Mapping Wetland Ecosystems Based on Satellite Geographical-landscape Data (Case Study in Ninh Binh Province)

Son Nguyen Phi[1], Huong Nguyen Thi Thanh[11]*, Thuy Nguyen Thanh[1], Thanh Dinh Thi[1]
The Viet Nam Institute of Surveying and Mapping
479 Hoang Quoc Viet, Bac Tu Liem, Ha Noi, Vietnam
npson@monre.gov.vn; thanhhuong@monre.gov.vn;
ntthuy_ddbd@monre.gov.vn; dtthanh5@monre.gov.vn

Abstract - This study proposes integrating satellite and geographical-landscape data to develop a wetland ecosystem map for Ninh Binh province at a 1:50,000 scale. Satellite images were used to interpret land cover and classify wetland types. Factors such as geology, topography, geomorphology, soil, climate, hydrology, and vegetation were analyzed to determine the factors that influence the distribution and characteristics of wetland ecosystems. The results show that Ninh Binh province has 07 types of wetland ecosystems (01 coastal, 01 inland, and 05 artificial) which were classified based on 50 landscape types. Wetland ecosystems account for 47.01% of the natural area, of which agricultural wetlands have the largest proportion (36.69%). The wetland ecosystem map is a useful tool for managing, planning, conserving, and rationally using wetland resources. The study contributes to providing a scientific basis for assessing the current status, monitoring changes, and formulating policies on wetland ecosystems in Ninh Binh and Vietnam.

Keywords: Wetland ecosystem, Satellite data, Geography, Landscape, Ninh Binh.

1. Introduction

Wetlands are diverse, with over 50 definitions worldwide, reflecting the complexity and diversity of wetland types [1]. However, most definitions emphasize the important factors that create wetlands, such as geology, topography-geomorphology, hydrology, soil, and vegetation, which are closely related and interact, forming wetland ecosystems [6].

With multi-spectral, multi-spatial, and temporal resolution observation capabilities, satellite data (remote sensing) allows for monitoring, updating, and quantifying some information about wetland ecosystems. Many studies have demonstrated the effectiveness of remote sensing in extracting information on vegetation cover [4, 9, 17, 21], wetland classification [8, 19], and creating thematic maps for the conservation and sustainable development of wetland areas [15, 16]; identifying the distribution and zoning of ecosystems [11, 14]. However, these studies mainly focus on the classification, interpretation, and digitization of ecosystem boundaries without considering the formation origin and influencing factors [10].

Landscape ecology synthesizes ecosystems within a landscape territory where organisms and their living environment are closely related [6]. Studies using the landscape ecology approach are diverse in scale, proportion, and approach method, focusing on planning, conservation, and sustainable development purposes [2, 4, 5, 10, 18, 20, 22]. Some studies also point out the complex relationship between landscape and ecosystem, according to which the landscape boundary is also the ecosystem boundary. Therefore, the landscape ecology method will provide an important theoretical basis for ecosystem zoning in general and wetland ecosystems in particular [10].

Determining the boundaries of wetland ecosystems is still difficult due to the always-moving and changing nature of ecosystems. Wetland ecosystems are influenced by many natural and anthropogenic factors, bringing both positive and negative impacts. The geographical perspective in wetland ecosystem research requires a comprehensive, holistic view of the natural-social relationship, assessing natural geographical, socio-economic, and environmental conditions according to landscape units, which is an approach that many scientists are interested in [3, 9]. However, few studies

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have proposed specific technological processes and technical guidelines for creating ecosystem maps based on the integration of remote sensing and geographical-landscape data.

Ninh Binh is a province with diverse wetland ecosystems, providing many important ecological services such as maintaining biodiversity, regulating water, protecting the coast, and developing tourism [7]. However, the area and quality of these ecosystems tend to decline due to the impact of human activities such as land use conversion, water pollution, overexploitation of resources, and the effects of climate change [13].

Currently, Ninh Binh province does not have a wetland ecosystem map established in a complete and systematic way. This leads to a lack of information and data on the current spatial distribution, ecological characteristics, and trends of wetland ecosystems. This shortage causes difficulties in managing, monitoring, and evaluating the effectiveness of policies and measures for local wetland resources' conservation and sustainable development.

Therefore, it is very necessary to create a wetland ecosystem map to provide a complete and reliable database for spatial planning, policy-making for management, conservation, and rational, effective exploitation of this important natural resource towards the goal of sustainable development.

2. Data and research methods
2.1. Study area and data used
Ninh Binh is a province located at the southern end of the Red River Delta, on an important North-South traffic route. Its position extends from 19°50' to 20°26' North latitude and from 105°32' to 106°20' East longitude [13]. The province's topography is divided into three main types: plains, hills and mountains, and semi-mountainous coastal areas. The province has diverse soil, from alluvial soil in low-lying areas to limestone soil in the mountains; the climate has typical tropical monsoon characteristics with a high-temperature base (23-24°C), high rainfall (1,700-1,800 mm/year) [12], dense river and stream network also creates conditions for the formation and maintenance of different ecosystems. The location map of the study area is shown in Figure 1.
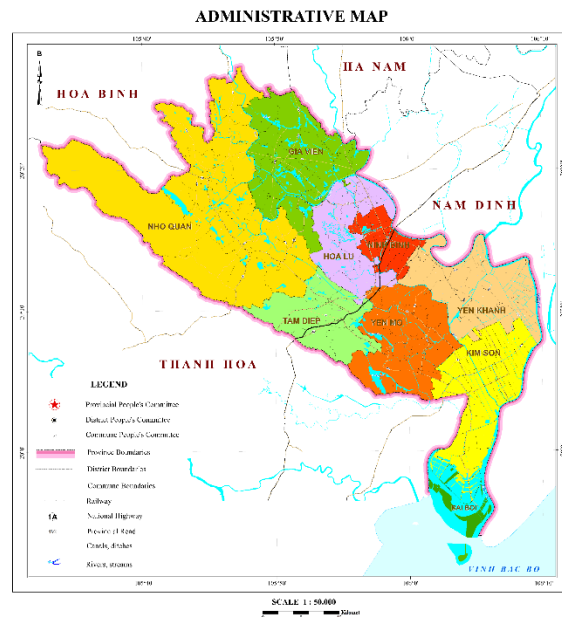

Figure 1: The location of Ninh Binh Province

The data used in the study are shown in Table 1.

Table 1: Data used for the study

No	Data group	Data layer	Data source
1	Topography	Geomorphology, slope, terrain stratification layers	1:50,000 scale topographic map
2	Current land use	Landcover layer	1:50,000 scale current land use map
3	Satellite imagery		Full coverage satellite image dataset of the province
4	Soil	Soil layer	1:50,000 scale soil map
5	Geological	Geological layer	1:250,000 scale geological map
6	Meteorological, hydrological data	Climate layer	The climate assessment report, the current state of the environment in Ninh Binh province

2.2. Research perspectives and methods
2.2.1. Perspectives on creating wetland ecosystem maps

Systems perspective: The ecosystem is considered a system with components (factors) that have close relationships, interact with each other regarding matter and energy, create unique structures and functions, and are governed by internal and external factors. Studying a component of the ecosystem requires linkage and calculation to other components of the system.

Historical perspective: Ecosystem research needs to consider the origin of formation, the process of development, and change over time, assess the ecosystem in terms of morphology, and clarify the internal laws of motion.

Integrated perspective: The ecosystem is a unified whole that includes elements of geology, topography, climate, hydrology, soil, and organisms. These elements interact and bind closely together to form an integral whole while being strongly influenced by human activities.

Territorial perspective: Each ecosystem clearly shows its own characteristics while reflecting the internal differentiation laws and spatial relationships with surrounding objects within a certain territory.

2.2.2. Research methods

- Method of collecting, analyzing, synthesizing, and inheriting documents and data:
Documents and data on natural conditions and the study area's socio-economy are collected, compared, cross-checked, and systematized to clarify the research issues posed.

- Group of methods for researching and evaluating landscapes including:
+ Method of combined analysis of component maps: Integrating synthesizing thematic maps such as topography, geomorphology, geology, climate, hydrology, soil, vegetation... to clarify landscape characteristics and the relationship between the constituent components.

+ Dominant factor analysis method: Identifying the dominant factors that influence landscape differentiation, thereby building a map of landscape units.

+ Landscape zoning method: Dividing the territory into different territorial zones based on the comprehensive analysis of natural geographical factors, assessing the relationship between them in each zone.

+ Method of building landscape ecology map: Integrating and analyzing remote sensing data, GIS, and thematic data to build a landscape ecology map with corresponding ecosystems.

- Mapping and GIS methods:
Used to represent research results in maps and diagrams; collect, standardize, process spatial data; analyze, synthesize, and present data in thematic maps (wetland ecosystem map, administrative map, geology, geomorphology, soil...).

- Remote sensing method: This method is used to correct and supplement some information for thematic map layers such as soil and climate. In addition, this method is also used to create image channels with supplementary information value and vegetation indices...

- Expert method: Consult opinions of experts and scientists on a theoretical basis, methodology, and appropriate socio-economic development solutions for the natural conditions of the study area.

- Field survey method: Conduct field surveys in the study areas to verify and calibrate the results of interpretation and analysis on remote sensing images, and maps while supplementing other necessary information for creating wetland ecosystem maps.

The research steps are carried out with the assistance of ArcGIS 10.8 software according to the diagram in Figure 2.
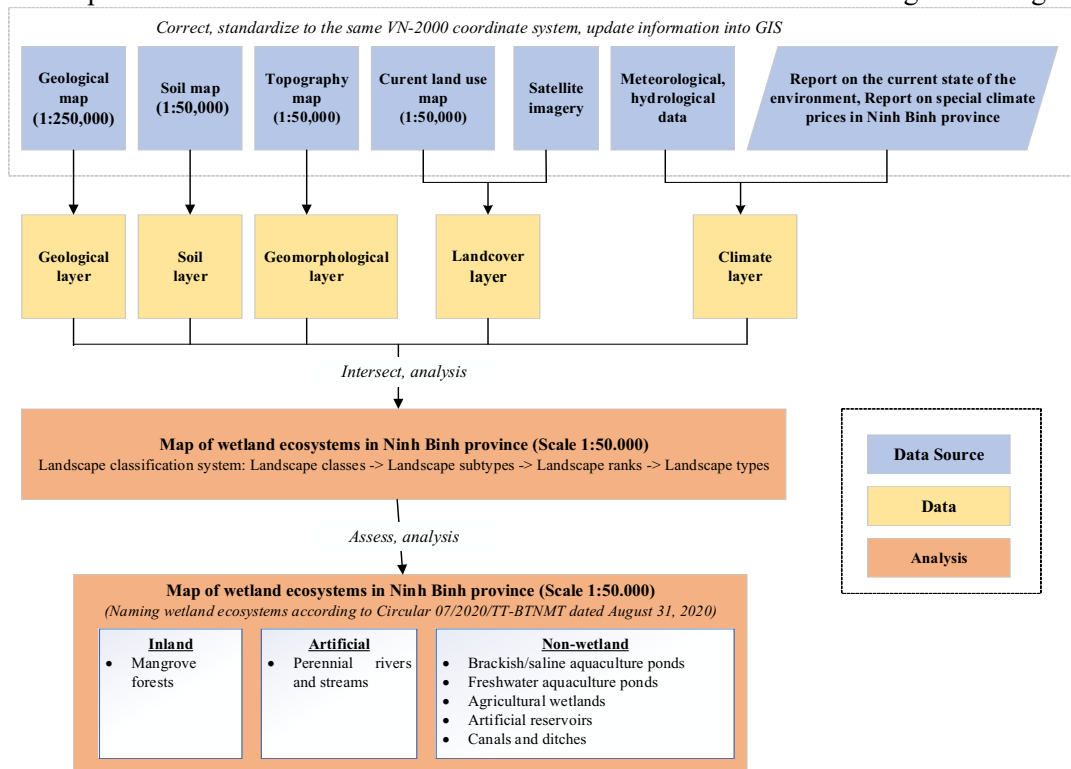
Figure 2: Research diagram for creating the wetland ecosystem map of Ninh Binh province

3. Research results and discussion

3.1. Factors forming landscapes and wetland ecosystems in Ninh Binh Province

With a complex and diverse geological structure in the Ninh Binh, Son La, and Hanoi tectonic zones belonging to the Northwest geological region of Vietnam [13], this study area has a base mainly of limestone sediments belonging to the Dong Giao formation, interspersed with some types of shale and siltstone distributed in the West and North. The plain area in the south and the low-lying regions are covered by Quaternary sediments [4].

The province's topography stretches in a northwest-southeast direction, dividing into two parts with clear gradation. The low and medium hill and mountain topography affects population distribution and human activities. The coastal plain and low-lying areas create favorable conditions for agricultural development, especially rice cultivation and aquaculture. Topography is the main factor that differentiates the territorial landscape.

Ninh Binh has all the characteristics of the climate of Northern Vietnam, which is a hot and humid tropical monsoon climate with cold winters, little rain, hot summers, and heavy rain. The differentiation of temperature-humidity conditions has created two bioclimatic subtypes, forming the basis for the formation of different landscape types.

The river systems, such as Hoang Long River, Vac River, Day River..., provide irrigation water and strongly influence the province's landscape characteristics. Moreover, the semi-diurnal tidal regime with small amplitude in the coastal area also causes great impacts, such as saline intrusion in the dry season or increased risk of flooding in the rainy season.

Ninh Binh province has a diverse soil system, reflecting the complexity of natural conditions and soil formation processes. The differentiation of climate, topography, geomorphology, and human activities has created 10 soil types that belong to 05 groups. The alluvial soil group has a large area (55.76%) mainly distributed in low-lying plains and riverside areas.

Land cover is considered an important indicator in landscape mapping [4]. Ninh Binh province has the largest area of specialized wet rice cultivation land (38.8%), forest (22.15%), annual crops (3.79%), perennial crops (2.59%), and aquaculture (3.54%).

The geological, topographic, geomorphological, and soil data layers were inherited and standardized from previous studies. Objects that change over time, such as the surface cover layer, were updated and supplemented with information by interpreting remote sensing images combined with current land use maps. Climate data at meteorological stations are the basis for classifying bioclimates in Ninh Binh province. The maps are built and presented sequentially in Figures 3 to 8.

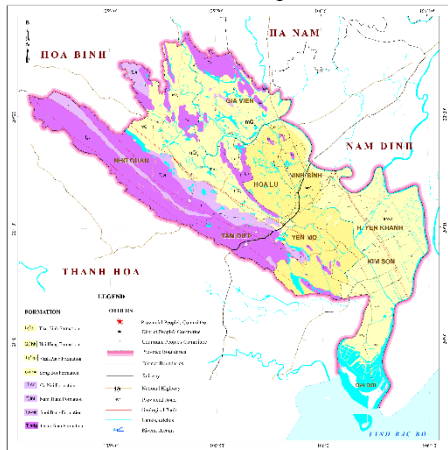[Figures 3-8: Various thematic maps of Ninh Binh province]

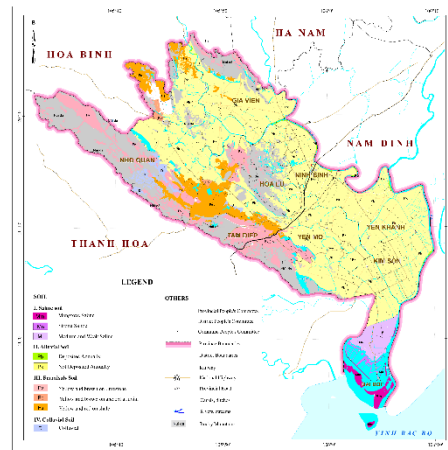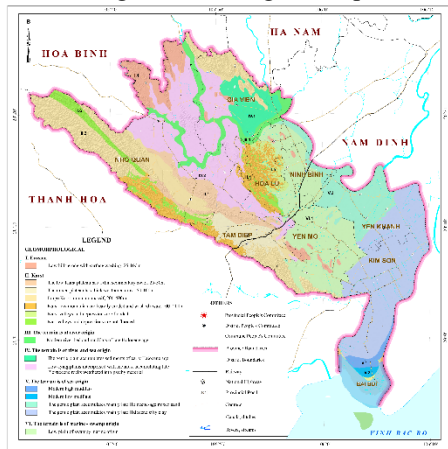

Figure 3: Geological map
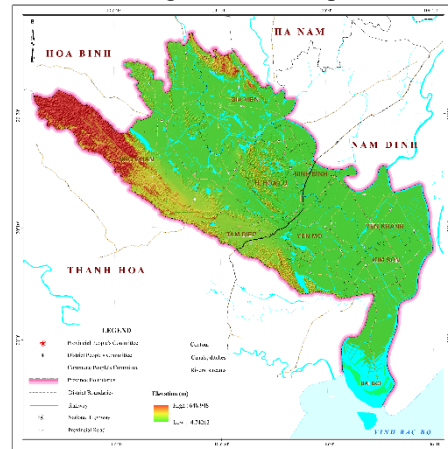

Figure 3: Soil map

Figure 5: Geomorphological map
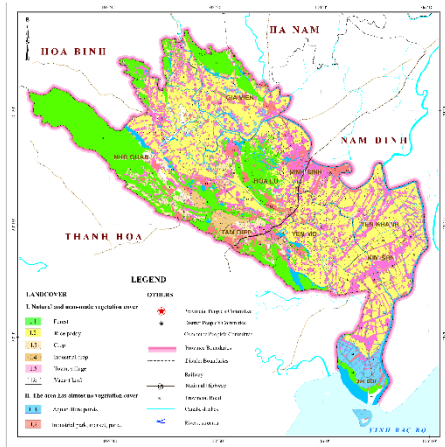

Figure 6: Digital elevation model
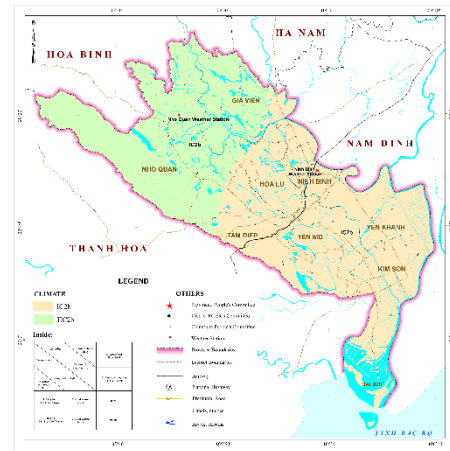
Figure 7: Landcover map

Figure 8: Climate map

3.2. Creating wetland ecosystem map of Ninh Binh

Based on the differentiation of natural conditions combined with mapping - GIS methods, the study has created a landscape map of Ninh Binh province at a scale of 1:50,000. Accordingly, the study uses the classification system of Pham Hoang Hai [3] because it clearly shows the ecological characteristics of landscape units suitable for Ninh Binh province. The landscape system of Ninh Binh province includes 02 landscape classes, 02 landscape subtypes, 06 landscape ranks, and 98 landscape types. The levels in the landscape classification system of Ninh Binh province are divided according to the characteristics and combination of two groups of factors, including "heat-humidity base" and "solid material base". The study area is divided into landscape units as follows:

- 02 landscape classes: Mountain landscape class, plain landscape class, and Anthropogenic tropical monsoon landscape type with cold and humid winter.

- 02 landscape subtypes: Landscape subtype with the hot climate, average cold season, average number of rainy days, little rain; Landscape subtype with very hot climate, average cold season, average number of rainy days, and little rain.

- 06 landscape ranks including: Low Karst mountain landscape rank; High erosion denudation hill landscape rank; Low denudation, leaching hill landscape rank; River and sea accumulation plain landscape rank; Sea-swamp accumulation plain landscape rank and Sea accumulation plain landscape rank.

- 98 landscape types: 53 landscape types belong to the low mountain class, 45 landscape types belong to the plain class, and all residential areas, transportation land, forests, etc., are classified into one separate class.

Of these, 50 landscape types were selected to determine the boundaries of wetland ecosystems for the study area. Wetland ecosystems in Ninh Binh province are divided into seven distribution types (01 coastal wetland ecosystem, 01 inland wetland ecosystem, and 05 artificial wetland ecosystems). The distribution of wetland ecosystem systems and their relationship with landscape types are shown as follows:

Table 2: Classification of Wetland Ecosystems in Ninh Binh Province

Wetland Group	Ecosystem Type	Code	Key Landscape Features and Distribution
Coastal	Mangrove forests	Rnm-I	Low-lying coastal plains (Landscape type 98)
Inland	Perennial rivers and streams	Stx-M	Major river systems (e.g., Hoang Long, Day, Vac rivers)
Artificial	Brackish/saline aquaculture ponds	Anm-1,2	Saline soils, tidal flats
	Freshwater aquaculture ponds		Alluvial soils, Thai Binh formation, near channels and rivers

Wetland Group	Ecosystem Type	Code	Key Landscape Features and Distribution
		Ann-1,2	
	Agricultural wetlands	Dnn-3	Alluvial plains (Multiple landscape types listed)
	Artificial reservoirs	Hnt-6	Scattered in residential and agricultural areas
	Canals and ditches	Sd-9	Distributed in residential and agricultural zones
Non-wetland	Residential, industrial, and service areas	-	Concentrated in lowland areas
	Transportation infrastructure	-	Province-wide
	Non-wetland areas	-	Includes perennial crops, fruit trees, annual crops, and forests on various terrain types

3.3. Characteristics and distribution of wetland ecosystems in Ninh Binh Province

The landscape of Ninh Binh province has a profound influence on the wetland ecosystems in the area. Landscape elements, including topography, geomorphology, soil, bioclimate, vegetation, and other geographical features, create specific environmental conditions, directly and indirectly affecting wetland ecosystems' formation, development, and maintenance. Based on the classified landscape units, the study created a distribution map of wetland ecosystems, as shown in Figure 9.

The distribution map of wetland ecosystems in Ninh Binh province shows that Wetland ecosystems are widely distributed, with a total area of 66,362.53 ha (accounting for 47.01% of the natural area). Of which, coastal wetland ecosystems are 722.61 ha (accounting for 0.51%), inland wetland ecosystems are 3,712.31 ha (accounting for 2.63%), artificial wetland ecosystems are 61,927.61 ha (accounting for 43.87%), the remaining area of other ecosystems (including non-wetland, forest) is 74,815.47 ha (accounting for 52.99%). In which:

- Coastal wetland ecosystem: Mangrove forests account for 0.51% of the natural area but have ecological significance and specific characteristics, are distributed in coastal alluvial areas, and are objects sensitive to the impacts of climate change.

- Inland ecosystem: Rivers and streams with permanent water account for 2.63% of the area, including Day River, Hoang Long River, and Vac River... distributed throughout Ninh Binh province, creating a large and diverse ecological network.

- Artificial wetland ecosystem:

+ Agricultural cultivation land (mainly rice fields) has the largest area, accounting for 36.69%, widely distributed in all districts of the province, concentrated on fertile alluvial soil. Agricultural activities are very important for the economy and people's lives in the province; however, if not well managed, they also cause many negative impacts on landscape structure and other ecosystems.

+ Ponds, lakes, and reservoirs for salt and freshwater aquaculture account for 2.63% and 2.31%. This shows a clear division between saltwater and freshwater aquaculture areas. This is also a positive sign of the diversification and expansion of the aquaculture industry in the province, which contributes to the local economy and provides food for the community.

+ Artificial water reservoirs account for 1.15%, including some large lakes such as Yen Quang, Dong Thai, Da Lai, Dong Chuong, and Yen Thang... they store a large amount of water to meet diverse human needs in production and life.

+ Canals, ditches, and channels account for 1.73%, helping to manage and regulate the province's water flow, prevent flooding, and provide irrigation water for agriculture; artificial water reservoirs account for 1.15%, playing a role in water storage, providing clean water sources for production and living activities.
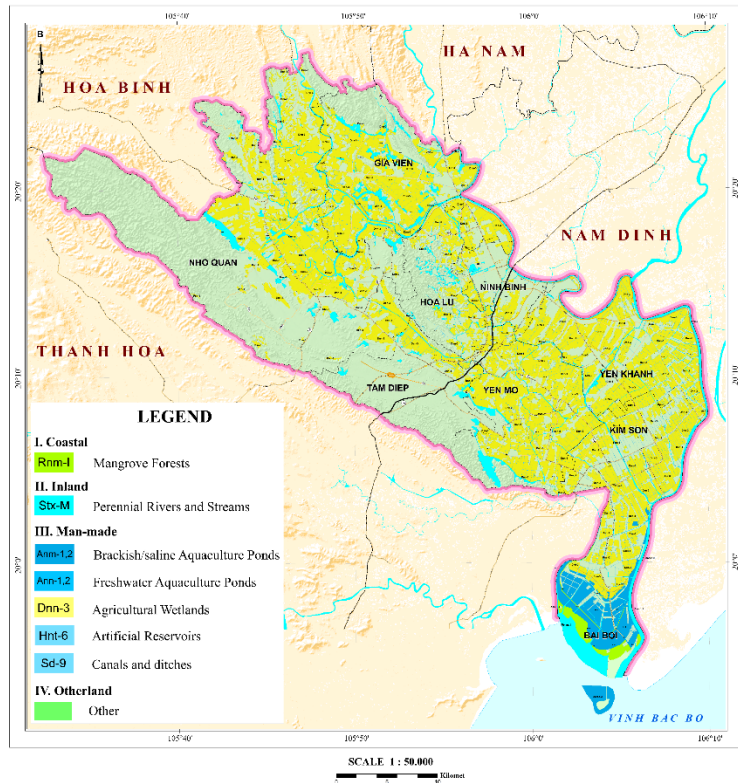
Figure 9: Map of wetland ecosystems in Ninh Binh province

- Non-wetland areas account for 52.99% of the total natural area. Of which residential areas account for 24.27%, transportation infrastructure (0.68%), and other ecosystems (including unused land, other natural ecosystems such as forests, annual crops, and perennial crops...) account for 28.04%.

The area and structure chart of ecosystems in Ninh Binh province are shown in Figure 10.
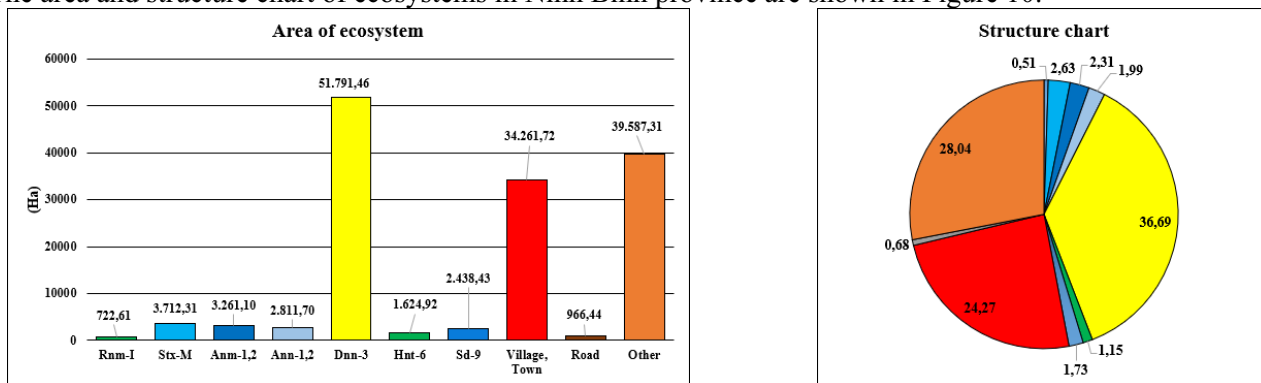

Figure 10: Area and structure chart of wetland ecosystems in Ninh Binh province

Understanding the relationship between landscape and wetland ecosystems is necessary to effectively protect and manage wetland ecosystems while ensuring the area's sustainable development. Creating a wetland ecosystem map will support the monitoring, management, and conservation of ecosystems, ensuring they continue to provide ecological services and economic value to the local community.

Comparison with previous studies shows that this study offers several advantages over previous wetland ecosystem mapping research: optimal integration of remote sensing and geographical-landscape data, compared to single-data source studies [8, 19]; detailed classification based on 50 landscape types, surpassing earlier studies [14]; multi-dimensional approach combining various spatial analysis methods, unlike single-aspect focused studies [11].

4. Conclusion

The paper has proposed a process of integrating remote sensing and geographical-landscape data to create a wetland ecosystem map in Ninh Binh province. Combining these data sources helps comprehensively and reasonably identify the boundaries of wetland ecosystems, harmonizing between socio-economic development goals and environmental protection. Remote sensing and landscape data play an important role in spatial analysis, establishing landscape units and wetland ecosystem boundaries.

With this approach, the wetland ecosystem system in Ninh Binh province is divided into 03 groups and 07 types, including 01 coastal wetland ecosystem type, 01 inland wetland ecosystem type, and 05 artificial wetland ecosystem types. However, the boundaries of some wetland ecosystem types are still unclear and need to be studied in more detail.

The research results open up a new, multi-dimensional approach to natural resource management and ecological spatial planning. This method can be expanded to include applications in different areas across the country. However, creating wetland ecosystem maps at different scales and scopes requires appropriate content, methods, and presentation adjustments.

The study only stops at identifying the spatial distribution boundaries of wetland ecosystems but has not assessed their changing trends over time due to limitations on multi-temporal data series. In addition, the quantitative assessment of structural and functional characteristics of wetland ecosystems has not been mentioned. This will be the direction for subsequent studies to improve further and perfect the process of creating wetland ecosystem maps in particular and landscape ecology maps in general.

Acknowledgments

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