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Research Article

Estimating scenic beauty in Chinese villages: a novel approach based on 3D real scene models

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Abstract: The color landscape is an essential aspect of each village, representing both natural scenery and human history. However, previous research has not provided a thorough and quantitative assessment of the color spatial pattern of regions and their surroundings. In this study, color patches were extracted from 3D real scene models, and color landscape indices were used to quantify the color landscape pattern. A questionnaire was utilized to establish the association between the color landscape indices and the Scenic Beauty Estimation (SBE) scores, which was then used to predict the SBE without the need for another questionnaire. The results showed that: 1) the color landscape indices extracted using 3D real scene models can reveal the scenic beauty of villages, with different villages presenting various color landscape patterns; 2) the SBE scores obtained through the questionnaire have a strong correlation with various color landscape indices, such as COHESION, LPI, SPILT, Y-MPS, and GE-MPS; 3) the SBE model based on color landscape indices was developed using stepwise linear regression, with an R2 value of 0.822 and an average error of 0.248, which can predict SBE in various places without the use of a questionnaire. This study introduces a new perspective and approach for estimating scenic beauty, which will help with rural planning and beautiful countryside development.

Keywords: scenic beauty estimation, rural landscape, color landscape pattern, color extraction, patch landscape

1 Introduction

Scenic beauty is defined as the visual attractiveness of a natural or man-made landscape that includes attractive environmental aspects that inspire aesthetic enjoyment and emotional responses [16, 43]. However, scenic beauty is frequently defined qualitatively, such as "beautiful," but it is difficult to quantify. The "Scenic Beauty Estimation" (SBE) score is a way of analyzing the beauty or aesthetics of a landscape, which is typically used to determine the degree of attractiveness and beauty of a natural or manmade landscape [13]. It is a widely used quantitative method of assessing scenic beauty. For example, several studies on SBE scores for plants [25, 26, 65] discovered that features such as high plant abundance and apparent seasonal fluctuations have a positive impact on SBE scores, offering recommendations for improving plant community landscapes. Peng and Han [42] used SBE to assess the impact of landscape features on the scenic attractiveness of a watershed, discovering that flowing water components and plant covers on structures had a positive impact on SBE ratings. Furthermore, landscape pattern quantifies a landscape's spatial composition, whereas landscape indices provide quantitative spatial information that can be used to suggest landscape improvements [39, 49]. For example, Fu and Chen [15] used landscape pattern indices to study land usage and advocated planting shrub buffer zones between slope tops and slopes to prevent soil erosion while increasing landscape variety and connectedness. Midha and Mathur [36] studied the ecology of two forest reserves and found that DNP forest fragmentation was reduced and habitat quality was higher than KAT. By integrating SBE with landscape indices, the elements that influence scenic attractiveness and aesthetic level could be statistically described. The appropriate landscape can then be modified, so contributing to the improvement of scenic attractiveness. Finally, policies that reflect the optimal direction of various indices may help in the development of regional landscape.

Color is vital in landscape design because it enhances the surroundings and highlights aesthetic features [17]. Color landscape patterns demonstrate the spatial structure of colors are effective for analyzing landscape quality and measuring a location's visual appeal [35,63]. However, the majority of current research on color landscape patterns focuses on the quantitative features of color types [7, 34, 35, 37, 45], rather than the quantitative analysis of color spatial patterns. Luo et al [35], for example, studied the link between the inherent features of fall plant color landscapes and the general public's aesthetic preferences. They discovered three forms of color compositions that enhance visual beauty: warm-toned dominant type, warm and cold-toned contrast type, and multicolored harmonic type. Jia et al [37]. analyzed forest color landscape patterns and discovered that a large panchromatic relative area and a small main color relative area lead to high SBE scores. Shen et al [45]. evaluated the color harmony of several urban parks, proposing a new method for optimizing the color allocation of plant community landscapes in urban parks. In addition, several studies have included color surveys of villages [7, 51], analyses of architectural structure, landscape, and development status, and recommendations for village conservation strategies. This study focuses on the spatial structure of color, with the goal of optimizing the color landscape pattern of rural regions, encouraging the building of rural color landscapes, and improving people's living conditions.

The viewpoint of landscape observation has a direct impact on the form and effect of landscape expression, and a best viewpoint allows for a more thorough understanding of information. Currently, the majority of color landscape research focuses on the traditional photos captured by ground cameras [45,50,51] and the fifth elevation [11,31,41]. The fifth elevation in remote sensing photography refers to the top of an object or building. They used remote sensing data to create a vertical image and then performed unsupervised color categorization. Wang et al. [51] investigated Nanjing Purple Mountain by photos captured by ground cameras and discovered that its visual value steadily declines from southwest to northeast. Gao et al. [11] studied the color of Northwest University's fifth elevation and discovered that the colors were predominantly cold, providing color optimization solutions. However, the traditional photos captured by ground cameras are excessively small and easily obscured by the tightly packed terrain. The fifth elevation's perspective is limited, as it ignores the colors of the facade, such as walls and ornamentations. This perspective differs greatly from that of humans and may not adequately represent people's impressions of the landscape. The current color landscape study lacks best viewpoint images which is conducive to the quantitative evaluation of the surrounding environment.

With the development of low-altitude oblique photogrammetry technology, the approach of getting high-precision photos based on this technology to generate 3D real scene models has become extensively used [9,18,29,56,57,68]. The 3D real scene model is a three-dimensional model created from real-world data that properly represents the spatial distribution of objects such as landscapes, buildings, and plants [28-30] [12,40,53]. This model is often created by employing low altitude oblique photography technologies to capture high-precision picture data for 3D reconstruction. 3D real scene models can easily rotate, zoom in, and out of the image to discover the most appropriate sizes and angles based on the size of the countryside. This study uses these procedures to determine the best viewpoint for each the village and extract the image for color analysis. These images differ from those obtained by traditional photos captured by ground cameras. They have a certain height and angle that enhances and completes the village's color landscape. From a broader viewpoint, the color analysis procedure based on these images can take into account the relationship between the village and its natural geographic surroundings. These best viewpoint images display more extensive color features than the horizontal viewpoints, and the observation angle is more consistent with people's lifestyles than the fifth elevation.

This study first created 3D real scene models of villages and then extracted color information from these models extensively. The study then aims to: 1) estimate the scenic beauty of villages in China based on 3D real scene models using SBE scores; 2) investigate the relationships between SBE scores and color landscape indices to analyze the factors contributing to scenic beauty; and 3) develop and evaluate a Scenic Beauty Estimation model based on color landscape indices.

2 Study areas and data

The Anhui Provincial Government picked "Beautiful Countryside" as part of China's Rural Revitalization Strategy, which aims to improve the natural environment, infrastructure, and rural communities in rural regions. In recent years, Jinzhai County has extensively investigated the advantages of the countryside landscape, such as ecological stability and old village conservation [10,58,62], and encouraged the building of "Beautiful Countryside" in Anhui Province, China [46,61]. As a result, selecting Jinzhai County as a sample region for research on rural landscape features is fairly representative. Figure 1 shows typical rural areas in China. This paper tried to guarantee that the population and size of the sample villages were not significantly different. All the villages (Table 1) in the experiment were selected from Jinzhai County. In this research, the first 16 villages were used to develop the SBE model, and the final 8 villages were used to test the model's dependability.

ID	Area	ID	Area
1	Banzhuyuan	13	Songziguan
2	Shuanghe	14	Huayuan
3	Baofan	15	Changchong
4	Hexi	16	Matou
5	Dawan	17	Xiaohe
6	Wufan	18	Wanhe
7	Gutang	19	Wangwan
8	Yuling	20	Wangshichi
9	Daqiao	21	Wangfan
10	Guoziyuan	22	Sima
11	Mehe	23	Qidan
12	Shayan	24	Menqian

Table 1: Selected villages in Jinzhai County.

The data used in this study was collected by UAV photogrammetry. The DJI Phantom 4 RTK was used to take aerial photos of 24 villages such as Dawan Village, Gutang Village, Hexi Village, Baofan Village, Wufan Village, etc. In order to avoid the influence of other natural factors such as light, the time of aerial photography is selected to start around 10: 00 am on sunny days in July and August in summer. The Bentley Context Capture modelling software was used to process the data to generate a 3D real scene model in OSGB format with a ground resolution of 4cm.

3 Study areas and data

3.1 Overview

The workflow of this study is shown in Figure 2. Different colors were extracted from the 3D real scene models. The color landscape of the villages was quantified by 12 color landscape indices which include landscape level indices and patch level indices. Meanwhile, the SBE scores of each village were evaluated by questionnaire. The Pearson coefficient between color landscape indices and SBE scores was evaluated to explore the relationship between them. Based on the landscape indices and SBE scores, the SBE models were constructed by the stepwise linear regression method. Finally, the new villages were used to verify the model accuracy.

3.2 Color extraction in 3D real scene models

Compared to extracting the color landscape from photos captured by ground cameras , 3D real scene models provide great flexibility for generating images of overview landscape. Images must be captured from the best possible viewpoint and angle. This research chose the best viewing viewpoint for each village after examining several directions and angles. When visitors arrive in the village, the first thing they see is the main road. Viewpoints

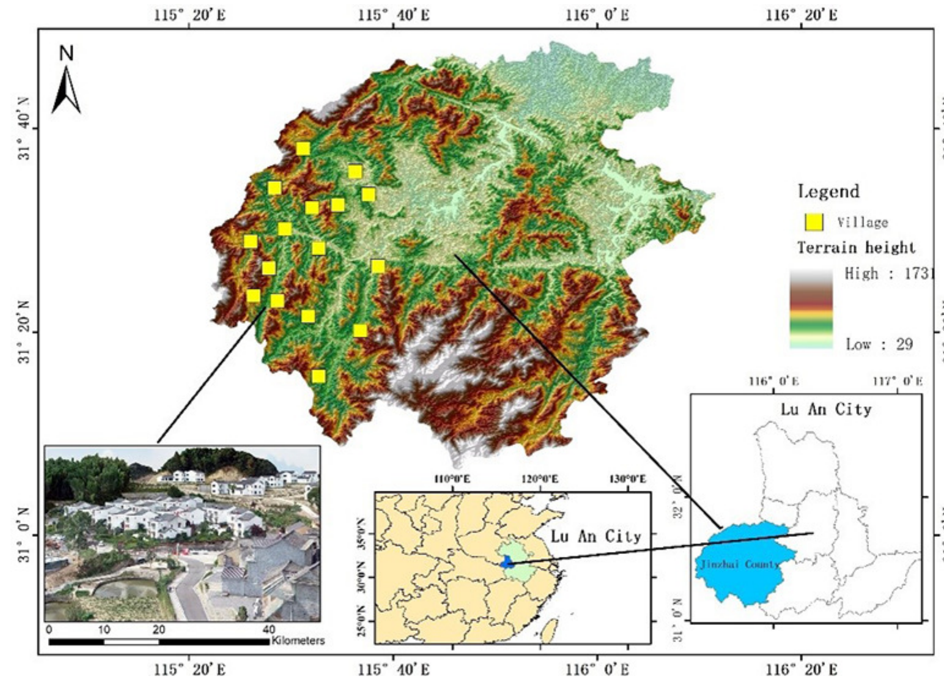

Figure 1: Geographical location of Jinzhai County.

were chosen along or perpendicular to the village's main road, taking into account the overall landscape environment and human observation perspective.

To ensure that a more comprehensive and cubic color landscape pattern can be observed, the angle and scale should be chosen to ensure a full view of the village. By adjusting different angles, it was found that the angles from 30 degrees to 45 degrees oblique angle are better. In these viewpoints, the color of the roof and the color of the walls may be considered simultaneously. To see the majority of the settlement, the scale must be adjusted in various models. Finally, scene photographs from the views were created (Figure 3).

Open-Source Computer Vision Library (OpenCV) was used to extract colors from scene photos. OpenCV is an open-source computer vision library with many algorithms for image processing and computer vision. The OpenCV environment was configured in Visual Studio (VS) to extract the color of the photo. This paper first converted the RGB format photos into HSV format photos and then used the value range of different colors of the H channel (hue) to extract different colors. Based on the HSV color classification rules (Table 2), different colors were extracted respectively in each scene photo (Figure 4).

Color type	black	grey	white	red	yellow	green	blue
Hue	0-180	0-180	0-180	0-10/156-180	26-34	35-77	78-124
Saturation	0-255	0-43	0-30	43-255	43-255	43-255	43-255
Value	0-46	46-220	221-255	46-255	46-255	46-255	46-255

Table 2: HSV color classification rules.

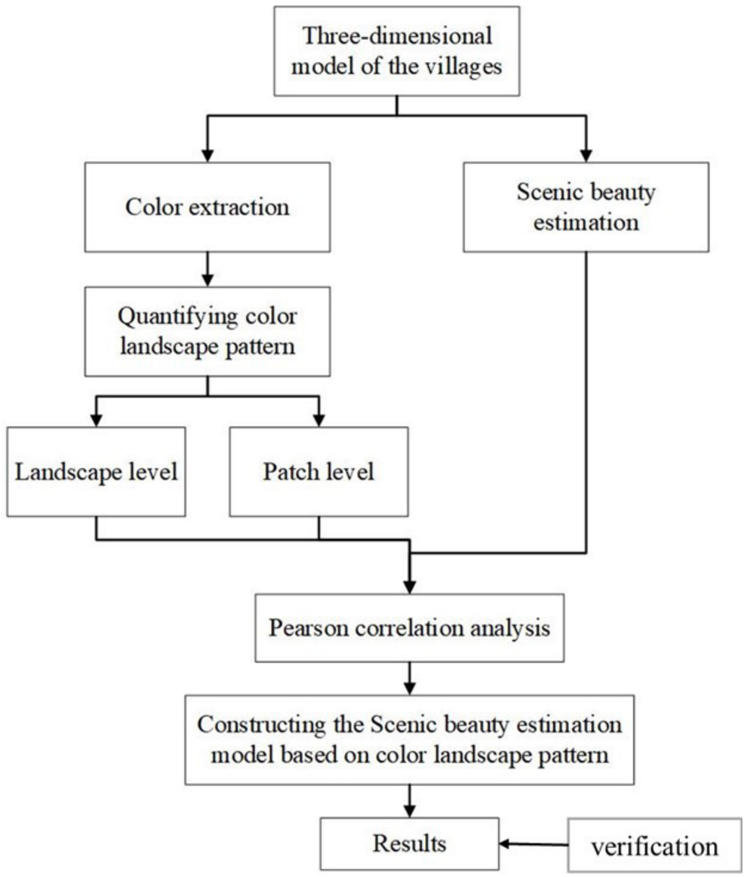

Figure 2: Technical process of the experimental steps.

Figure 3: Scene photos captured from 3D real scene models.

3.3 Quantifying color landscape pattern

Fragstats software is a landscape indices calculation software developed by the Department of Forest Science, Oregon State University. Landscape pattern analysis should take into account not only whether a single index can accurately describe the landscape pattern,

Figure 4: Automatic color extraction example.

but also the index system that depicts the entire landscape pattern [8]. As a result, the majority of landscape patterns were explored at two different scales: landscape and patch [5,14,28,30,55,64]. The color landscape indices produced by the Fragstats program include both landscape and patch levels. This study quantified color landscape patterns using two-level indices.

3.3.1 Landscape level

The landscape level indices focus on the study of the overall landscape pattern of the village and its surrounding environment. In this study, it includes interrelationships between different color types of patches, and its calculation is done with all color patches. According to village landscape characteristics and previous research [5,14,28,30,55,64], this paper selected 6 landscape level indices (Table 3) including area index, that is largest path index (LPI), shape index, that is landscape shape index (LSI), convergent divergence index, that is Splitting index (SPLIT), connectivity index, that is Patch cohesion index (COHESION), fragmentation index, that is Splitting index (SPLIT), and diversity index, that is Shannon's diversity index (SHDI).

3.3.2 Patch level

Patch level indices concentrate on patterns of patches that share the same hue. These indices will be calculated for patches with the same color. Through the observation of 3D real scene models, it is found that the areas of green (representing vegetation), gray (representing roads and buildings) and yellow (representing cultivated land) are relatively high, so this paper analyzes these colors. This paper selected 6 patch level (Table 4) indices (in-

ID	Landscape level	Unit	Value range	Description
1	Largest path index (LPI)	%	(0,100%)	The proportion of the largest patch in the overall landscape
2	Landscape shape index (LSI)	-	$(0, +\infty)$	The difference between the patch shape and the circle. Measuring the complexity of shape
3	Aggregation index (AI)	%	(0,100%)	The degree of aggregation of the same plaques (%). It can measure the degree of similar patches gathered together in the landscape
4	Patch cohesion index (COHESION)	%	(0,100%)	Describe the degree of connectivity between different landscape plaques in the landscape
5	Splitting index (SPLIT)	%	(0,100%)	Describes the degree of separation of different land types in the landscape (%)
6	ShannonâĂŹs diversity index (SHDI)	-	$(0, +\infty)$	Reflect the number of landscape elements and the proportion of each landscape element. It can reveal stability in the landscape

Table 3: Landscape level color landscape indices.

cluding Green relative area (GE-A), Gray relative area (GA-A), yellow relative area (Y-A), Green mean patch size (GE-MPS), Gray mean patch size (GA-MPS), Yellow mean patch size (Y-MPS).

ID	Patch level	Unit	Value range	Description
1	Green relative area (GE-A)	%	(0,100%)	The proportion of the total area of green patches (%)
2	Gray relative area (GA-A)	%	(0,100%)	The proportion of the total area of grey patches (%)
3	Yellow relative area (Y-A)	%	(0,100%)	Proportion of total area of yellow patches (%)
4	Green mean patch size (GE-MPS)	ha	$(0, +\infty)$	Mean size of patches of the green type (ha). It can be used to measure the green fragmentation degree of the landscape
5	Gray mean patch size (GA-MPS)	ha	$(0, +\infty)$	Mean size of patches of the gray type (ha). It can be used to measure the gray fragmentation degree of the landscape
6	Yellow mean patch size (Y-MPS)	ha	$(0, +\infty)$	Mean size of patches of the yellow type (ha). It can be used to measure the yellow fragmentation degree of the landscape

Table 4: Patch level color landscape indices.

3.4 Scenic Beauty Estimation

The "Scenic Beauty Estimation" (SBE) score is a way of analyzing the beauty or aesthetics of a landscape, which is typically used to determine the degree of attractiveness and beauty of a natural or manmade environment [13, 25, 26, 42, 65]. In these research, landscape photographs were utilized in questionnaires or review slides. A questionnaire was prepared using the SBE approach (see Appendix A). The first 16 village photographs were included in the questionnaire. The photographs were ordered at random, regardless of place or time. The assessment table standard was developed using the LIKERT five-point scale approach [2]. Previous research has indicated that the general public, specialists, non-professional and professional students all have the same aesthetic perception of natural scenery [59], however persons with professional expertise have a sharper impression of scenic beauty [48]. To assure the objectivity and correctness of the assessments, 118 undergraduate and postgraduate students majoring in geography and landscape design were invited to evaluate the rural color landscape, which indicated the level of scenic beauty of villages. Before scoring, the participants were suggested to mainly analyse the rural color landscape pattern and try to ignore the impacts on image quality and slight differences in angles. The evaluation procedures are as follows: (1) Each village's scenic attractiveness was graded into five categories: very poor (1 point), poor (2 points), general (3 points), good (4 points), and very good (5 points). (2) Before formal grading, the evaluator scanned the 16 example photos in 30 seconds. (3) The official scoring process began with the first image and continued for 5 seconds for each subsequent image. (4) Scoring each photo sequentially until the final one was completed. (5) Gathing questionnaires and excluding those that do not fit the time constraints. Finally, 118 questionnaires were gathered.

Although there is no significant difference in the aesthetic perception of natural scenery, there are considerable disparities in the criteria used by each individual to evaluate the landscape, which may alter the objectivity and consistency of the results. As a consequence, this study recalculated to minimize subjective variations between participants and standardise the scenic attractiveness ratings. The SBE score is calculated based on the standardization calculation according to the following formula.

$$\bar{R}_j = \frac{\sum_{i=1}^{n} R_{ij}}{n} \tag{1}$$

$$Z_{ij} = \frac{R_{ij} - \bar{R}_j}{S_j} \tag{2}$$

$$\mathrm{SBE}_i = \frac{\sum Z_{ij}}{N} \tag{3}$$

Where $\bar{R}_j$ represents the average value given by the j-th evaluator for all photos; R_{ij} represents the j-th evaluator's score for the i-th image; n represents the number of images; S_j is the standard deviation of the score values of all samples by the j-th evaluator; Z_{ij} represents the standardized value of the j-th evaluator's score for the i-th image; SBE_i represents the standardized value of the i-th image.

3.5 Constructing the SBE model based on color landscape pattern

After calculating the SBE scores and color landscape indices, the correlations were analyzed by Pearson correlation coefficient (r). The formula of Pearson correlation coefficient r is as follows:

$$r(X,Y) = \frac{\text{Cov}(X,Y)}{\sqrt{\text{Var}[X] \cdot \text{Var}[Y]}} \tag{4}$$

Where $r(X,Y)$ is the covariance of variables X and Y, and Var$[\cdot]$ is the variance of each variable. The r ranges from $[-1,1]$. The larger the absolute value of the correlation coefficient, the higher the degree of correlation, and vice versa. If it is 0, it indicates that there is no linear correlation between the two variables.

Based on the correlation analysis, the color landscape indices which have a significant and strong correlation with the SBE scores were selected to establish the SBE model. Here, the stepwise linear regression (SLR) was used to establish the SBE model. Stepwise linear regression analysis introduces independent variables one by one. Each time, the most significant independent variables affecting Y are introduced, and the old variables of the equation are tested one by one. Then the variables with insignificant changes are removed from the equation. Therefore, the stepwise linear regression equation can better overcome the problem of multicollinearity, that is the change of one variable causes the change of another variable. This method can make the obtained equation more concise and representative.

4 Results

4.1 Color landscape pattern

The color extraction findings were sent into the Fragstats program, where five landscape level indices and six patch level indices were produced. This paper estimated the mean value (ME) and coefficient variation (CV) to demonstrate the villages' overall color landscape pattern. ME is the average of a specific index across all villages, and it can represent the common traits of the color landscape to some extent. CV is the ratio of standard deviation to average value, which can reflect variability between villages. The bigger the value, the more variable it is.

4.1.1 Landscape level

Index	LPI	LSI	AI	COHESION	SPLIT	SHDI
Mean Value	30.963	23.502	84.550	98.304	11.996	1.352
Coefficient Variation	0.493	0.132	0.030	0.009	1.135	0.170

Table 5: landscape level indices.

Table 5 displays the findings of the landscape level indices. At the landscape level, the ME of the COHESION is 98.304, suggesting that color patches have excellent spatial connectedness and structural compactness in all villages. The AI's ME is 84.550, which indicates that it is performing at a high level. It indicates that the same patches are more closely packed together, and the same type of flora, land use, or other surface characteristics are more concentrated in space, resulting in a generally continuous region. SHDI is relatively high, suggesting that patch types are increasing or equally dispersed over the landscape. ME of LPI, LSI, SPILT are respectively 30.963, 20.502 and 11.996. They are at a moderate level and cannot find rules through the overall characteristics and distribution trend.

The CV of the SPLIT is 1.135. It is the highest index at the landscape level. This suggests a considerable difference in the degree of patch fragmentation between villages. Certain village landscapes are much more fractured. As a result, the landscape's spatial organization becomes relatively complicated, with changing sizes, forms, and hues. The CV of the LPI is 0.493, which is unusually high compared to other indices. The landscape structure of these villages varies significantly spatially indicating that their land use patterns differ. Certain villages may be more likely to have a vast region of identical land use types, whilst others may have a more diverse or decentralized structure. The CV of LSI, AI, COHESION and SHDI are respectively 0.132, 0.030, 0.009 and 0.170. The difference of these indices in different villages is not very large.

4.1.2 Patch level

Index	GE-A	GA-A	Y-A	GE-MPS	GA-MPS	Y-MPS
Mean Value	43.192%	24.448%	9.245%	0.031	0.011	0.003
Coefficient Variation	0.304	0.297	0.543	0.499	0.625	0.728

Table 6: Patch level indices.

At the patch level (Table 6), the ME of GE-A is 43.192%, which dominates the village color tone. It is due to the fact that the community is surrounded by a vast amount of woodland or crops. The ME of GA-A is 24.448%, which mostly reflects the proportion of architectural color in communities. It is mostly the color of outside walls, roofs, and roadways. The ME of Y-A is 9.245%, suggesting that the settlement contains barren ground with no plant or building cover. LG-A's ME is 8.27%, suggesting that communities have a limited amount of grassland and cultivated land area.

The Y-MPS and Y-A had CVs of 0.728 and 0.499, respectively. It denotes that certain regions may have large-scale barren land, resulting in bigger yellow color patches, whilst other areas may be more dispersed, resulting in smaller and more scattered patches. Furthermore, the wasteland and undeveloped landscape vary widely amongst villages. The CV of the GA-MPS is 0.625, which might be attributed to the various wall colors in villages that include the primary color tone. The CVs of the GE-MPS and GE-A are 0.499 and 0.304, respectively, indicating variances in vegetation cover among villages. Well-managed communities have planted more landscape vegetation than regular villages, and the green space is more concentrated, resulting in larger patch sizes. The CV of GA-A is relatively smaller than other indices.

Undergraduate Students Sex	Numbers	Average Values	Postgraduate Students Sex	Numbers	Average Values
Male	38	2.696	Male	30	2.775
Female	26	2.822	Female	24	2.705

Table 7: Sample composition.

4.2 The relations between SBE and color landscape pattern

Table 7 shows the sample composition of the survey. The examination involved 118 undergraduate and postgraduate students specializing in geography and landscape architecture. The table shows that there is little difference between how different age groups and genders evaluate scenic beauty, which supports Yu's perspective [59].

ID	Area	Standardized Values	ID	Area	Standardized Values
1	Banzhuyuan	0.153	9	Daqiao	0.004
2	Shuanghe	0.305	10	Guoziyuan	0.581
3	Baofan	-0.676	11	Mehe	0.266
4	Hexi	0.228	12	Shayan	-0.567
5	Dawan	0.217	13	Songziguan	0.147
6	Wufan	0.396	14	Huayuan	-1.065
7	Gutang	-0.647	15	Changchong	-0.137
8	Yuling	0.222	16	Matou	0.573

Table 8: SBE scores of first 16 villages.

Table 8 displays the data for the SBE scores. Among the 16 villages, the lowest standardized score is -1.065, while the best is 0.581. There are 11 villages with a positive scenic beauty rating, with an average score of 0.281. 5 villages have negative scenic attractiveness, with an average score of -0.618. It shows that there is no significant difference between villages with better scenic attractiveness. The average value of villages with low scenic attractiveness is greater. It shows that there is a significant difference between villages with low SBE scores and those with high SBE scores.

The Pearson correlation coefficient was utilized to investigate the relationship between the acquired SBE scores and the color landscape indices. The connection between each color landscape index and SBE scores was calculated individually. The selected indices all passed the test. The calculation results are shown in Table 9.

Landscape level indices represent the spatial interactions between various hues. Five of the six color landscape indices are less than the significance level of 0.01 for SBE scores. The first three indices with a significant correlation with SBE scores are COHESION (r = 0.854), LPI (r = 0.822), and SPILT (r = -0.750). The SHDI (r=-0.108) is a negative correlation index with a significance level greater than 0.05.

Patch level refers to the spatial connection of patches of the same color type. Only two of the six patch level color indices have SBE scores that are less than the significance level of 0.01: Y-MPS (-0.693) and GE-MPS (r=0.661). The GE-A (r=0.600) and GA-MPS (r=0.532) are positively correlated with a significance level between 0.01 and 0.05. The Y-A (r=-0.617) is negatively correlated with a significance level between 0.01 and 0.05. The significance level of GA-A (r=0.377) with SBE scores is larger than 0.05.

Index	SBE	LPI	LSI	AI	COHESION	SPLIT	SHDI	GE-A	GA-A	Y-A	GE-MPS	GA-MPS	Y-MPS
SBE	1.000	0.822**	-0.649**	0.659**	0.854**	-0.750**	-0.108	0.600*	0.377	-0.617*	0.661**	0.532*	-0.693**
LPI	0.822**	1.000	-0.671**	0.686**	0.803**	-0.751**	-0.447	0.782**	0.187	-0.304	0.735**	0.251	-0.417
LSI	-0.649**	-0.671**	1.000	-0.968**	-0.699**	0.603*	0.524*	-0.626**	-0.119	0.439	-0.811**	0.371	-0.349
AI	0.659**	0.686**	-0.968**	1.000	0.783**	-0.723**	-0.542*	0.591*	0.129	-0.356	0.821**	0.371	-0.349
COHESION	0.854**	0.803**	-0.699**	0.783**	1.000	-0.953**	-0.193	0.656**	0.445	-0.380	0.723**	0.560*	-0.561*
SPLIT	-0.750**	-0.751**	0.603*	-0.723**	-0.953**	1.000	0.244	-0.666**	0.328	0.146	0.667**	-0.454	0.388
SHDI	-0.108	-0.447	0.524*	-0.542*	-0.193	0.244	1.000	-0.310	0.337	-0.173	-0.391	0.138	-0.335
GE-A	0.600*	0.782**	-0.626**	0.591*	0.656**	-0.666**	-0.310	1.000	-0.016	-0.155	0.834**	-0.179	-0.431
GA-A	0.377	0.187	-0.119	0.129	0.445	0.328	0.337	-0.016					

Table 9: Pearson correlation coefficients between SBE scores and color landscape indices and Pearson correlation coefficients among indices.

The average correlation coefficient of the absolute values of the landscape level indices is 0.640 and the patch level indices are 0.580. It can be found that the influence of landscape level is greater than the patch level on the overall harmonious landscape of the village. In addition to the correlation between indices and SBE scores, the correlation between indices is also large. For example, the correlation between LPI and LSI is -0.671, and the correlation between AI and SPILT is -0.723. Therefore, it is necessary to screen indices when constructing the SBE model.

4.3 SBE model based on color landscape pattern

Using SPSS software, 7 color landscape indices with a significance level of less than 0.05 were employed as independent variables, while SBE scores were the dependent variables. A SBE estimation model was created using stepwise linear regression.

$$SBE = -17.521 + 0.176 \times COHESIOH - 67.988 \times Y - MPS + 0.013 \times LPI \quad (5)$$

where, $COHESION$ is the degree of connectivity between different landscape patches in the landscape; $Y - MPS$ is the Mean size of patches of the yellow type; LPI is the proportion of the largest patch in the overall landscape.

According to the model, the three key color landscape indices that influence the aesthetics of a village color landscape are COHESION, Y-MPS, and LPI. After then, the equation is evaluated for fit and significance. R2 reflects the equation's fit degree, with values ranging from -1 to 1. R2 is 0.822, suggesting a good model fitting effect. Significance indicates the degree to which the independent variable influences the dependent variable. The F value of 24.088 is high, and the p value of 0.000023 is much lower than 0.05, showing that the equation passes the significance test. Some of these three factors may not have a linear relationship with SBE scores.

The quadratic fitting impact of COHESION and Y-MPS is essentially equivalent to that of linear fitting. The SBE score increases with greater COHESION. COHESION indicates the degree of connectedness among several landscape plaques in the landscape. High COHESION shows a strong correlation and connection between the landscape's features, whereas low COHESION suggests a more scattered and alienated relationship. Coherence is essential for creating a landscape that people appreciate, and strong coherence produces aesthetic harmony and balance [24]. Low COHESION can decrease the attractiveness of specific landscapes, reducing the visual and aesthetic value of neighboring or complete structures [23]. Y-MPS represents the average size of yellow patches. High Y-MPS increases the visibility of barren or underutilized land in visual observations, which can have a negative influence on people's perceptions of the landscape. And high Y-MPS indicate a vulnerable ecological situation, which is not favorable to a higher aesthetics score. The quadratic curve fitting effects of LPI outperform the linear model. LPI refers to the proportion of the biggest patch in the entire landscape. Figure 5 shows that the LPI peaked at around 50. Higher and lower LPI result in lower SBE scores.

4.4 The evaluation of model

This study used the last eight villages as validation sets to assess the model's reliability. When the model was constructed, the same people who completed the first questionnaire

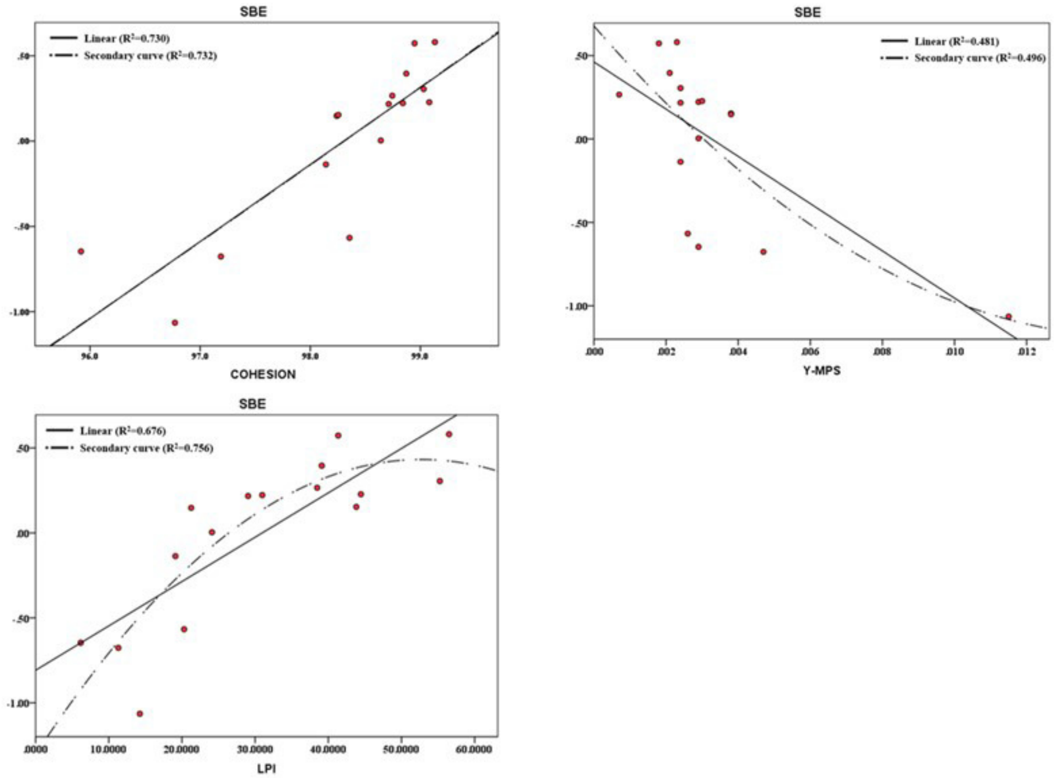

Figure 5: Automatic color extraction example.

were given a new set of questionnaires to score (Appendix B). The grading standards were uniform throughout the study. A total of 118 questionnaires were distributed, with 115 valid replies obtained. Table 10 shows the SBE scores for the validation set and their predicted values.

Among these 8 villages, the lowest standardized score is -0.673, while the best is 0.723. The largest error is 0.31, while the smallest error is 0.051. The average error is 0.248. The overall residual error is minimal, showing that the model is highly accurate in estimating village SBE and having a high level of reliability.

5 Discussion

Based on 3D real scene models, this study analyzes the attractiveness of communities using color landscape patterns. These models provide adjustable zooming in and out of the image, allowing to choose the best viewpoint images for studying the landscape of village. This broad observation allows for a better grasp of the color spatial pattern of settlements. The quantitative analysis is then conducted based on this comprehensive observation, obtaining the results of this study.

ID	Area	Predicted Values	Standardized Values
17	Xiaohe	0.550	0.723
18	Wanhe	0.116	0.223
19	Wangwan	0.263	0.374
20	Wangshichi	-0.071	-0.381
21	Wangfan	-0.212	-0.161
22	Sima	0.141	0.013
23	Qidan	-0.348	-0.117
24	Menqian	-0.430	-0.673

Table 10: SBE scores of last 8 villages.

In this study, mean value and coefficient fluctuation of color landscape indices were computed. When both the landscape and patch levels were taken into account, the SPILT index exhibits the greatest coefficient variation. A higher value indicates a more fragmented landscape with a greater influence on the ecology. This shows that the impact of different villages on the environment varies greatly and is strongly influenced by factors such as population, development plan, and geographical position. Zheng et al. [67] and Wu et al. [54] found that urbanization and human activities lead to increased landscape fragmentation and habitat degradation. This suggests that villages with more fragmentation may experience more human intervention activities, such as land development, agricultural expansion, or infrastructure building. Understanding the degree of fragmentation in various villages, as well as its relationship to the intensity of human activity, is critical for adopting successful ecological protection and land management strategies. On the other hand, it can be found from Table 4 and Table 5 that the coefficient of variation of patch level are generally higher than landscape level. This shows that there are obvious differences in the colors of different villages. This corresponds to Jin and Gao's research [20], which found regional disparities in color construction among villages. Through the study of color differences in different villages, the phenomenon of color abuse or color convergence can be reduced [54-56] [3, 60], so as to reduce the ignoration the regional characteristics of traditional villages and rural landscapes caused by overly modern color aesthetics.

Table 7 indicates the correlation between each index and SBE scores, although observation reveals a substantial link between each index. This is consistent with the findings of previous landscape indices research [4, 6, 66]. The relationship between these landscape indices illustrates not only the complexity of the landscape, but also the complicated connections between numer,result in an effective development of scenic attractiveness. COHESION and LPI showed a substantial correlation with all landscape level indices except SHDI. In patch level, only two indices, Y-MPS (-0.693) and GE-MPS (r=0.661), have SBE values that are less than the significance level of 0.05. However, Y-MPS was included in the final regression equation but GE-MPS was excluded. The investigation discovered that GE-MPS had a significant correlation with the LPI, LSI, AI, COHESION, SPILT, and GE-A indices, whereas COHESION and LPI were already in the regression equation, and the factors causing the strong correlation between these two indices overlapped with GE-MPS. Y-MPS shows a high association with Y-A. So Y-MPS entered the equation, but GE-MPS did not.

The final findings demonstrate that COHESION, Y-MPS, and LPI have entered the SBE model. These findings suggest that participants' preferences for village color landscapes follow certain rules: higher connectivity between landscapes, a smaller average size of undeveloped bare land and unutilized wasteland, and a more balanced proportion of the largest patch in the overall landscape all lead to higher SBE scores. The quadratic curves of some indices fit slightly better, as shown in previous studies [4, 37]. This research presents a Scenic Beauty Estimation methodology based on color landscape patterns. Because the color landscape indices show the various color landscape patterns. The findings also demonstrate the effect of these indices on SBE scores. Specific regulations may change the values of these indices, resulting in color landscape patterns that serve the landscape construction. These measures can be aligned with China's beautiful rural building strategy, therefore encouraging rural development.

But the model proposed in this paper has some limitations. First and foremost, population and size have a significant impact on landscape distribution. Large-scale human activities can result in fast changes in land types in the studied region [19, 52]. The population and size of villages vary, which may have an influence on scenic attractiveness. But the idea of this paper is suitable for all countryside. For countryside with large differences in scale, population and culture, it is only necessary to extract color patches from 3D real scene models to reconstruct the SBE model. Due to factors such as population, building distribution and altitude of different villages, fixed observation parameter would make it difficult to present the holistic perspective of each village. To ensure that a more comprehensive and cubic color landscape pattern can be observed, the angle and scale should be chosen to ensure a full view of the village. By adjusting different angles, it was found that the angles from 30 degrees to 45 degrees oblique angle are better. However, it is subjective to choose the angle of observation manually. This may affect the experimental effect and make the experiment difficult to repeat. Future experiments hope to take these into account and improve them.

Besides, the scenic beauty of the village is also related to the accuracy of the 3D real scene models. The accuracy of 3D model is affected by many factors [22, 27, 44], including shooting time, ambient light, shooting angle and so on. Different seasons and time caused the diversity of spatial distribution of color patches. In order to reduce errors, the time of aerial photography is selected to start around 10: 00 am on sunny days in July and August in summer. However, the flight route and operation during flight had caused difference which led to the low accuracy of some models. Although we suggest that the participants mainly analyze the rural color landscape pattern and try to ignore the impacts on image quality and slight differences in angles, these factors will still affect the scenic beauty of some villages. The fundamental restriction of the experiment is the shadow cast by the trees. Shadows provide a significant challenge in the interpretation of remote sensing photographs [1,32,47]. The shadow will be classified as grey or black, increasing the percentage of the color while decreasing the proportion of the original hue. The extraction findings of color patches show that some of the green patches are black or gray. As a result, there may be some mistakes during extraction. Currently, there are several ways for identifying and eradicating shadows in remote sensing photos, which are classified as image processing approaches [32, 47] and deep learning procedures [21, 38]. In the future, high precision results can be obtained by studying shadows in 3D real scene models.

In terms of color model selection, this study uses the RGB model to extract colors based on the values of three primary colors. However, RGB is mostly utilized in computer color design, whereas HSV is more compatible with human vision and intuitive [33]. The indices used in this paper may also have limitations. On the landscape level, this paper focuses on current indices rather than proposing a new indices system. Only three colors with a high percentage are chosen for assessment at the patch level, but colors with a low proportion may also have an influence on scenic beauty.

6 Conclusion

In this research, color patches have been extracted from 3D real scene models. The villages' color landscape patterns were then quantified at both the landscape and patch levels using 12 indices. The SBE model was constructed by analyzing the relationships between the 12 indices and the SBE scores obtained from the questionnaire. The results show that:

1. Among the first 16 villages, the standardized scores range from -1.065 to 0.581. 11 villages have positive scenic beauty, averaging at 0.281, while 5 villages have negative scenic beauty, averaging at -0.618. This suggests there is a significant gap between villages with lower and higher SBE scores.

2. The color landscape indices extracted from 3D real scene models reveal the scenic beauty of villages. Different villages present various color landscape patterns. The questionnaire-based SBE scores have a strong correlation with color landscape pattern indices, such as COHESION (r=0.854), LPI (r = 0.822), SPILT (r = -0.750), Y-MPS (-0.693) and GE-MPS (r=0.661) etc. These are important factors to interpret the scenic beauty. Estimation of SBE based on color landscape indices is possible.

3. The SBE model based on color landscape indices was established by stepwise linear regression. $SBE = -17.521 + 0.176 \times COHENSIOH - 67.988 \times Y - MPS + 0.013 \times LPI$ The R2 of the model is 0.822, indicating that the model fits the independent and dependent variables well. The quadratic curve fitting effects of LPI is better than the linear model which means moderate LPI can better promote scenic beauty. The results calculated by the SBE model were compared with those calculated by the questionnaire. The average error is 0.248, indicating that the model has high accuracy to evaluate the SBE of villages.

3D real scene models present multi-angle and multi-dimensional information that is not characterized in photos. Estimating the scenic beauty of rural villages from the 3D real scene models reveals comprehensive village landscape characteristics, deepens the understanding of the rural natural and human environment, and serves beautiful countryside construction. Future studies can select more unified samples and adopt more refined 3D real scene models for research. By selecting various color landscape indices, scenic beauty can be comprehensively analyzed.

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