Coupled Assessment of Ecosystem Health and Spatiotemporal Evolution Analysis in Fujian Province

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Abstract

As China' s first ecological civilization pilot zone, Fujian Province maintains excellent ecological environmental quality, with various ecological environment-related indices consistently ranking among the top nationwide. To investigate the causes of Fujian' s ecological excellence over the past fifteen years, this study selects MODIS imagery, land use data, and provincial/municipal statistical yearbook data covering Fujian Province from 2005 to 2020 as data sources, employs the Remote Sensing Ecological Index (RSEI) to evaluate the ecosystem health status of Fujian Province, simultaneously constructs a land use intensity system for Fujian, utilizes a coupling coordination model to analyze the coupling relationship between RSEI and land use intensity, and finally conducts a spatiotemporal evolution analysis of ecological health in Fujian Province from 2005 to 2020. The results indicate that during 2005–2020, the coupling coordination degree between land use intensity and ecosystem health status across Fujian Province showed a continuous upward trend, with Ningde City exhibiting the most significant increase, rising from 0.0993 to 0.963. The spatial distribution pattern was characterized by lower values in southeastern coastal areas compared to northwestern inland areas, higher values in southwestern regions compared to northwestern regions, and higher values in northeastern regions compared to southeastern regions. In terms of interaction types, land use intensity in most cities of Fujian Province in 2005 exerted a significant inhibitory effect on ecosystem health status. However, with temporal changes, urban land use has been continuously optimized, achieving moderate coordination and even high-quality coordination with ecological environmental quality. Nevertheless, Xiamen City has developed relatively slowly, with its coupling degree value in 2020 being 0.315, still in a state of mild disharmony. This study fills the research gap regarding the interaction mechanism between ecosystem health status and land use intensity, and also provides a new perspective for ecological civilization

construction and ecosystem health status assessment research in Fujian Province and even nationwide.

Full Text

Preamble

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Coupled Assessment of Ecosystem Health and Its Spatio-Temporal Evolution in Fujian Province

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Abstract

To investigate the causes of Fujian Province's excellent ecological status over the past 15 years, this study selected MODIS imagery and land use data at 5-year intervals from 2005 to 2020 as primary data sources. We constructed a land use intensity system and employed the Remote Sensing Ecological Index (RSEI) as the analytical method, utilizing a coupling coordination model to analyze the relationship between RSEI and land use intensity. Finally, we conducted a spatio-temporal evolution analysis of ecological health in Fujian Province from 2005 to 2020. The results indicate: (1) From 2005 to 2020, the province's ecological environment followed an "improvement-degradation-degradation" trajectory, with the mean RSEI value reaching 0.7048 in 2020, classifying the ecological environment as "good"; (2) Land use intensity across Fujian Province showed an increasing trend with a growth rate of 26.00%, with Sanming City experiencing the most significant increase at 160.91%; (3) The province's coupling coordination degree increased by 0.75, achieving "good coordination," with all cities showing improvement except Xiamen, where the coupling coordination degree decreased by 0.131, resulting in "mild disharmony." This study fills a research gap in the interaction mechanism between ecosystem health and land use intensity, while providing a new perspective for ecological civilization construction and ecosystem health assessment in Fujian Province and nationwide.

Keywords: Fujian; land use intensity; ecosystem health; coupling coordination

Introduction

With the deepening of new urbanization, a stable and healthy ecosystem has become a fundamental requirement for sustainable urban development. Addressing complex ecological challenges arising from economic growth remains a critical concern. The "society-economy-environment" nexus involves mutual influences among these three dimensions, with their coupling relationship emphasizing the synergistic effects generated during their interactions. Analyzing this coupling relationship can reveal urban development pathways and their constraints, providing valuable guidance for achieving sustainable development.

Since the 1970s, ecosystem health assessment has become a research hotspot internationally, with related studies proliferating. However, most research has relied on qualitative or quantitative evaluation based on single or specific dimensions, such as using the Normalized Difference Vegetation Index (NDVI) [3-6], Leaf Area Index (LAI) [7-8], and Net Primary Productivity (NPP) [9] to assess vegetation growth; employing thermal infrared bands from remote sensing imagery for urban heat island monitoring [10]; and constructing various drought indices to evaluate regional drought conditions [11-13]. Due to ecosystem complexity, single indicators often fail to provide comprehensive and effective analysis [14].

Remote sensing technology, with its advantages of large-scale monitoring, periodicity, and real-time capability, has been widely applied in ecosystem health assessment. Among current remote sensing-based ecological indices, the Remote Sensing Ecological Index (RSEI) integrates four ecological indicators—NDVI, Wetness Index (WET) [15], Normalized Difference Built-up and Impervious Surface Index (NDBSI) [16-17], and Land Surface Temperature (LST) [18] —using Principal Component Analysis (PCA). This approach enables systematic evaluation of regional ecosystem health [19] and has been validated by numerous experts and scholars [16-19].

In the Anthropocene, the world' s greatest challenge is how humanity responds to the coupling of "society-economy-environment," which has become an inseparable research entity. To quantify the relationship between regional ecological environment and economic development, Lu et al. [20] employed the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) extended model combined with principal component regression to analyze driving factors of three-dimensional ecological footprint evolution using indicators such as ecological pressure index, ecological coordination coefficient, and ecological footprint diversity index. Xiong Xi [21] introduced the European Environment Agency' s DPSIR (Driving-Pressure-State-Impact-Response) environmental management model into ecological civilization construction evaluation, applying rough set theory for analysis. Gao et al. [22] constructed a land use intensity indicator system and coupling coordination model to explore the relationship between ecosystem service value and land use intensity and its changing causes. Therefore, to comprehensively analyze and evaluate Fujian Province' s ecosystem health, it is essential to investigate the combined impacts of social and economic development on the ecological environment. This study constructs a land use intensity system for Fujian Province from social and economic dimensions.

In summary, using Fujian Province as the study area, we employed MODIS imagery, land use data, and statistical yearbooks at 5-year intervals from 2005 to 2020 as data sources. We calculated the RSEI index from MODIS imagery to conduct spatio-temporal analysis and assessment of ecological health across Fujian Province from 2005 to 2020. We constructed a land use intensity system comprising land use structure, land investment, and land use efficiency to analyze 15-year spatio-temporal changes in the province' s social and economic development. Finally, we developed a coupling coordination model between RSEI and land use intensity to examine the coordination between ecological health changes and socio-economic development. This study not only assesses Fujian' s ecological health status but also provides data support for ecological environment protection and development in the province.

1.1 Study Area

Fujian Province (E 115°50 ~120°40 , N 23°33 ~28°20) is located on the southeastern coast of China, bordering Zhejiang, Jiangxi, and Guangdong provinces (Fig. 1). The province governs nine prefecture-level cities: Fuzhou, Xiamen, Zhangzhou, Quanzhou, Sanming, Putian, Nanping, Longyan, and Ningde, covering an area of approximately 124,000 km^2 with a permanent population of 41.61 million (as of 2020) [23]. Fujian' s terrain is complex, with river valleys and basins in the central-western region and hills and coastal plains in the eastern region, generally sloping from high northwest to low southeast [24].

According to the Fujian Provincial Department of Ecology and Environment' s announcements from 2001 to 2020, Fujian' s ecological environment has maintained an excellent level, with its ecological environment status index consistently ranking among the top in China. As one of the first provinces to implement ecological province construction, Fujian has integrated resource consumption, environmental damage, and ecological benefits into its economic and social development evaluation system since 2000. However, challenges remain in ecological governance practice [25-26]. Therefore, this study takes Fujian Province as the primary research object, conducting data collection and analysis by prefecture-level city to provide theoretical support and technical assistance for Fujian' s ecological civilization construction.

1.2 Data Sources

To conduct dynamic monitoring and analysis of Fujian' s ecological environment, this study utilized multiple data sources at 5-year intervals from 2005 to 2020, including MODIS imagery, land use data, and economic data.

MODIS imagery was obtained from the Google Earth Engine (GEE) platform [27], comprising four time periods (2005, 2010, 2015, and 2020) with 500 m spatial resolution from three products (MOD09A1, MOD11A2, and MOD13A1). The RSEI spatial distribution results for the study area were calculated using the GEE platform.

Land use data for Fujian Province were derived from Wuhan University' s 1990-2020 China Land Cover Dataset [28] on the GEE platform, including eight types: cropland, forest, shrubland, grassland, water, ice/snow, built-up land, and wetland. To fully calculate ecosystem service values, we reclassified this dataset using ArcGIS 10.5 and calculated the area of reclassified land types at a raster scale (500 m × 500 m), resulting in five land use types: cropland, water, grassland, forest, and built-up land. Other socioeconomic data were obtained from provincial and municipal statistical yearbooks, ecological yearbooks, and environmental annual reports.

2 Methods

To investigate ecological environment changes in Fujian Province from 2005 to 2020 and evaluate the effectiveness of ecological governance over the past 15 years, we first calculated RSEI spatial distribution results for 2005, 2010, 2015, and 2020 using MODIS imagery on the GEE platform for spatio-temporal analysis. Second, we constructed a land use intensity indicator system to analyze land use conditions. Finally, we developed a coupling coordination model between RSEI and land use intensity to explore their relationship (Fig. 2).

2.1 RSEI Calculation

For large-scale remote sensing environmental monitoring, we used medium-low spatial resolution MODIS imagery to calculate RSEI values. The RSEI index [29-30] is established based on greenness, wetness, heat, and dryness indicators derived from remote sensing information and natural factors. The greenness indicator uses NDVI, heat uses LST, wetness uses WET, and dryness uses NDBSI. LST data were obtained from MODIS products, with other calculations as follows:

$$NDVI = \frac{NIR - Red}{NIR + Red}, \quad (1)$$

$$WET = 0.1147 \times Blue + 0.2489 \times Green + 0.2408 \times Red + 0.3132 \times NIR1 - 0.3122 \times NIR2 - 0.6416 \times SWIR1, \quad (2)$$

$$NDBSI = \frac{IBI + SI}{2}, \quad (3)$$

$$IBI = \frac{2 \times SWIR1}{SWIR1 + NIR1} - \frac{NIR1}{NIR1 + Red} - \frac{Green}{Green + SWIR1}, \quad (4)$$

$$SI = \frac{SWIR1 + Red}{SWIR1 + Red} - \frac{NIR1 + Blue}{NIR1 + Blue}, \quad (5)$$

where Blue, Green, Red, NIR1, NIR2, SWIR1, and SWIR2 represent reflectance values for blue, green, red, near-infrared 1, near-infrared 2, shortwave infrared 1, and shortwave infrared 2 bands, respectively; IBI is the built-up index; and SI is the soil index.

For RSEI calculation, considering that numerous water bodies in the study area affect RSEI computation, we first extracted water bodies using the Modified Normalized Difference Water Index (MNDWI) [31] for water masking. We then calculated NDVI, LST, WET, and NDBSI indices and normalized them using:

$$NI_i = \frac{I_i - I_{min}}{I_{max} - I_{min}}, \quad (6)$$

where NI_i is the normalized result for each indicator; I_i is the individual value of each indicator; and I_{max} and I_{min} are the maximum and minimum values of each indicator, respectively.

Finally, we employed Principal Component Analysis (PCA) [32] on the normalized indicators and used the first principal component as weights for weighted calculation to obtain the final RSEI:

$$RSEI_0 = PC1, \quad (7)$$

$$RSEI = \frac{RSEI_0 - RSEI_{min}}{RSEI_{max} - RSEI_{min}}, \quad (8)$$

where $RSEI_0$ is the initial ecological index value; $PC1$ is the first component of PCA; and $RSEI_{min}$ and $RSEI_{max}$ are the minimum and maximum RSEI values, respectively. To better reflect Fujian’ s ecological health status and enable spatial analysis, we classified RSEI into five levels following the “Technical Specifications for Ecological Evaluation” : worst [0, 0.2), poor [0.2, 0.4), moderate [0.4, 0.6), good [0.6, 0.8), and excellent [0.8, 1.0].

2.2 Land Use Intensity Calculation

To analyze and evaluate land use changes in Fujian Province from 2005 to 2020, we constructed a land use intensity indicator system comprising three components—land use structure, land investment, and land use efficiency—based on previous research [33] (Table 1). Land use structure includes four indicators:

cropland ratio, forest ratio, grassland ratio, and built-up land ratio. Land investment includes three indicators: crop sown area, fixed asset investment, and employment. Land use efficiency includes four indicators: grain yield, Gross Domestic Product (GDP), industrial output value, and agricultural output value. To construct the land use intensity indicator for Fujian' s prefecture-level cities, we first standardized the 11 indicators, then used the entropy weight method to determine indicator weights, calculated land use intensity, and classified it according to the system shown in Table 1.

2.3 Coupling Coordination Model

The coupling coordination model [34] measures the degree of association between different modules. More connections between modules indicate stronger coupling and lower independence. Originally applied primarily in software systems, it has been adopted in other fields such as environmental science and economics. This study used the coupling coordination model to examine the correlation between land use intensity and ecosystem service value in Fujian Province.

To better reflect the coupling coordination relationship, we classified the coupling coordination degree between land use intensity and ecological environment quality in the study area as shown in Table 2.

The model equations are:

$$C_t = \sqrt{\frac{RSEI_t \times Land_t}{(RSEI_t + Land_t)/2}}, \quad (10)$$

$$T_t = \alpha \times RSEI_t + \beta \times Land_t, \quad (11)$$

$$D_t = \sqrt{C_t \times T_t},$$

where $Land_t$ is the land use intensity in year t; $RSEI_t$ is the RSEI value in year t; C_t is the coupling degree between land use intensity and RSEI in year t; T_t is the comprehensive evaluation index of coordinated development between land use intensity and RSEI in year t; and D_t is the coupling coordination degree between land use intensity and RSEI in year t. This study assumes that land use and RSEI play equally important roles in the comprehensive development of the study area, so coefficients α and β are both set to 0.5 when calculating T_t.

3.1 Spatio-Temporal Analysis of Ecological Environment Quality in Fujian Province Based on RSEI (2005-2020)

Using MODIS imagery at 5-year intervals (2005, 2010, 2015, and 2020), we analyzed Fujian's ecological environment. Based on the RSEI calculation model and ecological environment quality classification, the spatial distribution of RSEI levels is shown in Fig. 3. From 2005 to 2020, the province' s overall ecological environment followed an "improvement-degradation-degradation" trend, with all prefecture-level cities achieving RSEI mean values above 0.6 in 2020 (Table 3), classifying them as "good" ecological environment level. Except for Fuzhou and Ningde, which showed an "improvement-degradation-improvement" pattern, all other cities followed the provincial trend. All cities had RSEI means above 0.6 (good level), except Xiamen, which had RSEI between 0.4-0.6 (moderate level). Fuzhou showed the largest RSEI increase at 9.14%, while Xiamen experienced a decrease of 1.24%.

During 2005-2010, the province' s ecological environment quality improved most significantly, with RSEI mean increasing by 13.47% and all cities achieving "good" status. Ningde showed the greatest improvement with a 19.07% increase. During 2010-2015, the provincial RSEI mean decreased by 5.34%, though remaining at "good" level, with all cities experiencing degradation. Xiamen showed the largest decline at 10.61%. During 2015-2020, the provincial RSEI mean decreased slightly by 0.94%, still classified as "good."Except for Fuzhou and Ningde, which increased by 3.94% and 5.68% respectively, all other cities declined, with Xiamen showing the most significant decrease at 5.64%.

3.2 Spatio-Temporal Analysis of Land Use Intensity in Fujian Province (2005-2020)

Based on land use data and socioeconomic statistics, we calculated land use intensity values for Fujian Province in 2005, 2010, 2015, and 2020. From 2005 to 2020, provincial land use intensity showed an increasing trend with a growth rate of 26.00% (Table 4). Except for Putian, which decreased by 3.52%, all cities experienced growth, with Sanming showing the most dramatic increase at 160.91% and Longyan increasing by 101.82%.

During 2005-2010, provincial land use intensity increased by 2.29%, though Fuzhou and Putian decreased by 13.71% and 8.46% respectively, while Sanming increased most significantly at 63.32%. During 2010-2015, provincial land use intensity surged by 22.16%, with Sanming again leading growth at 52.27%; only Xiamen experienced a decline of 16.07%. During 2015-2020, provincial land use intensity increased modestly by 0.84%, with only Putian decreasing (6.33%) and Longyan showing the highest growth at 28.71%.

3.3 Coupling Coordination Analysis

Using the coupling coordination model to analyze the relationship between RSEI and land use intensity, we conducted a spatio-temporal evolution analysis of Fujian' s ecological health development from 2005 to 2020 (Table 5 and Fig. 4). From 2005 to 2020, the provincial coupling coordination degree increased by 0.7290, with all cities showing improvement except Xiamen, which decreased by 0.1310.

During 2005–2010, the provincial coupling coordination degree rose from 0.1000 (severe disharmony) to 0.5550 (barely coordinated), an increase of 0.4550. Quanzhou showed remarkable improvement, rising from 0.0931 (severe disharmony) to 0.9110 (premium coordination), an increase of 0.8179. During 2010–2015, the provincial coupling coordination degree increased from 0.5550 (barely coordinated) to 0.8500 (good coordination), a rise of 0.2950. However, Xiamen, Quanzhou, Nanping, and Longyan experienced decreases of 0.6670, 0.0960, 0.1100, and 0.0630 respectively. During 2015–2020, the provincial coupling coordination degree declined slightly from 0.8500 (good coordination) to 0.8290 (good coordination), a decrease of 0.0210, with Putian and Zhangzhou falling by 0.2760 and 0.0050 respectively.

3.4 Discussion

From 2005 to 2020, Fujian' s coupling coordination level improved from "severe disharmony" to "good coordination," indicating increasingly harmonious development between ecological environment and socio-economic progress. During this period, Fuzhou and Ningde achieved "premium coordination," while Xiamen remained in "mild disharmony." As urbanization progressed and land use optimized across Fujian' s cities, most achieved moderate or premium coordination with ecological environment quality. However, Xiamen' s urban development and ecological protection became unbalanced, resulting in a 2020 coupling coordination value of 0.3150 and a downgrade from "approaching disharmony" to "mild disharmony."

Xiamen's ecological environment quality experienced "improvement-degradation-degradation" during 2005–2020, lagging behind other cities with an RSEI value around 0.5, indicating need for improvement. Comparing 2020 to 2005, Xiamen' s land use intensity increased by 0.0572. The city' s grain yield decreased by 78.95% (ranking first among all cities), while GDP, industrial output value, and agricultural output value increased by 622.80%, 297.69%, and 130.18% respectively (ranking fourth, eighth, and eighth). Crop planting area decreased by 55.76% (first in the province), while employment increased by 108.25% (also first). Fixed asset investment surged by 912.23% (eighth), and built-up land expanded by 78.58% (fifth). These changes—increased employment, rapid urbanization, declining agricultural investment, and expanded construction land—drove up land use intensity. Meanwhile, Xiamen' s ecological improvement was slow and significantly lagged other cities, primarily due to continuous growth in employment and construction land alongside declining agricultural investment, leading to persistently increasing land use intensity. Consequently, Xiamen' s relatively poor ecological quality and rising land use intensity resulted in low coupling coordination, placing it in "mild disharmony."

The coupling coordination between land use intensity and ecological environment reflects the relationship between ecological health and social development. Ecological health is influenced by land use changes, which are in turn affected by economic factors. Under ecological civilization policies, environmental protection has become a primary task for high-quality development in China. However, ecological civilization does not require halting social development; rather, it demands coordinating the relationship between development and ecological environment to enhance coupling coordination and ultimately promote sustainable development.

4 Conclusions

This study integrated Fujian' s remote sensing ecological index and land use intensity data to analyze their coupling coordination, establishing a 500 m × 500 m raster-based coupling coordination indicator system for land use and ecological environment quality in Fujian from 2005 to 2020. Under the coupling effects of these two systems, we analyzed spatio-temporal variation characteristics of ecosystem health in Fujian Province. The main conclusions are:

1) Fujian's ecological environment quality showed a stable and positive trend, achieving "good" status province-wide with a mean RSEI of 0.7048 (as of end-2020). Except for Xiamen ("moderate" status), all prefecture-level cities achieved "good"status. Compared to 2005, the provincial mean RSEI increased by 6.40% in 2020, with Ningde showing the most significant growth at 16.71% and Xiamen the largest decline at 1.24%. Other cities increased within the range of 9.14% to 2.27%.

2) Provincial land use intensity increased by 26.00%, with an absolute increase of 0.1114. Sanming showed the most dramatic growth at 160.91%, while Putian experienced the largest decline at 3.52%. Other cities increased within the range of 10.88% to 101.82%.

3) The coupling coordination degree between ecological environment quality and land use intensity achieved "good coordination" province-wide with a value of 0.8290. Among prefecture-level cities, Fuzhou and Ningde reached "premium coordination," while Xiamen remained in "mild disharmony." Compared to 2005, the provincial coupling coordination increased by 0.7290 in 2020, with Ningde showing the most significant improvement (0.8637) and Xiamen the largest decline (0.1310).

This study employed remote sensing methods and multi-source data to comprehensively analyze the coordination between ecological environment and socioeconomic development, providing technical references for ecological civilization research and decision-making support for Fujian' s ecological civilization construction. However, several limitations require improvement: (1) The RSEI index excludes water body information, ignoring the ecological effects of water on surrounding environments, and its PCA-based calculation using only the first principal component may cause information loss and affect results. Future research should optimize the ecological environment index for more comprehensive health assessment. (2) Ecological civilization construction requires effective natural resource management to promote coordinated development. Future studies should build upon these results to develop an ecological compensation system suitable for Fujian using ecological compensation mechanisms, providing clearer and more accurate decision-making support.

References

[1] Zuo L, Sun L G. MODIS-based comprehensive assessment and spatial-temporal change monitoring of ecological quality in Beijing-Tianjin-Hebei region[J]. Remote Sensing for Natural Resources, 2022, 34(2):203-214. doi:10.6046/zrzyyg.2021224.

[2] Chen M Y, Lin G S. Nature-based solutions: a new term that is easily misunderstood[J]. South Architecture, 2019(3):40-44.

[3] Morgan J A, LeCain D R, Pendall E, et al. C4 grasses prosper as carbon dioxide eliminates desiccation in warmed semi-arid grassland[J]. Nature, 2011, 476(7359):202-205.

[4] Dong S, Shang Z, Gao J, et al. Enhancing sustainability of grassland ecosystems through ecological restoration and grazing management in an era of climate change on Qinghai-Tibetan Plateau[J]. Agriculture, Ecosystems and Environment, 2020, 287:

[5] Liu Y M, Fan H J, Ge X H, et al. Estimation accuracy of fractional vegetation cover based on normalized difference vegetation index and UAV hyperspectral images[J]. Remote Sensing for Natural Resources, 2021, 33(3):11-17. doi:10.6046/zrzyyg.2020406.

[6] Zhang Y M, Zhang Z Y, Jiang W Y, et al. Remote sensing monitoring and analysis of ecological changes in important ecological spaces in Tianjin[J]. Environmental Ecology, 2020, 2(6):7-12.

[7] Wang G X, Li Y S, Wang Y B, et al. Effects of permafrost thawing on vegetation and soil carbon pool losses on the Qinghai–Tibet Plateau, China[J]. Geoderma, 2008, 143(1):143-152.

[8] Wang Y T, Zhu C M, Zhang T, et al. Remote sensing monitoring and analysis of the vegetation phenological characteristics of the Qinling Mountains-Huanghuai Plain ecotone from 2002 to 2020[J]. Remote Sensing for Natural Resources, 2022, 34(4):225-234. doi:10.6046/zrzyyg.2021400.

[9] Hu X F, Tang X, Hu Y M, et al. Estimation of net primary productivity of urban forest ecological system in Guangzhou city[J]. Journal of Central South University of Forestry and Technology, 2016, 36(5):19-25.

[10] Bosch A, Dörfer C, He J S, et al. Predicting soil respiration for the Qinghai-Tibet Plateau: An empirical comparison of regression models[J]. Pedobiologia, 2016, 59(1):41-49.

[11] Veldhuis M P, Ritchie M E, Ogutu J O, et al. Cross-boundary human impacts compromise the Serengeti-Mara ecosystem[J]. Science, 2019, 363(6434):1424-1428.

[12] R Klink, F Plas, C. G. E. Noordwijk, et al. Effects of large herbivores on grassland arthropod diversity[J]. Biological Reviews, 2015, 90(2):347-366.

[13] Cheng J, Li Y Z, Zou Y. Spatial and temporal dynamics of drought in Xinjiang and its response to climate change[J]. Remote Sensing for Natural Resources, 2022, 34(4):216-224. doi:10.6046/zrzyyg.2021389.

[14] Feng D Y, Zhang Q, Zhou M H. The future path of sustainable development from the perspective of ecological civilization[J]. Ecological Economy, 2022, 38(5):215-221.

[15] Song S, Tian D F, Mao L. Construction and application of evaluation index system of social functions of national wetland Park: A case study of Baiyupao national wetland park[J]. Wetland Science, 2019, 17(2):237-243.

[16] Li H X, Huang J J, Liang Y J, et al. Evaluating the quality of ecological environment in Wuhan based on remote sensing ecological index[J]. Journal of Yunnan University: Natural Sciences Edition, 2020, 42(1):81-90.

[17] Wu S. Remote sensing monitoring and evaluation of ecological environment in coal mine subsidence area[D]. Xuzhou: China University of Mining and Technology, 2021.

[18] Fang H, Zhang Y H, He Y, et al. Spatio-temporal variations of vegetation ecological quality in Zhejiang Province and their driving factors[J]. Remote Sensing for Natural Resources, 2023, 35(2):245-254. doi:10.6046/zrzyyg.2022070.

[19] Wang L C, Jiao L, Lai F B, et al. Evaluation of ecological changes based on a remote sensing ecological index in a Manas Lake wetland, Xinjiang[J]. Acta Ecologica Sinica, 2019, 39(8):2963-2972.

[20] Lu Y, Zhao Y D, Dong J H. Ecological security evaluation and driving force analysis of three-dimensional ecological footprint in Northwestern China[J]. Acta Ecologica Sinica, 2022, 42(4):1354-1367.

[21] Xiong X. Analysis and evaluation of ecological civilization construction in national-level ecological civilization demonstration zones based on DPSIR model[J]. Acta Ecologica Sinica, 2020, 40(14):5081-5091.

[22] Gao X, Shen J, He W, et al. Spatial-temporal analysis of ecosystem services value and research on ecological compensation in Taihu Lake basin of Jiangsu Province in China from 2005 to 2018[J]. Journal of Cleaner Production, 2021, 317:128241.

[23] Niu X N, Ni H, Chen G G, et al. Evaluation of ecological conservation importance of Fujian Province[J]. Acta Ecologica Sinica, 2022, 42(3):1130-1141.

[24] Liu Y X, Shi X L, Shi W J. Evaluation of water retention services of forest ecosystems in Fujian Province: Comparison between results from the InVEST model and meta-analysis[J]. Acta Ecologica Sinica, 2021, 41(4):1349-1361.

[25] Chai Z B, Sun Y, Fu C C, et al. Xi Jinping' s green development concept: improving the "top-level design" and strengthening the "four pillars" [J]. China Environment Supervision, 2017(6):9-13.

[26] Fujian provincial people' s government development research center subject group, Zhuo Z H, Li L M, et al. The history and inspiration of ecological civilization in Fujian Province[J]. Development Research, 2018(10):46-54.

[27] Wang X N, Tian J Y, Li X J, et al. Benefits of Google Earth Engine in remote sensing[J]. National Remote Sensing Bulletin, 2022, 26(2):299-309.

[28] Yang J, Huang X. The 30 m annual land cover dataset and its dynamics in China from 1990 to 2019[J]. Earth System Science Data, 2021, 13(8):3907-3925.

[29] Chen X H, Zeng X Y, Zhao C C, et al. The ecological effect of road network based on remote sensing ecological index: A case study of Fuzhou City, Fujian Province[J]. Acta Ecologica Sinica, 2021, 41(12):4732-4745.

[30] Kong L L, Feng X F, Wu S, et al. Spatiotemporal dynamics and driving factor analysis of ecological quality change in the Lhasa urban circle from 1994 to 2017[J]. Progress in Geography, 2022, 41(3):437-450.

[31] Xu H Q. Development of remote sensing water indices: A review[J]. Journal of Fuzhou University(Natural Science Edition), 2021, 49(05):613-625.

[32] Li X, Zhu W X, Shu S M, et al. Soil quality assessment of grassland in dry and warm valley of Dadu River based on principal component analysis[J]. Acta Ecologica Sinica, 2021, 41(10):3891-3900.

[33] Oehl F, Sieverding E, Ineichen K, et al. Impact of land use intensity on the species diversity of Arbuscular Mycorrhizal Fungi in agroecosystems of central Europe[J]. Applied and Environmental Microbiology, 2003, 69(5):2816-2824.

[34] Abecker A, Bernardi A, Maus H, et al. Information supply for business processes: coupling workflow with document analysis and information retrieval[J]. Knowledge-Based Systems, 2000, 13(5):271-284.