Predicting land cover changes in Xuan Lien Nature Reserve, Thanh Hoa province, Vietnam

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Dự báo biến động lớp phủ mặt đất tại Khu Bảo tồn thiên nhiên Xuân Liên, tỉnh Thanh Hóa, Việt Nam

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ABSTRACT

The research was carried out in Xuan Lien Nature Reserve, which is a specially protected natural area and one of the five main centers of biodiversity in Vietnam. The work is aimed at analyzing changes and predicting the state of land cover in Xuan Lien Reserve. For these purposes, Landsat-7, Landsat-5 and Landsat-8 images obtained in 2000, 2010 and 2020 were studied. Normalized Difference Vegetation Index (NDVI) method was used to isolate the vegetation cover on the land areas, and Normalized Difference Water Index (NDWI) method was used. The results of the study indicate that the vegetation on the land is transforming in Xuan Lien Reserve. The area of broadleaf forests decreased by 6.2% from 2000 to 2020, and the area of wetlands increased by 4.9% due to the construction of Cua Dat hydroelectric complex in Reserve. The model of Markov chains and cellular automata was used to predict the state of the allocated lands in the study area. The predicted results of the model have been successfully confirmed using the agreement indices. According to the results of the predicted, by 2035 the area of broadleaf forests and wetlands will increase to 86.3% and 7.4%. The change in the structure of the vegetation cover of Reserve's land is explained by the measures taken by the Vietnamese government to regulate the water level in Cua Dat reservoir and expand the forest area.

Từ khóa:
Ảnh vệ tinh, diện tích đất, lớp phủ mặt đất, mô hình CA-Markov, NDVI, NDWI.

TÓM TẮT

Nghiên cứu được thực hiện tại Khu Bảo tồn thiên nhiên Xuân Liên, đây là khu bảo tồn thiên nhiên rất quan trọng và là một trong 5 trung tâm đa dạng sinh học chính của Việt Nam. Nghiên cứu nhằm mục đích phân tích sự thay đổi và dự báo hiện trạng lớp phủ mặt đất tại Khu Bảo tồn thiên nhiên Xuân Liên. Vì mục đích này, các hình ảnh Landsat-7, Landsat-5 và Landsat-8 thu được vào các năm 2000, 2010 và 2020 đã được nghiên cứu. Chỉ số thực vật khác biệt chuẩn hóa (NDVI) được sử dụng để phân lập lớp phủ thực vật trên diện tích đất liền và chỉ số nước chênh lệch chuẩn hóa (NDWI) đã được sử dụng. Kết quả nghiên cứu cho thấy thảm thực vật bao phủ đang biến đổi ở Khu Bảo tồn thiên nhiên Xuân Liên. Diện tích rừng lá rộng giảm 6,2% từ năm 2000 đến năm 2020, diện tích đất ngập nước tăng 4,9% do xây dựng thủy điện Cửa Đạt trong

Khu bảo tồn. Mô hình chuỗi Markov được sử dụng để dự đoán hiện trạng các vùng đất trong khu vực nghiên cứu. Kết quả dự đoán của mô hình đã được xác nhận thành công bằng cách sử dụng các chỉ số thỏa thuận. Theo kết quả dự báo, đến năm 2035 diện tích rừng lá rộng và đất ngập nước sẽ tăng lên lần lượt là 86,3% và 7,4%. Sự thay đổi cấu trúc thảm thực vật bao phủ Khu bảo tồn được giải thích bằng các biện pháp của Việt Nam nhằm điều hòa mực nước hồ Cửa Đạt và mở rộng diện tích rừng.

1. INTRODUCTION

Vietnam is a biodiversity rich country and is also in the process of economic development. Vietnam's protected area system, with 167 sites, is a place to preserve the values of ecosystem biodiversity and provide water to the country's hydropower system. Vietnam's hydropower industry has made a significant contribution to economic development over the past two decades, producing over 43% of its electricity [1], but it is hydropower that has a negative impact on vegetation and biodiversity, including the country's Xuan Lien Nature Reserve.

Xuan Lien Nature Reserve was established in accordance with the Decision of the Chairman of the People's Committee of Thanh Hoa province of Vietnam № 1476/QĐ-UB dated 15.06.2000 [2]. Xuan Lien Nature Reserve is located in Thuong Xuan region, south-west of Thanh Hoa Province, Vietnam. The object of study, with an area of 27648,2 ha, is located between 19°50' – 20°02' north latitude and 104°58' –105°19' east longitude (Fig. 1). Xuan Lien Nature Reserve is one of 221 endemic bird zones in the world and four zones in Vietnam that are a priority for biodiversity conservation [3]. The Reserve is located in the Truong Son Ridge Region ecological zone. This area is included in the list of 200 ecological zones of Vietnam that should be protected globally for future generations [4].

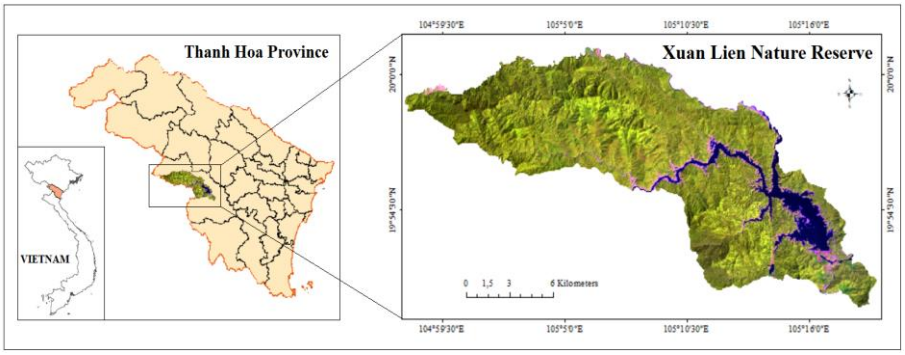

Figure 1. Scheme of location and boundaries of the research object

In addition, the Reserve is adjacent to Pu Hoat Nature Reserve (Nghe An province, Vietnam) and Nam Xam National Biodiversity Conservation Area in the Lao People's Democratic Republic [5]. Due to its special geographical position, Xuan Lien Nature Reserve and the two remaining protected areas form a large area, which contributes to the conservation of rare and endemic flora and fauna.

Xuan Lien Reserve is located on a high mountain range stretching from Houaphan province in Laos to Thanh Hoa province in Vietnam, with the highest peak at 1605 m above sea level. Prior to the establishment of Xuan Lien Nature Reserve, the area was home to more than 2,000 peasant families, of which 46.6% were poor, and their main occupation was the cultivation of wet rice in the hills. Before the creation of Reserve, the influence of

local residents on the current state of forest vegetation was obvious [6]. In addition, the problem of Xuan Lien Reserve is the change in landscape morphology in water resources caused by the development of hydropower. In Xuan Lien Nature Reserve, Cua Dat hydroelectric complex was built from 2004 to 2010 [3]. This is a promising period in the development of a number of hydroelectric projects in Vietnam since the beginning of the 21st century [1]. In addition to economic benefits, the development of hydropower in protected areas also has many consequences for the environment and natural ecosystems. Plants and animals are highly sensitive to changes in the water regime of the territory. This affected the effectiveness of the country's biodiversity conservation. Land cover change detection is very essential for better understanding of landscape dynamic during a known period of time having sustainable management [7].

Remote sensing of the Earth (ERS) provides a systematic, synoptic view of land cover at regular intervals and is useful for changes in land cover and direct study of biological diversity [8]. The contribution of remote sensing to effective assessment, monitoring and management of forests is invaluable in the developed countries of the world [9]. A Geographic Information System (GIS) is a useful tool for measuring changes between two or more time periods [10]. GIS has the ability to include multiple data sources in a change detection platform. Therefore, the Vietnamese government strongly recommends the use of remote sensing and GIS technologies for the management of forest protected areas in the mountainous areas of the country [4].

The process of predicting the state of land cover in Xuan Lien Reserve using the CA-Markov model was carried out in IDRISI program. The remote sensing data analysis procedure is shown in Fig. 2.

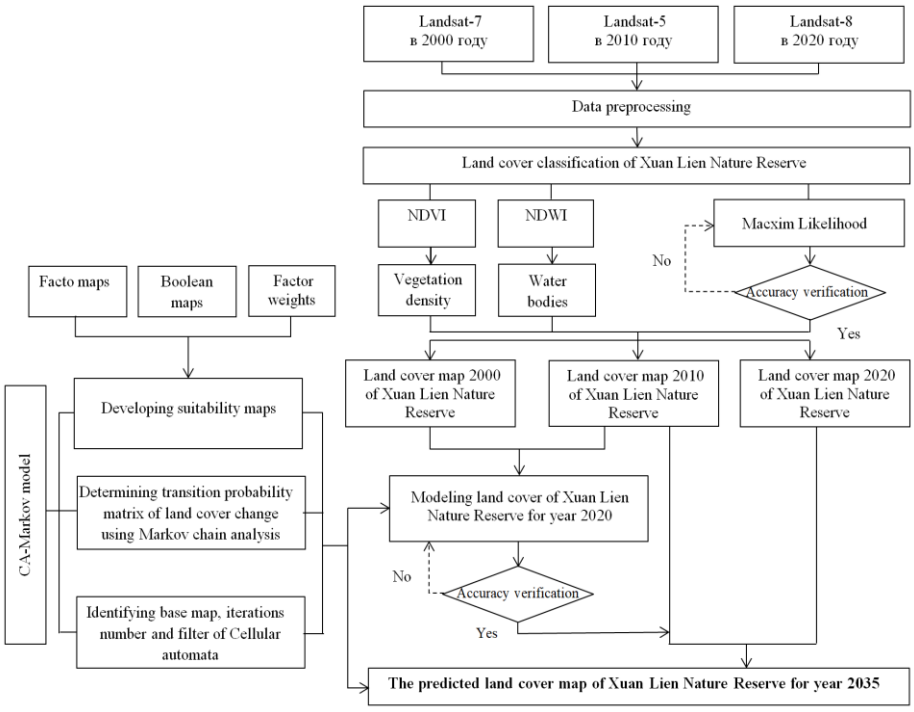

Figure 2. Block diagram of research methodology

2. RESEARCH METHODS

Landsat satellite images were used in the study of Reserve's land areas. Their detailed characteristics are given in Table 1.

Table 1. Characteristics of the satellite images used for the study

Entity ID	Data parameters	Date	Collected by
LE71270462000309SGS01	Landsat-7 Spatial resolution 30 m	11.04.2000	U.S. Geological Survey
LT51270462010040BKT00	Landsat-5 Spatial resolution 30 m	09.02.2010	U.S. Geological Survey
LC81270462020068LGN00	Landsat-8 Spatial resolution 30 m	08.03.2020	U.S. Geological Survey

All satellite images are downloaded from the US Department of State (USGS) free website. The shooting was carried out in a dry season, in cloudless weather and in the absence of fog. In addition to satellite imagery, additional information was used, such as a digital land-use map in 2020 of Thuong Xuan area, a Google Earth image, a map of forest conditions in Xuan Lien Nature Reserve in 2000, 2010 and 2020 and a digital terrain model (DEM) with a resolution of 30 m.

The change in vegetation cover was estimated using the normalized relative vegetation index NDVI (Normalized Difference Vegetation Index), proposed in 1974 by Rouse [11], which was determined from the intensity of plant development and calculated using the following formula (1):

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}, \quad (1)$$

where,

NIR – near infrared band;

RED – red band.

NDVI index can take values from -1 to 1.

Vegetation change in water bodies was assessed using the NDWI (Normalized Difference Water Index) proposed in 1996 by McFeeters [12, 13]. This index was used to identify water bodies and was calculated using the formula (2) [14]:

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR}, \quad (2)$$

where,

GREEN – green band;

NIR - near infrared band.

NDWI index values range from –1 to +1.

Based on the characteristics of Earth remote sensing data, the simplicity and efficiency of the description of the state of vegetation cover, the land areas of Reserve were divided into five categories (Table 2).

Table 2. Land cover classes considered for classification

Land cover classes	Description
Broad-leaved forest	Land covered with natural plantings with a predominance of broad-leaved timber plants.
Meadows and shrubs	Land covered with herbaceous vegetation (grass stand) and shrubs, fields
Land without vegetation cover	Land with bare soil, with single trees and sandy areas along rivers / lakes, built-up land
Wetlands	Land with water surface and aquatic vegetation (rivers, ponds and lakes)
Roads	Roads for the passage of equipment when protecting the flora and fauna of protected areas

To evaluate satellite images, we used the maximum likelihood classification method. It is one of the most commonly used methods for analyzing Earth remote sensing image data. For this classification, 262 regions of visually homogeneous spectral response were selected for each satellite image, at least 50 regions for each category of vegetation. Of the total

number of regions, 70% of them were used as training samples, and the rest were taken as test data. These areas were selected based on Google Earth images, aerial photographs, forest state maps of the reserve and Landsat data for different years.

The predicted of land cover in specially protected natural area was carried out using models of Markov chains and cellular automata. The CA-Markov model combines cellular automata, Markov chain, multicriteria and multipurpose land distributions to predict changes in the earth's surface over time [15]. A cellular automaton is a discrete dynamic system, which is a collection of cells that are equally interconnected. All cells form the so-called cellular automaton lattice [16]. In this study, the cells are image grids, the block size is 30×30m. The cellular automata model can be expressed as follows (3) [17].

$$S_{(t,t+1)} = f(S_{(t)}, N) \quad (3)$$

where,

S – a set of limited and discrete cellular states;

N – cell field;

t and t + 1 – different research times;

f – is the rule of transitions of cellular states in local space.

Markov chain is a statistical tool that describes the probability of changes in land conditions from one period (t) to another (t + 1) by developing a transition probability matrix between two periods [18], [19]. The state of land at the time t + 1 was calculated using the formula (4):

$$S_{t+1} = P * S_t \quad (4)$$

where,

S_t, S_{t+1} – is the state of land at the time t and t + 1;

P – is the transition probability matrix of the state of land with elements that are the probabilities of the transition (p_{ij}), *i, j* – are the category of land user/cover at the time t and t + 1 and *n* is the land cover type in the last order in the matrix. The matrix *P* has the following properties (5).

$$P = \begin{bmatrix} p_{11} & \cdots & p_{1n} \\ \vdots & \ddots & \vdots \\ p_{n1} & \cdots & p_{nn} \end{bmatrix} (0 \le p_{ij} < 1 \text{ and } \sum_{j=1}^{n} p_{ij} = 1, (i, j = 1,2,...,n)) \quad (5)$$

The CA-Markov model effectively combines the advantages of two models: a) the ability to simulate spatial changes in complex systems of the spacecraft model and b) long-term predictions of the Markov chain model [20]. Predicting the state of land using the CA-Markov model consisted of two stages. The first stage - a model was developed to assess the state of land in the past, and then the accuracy of the results was checked. At the second stage, the accuracy of the simulation results was determined. if acceptable, then the model was used to predict the state of land in the future. The predictive of the state of land use/cover using the CA-Markov model was built on the basis of 3 main components: 1) suitability maps for land use/cover classes; 2) probability transition matrix of the state of land and 3) base map, the number of iterations and filter.

The determination of the matrices of the transition probability of the state of land was carried out using the Markov chain. To model the vegetation cover in 2020 and predictive it until 2035, we calculated the matrices of the probability of land transition for 2000–2010 and 2010–2020, respectively.

In the CA-Markov model, which defines the

basemap, the number of iterations and cellular automata filters are important. In the study for modeling the state of cover in 2020 and its predictive in 2035, the maps of 2010 and 2020 were used as the basis, the number of iterations was 10 and 15, respectively, and the filter was 5x5 by default.

To assess the accuracy of the predictive model, we calculated the following indicators: Quantity disagreement (DisagreeQuantity), Allocation disagreement (DisagreeGridcell), overall accuracy of the predictive model (Kno), and Kappa index (Kstandard). These indicators can vary from 0 to 1. The lower the value of the unconformity indicators (close to zero) and the higher the value of the overall accuracy and the Kappa index (close to 1), then the simulation corresponds to reality.

3. RESULT AND DISCUSSION

The NDVI indices obtained for 2000, 2010 and 2020 show the dynamics of the land cover areas during the entire study period (Fig. 3).

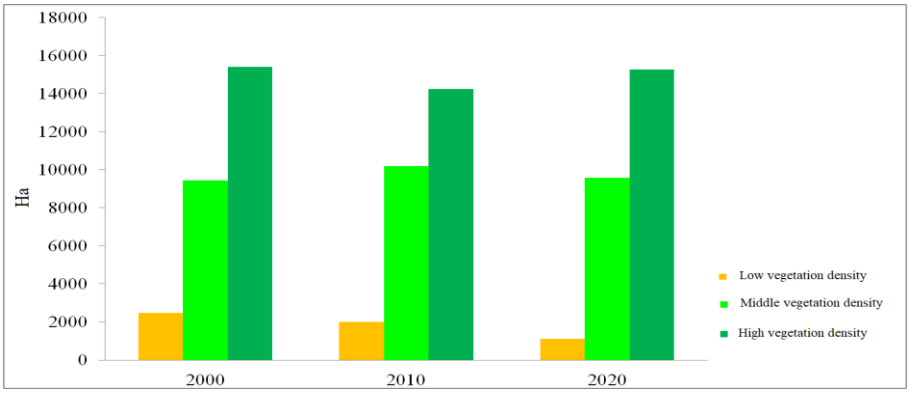

Figure 3. Dynamics of land areas by categories of vegetation density

Analysis of the data presented in Fig. 2 shows that from 2000 to 2010 there is a tendency towards degradation and restoration of vegetation in Reserve. In particular, the area of high vegetation density in 2020 was restored to almost its size in 2000. The vegetation of medium and low density has a small area and is mainly distributed in areas with low altitude (less than 500 m), with a low slope (less than 15^o) and near water bodies (rivers and Cua Dat reservoir). In addition, such land areas are distributed mainly along the boundaries of the reserve, near settlements and roads. This shows the relationship between anthropogenic impacts and the state of vegetation in Xuan Lien Nature Reserve. Throughout the reserve, a high NDVI index of 0.78, 0.69 and 0.70 was respectively recorded in 2000, 2010 and 2020. This indicates that forests with a high density of vegetation are prevalent in the protected area. The vegetation described in this study is almost similar to that described by other researchers such as Dang Quoc Vu (2015) [21]. It is a sub-tropical and tropical broadleaf forest. Typical tree species in protected areas are: *Fokienia hodginsii* (Dunn) A. Henry&H.H. Thomas, *Calocedrus macrolepis* Kurz, *Cinnamomum balansae* Lecomte, *Amentotaxus argotaenia* (Hance) Pilg. and *Ricinus communis* L..

The NDWI index maps obtained for 2000, 2010 and 2020 show the results of the dynamics of water bodies during the study period (Fig. 4).

Data analysis is shown in Fig. 4 shows that over the past 20 years, the area of water bodies of the reserve has constantly increased, especially from 2000 to 2010. This increase occurred mainly in the area of Cua Dat Lake. The results of monitoring land areas by categories of vegetation density and water bodies are the first experience of land cover change in Xuan Lien Nature Reserve.

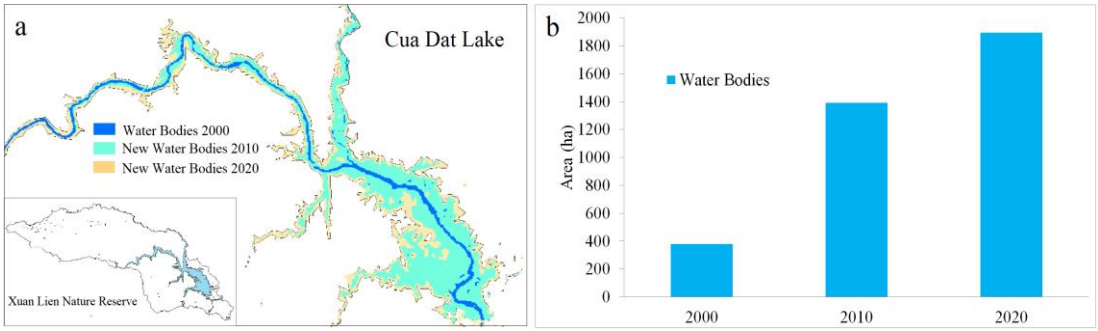

Figure 4. Map of the dynamics of the areas of water bodies in Cua Dat Lake from 2000 to 2020 (*a*) and their dynamics throughout Reserve (*b*)

Based on the results of the classification of the photographs, maps of the land cover of Xuan Lien Nature Reserve were developed (Fig. 5-a, b, c). The assessment of the accuracy of the classification of the images in the period from 2000 to 2020 is given in Table 3.

Table 3. Results of assessing the accuracy of image classification by years of research

Land cover classes	Accuracy (%)					
	Year 2000		Year 2010		Year 2020	
	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy
Broad-leaved forest	91.8	91.8	95.7	90.0	97.8	95.7
Meadows and shrubs	83.3	86.5	80.4	88.2	84.9	91.8
Land without vegetation cover	88.2	84.9	83.9	85.5	88.2	88.2
Wetlands	91.8	90.0	93.8	90.0	95.7	91.8
Roads	93.8	95.7	96.2	94.3	95.7	93.8
Overall accuracy, %	*89.8*		*90.0*		*92.5*	
Kappa index	*0.87*		*0.87*		*0.90*	

From the data in Table 3, it can be seen that the accuracy of the user and the manufacturer of the studies is quite high (more than 80%) The overall accuracy of the vegetation cover maps for 2000, 2010 and 2020 is not less than 89%. The Kappa index according to the results of land cover classification in Xuan Lien Lien Nature Reserve in 2000, 2010 and 2020, respectively, was 0.86, 0.87 and 0.90. This shows that we have achieved significant agreement between the classification results and the reference data. Thus, the results were initially considered acceptable for comparison after classification.

Table 4. Area statistics of land cover classes of years 2000, 2010 and 2020

Land cover classes	Year 2000		Year 2010		Year 2020	
	ha	%	ha	%	ha	%
Broad-leaved forest	25534.1	92.4	24934.7	90.2	23830.9	86.2
Meadows and shrubs	1413.4	5.1	926.8	3.4	1362.6	4.9
Land without vegetation cover	266.5	1.0	570.7	2.1	518.8	1.9
Wetlands	434.2	1.6	1065.8	3.9	1785.7	6.5
Roads	0	0.0	150.2	0.5	150.2	0.5
Total	27648.2	100.0	27648.2	100.0	27648.2	100.0

Land cover inventory data by category in Reserve in the period from 2000 to 2020 is shown in Table 4.

As can be seen from Table 4, the dominant category of vegetation cover on the land areas of Reserve is broad-leaved forest, the share of

which decreases and amounts to 92.4%, 90.2%, 86.2%, respectively, for 2000, 2010 and 2020. The density of vegetation is favorable for the conservation of biodiversity in Xuan Lien Nature Reserve. In order to reduce the anthropogenic impact on the natural forest ecosystems of the reserve and improve the quality of life of people, the policy of resettlement of people from the main zone of Reserve to the indicated territories of the buffer zone of the protected areas has been implemented. Accordingly, the land of the inhabitants for growing rice, after being abandoned, was converted in 2000 into land covered with meadow and shrub. These lands are clearly visible in satellite images from 2000. According to the inventory of the land cover, the area of meadows and shrubs in 2000 was the largest for all the years of research (1413.4 hectares or 5.1%). In the period 2000-2010, Cua Dat Lake was built in the reserve for irrigation work aimed at regulating floods downstream, to provide water to 87,000 hectares of crops and to generate electricity to ensure the energy security of the region.

After the completion of the construction of Cua Dat hydroelectric complex, the area of wetlands in the reserve has significantly increased from 1.6% in 2000 to 3.9% in 2010. However, at the end of the rainy season in 2010, rainfall in Thanh Hoa province reached only 80.9% of the average rainfall over many years. Therefore, the amount of water stored in Cua Dat Lake or in the entire reserve is still lower than expected.

To improve the efficiency of ground patrolling and protect the environment, the reserve has built new highways with an area of 150.2 ha. During the research period, the Reserve carried out afforestation activities aimed at restoring poor and depleted forests and developing stands in abandoned rice fields. As a result, in 2010 (after 10 years), most of the previously agricultural land was converted into forest land. However, the reclaimed land area is still less than the forests lost, mainly due to the development of construction work in 2010. Thus, overall, wetland area tended to increase and forest area tended to decrease between 2000 and 2010. From 2010 to 2020, the area of wetlands of Reserve continued to increase by 719.9 hectares (2.6%). The reason is that at the beginning of 2020, the amount of water stored in Cua Dat reservoir reached a high level due to the large amount of water flowing into the lake. In contrast, over the past 10 years, the forest area has continued to decline by 1103.8 ha (4.0%). The forested area has been largely converted to meadow and bushland. These lands are concentrated mainly on the shores of Cua Dat Lake. In 2020, the area of roads has not changed compared to 2010 due to the policy of limiting infrastructure development in the reserve to protect biodiversity.

The land use predictive model was verified by mathematical modeling of the past research period [22]. The results of modeling the state of land cover in Xuan Lien Nature Reserve in 2020 are shown in Fig. 5, and the estimation of the predictive model accuracy is presented in Table 5.

Table 5. Validation of projected land cover in Xuan Lien Nature Reserve in 2020

Indicators	Value
DisagreeQuantity	0.0292
DisagreeGridcell	0.0048
Kno	0.9593
Kstandard	0.9346

From the data in Table 5, it can be seen that the values of the indices "disagreement" are quite small: the disagreement in terms of quantity is 0.0292, and the disagreement due to location is 0.0048. The value of the overall accuracy index is 0.9593, and Kappa index is 0.9346. These indices show good agreement between the simulation map and real data. This

proves that the model for predicting the state of Reserve's land is reliable and significant predicting accuracy has been achieved.

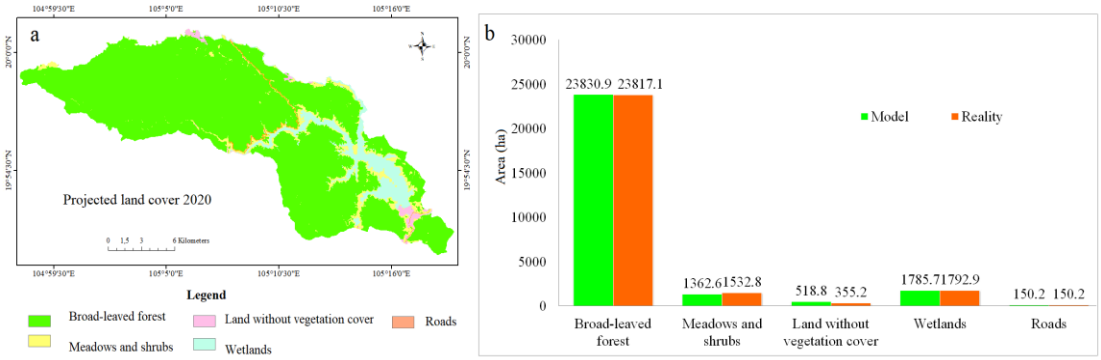

Figure 5. Results of modeling the state of land cover: a simulation map (a), comparison of data between simulated map and real map (b)

Land cover predictive maps for the area under study were created by combining the cellular automata model and Markov chains (Fig. 6-d). The results of predicting the state of land cover classes in Xuan Lien Nature Reserve in 2035 are given in Table 6.

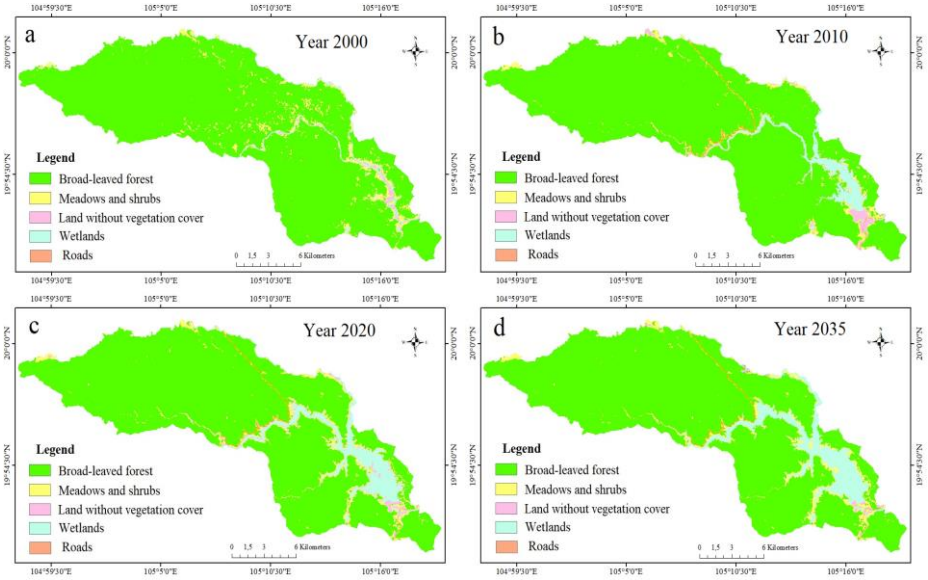

Figure 6. Land cover maps in the Xuan Lien Nature Reserve in 2000 *(a)*, in 2010 *(b)*, in 2020 *(c)* and prediction map for 2035 *(d)*

Table 6. Area statistics of predicted land cover classes in Xuan Lien Reserve for the years 2035

Land cover classes	ha	%
Broad-leaved forest	23872.6	86.3
Meadows and shrubs	1312.7	4.7
Land without vegetation cover	255.0	0.9
Wetlands	2057.7	7.4
Roads	150.2	0.5
Total	***27648.2***	***100***

The trend of changes in the state of land cover classes in Xuan Lien Nature Reserve from 2000 to 2035 is shown in Fig. 7.

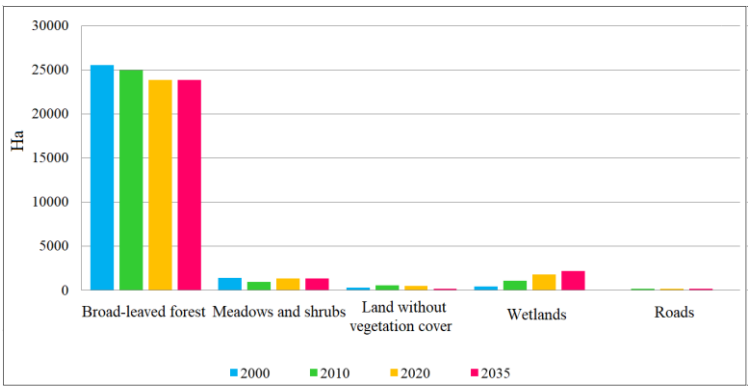

Figure 7. Dynamics of land cover class in Xuan Lien Nature Reserve and predicted for 2035

From the data in Table 6 and Figure 7, it can be seen that the predictive results indicate an increase in the area of wetlands of Reserve in the period from 2020 to 2035. In particular, by 2035, the area of wetlands will increase by 272.0 ha (1.0%). Forested area declined steadily from 2000 to 2020, but forested area is projected to remain stable or increase by 41.7 ha (0.2%) over the next 15 years. In addition, from 2020 to 2035, the area of meadows and shrubs and uncovered land will decrease by 313.7 ha (1.1%). The road area is expected to remain unchanged between 2020 and 2035. By the end of the predicting period, the structure of lands in Reserve will be as follows: broad-leaved forests will amount to 23872.6 ha (86.3%), meadows and shrubs - 1312.7 ha (4.7%), uncovered land - 255.0 ha (0.9%), wetlands - 2057.7 ha (7.4%) and roads - 150.2 ha (0.5%). According to the results of predicting, by 2035, changes in the state of vegetation on the land areas of Xuan Lien Nature Reserve are consistent with the plan and policy of the Government of Vietnam to preserve the biodiversity of natural ecosystems.

4. CONCLUSION

The classification of the state of vegetation on the land areas of Xuan Lien Nature Reserve was carried out according to 5 categories, the method of maximum likelihood was used. Studies have achieved significant agreement between the classification results and reference data, which is consistent with a Kappa index of 0.87. The result is consistent with the assessment of the land areas of various categories of protected areas from 2000 to 2020.

The CA-Markov model was used to predict the state of vegetation of land in Xuan Lien Nature Reserve in 2035. This model took into account the factors of the influence of height above sea level, slopes of the terrain, granulometric composition of the soil, distance to state roads of the country and distance to residential areas of settlements on the development and state of vegetation of land in Reserve. To assess the predictive model, the results of modeling the state of Reserve's land are compared with their real data in 2020. Accordingly, the predictive model has high overall accuracy and Kappa indices, their values are above 0.93.

According to the modeling results, by 2035 the area of broadleaf forests and wetlands will increase by 0.2% and 1.0%, respectively, compared to 2020. On the contrary, the area of meadows, bushes and uncovered vegetation will decrease by 1.1% in 15 years. The road area will remain unchanged. These changes indicate a trend towards stabilization and restoration of the state of soil vegetation until 2035. This trend will continue if Reserve continues to take measures to stabilize the water resources in Cua Dat Lake and preserve the region's biodiversity.

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