Spatiotemporal Variation of Habitat Quality and Its Driving Factors in Gonghe County Based on the InVEST Model (Postprint)

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Abstract

Against the backdrop of new-type urbanization, Gonghe County in Qinghai Province serves as a critical node in the construction of the Lanzhou–Xining urban agglomeration and represents a typical desert ecological fragile zone. The coordinated development of its economy and ecology holds significant importance for establishing the Hainan Prefecture Sustainable Development Agenda Innovation Demonstration Zone. Based on land use data from three periods (2000, 2010, and 2020), this study employs the InVEST model to investigate the spatiotemporal distribution of habitat quality and its effect variation characteristics in Gonghe County from 2000 to 2020, and further applies Geodetector and local spatial regression to analyze the influencing factors of habitat quality and their mechanisms. The results indicate that: (1) The overall habitat quality in Gonghe County showed an upward trend from 2000 to 2020, with mean values of 0.612 (2000), 0.626 (2010), and 0.627 (2020), respectively. The spatial distribution exhibited significant regional heterogeneity, presenting a pattern of high values in the north and low values in the south. (2) The primary driving factors influencing habitat quality were mean annual temperature (TEM) and Normalized Difference Vegetation Index (NDVI). Interaction effects between factors exerted stronger influence on the spatial differentiation of habitat quality than individual factors, with particularly strong interactions between TEM and Shannon's evenness index (SHEI) and Shannon's diversity index (SHDI). (3) TEM demonstrated a negative effect on habitat quality, with negatively affected areas concentrated mainly in the northern and eastern regions of Gonghe; NDVI exhibited a positive effect, with positively affected areas concentrated primarily in the central and southern regions. The positive effect of Gross Domestic Product (GDP) on habitat quality increased by 30% compared to 2000, and the Talatan photovoltaic project has promoted the coordinated development of ecological industries in Gonghe County. These findings can provide a scientific

basis for decision-making regarding local economic development and ecological conservation in arid regions.

Full Text

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Abstract

Against the backdrop of new urbanization, Gonghe County in Qinghai Province serves as a critical node in the Lanxi urban agglomeration and represents a typical ecologically fragile desert region. Coordinated economic and ecological development in this area holds significant importance for constructing the Hainan Prefecture Sustainable Development Agenda Innovation Demonstration Zone. This study employs three-phase land use data (2000, 2010, and 2020) and utilizes the InVEST model to investigate spatiotemporal distribution patterns and dynamic changes in habitat quality in Gonghe County from 2000 to 2020. Geographic detectors and geographically weighted regression (GWR) are further applied to analyze impact factors and their effects on habitat quality. Results indicate: (1) Overall habitat quality in Gonghe County exhibited an upward trend, with mean values of 0.612, 0.626, and 0.627 for 2000, 2010, and 2020, respectively. The spatial distribution showed marked regional disparities, following a north-high, south-low pattern. (2) Mean annual temperature (TEM) and normalized difference vegetation index (NDVI) constituted the primary driving factors influencing habitat quality. Interaction effects between factors demonstrated greater influence on spatial differentiation than single factors, with TEM showing strong interactions with Shannon's evenness index (SHEI) and Shannon's diversity index (SHDI). (3) The GWR model effectively revealed spatially varying relationships between influencing factors and habitat quality. TEM exerted negative effects, primarily concentrated in northern and eastern Gonghe County, while gross domestic product (GDP) showed positive effects, with the positive impact area increasing by 30% compared to 2000. The photovoltaic installation at Talatan promoted synergistic eco-industrial development in Gonghe County. These findings provide a scientific basis for decision-making to advance local economic construction and ecological environmental protection in arid regions.

Keywords: InVEST model; habitat quality; geographic detector; geographically weighted regression (GWR); Gonghe County; Qinghai Province

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Habitat quality refers to the capacity of ecological environments to provide suitable living conditions for individuals and populations. Changes in habitat quality result from the combined effects of regional location, geographic characteristics, climatic conditions, and human activities. Habitat quality assessment can specifically reflect the degree of regional biodiversity and environmental quality, and improving habitat quality helps protect and restore biodiversity while safeguarding regional ecological security. Consequently, dynamic monitoring, assessment, and analysis of influencing factor mechanisms are crucial for formulating sustainable development measures and hold significant importance for regional ecological construction.

Current habitat quality evaluation methods fall into two main categories. The first involves field surveys of specific species or habitat changes to establish evaluation systems. However, this approach suffers from high data collection costs and is unsuitable for large-scale comprehensive studies, generally limited to small-scale research areas. The second utilizes ecological models such as generalized additive models, InVEST, and MIMES for habitat quality assessment. Among these, the InVEST model quantifies ecosystem service values and spatial patterns under different land cover scenarios, providing scientific evidence for decision-makers to balance human activity impacts and benefits. Due to its convenient data integration, operational simplicity, and visualized results, InVEST has been widely applied in multi-scale, multi-level ecological environment quality assessments, including studies of nature reserves, coastal zones, watershed units, rapidly urbanizing areas, and future land use scenarios. However, most existing research focuses on developed regions where urban expansion pressures surrounding habitats and damages biodiversity. These studies often employ simple statistical or spatial analysis tools that cannot quantitatively reveal the spatial heterogeneity and intensity of influencing factors or their synergistic capabilities. Notably absent is quantitative expression and spatial analysis of habitat quality changes and influencing factor effects in China's ecologically fragile arid desert regions undergoing new urbanization and modern high-quality development.

Gonghe County, located in the northeastern Tibetan Plateau within the Gonghe Basin, features an arid climate with scarce rainfall and strong wind-sand activity, representing a typical desert ecologically fragile zone. As a strategic location for the national sustainable development agenda innovation demonstration zone and Lanxi urban agglomeration construction, Gonghe County constitutes an important node in the "Belt and Road" initiative and a key region for building national ecological environmental protection barriers. Accelerated new urbanization has intensified human activities, causing degradation of natural ecosystem functions in some areas and threatening survival environments for various flora and fauna. How to ensure the safety and stability of desert ecological environments in arid regions while achieving rapid urbanization and regional economic development through green coordination, and effectively improving habitat quality, represents an urgent issue requiring resolution.

1.1 Study Area Overview

Gonghe County in Qinghai Province is situated in the northeastern Tibetan Plateau (98°54 –101°22 E, 35°46 –37°10 N), covering a total area of 17,252.28 km^2. The northern region comprises the Qinghai Lake, Riyue Mountain uplift zone, and South Qinghai Mountain; the central area features an intermontane basin; the southern region consists of the Ela Mountains; and the eastern side forms the Yellow River valley. The terrain is dominated by plateau mountains with an average elevation of 3,200 m. The region experiences a plateau continental climate characterized by aridity, low rainfall, large diurnal temperature variations, and abundant sunshine. The mean annual temperature ranges from 0.7 to 6.3°C, with annual precipitation of 250–420 mm and annual evaporation of 1,500–1,900 mm. Strong wind-sand activity prevails. Surface vegetation types primarily include grassland, desert, and meadow.

1.2 Data Sources

Land use data were obtained from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/), comprising three-phase land use datasets for 2000, 2010, and 2020 with 30 m spatial resolution, generated through human-computer interactive interpretation. Annual mean temperature, precipitation, and vegetation type data were sourced from the National Earth System Science Data Center (http://www.geodata.cn/data/). The normalized difference vegetation index (NDVI) was extracted from Landsat remote sensing imagery using the Google Earth Engine (GEE) cloud platform, with 30 m spatial resolution. Landscape pattern indices were calculated using the moving window method in Fragstats 4.2 software, also at 30 m resolution. Digital elevation data (ASTER GDEM, 30 m resolution) were obtained from the Geospatial Data Cloud (https://www.gscloud.cn/), with slope derived using the ArcGIS 10.2 slope tool. Population density and GDP data were sourced from the Resource and Environmental Science Data Center (https://www.resdc.cn/) at 1 km spatial resolution. All data were uniformly projected to the same coordinate system, resampled to 30 m resolution, and a 3 km × 3 km grid was generated using the fishnet tool in GIS 10.2 to measure the influence of natural environmental and socioeconomic factors on habitat quality.

1.3 Research Methods

1.3.1 InVEST Model for Habitat Quality Calculation InVEST model habitat scarcity and quality can reflect biodiversity quality by evaluating the extent of different habitat or vegetation types and their respective degradation levels. Based on local conditions and literature, this study selected cropland, urban land, rural settlements, other construction land, and unused land—areas strongly disturbed by human activities—as threat factors. The calculation formula is as follows:

The habitat quality index for grid cell x in habitat type j is calculated as:

$$Q_{xj} = H_j \left(1 - \frac{D_{xj}^z}{D_{xj}^z + k^z}\right)$$

where Q_{xj} represents the habitat quality of grid cell x in habitat type j, ranging from 0 to 1. Values closer to 1 indicate more intact habitats that are more favorable for biodiversity maintenance. H_j denotes habitat suitability, z is a normalized constant, k is the half-saturation parameter, and D_{xj} is the habitat degradation degree, calculated as:

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{w_r}{\sum_{r=1}^{R} w_r} \right) r_y i_{rxy} \beta_x S_{jr}$$

where R is the number of threat factors, Y_r is the number of grids for threat factor r, w_r and r_y represent the weight and disturbance magnitude of threat source R at location y, β_x and S_{jr} indicate resistance to disturbance and sensitivity of the habitat, and i_{rxy} is the distance function between threat factor Y_r and grid cell x:

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_r}\right) \quad \text{or} \quad i_{rxy} = \exp(-2.99 \cdot d_r)$$

where d_{xy} is the distance from grid cell x to grid cell y, and d_r is the maximum threat distance.

1.3.2 Geographic Detector and Driving Factor Selection Geographic detector is a statistical method for detecting spatial heterogeneity and revealing how dependent variables are influenced by driving forces. Factor detection and interaction detection were employed to explore the explanatory power of different driving factors on habitat quality and their interactions. The factor detection formula is:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2}$$

where q represents the explanatory power of influencing factor X on the spatiotemporal variation of variable Y, ranging from 0 to 1. As q increases, the spatial heterogeneity of Y becomes more significant. L is the stratification of variable Y or factor X, N_h and N are the unit numbers in layer h and the entire region, respectively, and σ_h^2 and σ^2 are the variances of Y values in layer h and the entire region.

Interaction detection analyzes the combined effects of factors on variable Y. Interaction types include nonlinear weakening, single-factor nonlinear weakening, double-factor enhancement, independence, and nonlinear enhancement.

Habitat quality spatial patterns and changes result from multiple interacting factors. Based on literature review and study area conditions, this research selected 11 indicators from five dimensions: natural topography (elevation, slope), vegetation growth (NDVI, vegetation type), climate conditions (mean annual temperature, annual precipitation), socioeconomic factors (GDP, population density), and landscape pattern (largest patch index, Shannon's evenness index, Shannon's diversity index, and interspersion and juxtaposition index) to analyze their influence mechanisms on habitat quality.

Threat factors and their weights, as well as habitat suitability and sensitivity to threats for each land class, were determined based on the InVEST user manual and relevant studies [16-18,20].

1.3.3 Geographically Weighted Regression Model (GWR) Habitat quality changes under natural and anthropogenic influences exhibit significant spatial heterogeneity in their modes and degrees of impact. This study employed the GWR model to analyze spatial effects of anthropogenic disturbance and natural factors on habitat quality at the 3 km × 3 km scale. GWR allows relationships between dependent and independent variables to vary spatially, yielding spatially reliable results:

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{p} \beta_k(u_i, v_i) x_{ik} + \varepsilon_i$$

where y_i is the dependent variable value at sampling point i, (u_i, v_i) are the central geographic coordinates of location i, $\beta_0(u_i, v_i)$ is the intercept at location i, x_{ik} is the k-th independent variable at sampling point i, $\beta_k(u_i, v_i)$ is the coefficient for the k-th independent variable, and ε_i is the error term.

2.1 Spatiotemporal Variation Characteristics of Habitat Quality

From a temporal perspective, overall habitat quality in Gonghe County showed an upward trend from 2000 to 2020, with mean values of 0.612, 0.626, and 0.627, respectively. Using the natural breaks method, habitat quality indices were classified into five levels: high (0.8–1.0), relatively high (0.6–0.8), medium (0.4–0.6), relatively low (0.2–0.4), and low (0–0.2). The proportion of high-quality habitat area showed a decreasing trend, dropping from 45.96% to 43.11%, while the proportion of relatively high-quality habitat area increased from 23.50% to 25.81%. The proportion of medium-quality habitat area continued to decline, whereas low-quality habitat area proportions kept rising. These trends indicate that the substantial improvement in relatively high-quality habitat area contributed to the overall enhancement of habitat quality in Gonghe County, demonstrating sustained positive ecological development. However, the area of habitat with potential degradation risk decreased from 474.66 km^2 to 302.77 km^2 between 2000–2010, and further reduced to 181.25 km^2 between 2010–2020, indicating that habitat degradation trends in some areas have been curbed and the ecological environment has improved to some extent.

Spatially, habitat quality distribution in Gonghe County exhibited significant spatial heterogeneity, generally presenting a north-high, south-low pattern that aligns with actual habitat type distributions. Low-value areas (low and relatively low levels) were mainly distributed in the central Gonghe Basin within Qieji Township, Shazhuyu Township, and Tiegao Township. These regions suffer from frequent hail, drought, wind-sand disasters, and water scarcity, with extensive desert or sandy areas forming the primary desert zones of Gonghe County. High-value areas (high and relatively high levels) concentrated in protected regions of the northern Qinghai Lake Basin, characterized by large lakes, wetlands, forests, and grasslands with minimal human disturbance and high vegetation coverage. Additionally, some low hills and river areas also maintained relatively high habitat quality.

Using the natural breaks method, habitat quality index changes were categorized into five classes: significantly deteriorated, slightly deteriorated, unchanged, slightly improved, and significantly improved. Spatial variation maps revealed that improved habitat quality areas between 2000–2010 were distributed in Qinghai Lake waters, South Qinghai Mountain, some low hills, southern high mountains in Qieji Township, Talatan, and the Longyangxia Reservoir area of the Yellow River. Deteriorated areas concentrated along the southern coast of Qinghai Lake. Between 2010–2020, improved habitat quality areas were mainly concentrated in Qinghai Lake's western waters and the Talatan photovoltaic zone, while deteriorated areas primarily comprised construction land for Talatan substations. Other regions showed minimal land cover change and insignificant land use transfers, resulting in smaller variation amplitudes.

2.2 Geographic Detector Results

To further explore spatial differences in how environmental factors affect habitat quality, geographic detectors were applied to analyze single-factor and interactive effects on habitat quality in Gonghe County for 2000, 2010, and 2020. Single-factor detection results showed that the top five factors by q-value in 2000 were:

NDVI (0.667), vegetation type (0.624), temperature (0.618), SHDI (0.611), and SHEI (0.603). In 2020, the ranking changed to: temperature (0.667), NDVI (0.624), vegetation type (0.618), SHDI (0.611), and SHEI (0.603). Temperature became the most explanatory factor for habitat quality in 2020, with its q-value increasing from 0.618 to 0.667, indicating significantly enhanced influence.

Interaction analysis revealed that all two-factor interaction q-values exceeded single-factor q-values, with interactions showing either double-factor enhancement or nonlinear enhancement. The most influential interaction factors were TEM SHEI and TEM SHDI in 2000, and NDVI VEG and VEG TEM in 2020. These interactions, along with NDVI SHEI, NDVI LPI, and TEM SHEI, collectively determined the spatial distribution of different habitat types. The combination of temperature, vegetation, and landscape pattern factors demonstrated strong interactive effects on habitat quality spatial differentiation.

2.3 GWR Model Results

To examine spatial variations in the direction and intensity of environmental factor impacts on habitat quality, GWR was employed for local spatial regression analysis. Considering that multicollinearity among variables could cause result errors, variance inflation factor (VIF) tests were conducted. Based on VIF values, factors with high collinearity (VIF > 10) were excluded before analyzing spatial mechanisms of remaining factors on habitat quality.

The GWR model, constructed using MGWR 2.2 software, showed good overall performance, with mean R^2 values of 0.721, 0.743, and 0.756 for 2000, 2010, and 2020, respectively. Results revealed distinct spatial patterns:

In 2000, temperature showed negative effects on habitat quality, with negative impact areas concentrated in the northern and eastern parts of Gonghe County. Slope exhibited strong positive effects, with positive regression coefficient areas covering 62.1% of the region, primarily in intermontane basins and some low hills. NDVI demonstrated strong negative effects, with negative coefficient areas accounting for 62.4%, mainly concentrated around Qinghai Lake. GDP showed significant positive effects, with positive areas covering 66.4% of the region, particularly in the Talatan desert zone in southern Gonghe County. Population density displayed significant negative effects, with negative areas comprising 65.1% of the region, concentrated around Qinghai Lake. Shannon's diversity index showed both positive and negative effects, with positive areas (48.4%) mainly on Qinghai Lake's east coast and negative areas (51.6%) concentrated on its south shore. Shannon's evenness index showed significant negative effects, with negative areas reaching 78.4% and widely distributed across the county.

By 2020, temperature's negative effects intensified, with negative value proportion rising to 80.8%. Slope's positive effects strengthened, with positive area proportion increasing from 62.1% to 66.4%. NDVI's negative effects weakened while positive effects strengthened, with positive proportion rising by 34.9% to 45.3%. GDP's positive effects further intensified, with positive area proportion increasing to 45.3%. Population density's negative effects weakened while positive effects strengthened. Shannon's diversity index's negative effects intensified, with maximum negative impact areas more concentrated around Qinghai Lake and some southern edges. Shannon's evenness index's negative effects weakened while positive effects strengthened.

Discussion

Changes in landscape patterns and production capacity resulting from urbanization and local industrial development significantly impact ecological environments. This study examined habitat quality levels in Gonghe County, evaluated their spatiotemporal characteristics, and revealed impacts of environmental and economic development changes on habitat quality from multiple perspectives.

Overall habitat quality in Gonghe County showed an upward trend, with high-grade habitat areas continuously increasing. This aligns with China's ecological protection and governance enhancement policies for regions with fragile ecological foundations and weak industrial bases. As a typical agricultural-pastoral economic development system, Gonghe County promotes high-quality modern ecological agriculture and animal husbandry development as its core, with ecological protection as the prerequisite. The county focuses on upgrading agricultural-pastoral structures to achieve agricultural and livestock product output, promoting production efficiency while ensuring ecological security and habitat quality improvement. However, unbalanced regional economic development also causes spatial heterogeneity in habitat quality. Jiangxigou Town along the southern coast of Qinghai Lake experienced notable habitat degradation between 2000–2010. Located in the lake's southern 环湖 area with extensive inclined plains and lakeside plains, this region possesses vast natural pastures and abundant water resources suitable for agricultural development. The western development strategy has made Qinghai Lake a tourism representative for Qinghai Province, with the 环湖 area becoming an important tourism economic zone. The economic system in Jiangxigou Town forms a pattern dominated by animal husbandry supplemented by crop farming and tourism, leading to dense regional populations. Large-scale consumption and disturbance of cultivated land and construction resources have caused more severe surrounding habitat degradation.

Improved habitat quality areas between 2000–2010 were mainly distributed in Qinghai Lake, high mountains on both sides of the Gonghe Basin, and some desert areas. This improvement stems from two factors: First, climate warming and humidification on the Tibetan Plateau have increased summer precipitation intensity and rainfall, with Qinghai Lake's water level continuously rising. Studies show that temperature increases and precipitation can significantly stimulate vegetation growth in alpine meadows and alpine grasslands, with climate change contributing up to 70% to NDVI growth. Although precipitation alone shows low explanatory power for habitat quality spatial heterogeneity, increased rainfall alleviates water stress on vegetation in arid regions. Since 2010, precipitation's explanatory power for habitat quality has increased, indicating that plateau climate warming and humidification promote vegetation growth and enhance habitat quality impacts. Second, influenced by ecological protection policies, the Gonghe County government actively promoted ecological governance and restoration in the Longyangxia Reservoir area of the Yellow River and abandoned mining sites, resulting in significant ecological environment improvements.

Habitat quality improvement areas between 2010–2020 concentrated in Talatan of Gonghe County. Due to its flat terrain and abundant sunshine, this region has vigorously developed new energy industries since 2015, creating a photovoltaic ecological demonstration zone. Research indicates that the regular arrangement of photovoltaic arrays can reduce surrounding air turbulence intensity, thereby hindering wind-sand movement. Photovoltaic panels' shading and precipitation redistribution directly affect soil temperature and moisture, altering regional soil water dynamics and promoting vegetation growth, with significant impacts on local ecological environments. The habitat quality changes in the photovoltaic park observed in this study align with these conclusions. Additionally, compared to 2000–2010, the magnitude of habitat quality change in Gonghe County was smaller during 2010–2020, primarily because afforestation, mountain closure for forest cultivation, and sand control projects implemented during 2010–2020 focused on maintaining existing protected or governance areas established by 2010, such as Qinghai Lake, South Qinghai Mountain, Shazhuyu, and the Three-River-Source areas. This resulted in small land cover changes and insignificant land use transfers.

Both geographic detector and GWR results indicate that climate and vegetation are crucial factors affecting community population distribution and biodiversity maintenance. Located on the Tibetan Plateau where climate change is the dominant factor controlling ecosystem dynamics, vegetation growth in Gonghe County is highly sensitive to water and heat factors. GWR coefficient maps show that the combined positive impact areas of temperature and vegetation type are concentrated in South Qinghai Mountain, where forests and grasslands are protected by policy with low development intensity and stable landscape distributions. The coupling and coordination between ecological protection and new urbanization construction is systematic and holistic, with good coordination forming a virtuous cycle that enables green development-oriented sustainable development. This study found that with Gonghe County's economic development and population growth, GDP's positive effect on habitat quality increased by 30% from 2000 to 2020, with positive impact areas mainly distributed in Qieji Township, Tiegao Township, and Shazhuyu Township. These areas have established green development systems for agricultural-pastoral cycling and grassland animal husbandry transformation and upgrading, achieving modern ecological agricultural-pastoral economic development with "dual promotion and dual development." Additionally, GDP showed significant positive effects on the Talatan photovoltaic base, demonstrating that green photovoltaics can achieve synergistic eco-industry development. Therefore, while developing the social economy, attention should be paid to protecting the natural environment, optimizing living and production spaces, balancing urban development and ecological protection, strictly observing ecological red lines, and achieving sustainable, high-quality development.

This study evaluated spatiotemporal changes in habitat quality in Gonghe County, Qinghai Province using the InVEST model, and comprehensively explored spatial heterogeneity and mechanisms of habitat quality changes under natural environmental and anthropogenic disturbances using geographic detectors and GWR models. The results indicate that temperature, vegetation, and landscape pattern factors jointly influence habitat quality changes in Gonghe County. Due to the small land cover changes between 2010–2020, this study used vegetation type and growth status indicators to modify habitat suitability for each type, enhancing scientific rigor. However, because GWR may produce result fluctuations for analysis units with low spatial correlation, future research should improve data precision, optimize model parameters, and refine analysis units to more accurately parse influence mechanisms and enhance practical significance of assessment results.

Conclusions

This study reveals that: (1) Habitat quality in Gonghe County, Qinghai Province, showed an overall upward trend from 2000 to 2020, with mean values of 0.612, 0.626, and 0.627, respectively. Spatial distribution exhibited significant heterogeneity, following a north-high, south-low pattern consistent with regional land use distributions. (2) Mean annual temperature and NDVI were the main driving factors affecting spatial distribution differences in habitat quality. Interaction q-values between any two factors exceeded single-factor q-values, with interactions showing double-factor enhancement or nonlinear enhancement. (3) The most influential interactive factors were TEM SHEI and NDVI VEG in 2000, and NDVI VEG and VEG TEM in 2020. Natural environmental factors including temperature, vegetation, and landscape pattern jointly influenced habitat quality changes in Gonghe County. (4) The GWR model effectively revealed varying relationships between influencing factors and habitat quality. Temperature showed significant positive effects on central and southern Gonghe County, while GDP exhibited significant positive effects with a spatial distribution pattern of "negative in the north, positive in the south" relative to Qinghai Lake. GDP demonstrated obvious positive effects on the Talatan photovoltaic zone. Slope and NDVI showed positive or negative impacts on habitat quality in different regions.

References

[1] Mohan M, Kandya A. Impact of urbanization and land use/land cover change on diurnal temperature range: A case study of tropical urban airshed of India using remote sensing data[J]. Science of the Total Environment, 2015, 506: 453-

465.

[2] Fellman J B, Hood E, Dryer W, et al. Stream physical characteristics impact habitat quality for Pacific salmon in two temperate coastal watersheds[J]. PloS one, 2015, 10(7): e0132652.

[3] Hillard E M, Nielsen C K, Groninger J W. Swamp rabbits as indicators of wildlife habitat quality in bottomland hardwood forest ecosystems[J]. Ecological Indicators, 2017, 79: 47-53.

[4] Peng Jian, Xu Feixiong, Wu Jian, et al. Spatial differentiation of habitat quality in typical tourist city and their Influencing factors mechanisms: A case study of Huangshan City[J]. Resources and Environment in the Yangtze Basin, 2019, 28(10): 2397-2409.

[5] Su Yifan, Li Weiming, Li Jinjing, et al. Habitat suitability of macroinvertebrates: A case study in Qiaobian River, a tributary of Yangtze River, China[J]. Acta Ecologica Sinica, 2020, 40(16): 5844-5854.

[6] Boumans R, Roman J, Altman I, et al. The Multiscale Integrated Model of Ecosystem Services (MIMES): Simulating the interactions of coupled human and natural systems[J]. Ecosystem Services, 2015, 12: 30-41.

[7] Liu Yongting, Yang Zhao, Xu Guanglai, et al. Impacts of urbanization on habitat quality using MGWR models in Wanjiang City Belt[J]. Scientia Geographica Sinica, 2023, 43(2): 280-290.

[8] Ti Yang, Zhuang Hongfei, Chen Minhao, et al. Spatio-temporal evolution pattern of protected areas and regional habitat quality in Tianjin[J]. Acta Ecologica Sinica, 2023, 43(7): 2770-2780.

[9] Zhang Haitao, Li Jialin, Tian Peng, et al. Spatio-temporal evolution of habitat quality in the East China Sea continental coastal zone based on land use changes[J]. Acta Ecologica Sinica, 2023, 43(3): 937-947.

[10] Cheng Jing, Wang Peng, Chen Hongxiang, et al. Spatiotemporal evolution of habitat quality in the Weihe River Basin and its topographic gradient effects and influencing factors[J]. Arid Land Geography, 2023, 46(3): 481-491.

[11] Chen Shi, Jin Yunxiang, Huang Yinlan. Spatio-temporal variations of habitat quality and its underlying mechanism in the central region of Yangtze River Delta[J]. Chinese Journal of Ecology, 2023, 42(5): 1175-1185.

[12] Ren Yinming, Liu Xiaopin, Xu Xiaocong, et al. Multi-scenario simulation of land use change and its impact on ecosystem services in Beijing-Tianjin-Hebei region based on the FLUS-InVEST model[J]. Acta Ecologica Sinica, 2023, 43(11): 4473-4487.

[13] Zhao Henglun. Social and Economic Statistics Yearbook of Qinghai Province[M]. Qinghai: China Statistics Press, 1986: 251-258.

[14] Hu Feng, Zhang Yan, Guo Yu, et al. Spatial and temporal changes in land use and habitat quality in the Weihe River Basin based on the PLUS and InVEST models and predictions[J]. Arid Land Geography, 2022, 45(4): 1125-1136.

[15] Xu Baorong, Liu Yichuan, Dong Ying, et al. Evaluation of habitat quality in Lanzhou region based on InVEST model[J]. Journal of Desert Research, 2021, 41(5): 120-129.

[16] Bao Yubin, Liu Kang, Li Ting, et al. Effects of land use change on habitat based on InVEST model: Taking Yellow River wetland nature reserve in Shaanxi Province as an example[J]. Arid Zone Research, 2015, 32(3): 622-629.

[17] Zhao Zhangdong, Zhang Fei, Wang Hongli, et al. Research on the impact of land use change on habitat quality in Minjiang River Basin based on InVEST Model[J]. Ecological Science, 2022, 41(6): 1-10.

[18] Jing Qingjian, WU Xiaozhen. The reasons of rising water level in Lake Qinghai since 2005[J]. Journal of Earth Environment, 2013, 4(3): 1355-1362.

[19] Han Yanhong, Liu Yanjun, et al. Water storage variation of the Qinghai Lake in recent decades based on satellite observation[J]. Progress in Geography, 2018, 37(6): 823-832.

[20] Zhang Hongyuan, Wu li, Chen Kelong, Yu Deyong. Evaluation on the impact of land use change on habitat quality in Qinghai Lake Basin[J]. Ecology and Environmental Sciences, 2019, 28(10): 2035-2044.

[21] Pan Yao, Yin Yunhe, Hou Wenjuan, et al. Spatiotemporal variation of habitat quality in the Source Region of the Yellow River based on land use and vegetation cover changes[J]. Acta Ecologica Sinica, 2022, 42(19): 7978-7988.

[22] Wang Jinfeng, Xu Chengdong. Geodetector: Principle and prospective[J]. Acta Geographica Sinica, 2017, 72(1): 116-134.

[23] Wu Yanxia, Liu Fangnan, Chen Baotong. Spatial and temporal evolution and drivers of habitat quality in lower Yellow River Basin urban agglomeration[J]. Bulletin of Soil and Water Conservation, 2023, 43(4): 396-404.

[24] Wang Qikun, Wu Wei, Yang Xueqi, et al. Spatial-temporal changes and driving factors of habitat quality in Shaanxi Province during the past 20 years[J]. Arid Zone Research, 2022, 39(5): 1684-1694.

[25] Ma Fulin, Liu Xiaowei, Duo Ying, et al. Effects of daily variation of hydro-thermal factors on alpine grassland productivity on the Qinghai-Tibet Plateau[J]. Acta Ecologica Sinica, 2023, 43(9): 3719-3728.

[26] Brunsdon C, Fotheringham A S, Charlton M E. Geographically weighted regression: A method for exploring spatial nonstationarity[J]. Geographical Analysis, 1996, 28(4): 281-298.

[27] Dominique W, Gabriela S, Klaus E. Predicting habitat quality of protected dry grasslands using landsat NDVI phenology[J]. Ecological Indicators, 2018, 91: 447-460.

[28] Fellman J B, Hood E, Dryer W, et al. Stream physical characteristics impact habitat quality for Pacific salmon in two temperate coastal watersheds[J]. PloS one, 2015, 10(7): e0132652.

[29] Hillard E M, Nielsen C K, Groninger J W. Swamp rabbits as indicators of wildlife habitat quality in bottomland hardwood forest ecosystems[J]. Ecological Indicators, 2017, 79: 47-53.

[30] Barbara R, Stefan L. A spatially explicit patch model of habitat quality, integrating spatio-structural indicators[J]. Ecological Indicators, 2018, 94: 128-141.

[31] Pratt R N, Kopp G A. Velocity measurements around low profile, tilted, solar arrays mounted on large flat roofs, for wall normal wind directions[J]. Journal of Wind Engineering and Industrial Aerodynamics, 2013, 123: 226-238.

[32] Thorne J H, Boynton R M, Flint L E, et al. The magnitude and spatial patterns of historical and future hydrologic change in California's watersheds[J]. Ecosphere, 2015, 6(2): 1-30.

[33] Yang Da, Yi Guihua, Zhang Tingbin, et al. Spatiotemporal variation and driving factors of growing season NDVI in the Tibetan Plateau, China[J]. Chinese Journal of Applied Ecology, 2021, 32(4): 1361-1372.

[34] Bao Yan, Wang Yuqi, Nan Sulan, et al. Response of vegetation over the Qinghai-Xizang Plateau to projected warming climate[J]. Plateau Meteorology, 2023, 42(3): 553-563.

[35] Xie Baoni. Vegetation Dynamics and Climate Change on the Loess Plateau, China: 1982-2014[D]. Yangling: Northwest A & F University, 2016.

[36] Fan Yingping, Jin Xiaobin, Chen Chuanzhao, et al. Spatial-temporal evolution and correlation analysis of landscape pattern and ecological environment quality in coastal metropolitan area: A case study of Xiuying District, Haikou[J]. Modern Urban Research, 2023(3): 116-124, 132.

[37] Zhang Jie, Zhang Jianyong, Ma Lan. An empirical analysis of the coupled and coordinated relationship between ecological protection and quality development in the Yellow River Basin[J]. People's Yellow River, 2024, 46(1): 19-24.

[38] Zhu C, Zhang X, Zhou M, et al. Impacts of urbanization and landscape pattern on habitat quality using OLS and GWR models in Hangzhou, China[J]. Ecological Indicators, 2020, 117: 106654.

[39] Chen Huihui. Research on the development of Qinghai Lake scenic area and the current situation of community participation in tourism around the lake: An anthropological investigation based on Yuanzhi Village in Jiangxi Gou Township as a case study[J]. Qinghai-Tibetan Plateau Forum, 2015, 3(1): 66-71.

[40] Du Jiani, Li Qijiang, Liu Xisheng, et al. Characterisation of hydrological changes in Qinghai Lake from 1956 to 2017[J]. Journal of Water Ecology, 2020, 41(4): 27-33.

Note: Figure translations are in progress. See original paper for figures.