Study on Eco-Safety Early-Warning and Assessment Index System of Hainan Province

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Abstract To have a comprehensive evaluation on the safety of regional ecology, research is required within the fields of eco-safety and early warning on all relevant elements that affect the ecological environment of a given region. This should be complemented by research on influential elements based on regional characteristics and then followed by the construction of an eco-safety early-warning assessment index system. This article analyzes research findings of related ecological assessments and eco-safety problems of Hainan province in particular. With a focus on economic construction and sustainabe development, this analysis reflects on economic, social, environmental, technological, and institutional factors and proposes an eco-safety early-warning assessment index system which suits Hainan's ecological situation. This index system synthesizes Hainan's natural resources, ecological situation, degree of pollution, and economic development and consists of five first-class indicators (low-carbon society, land resource safety, water resource safety, air resource safety, and biological species safety), ten second-class indicators (economy, society, environmental resources, technology, low carbon, system, arable land safety, forest safety, land pollution, etc.) and 90 third-class indicators.

Keywords Eco-safety · Ecological assessment · Safety early-warning · Index system · Hainan Province

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1 Introduction

With the strategy of 'Develop[ing] Hainan [as an] International Tourism Island' being implemented, Hainan will certainly increase its pace of urbanization and industrialization, drawing an abundance of tourists and leading to negative impacts on the local ecology. How to rationally develop and use natural resources; reduce the pressure of human activities on the local environment; explore the potential of available resources; ensure ecological safety; and promote sustainable local economic development have become key research foci in local development processes. Going deeply on current Hainan eco-safety status, assessing eco-safety are particularly important to guarantee the sustainable development of Hainan's economy. Eco-safety refers to the level of danger present in a system composed of human, economic, social, and environmental elements. The sources of danger are excessive consumption of natural resources and environmental degradation caused by human economic activities. The objective of the eco-safety assessment is to develop a strategy for sustainable development between humans and the environment.

2 Ecological Resource Survey of Hainan Province [1, 6]

Hainan became a province in 1988, but has a history spanning more than 2,000 years since its establishment as an administrative division in 110 BC. Now, it contains three prefecture-level cities (Hainan, Sanya, Sansha), six county-level cities, and 10 counties. In 2011, the total population was 9,078,200, among them mainly Han people, followed by Li, Miao, Zhuang, Hui, and other ethnic minorities. The Hainan minorities have long histories, profound cultural heritages, and diversified folk cultures.

Hainan province is located in the southernmost point of China between 3°20′–20°18′ north latitude and 107°50′–119°10′ east longitude. In the north, there is Qiongzhou Strait facing Leizhou Peninsula; to the West, there is Beibu Gulf opposite Vietnam. It is only about 220 nautical miles from the city of Haikou to Haiphong, in Vietnam. It faces Taiwan across the South China Sea on the east, neighbors the Philippines, Brunei, and Malaysia on the Southeast and South in the South China Sea. Hainan Island circled by the sea and neighboring other countries on three sides is the South gate of China.

The administrative region of Hainan province consists of Hainan Island, Xisha Islands, the Zhongsha Islands, the Nansha Islands, and their respective maritime spaces. The land area of the whole province covers 35,400 km^2. Hainan Island, occupying more than 34,000 km^2, is the second largest island in China next to Taiwan, and its sea territory, covering an area of around 2 million km^2, is about two-thirds of the sea space that China governs. This makes Hainan a tropical island province with the smallest land area and largest sea area in China.

The mountainous and hilly land in Hainan, concentrated in the central south of the island, takes up 38.7 % of the total area. Around the mountainous and hilly lands, there are platforms and terraces which occupy 49.5 % of the total area. The roundabouts account for 11.2 % of the total area. The coasts are formed from marine abrasion of the volcano basalt platforms, small harbors or accumulative landforms evolved from drowned valleys, and terraces surrounded by sand bank. The coast ecology is characterized by tropical mangrove and coral reef coasts.

The Xisha, Nansha, and Zhongsha Islands are relatively low and flat with an elevation of 4–5 m generally. The vrakhonisis of the Xisha Islands is the highest with an elevation of 15.9 m or so.

The mountain ranges in Hainan Island are mostly 500–800 m high. The Wuzhi, Yinggeling, Bawangling, Diaoluoshan, and Limuling Mountains are more than 1,500 m above sea level, and they are divided into three mountain ranges: Wuzhi, Yinggoling, and Yajiadaling from east to west. Wuzhi Mountain Range, the highest mountain in Hainan, is in the middle of the Island with its largest peak reaching 1,867 m above sea level. Yinggoling Mountain Range lies northwest of Wuzhi Mountain, with its largest peak being 1,811 m above sea level, while Yajialing, located in the west of the Island, has a main peak that reaches 1,519.1 m above sea level.

Hainan Island has a much higher elevation in the center of the island, with its largest rivers located in the central mountainous area, forming a radiation-like river system. There are 154 rivers flowing from Hainan into the sea, 38 of which have more than 100 km^2 of water-collecting area. The Nandujiang, Changhua, and Wanquan Rivers are the three biggest rivers in Hainan, with water-collecting areas exceeding 3,000 km^2, and a drainage area occupying 47 % of Hainan. Nandujiang River originates from Nanfeng Mountain of Baisha and passes through the middle and north part of Hainan, with a length of 331 km and a drainage area of 7,176 km^2. Changhuajiang River originates from Qiongzhong and traverses the middle and west part of Hainan, with a length of 230 km and a drainage area of 5,070 km^2. There are two branches in the upper reach of the Wanquan River, one in the north and the other in the south, both originating from Qiongzhong with its main stream being 163 km long, and with a total catchment area of 3,683 km^2.

Hainan Island is a tropical oceanic monsoon climate, warm and hot all year round with abundant rainfall, dry and wet seasons, windy weather, and frequent tropical storms and typhoons. It has an annual average temperature of 22.8–25.8 °C, with an average temperature during the hottest month (July and August) 25–28 °C, that of the coldest month (January and February) between 16 and 24 °C, and with an average extreme low temperature of above 5 °C, thus with no severe heat in summer and no severe cold in Winter. There is abundant rainfall in most areas of Hainan, with an annual average rainfall of over 1,640 mm. It is wet in the east and dry in the west, while the rainy area in the east-central mountainous area has an annual rainfall of about 2,000–2,400 mm. There is less rain in the west, with an annual average rainfall of about 1,000–1,200 mm. The rain distributes unevenly in the year with a dry season from November–May, and a

wet season in May–October, with rainfall in the latter accounting for 70–90 % of that of the full year.

Xisha, Nansha, Zhongsha Islands have tropical marine climates. With long summers and no winters, the annual average temperature of these places is 26.5 °C. The highest temperature is in August, with an average temperature of 29.5 °C, and with the lowest temperature in February, with an average temperature of 22.9 °C.

Hainan province is the largest tropical area in China, not only is the natural condition superior, but the natural resources are very rich. Thanks to superior light, heat, water, and other natural resources, plants grow much more rapidly than those in other areas of China. Farm lands can be cultivated all year round, and many crops can be harvested 2–3 times a year. Hainan's land is suitable for cultivation, with the exception of steep slope lands that are more than 800 m above sea level, and sandy areas being short of water and dry that both suit only forest planting. Potential land productivity in Hainan is high, not just for general agricultural products, forest products, and animal husbandry, but also for tropical crops, rare herbs and medicines that are of high economic value.

Hainan has abundant rainfall and large river runoff. There are multiple large reservoirs in Hainan, the best of which are the Songtao, Nanfu, Changmao, and Shilu reservoirs.

The annual precipitation of Hainan is 59.6 billion cubic meters, yielding water resources of 29.7 billion cubic meters. Its fresh water resources can meet lifestyle, industrial, and agricultural demands.

Hainan is the major tropical crop producing area in China. At present, the tropical crops of high economic value in Hainan are rubber, coconut, areca-nut, black pepper, coffee, sisal hemp, citronella, cashew nut, and cocoa. Known as a 'natural greenhouse', 'tropic orchard', and 'four-season garden', Hainan is the major province developing tropical agriculture in China.

There are more than 2,000 different species of trees and shrubs in Hainan, among them, 800 of high economic value and 20 of which are subject to national protection policies. Among 4,000 plant species on the island, 3,100 are medicinal, including four famous South medicines areca-nut, alpinia oxyphylla, fructus amomi, and Radix Morindae Officinalis. Hainan accounts for 99.9 % of the total output for these medicinal plants in China.

Among animal resources in Hainan, 561 are terrestrial vertebrates and 102 are subject to national protection. There is a variety of rare animals in Hainan, among them the Eastern black crested gibbon (*Nomascus nasutus*) being one of the four anthropoids in the world and known as 'the treasure of China'; and Eld's deer (cervus eldii) being praised as a 'rare treasure'. Other animals include red deer, macaque, black bear, and the clouded leopard.

There are eight national level natural reserves covering 22,900 ha and 21 provincial level natural reserves. The national level natural reserves are Datian Natural Reserve (founded in 1986 and home to the aforementioned Eld's deer), Dongzhai Port Mangrove reserve (founded in 1980 and home to a mangrove forest), Sanya Coral Reef reserve (founded in 1990 for its coral reef), Bawangling

reserve (founded in 1988, contains Nomascus hainnanus), Dazhou Island reserve (founded in 1990 for its esculent swift), Jianfengling reserve (founded in 2002), Tongguling reserve (founded in 2003), and Wuzhishan Mountain reserve (founded in 2003).

Hainan, possessing a wealth of offshore fishing grounds, a variety of species and a long catching season, is the ideal place to develop a tropical marine fishery in China. There are more than 800 aquatic products in Hainan, 600 of which are fish, 40 of which are of high economic value with muraenesox, large yellow croaker, trichiurus haumela, dogfishes, and garrupa being the main species. Marine mollusks include cuttlefish, sleeve fish, sea cucumber, and sandworms. At present, more than 20 kinds of fish, shrimp, shellfish, algae that are of high economic value are cultivated in shallow marine areas, including garrupa, abalone, knob prawn, China lobster, Pinctada maxima jameson, Madai pearl shell, and offshore oyster. Special fresh water aquaculture resources include soft-shelled turtle, frog, otter, mink, and giant salamander. The temperature of the offshore sea water is moderate, with more than 3,000 marine organisms growing in it, including more than 1,000 fish species, more than 200 algae species and more than 100 kinds of coral reef. The diverse tropical fish and coral reefs provide a beautiful view in diving tours.

Hainan is also rich in ore resources. Ninety kinds of minerals have been discovered, accounting for 55 % of all discovered minerals in China. Hainan has explored 67 kinds of minerals with proved reserves, of which 41 have been entered into national reserves. There are energy (ilmenite, zirconite, monohydralite) and nonmetal (sapphire, red diamonds, crystal, silica sand) mineral resources.

The South China Sea is one of four marine oil storage areas in the world. Shilu iron deposits account for 71 % of total national high-grade iron ore reserves. Titanium, silica, sapphire, and chemical fertilizer limestone reserves are most valuable in China, while oil shale and granite reserves are among the top in the whole nation.

Hainan Island, having a pleasant climate that remains green through the year, with an attractive tropical landscape and unique oceanic islands, has great potential for developing tourism. According to a general survey, there are a total of 241 exploitable natural and cultural resources in Hainan categorized into 11 types as follows[1, 2]:

1. 38 sandy beaches including Yalong Bay, Dadong Sea, Ends of the Sea, Gaolong Bay, Shimei Bay, etc;
2. 28 mountains including Wuzhishan Mountain, Jianfengling Mountain, Qizhiling Mountain, Dongshanling Mountain, Tongguling Mountain, etc;
3. 18 rare stone and bizarre caves including Maogongshan Mountain, Jigongshan Mountain, Emperor Cave, Pen Dropping Cave, etc;
4. 19 rivers and lakes including Wanquan River, Songtao reservoir, Nanli Lake, etc;
5. 11 waterfalls including Fengguoshan Waterfall, Baihualing Waterfall, Taipingshan Waterfall, etc;

6. 38 hot springs including Xinglong Hot Spring, Guantang Hot Spring, Nantian Hot Spring, Lanyang Hot Spring, Qixianling Hot Spring, etc;
7. 18 wildlife sightseeing spots including Datian cervus eldii, Bawangling nomascus hainnanus, Nanwan Monkey Island, Dongzhai Harbor mangrove forest, Eastern Suburb coconut forest, etc;
8. 13 islands including Wuzhizhou Island, Dazhou Island, Wild Boar Island, etc;
9. 25 historic buildings including the five Saints Temple, Qiongtai Ancient Academy, Dongpo Ancient Academy and eight ancient tombs including Hairui Tomb, Qiujun Tomb, Zhang Yuesong Tomb and Zhaoding cenotaph, etc;
10. modern historical sites including the ancestral home of Soong family, Feng Baiju Former residence; former site of Hainan Column headquarter, etc; and
11. revolutionary martyrs monuments including Hainan Revolutionary martyrs Monument, the memorial statue of the Red Detachment of Women; Statue of General Feng Baiju and the Memorial Pavilion, Tomb of Martyr Li Shuoxun, Jinniuling Martyrs Cemetery, and the Memorial Hall of Baisha Uprising.

3 Building Hainan Eco-Safety Early-Warning and Assessment Index System

The comprehensive assessment of Hainan eco-safety involves natural resources, the eco-environment, the degree of environmental pollution and economic development. Statistical data being were difficult to obtain due to the prefectures being too big while villages and towns were too small. Additionally, most statistical data are using the county as the basic statistical unit, as this facilitates the collection of data and limits mistakes. The county is in the middle of the administration divisions of prefecture and township and is the basic implementation unit of all eco-environmental protection policies. Thus, to some extent, the eco-environment situation of a certain county reflects or represents the eco-safety of the region. So, the basic units of Hainan eco-safety early-warning assessment are the 19 existing counties (cities), which are Haikou city, Sanya city, Sansha city, Wuzhishan city, Wenchang city, Qionghai city, Wanning city, Danzhou city, Dongfang city, Ding'an county, Tunchang county, Chengmai county, Lingao county, Baisha Li Autonomous county, Changjiang Li Autonomous county, Ledong Li Autonomous county, Lingshui Li Autonomous county, Baoting Li and Miao Autonomous county, Qiongzhou Li, and Miao Autonomous county. According to the above discussion on devising Hainan eco-safety early-warning and assessment index system [4–8], the index system is as follows (Table 1).

Table 1 Hainan eco-safety comprehensive assessment index system

First level	Second level	Third level	Unit
Comprehensive assessment indicators of low-carbon society	Economic indicators	GDP/GDP per capita	Yuan
		Population growth rate	%
		Population density	Person/km^2
		Proportion of growth value of tertiary industry accounting for GDP	%
		GDP growth rate	%
		GDP/green GDP per capita	Yuan
		Contribution rate of technical progress on GDP	%
		Three industrial structures	
		Growth rate of domestic investment	%
		Proportion of foreign investment accounting for fixed investments of all society	%
		Net income of rural residents	Yuan
		Disposable income of urban residents	Yuan
		Fiscal revenue per capita	Yuan
		Employment rate	%
	Social indicators	Engel coefficient	
		Urbanization ratio	%
		Illiteracy rate of population aged over 15 years old	%
		Natural growth rate of population	%
		Average life expectancy	Years old
		Gross dependency ratio	%
		Social insurance coverage rate	%
	Resource environment indicators	GDP output–input ration of main mineral products	%
		Proportion of low carbon or new energy accounting for total energy resources	%
		Disposal rate of household garbage	%
		Urban air quality	%
		Comprehensive disposing rate of three industrial wastes	%
		Proportion of environmental protection investment accounting for GDP	%
		Investment strength of ecological construction	

Table 1 (coninued)

First level	Second level	Third level	Unit
		Investment strength of pollution management	
		Generalization rate of environment education	
	Technology indicators	Energy consumption per GDP	
		Carbon dioxide emission per GDP	
		Renewable energy and new energy technology	
		Carbon dioxide catchment and burial technology	
		Resource cyclic utilization rate	%
		New energy elasticity coefficient	
		Proportion of R&D investment accounting for GDP	%
		Proportion of environmental protection investment accounting for GDP	%
	Low-carbon indicators	Proportion of buildings with low carbon energy consumption	
		Utilization rate of heat insulation building materials	
		Rate of approval of CDM projects accounting for that of the world	
		Development degree of carbon finance market	
		Gross carbon dioxide emission load	Ton
		Carbon dioxide emission load per capita	Ton
		Production value of low-carbon products	Yuan
		Development degree of low-carbon agriculture	
		Recognizing degree of low-carbon awareness	
		Publicity degree of low carbon conception	
	Institutional indicators	Mechanism and policy of eco-safety system	
		Improvement degree of ecological early-warning mechanism	
		Institutional norm of eco-safety	

Table 1 (coninued)

First level	Second level	Third level	Unit
		Construction effect of eco-safety system	
		Publicity degree of government affairs	
		Administrative supervision	
		Social responsibility assessment of the enterprises	
Safety of territorial resources	Safety of arable land	Total arable area	10,000 ha
		Arable land per capita	Hectare
		Quality index of arable land	%
		Harvest-guarantee rate of farmland during droughts and floods	%
	Safety of forest	Forest coverage rate	%
		Decrease rate of forest coverage	%
		Ecological forest area ratio	%
	Land pollution	Land pollution rate	%
		Load of three industrial wastes per unit area land	Ton/km^2
		Load of fertilizer, pesticides, agricultural film per unit area arable land	Ton/km^2
	Others	Water and soil erosion	%
		Bearing rate of population	%
		Land reserves	%
		Soil gleization	%
		Land impoverishment rate	%
		Coordination degree of water and soil	%
		Urban green space per 10,000 persons	km^2
Safety of water resource		Total water resources per capita	Cubic meter
		Fresh water resources per capita	Cubic meter
		Industrial wastewater discharge	100 million ton
		Load of industrial wastewater per unit water resource	Ton/cubic meter
		Surface water quality index	%
		Proportion of safe drinking water obtainable in urban area	%
		Proportion of safe drinking water obtainable in rural area	%
		Annual fresh water extraction accounting for total water resources	%
		Proportion of irrigable land accounting for farmland	%

(continued)

Table 1 (continued)

First level	Second level	Third level	Unit
Atmosphere safety		Sulfur dioxide emission load	10,000 ton
		Sulfur dioxide emission load per capita	Ton
		Industrial tailpipe emission	10,000 ton
		Air quality index	%
		Proportion of power generation coming from mineral fuels	%
Safety of species		Proportion of endangered mammalian and bird species	%
		Proportion of endangered higher plant species	%
		Proportion of nation-level natural reserve area accounting for national land area	%

4 Conclusion

This article discusses the frame of Hainan eco-safety early-warning assessment index system from comprehensive evaluation indicators of low-carbon society, safety of territorial resources, safety of water resources, of atmospheric and biological species, using the construction principle of eco-safety index system. It should be emphasized that building an eco-safety early-warning assessment index system must center on economic construction, target sustainable development, and integrate representative indicators of economy, society, resources environment, technology, low carbon and institutions so as to build a feasible eco-safety early-warning index system and provide a scientific basis for the sustainable development of Hainan [5–8].

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