3	41.5	35.2	32.4	56.7	70.2	39.7	93.2	259	236	176	75.2
	LULC+RCP 8.5	51.5	42.6	34.6	30.2	58.8	74.5	43.8	95.2	262	242	189	80.3
Quy Chau	Baseline	50.7	44.0	38.6	37.8	63.5	89.7	91.0	137.9	168.5	144.0	87.9	63.6
	RCP 4.5	48.7	43.1	40.6	34.0	65.5	86.9	94.6	144	181	155.5	86.8	61.7
	RCP 8.5	51.7	43.0	39.5	32.9	66.7	89.9	104.6	152	184	156.5	114.3	61.3
	LULC+RCP 4.5	46.9	40.9	34.8	29.9	68.3	88.6	98.3	148	186	162.8	89.8	62.8
	LULC+RCP 8.5	50.1	40.4	33.9	28.5	71.9	92.5	110.9	157	187	161.1	113.2	62.0
Nghia Khanh	Baseline	57.7	51.4	48.4	49.5	95.0	121.0	120.5	207.1	308.8	251.7	119.6	69.4
	RCP 4.5	56.8	49.6	50.0	43.7	96.4	130.7	125	217	334	288	121	66.6
	RCP 8.5	59.4	49.9	50.6	42.2	96.9	127.1	139	235	327	289	155	67.5
	LULC+RCP 4.5	52.4	47.3	47.3	40.2	98.9	135.0	133	228	343	295	128	68.7
	LULC+RCP 8.5	53.3	48.2	47.5	39.5	100.3	134.0	145	244	335	297	163	80.0
Dua	Baseline	153	127	116	111	222	364	513	837	1038	709	359	197
	RCP 4.5	155	130	121	108	235	393	534	870	1062	759	351	196
	RCP 8.5	157	129	116	94	244	395	548	887	1013	749	406	193
	LULC+RCP 4.5	152	126	116	102	237	397	546	886	1076	766	362	200
	LULC+RCP 8.5	152	126	113	91	250	401	557	902	1025	768	415	197

4. Conclusion

The study has calibrated and verified the suitable set of parameters for the Ca river basin by SWAT model. Thenceforth, the flow simulation evaluates the impacts of climate change and land-use change on the Ca river basin flow at 5 stations Son Diem, Hoa Duyet, Quy Chau, Nghia Khanh and Dua on the Ca river basin.

In the context of climate change, in the Ca river basin, the rainfall in the rainy season tends to increase, leading to an increase in flood flows, making the flood situation in the downstream area prone to become more and more serious. In contrast, rainfall in the dry season tends to decrease, leading to a decrease in dry season flow, which makes saltwater penetrate deeper into the river.

Through the research results, it can be seen that the water source in the basin increases and the flow variation is unevenly distributed in space. The flood season is a time of significant increase. However, in the dry season, the flow tends to decrease. Especially when there is a change in land use, the intensity of the change increases.

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