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Evaluation and drive mechanism of tourism ecological security based on the DPSIR-DEA model

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ABSTRACT

Tourism ecological security evaluation is a critical way of measuring the sustainable development of tourism destinations. Based on ecological system theory, this study creates a new comprehensive evaluation model, "Driver-Pressure-State- Impact-Response"—"Data Envelopment Analysis" (DPSIR-DEA), to measure tourism ecological security, which is an evaluation of "Quality" from the perspective of "Efficiency". The Yangtze River Delta (YRD) is chosen as the study site, and methods including Geo-Detector and spatial autocorrelation are used to analyze space-time law and influence factors. Results indicate that the spatial differentiation pattern of southeast–northwest is gradually presented from hot-spot to cold-spot. Moreover, some critical impact factors affecting tourism ecological security are identified, including third-industry growth rate, tourist density, etc, and the driving mechanism is constructed. We not only introduces a new evaluation of tourism ecological security but also explores the crucial impact indexed and the driving mechanism.

1. Introduction

Recently, the world has been focusing on the sustainable development of tourism (Ahmad, Draz, Su, Ozturk, & Rauf, 2018), which has been a key policy objective at the global, national and regional levels (Peng et al., 2017). The sustainable development of tourism is characterized by a strong emphasis on the environmental impact of short-term and long-term development of tourism (Tepelus & Córdoba, 2005). As an important research field of sustainable tourism development, tourism eco-security has assumed an increasingly prominent position (Qian, Shen, & Law, 2018). However, with the rapid development of the tourism industry around the world, the negative impacts on the ecological environment are increasing. These negative impacts not only affect the self-integrity and ecological service function of the tourism destination ecosystem but also threaten the ecological security of tourism destinations (Qiu, Fang, Yang, & Zhu, 2017). The sustainable development of tourism must be achieved when the natural resources and ecological environment that depend on tourism development are in balance and there is no threat or risk (George Assaf, 2012). How to maintain tourism ecological security has become the consensus goal of the international community. Tourism ecological security ensures that the resources on which tourism depends are in a state of sustainable and healthy balance. In other words, in tourist areas and for specific periods of time, natural resources, the ecological environment, tourism and other system elements maintain a normal healthy structure and function (Liu, Yang, Di, & Chen, 2009). Some scholars have asserted that tourism ecological security has become the main index with which to measure environmental impact and sustainable development (Liu, Zhang, & Fu, 2017), which was the guiding ideology of regional long term sustainable development (Costanza et al., 1997; Yang et al., 2018). Regarding this critical issue, we analyze the current situation of tourism ecological security development, identify its critical influencing factors and driving mechanisms, and discover how it influences the development of tourism ecological security. Finding solutions to these issues can not only provide a constructive perspective and development solution for practitioners but also have significant implications on the sustainable development of regional tourism.

Ecological pattern and ecosystem theory is used as the theoretical foundational theory and provides a theoretical basis for the development of new evaluation methods. On the one hand, the essence of this theory is that in a certain period of time in the ecosystem, some elements, including organisms, environments, and organisms, through energy flow, material circulation and information transfer, will ultimately reach a highly adaptive, coordinated and unified state (Reynolds, 2002). Theoretically, ecological pattern and ecosystem theory provides foundational guidance for the maintenance of the

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security state of tourism ecosystem and also highlights the multi-level and multi-dimensional characteristics of ecosystem elements.

Similarly, if the relationship between tourism ecosystem elements, such as that between tourists and the environment, tourists and the tourism destination, and tourism and the environment, is able to maintain a harmonious and unified state, the tourism industry will maintain a healthy and effective development trend, and tourism ecological security will also be guaranteed (Liu et al., 2009). On the other hand, ecological pattern and ecosystem theory also emphasizes that the coordinated development of various elements will contribute to the effective operation of the ecosystem (Kurniawan, Adrianto, Bengen, & Prasetyo, 2019), which is crucial for tourism ecological security. It is worth noting that the ecological security system shows a combination of social, economic and environmental effects. Therefore, a particularly important issue must explore whether all the elements of tourism ecosystems are in a state of coordinated and efficient operation. Previous studies have focused on evaluating the tourism ecosystem (Yang et al., 2018), tourism ecological footprint (Wang, Hu, He, & Wang, 2017), carrying capacity (Navarro Jurado et al., 2012; Mccool & Lime, 2001), and sustainable tourism (Buijtendijk, Blom, Vermeer, & van dar Duim, 2018), which only measure the current situation of ecological security and the coordinated development of the system through "quantitative evaluation", ignoring the evaluation of the "quality" of tourism ecological security. Further, few studies pay sufficient attention to ecosystem balance and efficiency. More importantly, the evaluation of tourism ecological security is the basis for and an important topic of present and future research in this field that must be further addressed. Peng et al. (2017) asserted that efficiency was the best way to measure whether tourism destinations had the greatest effect with the lowest resource and environmental costs in the system. It is also a good indicator that reflects the operating state of the tourism ecological system and the perfect way to measure tourism ecological security. Specifically, we will address the efficiency of this critical issue, one that evaluates the operating state of tourism eco-systems. However, few studies measure tourism ecological security from an efficiency perspective, which not only ignores the essential issue of ecological security but also fails to evaluate the interaction effects of the internal factors of the system. Therefore, this study focuses on addressing these unsolved questions pertaining to tourism sustainable development. They include how to scientifically analyze tourism ecological security; innovative tourism ecological security evaluation methods; and explaining the interaction mechanism among tourism development, social economy and environmental quality.

Analyzing tourism ecological security is conducive to grasping the current status of an ecosystem's inputs and outputs, which are critical attributes in evaluating tourism ecological security. However, the existing literature still lacks in-depth research. To fill this significant void, this study has three critical aims: (1) create and innovate a new tourism ecological security evaluation model; (2) explore the time evolution and spatial distribution of tourism ecological security; and (3) identify the critical factors affecting tourism ecological security and build a driving mechanism for tourism ecological security. To address these unsolved and crucial questions, this study will use the Slack Based Measure-Data Envelopment Analysis (SBM-DEA) to measure tourism ecological security based on the Driver-Pressure-State-Impact-Response (DPSIR) framework. Further, SBM-DEA is an important evaluation model of ecological efficiency, DPSIR is a comprehensive evaluation framework that includes social, economic, ecological factors, etc. The combination of these two methods can benefit to the innovation of tourism ecological security evaluation methods. Further, China' s Yangtze River Delta urban agglomeration is chosen as the study site, and some methods, including space autocorrelation and geo-detectors, are applied to explore the spatial and temporal patterns and driving factors of tourism ecological security. Lastly, some of our results may provide solutions for the sustainable development of tourism in the future.

Innovations and theoretical and practical contributions are provided in this study. First, our research focuses on critical issues unsolved by previous studies regarding the "equality" evaluation of tourism ecological security from the perspective of efficiency, rather than a simple "quantity" measurement. Specifically, the DPSIR-DEA analysis framework, different from the previous model, is able to consider the comprehensiveness and scientific nature of the evaluation from other dimensions. Further, it provides an innovative evaluation model and research method to measure tourism ecological security. Second, the method to identify critical impact factors used in this study is more effective than the regression model used in previous influence research (Qiu et al., 2017). The Geo-Detector method applied in this study is a new method to explore the influence factors in the field of tourism geography. It can effectively identify the critical factors pertaining to tourism ecological security and help to build a tourism ecosystem operation mechanism. This study not only contributes to discovering the time and space heterogeneity of tourism ecological security but also fills in the gap in the tourism ecological security evaluation model. Moreover, the critical influencing factors and driving mechanisms of this research provide a theoretical reference and policy implications for sustainable tourism development.

2. Literature review

2.1. Tourism ecological security

Ecological security is one of the important fields of sustainable development research in tourism destinations (Liu et al., 2009). Tourism ecological security is a state that ensures the normal functioning of the tourism ecosystem and shows a healthy and stable operation. The balanced conditions of an effective development of tourism, economy and ecology can satisfy the sustainable development of tourism (Dong, 2004). It should be noted that tourism ecological security research is still in its infancy. With the rapid development of the tourism economy, the problem of tourism ecological security has gradually taken shape and begun to stand out. Mccool and Lime (2001) performed the first study to examine tourism ecological security from the perspective of tourism carrying capacity. Subsequently, following the perspective changes, scholars began to discuss tourism ecological security assessment and its relationship with the environment (Navarro Jurado et al., 2012). Studies discussed the vulnerability problem of tourism ecological security (Petrosillo, Zurlini, Grato, & Zaccarelli, 2006), the relationship between tourism activities and the social ecosystem (Gari, Newton, & Icely, 2015), and the influencing factors of tourism ecological security (Sun & Pratt, 2014; Ahmad et al., 2018; Peña-Alonso, Ariza, Hernández- Calvento, & Pérez-Chacón, 2018). These studies provide the research foundation for restoring the tourism ecosystem (Pueyo-Ros, Garcia, Ribas, & Fraguell, 2018), ecotourism management and tourism ecosystem development (Arenas, Goh, & Urueña, 2019). Integrated with the opinions of the above studies, the evaluation methods of tourism ecological security and the relationship between tourism ecological security and sustainable development have become mainstream for future research. Specifically, tourism ecological security assessment includes evaluation model construction and application (Tang, Wu, Zheng, & Lyu, 2018; Wu et al., 2019; Yang et al., 2018), as well as considerations of the tourist ecological footprint (Castellani & Sala, 2012; Gössling, Hansson, Hörstmeier, & Saggel, 2002), tourism ecological efficiency (Liu et al., 2017; Qiu et al., 2017), and so on. With an overview of the previous studies, the measurement of tourism ecological security is a critical issue and provides a foundation for the current and future basis of tourism studies. The measurement can not only help us to effectively understand the current situation of regional tourism ecological security but also provide theoretical guidance for the sustainable development of tourism.

2.2. Evaluation method of tourism ecological security

To present tourism ecological security and system operation status scientifically and reasonably, the selection of measurement models is crucial. On the one hand, scholars conducted quantitative data analysis by constructing the evaluation model to explore the development status of tourism ecological security. Li, Wu, Wu, and Zhou (2017) used mathematical statistics and the GIS spatial analysis method to measure and analyze the tourism ecological security in 31 Chinese provinces, and constructed an obstacle factor diagnostic model to explore the obstacle factors of tourism ecological security. Chen (2017) applied the ecological footprint model to measure the tourism ecology in Taiwan, and the grey model is used to predict the tourism ecological carrying capacity. Liu, Zhang, Wang, and Xu (2018) constructed a more comprehensive and scientific tourism sustainable development index system from the perspectives of economic, social, resources and environment, and used the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method to evaluate the sustainable tourism development of 11 provinces and cities in the Yangtze river economic zone. Pueyo-Ros et al. (2018) created a comprehensive model of tourism cost and emergency managemen, the Travel Costs and Contingent Behavior (TC + CB), to evaluate the impact of ecological restoration on the recreation value of tourist destinations. On the other hand, qualitative research method is also used to explore the evaluation system of tourism ecological security. For example, Liu et al. (2009) used the Analytical Hierarchy Process and the Delphi Method to construct the evaluation index system of ecological security of natural heritage tourism. Although the previous literature has made numerous efforts to measure tourism ecological security from different research perspectives, there remains the unsolved question of index comprehensiveness and internal system operation. Some controversies surrounding the methods used to measure tourism ecological security, such as incomplete measurement methods and inadequate selection of indicators, meaning the status of tourism ecological security cannot be accurately evaluated. Therefore, to improve the important evaluation method of tourism ecological security, this study is based on ecosystem theory, and deeply analyses the definition and connotations of tourism ecological security in several steps. First, we select a relatively comprehensive DPSIR framework to create the evaluation system, which makes up for the problem of incomplete index selection in previous studies. Second, we combine the efficiency evaluation method to measure the "quality" of tourism ecological security, which can address the problem of previous research only evaluating the "quantity" of tourism ecological security (Dong et al., 2018).

2.3. DPSIR framework

The Driver-Pressure-State-Impact-Response (DPSIR) model was established in 1993 by the European Environmental Agency (OECD) based on the PSR and DSR frameworks: "Driver" and "Impact" indicators were added in DPSIR conceptual framework (Waheed, Khan, & Veitch, 2009). The DPSIR model examines the interrelationship between people and the environment from a system perspective. This model is systematic and comprehensive, and enables a more comprehensive monitoring of the continuous feedback mechanism between the indicators. Importantly, one of the main goals of the DPSIR model is to assess efficiency (Ness, Anderberg, & Olsson, 2010), which is mostly used for environmental assessment, resource management (Kagalou, Leonardos, Anastasiadou, & Neofytou, 2012), etc. However, few studies have focused on it. Only the latest research regards DPSIR model as an important guiding framework to explore the index construction of sustainable development (Asmelash & Kumar, 2019), which shows the completeness and effectiveness of the DPSIR model.

The DPSIR model can effectively measure the operational status of the tourism ecosystem. Compared with other evaluation models, the advantages of the DPSIR model are found in two aspects. First, the DPSIR model has the advantages of comprehensive content and strong logic (Ehara et al., 2018), and DPSIR framework fully reflects the interaction relationship among tourists, tourism destinations and environment. Specifically, "driver" is a potential factor that puts pressure on the tourism ecosystem, including the direct drivers and indirect drivers of tourism economic development and social and economic development. 'Pressure' comprises the factors that pose a threat to tourism ecological security through the direct effects of the driver, reflecting the consumption of resources by tourists and local residents that end up causing environmental pollution and other pressures (Benitez-Capistros, Hugé, & Koedam, 2014). "State" is the state of coordination of the tourism economy, ecological environment and tourism industry under pressure. The "impact" is the comprehensive impact on the development of the social economy and the tourism industry when the tourism ecosystem is under shock and pressure (Li, 2004). "Response" comprises some measures provided to maintain the stable operation of the tourism ecosystem; these measures include prevention, compensation, and improvement (Cooper, 2013). Second, the DPSIR framework shows that the "circulation" characteristics of the ecosystem operation and its critical five indicators have a "ring" relationship with a single direction (Wang, Sun, Li, & Zou, 2016). The hidden drivers that cause risks affect the good environmental status, resulting in a series of pressures, such as people and nature, people and tourism, tourism and nature. Once the tourism ecosystem is in an unbalanced state, it will counteract the social economy and tourism development. In this case, a series of corresponding measures are needed to actively respond, and the response levels will affect the coordinated development of the tourism ecosystem.

Importantly, scholars have proposed that it could be improved in combination with other methods (Bell, 2012; Maxim, Spangenberg, & O'Connor, 2009). The traditional DPSIR model only measures the development status of each subject of regional tourism ecological security (Malekmohammadi & Jahanishakib, 2017). It cannot comprehensively evaluate the internal interaction and operational efficiency of the tourism ecosystem, however, and unable to evaluate whether the factor investment of tourism destination effectively meets its ecological security needs. Moreover, ecosystem theory asserts that the elements of the system must reach a state of coordination and unification (Reynolds, 2002), and this kind of harmonious and unified state can be measured through efficiency. Therefore, efficiency evaluation is the best way to measure the input and output of resources to reflect the comprehensive effect of the input and output of factors such as the economic development of tourism activities and ecological environment, rather than the result of a single factor input or output (Zha, He, Liu, & Shao, 2019). Which reflects that tourism ecological security is the comprehensive effect of the input and output of factors such as economic development of tourism activities and ecological environment etc, rather than the result of a single factor input or output. Therefore, this study combines the DPSIR framework with the DEA efficiency model to improve the tourism ecological security evaluation model.

2.4. Current gaps in the literature

To better clarify the necessity of this study' s exploration of the innovation of tourism ecological security evaluation methods and the critical driving mechanism, we comprehensively review the related previous studies, and highlight the current research gaps in the tourism studies sector.

First, we examine the perspective of the foundational theory for tourism ecological security evaluation. Previous studies have ignored the need to provide a theoretical basis for tourism ecological security measures; however, a strong theoretical background is not only helpful to clarify the interactions among the multiple subjects in the tourism ecosystem but also to transform the complex system operation mechanism into simple explanations (Gursoy & Nunkoo, 2019). Peng et al. (2018) asserted that to maintain the security of the ecosystem, certain elements must be maintained in a coordinated and unified state. Further, ecosystem theory provides important theoretical background and guides us to realize that tourism ecological security must consider the balanced state of the input and output of each factor in the system evaluation (Dong et al., 2018). Therefore, this paper introduces the ecosystem theory as the foundation of the explanation of the tourism ecological security.

Second, although many evaluation models for tourism ecological security have been established by tourism scholars, such as Ecological Conservation Development Areas(ECDA) (Tang et al., 2018), the TOPSIS method (Xu, Liu, Li, & Zhong, 2017), and spatio-temporal dynamics analysis (Lu, Wang, Xie, Li, & Xu, 2016), they cannot fully cover the multiple elements in the system, which shows the unilateral evaluation results, ignoring the comprehensive index and the dynamic development. This study introduces the “Driver-Pressure-State-Impact-Response" framework, which not only fully reflects the affinity relationships among the tourist, destination and environment and multilevel characteristics of the assessment element but also notes the circulation characteristics of the system’ s dynamic development.

Third, scholars often use a single evaluation framework or model to evaluate tourism ecological security. Tourism scholars note, however, that the combination of assessment framework and multiple methods is the trend of future assessment, which not only provides diverse perspectives for phenomena explanations, but is also helpful in examining complex systems (Bell, 2012). Therefore, this study integrates the DPSIR framework and SBM-DEA method and provides innovative perspective in the evaluation of tourism ecological security.

Fourth, previous studies have asserted that exploring the influencing factors is helpful to identify the obstacles to tourism ecological security (Peng et al., 2018). Most scholars, however, used regression equations or qualitative studies to explain tourism ecological security (Tang et al., 2018), which failed to identify the core influencing factors, and supplied no addition detail with regard to developmental strategies. Therefore, this study uses the Geo-Detector method to identify the core influencing factors of tourism ecological security.

Fifth and finally, although previous studies have summarized the formation path of tourism ecological security, the construction of the driving mechanism remains an unsolved question, and as a result, the operation mechanism of tourism ecological security cannot be systematically constructed (Xu et al., 2017). Based on the DPSIR framework and the core influencing factors, this study constructs the driving mechanism of tourism ecological security in an all-around and multi-level way, which is a key contribution.

3. Method and data

3.1. Research method

3.1.1. DPSIR-DEA model

The DPSIR-DEA framework was used to measure the tourism ecological security of the Yangtze River Delta (YRD). Data Envelopment Analysis (DEA) is an analytical method proposed by two American operation researchers, Charnes, Cooper and Rhodes in 1978 to evaluate relative efficiency. However, because of today's more complex economic, social and ecological systems, the selection of a single DEA indicator faces a series problems, such as incompleteness and lack of rationality. Thus, the combination of the DPSIR framework and the DEA model not only comprehensively covers relevant indicators but also accurately measures operational efficiency. It is worth noting that the classical DEA method based on the CCR and BCC models fails to fully consider relaxation problems of input and output, resulting in deviations efficiency measurement (Hosseinzadeh Lotfi, Jahanshahloo, Givehchi, & Vaez-Ghasemi, 2013). Subsequently, Tone constructed an undesirable output relaxation metric (Super-SBM) model based on environmental production techniques, which solved the problem of non-zero slack in input or output, and undesired output problems in the production process. Further, these model changes avoid radial and deviation problems caused by radial and angle selection differences (Tone, 2001), better reflecting the nature of tourism ecological security evaluation. Therefore, DPSIR, an evaluation framework covering multiple system elements, was introduced, and SMB-DEA is used to solve the problem of undesired output and measurement of environmental efficiency (Wang, Zhang, Fan, Lu, & Yang, 2019). A new evaluation method that combines the DPSIR framework with SMB-DEA model was created. The mathematical expression is as follows:

$$\rho^* = \min\rho = \min\frac{1-\left(\frac{1}{N}\sum_{n=1}^{N}\frac{s_n^x}{x_n^{k'}}\right)}{1+\left[\frac{1}{M+1}\left(\sum_{m=1}^{M}\frac{s_m^y}{y_m^{k'}}\right)+\sum_{i=1}^{I}\frac{s_j^b}{b_i^{k'}}\right]}$$

$$s.\,v.\begin{cases}\sum_{k=1}^{K} z_k^y y_m^k - s_m^y = y_m^{k'},\ m = 1\cdots,M;\\ \sum_{k=1}^{K} z_k^y b_i^k + s_i^b = b_i^{k'},\ i = 1\cdots,I;\\ \sum_{k=1}^{K} z_k^y x_n^k + s_m^x = x_n^{k'},\ n = 1\cdots,N;\\ z_i^k \geq 0,\ s_m^y \geq 0,\ s_i^b \geq 0,\ s_n^b \geq 0,\ k = 1,\ \cdots,K\end{cases} \tag{1}$$

where ρ* represents tourism ecological security while *N*, *M*, and *I* represent the number of inputs, desirable outputs, and undesirable outputs, respectively. (s_m^y, s_i^b, s_n^x), $(y_m^k, b_i^k, x_n^k)$and (z_k^y, z_k^x)represent the slack variables of the input-output, the input-output values of the production unit *k* at time *v*, and the weight of each input-output. Moreover, the greater the ρ value, the higher the security.

In addition, this study used Wang's et al. (2016) suggestion to disassemble the DPSIR ring structure into an annual linear structure to more intuitively present the cyclic characteristics of the DPSIR model (Wang et al., 2016). Impact and State are the output factors in the operation of the tourism ecosystem. Moreover, Driver, Pressure and the Response of the previous year are the necessary input factors for the efficiency result, which affects the cyclic operation of the system. Therefore, the study uses Driver, Pressure of tourism and social response as the input factors, the State and Impact as the desirable output factors, and the ecological destruction pressure as the undesirable output factor in the DEA model.

3.1.2. Spatial autocorrelation

3.1.2.1. Global spatial autocorrelation. Global autocorrelation is used to measure the spatial agglomeration characteristics of tourism ecological security in the YRD. Moran's I index is a commonly used indicator for global spatial agglomeration effects. The formulas are as follows:

$$I = \frac{N}{S_0}\times\frac{\sum_{i=i}^{N}\sum_{j=1}^{N} w_{ij}(x_i-\overline{x})(x_j-\overline{x})}{\sum_{i=1}^{n}(x_i-\overline{x})^2} \tag{2}$$

where *I* indicates Moran's I index; *N* is the number of research units; x_i and x_j are the attribute values on the *i* and *j* study units, respectively; $\overline{x}$ is the average value ofx_i; S_0 is the sum of all the elements of the spatial weight matrix; andw_{ij} is the spatial weight matrix of the study units *i* and *j*. The value of *Moran's I* ranges from −1 to 1.

3.1.2.2. Local spatial autocorrelation. Spatial autocorrelation describes the spatial differentiation characteristic of the research units in the region in more detail. *Getis-Ord* G_i^* is used to measure local spatial differentiation characteristics and to identify the spatial distribution of cold spots and hot spots, using the following mathematical expression:

$$G_i^*(d) = \sum_{j=1}^{n} w_{ij}x_j / \sum_{j=1}^{n} x_j \tag{3}$$

where *n* is the number of research units; $x_i$andx_j are the attribute values on the *i* and *j* space units, respectively; andw_{ij} is the spatial weight matrix. If G_i^* is positive and significant, indicating the value of position *i*, and the surrounding areas are relatively high, that is the high level accumulation area (hot spot area). Conversely, G_i^* is negative and significant, this indicates that the value around position i is lower than the mean, belonging to the low level accumulation area (cold spot area).

3.1.3. Geo-detector

Geo-Detector is mainly used to detect differences in geographical elements and the influencing factors of spatial distribution. Further, the factor detector is used to detect whether a certain geographical factor is the reason for the difference in spatial distribution (Wang et al., 2010). This study uses the Geo-Detector factor detection model to explore the influencing factors of the spatial characteristics of tourism ecological security. The main idea is that the relevant factors affecting tourism ecological security are spatially different. If the factor and the level of tourism ecological security are spatially significant, it indicates that this factor is decisive for the spatial distribution of tourism ecological security. The Geo-Detector method used can effectively detect the core influencing factors of regional tourism ecological security (Shi et al., 2018). Compared with the traditional regression method used in previous studies, Geo-Detector can not only effectively analyze the differences of spatial influencing factors but also identify the core factors. Geo-Detector provides a powerful methodological application foundation for how practitioners take action in the future. The specific calculation formula is as follows (Wang & Hu, 2012):

$$q = 1 - \frac{1}{n\sigma_U^2}\sum_{i=1}^{m} n_{D,i}\sigma_{U_{D,i}}^2 \tag{4}$$

where$q$ presents the detection force value of the detection factor D; n is the sample size of the entire region; $n_{D,i}$ is the number of samples in the sublevel region; m is the number of sublevel regions; σ_U^2 is the variance of the tourism ecological security value; and $\sigma_{U_{D,i}}^2$ is the variance in the sublevel region. $0 \le q \le 1$ indicates that the larger the$q$ value is, the greater the influence of the D factor on tourism ecological security.

3.2. Index selection

Evaluation indicators for tourism ecological security include inputs, desirable outputs and undesirable outputs. In addition, the selection of input and output indicators is directly related to the science and accuracy of the evaluation (Korhonen & Luptacik, 2004). The tourism ecosystem covers all aspects of society: the economy, the environment and tourism development. Combined with relevant research, the indicators of this study include tourism industry development, economy, population, environment, and resources.

(1) Driver (D) (Lu et al., 2015; Wang et al., 2016). Six indexes are applied: tourism income growth rate, tourist growth rate, tertiary industry growth rate, natural population growth rate, GDP per capita, and urbanization rate. These indicators are selected from the tourism industry development and social economic development aspects, which are important input factors for the operation of the tourism ecosystem. Tourism income growth rate and tourists growth rate selected in this study represent the development of the tourism industry. Meanwhile, the tertiary industry growth rate, natural population growth rate, GDP per capita, and urbanization rate illustrate the current social and economic development situation.

(2) Pressure (P) (Liu et al., 2017, Liu, Zhang et al., 2018; Wang et al., 2016). Population density, tourist density, and water consumption per 10,000 yuan are selected as tourism and social pressure (P1). Meanwhile, waste water discharge and soot emissions are selected as ecological damage pressure (P2). Specifically, population density and tourist density may cause a comprehensive pressure on tourism activities. Moreover, water consumption per 10,000 yuan reflects the levels of energy consumption and regional energy use efficiency. Further, waste water discharge and soot emissions as negative factors in economic development may cause serious damage to regional ecological environment.

(3) State (S) (Chen, Thapa, & Yan, 2018; Lu, Li, Pang, Xue, & Miao, 2018). Five indexes – garden green space, per capita park green area, green area of built-up area, proportion of tertiary industry in GDP, and total tourism revenue in GDP – are selected as output indicators. The status indexes are mainly selected from the ecological environment and industrial economic development aspects. Specifically, the area of garden green space, the per capita park green area, and green coverage area of established areas represent the levels of environmental health and sustainable development. Moreover, the proportion of tertiary industry in GDP reflects the industrial structure of regions, and the proportion of total tourism revenue in GDP reflects the contribution of the tourism industry.

(4) Impact (I) (Liu et al., 2017; Wang et al., 2016). Six indexes, such as tourism economic density, per capita tourism income, tourism foreign exchange income, domestic tourism income, tourist reception volume and population ratio, and the number of employees, are selected, describing the development levels of a region's tourism industry and service industry. As the output factors of the tourism ecosystem, these indexes can reflect the impact of system operations on tourism.

(5) Response (R) (Liu, Zhang, et al., 2018; Wang et al., 2016). The sewage treatment rate, life garbage treatment rate, the proportion of fiscal expenditure to GDP, and the number of students in ordinary high schools are selected as the input factors for the following year. The sewage treatment rate and life garbage treatment rate are critical contributors to the sustainable development of the ecological environment. Moreover, fiscal expenditure reflects the economic impetus to invest in the ecological environment, and the number of students in ordinary colleges and universities reflects the supply of talent for response measures.

Combining the needs and data availability of the DPSIR and DEA models, this study selects 6 secondary indicators and 26 tertiary indicators, including driver, tourism and social pressure, ecological pressure, states, impact and response. Among them, driver, tourism and social pressure and response are input factors. The state and impact are the desirable output factors, and the ecological pressure is the undesirable output factor. Lastly, the index is standardized, and the weight of the index is calculated using the entropy method (Wang et al., 2016). The evaluation index system is shown in Table 1.

3.3. Data collection

This study takes 26 cities in the Yangtze River Delta urban agglomeration (YRD), China, as the study site, and Fig. 1 indicates the 26 cities of the YRD. The YRD is one of the regions with the highest levels of urbanization and economic development, and the largest population of foreigners. With its powerful economic forces and rapid development, the YRD has become the sixth largest metropolitan area in the world (Chen et al., 2018). The YRD is the most mature area for tourism development in China. Because of its rich cultural, historical, natural and other tourist attractions, it has laid an important foundation for the rapid development of tourism, which is known as the “Golden Triangle” in the Chinese tourism industry (Zhang, Gu, Gu, & Zhang, 2011). As of the end of February 2017, there were 38 scenic spots at the 5A-level in 26 cities in the YRD, including 3 scenic spots at the 5A-level in Shanghai, 18 scenic spots at the 5A-level in Jiangsu, 12 scenic spots at the 5A-level in Zhejiang, and 5 scenic spots the 5A-level in Anhui, evidence that tourism resources are extremely rich and highly complementary. However, there have also been resource shortages and environmental pollution in the rapid development of tourism in the YRD, which these have become a potential danger in the sustainable development of tourism. Therefore, the YRD is a typical and representative study site.

In 2012, China outlined strategic goals for the “Promotion of ecological civilization”. Taking into account the changes and lags in the implementation of that policy, and the availability of data, 2011–2016 is selected as the research period. Because the response is often used as

Table 1
Evaluation index system tourism ecological security.

Evaluation system		Evaluation index	Measuring unit	Weight
Driver(D)		Tourism income growth	%	0.155
		Tourist growth rate	%	0.355
		Tertiary industry growth rate	%	0.069
		Natural population growth rate	‰	0.179
		GDP per capita	yuan	0.155
		Urbanization rate	%	0.087
Pressure(P)	Tourism and social pressure	Population density	person/hm^2	0.344
		Tourist density	10,000 person/km^2	0.389
		Water consumption per 10,000 yuan	m^3/10,000 Yuan	0.266
	Ecological damage pressure	Waste water discharge	10,000 tons	0.780
		Soot emissions	tons	0.220
State(S)		Garden green space	hm^2	0.457
		Per capita park green area	m^2	0.051
		Green coverage area of established areas	hm^2	0.227
		Proportion of tertiary industry in GDP	%	0.051
		Total tourism revenue in GDP	%	0.215
Impact(I)		Tourism economic density	10,000 person/km^2	0.182
		Per capita tourism income	yuan	0.108
		Travel foreign exchange income	10,000 USD	0.315
		Domestic tourism income	100 million yuan	0.147
		Tourist reception volume and population ratio	%	0.079
		Number of employees in the tertiary industry	10,000 person	0.168
Response(R)		Sewage treatment rate	%	0.037
		Life garbage treatment rate	%	0.118
		The proportion of fiscal expenditure to GDP	%	0.015
		The number of students in ordinary higher schools	person	0.830

an input indicator for the following year, the four indexes of response are used from 2010 to 2015. Lastly, the data sources come mainly from statistical data, such as the China's Statistic Yearbook, China City Statistical Yearbook, China Tourism Statistics Yearbook and China Environmental Statistics Yearbook.

4. Results

4.1. Temporal and spatial characteristics of tourism ecological security

4.1.1. Temporal evolution characteristics

According to formula (1), Max DEA software was used to calculate the tourism ecological security evaluation values for 2011–2016 in the YRD. As shown in Table 2, tourism ecological security of the YRD displayed an "N" type time evolution law of "first rise – then fall – then rise again". The average values of tourism ecological security in 2011–2016 were 0.667, 0.741, 0.735, 0.543, 0.652 and 0.696, respectively for each year. The results showed a volatility growth trend with an overall security evaluation value greater than 0.5, reflecting a good development trend of the tourism ecosystem in the YRD. Specifically, the tourism ecological security evaluation value increased rapidly in 2011–2013, declined in 2014, recovered and gradually improved in 2015. In 2014, the "Guidelines for Promoting the Development of the Yangtze River Economic Belt by Relying on the Golden Waterway" was issued. The policy aimed to comprehensively promote the regional construction of the Yangtze River Economic Belt

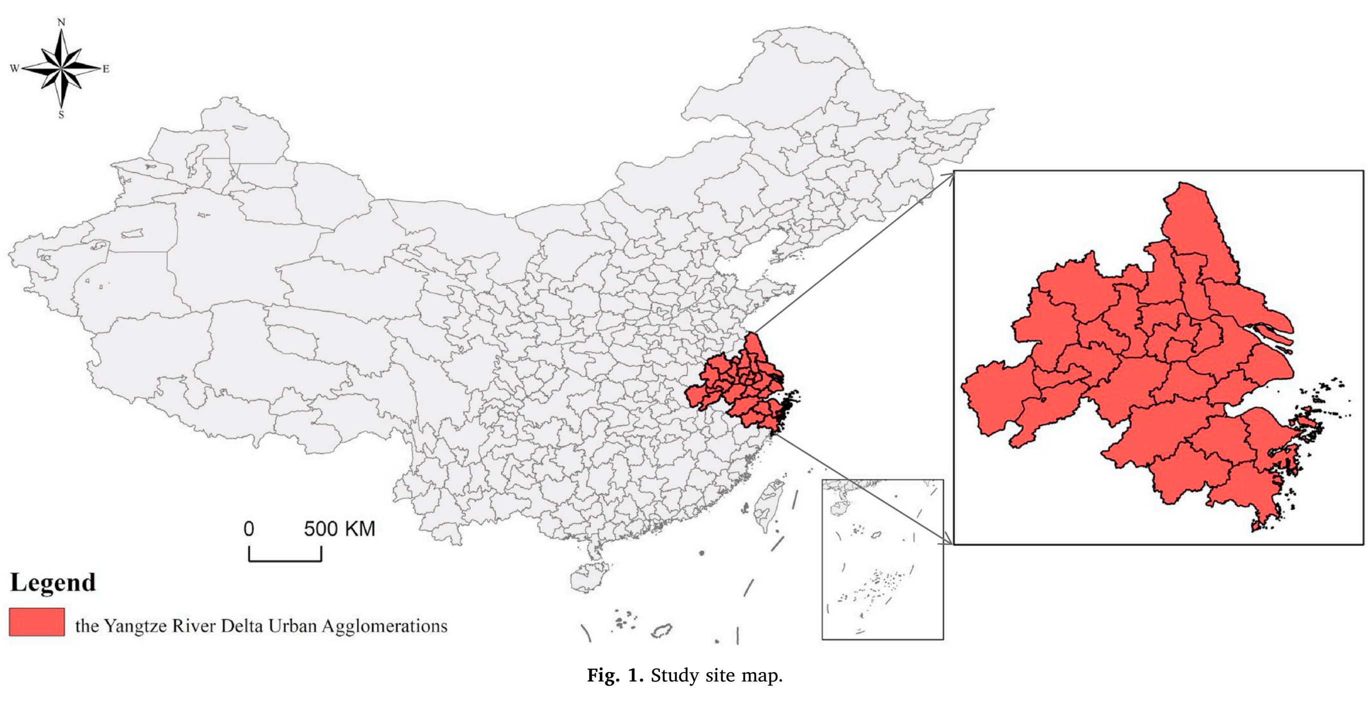


Fig. 1. Study site map.

Table 2
Evaluation value of tourism ecological security in the YRD.

City	2011	2012	2013	2014	2015	2016
Shanghai	1.599	1.504	1.452	1.162	1.438	1.332
Nanjing	1.210	1.241	1.202	1.165	1.164	1.131
Wuxi	0.653	0.820	0.668	0.319	0.599	0.590
Changzhou	0.473	0.557	0.499	0.216	0.416	0.403
Suzhou	0.730	1.035	1.019	0.386	0.761	0.733
Nantong	0.270	0.426	0.390	0.187	0.347	0.314
Yancheng	0.082	0.123	0.126	0.063	0.129	0.130
Yangzhou	0.588	0.738	0.614	0.285	0.412	0.398
Zhenjiang	0.517	0.618	0.617	0.285	0.458	0.427
Taizhou	0.157	0.236	0.226	0.109	0.197	0.178
Hangzhou	1.141	1.141	1.147	1.030	1.281	1.264
Ningbo	1.047	1.073	1.065	0.417	1.034	1.051
Jiaxing	0.519	0.570	0.472	1.583	0.396	0.434
Huzhou	0.631	1.043	1.007	0.393	0.635	0.689
Shaoxing	0.688	1.044	1.036	0.325	0.562	0.572
Jinhua	0.823	0.740	0.622	0.332	1.041	1.010
Zhoushan	2.412	2.234	2.708	2.693	2.194	2.518
Taizhou	1.178	1.065	1.057	1.044	1.020	1.182
Hefei	0.449	0.425	0.464	0.329	0.472	1.007
Wuhu	0.191	0.255	0.263	0.141	0.231	0.309
Ma On Shan	0.194	0.249	0.232	0.108	0.200	0.203
Chuzhou	0.104	0.186	0.126	0.084	0.118	0.134
Chizhou	1.073	1.102	1.061	1.022	1.141	1.188
Xuancheng	0.144	0.187	0.198	0.139	0.224	0.260
Anqing	0.286	0.395	0.588	0.170	0.385	0.487
Tongling	0.194	0.262	0.247	0.140	0.109	0.143
Mean	0.667	0.741	0.735	0.543	0.652	0.696

as a pioneering demonstration zone for ecological civilization construction, which further promoted the restoration and development of the tourism ecosystem. It is worth noting that due to a lag in implementing the policy, the relevant responses became effective in 2015. Therefore, the status of tourism ecological security in the YRD steadily increased after 2014.

In addition, the results showed that the evolution trends of tourism ecological security in 26 cities were more obviously different. Further, Zhoushan, Shanghai, Nanjing and Hangzhou were the safest, and Yancheng, Nantong, Taizhou, Zhangzhou, Maanshan, Xuancheng and Tongling were not safe. The tourism ecological security of the rest of the region showed volatility changes, indicating that there were obvious differences between the local evolution model and the global evolution model.

4.1.2. Spatial pattern and development characteristics

4.1.2.1. Global spatial distribution. Moran's I values of tourism ecological security in 2011–2016 were calculated using formula (2). As illustrated in Table 3, the *Moran's I* values of tourism ecological security are positive, but the normal statistics of *Moran's I* in all years was not significant ($Z(I) > 1.96$, $P(I) < 0.05$) (Li, Xu, Wang, & Tan, 2018). The *Moran's I* value exhibited a volatility of decreasing evolution over time, demonstrating that tourism ecological security of the YRD in 2011–2016 presented a random distribution of spatial characteristics. Moreover, the random distribution trend was more obvious with time, and the spatial correlation effects among regions were extremely weak. Overall, since 2011, there has been no spatial spillover effect and interaction effect on the tourism ecological security of the YRD, reflecting that tourism ecological security is an internal circulation system and is less affected by surrounding areas.

Table 3
Moran' I for tourism ecological security in YRD.

Year	Moran's I	*Z* (I)	*P* (I)	Spatial pattern
2011	0.126	1.162	0.245	Random distribution
2012	0.160	1.361	0.174	Random distribution
2013	0.128	1.230	0.219	Random distribution
2014	0.001	0.303	0.762	Random distribution
2015	0.117	1.074	0.283	Random distribution
2016	0.097	0.970	0.332	Random distribution

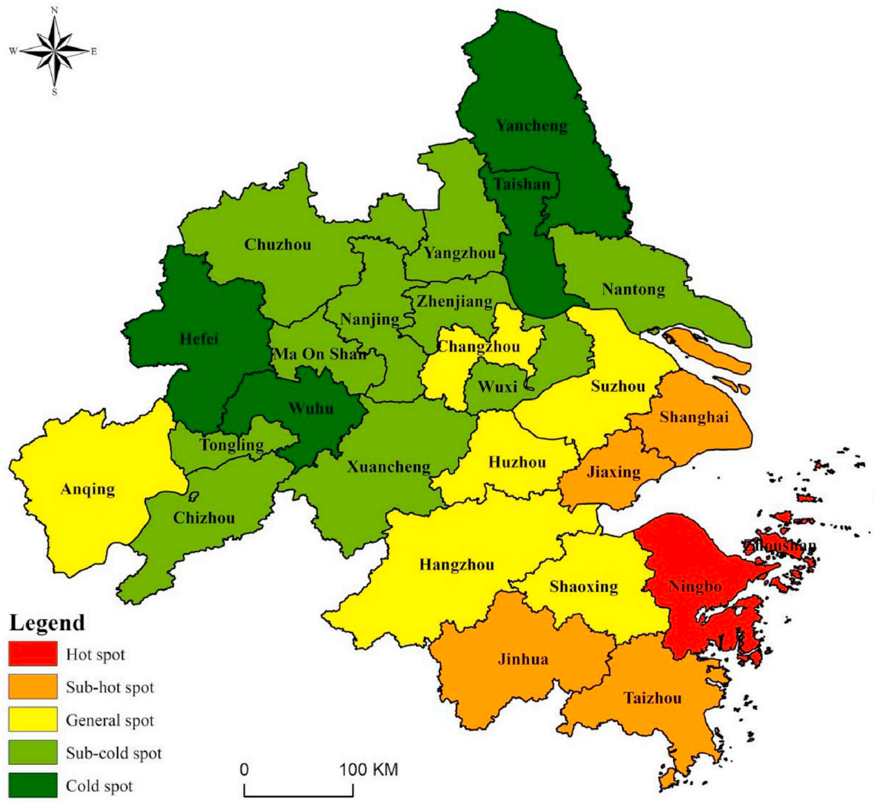
This study further measured the spatial heterogeneity of tourism ecological security using Geo-Detectors software. Specifically, when the basic units in each type of zone were completely homogeneous and various types of regions were different, the spatial differentiation level was 1. In addition, when the basic units within each type of area were randomly distributed, the spatial differentiation strength was 0. In short, the value of the detection value q was from 0 to 1, and the larger the value, the more obvious the spatial differentiation. Therefore, spatial heterogeneity analysis was divided into two division models: (1) according to the classification of provinces, the YRD comprised some cities in Shanghai, Jiangsu, Zhejiang and Anhui provinces; (2) according to the regional changes in the YRD, the early 16 core cities expanded to 26 cities in the current period.

The results in Table 4 show that the tourism ecological security of the YRD had obvious spatial differentiation characteristics and that spatial heterogeneity weakened over time, which sped up the unification of regional tourism trends. On the one hand, the *q* value by province was larger than the value of the change in the YRD, demonstrating that there were large differences in the evaluation values of tourism ecological security between provinces, and the boundary effect was obvious. Further, the economic, social and environmental developments of the provinces showed significant differences, which also affected regional tourism ecological security. On the other hand, the previous 16 cities of the YRD became the “core area” of the current Pan-Yangtze Delta development plan, and the area's internal development had strong connectivity and consistency. However, the differences between the previous 16 cities and the later 26 cities were more obvious. Over time, the differences weakened with the development of the new model of the “Pan-Yangtze Delta”, which statistically showed there was spatial heterogeneity in the YRD.

4.1.2.2. Local spatial pattern. To further explore the local spatial pattern of the YRD, according to formula (3), ArcGIS10.2 software was used to analyze the$Getis - OrdG_i^*$ of the indexes. The index values were divided into five types using the natural discontinuity method (Miao & Ding, 2015), and cold-hot spots pattern evolution maps are reported in Fig. 2. The results showed that the hot-spots and cold-spots were less and more stable, and the sub-hot spots, sub-cold spots, and general areas were more numerous and vary significantly over time. Specifically, (1) the hot-spots were mainly concentrated in two cities, Zhoushan and Ningbo, and the changes were relatively stable. (2) The sub-hot spots changed significantly, showed an expanding trend, and were mainly concentrated in Shanghai and Zhejiang provinces. (3) The general region experienced two periods (the expansion period in 2011–2014 and the contraction period in 2014–2016) showing a “banded” distribution and located mostly in some cities in Jiangsu Province. (4) There were significant spatial transitions in the sub-cold spot area in 2011–2016. It was shown that Tongling and Chizhou changed from sub-cold spots to general areas, Anqing changed from a general area to a sub-cold spot, and sub-cold spots were mostly concentrated in Jiangsu and Anhui provinces. (5) Hefei and Huzhou transitioned from cold spots to sub-cold spots, and Yangzhou changed from a sub-cold spot to a cold spot. In addition, other areas remained

Table 4
Spatial differentiation of tourism ecological security.

Type	Year					
	2011	2012	2013	2014	2015	2016
Division by province	0.433	0.453	0.376	0.313	0.407	0.339
Division by regional change	0.218	0.319	0.246	0.148	0.156	0.096



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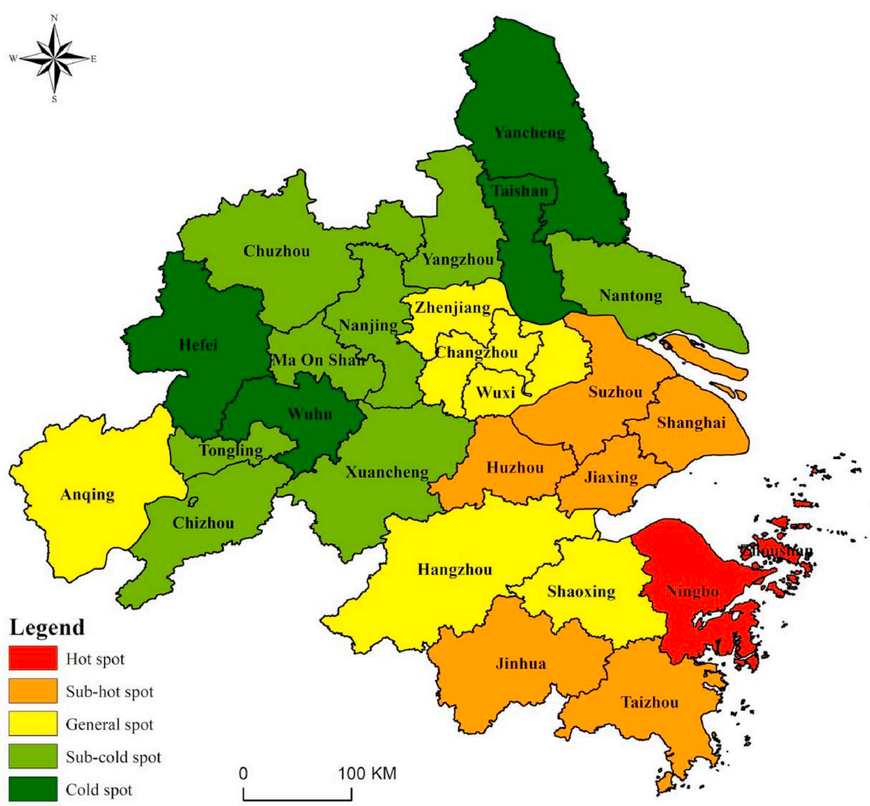
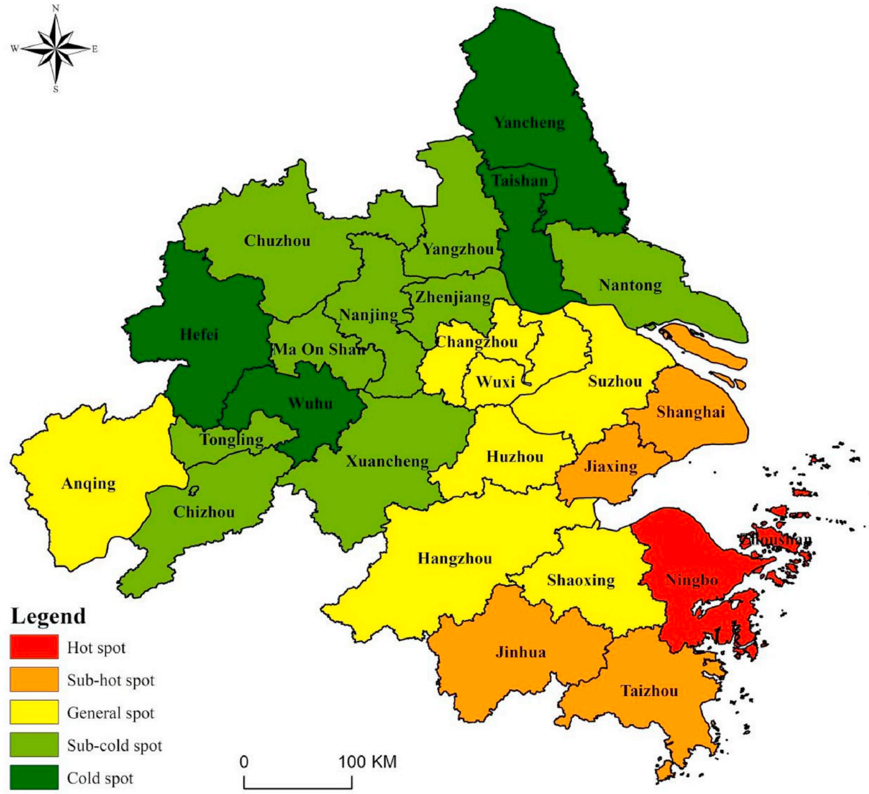


b

Fig. 2. (a). Cold-hot spots of the tourism ecological security in the YRD, 2011. **(b).** Cold-hot spots of the tourism ecological security in the YRD, 2012. **(c).** Cold-hot spots of the tourism ecological security in the YRD, 2013. **(d).** Cold-hot spots of the tourism ecological security in the YRD, 2014. **(e).** Cold-hot spots of the tourism ecological security in the YRD, 2015. **(f).** Cold-hot spots of the tourism ecological security in the YRD, 2016.



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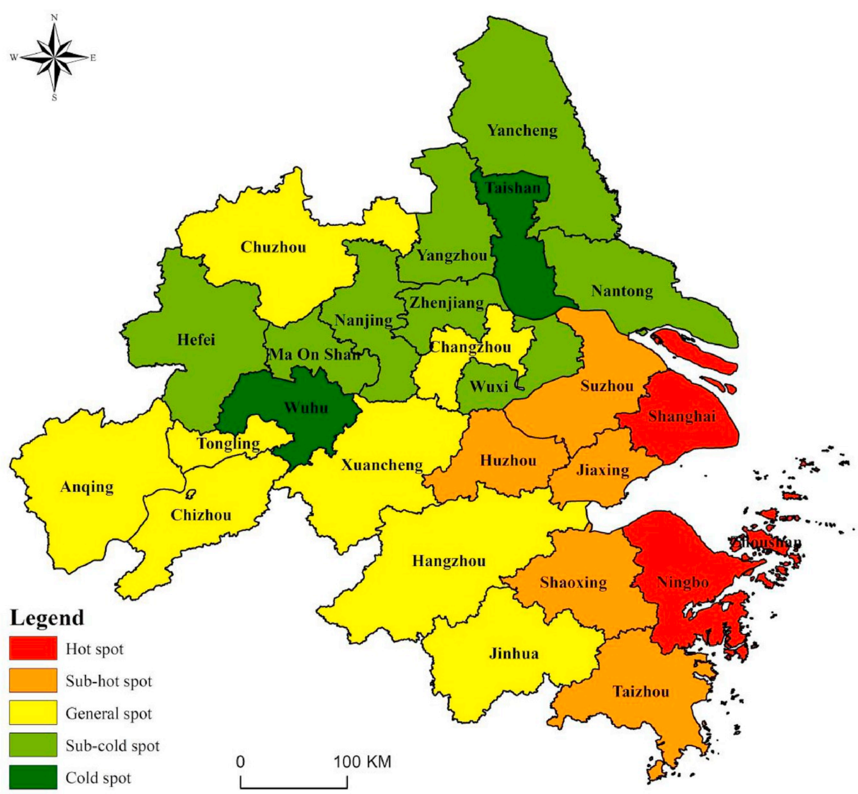

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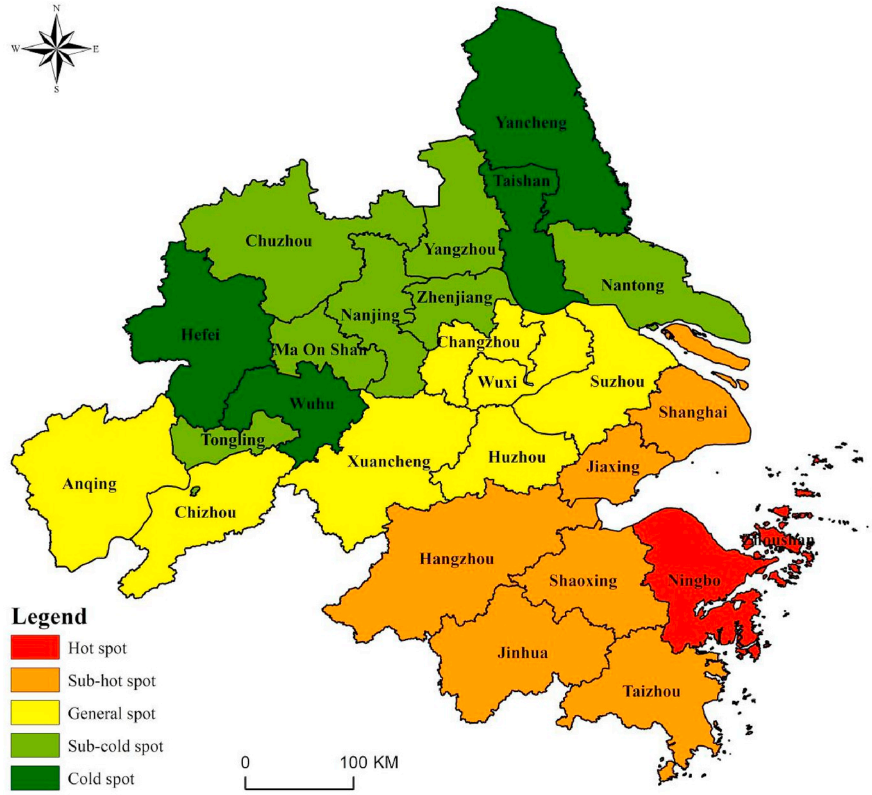
Fig. 2. (*continued*)



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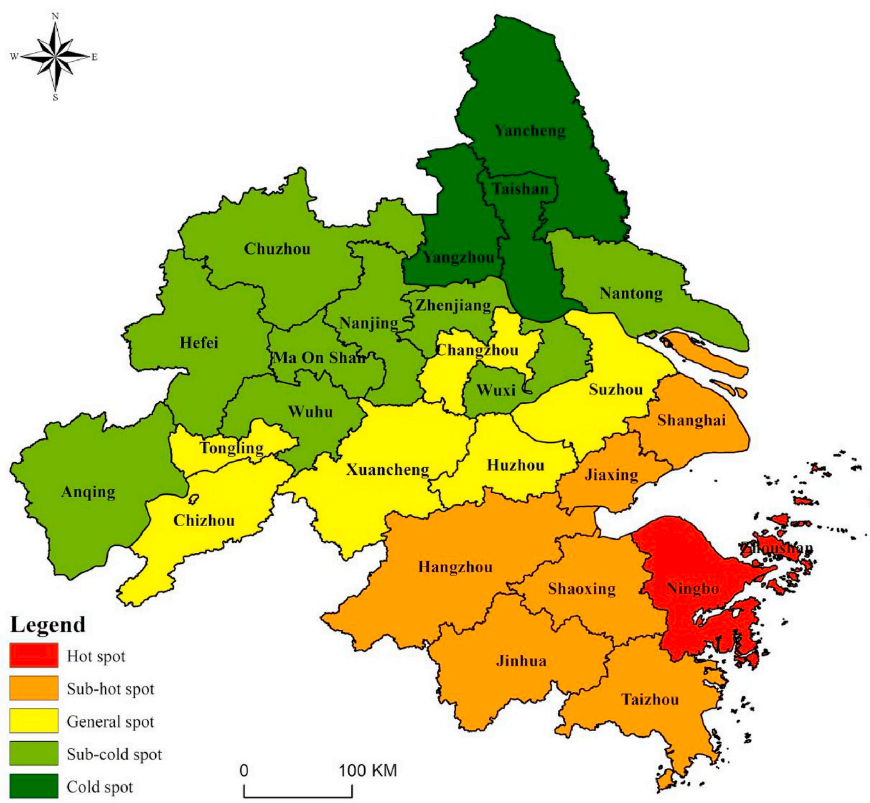

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Fig. 2. (*continued*)

stable. Furthermore, these results indicate that the regional differences in tourism ecological security in the YRD are obvious. Ecological security areas were mostly concentrated in cities with developed economies or a good ecological environment. In addition, these cities had a large amount of funds invested in the maintenance and response of ecosystems. Moreover, Zhoushan, an island city, had always attached great importance to the construction of marine ecological civilization, and its tourism ecosystem was relatively stable and safe. In all, during the period covering 2011–2016, the tourism ecological security of the YRD gradually formed a spatial distribution pattern from the southeast to the northwest, and gradually transitioned from hot-spots to cold-spots. Specifically, the southeastern cities of the YRD were mainly hot-spots, and the northwest cities were mainly cold-spots, which further proved that tourism ecological security showed a "south-northwest" orientation spatial distribution pattern.

4.2. Driving mechanism of tourism ecological security

The tourism ecological security of the YRD has obvious time-space characteristics. To explore the influencing factors and driving mechanism of its formation, this study examined the impact effects of 26 evaluation indexes on system security. We followed Cang and Luo's (2018) suggestion that the variables in the Geo-Detector analysis must be type variables. If the independent variables were the continuous variables, independent variables needed to be discretized to the type variables. Therefore, the Natural Breaks (Jenks) was used to classify the various elements using ArcGIS 10.2 software (Tan, Zhang, Lo, Li, & Liu, 2016). Next, according to formula (4), the detection force value of each influence factor was calculated. Results in Table 5 showed that there were significant differences in the intensity of the impact of various detection factors on tourism ecological security. From 2011 to 2016, the values of each impact factor showed a general downward trend and the number of critical impact factors decreased, while the influence of a single critical factor on tourism ecological security increased.

Table 5
Results of impact factor.

Detection factor	Detection index	q in 2011	q in 2016
Driver(D)	Tourism income growth	0.252	0.041
	Tourist growth rate	0.148	0.184
	Tertiary industry growth rate	0.252	0.388
	Natural population growth rate	0.164	0.134
	GDP per capita	0.270	0.288
	Urbanization rate	0.257	0.267
Pressure(P)	Population density	0.185	0.138
	Tourist density	0.739	0.677
	Water consumption per 10,000 yuan	0.488	0.528
	Waste water discharge	0.154	0.139
	Soot emissions	0.236	0.101
State(S)	Garden green space	0.294	0.316
	Per capita park green area	0.600	0.481
	Green coverage area of established areas	0.253	0.229
	Proportion of tertiary industry in GDP	0.483	0.294
	Total tourism revenue in GDP	0.553	0.467
Impact(I)	Tourism economic density	0.502	0.664
	Per capita tourism income	0.611	0.780
	Travel foreign exchange income	0.352	0.139
	Domestic tourism income	0.415	0.328
	Tourist reception volume and population ratio	0.738	0.462
	Number of employees in the tertiary industry	0.288	0.305
Response(R)	Sewage treatment rate	0.136	0.274
	Life garbage treatment rate	0.229	0.069
	The proportion of fiscal expenditure to GDP	0.173	0.492
	The number of students in ordinary high schools	0.204	0.349

(1) Driver influencing factors. The impact levels of each indicator were relatively balanced, and the influence of tertiary industry growth rate was relatively large. Tertiary industry played a crucial role in the development of the tourism economy, not only in promoting the development of primary and secondary industries but also in cultivating new economic growth points. Meanwhile, tertiary industry was less constrained by land and resources and suffered fewer negative effects, such as environmental pollution. Tertiary industry in the YRD was relatively well developed, which was a crucial driver factor in the improvement of tourism ecological security. In addition, per capita GDP and urbanization rate were also critical economic drivers of tourism ecological security.

(2) Pressure influencing factors. Tourist density and water consumption per 10,000 yuan of GDP were the main factors causing the ecological security of the YRD. Tourists were a movable corpus of the tourism ecosystem and the most difficult factor to be controlled in this system. For example, the uncivilized behavior of tourists could cause environmental pollution. Moreover, the tourist density reflected the number of tourists to the city; once the tourist density exceeded the environmental carrying capacity of the tourism destination, a series of ecological imbalances would occur. What's more, water consumption per 10,000 yuan of GDP reflected the levels of resource consumption under the influence of tourism activities and regular life. The q value of this detection index increased from 0.488 in 2011 to 0.528 in 2016, indicating that when the intensity of water resources increases, the impact of water consumption also increases. In addition, it would also put pressure on the ecological environment of tourism destinations in the future.

(3) State influencing factors. Results showed that the per capita park green area had a significant promotion effect. Specifically, greening was an important factor in keeping the balance of the ecological environment. If the tourism city maintained a certain level of green functions, such as purifying air, water and soil, one could reduce the dust and regulate airflow. On the other hand, total tourism revenue in GDP also had a major impact. It represented the levels of tourism economic development, reflecting the status of tourism in the economic system, which was also a critical economic factor in tourism ecological security. These two indexes were important factors influencing the balance of the ecological environment and the coordinated development of tourism.

(4) Impact influencing factors. Tourism economic density and per capita tourism income played an important role in tourism ecological security. The YRD covered many well-known tourism cities with a high level tourism economy. Thus, the tourism economy promoted the willingness of these regions to invest more resources in maintaining the good functioning of the tourism ecosystem. In addition, the detection q value of the tourist reception volume and population ratio decreased from 0.738 to 0.462, indicating that the growth of tourists and local residents was more coordinated.

(5) Response influencing factors. The response was mainly reflected in short-term measures and long-term measures. The results showed that the detection levels of the sewage treatment rate and the proportion of fiscal expenditure to GDP increased, which reflected that these short-term measures could directly improve the ecological environment. Moreover, the q value of the number of students in ordinary high schools also showed a growing trend, which reflected that talent cultivation was a long-term response. Talent investment was a crucial factor in responses, and the effects of improving tourism ecological security gradually emerged.

According to ecological pattern and ecosystem theory, the internal elements of tourism ecosystems are in a state of mutual influence and cyclical operation. To maintain the stable operation of the tourism ecosystem, it is necessary to upgrade or control for key factors.

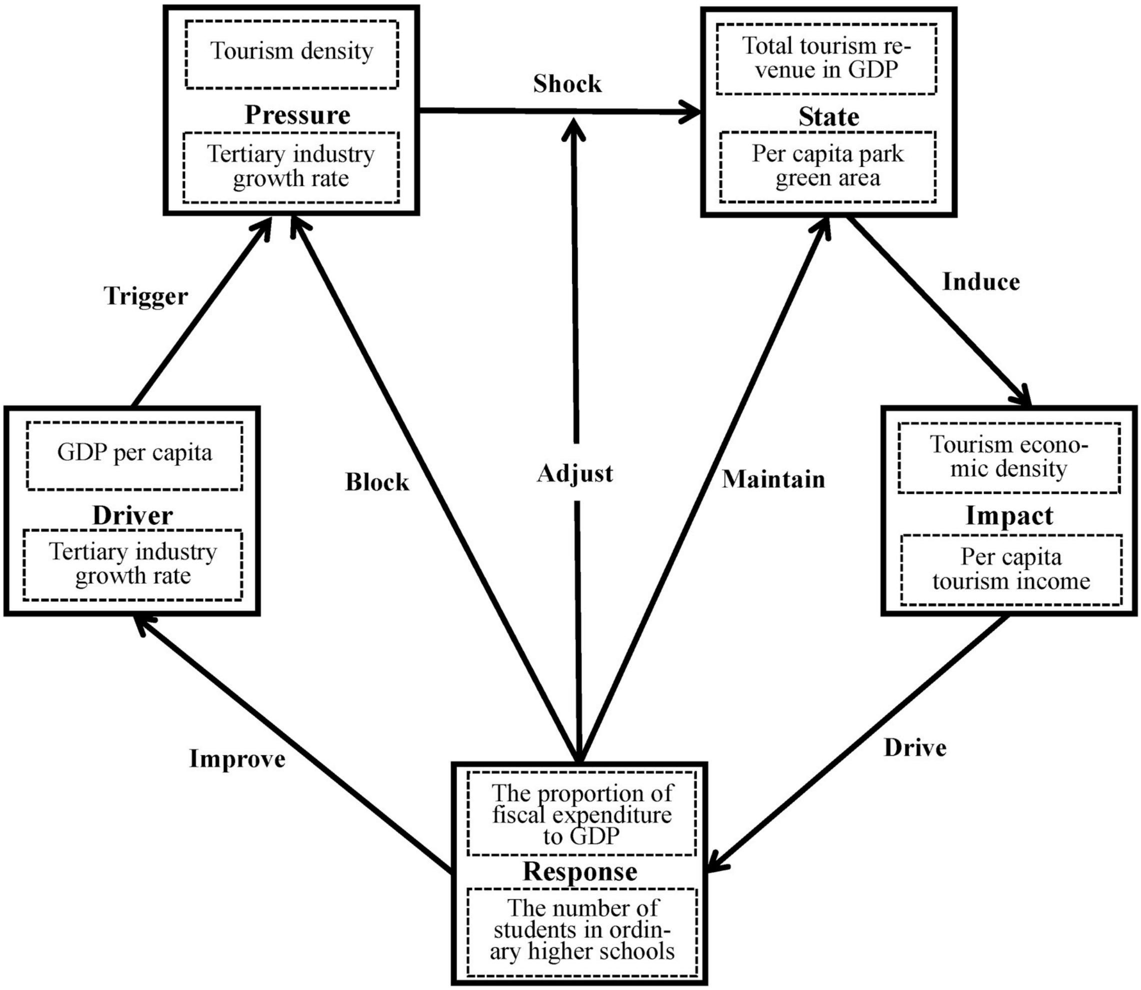

Fig. 3. Driving mechanism of tourism ecosystem.

Therefore, exploring the driving mechanism of the system contributed to clarifying the conduction path and causing the formation between elements (Liu, Zeng, Cui, & Song, 2018) Based on the influencing factors of tourism ecological security in the YRD, the driving mechanism was constructed in Fig. 3. Essentially, the tourism ecosystem is a complex variable system consisting of tourism environment impacts and tourism economic development. The driver was the source of the evolution of the entire tourism ecological security. On the one hand, the driver, driven by the regional economic development level and tertiary industry growth, changed regional tourism development. On the other hand, a series of resource consumption and pollutant emissions caused by tourism activities brought about population pressure, resource consumption pressure and environmental pressure. Lastly, negative impacts on the local tourism ecosystem were created. As a result, pressure caused by the driver formed an unstable state, which reflected an imbalance between tourism economy and ecological environment. In addition, the greening degree and the economic status of tourism were the critical factors affecting state. Further, the tourism ecosystem in this state would also affect the development of the tourism economy. Lastly, faced with this ecosystem, the response was to take management decisions and measures that considered both short-term environmental treatment measures and long-term investment in talent education. Importantly, the response could directly affect the pressure and state, effectively relieved stress and maintained a good ecosystem. Meanwhile, the response moderated pressure was caused by resource consumption and tourism economic activities. When the tourism ecosystem was negatively affected, response played a critical controlling role (Li, 2004).

5. Conclusions

Based on ecological pattern and ecosystem theory, a DPSIR-DEA model was proposed to evaluate tourism ecological security. Taking the YRD as a study site, this study discussed the spatial and temporal distribution of tourism ecological security and its crucial driving factors. Moreover, the driving mechanism of tourism ecological security was constructed. Our research produced some new findings:

First, from the perspective of time evolution, the tourism ecological security of the YRD showed an evolution of the "N" type of "first rise – then fall – then rise again". Meanwhile, the changing trends of cities showed obvious volatility and differences. Because the overall urbanization level was high, the economy developed rapidly and the tourism industry was mature in the YRD, the tourism ecosystem was in an alternating state of imbalance and governance. The Yangtze River Delta tourism network officially opened in December 2010. The purpose was to reflect the "low-carbon lifestyle, ecotourism, civilized tourism, environmental protection", and provide a public tourism information platform for tourists. Driven by these ideas, the tourism ecological security of the Yangtze River Delta region earned widespread respect from 2010 to 2013, but it also greatly stimulated travel demand due to the highly publicized opening. Increasing tourist information demand will lead to an imbalance between supply and demand, however, which will affect the regional tourism ecological development. Therefore, the tourism ecological security value of Yangtze River Delta tourism bottomed out in 2014. Meanwhile, "Guidelines for Promoting the Development of the Yangtze River Economic Belt by Relying on the

Golden Waterway" proposed building the Yangtze River Delta into an ecological construction demonstration zone. Because of the lag in policy guidance since 2015, tourism ecological security in this area showed a trend toward volatility (Wang et al., 2016). Moreover, the ecological security values of local areas were declining, reflecting that the effective development of a few cities promoted the overall security status. However, there were also potential dangers related to the unstable operation of tourism ecosystems.

Second, from the perspective of spatial distribution, (1) the overall spatial tourism ecological security of the YRD presented a random distribution, but the spatial differentiation was obvious in 2011–2016. Conversely, the results differed from previous studies, which found that tourism ecological security showed such characteristics as spatial dependence and spatial correlation, and the effects of spatial spillover were obvious (Li et al., 2017). However, tourism ecological security in previous studies was a measure of "quantity", while our research was a "quality" evaluation. Specifically, the quantity measurement reflected that tourism ecological security would be affected by the surrounding areas. Moreover, there were effects of spatial spillover, which showed that the spatial correlation level was high. Importantly, the evaluation of the "quality" of tourism ecological security in this study reflected the input and output in the internal system cycle, which was less affected and interfered with by the external ecosystems. Therefore, the spatial correlation was weak. Additionally, the results demonstrate that there are large differences in tourism ecological security in the Yangtze River Delta region, which shows that regional tourism ecological security has obvious spatial differentiation. This conclusion is consistent with Liu et al. (2017). (2) The tourism ecological security of the YRD in the local space was obviously different, which showed that the number of high ecological security areas was small, and there were many low ecological security areas. In 2011–2016, the local area gradually formed cold-hot spots in a "southeast-northwest" transition; that is, the southeast was hot spots and the northwest was cold spots. Similarly, previous studies have shown that areas with high ecological benefits are concentrated in coastal areas and economically developed areas (Yin, Wang, An, Yao, & Liang, 2014). This study also proves that the spatial distribution of tourism ecological security has economic advantages. Because the southeastern region of the YRD is near the ocean, and the marine ecological civilization policy affected the ecological environment construction (Ma, de Jong, & den Hartog, 2018). For example, economically developed cities such as Shanghai and Hangzhou are clustered in the southeast of the YRD. The tourism economy in the southeastern region had a high level of development and the tourism infrastructure was well established, which helped to improve the efficiency of the tourism ecosystem.

Third, from the perspective of the drive mechanism, there were significant differences in the decision levels of tourism ecological security impact factors. The number of critical impact factors decreased in 2011–2016, but the influence level increased, indicating that crucial factors played a key role in the development of tourism ecological security. Critical impact factors were identified, including the per capita GDP and tertiary industry growth rate in Driver, the tourist density and the water consumption per 10,000 yuan of GDP in Pressure, the per capita park green area and total tourism revenue in GDP in State, tourism economic density and per capita tourism income in Impact, and the proportion of fiscal expenditure to GDP and the number of students in ordinary high schools in Response. Tourism-related factors and ecological environmental factors were important in promoting the stable development of tourism ecological security. Liu et al.'s (2017) research shows that economic and ecological indicators have significant positive effects on tourism eco-efficiency, which reflects the robustness of this study. Contrarily, our study responses to critical means of sustainable development. The research results showed that the responses were comprised short-term measures and long-term measures, which further confirmed that talent cultivation was a fundamental strategy for sustainable development. Our results further indicate that the response mechanism should not only focus on short-term investment ecological construction, but must also pay attention to talent, such as a sustainable guarantee factor in the response mechanism.

Lastly, the driving mechanism of tourism ecological security we constructed further verified the conduction path between the tourism ecosystems and the circulation. The driving mechanism effectively analyses and reveals the formation path of internal security for the tourism ecosystem, which is an important theoretical basis for the sustainable development of tourism.

5.1. Theoretical contribution

This paper has made outstanding contributions to the research on tourism ecological security. Importantly, it has a strong universal value for the evaluation of tourism ecological security, identifying the core influencing factors and the construction of the driving mechanism. This study not only innovates with regard to the research perspective and evaluation method of tourism ecological security but also draws conclusions with practical significance.

First, this study begins by explaining the issue of tourism ecological security from the new perspective of efficiency and then a new "DPSIR-DEA" tourism ecological security evaluation model is proposed. Importantly, the evaluation of tourism ecological security from the perspective of efficiency is a "quality" rather than a "quantity" assessment (Chen, 2017; Qiu et al., 2017). Based on the connotation of tourism ecological security and ecological system theory, this research is a new attempt at measurement perspective and contributes to measuring tourism ecological security more scientifically and effectively. The evaluation and measurement of tourism ecological security has always been the critical issue of tourism sustainable research, and an analytic hierarchy process and ecological footprint model for evaluation have been used in previous studies (Chen, 2017; Liu et al., 2009). Although scholars have expended much effort in assessments of tourism ecological security, which are used in numerous studies (Chen, Liu, & Hsieh, 2017; Katircioglu, Gokmenoglu, & Eren, 2018), all these assessments are considered from the perspective of "quantity", ignoring the "input-output" cycle in the tourism ecosystem, which does not effectively reflect the coordinated development of the tourism ecosystem, and does not grasp its dynamic changes. In addition, efficiency is a critical indicator for assessing the operational capability of the system, which can fundamentally determine if the tourism ecosystem is stable. Therefore, this study conducted new evaluation method for the "quality" evaluation and brought the perspective of efficiency to tourism ecological security, which not only expands the depth of research on tourism ecological security, but also significantly promotes the development of tourism ecosystem theory.

Second, the "DPSIR-DEA" framework used in this study can measure tourism ecological security more rigorously and scientifically; the "SBM-DEA" model used to measure efficiency not only solved the problem of nonzero slack in the input or output of traditional DEA models and the undesired output problems in the production process but also subdivided the measurement function of the indicator (Liu et al., 2017). In addition, compared with the "pressure-state-response" model, the DPSIR model can better reflect the role of driving force and influence in system operation, which highlights the comprehensiveness of input and output index selection. Meanwhile, the output of the previous year is used as the input of the following year to reflect as much as possible the "input-output" lag within the system, which also reflects the cyclical effects of various indicators and supplements previous literature (Liu, Zhang, et al., 2018). The combination of the DPSIR framework and efficiency model not only addresses the problem of single and incomplete indicators in the evaluation framework but also solves the problem ignored in previous studies regarding the internal circulation and dynamic operation of the tourism ecosystem (Ehara et al., 2018). The evaluation method of tourism ecological security is the basis and important part of the research in this field, and this study, which constructs a more rigorous and comprehensive evaluation method, has important theoretical contributions in addition to practical significance.

Third, it is worth noting that the critical influencing factors of tourism ecological security are identified and a framework for tourism ecological security driving mechanism is constructed. The research not only provides a strong theoretical basis for the future development of tourism ecological security but also greatly contributes to policy implementation. In addition, regression methods are used to explore the influencing factors of ecological security in the previous studies (Qiu et al., 2017). However, the Geo-Detector analysis method used in this study is an effective method of solving the spatial influencing factors, which can more effectively discriminate the crucial influencing factors and identify the best improvement or control factors for tourism ecological security. Further, previous literature ignored the internal operation of the tourism ecological security system. Moreover, the selection of influencing factors in previous research is not comprehensive enough and ignores the role of negative impact factors (Chen, 2017; Schianetz & Kavanagh, 2008). The results show that economic factors and ecological factors are the core influencing factors for improving tourism ecological security, and response measures must also consider short-term investment in environmental protection and long-term talent supply, which provides an important direction for the implementation and guarantee of tourism ecological security. More importantly, the driving mechanism framework used in this study not only includes economic, ecological, tourism and other aspects but also effectively illustrates the conduction path of the tourism ecosystem, which promotes the progress of the ecological security of tourism. This study constructs a comprehensive driving mechanism of tourism ecological security, which is a multi-angle, multi-dimensional and multilevel circulatory system. This study provides great theoretical contributions and practical value to the sustainable development of tourism.

5.2. Policy implications

The results of this study contribute to the suggestion of how to maintain a good state of tourism ecological security. They contribute to the proposal of how to maintain a good state of tourism ecological security. The DPSIR model reconstructed in this study can effectively evaluate the ecological security of tourism, which is also refined with the inclusion of desirable and undesirable output factors. Additionally, the core influencing factors identified and the driving mechanism constructed can effectively guide practitioners to improve the ecological security of tourism, which is especially suitable in situations in developing countries, such as China's ecological security system development (Yang, Dong, & Li, 2019). We also describe practical guidance in detail based on five aspects of the research results: driver-pressure-state-impact-response.

First, the positive thrust of the driver must be fully utilized. The research results and previous literature have confirmed the importance of economic development in the maintenance of tourism ecological security. And we cannot ignore the positive impact of tourism income on tourism ecological security. Therefore, ensuring the quality of economic development is the key issue (Luo, 2018). Coordinating the economic development of tourism should be highly valued and should also promote the quality of tourism development and overall efficiency value improvement. Moreover, the investment in environmental protection and ecological construction in the pursuit of economic development also be valued. Policy makers can formulate promotion or restriction measures conducive to improving the ecological security of tourism (Cernat & Gourdon, 2012). For example, the application of energy conservation and emission reduction technologies should be used to improve the efficiency of tourism investment allocation and utilization and thereby avoid the unlimited expansion of future tourism investment scale (Peng et al., 2017). In addition, the growth rate of the tertiary industry must be brought into the consideration of economic drivers. The government should support the development of the ecotourism industry, cultural and creative tourism industry and other light pollution industries.

Second, tourism ecosystem pressures must be alleviated. The results show that tourist density and resource consumption are the main sources of ecological security pressure. To reduce the pressure of tourist activities on tourism ecological security constraints and obstacles, managers must strive for a timely assessment of the tourist capacity of tourism destinations and the implementation of safety warnings for peak tourist seasons and high-density tourist destinations. During the holidays, reasonable diversion and effective evacuation will be carried out to maintain tourism ecological security. More specifically, big data analysis technology must be used to monitor the tourists and carrying capacity of traffic flow in real time to promote nature-based tourism (Kim, Kim, Lee, Lee, & Andrada, 2019). Accurate measurements of passenger flow can be taken to prevent peak traffic stress early by strengthening the construction of smart tourism. Further, price leverage can be used to reduce tourists' pressure on the tourism environment because price increases effectively limit the number of tourists in the peak tourist season and relieve the pressure on the environment (Huiqin & Linchun, 2011). For example, scenic spots can implement a variety of pricing strategies to regulate passenger flow. Moreover, we must realize that tourists' consumption of resources is a long-term behavior. Governments and scenic spots can improve their ecological and environmental responsibilities through management, guidance and propaganda. The improvement of tourists' civilization quality and the enhancement of ecological consciousness can effectively reduce the consumption of energy and resources (Liu et al., 2017). On the other hand, the rational use of resources reduces waste and consumption of resources as well as pollutant emissions, which is helpful to promoting the mechanism of energy conservation in addition to realizing the common governance of the government (Ahmad et al., 2018).

Third, one should strive to maintain the good state of the tourism ecological environment and balance the sustainable development strategy of tourism growth and environmental protection (Tang, 2015). The results show that the greening degree is an important factor to promote the ecological security of tourism. Therefore, government budgets should focus on developing green infrastructure, such as building green wall and tree health maps (Nepal, Indra al Irsyad, & Nepal, 2019). Further, green practices can also be promoted, such as the efficient use of energy and water and integrated waste management (Pan et al., 2018). Meanwhile, the purification function of the greening facilities in the city is fully utilized and the state of urban tourism ecological environment must be assessed in time. These expenditures not only support tourism development but also decrease the negative impact of environmental pressures on tourism (Nepal, 2008). Further, one must advocate and promote the use of new energy and clean energy to promote the prevention and governance of tourism ecosystem security.

Fourth, strengthen the role of beneficial influence factors. The results indicate that the level of tourism development and number of employees in tertiary industry are important positive factors affecting tourism ecological security. For the sustainable development of the tourism industry, the government should promote the transformation and upgrading of tourism. The tourism economy development mode must change from the traditional, backward extensive mode to a sustainable, green and low carbon mode, which contributes to coordinating the relationship between the tourism economy and ecological security. Promote the development of light pollution tourism, such as sports tourism, health tourism, and ecological tourism. On the other hand, through multiple channels, encourage and promote employment in the tertiary industry, and support the development of nonpolluting or less polluting enterprises such as the service industry, light industry, and innovative industries. Therefore, the department of tourism management must seek a light pollution development pattern, which promotes the healthy and coordinated development of tourism and environmental protection (Badola et al., 2018).

Lastly, a variety of measures are used to respond positively. Based on the research results, we must realize that the implementation of response measures should be based on short-term environmental input and long-term talent output. On the one hand, carry out short-term pollution control measures, which solve short-term environmental problems in good time (Wang et al., 2016). To coordinate the relationship between environmental protection and tourism development, environmental laws and regulations must be formulated and investment in tourism pollution control should be increased (Liu et al., 2017). Moreover, the government should promote the application of low-carbon technology, provide sufficient space for promoting the green development of tourism (Ahmad et al., 2018), and cultivate the eco-environmental consciousness and social responsibility of tourism enterprises, operator and tourists (Nepal et al., 2019). On the other hand, the government should also form a long-term development talent pool and accelerate the cultivation of environmental governance market subjects. These actions will not only drive the expansion of the environmental talent pool but also affect the innovation and application of ecological management technology, which is a long-term solution to realize the improvement of regional tourism ecological security. On the other hand, form a long-term development talent pool and accelerate the cultivation of environmental governance market subjects. It not only drives the expansion of the environmental talent pool, but also affects the innovation and application of ecological management technology, which is a long-term solution to realize the improvement of regional tourism ecological security.

5.3. Limitations and future research

Although the results of this study have made substantial contributions to the evaluation and driving mechanism of tourism ecological security, some limitations point to future research. First, as this study takes the Yangtze River Delta urban agglomeration as a study site and the city as a research unit, the research scale is relatively macroscopic. However, there are some differences in the current status and mechanisms of small-scale tourism ecosystems, and the interaction effects between tourism ecosystems may be more obvious between small scales. Therefore, the spatial correlation and spillover effects of county-level tourism ecological security will be explored in the future. Second, Geo-Detector is an effective method of exploring the critical drivers of tourism ecological security and building a theoretical model of the driving mechanism. However, the driving mechanism model is constructed through theoretical discussion, which cannot effectively reveal the conduction path and action mechanism among the various elements of the tourism ecosystem. The theoretical model will be verified using the structural equation model (SEM) in the future. Further, the mechanism of tourism ecosystem security will be analyzed, and the conduction path among the five main dimensions and subdimensions will be explored. Meanwhile, one should compare and study groups with different cities to more effectively grasp the internal mechanism of the tourism ecological security system and provide theoretical references for proposing development models and management recommendations.

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Appendix A. Supplementary data

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