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STUDY TO ASSESS THE IMPACT OF LAND USE/LAND COVER CHANGE AND CLIMATE CHANGE ON THE FLOW OF THE CA RIVER BASIN

Major: Climate Change

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The dissertation can be found in the library of:

1. Viet Nam Institute of Meteorology, Hydrology and Climate Change
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LIST OF AUTHOR’S PUBLICATIONS

1. Nguyen Thanh Bang, Doan Ha Phong (2021), *Assessment of the Impacts of Climate and Land Use/Land Cover Changes on Water Runoff in Ca River Basin in Vietnam*, Natural Volatiles and Essential Oils, Vol. 8 (5) 2021.
2. Nguyen Thanh Bang, Le Phuong Ha, Tran Dang Hung, Dao Xuan Hoang (2018), *Research on assessment of changes in land use/land cover in Ca river basin (“Nghiên cứu đánh giá biến động thảm phủ lưu vực sông Cả” in Vietnamese)*, Journal of Climate Change Science, No.07 – September, 2018.
3. Bang Nguyen Thanh, Phong Doan Ha (2022), *Spatial and Temporal Modeling of Land use/Land cover Change at the Ca River Basin (North Central Viet Nam) Using Markov Chain and Cellular Automata Approach*, Vietnam Journal of Hydro – Meteorology, No. 10 – 3/2022.

INTRODUCTION

1. Rationale

The North Central region has experienced rapid socio-economic development in the past 15 years, from 2005 onwards, with an increasing urbanization rate leading to changes in LULC: a decrease in agricultural land cover, forest cover, etc., causing river basins to face drastic changes. Changes in LULC can have both positive and negative impacts on water resources in both space and time. Climate change also aggravates climate factors such as: rapidly increasing temperature, decreasing dry season precipitation, increasing flood season precipitation, and increasing frequency and irregularity of extreme weather events. Those changes, especially in temperature and precipitation, will directly affect the water resources of the North Central region in general and the Ca river basin in particular.

Therefore, it is extremely important to simulate the change of LULC in space and time to project the future LULC scenarios of the study area. LULC scenarios combined with climate change scenarios will supplement the knowledge on the process of stream formation and quantitative assessment of the impacts of LULC change and climate change on the Ca river basin flow.

2. Aims of the study

Simulating LULC changes and projecting the future Ca river basin LULC scenarios by Markov chain analysis and Cellular Automata principles;

Quantitative assessment of the simultaneous impacts of LULC changes and climate change on future flows in the Ca river basin.

3. Objectives and scope of the study

Objectives of the study:

- 5 main LULCs affecting the flow of the Ca river basin include Forest, Agriculture, Built-up, Water and Bare area.
- Flow (year, flood season, dry season) in the Ca river basin.

- Precipitation, temperature (average, minimum, maximum daily) in 2030 according to RCP 4.5, and RCP 8.5 scenarios.

Scope of the study:

- Space extent: The Ca river basin from 18°15’50” to 20°10’30” North latitude, and 103°45'20" to 105°15'20" East longitude.
- Time range: LULC and flow data were collected for the period 2005-2015; The temperature and precipitation scenario data in 2030 is based on the Climate Change Scenario implemented by the Viet Nam Institute of Meteorology, Hydrology and Climate Change.
- Evaluation period: 2030.

4. Research questions

- Is it possible to simulate change and project future LULC for the Ca river basin by applying Markov chain analysis and Cellular Automata?
- How will the flow of the Ca river basin change in the future under the impact of LULC changes and climate change?

5. Arguments

- Markov chain analysis and Cellular Automata can simulate past LULC changes and project future scenarios through factors, constraints, and transformation rules built on the conditions of the Ca river basin.
- The simultaneous impacts of LULC changes and climate change will change the flow of the Ca river basin in the future and tend to be more severe.

6. Research methods

Data collection, statistics and synthesis method: The study will collect, synthesize and calculate the characteristic data of the study area.

Expert consultation method: It is used to remove or reduce the main LULC, as well as determine the weight for calculation.

Simulation model method:

- An integrated model of Markov chain analysis - Cellular Automata: LULC map layers are included to build a transformation matrix, thereby determining the change probability of each type of LULC and making predictions about future LULC.

- Hydrological model: Specifically, the SWAT model (Soil and Water Assessment Tool) is one of the most suitable models to simulate hydrological factors under the impact of LULC changes and climate change scenarios.

Delphi method: is applied to utilize the knowledge and opinions of experts and quantify their consensus on the issues to be consulted.

7. Scientific and practical significances

7.1. Scientific significances

- Scientific arguments, practices and simulation processes, predicting future LULC scenarios for the Ca river basin are meaningful as a scientific basis for applicability to similar basins.

- Simulation results and future LULC projections are intuitive and quantitative with 5 main classes: Forest, Agriculture, Built-up, Water, and Bare area, supplementing knowledge and reliable information about LULC of the Ca river basin and providing important input for other studies on the land, water and environmental resources of this basin.

- The results of the assessment of the simultaneous impacts of LULC changes and climate change on water resources, in particular, surface flows in the Ca river basin, contribute to scientists' understanding when researching water resources for the Ca river basin, especially in the context of climate change.

7.2. Practical significances

- The 2030 LULC scenario will support policymakers in planning, and decision-making in the most effective way on land use management in the Ca river basin and Nghe An and Ha Tinh provinces.

- The dissertation results can be used to support the overall management of water resources, especially surface flows, and provide a scientific basis for adjusting and amending legal documents on state management to mitigate the negative impacts of climate change on water resources in the study area.

8. Contributions

- The dissertation has identified the factors, constraints and successfully built the transformation rule suitable for the conditions of the Ca river basin to simulate the change of LULC and project the future LULC of the Ca river basin with 05 classes: Forest, Agriculture, Built-up, Water, Bare area.
- The dissertation has quantitatively assessed the change in the flow of the Ca river basin under the simultaneous impact of climate change and with or without changes in LULC.

CHAPTER 1: OVERVIEW OF IMPACT ASSESSMENT OF LULC CHANGE AND CLIMATE CHANGE ON THE FLOW OF THE CA RIVER BASIN

1.2. Review of studies on the simulation of LULC changes

1.2.1. Foreign studies on simulation of LULC changes

In 2011, the study "Assessment and prediction of land use changes affecting urban areas by multi-spectral satellite images" by Zanjan University, Iran.

The study "Modeling and analyzing watershed fluctuations using the Cellular Automata - Markov model" of the Centre for Ocean, River, Atmosphere & Land Sciences (CORAL) used the Cellular Automata (CA) - Markov model and predict future LULC scenarios.

The Center for Environmental Resource Science of Hubei University studied “The Markov-Kalman model for forecasting land use change in the XiuHe basin, China”.

In 2015, a collaborative study between two universities Payame Noor and the Isfahan University of Technology of Iran "Modelling land cover/land use changes by combining Markov chain and Cellular Automata Markov model" evaluated this model as essential for land use planning and management.

Griselda Vázquez-Quintero et al. (Mexico) 2016 studied "Detecting and predicting forest land changes using Markov chain and Cellular Automata models”

1.2.2. Domestic studies on simulation of LULC changes

Pham Van Cu et al. (2006) conducted the topic "Using multi-temporal remote sensing data to assess the change in vegetation index of the status cover and its relationship with land use change in Thai Binh province".

The topic "Application of GIS and remote sensing in the establishment of vegetation status map in 2008 at the scale of 1/50.000 in Ky Anh district, Ha Tinh province" by Nguyen Quang Tuan, Tran Van No, Do Thi Viet Huong, Hue University.

In the study "Application of remote sensing and GIS to establish land cover map of Chan May area, Phu Loc district, Thua Thien Hue province" the author used the maximum likelihood classification method with Landsat TM image data combined with field samples to distinguish 13 types of land covers with relatively high accuracy.

In the topic "Using MODIS satellite image data to study crop seasons, mapping the current status and change of land cover in the Red River Delta in the period 2008 - 2010", the author has classified the cover based on the NDVI dataset by the maximum likelihood classification.

1.3. Review of studies on impact assessment of LULC on river basin flows

1.3.1. Foreign studies on impact assessment of LULC on river basin flows

In 1987, Peck A.J. and Williamson D.R. studied the effects of deforestation on groundwater.

For tropical watersheds, Costa (2003) found that if the forest-to-agricultural conversion rate is about 30% of the basin area, the average annual discharge increases by about 24%. Farley (2005) has shown that when grasslands and shrublands are converted to plantations, annual runoff decreases by 44% and 31% respectively.

According to Zhang (2007), if the indicators of forest land status (structure, soil type, topography...) affect the flow of the basin, the spatial distribution of forests also has an important influence, especially when forests are distributed in areas that are directly connected to the water storage system of the basin such as rivers, streams, lakes...

According to M. Guardiola (2010), the replacement of indigenous forests with rubber forests in Nam Keng (China) and Pang Khum (Northern Thailand) has increased evapotranspiration, thereby reducing runoff as well as the amount of water stored in the basin.

1.3.2. Domestic studies on impact assessment of LULC on river basin flows

In 2003, Tran Thuc and Huynh Thi Lan Huong used the SWAT model to calculate and evaluate the impact of land use change on the flow of the Tra Khuc river basin. The authors clearly stated the role of forests in flow regulation and flood control.

Also in 2003, Pham Thi Huong Lan (University of Irrigation) reviewed and introduced several hydrological models such as HEC1, SSARR, HEC-HMS, MIKE BASIN, USDAHL, RAINRUN etc. and proposed to use the SWAT model to solve water resource management problems in river basins to evaluate the efficiency and improve the management of the basin.

In 2009, a case study by Nguyen Y Nhu, and Nguyen Thanh Son on "Application of the SWAT model to investigate the effects of land use scenarios on the flow of the Ben Hai river basin" showed land use change is a factor that greatly affects the change of components in the hydrological process in both space and time, causing changes in the flow value.

In 2013, Nguyen Thi Tinh Au, Nguyen Duy Liem, and Nguyen Kim Loi applied the SWAT model and GIS technology to evaluate the flow in the Dak Bla river basin.

1.4. Review of studies on impact assessment of climate change on river basin flows

1.4.1. Foreign studies on impact assessment of climate change on river basin flows

Manoj Jha in 2004 studied the impact of climate change on flows in the upper Mississippi River using regional climate models combined with SWAT hydrological models.

Karim C. Abbaspour 2009 studied the impact of climate change on water resources in Iran. The study used a SWAT model calibrated for the period 1980 to 2002 using daily and annual monitoring data.

Joshua Kiprotich Kibii et al. (2020) also used the SWAT model to assess the impact of land use change and climate change on the basin, leading to changes in river flows and reservoir water levels in Eldorer Kenya.

1.4.2. Domestic studies on impact assessment of climate change on river basin flows

In 2012, Nguyen Ky Phung in the study "Application of the SWAT model to assess the impact of climate change on the flow of the Dong Nai river basin" applied the SWAT model to simulate the change of flow in the Dong Nai river basin in the context of climate change.

In 2015, Nguyen Hoang Minh assessed the impact of climate change on the water resources of the Lo river basin. The study used MIKE NAM and MIKE BASIN models to calculate the flow and water balance of the Lo river basin system.

In 2013, Huynh Thi Lan Huong assessed the impact of climate change on flows in the Ba river basin. In 2021, author Huynh Thi

Lan Huong also assessed the impact of climate change on the distribution of seasonal flows in the Ca river basin.

CHƯƠNG 2: THEORETICAL BASIS, RESEARCH METHODS FOR IMPACT ASSESSMENT OF LULC CHANGES AND CLIMATE CHANGE ON THE FLOW OF THE CA RIVER BASIN

2.1. Theoretical basis for impact assessment of LULC changes and climate change on river basin flows

2.1.1. Theoretical basis for LULC simulation based on Markov chain and Cellular Automata

Markov process is a special random moving from one state to another state at each time step via the use of transition probability matrices (in this case is Ca river basin system). The transition probability matrix is calculated by assuming that probability distribution over the next state only depends on the current state, but not on previous ones. The transition matrix can be presented as follows:

$$P = (P_{ij}) = \begin{vmatrix} P_{11} P_{12} \dots P_{1n} \\ P_{21} P_{22} \dots P_{2n} \\ \dots \\ P_{n1} P_{n2} \dots P_{nn} \end{vmatrix} \quad 0 \le P_{ij} \le 1 \qquad \sum_{i=1}^{n} P_{ij} = 1 \qquad [2.3]$$

Where *P* is the transition probability matrix, *Pij* is the probability of the i^{th} LULC changing to j^{th} LULC from the initial year to the illation year and *n* is the number of LULC classes. The dissertation uses the Markov chain to calculate the conversion ability between 5 LULC classes (Table 1) in 2005, 2010 and 2015 to predict LULC by 2030, and is presented in the form of a matrix as follows:

$$\begin{bmatrix} P'r \\ P'nn \\ P'nc \\ P'dt \\ P'xd \end{bmatrix} = \begin{pmatrix} Pr,r & \cdots & Pr,xd \\ \vdots & \ddots & \vdots \\ Pxd,r & \cdots & Pxd,xd \end{pmatrix} * \begin{bmatrix} Pr \\ Pnn \\ Pnc \\ Pdt \\ Pxd \end{bmatrix} \quad [2.4]$$

Where: *r* is Forest, *nn* is Agriculture, *nc* is Water, *dt* is Bare area, *xd* is Built-up class, *P'* is the probability at time *t+1*, *P* is the probability at the beginning of the forecast.

The Cellular Automata model provides spatial projections with transition probabilities and the current state of the LULC layers as input. LULC change modelling using the CA technique gives explicit spatial modelling results based on defined transition rules. A simple CA includes the following components: (1) a grid space L on which the model operates, (2) cell states Q in the grid space, (3) transition rules f, which determine the spatial dynamic process, (4) status of the neighbourhood Δ that influences the central cell. Hence, the spatiotemporal changes of state in a system can be described as:

$$A = [L, Q, \Delta, f] \quad [2.5]$$

The state of cell *Q* depends on its neighbourhood Δ (the surrounding cells) and the corresponding *f* transition rules. The corresponding transition rule *f* can be a deterministic or random function, expressed as:

$$a_{t+1}^{s} = f(a_t^{s-r}, \dots, a_t^{s}, \dots, a_t^{s+r}) \ [2.6]$$

Where, a_t^s is the state of cell *s* at time *t*, *r* is the interval of cells adjacent to cell *s*, and *f* lis a transition function representing the state transition rule. The set of values of $\{a_t^s | \forall s \in I\}$ is called the configuration of the CA at time *t*.

2.1.2. Theoretical basis for quantitative assessment of the impact of LULC changes and climate change on river basin flows

The SWAT model has proven to be an effective tool for assessing the impact of LULC on a watershed system. SWAT models the water cycle based on the following water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \ [2.8]$$

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

2.2. Research methods for impact assessment of LULC changes and climate change on the flow of the Ca river basin

2.2.1. Research framework

With the presented scientific basis, the dissertation proposes a methodology to simulate LULC changes and climate change to flow, including 2 main stages: building a simulation model to predict the future LULC using an integrated model of Markov - Cellular Automata and building a simulation model of the impact of LULC changes and climate change on flow using the SWAT model.

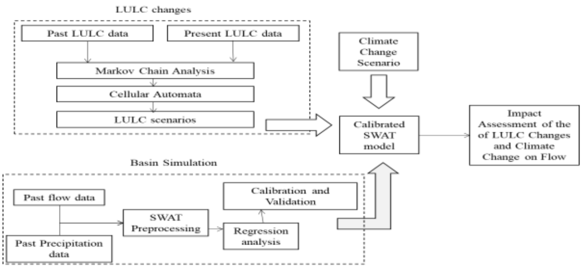


Figure 2.6. Research framework for simulating LULC changes and climate change to flow

2.2.2. The process of simulating LULC changes and projecting future LULC scenarios

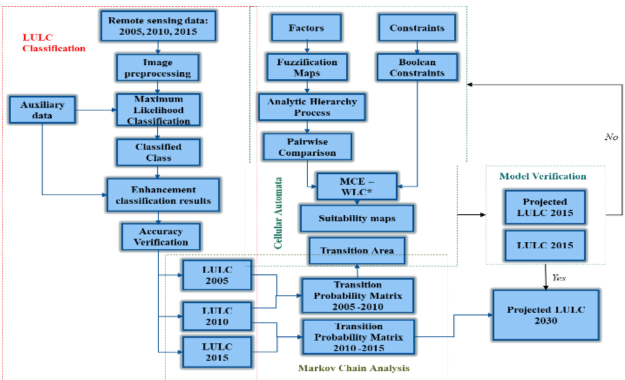


Figure 2.7. The process of simulating LULC changes

2.2.4. The process of simulating basin flow under the impact of LULC changes and climate change

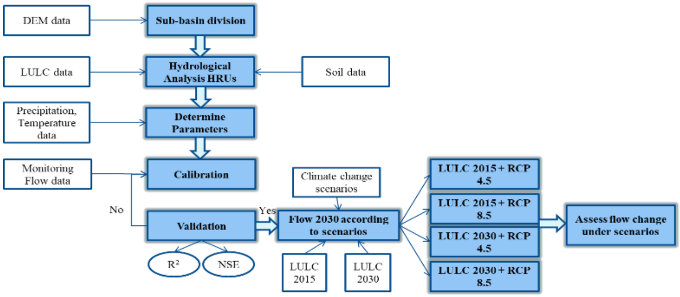


Figure 2.8. The process of simulating the impact of LULC changes and climate change on the flow using the SWAT model

CHƯƠNG 3: IMPACT ASSESSMENT OF LULC CHANGES AND CLIMATE CHANGE ON THE FLOW OF THE CA RIVER BASIN

3.1. Simulation of spatial and temporal changes of LULC for the Ca river basin

3.1.1. LULC classification

Landsat images were collected according to Table 2 and classified using the maximum likelihood classification (MLC). The results of the validation for the years 2005, 2010, and 2015 are shown in Table 3.1.

Table 3.1. Accuracy assessment of the LULC classification

LULC classes	2005		2010		2015	
	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)
Agriculture	68.40	74.28	77.77	80.00	83.33	85.71
Bare Area	74.19	65.71	84.85	80.00	86.11	88.57
Forest	78.38	82.86	80.00	91.43	91.67	94.29
Water	87.88	82.86	94.44	97.14	100	100
Built-up	77.78	80.00	93.33	80.00	93.75	85.71
Overall CA	77.14		85.71		90.86	
Kappa Index	0.7143		0.8214		0.8857	

3.1.2. Calculate the transition probability matrix, the transition area matrix

These matrices are calculated by cross-comparing between pairs of LULC maps (2005-2010 and 2010-2015).

Table 3.2. Transition probability matrix for the period 2005 - 2010 and 2010 - 2015 in the Ca river basin (%)

		Agriculture	Bare Area	Forest	Water	Built-up
2005 - 2010	**Agriculture**	42.98	7.14	38.58	1.76	9.54
	Bare Area	35.74	17.35	43.15	0.39	3.37
	Forest	22.53	5.97	70.52	0.37	0.61
	Water	24.07	0.63	7.92	63.22	4.15
	Built-up	18.75	3.15	5.71	1.96	70.43
2010 - 2015	**Agriculture**	63.89	4.26	21.69	1.20	8.96
	Bare Area	25.76	66.40	4.70	0.38	2.75
	Forest	24.81	3.34	70.76	0.47	0.63
	Water	15.00	0	0	85.00	0
	Built-up	0	0	0.01	15.97	84.02

3.1.3. Determine the factors and constraints to simulate spatial changes of LULC

The selection of factors and constraints affecting the spatial change of LULC completely depends on the natural, and socio-economic conditions of the studied river basin and consultation with experts via the Delphi method.

Table 3.6. Level of agreement of experts round 3rd Delphi

Factors & Constraints	**Level of agreement of experts**							**Median M_d**	**Quartile Deviation Q**	**Average q_i**	**Standard deviation**
	1	**2**	**3**	**4**	**5**	**6**	**7**				
Physiological factors											
DEM	4	4	5	5	4	5	5	5	0.5	4.6	0.53
Slope	4	5	5	4	5	5	4	5	0.5	4.6	0.53
Topography	3	4	3	3	3	3	3	3	0	3.1	0.38
Human factors											
Road	5	5	4	4	5	5	5	5	0.5	4.7	0.49
River	4	5	5	4	5	5	5	5	0.5	4.7	0.49
Planning	3	4	4	3	3	3	3	3	0.5	3.3	0.49

area										
Constraints										
Conservation area	4	5	5	5	5	5	5	5	0	4.9	0.38
Built-up area	5	5	5	4	5	5	5	5	0	4.9	0.38

3.1.4. Suitability maps

The constraints and factors were standardized into a Boolean (0 and 1) character and a continuous scale of suitability from 0 (least suitable) to 255 (most suitable), respectively (Table 3.7).

Table 3.7. Standardization of factors by Fuzzy module

Class	Factors	Functions	Control Points
Agriculture	**Slope**	J-shaped	0 degree highest suitability 0-20 degrees decreasing suitability >20 degrees no suitability
	DEM	J-shaped	0 m highest suitability 0-350 m decreasing suitability >350 m no suitability
	Distance to rivers	Sigmoidal	<1.5 km highest suitability 1.5-5.5 km decreasing suitability >5.5 km no suitability
	Distance to main roads	J-shaped	<0.2 km highest suitability 0.2-5 km decreasing suitability >5 km no suitability
Water	**Slope**	J-shaped	0 degree highest suitability 0-15 degrees decreasing suitability >15 degrees no suitability
	DEM	J-shaped	0 m highest suitability 0-300 m decreasing suitability >300 m no suitability
	Distance to rivers	Sigmoidal	<1 km highest suitability 1-5 km decreasing suitability >5 km no suitability
Built-up	**Slope**	J-shaped	0 degree highest suitability 0-20 degrees decreasing suitability >20 degrees no suitability
	DEM	J-shaped	0 m highest suitability 0-150 m decreasing suitability >150 m no suitability
	Distance to	Sigmoidal	<1.5 km highest suitability

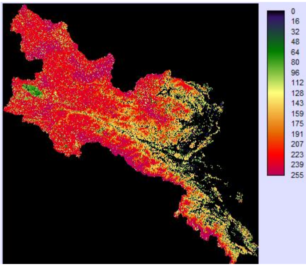
	rivers		1.5-5.5 km decreasing suitability >5.5 km no suitability
	Distance to main roads	J-shaped	<0.2 km highest suitability 0.2-5 km decreasing suitability >5 km no suitability
Forest	**Slope**	Sigmoidal	<5 degrees no suitability 5-18 degrees increasing suitability >18 degrees highest suitability
	DEM	Sigmoidal	<150 m no suitability 150-700 m increasing suitability >700 m highest suitability
	Distance to main roads	Sigmoidal	<1 km no suitability 1-10 km increasing suitability >10 km highest suitability
Bare area	**Slope**	Sigmoidal	<20 degrees no suitability 20-40 degrees increasing suitability >40 degrees highest suitability
	DEM	Sigmoidal	<1300 m no suitability 1300-1700 m increasing suitability >1700 m no suitability
	Distance to main roads	Sigmoidal	<1 km no suitability 1-10 km increasing suitability >10 km highest suitability

Next, the factors are assessed for their importance for each type of LULC class (Table 3.8).

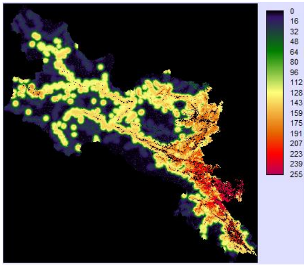
Table 3.8. Weighted values of factors for each class

Factors	**Forest**	**Agriculture**	**Built-up**	**Water**	**Bare area**
Slope	0.5917	0.1740	0.5232	0.3874	0.1571
DEM	0.3332	0.2696	0.2976	0.1692	0.2493
Distance to main roads	0.0751	0.0795	0.1222		0.5936
Distance to rivers		0.4768	0.0570	0.4434	
Consistency ratio	0.01	0.02	0.03	0.02	0.05

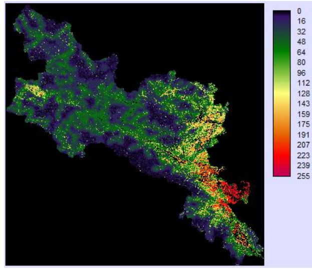
The MCE-WLC Multi-Criteria Assessment is used to combine information from multiple criteria into a single indicator.



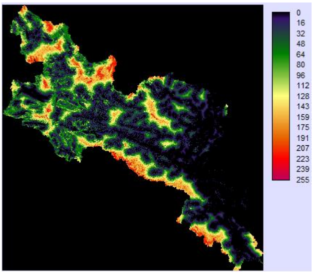
a) Forest



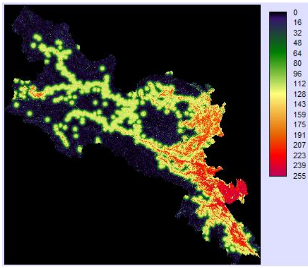
b) Agriculture



c) Built-up



e) Bare area



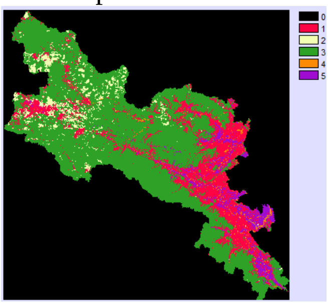
d) Water

Figure 3.2. Suitability maps for various LULC categories (map created using TerrSet);

**0 to 255 shows the scale from unsuitability to high suitability)*

3.1.5. Simulation of LULC of the Ca river basin in 2015

In the next step, the CA-Markov module is used to simulate the LULC map of the Ca river basin in 2015.



Simulation map LULC 2015 at *i*=15

1 Agriculture
2 Bare area
3 Forest
4 Water
5 Built-up

Figure 3.3. Simulation map of 2015 LULC with different numbers of iterations via CA-Markov

3.1.6. Validate simulation results

The results of the LULC simulation of the Ca river basin in 2015 are compared with the LULC map of the Ca river basin in 2015 built from remote sensing images, field data and land use map in 2015.

Table 3.9. Statistics of Kappa coefficient of simulation results

Hệ số Kappa	***i* = 5**	***i* = 10**	***i* = 15**
K_{no}	0.9507	0.9349	0.9119
$K_{location}$	0.9178	0.8887	0.8451
$K_{locationStrata}$	0.9178	0.8887	0.8451
$K_{standard}$	0.9156	0.8865	0.8420

3.1.7. Projected LULC in the Ca river basin in 2030

Then, the CA-Markov model is used with verified parameters to project the LULC of the Ca river basin in 2030.

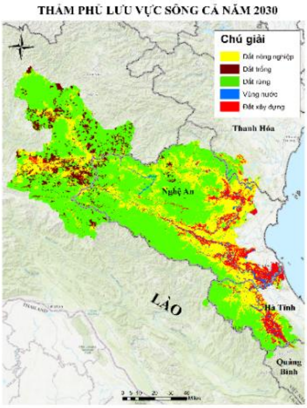


Figure 3.4. LULC map of Ca river basin projected in 2030

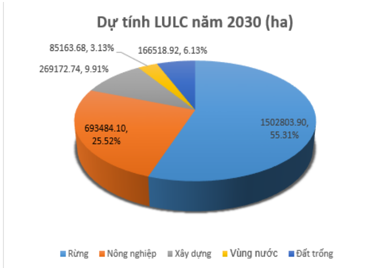


Figure 3.5. Area (ha) and distribution rate (%) for each LULC class of the Ca river basin in 2030

3.2. Impact assessment of LULC changes and climate change on the flow of the Ca river basin

3.2.4. Calibration, verification of simulation parameters

To test the model's ability, calibration and verification are carried out. The results of the calibration are shown below:

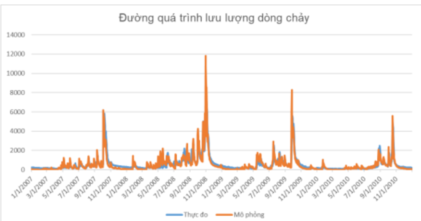


Figure 3.12. Yen Thuong

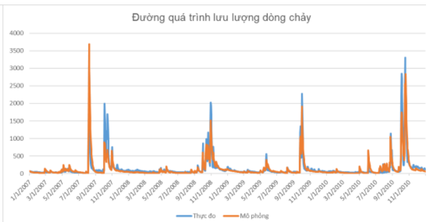


Figure 3.13. Hoa Duyet

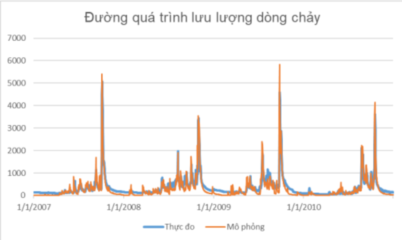


Figure 3.14. Dua

Figure 3.15. Quy Chau

Average daily flow calculated and observed in 2007 - 2010

Figure 3.16. Son Diem

Maintain the same set of parameters for verification with 2011-2014 data. The results are shown in Figure 3.17 to Figure 3.21:

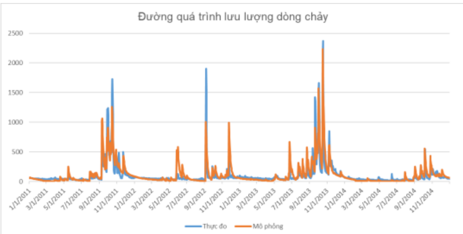


Figure 3.17. Hoa Duyet

Figure 3.18. Yen Thuong

Figure 3.19. Dua

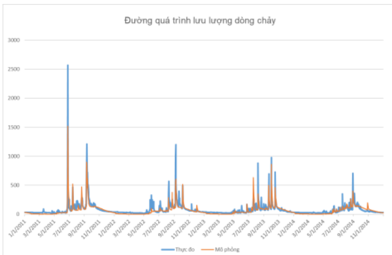


Figure 3.20. Quy Chau

Average daily flow calculated and observed in 2007 - 2010

Figure 3.21. Son Diem

The thesis evaluates the simulation results based on the Nash index.

Table 3.10. Assessment results of calibration and verification

Station	**Time**		**Nash**	
	Calibration	Verification	Calibration	Verification
Yen Thuong	2007-2010	2011-2014	0.73	0.76
Hoa Duyet	2007-2010	2011-2014	0.85	0.76
Dua	2007-2010	2011-2014	0.75	0.76
Quy Chau	2007-2010	2011-2014	0.73	0.73
Son Diem	2007-2010	2011-2014	0.74	0.72

3.2.6. Simulation of the Ca river basin flow under the impact of LULC changes and climate change

To assess the impact of climate change and LULC changes on the Ca river basin, the dissertation simulates the flow with 4 scenarios: Climate change scenario RCP 4.5; Climate change scenario RCP 8.5; LULC changes + climate change scenario RCP 4.5; LULC changes + climate change scenario RCP 8.5.

Table 3.14. Statistics on changes in annual, flood and dry flows in the period of 2020-2039 compared to the baseline period (1986-2005)

Kịch bản	Annual Flow			Flood Flow			Dry Flow		
	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
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

Table 3.14. Average monthly flow by scenarios

Station	**Scenarios**	**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

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The dissertation has met the objectives:

1. Research on a scientific and practical basis to develop a method to assess the impact of LULC changes on the Ca river basin flow in the context of climate change.

From the review of domestic and foreign documents, the dissertation has selected an appropriate method to assess the impact of LULC changes and climate change on the surface flow of the Ca river basin: Markov Chain analysis, Cellular Automata model and SWAT model.

The dissertation also clarified the scientific basis for building a method that combines remote sensing, field investigation, Delphi consultation and modelling to assess the impact of LULC changes and climate change on surface flow by the natural, socio-economic conditions of the Ca river basin.

The dissertation has proposed a process to assess the impact of the LULC changes and climate change on the surface flow of the Ca river basin. Through the Delphi method, the dissertation has identified the factors and constraints affecting the simulation of LULC changes, namely: elevation, slope, distance to roads, distance to river and constraints: water area – built-up - bare area.

2. About simulating LULC change and predicting future LULC scenarios for the Ca river basin using the Markov chain analysis method and Cellular Automata model

The dissertation has proved the feasibility of the Markov chain method and Cellular Automata to simulate LULC changes in the Ca river basin up to 2030 by development orientations in the fields of land management, forest protection, and land use change in the context of climate change.

The study also built the transition rule *f* and the calibration model with the parameters suitable for the conditions of the study area.

Validation results by the Kappa coefficient between LULC maps established from remote sensing images and simulation also show that the model has good reliability.

The results of the dissertation show that the LULC in the Ca river basin has been, is and will continue to change. Especially, in 2030 the area of forest land will still tend to decrease slightly and turn into other types of land such as agricultural land, construction land, and bare land. Specifically from 2015 to 2030: forest area decreased by 17.71%, agricultural land, construction, water area and bare land increased by 6.70%, 4.17%, 2.27%, and 4.55%, respectively. This also accurately reflects current socio-economic development trends: urbanization, agricultural land expansion, and deforestation...

Quantitative, spatial and temporal results of the LULC change scenario in the Ca river basin outside the country will greatly assist in the assessment of impacts with other natural factors, especially under climate change conditions.

3. About quantitative assessment of impacts of LULC changes and climate change on Ca river basin flows.

The dissertation has succeeded in calibrating, verifying and thereby determining the SWAT model parameters suitable for the Ca river basin.

The dissertation has applied the process of assessing the impact of LULC changes on the surface flow of the Ca river basin under climate change conditions at 5 stations Son Diem, Hoa Duyet, Quy Chau, Nghia Khanh, and Dua.

Through simulation results, it can be seen that the Ca river basin is facing major changes from climate change. Water sources in the Ca river basin tend to increase and the flow variation is unevenly distributed in space and time. Increased rainfall in the rainy season leads to an increase in flood flows, making flooding in the downstream area likely to become more and more serious. On the contrary, the rainfall in the dry season tends to decrease, leading to a decrease in the dry season flow, causing salt to penetrate deeper into the river. Under the impact of LULC changes combined with climate change, annual discharge at 5 stations of Son Diem, Hoa Duyet, Quy Chau, Nghia Khanh, and Dua in the Ca river basin increases in all 4 scenarios. The largest increase is 4997.3 m^3/s at Dua station under scenario LULC+ RCP8.5. Regarding the flow in the flood season and dry season at the stations, there is an increasing trend in the flood season and a decrease in the dry season. In particular, when the impact of LULC changes is added, the magnitude of these changes becomes even more obvious and severe.

Limitations and recommendations

Limitations:

The selected factors and constraints only reflect part of the influence of natural, socio-economic conditions on the change of LULC in the Ca river basin. Although the LULC simulation results have relatively high accuracy, it is confirmed that some other factors and constraints can affect the results and enhance the simulation accuracy.

- Some input data to simulate the flow of the Ca river basin have not reached the desired detail such as soil data, topographic data, flow data, and hydrological data of Laos territory is still limited, leading to the simulation results at some stations have not reached high accuracy. In addition, when assessing future flow changes, the dissertation has not considered the factors of reservoir regulation and water use in the Ca river basin.
- The assessment of changes in the flow of the Ca River basin in the future is under the combined impact of LULC changes and climate change, but does not consider the interactions between them such as climate change can also change the cover, although, in a short time, these changes are not large, but confirmed yes.

Recommendations:

- The scientific basis, methodology and process of assessing the impact of LULC changes and climate change on the flow are completely applicable to other basins outside the Ca river basin.
- The factors, constraints, and transition rules *f* can be inherited with appropriate parameters adjusted to apply simulation of LULC changes in other river basins.
- The SWAT model parameter set can also be inherited with adjustments to quantitatively assess the impact of LULC changes and climate change on the flows of other river basins.
- The results of quantitative simulations of the impacts of LULC changes and climate change on the Ca river basin flow can be used to assess other impacts.