Assessment of the Ecological Environmental Impact of Huizhou's Urban Built-up Area Using the STIRPAT Model

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Abstract. This study systematically assesses the ecological environmental impact of Huizhou's urban built-up area based on the extended STIRPAT model. Through multivariate nonlinear regression analysis, we quantified the impact of population, economy, and technology on the ecological environment. The results show that per capita consumption level, energy consumption structure, per capita building area, and per household population all have significant positive impacts on the ecological environment. The model fit is excellent, with an R-squared value of 0.902 and an adjusted R-squared value of 0.875, and the F-statistic is 33.14 with a high level of significance. The study reveals the key roles of consumption level and energy structure in environmental impact, providing important references for local governments to formulate scientific environmental management policies. Future research can further explore the specific mechanisms of each factor to enhance urban ecological environment management.

Keywords: STIRPAT Model, Ecological Environmental Impact, Multivariate Nonlinear Regression.

1 Introduction

With the rapid acceleration of global urbanization and industrialization, environmental issues in urban built-up areas have become increasingly prominent[1]. As one of China's rapidly developing coastal cities, Huizhou has achieved significant accomplishments in urban construction and economic development. Figure 1 shows the expansion of urban construction areas from 2000 to 2020, but it also faces severe environmental pressures[2-4]. These pressures are mainly reflected in resource consumption and environmental pollution, such as increased energy consumption, emissions of air pollutants, overuse and pollution of water resources, and so on. These issues not only threaten the sustainability of the urban ecological environment but also have a serious impact on the quality of life and health of residents[5, 6].

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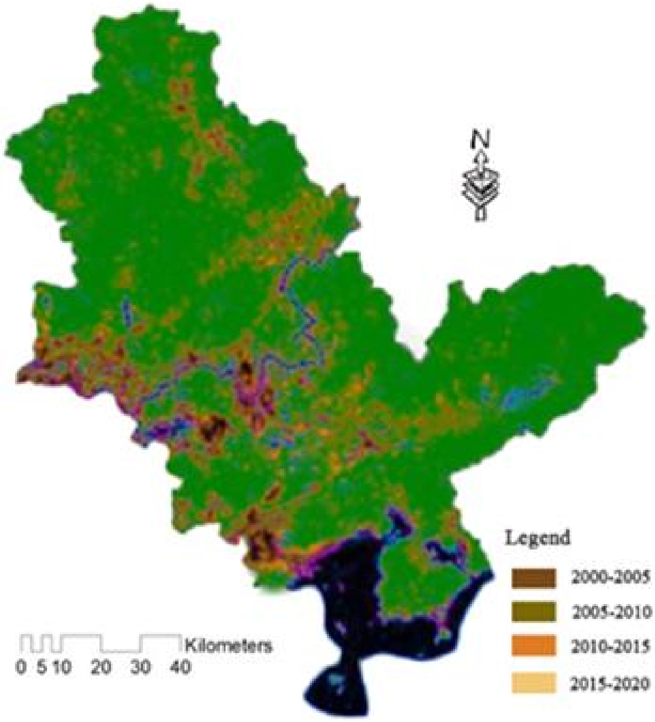

Fig. 1. Expansion of the Built-up Area in Huizhou from 2000 to 2020 [4]

In this context, the critical issue that urgently needs to be addressed is how to scientifically and systematically evaluate and analyze the environmental impact of urban built-up areas, identify the main factors affecting environmental quality, and formulate effective environmental management strategies[7]. The STIRPAT model (Stochastic Impacts by Regression on Population, Affluence, and Technology), an improved version of the IPAT model, can more accurately describe the impact of population, economy, and technology on the environment by introducing nonlinear and stochastic effects, providing an important theoretical tool for environmental impact assessment[8-10].

This study aims to systematically evaluate and analyze the environmental impact of Huizhou's urban built-up area based on the STIRPAT model. By establishing an extended STIRPAT model and selecting representative environmental impact indicators, we comprehensively consider factors such as population, economy, technology, and energy to quantitatively analyze the contribution of each factor to environmental impact. The study not only reveals the causes and evolution of Huizhou's environmental problems but also provides a decision-making basis for local governments to formulate scientific environmental management policies.

2 Methods

2.1 Selection of Model Parameters

The STIRPAT model is used to quantitatively analyze the nonlinear relationship between population, economic activities, and technological changes on environmental impact. Its basic formula is as follows:

$$I = aP^{b}A^{c}T^{d}e \tag{1}$$

In the formula: I represents the environmental impact effect, which is expressed in this paper as ecological environment quantity; P, A, and T respectively represent the three dimensions of population, economy, and technology.

Table 1. Description of Variables in the STIRPAT Model

Variable	Description	Unit
Consumption Intensity (Q)	Energy consumption contained in the residential building consumption expenditure per 10,000 yuan during the use phase	kg CO_2/10,000 yuan
Per Capita Consumption Level (G)	Average per capita consumption in daily life	yuan
Energy Consumption Structure (S)	Proportion of natural gas in total energy consumption	%
Construction land per capita (K)	Average building area per capita	m^2/person

a represents the model coefficient; b, c, and d respectively represent the coefficients of population, economy, and technology factors; e represents the random error term.

Therefore, based on the three aspects of population, technology, and economy in formula (1), combined with the analysis of the specific actual situation of the urban built-up area, the final selected influencing factors are consumption intensity, per capita consumption level, energy consumption structure, and per capita construction land. The meanings and dimensions of each influencing factor are shown in Table 1.

2.2 Data Normalization Processing

To eliminate the effects of different dimensions, it is necessary to standardize the data of the ecological environment and various influencing factors. This involves calculating the sum of each type of indicator data and the proportion of each factor's data in the total sum of factor data:

$$x'_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} (i = 1,2,\cdots,m; j = 1,2,\cdots,n) \tag{2}$$

The new data after standardization is:

$$\sum_{i=1}^{m} x'_{ij} = 1 \tag{3}$$

2.3 Construction of the STIRPAT Model

First, formula (1) is expanded according to the selected parameters to obtain:

$$I = aQ^b G^c S^d K^e e \tag{4}$$

Where: Q represents consumption intensity, G represents per capita consumption level, S represents energy consumption structure, and K represents per capita building area; a, b, c, d, and e are the parameters to be determined.

Formula (4) is logarithmically transformed to establish the model of influencing factors for the built-up area of Huizhou City as follows:

$$ln\ I = ln\ \alpha + \beta_1 ln\ Q + \beta_2 ln\ G + \beta_3 ln\ S + \beta_4 ln\ K + ln\ e \tag{5}$$

In the formula: Q: Consumption Intensity; G: Per Capita Consumption Level; S: Energy Consumption Structure; K: Construction Land Per Capita. For specific parameter descriptions, see Table 1. Significance tests are performed through the multivariate linear regression model, where the respective values represent the elasticity coefficients of each indicator. The higher the value, the greater the impact of the corresponding influencing factor on the ecological environment.

3 Results

3.1 Trend of Model Parameter Changes

After normalization, the trend of influencing factors in the built-up area of Huizhou City is shown in Figure 2. As can be seen from Figure 2, during the period from 2000 to 2020, except for a slight decline in consumption intensity, other factors showed an upward trend. Among them, the per capita consumption level and the urban per capita housing area have been growing steadily each year with the rapid economic development of Huizhou. The average household population in urban areas of Huizhou has remained stable.

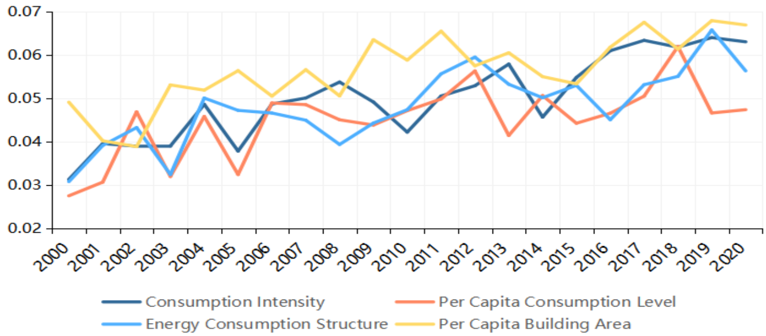

Fig. 2. Trend of STIRPAT Model Parameters from 2000 to 2020

3.2 Nonlinear Regression Model of STIRPAT

Based on the collected data of influencing factors, a multivariate nonlinear regression analysis was conducted using SPSS software with formula (5) as the model to check for collinearity. The results are shown in Table 2.

Table 2. Regression Model Statistics

Variable	Coeffi-cient	Standard Error	t-value (t)	p-value (P>|t|)	Confdence Interval (0.025)	Confidence Interval (0.975)
Intercept	0.0346	0.008	4.325	0	0.017	0.052
lnG	0.4523	0.123	3.678	0.002	0.189	0.715
lnS	0.2987	0.115	2.595	0.02	0.05	0.548
lnK	0.1894	0.081	2.339	0.033	0.016	0.362
lnQ	0.2778	0.095	2.925	0.01	0.076	0.48

As shown in Table 2, the coefficients obtained through multivariate linear regression not only passed the 5% significance level test with an R-squared value of 0.902, but the F-statistic also significantly passed the 1% significance level test. The regression model is as follows:

$$lnI = 0.2778lnQ + 0.4523lnG + 0.2987lnS + 0.1894lnK - 0.0346 \quad (6)$$

4 Conclusion

In this study, we systematically evaluated and analyzed the ecological environmental impact of Huizhou's urban built-up area based on the extended STIRPAT model. By introducing a multivariate nonlinear regression model, we were able to quantitatively analyze the impact of population, economy, technology, and other factors on the ecological environment. This study, through the extended STIRPAT model and multivariate nonlinear regression analysis, revealed the main driving factors of the ecological environment in Huizhou's urban built-up area and provided corresponding quantitative data support.

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