Chapter 30
Mapping Wetland Ecosystems Protection and Restoration Priority Using GIS, Remote Sensing, Landscape Ecology, and Multi-criteria Analysis (Case Study in Dong Thap Muoi)

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Abstract The prioritisation of wetland ecosystems is the essential information contributing to scientific and methodological fundamentals for establishing the National strategy and plan on environment protection and biodiversity conservation for each wetland ecosystem in Vietnam. This paper proposes the method of mapping and ordering the priority of wetland ecosystems protection and restoration based on the application of GIS, remote sensing, landscape ecology approach, and multi-criteria analysis. The primary method consists of 3 phases: (i) Defining the protection and restoration criteria; (ii) Mapping wetland ecosystems and building criteria layers based on GIS, remote sensing, and landscape ecology approach; (iii) Determining the priority of wetland ecosystems using multi-criteria analysis. This method is applied to Dong Thap Muoi—a high biodiversity wetland region composing two Ramsar sites and conservation areas. The data of 14 criteria on capacity, degradation services, and pressures on each wetland ecosystem are synthesised using GIS and remote sensing images. AHP-TOPSIS—a hybrid multi-criteria assessment method prioritises wetland ecosystems' conservation and restoration. The study indicated that the criteria of the number of endangered and rare species, total species, invasive alien species, and the lost number of endangered, rare animals and plants play a crucial role in prioritising protection and restoration. The results are the wetland ecosystems protection and restoration priority order maps, which support making appropriate

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decisions to formulate policies and build conservation strategies and plans in the Dong Thap Muoi region.

Keywords Wetland ecosystem · GIS · Remote sensing · Landscape ecology · Multi-criteria analysis · Priority order · Wetland protection · Restoration

30.1 Introduction

Wetland is among the most valuable environments globally, essential for the survival, reproduction, and biodiversity of animals and plants, where birds, mammals, reptiles, amphibians, fish, and invertebrates are densely gathered and store the vital plant gene sources. The interaction of physical, biological, and chemical elements of the wetlands as part of the "infrastructure nature" of the Earth forms the functions for life, such as water storage, storm shielding, flood mitigation, coastal stability and erosion control, groundwater supply and storage, water purification, nutrients, sediments, and contaminants retention, local climatic condition regulation. Besides that, wetland ecosystems also provide education, entertainment, travel services, and human livelihoods (Ramsar Convention Secretariat 2013a, b; Vietnam Environmental Protection Department 2005).

Having had 12 million ha of wetland (https:// baotainguyenmoitruong.vn/bao-ton-va-su-dung-ben-vung-cac-vung-dat-ngap-nuoc-298871.html), Vietnam is known as one of the high biodiversity countries in the world with a variety of wetland ecosystem types, species of creatures, and richness of gen source. Economic development and climate change have been making a significant negative impact on wetland ecosystems. Human activities have significantly resulted in the lost and degraded biodiversity lost and degraded, such as mangrove deforestation, forest burning, destructive fishing practices, environmental pollution, overexploitation, and the introduction of invasive species. Besides, such natural disasters as fires, storms, drought, salinisation, cyclones, and epidemics, are also other factors that badly affect the condition and primary natural resources of wetlands (Vietnam Environmental Protection Department 2005; Ministry of Natural Resources and Environment 2021; Nhan 2014). Consideration of great biodiversity potentials, services, and the threats to the wetland ecosystems, it is vital to investigate and evaluate the environmental status, the gen and the species richness, and the degraded natural ecosystem to find possible solutions for restoration, conservation, and wise and resilient usage of Vietnam's biological resources.

In Vietnam, the contents of planning for environmental protection and biodiversity conservation include: assessing the status and evolution of environmental quality, natural landscape, biodiversity, and climate change effects; defining the objectives, the tasks, and solutions for environmental protection; zoning the environment; conserving nature and biodiversity; and building criteria to determine the critical level and the implement priority order of national projects, (National Assembly of the Socialist Republic of Vietnam 2020; National Assembly of the Socialist Republic of Vietnam 2017). The decrees detail several articles of the Law on Environmental protection and planning (Government of the Socialist Republic of Vietnam 2019; Government of the Socialist Republic of Vietnam 2022) show that wetland ecosystem is one content of biodiversity conservation planning, which has to evaluate and order the priority for investment and implementation.

By 2030, Vietnam's National strategy on biodiversity (Prime Minister of the Socialist Republic of Vietnam 2022) is conservation with sustainable ecosystem services usage, and biodiversity contributes to developing the social economy, reducing poverty, and improving people's living standards by applying the ecosystem approach to conservation and biodiversity. The National strategy's general target on biodiversity is increasing the area of protected and restored natural ecosystems, keeping the integrity and connection. Besides, the strategy also defines some of the content and critical building the processes and technical guidance for restoring the degraded natural ecosystems, especially wetland ecosystems, coral reefs, and seagrass, and developing the guide of ecosystem services quantification.

Previous studies and projects mainly focused on wetland classification based on water and land cover elements without indicating the different conditions of wetland ecosystems such as forming origin, soil, elevation, climate, hydrology, oceanography (Hai et al. 2015; Phuong and Hoe 2015; Linh et al. 2018; Vietnam Institute and of Geodesy and Cartography 2012; Vietnam Institute and of Geodesy and Cartography 2018; Vietnam Institute and of Geodesy and Cartography 2020; Xuan and Hoa 2015). These are also the essential elements that form in a particular wetland ecosystem.

In Vietnam, the ecological landscape approach has been applied to study the adaptation of some plants to develop the economy and conserve mangrove forests (Nguyen et al. 2015); zone and evaluate the ecological landscape potential for territorial organisation, planning for sustainable development of coastal wetland ecosystem (Hang 2012; Duong 2009) or assess landscape according to ecological-economic approach (Huan 2005). Landscape analysis is also used in the world to research wetlands (Tudor 2014; Environmental Law Institute 2013; Lopez et al. 2013; Malekmohammadi and Jahanishakib 2017); there has not been any proposal on the mapping process of wetland ecosystems based on the ecological landscape approach in all the above papers and books.

The requirements to show that the project or wetland ecosystem needs to be prioritised for protection and restoration are appropriate criteria and assessment methods. Globally, there are a significant number of studies to identify wetlands that need conservation based on assessing the criteria about biodiversity value, role of ecosystem functions and services (Ramsar Convention Secretariat 2013a, b; Mekong River Commission 2017), risks and vulnerabilities (Malekmohammadi and Jahanishakib 2017; Jiang et al. 2017; Sarkar et al. 2016; Malekmohammadi and Rahimi Blouchi 2014). In Vietnam, the papers often focus on the vital status, pressor, and benefits indicators for measuring and monitoring wetland ecosystems

(Nhan 2010, 2014; Lan and Hai 2009)[1]; sensitive and degradation assessment criteria for coastal wetland ecosystems (Yet et al. 2010; Hung and Hoe 2014), … Using the proposed criteria separately in these studies may not have been sufficient; therefore, the combination usage will comprehensively assess priorities for protecting and restoring wetland ecosystems.

The multi-criteria assessment methods are widely used around the world in many fields. The MCA, AHP, F-AHP, TOPSIS, and F-TOPSIS methods are used to assess and choose the solution for waste management, finding the best position for burying waste. The combinations of MCA, ELECTRE, Delphi, DA, F-MAA, F-AHP, TOPSIS, SWOT, ANP, DPSIR and MUPOM are used to assess environmental quality and climate change, sustainability and ecology. Based upon the association of the DPSIR model with DSS, MCA, MCDA, TOPSIS, and CP, combining Delphi and AHP methods, integrated AHP—GIS to evaluate and manage water resources, river basin, reservoir, flood, and hazards. Using ANP, MCA, MCDA, AHP-TOPSIS for land management; assessing crop selection, agricultural risks, and deciding in agriculture (Chan et al. 2019; Hajkowicz and Higgins 2008; Jozaghi et al. 2018; Opricovic and Tzeng 2004; Velasquez and Hester 2013).

In Vietnam, AHP, PCA, PRA, and SAW methods are used to assess land-use sustainability, select crop models, and determine the weight of the component indexes in the green urban index set. PAM, MFA, AHP, and PCA are used to evaluate green growth. Assessment of landscape ecological adaptation is done by using AHP and F-AHP. The selection of locations for the planning of waste burial using AHP, F-AHP GIS (Cuong 2009; Dat et al. 2017; Dinh 2016; Huong 2030; Linh et al. 2017; Luan and Tram 2013) … However, the multi-criteria analysis method to prioritise wetland ecosystems protection and restoration in Vietnam has not been studied yet.

Remote sensing and GIS have been popularly used to extract, process, and analyse data from multiple sources such as satellite images, geodatabase, topographic maps, elevation data, and LiDAR data… for many applications. The wetland's information on the cover, water quality, landscape degradation, fire risk, and elevation can be captured using remote sensing data. GIS is used to model spatial distribution, character, and attributes of natural, social-economic features by using the algorithm of assign information, overlay, analyzation, calculation, interpolation; editing and publishing thematic maps (Linh et al. 2018; Vietnam Institute and of Geodesy and Cartography 2012; Vietnam Institute and of Geodesy and Cartography 2018; Vietnam Institute and of Geodesy and Cartography 2020; Xuan and Hoa 2015; Hang 2012; Kien et al. 2013; Vietnam Environment Administration 2011; Ve et al. 2013; Tin et al. 2011; Phu 2009; Son 2008).[2] Therefore, remote sensing and GIS are useful

[1] Nhan, H.T.T., Hai, H.T.: Building biodiversity indicators for surveying the wetland ecosystems of Xuan Thuy national park, Nam Dinh province. The 5th National Scientific Conference on Ecology and Biological Resources, pp. 1498–1505. (in Vietnamese).

[2] Thuy, N.T.: Proposing the process of mapping inland wetlands. In: The 9th National Geography Conference, pp. 1097–1100. (Year) (in Vietnamese).

technologies to extract and build data to prioritise wetland ecosystem protection and restoration.

Dong Thap Muoi stretches over three Long An, Tien Giang, and Dong Thap provinces, with about 700,000 ha of Melaleuca forest and water surface. The region is a closed floodplain surrounded by high mounds along the Vietnam-Cambodia border with the storage of over 100 billion m^3 of water storage. Dong Thap Muoi is the last place where the flooded cane and reed forest, one of the typical wetland ecosystems, still exists. Dong Thap Muoi has a relatively sizeable flooded area and high biodiversity in Vietnam with two Ramsar sites, namely Tram Chim National Park in Dong Thap and Lang Sen wetland reserve in Long An. In addition, there are Dong Thap Muoi ecological reserve, biodiversity conservation areas such as Xeo Quyt relic site, and Gao Giong eco-tourism area. These places are the habitat of many species of birds, fish, reptiles, and benthic animals, including many endemic and rare species that need to be protected, and several species, that are in danger of extinction. The wetlands in this area face many problems such as drought, saltwater intrusion, forest fires, sea-level rise, the invasion of alien species due to agricultural production and farming activities, aquaculture, industrial development, tourism, and other human factors demands (Vietnam Institute of Geodesy and Cartography 2012). The ongoing conducted studies in the Dong Thap Muoi region mainly focus on solutions to improve the land and the economic efficiency of the rice-growing wetlands, evaluate the potential for tourism development; conservation of ecosystems, wetlands, and adaptation to climate change with no research related to determining the priority level of protection and restoration of wetland ecosystems. Therefore, the study and application of GIS, remote sensing, landscape ecology approach, and multi-criteria analysis for mapping and ordering priority of wetland ecosystems protection and restoration is essential (Fig. 30.1).

30.2 Researching Data and Methodology

30.2.1 Researching Data

This paper used the data below to build the thematic data layer for each protection and restoration assessment criteria. The detail is shown in Table 30.1. Dong Thap Muoi's data is shown in the VN2000 coordinate system.

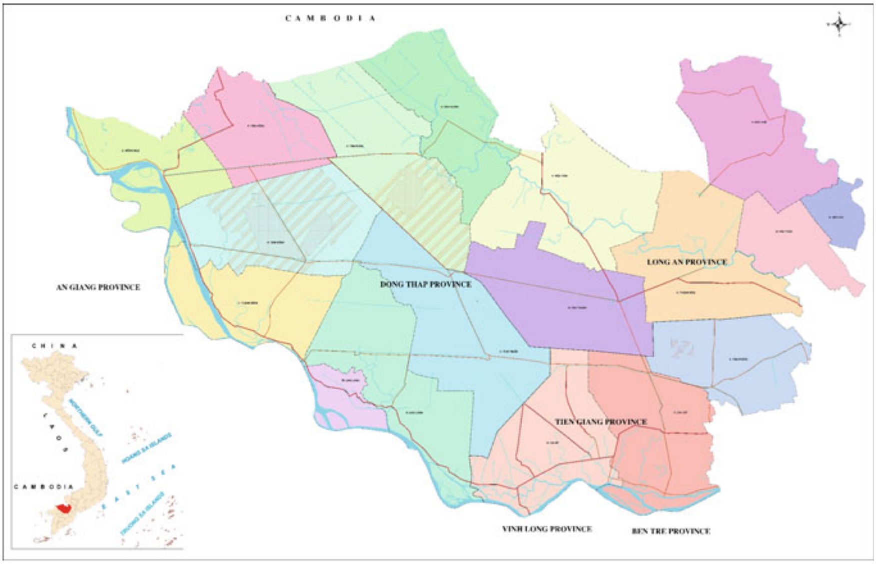

Fig. 30.1 Location of the Dong Thap Muoi (Vietnam Institute and of Geodesy and Cartography 2012)

Table 30.1 Data used for research

Ord	Data	Source
1	Hydrological network	Geodatabase 1:2000 and 1:5000
2	Roads network	Geodatabase 1:2000 and 1:5000
3	Fire points	https://earthdata.nasa.gov/data/near-real-time-data/firms/active-fire-data
4	Water quality	People's Committees of Dong Thap, Tien Giang, Long An
5	Landsat 7, 8 images	http://earthexplorer.usgs.gov/ LE07_L1TP_125052_20100424_20161215_01, LE07_L1TP_125053_20100424_20161215_01, LC08_L1TP_125052_20181031_20181115_01, LC08_L1TP_125053_20181031_20181115_01
6	Land use map	People's Committees of Dong Thap, Tien Giang, Long An
7	Biodiversity, invasion species, strategies, planning map …	Statistical yearbook of Long An, Tien Giang, Dong Thap provinces; Vietnam institute of Geodesy and Cartography; the investigation and survey data, papers and documents …

30.2.2 Researching Methodology

The mapping and ordering of wetland ecosystem protection and restoration priority shown in Fig. 30.2 include three main phases: (i) Defining the protection and restoration definition criteria; (ii) Mapping wetland ecosystems and building criteria layers; (iii) Ordering the protection and restoration priority of wetland ecosystems.

30.2.2.1 Defining the Wetland Ecosystem Protection and Restoration Priority Criteria

The targets of wetland ecosystem protection and restoration are defined based on the referenced documents and data on natural, socio-economic, and environmental conditions and previous research results or use survey consultation results with people,

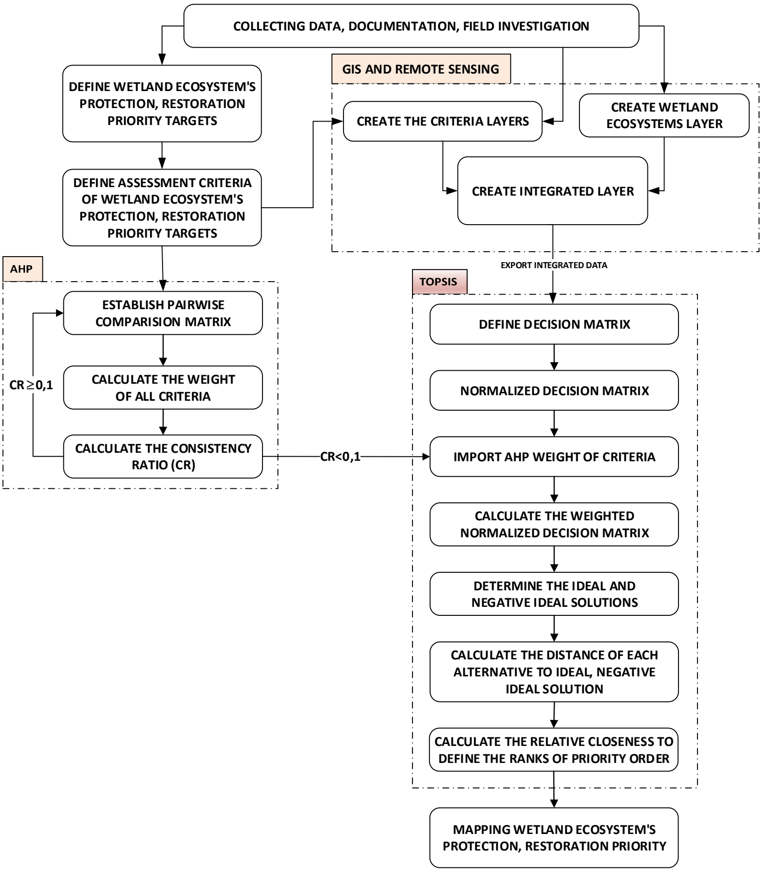

Fig. 30.2 Process of mapping and ordering wetland ecosystem protection, restoration priority

managers, or experts. For each aim, criteria for ordering protection and restoration priority of wetland ecosystems are defined based on ecosystem service values, potential risk pressures, and external factors (natural or man-made hazards).

30.2.2.2 Mapping Wetland Ecosystems and Building Criteria Layers

(a) *Mapping wetland ecosystems*
The wetland ecosystems mapping process is indicated in Fig. 30.3. In this step, the wetland ecosystems map is built using seven thematic landscape ecology data: geology, topography and geomorphology, oceanology and hydrology, bioclimate, soil, vegetation cover, and land use status. These data are created from existing ones or extracted from satellite data and normalised the attribute, boundaries, and topology by GIS. Classifying and numbering landscape types is carried out by overlaying thematic layers. The next step is establishing the wetland ecosystems map based on numbered landscape types using criteria to identify wetland types. The steps as shown in Thuy (2020).

(b) *Building criteria layers*
Using the methods such as collection, statistic, synthesis document, data; field interview, investigation, and survey; measuring, sampling, and analysing samples; modelling; analysing and processing information; and mapping, remote sensing, and GIS to extract and build criteria layers. Area and density

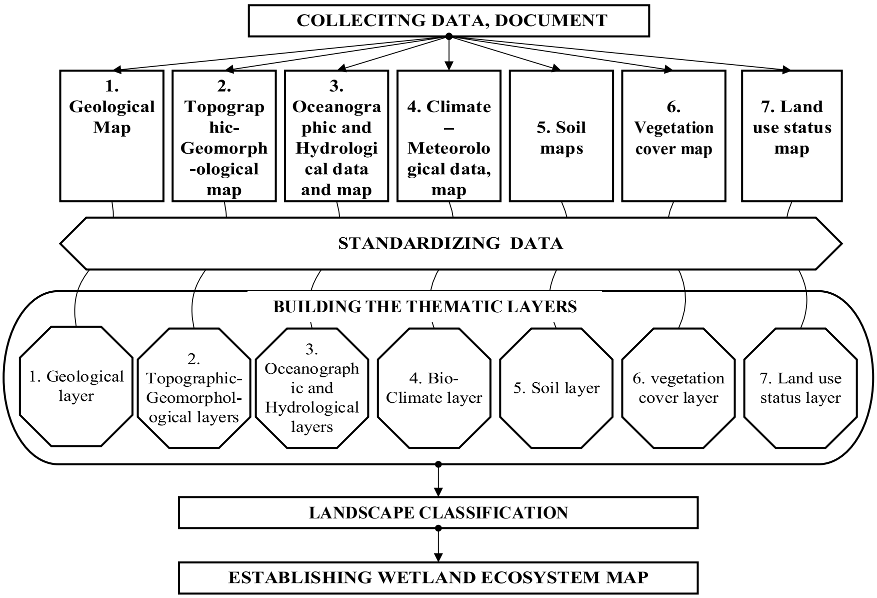

Fig. 30.3 The process of wetland ecosystems mapping

of vegetation, land-use change, surface water quality indicators, land surface temperature, and moisture content are extracted from satellite images combined with field observation data. GIS technology is used to assign and spatialise attributes, overlay, and calculate change; interpolate, re-classify, and construct raster data layers on distance, slope, terrain elevation, temperature, humidity, and precipitation.

The above methods will be chosen depending on the studying regions to collect, extract, model data, and information for the proposed method's input data.

(c) *Creating the integrated map*
The integrated criteria data layer is done by joining the attribute information according to each criterion into the wetland ecosystem layer (map). This step is performed using data superposition techniques, spatial queries, raster data analysis, and attribute association of GIS tools. The result will be exported to build a decision matrix—input data for assessing and ranking priority levels for the protection and restoration of wetland ecosystems.

30.2.2.3 Ordering the Protection and Restoration Priority of Wetland Ecosystems

Analysing many multi-criteria assessment methods shows that the AHP method provides a solution to determine the weights of the reliable criteria through assessing consistency. This solution eliminates the disadvantage of the TOPSIS in that there is no technique to control the reliability of the input criteria weight set. TOPSIS provides a solution to determine the distances from alternatives to the positive and negative ideal solutions, determining the order of priority and overcoming the weakness of AHP, which is the ranking permutation (Velasquez and Hester 2013; Dat et al. 2017) … From these characteristics, this paper proposes a combination of AHP and TOPSIS to order the priority of wetland ecosystems.

(a) *Defining the input criteria weight set by using AHP*
AHP method is used to construct the pair-wise comparison matrix, calculate the weighted set of the evaluation criteria, and determine the consistency in assessing the importance of the criteria. The comparisons are made in pairs and aggregated into a pair-wise comparison matrix of n rows and n columns (n is the number of criteria).

The pair-wise comparison matrix is represented by the following formula (Saaty 1980; Phuong and Mai 2018):

$$A = \left(a_{ij}\right)_{n\times n} = [\,1\ a_{12}\ \ldots\ a_{1n}\ a_{21}\ \vdots\ a_{n1}\ 1\ \vdots\ a_{n2}\ \ldots\ \ddots\ \cdots\ a_{2n}\ \vdots\ 1\,] \quad (30.1)$$

Table 30.2 Table to look up RI values according to the number of criteria (Saaty 1980)

n	1	2	3	4	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

In which, a_{ij} shows the importance of the ith row criterion compared to the j column criterion. The relative importance of criterion i compared to criterion j is calculated according to the ratio k, whereas criterion j compared to criterion i is $1/k$ thus $a_{ij} = \frac{1}{a_{ji}}$. The level of importance is referenced in Saaty's pair-wise comparison table (Saaty 1980).

The AHP determines the inconsistency of pair-wise comparisons (expert judgments) through the consistency ratio (CR) according to the following formula (Saaty 1980):

$$CR = \frac{CI}{RI} \tag{30.2}$$

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{30.3}$$

where CR is the consistency ratio, CI is the consistency index, and RI is the random consistency index corresponding to the number of criteria (n) provided in Table 30.2.

If CR < 0.1, the pair-wise comparison matrix is consistent, so the set of weights is accepted to move on to the next step. Use the AHP method's weights to calculate, process, and rank the wetland ecosystems that must be prioritised for protection and restoration.

(b) *Ordering the protection and restoration priority of wetland ecosystems*
TOPSIS based on the fundamental premise that the best solution has the shortest distance from each alternative to the positive-ideal solution and the longest distance from each alternative to the negative-ideal one. Alternatives are ranked using an overall index calculated based on the distances from the ideal solutions. The ordering of the protection and restoration priority of wetland ecosystems by TOPSIS contains the below steps (Jozaghi et al. 2018):

Step 1 *Building the decision matrix*
The decision matrix $X = (x_{ij})_{m\times n}$ has the number of rows as the wetland ecosystems to be ranked and the number of columns as the criteria used to calculate the order of protection and restoration priority.

Step 2 *Calculating the normalised decision matrix*
The normalised decision matrix is built to transform the dimensional units into scalar units to compare the criteria values in the matrix $X = (x_{ij})_{m\times n}$. The normalised value r_{ij} is calculated by the following formulas:

$$R = \left(r_{ij}\right)_{m\times n} = A_1 \; A_2$$

$$\vdots\ A_m\ (r_{11}\ r_{12}\ r_{21}\ r_{22}\ \ldots\ r_{1n}\ \ldots\ r_{\ldots n}\ \ldots$$

$$\vdots\ \ldots\ldots\cdot_{m1}\ r_{m\ldots}\ \vdots\ \vdots\ \ldots\ r_{mn}\ ) \tag{30.4}$$

where

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{m} \left(x_{ij}\right)^2} \tag{30.5}$$

$$r_{ij} = 1 - (x_{ij} / \sqrt{\sum_{i=1}^{m} \left(x_{ij}\right)^2}) \tag{30.6}$$

The formula (30.5) is used to calculate normalised values of the positive (good) criteria, and formula (30.6) is applied for the negative (bad) criteria.

Step 3 *Calculating the weighted normalised decision matrix*

The weighted normalised matrix is calculated by multiplying the value normalised decision matrix r_{ij} by the weight of corresponding criteria (which is calculated by AHP). The weighted normalised value υ_{ij} is presented by the formula (30.7):

$$\upsilon_{ij} = w_j \times r_{ij} \tag{30.7}$$

where $i = 1,\ldots, m; j = 1,\ldots, n$; m is the number of attribute values in each criterion, n is the number of criteria, w_j is the weight of jth criteria.

Step 4 *Calculating the positive and negative ideal solutions*

The positive (A^+) and negative (A^-) ideal solutions are defined by using formula (30.8) and formula (30.9) as:

$$A^+ = \left[\upsilon_1^+, \ldots, \upsilon_2^+, \ldots, \upsilon_n^+\right] \tag{30.8}$$

$$A^- = \left[\upsilon_1^-, \ldots, \upsilon_{\ldots}^-, \ldots, \ldots_n^-\right] \tag{30.9}$$

where $\{\upsilon_j^+ = \{\upsilon_{\ldots}\};\ \ i = 1, 2, \ldots, m\upsilon_j^- = \left\{\upsilon_{ij}\right\};\ \ i = 1, 2, \ldots, m$ if jth criterion is positive.

$\{\upsilon_j^+ = \left\{\upsilon_{ij}\right\};\ \ i = 1, 2, \ldots, m\upsilon_j^- = \left\{\upsilon_{\ldots j}\right\};\ \ i = 1, 2, \ldots, m$ if jth criterion is negative.

Step 5 *Calculating the distance from each alternative (wetland ecosystem) to the positive and negative ideal solution*

The distance from each alternative to the positive and negative ideal solutions is obtained by applying the Euclidean distance theory. Formulas (30.10) and (30.11) show positive and negative distance calculation processes.

$$S_i^+ = \sqrt{\sum_{j=1}^{n}\left(\upsilon_{ij} - \upsilon_j^+\right)^2} \tag{30.10}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}\left(\upsilon_{ij} - \upsilon_j^-\right)^2} \tag{30.11}$$

Step 6 *Calculating the relative proximity of each alternative (wetland ecosystem) to the positive ideal solution*
The below formula determines the relative closeness of the *i*th alternative:

$$C_i^+ = S_i^- / \left(S_i^+ + S_i^-\right) \tag{30.12}$$

where $0 \leq C_i^+ \leq 1, \quad i = 1, 2, \ldots, m$

Step 7 *Ordering the protection and restoration priority of wetland ecosystem*
The order of wetland ecosystem protection and restoration priority is based on the relative proximity calculated in the previous step. The wetland ecosystems with a high priority will have higher C_i^+values and are closer to the ideal positive solution. They are suitable and should be chosen. The orders in this step are assigned to the wetland ecosystem data layer to present the wetland ecosystem protection and restoration priority map.

30.3 Results and Discussion

30.3.1 Defining Dong Thap Muoi's Wetland Ecosystems Protection and Restoration Criteria

The selected objectives and criteria for assessing the wetland ecosystems protection and restoration priority of Dong Thap Muoi region are proposed based on synthesising the collected documents, research, and interviewed local people and managers about the natural, social-economic, ecological conditions, master plan, planning, plan. After considering all interviews and available data of Tram Chim National Park (TC), Lang Sen Wetland Reserve (LS), Dong Thap Muoi Ecological Reserve (DTME), Xeo Quyt relic site (XQ), Gao Giong eco-tourism area (GG), Dong Thap Muoi medicinal plant conservation area (DTMM), Tan Lap floating village tourist site, Dong Sen Go Thap ecological area (DSGT), the authors decided to select objectives and criteria that are protecting and restoring the cultural and supporting services. The criteria are listed in Table 30.3.

Table 30.3 Selected criteria for ordering protection and restoration wetland ecosystems priority of Dong Thap Muoi region

No	Name of the criteria	Unit	Sign
A	**Protection**		
I	**Support Services**		
1	*Biodiversity*		
1.1	Total species	Species	BV1
1.2	The number of endangered and rare species	Species	BV2
2	*Pressure on biodiversity*		
2.1	The number of invasive alien species	Species	BV3
2.2	Water salinity	‰	BV8
2.3	Forest fire sensitivity		BV9
II	**Cultural services**		
1	*Ability to provide tourism and entertainment services*		
1.1	The average number of tourists per year	Person	BV10
1.2	Average annual revenue from tourism	Million	BV11
2	*Pressure on tourism and entertainment*		
2.1	Distance from livestock areas to wetland regions	m	BV4
2.2	Distance from industrial areas to wetland regions	m	BV5
2.3	Distance from residential areas to wetland regions	m	BV6
2.4	Distance from roads to wetland regions	m	BV7
B	**Restoration**		
I	**Support services**		
1	Decreased vegetation cover area	ha	PH1
2	The lost number of endangered, rare animals and plants	Individual	PH2
3	Surface water quality		PH3

30.3.2 Creating Wetland Ecosystems Map

The wetland ecosystems map is inherited from previous research (Thuy 2020), which was established using seven thematic landscape ecology data: geology, topography and geomorphology, hydrology, bio-climate, soil, vegetation cover, and land use. The Landsat satellite images were used to correct the vegetation cover and land use layers. The wetland ecosystems map is shown in Fig. 30.4.

30.3.3 Building Criteria Data Layers

The decreased vegetation cover area (PH1) is extracted and calculated using Landsat 7 and 8 imagery on 24/4/2010 and 15/11/2018. All of them are converted from the

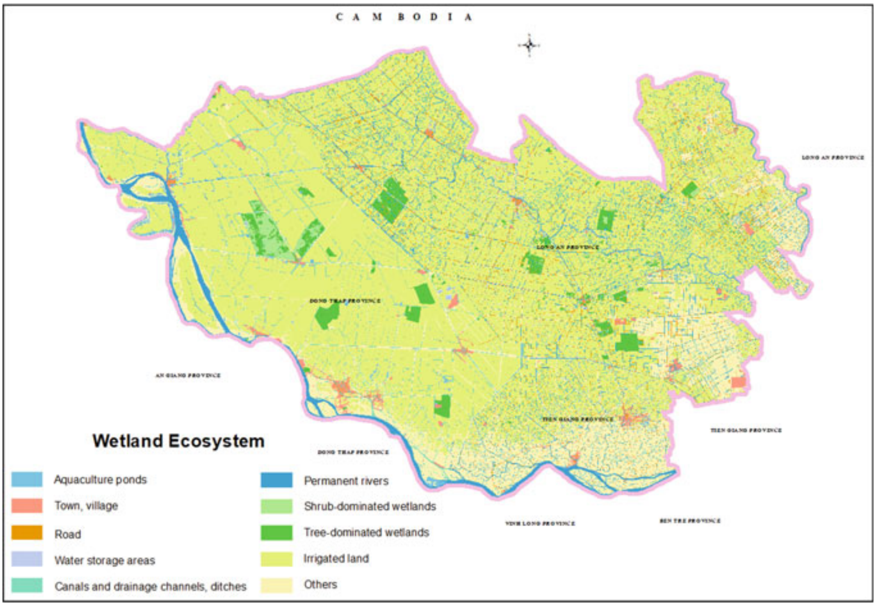

Fig. 30.4 Wetland ecosystems map (Thuy 2020)

WGS-84 coordinate system to the VN2000 coordinate system. Landsat 7 images are filled gaps using the SCP tool of QGIS to fix scan line errors.

The criteria values of BV1, BV2, BV3, and PH2 are collected from papers, projects and field investigations. The livestock, industrial, and residential areas are extracted from the land-use map; the road network is derivated from the geodatabase at scales 1:2000 and 1:5000. Using ArcGIS 10.5 Euclidean Distance tool creates distance rasters of BV4, BV5, BV6, and BV7. The water salinity (BV8) layer referenced the data of saltwater intrusion in the state scientific project BĐKH.11/16-20 (Nghi et al. 2019).

The forest fire sensitivity (BV9) data layer is an algorithm of density (D), humidity (H), vegetation types (LC); land surface temperature (LST); distances from wetland ecosystems to water sources (WS), residential areas (RA), and roads (RO). The characteristic vegetation and land surface temperature rasters are achieved from satellite images; the water sources (hydrological network) are derivated from the geodatabase at scales 1:2000 and 1:5000; the distance rasters are done the same as BV4, BV5, BV6 and BV7. The fire sensitivity can be explained as below:

$$\begin{aligned} \mathrm{FI} = {} & 0.35 \times \mathrm{LC} + 0.25 \times \mathrm{LST} + 0.05 \times \mathrm{H} + 0.11 \times \mathrm{D} \\ & + 0.15 \times \mathrm{RA} + 0.04 \times \mathrm{RO} + 0.05 \times \mathrm{WS} \end{aligned} \tag{30.13}$$

The forest fire sensitivity raster is compared with fire points data and inquired fire information, indicating the suitable fire happening in Dong Thap Muoi region.

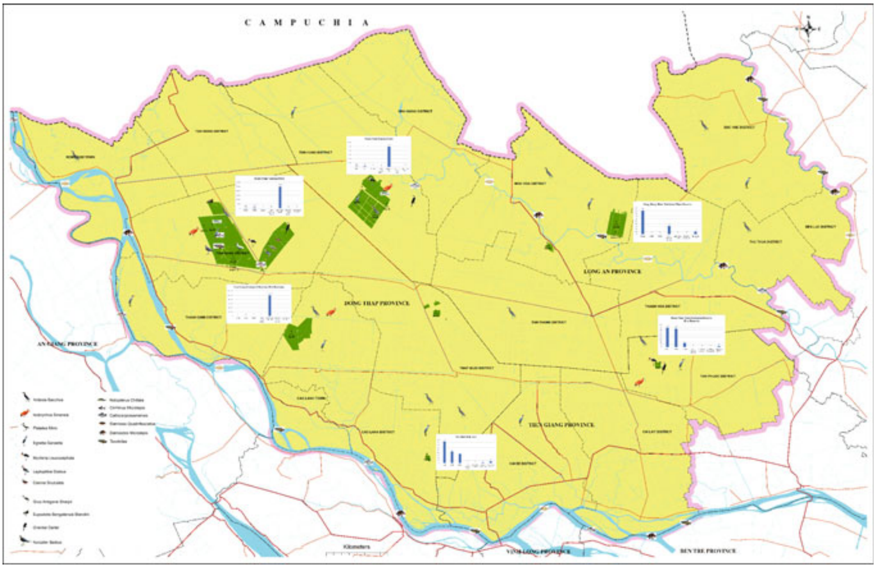

Fig. 30.5 Biodiversity data

The potential provision of tourism and entertainment service is counted through two parameters: the average number of tourists per year (BV10) and the average annual revenue from tourism (BV11). These data are collected, processed, and converted to the current time in 2018.

Surface water quality data (DO, COD, TSS) is defined based on regression Landsat 8 images (Band 1, 2, 3, and 5) and sampled data on 11/2018, in Dong Thap Muoi region.

All criteria layers will be spatialised and assigned to each wetland ecosystem using ArcGIS 10.5 software (Figs. 30.5, 30.6, 30.7, 30.8, 30.9, 30.10, 30.11 and 30.12).

30.3.4 Ordering and Mapping Dong Thap Muoi's Wetland Ecosystems Protection, Restoration Priority

The assigned data of 14 protection and restoration criteria in the wetland ecosystems map are exported by ArcGIS 10.5 tool to excel format to calculate and rank the priority protection and restoration of wetland ecosystems. The detailed data are shown in Tables 30.4 and 30.5.

This study determined the importance of each pair of all protection and restoration criteria based on surveys and interviews with experts who are managers and

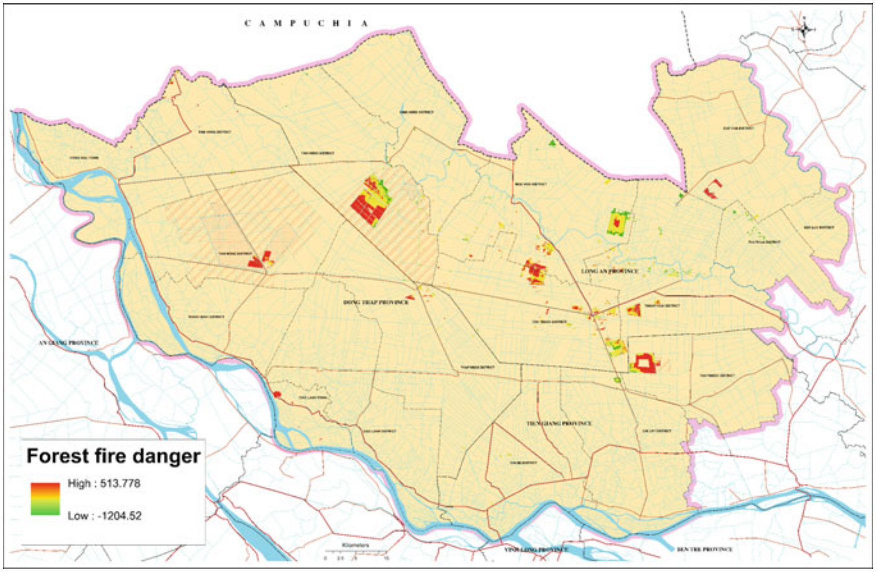

Fig. 30.6 Forest fire sensitivity data

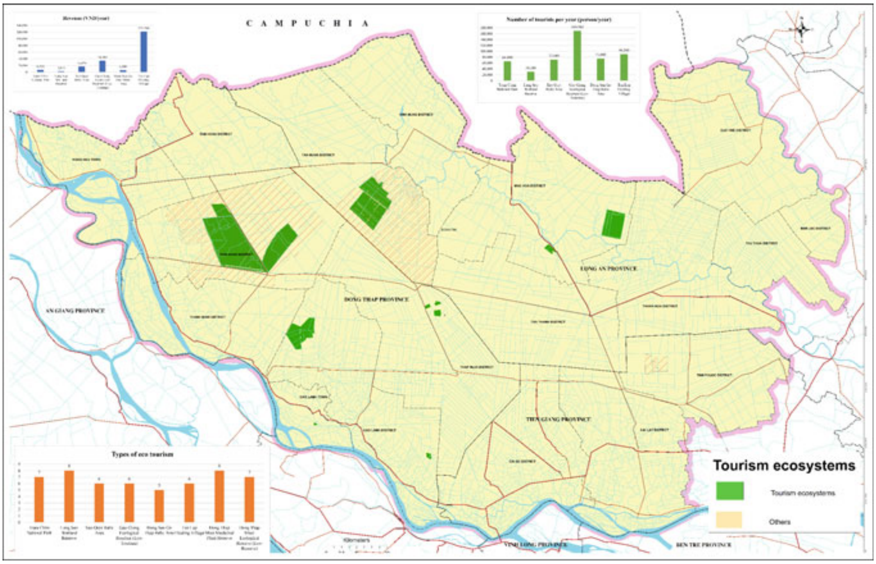

Fig. 30.7 Tourism and entertainment data

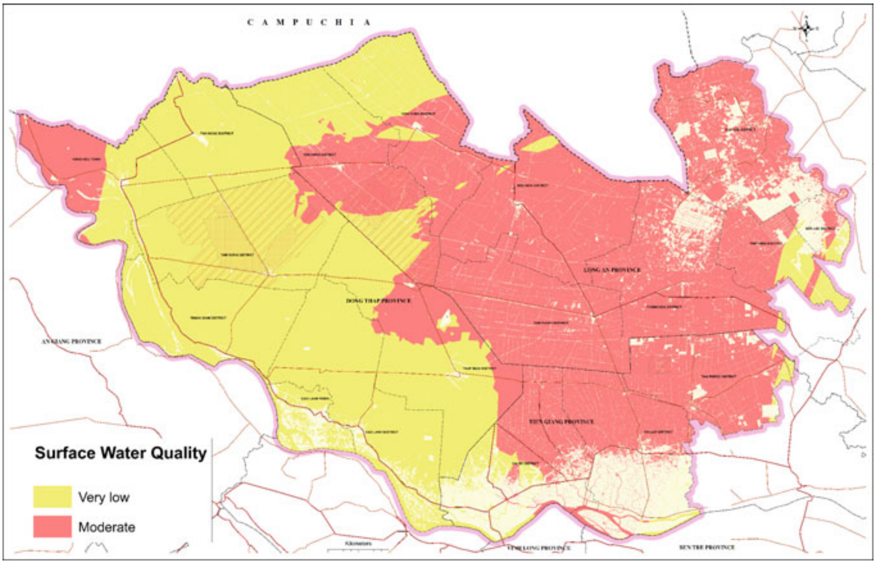

Fig. 30.8 Surface water quality data

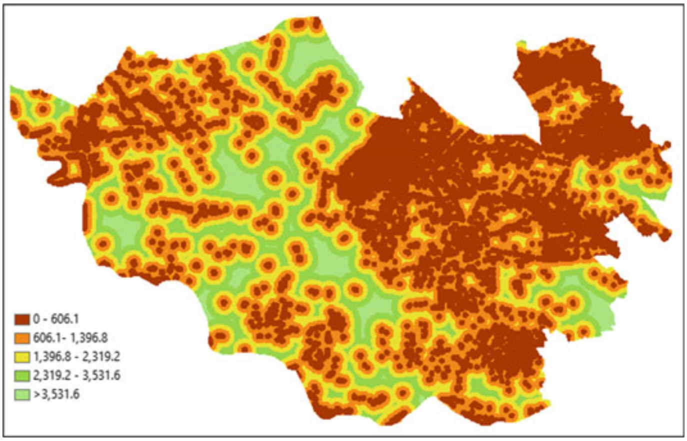

Fig. 30.9 Distance from livestock areas

researchers in the fields of nature and biodiversity conservation, environment, land management, economy and society.

Protection and restoration criteria weights are calculated by the AHP method because they have CR < 0.1. Tables 30.6 and 30.7 show the results.

The weights of these criteria were also discussed and confirmed by many landscape ecological experts in three workshops.

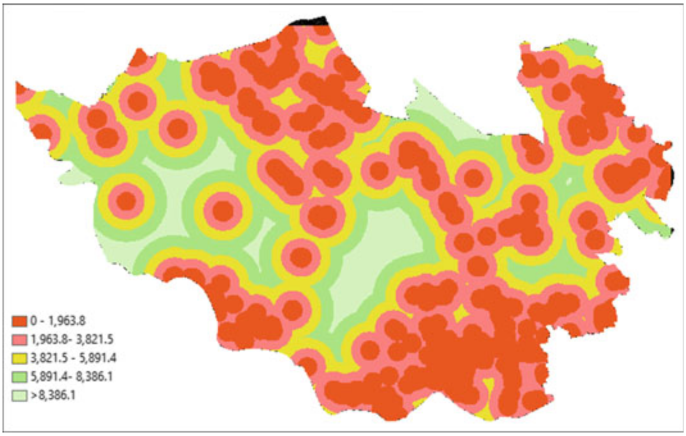

Fig. 30.10 Distance from industrial areas

Fig. 30.11 Distance from roads

The protection and restoration priority orders of 8 wetland ecosystems are computed by the TOPSIS method. The results are respectively shown in Tables 30.8 and 30.9.

The calculated orders are reassigned into the wetland ecosystem layer to establish the wetland ecosystem protection and restoration priority maps. The symbols are expressed in fractions $\frac{8}{\text{Stx}-\text{M}}$, in which the numerator (8) is priority order, and the denominator is the ecosystems wetland sign names (Vietnam (Stx)—Ramsar (M)). These maps are shown in Figs. 30.13 and 30.14.

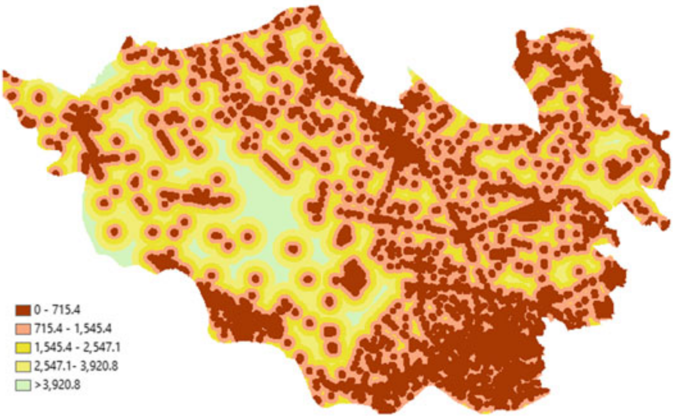

Fig. 30.12 Distance from residential areas

Table 30.4 Detailed criteria data to evaluate the priority of protection

Wetland ecosystem	Criteria										
	BV1	BV2	BV3	BV4	BV5	BV6	BV7	BV8	BV9	BV10	BV11
TC	667	57	12	2280.9	1066.7	937.9	210.9	0	189.1	66,000	6.7
LS	382	20	3	2036.2	1149.6	774.5	127.7	0	38.9	30,200	2.833
DTME	337	8	0	1942.2	1975.6	655.7	163.9	0.25	37.5	0	0
XQ	334	15	6	3037.4	2146.9	313.1	84.6	0	0	72,000	16.92
GG	389	7	0	2870.9	1337.9	1368.7	124.1	0	0	169,582	34.5
DTMM	91	10	0	2361.9	1094.2	810.6	909.4	0	35.0	0	0
TL	0	0	0	2439.7	1174.8	694.7	620.5	0	29.8	90,500	121.5
DSGT	0	0	0	3380.1	1821.1	1812.4	186.7	0	0	75,600	6.3

Table 30.5 Detailed criteria data to evaluate the priority of restoration

Wetland ecosystem	Criteria		
	PH1	PH2	PH3
TC	−383.8	1042	4
LS	0.0	258	5
DTME	0.0	0	4
XQ	−24.3	0	3
GG	0.0	0	5
DTMM	0.0	0	5
TL	0.0	0	4
DSGT	0.0	0	4

Table 30.6 Protection criteria weights

Criteria	BV1	BV2	BV3	BV4	BV5	BV6	BV7	BV8	BV9	BV10	BV11
Weight (AHP)	0.19	0.23	0.14	0.11	0.08	0.08	0.06	0.05	0.03	0.04	0.01

Table 30.7 Restoration criteria weights

Criteria	PH1	PH2	PH3
Weight (AHP)	0.29	0.65	0.06

Table 30.8 Wetland ecosystems protection priority order

Wetland ecosystem	Solution			
	$S^{+}{}_{i}$	$S^{-}{}_{i}$	C_{+i}	Rank of protection
TC	0.071	0.268	0.791	1
LS	0.184	0.107	0.366	2
DTME	0.227	0.088	0.289	4
XQ	0.190	0.105	0.356	3
GG	0.230	0.086	0.272	5
DTMM	0.241	0.059	0.196	6
TL	0.274	0.034	0.109	8
DSGT	0.274	0.047	0.147	7

Table 30.9 Wetland ecosystems restoration priority order

Wetland ecosystem	Solution			
	$S^{+}{}_{i}$	$S^{-}{}_{i}$	$C^{+}{}_{i}$	Rank of restoration
TC	0.294	0.630	0.682	1
LS	0.474	0.333	0.413	2
DTME	0.630	0.294	0.318	5
XQ	0.630	0.275	0.304	8
GG	0.630	0.295	0.318	3
DTMM	0.630	0.295	0.318	3
TL	0.630	0.294	0.318	5
DSGT	0.630	0.294	0.318	5

30.3.5 Verifying and Discussing Results

In order to verify the accuracy of the results, the study: (i) Conducts a field investigation as interviews and surveys; (ii) Compares the results with information on planning and existing studies on these rated sites. Collected data for assessing wetland ecosystem protection and restoration priority are shown in Table 30.10.

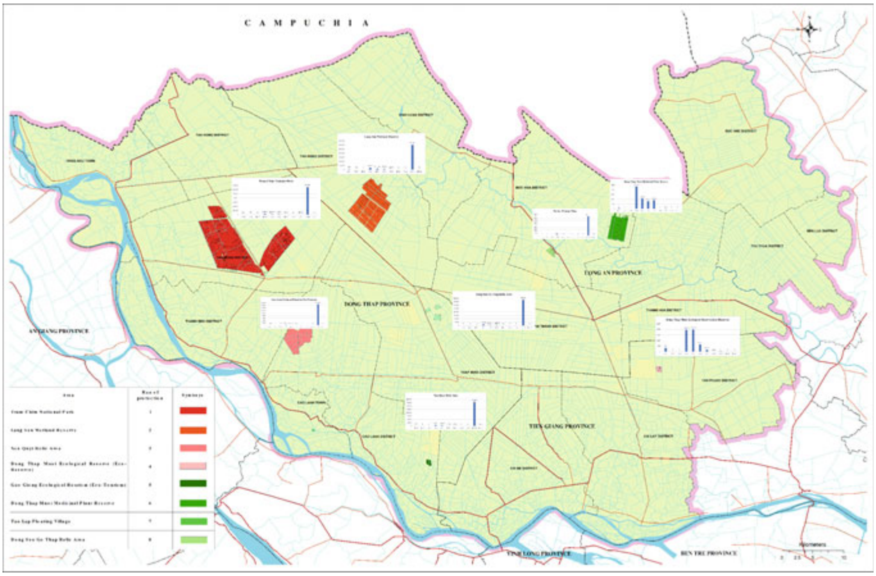

Fig. 30.13 Wetland ecosystem protection priority map

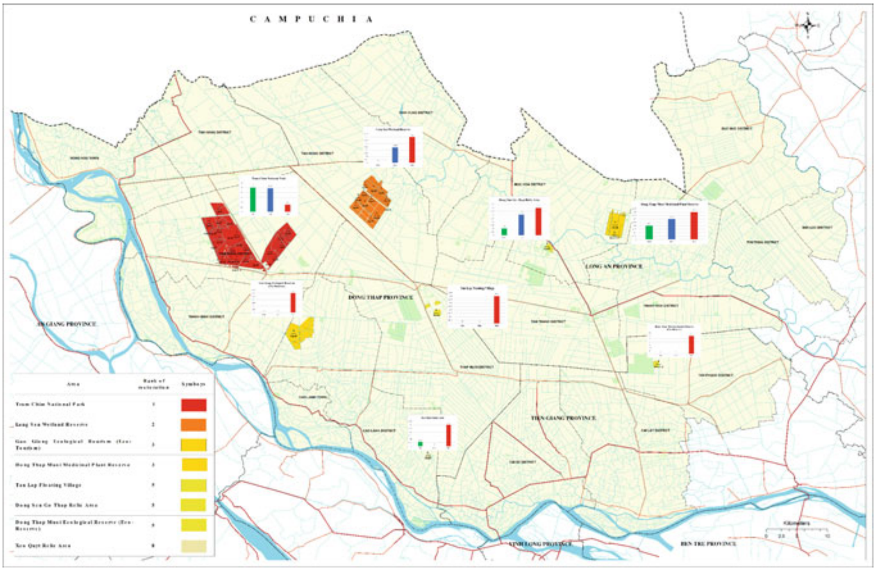

Fig. 30.14 Wetland ecosystem restoration priority map

Table 30.10 Data for assessing wetland ecosystem protection and restoration priority

No	Area	Protection						Restoration		
		Total species	Plant (species)	Bird (species)	Fish (species)	Endangered and rare species	Invasive alien species	Land use change	Sarus crane change	Surface water quality
1	TC	667	304	230	133	57	12	−383.75	1042	4
2	LS	382	156	148	78	20	3		258	5
3	DTME	337	156	147	34	8	–		–	4
4	XQ	334	170	91	73	15	6	−24.30	–	3
5	GG	389	326	63	–	7	–		–	5
6	DTMM	91	91	–	–	10	–			5

Tram Chim's biodiversity is the richest: (the total number of plants, birds, and fish is 667 species), 57 species are endangered and rare, but some of the invasive alien species are the largest (12). Therefore, the value of diversity and the pressure is also the largest. Tram Chim is also the area that meets 7 out of 9 Ramsar international convention standards on wetlands, recognised as the 2000th Ramsar site in the world, the 4th in Vietnam on May 22, 2012. In addition, Tram Chim also has an eco-tourism function with increasingly diverse forms, attracting a significant number of domestic tourists. In 2018, there were over 66,000 visitors with total revenue of over 6.7 billion VND. Therefore, it indicates that the research results that rank this area at the top regarding protection priority are entirely consistent with reality.

Tram Chim ranked first in the restoration priority because the number of Red-crowned Cranes has decreased from 1052 (in 1988) to 11 individuals (in 2018). The lack of food due to the shrinking and degradation of hemp grass area when the local government allows year-round water storage to prevent forest fires and convert the wetlands using the purpose of Melaleuca forest into agricultural land. Satellite data shows an increase in vegetation area of 383.75 ha, which can be explained by the growing area of Mimosa pigra trees. Overexploitation and tourism without reinvestment in planting and restoring *Eleocharis ochrostachys* grass is also a reason for the decline of cranes.

Lang Sen Wetland Reserve has the second protection and restoration priority order, consistent with the fact that data was collected, surveyed, interviewed, and extracted from satellite images. In terms of the total number of species, this is the area with the third highest biodiversity after Xeo Quyt relic site (382 compared to 389) but has 20 endangered and rare species, ranked 2nd after Tram Chim; there are three invasive alien species which is lower than 6 in Xeo Quyt. With the priority level of endangered and rare species protection, Lang Sen is appropriate, and this has also been proven when Lang Sen was recognised as the 2227th Ramsar site in the world and the 7th in Vietnam (27/11/2015). The number of Red-crowned Cranes in decline is 258, so a high restoration priority is appropriate.

In comparison with the total number of species, Xeo Quyt is the 5th; however, the number of endangered and rare species ranks the third, and the number of invasive alien species ranks the second. Therefore, the protection priority ranked 3/6 sites is consistent with the logic and criteria importance level. In terms of priority for restoration, Xeo Quyt is at a low priority because this area has the best surface water quality in the ranked areas and the reduced cover area is −24.30 ha (an increase of 24.3 ha compared to 2010).

Results were verified by the overall planning conservation of biodiversity in Dong Thap 2020, including Tram Chim, Gao Giong, Go Thap, Xeo Quyt are the areas prioritised for conservation (Dong Thap Department of Natural Resources and Environment 2020).

Tables 30.6 and 30.8 show the number of endangered and rare species, total species, the number of invasive alien species, and the distance from livestock areas to wetland regions significantly affect ranking wetland ecosystems protection priority. Tables 30.7 and 30.9 indicate that the loss number of endangered, rare animals and plants is the most considerable and following is decreased vegetation cover area effect on ordering wetland ecosystems restoration priority.

30.3.6 Solution

For such areas as Tram Chim, Lang Sen, Gao Giong, Dong Thap Muoi ecological reserve, Xeo Quyt, Dong Thap Muoi medicinal plants conservation, it is vital to improve and restore the habitat for grass species, especially for *Eleocharis ochrostachys* grass as this is the primary food source for the Red-Crowned crane. It is recommended to plant and protect the melaleuca forest system as a shelter and breeding ground for water birds. Consider keeping the water to prevent forest fires while maintaining and developing grassland ecosystems to attract birds, especially cranes. Having a suitable management mechanism to avoid converting natural land to agricultural production. Developing a mechanism for sustainable ecological and green economic development, combining conservation with tourism development to bring livelihoods and generate incomes to people, and involve them in protecting wetland ecosystems. In areas invaded by alien species, it is necessary to take measures to destroy and limit their spread and development, especially Mimosa pigra trees in Tram Chim. It is essential to further promote people's education through local authorities' propaganda and advocacy of protecting wetland ecosystems with specific policies for protection participants.

For areas with potential for eco-tourism development, such as Tan Lap, Gao Giong, and Xeo Quyt, it is necessary to have solutions to ensure economic development without affecting the ecological habitats of species. There should be a mechanism for reinvesting in improving the living environment, increasing the vegetation cover to attract animals, especially resident birds, to nest, lay, and live.

30.4 Conclusions

Proposing the method of mapping and ordering priority of wetland ecosystems protection and restoration based on the application of GIS, remote sensing, landscape ecology approach, and AHP is the basis for policymaking, environmental protection, and biodiversity conservation planning.

Experimental results show that the application of remote sensing and GIS in establishing, extracting, and modelling input data for assessment, ranking, and mapping protection and restoration of wetland ecosystems is entirely achievable. The results also are valuable in referencing documents and data for Dong Thap Muoi's environmental protection and biodiversity conservation planning.

Besides, the proposed method also has some limitations. It requires having landscape ecological experts and much data to establish the wetland ecosystems map. The input data are often derivated from multiple sources, scales and times. Defining the criteria weights also demands expert and indigenous knowledge. Therefore, this method requires local managers and experts to define the criteria' importance and use many techniques to process and normalise data to the same scale and time.

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