Mathematical Biosciences and Engineering

http://www.aimspress.com/journal/mbe

MBE, 20(12): 20852–20880.
DOI: 10.3934/mbe.2023923
Received: 08 September 2023
Revised: 02 November 2023
Accepted: 06 November 2023
Published: 20 November 2023

Research article

Research on the sustainable development of tourism coupled with economic and environment data —— a case study of Hangzhou

Haifeng Song, Weijia Wang, Jiaqi Zhu, Cong Ren, Xin Li, Wenyi Lou, Weiwei Yang and Lei Du*

School of Electronics and Information Engineering, Taizhou University, Taizhou 318000, China

* **Correspondence:** Email: dulei2@mail2.sysu.edu.cn.

Abstract: The scale of tourism has continued to expand in recent years, and many associated activities cause damage to the natural environment. The tourism, economy and natural environment constitute a system: destruction of the natural environment reduces the value of tourism and a lack of tourism affects the development of the economy. To explore the relationship between the tourism, economy and natural environment, and to explore possibilities for sustainable development, this paper takes Hangzhou, a tourist city in China, as a research object. An analysis of time series data is carried out. First, the tourism, economy and natural environment subsystems are constructed by extracting time series data acquired between 2010 and 2020. Second, a tourism evaluation model with coupled economic and natural environment data is constructed and the coupling degree and coupling coordination level in Hangzhou are evaluated. Third, the time series of each subsystem and the coupling coordination level of the whole system are analyzed. Finally, an optimization strategy is proposed for the coupled coordinated development of the tourism, economy and natural environment in Hangzhou. A key result is that the tertiary industry represented by tourism has become the main source of local income. Hangzhou's tourism coupling coordination level has changed from slight disorder in 2010 to good in 2020. It is also found that the COVID-19 pandemic has become a major factor restricting the development of tourism. Before the outbreak of COVID-19, Hangzhou's tourism industry and economy were synchronized. After the outbreak of COVID-19, both the number of tourists and tourism revenue in Hangzhou fell by nearly 15%.

Keywords: tourism; economics; natural environment; coupling coordinated development; remote sensing images; Hangzhou

1. Introduction

The tourism bureau founded by Thomas Cook in 1841 is a symbol of the birth of modern tourism [1]. Since the birth of tourism, the attention of countries around the world has mainly been

focused on economic development. Tourism has grown rapidly to become the world's largest emerging industry and a new engine for economic development [2]. Although a booming tourism sector strengthens the economy, it can also cause harm to the natural environment. Heavier tourist traffic leads to sharp increases in automobile exhaust emissions, polluting the atmospheric environment. A large number of tourists also produces a large amount of garbage, which can not only damage the beauty of scenic areas but also the arable environment on which vegetation depends for survival. Building tourist facilities without adequate planning and care for the environment and historical features will cause tourism resources to be damaged. The development of tourism activities can promote the development of the economy, but at the same time, frequent tourism activities will certainly cause damage to the natural environment [3]. Tourism, the economy and the natural environment therefore form an interrelated feedback system [4].

A good natural environment is a prerequisite for tourism activities, yet booming tourism can not only reflect the value of the natural environment but also promote economic development. If there is no tourism, the economic and social value of natural resources cannot be well-realized [5, 6]. The scale of the tourism industry expands year after year. The negative impact of tourism activities on the natural environment is becoming apparent [7]. Around the world, more and more natural environments have been compromised by tourism. The destruction of the natural environment leads to a reduction in the value of tourism. The absence of tourism will inevitably affect the development of economies [8]. The tourism, economy, and natural environment are related to each other, forming a mutual influence system [9, 10]. Researching the relationships between various factors in this system can help us understand the coupling coordinated development of the system. Therefore, the relationship between tourism, the economy and the natural environment has become a hot topic of research among scholars [11].

Although many scholars have researched tourism and the environment, most of them have focused on environmental change in a specific region, with few studies investigating the system of tourism, the economy and the natural environment across an entire region [12]. To research the relationship between tourism, the economy and the natural environment, this paper takes Hangzhou, a tourist city in China, as its research object. The main contributions of this work are as follows:

1) A coupling coordination evaluation indicator system of the tourism, economy, and natural environment is constructed, and multi-source time series data are used to ensure the scientific validity of the system.
2) The evaluation level, coupling degree and coupling coordination level between tourism, the economy and the natural environment are calculated using the proposed method. The coupling coordination relationships between these subsystems are determined.
3) Based on the above empirical analysis, countermeasures and suggestions to promote the coordinated development of tourism, the economy and the natural environment of Hangzhou are proposed.

2. Literature review

2.1. Research on the relationship between tourism and the economy

Researchers have paid significant attention to the concepts and methods related to the relationship between tourism and the economy. In the last three years, the keyword "circular economy"

appeared 33 times in [13], "tourism" appeared 93 times in [14] and "strategy" appeared 28 times in [15]. The consensus of many scholars is that "in order to achieve sustainable development of tourism and economy, the traditional mode of obtaining economic benefits by destroying the nature sources must be changed" [16, 17].

In an analysis of the tradition and evolution of Japanese tourism geography, it was found that the empirical research into micro-tourism and the practical methods of intergenerational inheritance based on the perspective of regional geography have significance and applicability for related research in China [18, 19]. Based on analysis of the concept of "low-carbon tourism", it is believed that energy savings, emission reductions, and cost cutting are important ways to achieve low-carbon tourism, and that the realization of a low-carbon economy should not be forced by deliberate constraints [20–22]. Global and local tourism (in wilderness, rural, and urban areas) was analyzed comparatively in emerging economies (China, Malaysia, Thailand), a developed country (Spain), and developing countries (Peru, Argentina, Bolivia). The results suggest that policies should be changed to prevent pollution from the economy and damaging activities associated with tourism [23]. Based on an application of triple bottom line theory, it is believed that the trade-off between the three dimensions of the economy, society, and the environment can change ecologically harmful behavior so as to successfully realize the sustainable development of rural tourism [24, 25].

As can be seen from the research described above, the relevant theories and methods of tourism and economic research are still in the exploratory stage, and the results are mostly based on past and foreign experience and references to relevant disciplines. A complete theoretical system has not yet been formed.

2.2. Research on the relationship between tourism and sustainable development

In the last three years, the keyword "sustainable" appeared 104 times in [26], "development" appeared 166 times in [27], "rural tourism" appeared 32 times in [28], and "policies" appeared 82 times in [29, 30]. It can also be found from the above works that the importance of "sustainable development" is closely followed by that of "tourism", and that the two are closely related. The consensus of many scholars is that the method of interconnection between development and management should be adopted, and that effective management methods should be selected to promote coordinated development. In the context of green development, the method of "grasping the large, linking up and releasing the small" should be adopted, highly competitive tourism projects should be promoted and small projects in characteristic regions should be encouraged to give full play to the advantages of comprehensiveness [31, 32]. From the Belt and Road perspective, the development opportunity of national strategic policies should be seized, and the trade and cultural network of the Silk Road should be developed to fully display its unique style and charm [33–35].

As can be seen from the research described above, regardless of context, factors such as social background and contemporary trends should be fully considered to ensure the timeliness and inform the characteristics of sustainable development research. Research should take the promotion of all-around balanced development as the primary development goal and pay attention to cooperation and exchanges with various parties.

2.3. Research on the relationship between tourism and the natural environment

Protection of the natural environment is a key goal in the development of tourism and the wider economy. By analyzing environmental conditions under different development scenarios, this research explores countermeasures devised to ensure harmonious economic development and environmental protection, and provides a development direction for tourism and the economy. In the last three years, the keyword "nature environment" appeared 68 times in [36], "biodiversity" appeared 62 times in [6, 37], "bearing capacity" appeared 23 times in [38], and "nature reserve" appeared 62 times in [39]. These research topics were therefore adopted in this research. The consensus of many scholars is that the entropy weight method is well suited to the analysis of tourism carrying capacity [40].

The rational development of tourism resources, the improvement of reception facilities, and the establishment of a brand effect for tourist attractions can improve the carrying capacity of tourism environments [41]. Through the construction of an indicator system and use of the coordinated development degree model, it has been shown that the coordinated development of economic benefits and the natural environment need to take into account its superior geographical environment and steadily promote the process of urban and rural environmental governance [42, 43]. Through the application of the relevant coupling system and the entropy value method, it was found that the natural environment and economy as a whole belong to a harmonious state of development. However, there are sharp differences between regions, and the economic benefits of tourism and the natural environment in some regions are retrospective [44].

As can be seen from the above-described research, promoting environmental protection can be carried out with respect to both resources and external influences simultaneously. Control over external negative forces should be strengthened while improving the ability of resources to resist and repair, and the efficiency of the economy and the natural environment should be developed in coordination so as to promote the rational progress of ecological protection.

3. Study area

In the past 10 years, Hangzhou's economy has developed rapidly. In 2020, its GDP ranked among the top eight cities in China for the first time, having risen from 604.956 billion yuan in 2010 to 1610.6 billion yuan in 2020. In 2020, the tertiary industry represented by tourism accounted for 68% of the total GDP. With its rapid economic growth, the urban extent of Hangzhou has also expanded rapidly, a large amount of undeveloped land has been built upon, the quality of the urban living environment has decreased, the ecosystem service function has decreased, and the urban heat island effect has increased. However, in October 2016, Hangzhou was officially identified as the world's first ISO 37101 (Sustainable development in communities) pilot city by the International Organization for Standardization Technical Committee for Urban Sustainable Development (ISO/TC268). Hangzhou has, therefore, become a leader in global urban sustainable development. The Hangzhou government proposed to prevent and resolve various risks and challenges with a pre-planned layout, and to constantly enhance the resilience of urban development. It is thus appropriate to take Hangzhou as a case study for the sustainable and coordinated development of tourism, the economy and the natural environment.

Hangzhou is one of China's National Famous Historical and Cultural Cities. Humans have lived and thrived there for over 8,000 years, and it is known as "heaven on earth" because of its scenic

environment [45]. Hangzhou is located in northern Zhejiang Province in eastern China, and its geographical coordinates are 29° 11′–30° 33′ N, 118° 21′–120° 30′ E. Hangzhou comprises the ten districts of Shangcheng, Gongshu, West Lake, Binjiang, Xiaoshan, Yuhang, Linping, Qiantang, Fuyang and Linan, the two counties of Tonglu and Chunan and the county-level city of Jiande, as shown in Figure 1.

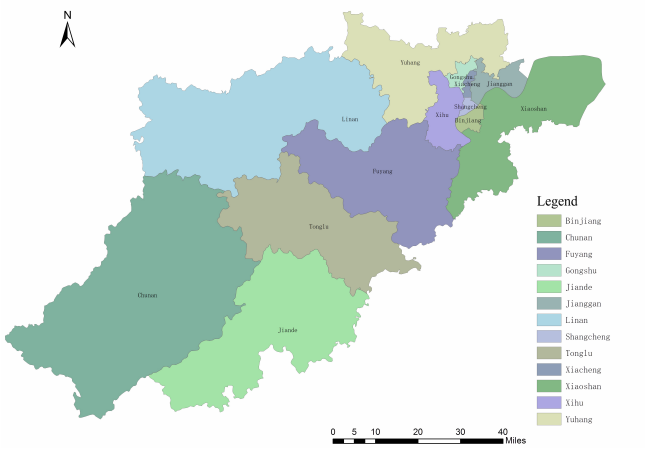


Figure 1. The map of the study area.

In 2021, Hangzhou received 895.18 million tourists from China and abroad, an increase of 5.9% from the previous year. Total tourism revenue reached 152.418 billion yuan, an increase of 6.9%. The added value of the city's tourism and leisure industry was 106.8 billion yuan, an increase of 4.5%. The industry accounted for 5.9% of the city's GDP. Statistics on the tourism industries of major regions and cities in 2021 are shown in Figure 2. There were 848 travel agencies of various types, up by 11.0%, and there were 109 A scenic areas, of which three were 5A [46]. (A and 5A are quality levels of scenic areas in China. They are divided into five levels, from high to low, 5A, 4A, 3A, 2A and A.)

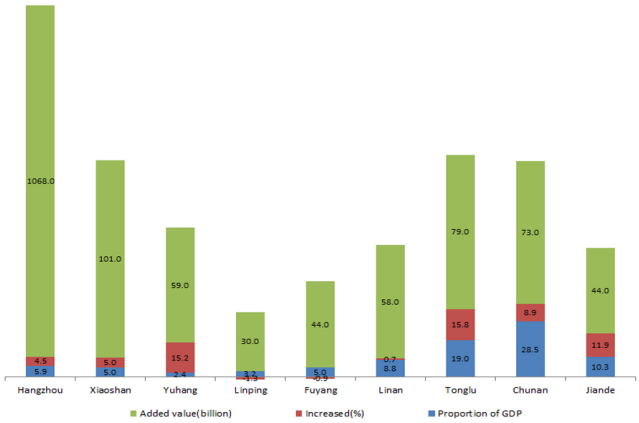


Figure 2. The tourism industry of major regions and cities in 2021.

In 2021, Hangzhou's gross domestic product (GDP) reached 1810.9 billion yuan, an increase of 8.5% over 2020, which is 0.4 percentage points higher than the national increase and equal to that of the whole province. The average GDP growth over the past two years was 6.2%, which is 1.1 percentage points higher than the national GDP growth and 0.2 percentage points higher than the

provincial GDP growth. The per capita regional GDP was 149,857 yuan. The added value of the primary industry was 33.3 billion yuan, up by 1.8% over 2020, with a two-year average growth of 0.6%; the added value of secondary industry was 548.9 billion yuan, up by 8.6% over 2020, with an average two-year growth of 5.4%; and the added value of tertiary industry was 1,228.7 billion yuan, up by 8.7% over 2020 and up 6.8% on average in two years. The growth of the secondary and tertiary industries tended to be synchronized. The structure of added value of the three industries changed from 2.0:29.8:68.2 in the previous year to 1.8:30.3:67.9, with industrial added value accounting for 26.5%, an increase of 0.4% over the previous year. The total fiscal revenue for the whole year was 456.17 billion yuan, an increase of 18.4%. The general public budget revenue was 238.66 billion yuan, an increase of 14.0%, of which tax revenue was 223.36 billion yuan, an increase of 12.9%, accounting for 93.6% of the general public revenue. The general public budget expenditure was 239.26 billion yuan, an increase of 15.6%, of which the people's livelihood expenditure was 183.97 billion yuan, accounting for 76.9% of the general public expenditure.

4. Data and research methods

4.1. Selection and processing of evaluation indicators

4.1.1. Selection of evaluation indicators

In this paper, six evaluation indicators were selected from each subsystem in the city of Hangzhou: the tourism, economy, and natural environment. All the indicator data in this paper are from the website of the Zhejiang provincial government [47]. It was necessary to conduct the research with a small volume of data, because much of the authoritative data on tourism is not publicly available. We must therefore make a trade-off between reliability and appropriateness.

Table 1. The indicators of tourism system with coupled economic and remote sensing data.

Evaluation System	Evaluation indicators	Weights	Character
Tourism subsystem	Number of domestic tourists	0.366	positive
	Domestic tourism revenue	0.264	positive
	Number of travel agencies	0.112	positive
	Number of star hotels	0.106	positive
	Number of accommodation enterprises	0.093	positive
	Number of Catering Enterprises	0.059	positive
Economic subsystem	Gross domestic product	0.180	positive
	GDP of the primary industry	0.264	positive
	GDP of the tertiary industry	0.112	positive
	Total retail sales	0.106	positive
	Total fixed asset investment	0.093	positive
	Number of employees of the tertiary industry	0.059	positive
natural environment subsystem	Area of water	0.226	positive
	Area of forestry	0.185	positive
	Area of cultivated land	0.214	positive
	Area of grassland	0.146	positive
	Area of urban and rural residential land	0.106	negative
	Amount of fertilizer applied	0.123	negative

However, there is no unified indicator for evaluating the tourism, economic and natural

environment. There are many indicators involved in these subsystems, and it is impossible to evaluate them all. When constructing the evaluation indicators system, we follow the principles of combining total indicators and average indicators, highlighting focus, maintaining appropriate proportions, and ensuring that the data are characterizable, measurable, usable and authentic. The establishment of the evaluation indicator system in this paper refers to the work of [48]. The indicator system is constructed as follows:

1) Subjective screening. A questionnaire was used to determine the subjective component of the indicator system. A total of 24 questionnaires were sent out and 24 were recovered, with a valid questionnaire ratio of 100%. The survey subjects were primarily professionals such as industry experts, government administrators and teachers. The diversity of the sample ensures the universal significance of the survey.
2) Statistical analysis. This study involves 18 evaluation indicators. The SPSS statistical analysis software was used. The process of defining variables, performing data entry and conducting statistical analysis depended on the type of question.
3) Indicator weights. The Delphi method [49] and the entropy method were used to determine the weights of the indicators for each subsystem, which were used to quantify and synthesize information on all indicators.

The indicators of the tourism system with coupled economic and remote sensing data are shown in Table 1.

4.1.2. Dimensionless processing of evaluation indicators

Dimensionless processing eliminates the original metric dimension effect through a certain mathematical transformation. Understanding the levels of coupling and coordinated development of the three subsystems to be researched in Hangzhou required a wide range of evaluation indicators. There was no unified metric standard across these multiple indicators, making comparisons difficult. Therefore, to integrate the evaluation indicators for the three subsystems and jointly characterize their coupling and coordinated development levels, it was necessary to carry out dimensionless processing of each subsystem indicator to eliminate the influence of the different dimensions of each subsystem on the overall evaluation results. We evaluated several commonly used normalization methods:

1) Z-score normalization. This method subtracts the mean and divides by the variance for each data point, which requires knowledge of the overall mean and standard deviation. This is difficult to achieve when there is a large volume of data.
2) 0–1 normalization. This method performs a linear transformation of the data to the interval [0,1]. However, when adding new data, it is necessary to redefine the standardized variables, which significantly increases the computational complexity. After standardization, only the distribution of data can be compared, limiting the applicability.
3) RobustScaler. This method uses quartiles for normalization. However, it is not appropriate for large quantities of data or high-dimensional data.
4) Range normalization. This method is often used in scenarios with large volumes of data, as it retains the relationships existing in the original data, and is the most effective method to eliminate the influence of dimensionality and the data value ranges.

In light of the research content of this paper and the interrelation between each indicator, the range normalization method [50–52] was adopted to carry out dimensionless processing on the selected original indicator data. The normalization transformation formula for a positive indicator is as follows:

$$x_i' = \frac{x_i - minx_i}{maxx_i - minx_i.} \tag{4.1}$$

The normalization transformation formula for a negative indicator is as follows:

$$x_i' = \frac{maxx_i - x_i}{maxx_i - minx_i.} \tag{4.2}$$

where $maxx_i$ and $minx_i$ represent the maximum and minimum values of the selected metric i, respectively. After dimensionless processing, the maximum value of each indicator is 1, the minimum value is 0, and the indicator value of each subsystem is between 0 and 1. Thus, the processed indicator values no longer have the original dimensions, making them more convenient for comparison.

4.1.3. Weights of evaluation indicators

After selecting the evaluation indicators for each subsystem and performing dimensionless processing, the values for each subsystem can be compared. However, as the indicators for each subsystem have different levels of importance to the research questions, methods should be used to determine the weight of each subsystem indicator in the overall evaluation. The Delphi method [49] and the entropy method were used to determine the weights of the indicators for each subsystem. The weights of each indicator in the overall system are shown in Table 1.

4.2. Collection of tourism data

The tourism-related data used in this paper were collected from the Data Zhejiang website of the Zhejiang Provincial People's Government and cover the period from 2010 to 2020 [47]. Table 2 shows the tourism data for the city of Hangzhou used in this research.

Table 2. The tourism data for Hangzhou.

Year	Number of domestic tourists (100 million people)	Revenue of domestic tourists (billion yuan)	Number of tourists agencies	Total number of star hotels	Number of accommodation enterprises	Number of catering enterprises
2020	1.7559	3331.3	926	121	510	626
2019	2.0700	3953.7	895	123	531	594
2018	1.7983	3335.6	848	143	449	518
2017	1.5884	2802.1	767	148	446	506
2016	1.3695	2362.6	717	173	417	477
2015	1.2040	2019.7	685	186	417	477
2014	1.0606	1743.9	658	199	409	464
2013	0.9409	1469.9	632	208	413	461
2012	0.8237	1253.2	606	217	408	426
2011	0.7181	1063.8	562	230	425	428
2010	0.6305	910.9	504	236	383	378

After obtaining the original indicator data for the tourism subsystem, but before performing dimensionless processing, the selected indicator data were expressed in different units, meaning that

Table 3. The standard data of the tourism subsystem.

Year	Number of domestic tourists	Revenue of domestic tourists	Number of tourists agencies	Total number of star hotels	Number of accommodation enterprises	Number of catering enterprises
2020	0.7818	0.7955	1.0000	0.0000	0.8581	1.0000
2019	1.0000	1.0000	0.9265	0.0174	1.0000	0.8710
2018	0.8113	0.7969	0.8152	0.1913	0.4459	0.5645
2017	0.6654	0.6215	0.6232	0.2348	0.4257	0.5161
2016	0.5134	0.4771	0.5047	0.4522	0.2297	0.3992
2015	0.3984	0.3644	0.4289	0.5652	0.2297	0.3992
2014	0.2988	0.2738	0.3649	0.6783	0.1757	0.3468
2013	0.2156	0.1837	0.3033	0.7565	0.2027	0.3347
2012	0.1342	0.1125	0.2417	0.8348	0.1689	0.1935
2011	0.0609	0.0502	0.1374	0.9478	0.2838	0.2016
2010	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000

their values could not be directly compared. Therefore, it was necessary to carry out dimensionless processing on the original indicator data to obtain the final standardized data representing the tourism subsystem. The data for the tourism subsystem after standardization using dimensionless processing are shown in Table 3.

4.3. Collection of economic data

Table 4. The economic data for Hangzhou.

Year	Gross domestic product (billion yuan)	GDP of the primary industry (billion yuan)	GDP of the tertiary industry (billion yuan)	Total retail sales of consumer goods (billion yuan)	Total investment in fixed assets (billion yuan)	People working in the tertiary industry (ten thousand)
2020	16106.00	326.00	10959.00	7820.55	426.73	6055.47
2019	15373.05	325.70	10172.28	7207.88	406.70	6187.60
2018	14306.72	305.56	9307.10	6401.32	392.10	5715.33
2017	13160.72	299.96	8407.32	5856.65	357.17	5717.43
2016	11709.45	293.63	7188.96	5842.42	349.06	5176.20
2015	10495.28	278.98	6082.38	5556.32	324.08	4697.23
2014	9502.21	266.62	5282.07	4952.70	301.54	4201.46
2013	8639.91	254.74	4735.54	4263.87	288.93	3531.17
2012	7968.58	249.44	4165.95	3722.75	264.58	2944.63
2011	7153.03	232.32	3594.38	3100.02	224.04	2548.36
2010	6049.56	205.34	2982.77	2753.13	244.31	2146.08

The economic data used in this paper were obtained from the Data Zhejiang website of the Zhejiang Provincial People's Government and represent the period 2010 to 2020 [47]. Table 4 shows the economic data for Hangzhou used in this research.

Similarly to the tourism data, for the economic subsystem, it was necessary to transform the economic indicators using dimensionless processing to enable direct comparisons. The data for the economic subsystem after standardization using dimensionless processing are shown in Table 5.

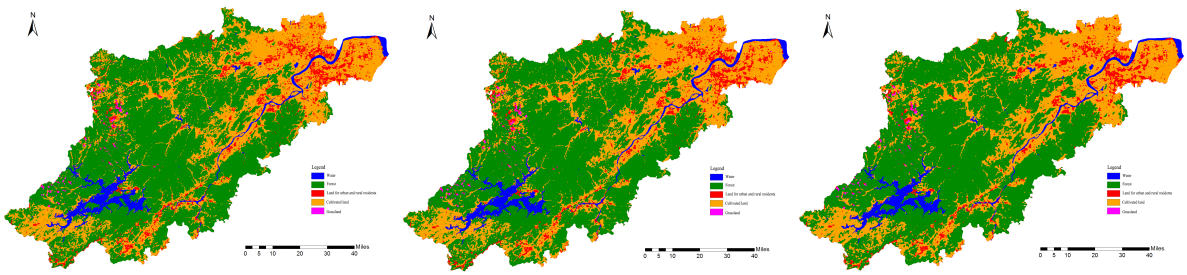
Table 5. The standard data of the economic subsystem.

Year	Gross domestic product	GDP of the primary industry	GDP of the tertiary industry	Total retail sales of consumer goods	Total investment in fixed assets	People working in the tertiary industry
2020	1.0000	1.0000	1.0000	1.0000	1.0000	0.9673
2019	0.9271	0.9975	0.9014	0.8791	0.9012	1.0000
2018	0.8211	0.8306	0.7929	0.7199	0.8291	0.8831
2017	0.7071	0.7842	0.6801	0.6124	0.6568	0.8837
2016	0.5628	0.7317	0.5273	0.6096	0.6168	0.7497
2015	0.4421	0.6103	0.3886	0.5532	0.4936	0.6312
2014	0.3433	0.5079	0.2883	0.4341	0.3824	0.5086
2013	0.2576	0.4094	0.2197	0.2981	0.3201	0.3427
2012	0.1908	0.3655	0.1483	0.1913	0.2000	0.1976
2011	0.1097	0.2236	0.0767	0.0685	0.0000	0.0995
2010	0.0000	0.0000	0.0000	0.0000	0.1111	0.0000

4.4. Collection of natural environment data

The steps taken to extract natural environment information are as follows: First, a representative set of areas was selected for unsupervised classification of remote sensing images from each year. These areas included as many elements of ecological indicators as possible. Second, using existing knowledge and experience for discrimination and verification of the field investigation, the prior knowledge of each category was obtained, and the most suitable feature was selected for further classification. Third, a classifier was designed based on the acquired prior knowledge and sample data to classify all remote sensing images of Hangzhou and obtain the corresponding indicators of the natural environment. Full details are provided in Appendix.

The accuracy was verified based on the confusion matrix obtained using the ground truth regions of interest (ROIs) feature of the toolbox in the ENVI software. Regardless of the classification method, some small patches will inevitably be produced in the classification results, which can affect their validity and must be dealt with accordingly. The majority/minority method was used to deal with these small patches. The processed results were saved in the required file format and imported into the ArcGIS software, in which the colors of the classification indicators were adjusted to obtain the final remote sensing classification results, which are shown in Figure 3. Finally, the relevant statistics were calculated for the research area. The interpretation results for the remote sensing images are shown in Table 6.



(a) 2010 **(b)** 2015 **(c)** 2020

Figure 3. Time series interpretation result from 2010 to 2020.

Table 6. The interpretation results of the remote sensing images.

Natural environment indicators	Code	Year	Area	Rate
Water	11	2010	807238	4.31%
		2015	808806	4.32%
		2020	809599	4.32%
Forest	22	2010	10428720	55.67%
		2015	10736207	57.31%
		2020	10943018	58.42%
Cultivated land	33	2010	4829328	25.78%
		2015	4782304	25.53%
		2020	4740791	25.31%
Grassland	44	2010	61593	0.33%
		2015	54700	0.29%
		2020	44554	0.24%
Land for urban and rural residents	55	2010	2605147	13.91%
		2015	2350009	12.55%
		2020	2194064	11.71%

According to the Data Zhejiang website [47], 922,000 tons of chemical fertilizer were applied in 2010, 875,200 tons in 2015, and 696,100 tons in 2020. The original natural environment indicator data were obtained through remote sensing image interpretation, as shown in Table 7. The standardized data for the natural environment subsystem after dimensionless processing are shown in Table 8.

Table 7. The original data of natural environment indicators.

Year	Water	Forest	Cultivated land	Grassland	Land for urban and rural residents	Amount of chemical fertilizer
2010	807238	10428720	4829328	61593	2605147	92.20
2015	808806	10736207	4782304	54700	2350009	87.52
2020	809599	10943018	4740791	44554	2194064	69.61

Table 8. The standard data of natural environment subsystem after dimensionlessness processing.

Year	Water	Forest	Cultivated land	Grassland	Land for urban and rural residents	Amount of chemical fertilizer
2010	0.00	0.00	1.00	1.00	1.00	1.00
2015	0.66	0.60	0.47	0.60	0.38	0.79
2020	1.00	1.00	0.00	0.00	0.00	0.00

4.5. Evaluation method based on coupled tourism, economic and natural environment data

The evaluation functions for each subsystem (tourism, economy, natural environment) are denoted by $f(x)$, $g(y)$ and $h(z)$, respectively. The calculation methods are as follows:

$$f(x) = \sum_{i=1}^{m} a_i x_i'. \tag{4.3}$$

$$g(y) = \sum_{i=1}^{n} b_i y_i'. \tag{4.4}$$

$$h(z) = \sum_{i=1}^{k} c_i z_i'. \tag{4.5}$$

where a_i, b_i and c_i represent the weights of the tourism, economy and natural environment subsystems, respectively; x_i', y_i' and z_i' represent the indicators of the corresponding subsystems; and all values are dimensionless. Referring to the definition of coupling and the coupling coefficient model used in physics [53], the calculation model for the coupling degree of the tourism–economy–natural environment system can be expressed as

$$C = \frac{3 \times \sqrt[3]{f(x) \times g(y) \times h(z)}}{f(x) + g(y) + h(z)}. \tag{4.6}$$

The result of Eq (4.6) represents the strength of the interaction between the tourism, economy and natural environment subsystems. However, it does not reflect the level of coupling and coordinated development of the entire system. Coordination refers to the phenomenon in which two or more subsystems influence each other through various interactions. The coordination degree is an important indicator to describe the interaction between subsystems, and it is important to distinguish the intensity of each subsystem. However, due to the staggered, dynamic, and unbalanced characteristics of each subsystem, the coordination degree cannot reflect the overall "efficacy" and "synergy" of the interactions between the subsystems. For this reason, the concept of coupling coordination level is introduced in this paper. The coupling coordination level reflects the overall level of coordination development between subsystems, which synthesizes the coordination status and development level between subsystems. As a quantitative indicator to measure the level of coordinated development of tourism, the economy and the natural environment, the coupling coordination level takes into account not only the coordination C of tourism, the economy and the natural environment, but also the combination T of the benefits of these subsystems, so it comprehensively reflects their overall synergy or contribution. The coupling coordination level is calculated as follows:

$$D = \sqrt{C \times T}. \tag{4.7}$$

$$T = \alpha f(x) + \beta g(y) + \theta h(z). \tag{4.8}$$

Based on the existing literature and opinions of experts and scholars, this article argues that the three systems' values are $\alpha = 0.3$, $\beta = 0.3$ and $\theta = 0.4$. The classification criteria for the coupling coordination level are shown in Table 9.

Table 9. The classification criteria of coupling coordination level.

Coupling coordination level	Description	Coupling coordination level	Description
0.90–1.00	Best	0.40–0.49	Slight disorder
0.80–0.89	Good	0.30–0.39	Mild disorder
0.70–0.79	Medium	0.20–0.29	Moderate disorder
0.60–0.69	Elementary	0.10–0.19	Severe disorder
0.50–0.59	Barely	0–0.09	Extreme disorder

5. Results

5.1. Calculation results

In the previous section, the relevant data for the tourism, economy and natural environment evaluation indicators were presented and considered separately, and dimensionless processing was carried out. Combined with the weights of each indicator, the comprehensive evaluation functions $f(x)$, $g(y)$ and $h(z)$ for each subsystem were first calculated using Eqs (4.3)–(4.5). The calculation results are shown in Tables 10–12. It can be seen from these results that the values of $f(x)$ and $g(y)$ increase from 2010 to 2020. The value of $h(z)$ does not change significantly from 2010 to 2020.

Table 10. The evaluation functions of the tourism subsystem.

Weights / Year	0.366	0.264	0.112	0.106	0.093	0.059	f(x)
2010	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.1060
2015	0.3984	0.3644	0.4289	0.5652	0.2297	0.3992	0.3949
2020	0.7818	0.7955	1.0000	1.0000	0.8581	1.0000	0.8530

Table 11. The evaluation functions of the economic subsystem.

Weights / Year	0.180	0.142	0.174	0.143	0.185	0.176	g(y)
2010	0.0000	0.0000	0.1060	0.1460	0.1111	0.0000	0.0599
2015	0.4421	0.6103	0.3886	0.5532	0.4936	0.6312	0.5154
2020	1.0000	1.0000	1.0000	1.0000	1.0000	0.9673	0.9942

Table 12. The evaluation functions of the natural environment subsystem.

Weights / Year	0.185	0.226	0.106	0.146	0.214	0.123	h(z)
2010	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000	0.5890
2015	0.6600	0.6000	0.4700	0.6000	0.3800	0.7900	0.5736
2020	1.0000	1.0000	0.0000	0.0000	0.0000	0.9673	0.5300

Next, Eqs (4.6)–(4.8) were used to calculate the comprehensive evaluation indicator, coupling degree and coupling coordination level indicators for townships in Hangzhou in the research area in 2010, 2015 and 2020. The results are shown in Table 13.

Table 13. Calculation results.

Year	Evaluation level (T)		Coupling degree (C)		Coupling coordination level (D)	
	Ours	CCDEM	Outs	CCDEM	Ours	CCDEM
2010	0.2854	0.2763	0.5087	0.4856	0.7662	0.7639
2015	0.6168	0.6231	0.9881	0.9854	0.9667	0.9774
2020	0.4195	0.3979	0.7090	0.6979	0.8606	0.8548

It can be seen from Tables 11–13 that the values of the valuation level T, the coupling degree C and the coupling coordination level D, increased from 2010 to 2015, decreased slightly by 2020. We also compared the results produced using the method proposed in this paper with the CCDM (Coupling Coordination Degree Model), which is proposed in [48]. It can be seen from Table 13 that the overall

trends in the evaluation level, coupling degree and coupling coordination level are consistent between the two methods. However, the indicators used in this paper are lower than those used in the CCDM method. This shows that the proposed method has higher computational efficiency and robustness.

5.2. *Time series analysis of coupling coordination level*

Based on the calculation results, the comprehensive T, C and D values of each subsystem in 2010, 2015 and 2020 are shown in Figure 4. In 2010, when the tourism industry in the research area was less developed, the evaluation indicator of each subsystem was low (only 0.27), indicating that the overall development of Hangzhou was relatively slow at that time. In 2010, the State Council officially approved the implementation of the Yangtze Delta Regional Plan [54], which positioned Hangzhou as an "internationally important tourism and leisure center." However, in the first few years, the development of tourism was slow. The coupling degree of the tourist sector, the economy and the natural environment system was 0.5087, and the connections between the subsystems were not strong, indicating that the economic benefits brought by tourism to the local area were not significant at this time.

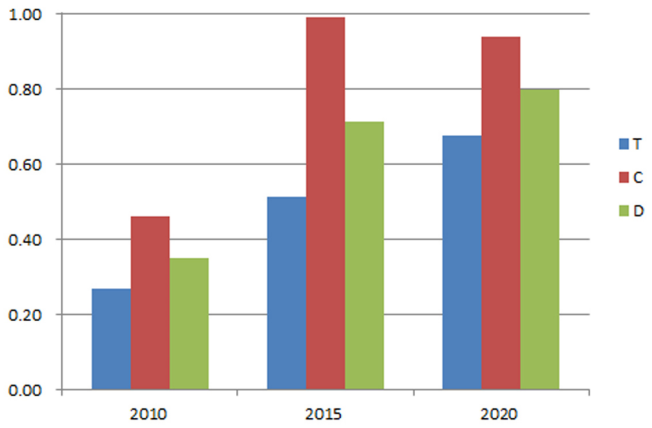
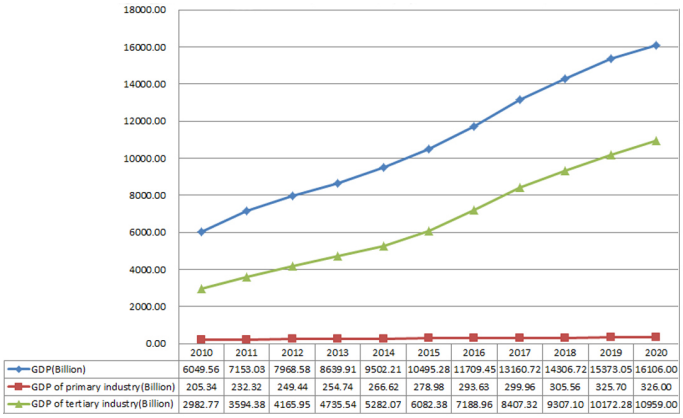


Figure 4. The comprehensive evaluation level, the coupling degree and the coupling coordination level of each subsystem.

5.3. *Time series analysis of the economy subsystem*

In 2015, the gross output of the tertiary sector in Hangzhou (including tourism) was 608.238 billion yuan, accounting for 57.95% of the regional GDP, and the total output value of primary industry was 27.898 billion yuan. Thus, the total output of tertiary industries was more than 21 times that of primary industries. The trend of Hangzhou's economic development from 2010 to 2020 is shown in Figure 5. As shown in the figure, between 2010 and 2020, the overall economy of Hangzhou steadily grew, the regional GDP increased year after year, and tertiary industry (including tourism) also expanded each year, consistent with the trend of increasing regional GDP. This indicates that tourism became the pillar industry of Hangzhou's economy, the Yangtze River Delta Regional Plan issued by the State Council in 2010 had significant effects, and Hangzhou gradually developed into an international center for tourism and leisure.

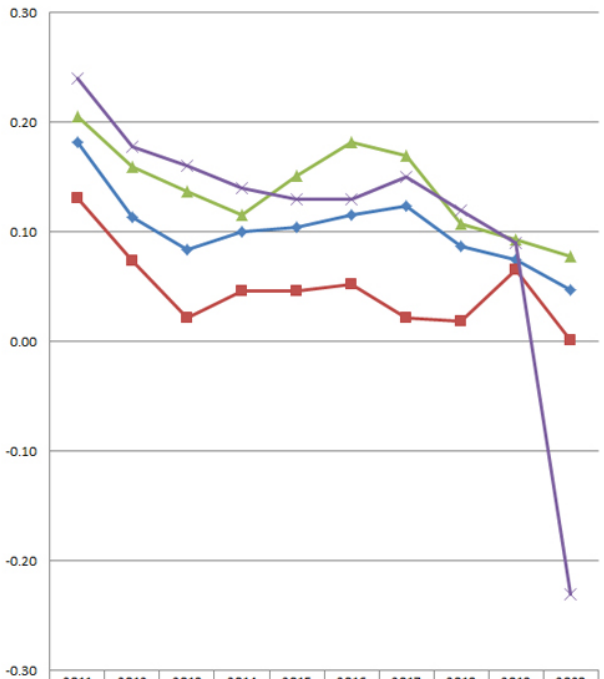
The impact of tourism can be seen even more clearly in the annual growth rate, shown in Figure 6,



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
GDP(Billion)	6049.56	7153.03	7968.58	8639.91	9502.21	10495.28	11709.45	13160.72	14306.72	15373.05	16106.00
GDP of primary industry(Billion)	205.34	232.32	249.44	254.74	266.62	278.98	293.63	299.96	305.56	325.70	326.00
GDP of tertiary industry(Billion)	2982.77	3594.38	4165.95	4735.54	5282.07	6082.38	7188.96	8407.32	9307.10	10172.28	10959.00

Figure 5. The economic development trend of Hangzhou from 2010 to 2020.

which indicates that Hangzhou's annual economic growth rate is roughly consistent with the annual growth rate of tourism revenue. The change in tourism revenue directly affects the trend in the growth of tertiary industry and the GDP. Between 2010 and 2020, the relationship between tourism and the economy became increasingly close, with the coupling degree increasing from 0.46 to 0.94. In 2020, due to the impact of the COVID-19 pandemic, the growth rate of tourism revenue declined significantly, and the economic output of the whole region fell sharply.

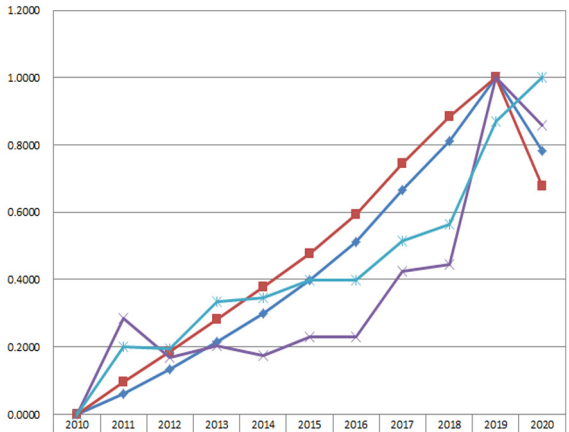


	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
GDP(Billion)	0.18	0.11	0.08	0.10	0.10	0.12	0.12	0.09	0.07	0.05
GDP of primary industry(Billion)	0.13	0.07	0.02	0.05	0.05	0.05	0.02	0.02	0.07	0.00
GDP of tertiary industry(Billion)	0.21	0.16	0.14	0.12	0.15	0.18	0.17	0.11	0.09	0.08
Domestic tourism(Billion)	0.24	0.18	0.16	0.14	0.13	0.13	0.15	0.12	0.09	-0.23

Figure 6. The economic annual growth rate trend of Hangzhou from 2010 to 2020.

5.4. Time series analysis of the tourism subsystem

The development of tourism is accompanied by a large increase in tourists, which can in turn greatly promote the development of the economy. Figure 7 indicates that both the number of domestic tourists and domestic tourism revenue showed a linear growth trend from 2010 to 2019. The development of tourism led to an increase in the number of accommodation and catering enterprises, which can effectively promote local employment and raise incomes. Similarly, due to the impact of COVID-19, both the number of domestic tourists and the revenue from domestic tourism declined from 2019 to 2020.

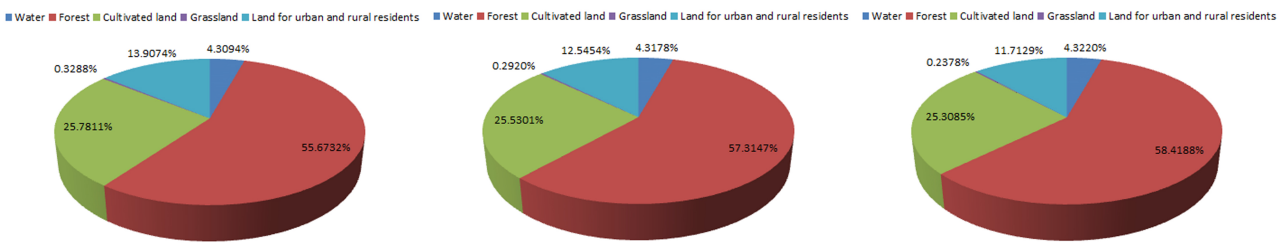


	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Number of domestic tourists(Billion)	0.0000	0.0609	0.1342	0.2156	0.2988	0.3984	0.5134	0.6654	0.8113	1.0000	0.7818
Domestic tourism revenue(Billion)	0.0000	0.0963	0.1862	0.2808	0.3777	0.4784	0.5929	0.7445	0.8837	1.0000	0.6793
Number of accommodation enterprises	0.0000	0.2838	0.1689	0.2027	0.1757	0.2297	0.2297	0.4257	0.4459	1.0000	0.8581
Number of catering enterprises	0.0000	0.2016	0.1935	0.3347	0.3468	0.3992	0.3992	0.5161	0.5645	0.8710	1.0000

Figure 7. Tourism trends in Hangzhou from 2010 to 2020.

As can be seen from these statistics, the development of tourism in Hangzhou drove the development of the economy, and Hangzhou gradually emerged as an important center for tourism and leisure. The continuous development and growth of tertiary industry, dominated by tourism, has changed the previous primary industrial structure of Hangzhou's economy, and the number of residents choosing to engage in tourism has increased year after year. From 2010 to 2020, the number of employees nearly tripled, greatly easing local unemployment.

5.5. Time series analysis of the natural environment subsystem



(a) 2010 **(b)** 2015 **(c)** 2020

Figure 8. The natural environment status of Hangzhou from 2010 to 2020.

The information extracted from the remote sensing images was used to obtain a measure of the natural environment status of Hangzhou in 2010, 2015 and 2020, as shown in Figure 8.

To maintain the development of tourism, the local government adopted a series of environmental protection measures, such as restoring farmland to lakes and grazing land to grassland, and several programs conducive to environmental protection were implemented in rapid succession. From 2010 to 2020, the extent of forest and wetland areas in Hangzhou increased, and the natural environment improved. A good natural environment led to the emergence of tourism, which lead to economic development that ultimately promoted the protection of the natural environment.

As can be seen from Figure 8, with the introduction of a series of environmental protection plans, many local residents responded to the government's call to restore farmland to forest. The size of the cultivated land area shows a decreasing trend year after year. As shown in Figure 9, the amount of fertilizer used also decreased each year, from 92.2 tons in 2010 to 69.61 tons in 2020, a reduction of almost 25%. These are important drivers for improving the local natural environment.

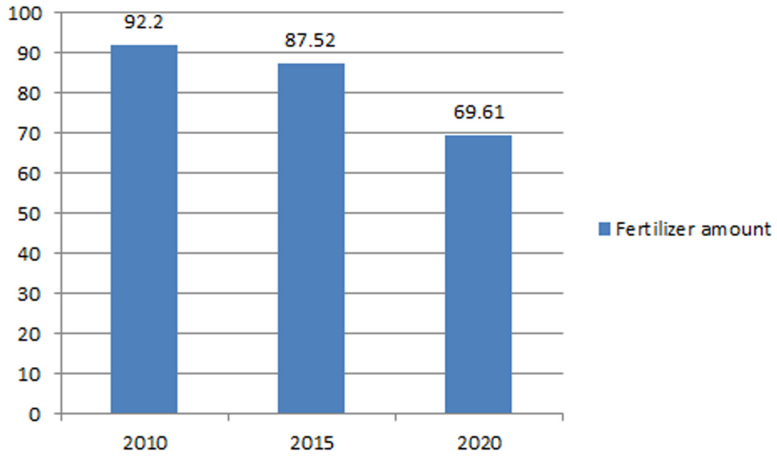


Figure 9. The amount of fertilizer in Hangzhou from 2010 to 2020.

6. Discussion and optimization strategies

The development of tourism has brought substantial economic benefits to Hangzhou. The GDP of tertiary industry, dominated by tourism, more than tripled within the study period from 2,982.77 billion yuan in 2010 to 10,959.00 billion yuan in 2020. During this period, the local government continuously introduced relevant policies and launched many new tourism projects. Implementing environmental protection measures, such as setting a list of polluting enterprises prohibited from entering Hangzhou, and closing a large number of highly polluting enterprises, delivered significant positive results. At the same time, Hangzhou made full use of the advantages of tourism to strengthen its external publicity and enhance local tourism brand awareness, attracting foreign investments, developing a local tea culture, expanding sales, and bringing new vitality to local economic development. The coupling and coordination of tourism, the economy and the natural environment also changed from a primary imbalance in 2010 to good coordination in 2020. Tourism in Hangzhou is maturing, and the development trend is consistently improving.

To promote the coupling and coordinated development of the tourism, economy and the natural

environment in Hangzhou and realize sustainable development, an optimization strategy is proposed based on the previously described research results:

1) Improve the overall plan and promote the construction of supporting facilities. We recommend promoting the integration of the Hangzhou Tourism Development Master Plan with other relevant plans. From Table 13, it can be seen that from 2010 to 2015, the coupling coordination level increased from 0.7662 to 0.9667, which indicates that through the joint efforts of Hangzhou's government and citizens, its tourism–economy–natural environment system has gradually entered a new stage of benign coupling. However, the COVID-19 outbreak in 2019 greatly affected Hangzhou's economy and tourism industry, resulting in the coupling coordination level decreasing from 0.9667 to 0.8606. As can be seen from the above, due to the continuous development of tourism in Hangzhou, the number of hotels and restaurants is continuously increasing to meet the needs of tourists. However, the hotels and restaurants are generally driven by the interests of the market economy, and the facilities are often rudimentary, making it difficult to meet the different consumption needs of various tourists. In some scenic areas, due to poor infrastructure, there is not enough parking space to accommodate vehicles, and some vehicles can only be parked on grassland. Improving Hangzhou's tourism service facilities depends on the unified planning of the government, taking into account local conditions.
2) Strengthen the management of tourism activities and protect tourism resources. From Table 12, it can be seen that from 2010 to 2015, the overall natural environment status of Hangzhou has seen little change ($h(z)$ between 0.5 and 0.6). From Tables 10 and 12, it can be seen that from 2010 to 2015, the development of Hangzhou's natural environment has been ahead of the development of tourism ($h(z) > f(x)$). However, by 2020, Hangzhou's natural environment development began to lag behind the development of the tourist industry ($h(z) < f(x)$), which underscores the importance of paying attention to environmental protection while developing the economy and tourism. Through field investigations, it was found that private shopping vendors can be seen throughout forest areas, selling souvenirs at high prices to tourists in crowded areas. These individual activities undertaken without the approval of the local government can cause a large number of people to be stranded, often in the core areas of tourist attractions, resulting in irreparable damage to local vegetation. Thus, we recommend regularly carrying out comprehensive tourism market rectification activities, resolutely investigate and deal with violations of laws and regulations that damage the tourism environment, strengthen environmental education for residents and tourists, set up harmonious tourism scenic spots, gradually standardize tourism management, continuously improve tourism quality, protect tourism resources, and emphasize long-term development of tourism.
3) Standardize the tourism market management and improve tourism quality. From Tables 10 and 11, it can be seen that from 2010 to 2015, Hangzhou's economic development was ahead of tourism ($g(y) > f(y)$), and the economy and tourism showed a positive trend of simultaneous progress. This demonstrates that Hangzhou's economic foundation is strong, and that this solid economic foundation has driven the vigorous development of tourism. We recommend gradually standardizing tourism management, continuously improving tourism quality, protecting tourism resources and emphasizing the long-term development of tourism. From the results of this research, it can be seen that, since the State Council officially approved the implementation of

the Yangtze River Delta Regional Plan in 2010, the tertiary industry represented by tourism has become a pillar industry in Hangzhou. Therefore, gradually standardizing tourism management, continuously improving tourism quality, protecting tourism resources, and realizing the long-term development of tourism should be the main priorities for future projects.

4) Improve tourism shopping. In 2021, Hangzhou ranked first in the Zhejiang province for its per capita domestic tourism expenditure, higher than the provincial average of 205.31 yuan. From the perspective of consumption structure, accommodation, catering, tourist attractions, shopping, culture, and entertainment are the main expenditures of domestic tourists in Hangzhou, together accounting for 83.05%. Shopping accounts for the highest proportion, at 36.26%. This shows that tourism shopping, as a component of the non-basic consumption of the tourism industry, plays an important role in improving tourism consumption. Based on the above data analysis, we suggest that, on the one hand, innovation should be promoted in cultural and tourism integration products in culture and art, so as to increase the proportion of culture, art and entertainment consumption, and further optimize the tourism consumption structure. On the other hand, tourism shopping accounts for the highest proportion of tourism consumption, and it is also a way for tourism to enrich people's wellbeing, so we should strengthen the guidance for tourism shopping practitioners and focus on improving the characteristics and quality of tourism products.
5) Improve transportation infrastructure, especially for self-driving tourists. In 2021, the proportion of domestic one-day tours in Hangzhou was 37.20% and the proportion of overnight tours was 62.80%. The proportion of overnight tours was 3.37% lower than the average for Zhejiang Province, and the proportion of overnight tours decreased by 11.08% compared with 2020. External factors, such as transportation convenience, the richness of tourism experiences, and COVID-19, all contributed to the decline in the proportion of overnight tours. Among domestic tourists, more than half take public transportation, significantly higher than the average level of 4.99% for Zhejiang Province, and ranking second in the province, which is correlated with the convenience of public transportation such as Hangzhou Airlines and high-speed rail. The proportion of self-driving tours is the lowest in the province, so attention should be paid to providing basic services for self-driving, such as parking services, guidance services and charging services.
6) Improve the service quality of accommodation. In 2021, the proportion of overnight tourists in Hangzhou staying in star-rated hotels decreased by 14.18% compared with 2020, the proportion staying in non-star-rated hotels increased by 36.23% and the proportion staying in relatives' and friends' homes decreased by 24.46%. According to field research, overnight tourists have higher requirements for the quality of accommodation settings, and tourists increasingly prefer to stay in non-star-rated hotels such as homestays rather than relatives' and friends' homes. The accommodation demand of overnight tourists in Hangzhou is differentiated and personalized, and the proportion of non-star-rated hotels has increased significantly. Hangzhou should pay attention to improving the service quality of different types of accommodation facilities to meet the increasingly high quality requirements of overnight tourists. Among overnight tourists, the number of nights spent in non-star hotels is significantly higher than for other types of tourists, which indicates that non-star hotels such as homestays have advantages for tourists who stay longer. Therefore, improving the quality of non-star-rated hotels is conducive to lengthening the stay time of overnight visitors in Hangzhou.

7) During the COVID-19 pandemic, shift the focus away from long-distance tourism and instead vigorously develop local leisure tourism. The recurrence of COVID-19 outbreaks has brought unprecedented difficulties to the tourism industry. People's travel plans have slowed down, and all types of tourism businesses have stalled. Tourism practitioners have struggled to support themselves in light of the challenges of decreasing numbers of tourists and declining incomes. From the previously summarized research results, it can be seen that Hangzhou's tourism revenue fell by 23% from 2019 to 2020. This is because the number of domestic and foreign tourists dropped sharply due to the COVID-19 pandemic. However, local residents' short-distance tourism, inner-city tourism and camping (including luxury camping) have allowed new types of businesses to meet citizens' demands for outdoor leisure and consumption upgrades. Data provided by platforms such as Meituan show that, in the first quarter of 2022, the search volume for camping products in Hangzhou increased by 240.8% and product sales increased by 342.0% on online platforms. Therefore, against the backdrop of the COVID-19 pandemic, vigorously developing local leisure tourism is an effective means of promoting the growth of the tourism economy.
8) Adhere to the basic principles of natural environment protection and promote harmonious coexistence between humanity and nature. Development must simultaneously promote environmental protection and rewilding. Socioeconomic development is inseparable from natural resources, which necessitates appropriate handling of the relationship between environmental protections and the development and utilization of natural resources, reducing the use of chemical fertilizers and pesticides, and applying more organic fertilizers. We also recommend controlling the number of tourists, and emphasizing sustainable development of local tourism, the economy and the natural environment. As can be seen from Figure 3 and Tables A2 and A3, the size of Hangzhou's urban area has decreased from 2,605,147 to 2,194,064. The reduction of hardened surfaces is beneficial for animal survival and normal hydrological processes. Therefore, it is necessary to plan construction land well, reduce the impact of social and economic development on the natural environment, and thus achieve harmonious coexistence between humanity and nature.

Further details of the justifications for these recommendations are presented in Table 14.

7. Conclusions and research limitations

7.1. Conclusions

In this work, tourism, economy and the natural environment are regarded as an open system. They are interconnected and inseparable, forming a cycle of mutual influence and interaction. The coupling system of tourism, economy and the natural environment was qualitatively analyzed, and the interactions between each subsystem were defined. The main conclusions of this paper are as follows:

1) A method with a solid theoretical foundation was employed, drawing on the concept of coupling from physics, and connecting the tourism, economic and natural environment processes in the research area to build a model that treats them as a strongly coupled system. Appropriate evaluation indicators were selected for each system, and the coupling system was qualitatively analyzed. The results show that the coordinated coupling level of the economy, tourism and

Table 14. The summary of the result analysis and suggestions.

Subsystems	Phenomenon	Reasons	Suggestions
Tourism	The hotels and restaurants are increasing, but the facilities are rudimentary. There is not enough parking, some vehicles parked on grassland.	The planning cannot combine with the local conditions, and lack of overall planning, and unified deployment.	Improve the overall plan and promote the construction of supporting facilities.
	In 2021, the one-day tour in Hangzhou is 37.20%, and the overnight tour is 62.80%. The overnight tour is 3.37% lower than the average of Zhejiang Province. The overnight tourists decreased by 11.08% compared with 2020. The self-driving tour is the lowest in the province	External environment affects to the decline of overnight tour. The infrastructure construction for the self-driving tour is not convenient enough.	Enhance the ability to resist external risks and pay more attention to providing basic services for self-driving.
	In 2021, the overnight tourists staying in star-rated hotels decreased by 14.18% compared with 2020, the staying in non-star-rated hotels increased by 36.23%, and the staying in relatives and friends' homes decreased by 24.46%. The number of days of tourists staying in non-star hotels is significantly higher than that of other types of tourists.	The accommodation demand of overnight tourists is differentiated and personalized, and the non-star-rated hotels have increased significantly. Non-star hotels have more significant holiday attributes.	Improving the service quality of different types of accommodation facilities. Improving the quality of non-star products.
Economic	Hangzhou's economic development was ahead of tourism, the economy and tourism showed a good trend of simultaneous progress.	Hangzhou's economic foundation is very strong, it has driven the vigorous development of tourism.	Standardize tourism management, improve tourism quality and protect tourism resources.
	Accommodation, catering, tourist attractions, shopping, culture and entertainment are the main expenses in Hangzhou, accounting for 83.05%. The proportion of tourism shopping consumption is the highest.	Tourism shopping, as one of the non-basic consumptions of the tourism industry, plays a very important role in improving tourism consumption.	Strengthen the innovation of cultural and tourism integration products. Improve the characteristics, quality and taste of tourism products.
	Hangzhou's tourism revenue fell by 23% from 2019 to 2020. Local residents' short-distance tourism, inner-city tourism and camping have become a new type of business to meet citizens' demands for outdoor leisure and consumption upgrades.	In the situation of the COVID-19 pandemic, avoid traveling far and instead vigorously develop local leisure tourism.	Against the COVID-19 pandemic, vigorously developing local leisure tourism is an effective means of promoting the tourism economy.
Environment	The development of the natural environment lag behind the development of tourism and economic processes. Private shopping vendors can be seen throughout forest areas, selling souvenirs at high prices.	These individual activities undertaken without the approval of the local government in the core areas of tourist attractions cause damage to vegetation.	Deal with violations of laws and regulations that damage the tourism environment, strengthen environmental education for residents and tourists. Standardize tourism management.
	The size of Hangzhou's urban areas has decreased from 2,605,147 to 2,194,064. The reduction of hardened surfaces is beneficial for animal survival and for normal hydrological processes.	Adhere to the basic principles of natural environment protection and promote harmonious coexistence between humanity and nature.	Land for construction should be well-planned, reduce the impact of social and economic development on the natural environment.

natural environment in Hangzhou was between 0.7662 and 0.966 from 2010 to 2020. In 2010, it was in the medium-level coupling stage; a series of policies issued by Hangzhou's government subsequently promoted the development of the tourism sector, and the coupling reached a peak in 2015. The COVID-19 outbreak in 2019 has severely affected both tourism and the wider economy in many cities, including Hangzhou. By 2020, the coordination coupling level of Hangzhou's economy, tourism and natural environment had decreased to 0.8606. The research results show that the method proposed in this paper can capture the coupling state of tourism, the economy and the natural environment.

2) To quantitatively evaluate the status of tourism, the economy and the natural environment, combined with the existing research results, this paper proposed an evaluation function for quantitatively calculating the overall development of these three subsystems in the research area. The results show that Hangzhou's economic development was ahead of tourism from 2010 to 2020, and the economy and tourism showed positive trend of simultaneous progress. They also show that Hangzhou's economic foundation is strong, and that this has driven the vigorous development of tourism.
3) The coupling relationship between tourism, economy and natural environment was analyzed and calculated. The evaluation indicators, evaluation levels, coupling degrees and coupling coordination levels of the three subsystems were calculated. From the results, it can be seen that Hangzhou's tourism industry has changed from moderate disorder in 2010 to elementary coordination in 2020. The research results show that the overall natural environment status of Hangzhou has changed little. The development of Hangzhou's natural environment was ahead of the development of tourism from 2010 to 2015. However, by 2020, Hangzhou's natural environment development began to lag behind the development of tourism and the economy, which highlights the need to pay attention to ecological protection while developing tourism and the wider economy.
4) The method employs long time series of tourism, economic and natural environment data to avoid the impact of short-term or discrete fluctuations on the analysis, so as to achieve an accurate assessment of the sustainable development status of these three subsystems and to forecast development trends. A time series analysis of the coupling coordination degree from 2010 to 2020 was carried out, and optimization strategies have been proposed to realize the sustainable development of tourism, the economy and the natural environment in the study area. The coupling coordination level steadily improved from 2010 to 2015. In addition, the degree of coupling increased significantly and reached a peak in 2015, at which point the coordinated development effect of the coupling coordination level and coupling degree were significantly improved. However, the growth of coupling degree was lower than that of the coupling coordination level. The coordinated development of the two will take many years, so it is necessary to adopt active policies to promote their coordinated development.
5) Comprehensive evaluation functions representing the overall development of each subsystem, a coupling development level calculation model representing the interaction strength of each subsystem, and a coupling coordination degree calculation model representing the development level of the coupling coordination degree between each subsystem were constructed. The coupling coordination degree of tourism, the economy and the natural environment in the study area was calculated quantitatively.

7.2. Research limitations

Although some conclusions can be drawn from the results presented in this work, and these conclusions can be used to guide future decision-making, the results have certain limitations, which mainly fall into the following categories:

1) This research regards tourism, the economy and the natural environment as a coupled system, and chooses some indicators to represent the three subsystems. However, these subsystems are all complex systems in themselves, and it is difficult to describe each system accurately with a small number of indicators. Therefore, different choices of indicators describe different aspects of the system and may produce different results.
2) The evaluation level, coupling degree and coupling coordination level reflect the sustainable and coordinated development state and predict future trends to help governments make decisions. However, different study areas have substantially different economies, tourism industries and natural environments, and so the choice of study areas could greatly affect the results. Therefore, the generalizability of the results needs further research.
3) Although we have carried out qualitative and quantitative analysis on the tourism industry, economy and natural environment of the study area, this study is still in the primary research stage. To better reveal the sustainable development status of these three subsystems, long-term time series assessment is needed. This will be the main direction of our future research.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Acknowledgments

This work was supported in part by the National Natural Science Foundation of China (No. 62101375), the Zhejiang Provincial Natural Science Foundation of China (Nos. LQ21F020001, LQ21A010001), and the Undergraduate Science and Technology Innovation Project of Taizhou (No. 202201).

Conflict of interest

The authors declare there is no conflict of interest.

References

1. J. M. Ahmed, A review and situational analysis of Thomas cook business failure, a successful business model for 178 years: A case study, *Int. J. Inc. Dev.*, **6** (2020), 60–38. https://doi.org/10.30954/2454-4132.1.2020.9
2. F. Higgins-Desbiolles, The "war over tourism": challenges to sustainable tourism in the tourism academy after COVID-19, *J. Sustain. Tour.*, **29** (2020), 551–569. https://doi.org/10.1080/09669582.2020.1803334

3. K. Aliyev, N. Ahmadova, Testing tourism-led economic growth and economic-driven tourism growth hypotheses: The case of Georgia, *Tourism*, **68** (2020), 43–57. https://doi.org/10.37741/t.68.1.4
4. Q. Dang, C. Wu, A research on the Tourists' perceived evaluation and management of safety risks for Tourism cities: A case study of HangZhou, in *2nd International Forum on Management, Education and Information Technology Application (IFMEITA 2017)*, (2018), 55–65. https://doi.org/10.2991/ifmeita-17.2018.10
5. Z. W. Wang, Interaction between the tourism industry and ecological environment based on the Complicated Adaptation System (CAS) theory: A case study on Henan Province, China, *Nat. Environ. Pollut. Technol.*, **19** (2020), 1039–1045. https://doi.org/10.46488/NEPT.2020.v19i03.014
6. D. Wang, X. Zhao, Affective video recommender systems: A survey, *Front. Neurosci.*, **16** (2022), 1–20. https://doi.org/10.3389/fnins.2022.984404
7. Y. F. Shen, Measurement of tourism industry-ecological environment coupling degree and management and control measures for tourism environment: A case study of Henan Province, China, *Nat. Environ. Pollut. Technol.*, **19** (2020), 857–864. https://doi.org/10.46488/NEPT.2020.V19I02.045
8. Q. Cheng, Z. Luo, L. Xiang, Spatiotemporal differentiation of coupling and coordination relationship of the tea industry–Tourism–ecological environment system in Fujian Province, China, *Sustainability (Switzerland)*, **13** (2021), 10628. https://doi.org/10.3390/su131910628
9. X. Yang, Study on the coordinated development of regional economic, tourism and ecology coupling: Taking Henan Province as an example, *Fresen. Environ. Bull.*, **39** (2021), 210–215.
10. L. Sun, L. Zeng, H. Zhou, L. Zhang, Strip thickness prediction method based on improved border collie optimizing LSTM, *PeerJ Comput. Sci.*, **2022** (2022), 1–22. https://doi.org/10.7717/peerj-cs.1114
11. X. Qin, X. M. Li, Evaluate on the decoupling of tourism economic development and ecological-environmental stress in China, *Sustainability (Switzerland)*, **13** (2021), 2149. https://doi.org/10.3390/su13042149
12. H. Song, W. Yang, GSCCTL: a general semi-supervised scene classification method for remote sensing images based on clustering and transfer learning, *Int. J. Remote Sens.*, **43** (2022), 15-16. https://doi.org/10.1080/01431161.2021.2019851
13. P. del Vecchio, C. Malandugno, G. Passiante, G. Sakka, Circular economy business model for smart tourism: the case of Ecobnb, *EuroMed J. Bus.*, **17** (2022), 88–104. https://doi.org/10.1108/EMJB-09-2020-0098
14. J. M. Beall, B. B. Boley, A. C. Landon, K. M. Woosnam, What drives ecotourism: environmental values or symbolic conspicuous consumption?, *J. Sustain. Tour.*, **29** (2021), 1215–1234. https://doi.org/10.1080/09669582.2020.1825458
15. V. Lopes, S. M. Pires, R. Costa, A strategy for a sustainable tourism development of the Greek Island of Chios, *Tourism*, **68** (2020), 243–260. https://doi.org/10.37741/T.68.3.1

16. B. K. Mudzengi, E. Gandiwa, N. Muboko, C. N. Mutanga, Towards sustainable community conservation in tropical savanna ecosystems: a management framework for ecotourism ventures in a changing environment, *Environ., Dev. Sustain.*, **23** (2021), 3028–3047. https://doi.org/10.1007/s10668-020-00772-4

17. S. K. Mallick, S. Rudra, R. Samanta, Sustainable ecotourism development using SWOT and QSPM approach: A study on Rameswaram, Tamil Nadu, *Int. J. Geo. Park.*, **8** (2020), 185–193. https://doi.org/10.1016/j.ijgeop.2020.06.001

18. J. Yushi, Z. Yuzong, Centennial research process of tourism geography in Japan, *Geogr. Res.*, **37** (2018), 2039–2057.

19. S. Shigeru, Kureha, M.: Development process of Ski resorts: A comparative study of Japan and Austria, *Geogr. Rev. Japan Series A*, **90** (2017), 519–523. https://doi.org/10.4157/grj.90.519

20. J. Zhang, Y. Zhang, Assessing the low-carbon tourism in the tourism-based urban destinations, *J. Clean. Prod.*, **276** (2020), 124303. https://doi.org/10.1016/j.jclepro.2020.124303

21. K. Bhaktikul, S. Aroonsrimorakot, M. Laiphrakpam, W. Paisantanakij, Toward a low-carbon tourism for sustainable development: a study based on a royal project for highland community development in Chiang Rai, Thailand, *Environ., Dev. Sustain.*, **23** (2021), 743–762. https://doi.org/10.1007/s10668-020-01083-4

22. H. Sun, T. Chen, C. N. Wang, Spatial impact of digital finance on carbon productivity, *Geosci. Front.*, (2023), 101674. https://doi.org/https://doi.org/10.1016/j.gsf.2023.101674

23. V. M. Quintana, Eco-cultural tourism: Sustainable development and promotion of natural and cultural heritage, in *Tourism*, IntechOpen, (2020), 1–17. https://doi.org/10.5772/intechopen.93897

24. K. J. Wu, Y. Zhu, Q. Chen, M. L. Tseng, Building sustainable tourism hierarchical framework: Coordinated triple bottom line approach in linguistic preferences, *J. Clean. Prod.*, **229** (2019), 157–168. https://doi.org/10.1016/j.jclepro.2019.04.212

25. A. Csikósová, M. Janošková, K. Čulková, Providing of tourism organizations sustainability through triple bottom line approach, *Entrep. Sustain. Iss.*, **8** (2020), 764–776. https://doi.org/10.9770/jesi.2020.8.2(46)

26. B. Grah, V. Dimovski, J. Peterlin, Managing Sustainable Urban Tourism Development: The Case of Ljubljana, *Sustainability (Switzerland)*, **12** (2020), 792. https://doi.org/10.3390/su12030792

27. M. Wang, J. Jiang, S. Xu, Y. Guo, Community participation and residents' support for tourism development in ancient villages: The mediating role of perceptions of conflicts in the tourism community, *Sustainability (Switzerland)*, **13** (2021), 1–16. https://doi.org/10.3390/su13052455

28. J. Yang, R. Yang, M. H. Chen, C. H. J. Su, Y. Zhi, J. Xi, Effects of rural revitalization on rural tourism, *J. Hosp. Tour. Manag.*, **47** (2021), 35–45. https://doi.org/10.1016/j.jhtm.2021.02.008

29. A. P. Marlinda, B. Cipto, F. Al-Fadhat, H. Jubba, South korea's halal tourism policy - The primacy of demographic changes and regional diplomacy, *Acad. J. Interdiscipl. Stud.*, **10** (2021), 253–263. https://doi.org/10.36941/AJIS-2021-0081

30. H. Sun, B. K. Edziah, C. Sun, A. K. Kporsu, Institutional quality and its spatial spillover effects on energy efficiency, *Socio-Economic Plan. Sci.*, **83** (2022), 101023. https://doi.org/10.1016/j.seps.2021.101023

31. W. Danjie, S. Junhua, Z. Jianxing, Study on the development path of Fujian coastal ecotourism under the background of green development: Taking Fuzhou, Xiamen and Zhangzhou as examples, *Ecol. Econ.*, **33** (2017), 127–144.
32. S. Ma, Y. He, R. Gu, Joint service, pricing and advertising strategies with tourists' green tourism experience in a tourism supply chain, *J. Retail. Consum. Serv.*, **61** (2021), 102563. https://doi.org/10.1016/j.jretconser.2021.102563
33. L. Zhihua, M. Chenlian, Research on the development of Tourism in Shaanxi province under the background of "The Belt and Road", *Sci. Soc.*, **12** (2017), 49–61.
34. T. Li, H. Shi, Z. Yang, Y. Ren, Does the belt and road initiative boost tourism economy?, *Asia Pac. J. Tour. Res.*, **25** (2020), 311–322. https://doi.org/10.1080/10941665.2019.1708758
35. H. Sun, C. A. Samuel, J. C. Kofi Amissah, F. Taghizadeh-Hesary, I. A. Mensah, Non-linear nexus between CO2 emissions and economic growth: A comparison of OECD and B&R countries, *Energy*, **212** (2020), 118637. https://doi.org/10.1016/j.energy.2020.118637
36. X. Xie, H. Sun, J. Gao, F. Chen, C. Zhou, Spatiotemporal differentiation of coupling and coordination relationship of tourism–urbanization–ecological environment system in china's major tourist cities, *Sustainability (Switzerland)*, **13** (2021), 5867. https://doi.org/10.3390/su13115867
37. A. Echeverri, J. R. Smith, D. MacArthur-Waltz, K. S. Lauck, C. B. Anderson, R. M. Vargas, et al., Biodiversity and infrastructure interact to drive tourism to and within Costa Rica, *P. Nati. Acad. Sci. USA*, **119** (2022), 2107662119. https://doi.org/10.1073/pnas.2107662119
38. Y. Zhipeng, X. Ying, Analysis of bearing capacity of kunming dianchi national tourism resort, *IOP Conf. Ser.: Earth Environ. Sci.*, **332** (2019), 042029. https://doi.org/10.1088/1755-1315/332/4/042029
39. A. Gonia, A. Jezierska-Thöle, Sustainable Tourism in cities—nature reserves as a 'New' city space for nature-based Tourism, *Sustainability (Switzerland)*, **14** (2022), 1581. https://doi.org/10.3390/su14031581
40. Y. Geng, R. Wang, Z. Wei, Q. Zhai, Temporal-spatial measurement and prediction between air environment and inbound tourism: Case of China, *J. Clean. Prod.*, **287** (2021), 125486. https://doi.org/10.1016/j.jclepro.2020.125486
41. J. Andria, G. di Tollo, R. Pesenti, Fuzzy multi-criteria decision-making: An entropy-based approach to assess tourism sustainability, *Tour. Econ.*, **27** (2021), 168–186. https://doi.org/10.1177/1354816619885207
42. J. Jucai, K. Wei, R. Liang, Research on coordinated development of tourism economy and ecological environment in the northwest of hebei province under the background of coordinated development of Beijing-Tianjin-Hebei, *Chin. J. Agr. Resour. Reg. Plan.*, **40** (2019), 167–173.
43. T. Pimonenko, O. Lyulyov, Y. Us, Cointegration between Economic, Ecological and Tourism Development, *J. Tour. Serv.*, **12** (2021), 169–180. https://doi.org/10.29036/JOTS.V12I23.293
44. X. Kai, Z. Liyue, Coordinated Development Evaluation of Tourism Economy and Ecological Environment in Cities of Eight Maritime Economic Zones in China, *Resour. Dev. Mark.*,**31** (2015), 712–717.

45. Y. Zhou, T. Wu, Y. Wang, Urban expansion simulation and development-oriented zoning of rapidly urbanising areas: A case study of Hangzhou, *Sci. Total Environ.*, **807** (2022), 15083. https://doi.org/10.1016/j.scitotenv.2021.150813

46. Hangzhou Bureau of Statistics, 2018 Hangzhou National Economic and Social Development Statistical Bulletin. Available from: http://www.hangzhou.gov.cn/art/2019/3/4/art_805865_30593279.html

47. Zhejiang Government Service Network, Data Zhejiang. Available from: http://data.tjj.zj.gov.cn/

48. Y. Yun, W. Rong, T. Junlan, Coupling Coordination and Prediction Research of Tourism Industry Development and Ecological Environment in China, *Discrete Dyn. Nat. Soc.*, **2021** (2021), 6647781. https://doi.org/10.1155/2021/6647781

49. P. Galanis, The Delphi method, *Arch. Hell. Med.*, **35** (2018), 564–570. https://doi.org/10.4324/9781315728513-10

50. S. Gayen, L. Vallejo-Villalta, H. SM, Assessment of social vulnerability in Malaga province, Spain: A comparison of indicator standardization techniques, *Rev. de Estud. Andal.*, **2021** (2021), 87–108. https://doi.org/10.12795/rea.2021.i41.05

51. M. K. A. Kablan, K. Dongo, M. Coulibaly, Assessment of social vulnerability to flood in urban Côte d'Ivoire using the MOVE framework, *Water (Switzerland)*, **9** (2017), 292. https://doi.org/10.3390/w9040292

52. O. Žurovec, S. Čadro, B. K. Sitaula, Quantitative assessment of vulnerability to climate change in rural municipalities of Bosnia and Herzegovina, *Sustainability (Switzerland)*, **9** (2017), 1208. https://doi.org/10.3390/su9071208

53. A. Zhao, Coupling research of Liaoning Tourism and economic growth based on grey relational theory, in *2020 International Conference on Modern Education and Information Management (ICMEIM)*, (2020), 574–578. https://doi.org/10.1109/ICMEIM51375.2020.00132

54. National Development and Reform Commission, Notice on the distribution of the Regional Plan for the Yangtze River Delta Region, 2010.

55. Computer Network Information Center, The Geospatial Data Cloud website. Available from: http://www.gscloud.cn/.

Appendix

A.1.1. Remote sensing image processing

The data selected to represent natural environment indicators in this paper encompass six categories: water, forest, cultivated land, grassland, land for urban and rural residents and fertilizer application amount. The natural environment indicators refer to the remote sensing monitoring data from Resource and Environment Science and Data Center in Chinese Academy of Sciences [55]. These data are used in the construction of a national natural environment monitoring network. These data can reflect the state of China's natural environment. To easily and quickly obtain natural environmental indicator data for the research area in the years 2010, 2015 and 2020, remote sensing technology was used to extract the necessary original natural environment indicator data from remote sensing images of the research area in the corresponding years.

In this paper, natural environment data for Hangzhou were extracted from Landsat images. The strip and flight numbers of Landsat satellite images of Hangzhou were searched and downloaded from the Geospatial Data Cloud [55]. The specific parameters of each remote sensing image used are shown in Table A1.

Table A1. The parameters of remote sensing images.

Remote sensing images	Strip number	Flight number	Date
Landsat8	119	39	2020-05-03
Landsat8	119	40	2020-11-11
Landsat8	120	39	2020-10-01
Landsat8	120	40	2020-02-20
Landsat8	119	39	2015-05-22
Landsat8	119	40	2015-10-13
Landsat8	120	39	2015-01-21
Landsat8	120	40	2015-04-11
Landsat5	119	39	2010-05-24
Landsat5	119	40	2010-05-24
Landsat5	120	39	2010-12-09
Landsat5	120	40	2010-12-09

Table A2. Specific band information for Landsat 8.

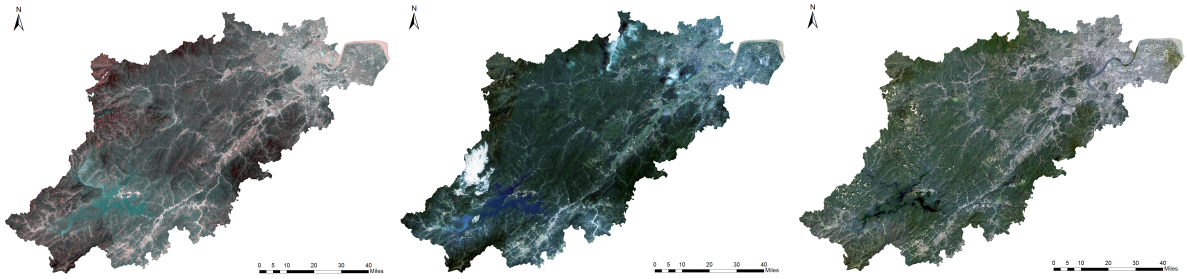
Landset 8	Band	Wavelength (micron)	Resolution (m)
Landsat-8 Operational Land Imager and TIRS Thermal Infrared sensors	Band1-aerosol	0.43–0.45	30
	Band2-blue	0.45–0.51	30
	Band3-green	0.53–0.59	30
	Band4-red	0.64–0.67	30
	Band5-near red	0.85–0.88	30
	Band6-SWIR1	1.57–1.65	30
	Band7-SWIR2	2.11–2.29	30
	Band8-panchromatic	0.50–0.68	15
	Band9-Cirrus	1.36–1.38	30
	Band10-TIRS1	10.60–11.19	100
	Band11-TIRS2	11.50–12.51	100

The Landsat 8 satellite was launched by NASA on February 11, 2013. It is used to provide long-term Earth observation and reliable data for resources, water, forest, environment, and urban planning. Landsat 8 carries the Operational Land Imager and thermal infrared sensors and has 11 bands. The spatial resolution of bands 1–7 and 9–11 is 30 meters, while band 8 is a panchromatic band with a resolution of 15 meters. Table A2 details specific band information.

Band combinations for multispectral images can help highlight features of interest. Taking Landsat 8 as an example and the natural environment of Hangzhou as the research context, it is necessary to extract the cultivated land, forest land, grassland, water area, and information on other elements from the remote sensing images, which encompass a wide range of content. Thus, it is difficult for any special band combination method to meet the needs of all research elements. Therefore, the natural true-color combination of bands 2–4 was selected to obtain the true-color composite image of the research area, which is convenient for the recognition and classification of various ground objects, as shown in Figure A1.

A.1.2. Establishment of interpretation labels

According to the national classification standard for remote sensing image interpretation, the research area was divided into cultivated land (11), forest land (22), grassland (33), water (44), and land for urban and rural residents (55). The natural environment interpretation labels established for Hangzhou are described in Table A3.



(a) 2010 **(b)** 2015 **(c)** 2020

Figure A1. Remote sensing image of the research area from 2010 to 2020.

Table A3. The natural environment interpretation labels of Hangzhou.

Natural environment indicators	Code	Annotation	Labels
Cultivated land	11	Refers to land where crops are grown, including mature arable land, newly opened land, recreational land, rotational land, grass field and crop rotation land; land for agricultural fruits, agricultural mulberry, agriculture and forestry mainly for growing crops; beach and tidal flats that have been cultivated for more than three years.	
Forest	22	Refers to forestry land for the growth of trees, shrubs, bamboos, and coastal mangrove woodlands.	
Grassland	33	Refers to all kinds of grasslands that mainly grow herbs and cover more than 5%, including shrub grasslands dominated by pasture and thinly forested grasslands with canopy closure of less than 10%.	
Water	44	Refers to natural land waters and land for water conservancy facilities.	
Land for urban and rural residents	55	Refers to urban and rural settlements and other industrial and mining land, transportation and other land.