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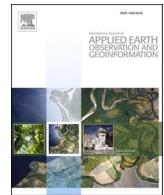
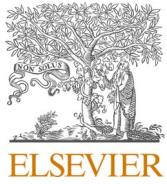
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Towards religious landscape: Protection of Tibetan Buddhist heritage in Aba Prefecture



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ABSTRACT

Aba Prefecture is a prominent Tibetan inhabited area with profound Tibetan Buddhist sites that need to be protected. This study demonstrates that the value of religious sites lies in their terrain-based nature with perceptions by people, and advocates to interpret and preserve them from the religious landscape perspective. Using geographic data and online geo-tagged images, geographical and visual characteristics of religious landscapes in Aba Prefecture are drawn with the support of MaxEnt and FCN models. The results of the two models are cross-validated and complimented, to ensure that the analyzed religious landscape is interpreted in religious atmosphere, geographic context, and visual perception. Further, this study provides region-specific preservation proposals for religious landscapes in Aba Prefecture and a transferable preservation framework for religious landscapes in other regions.

1. Introduction

Tibetan Buddhism was introduced to Tibet in the mid-seventh century A.D. and grew under the auspices of the Tubo Kingdom (Zhu, 1997). To consolidate the regime, Tibetan king Songtsen Gampo marched into Western Sichuan Plateau, forming a supply depot for his army in the Aba Tibetan and Qiang Autonomous Prefecture (hereafter Aba Prefecture) of today. Many Tibetan tribes were formed in this region and developed into one of the significant Tibetan-inhabited areas of China (Mao et al., 2020), which also brought Tibetan Buddhism to the region.

Religion is a complex cultural phenomenon that requires not only the establishment of a devotional spiritual space for followers, but also the expansion of its teachings in social networks, and the construction of religious sites hosting stable religious practices (Fang et al., 2022; Chao et al., 2022). Unlike the centralized control in Tibet, Tibetan Buddhism in Aba Prefecture has a favorable environment of autonomy, which allows religious sites to be run by the faithful themselves (Song, 2011; Zhou and Li, 2010). Religious sites in this region contain distinctive regional building styles (Yangs gling rdo rje, 1993). Besides, their religious symbolism is embodied in the scene formed by the religious site and its surroundings: Tibetan Buddhism believes that the sky symbolizes the light that dispels wickedness and desires to approach the sky in the

religious sites (Karmay, 2016). Further, the aborigines were originally pantheistic and revered the earth and nature, so the missionaries respected this custom, enabling the religious sites to be constructed in the surrounding topography. Aside from being a pilgrimage, religious sites in Aba Prefecture perform a missionary function, attracting aboriginal people to practice Tibetan Buddhism through inclusive visual features (Bi, 2008). The above contexts have led to a unique landscape of religious sites that not only encompasses the building forms, but also performs its relevance to the surrounding natural environment and humanistic society. Much of the current archaeological studies on religious sites in Aba Prefecture have focused on distinctive cases, excavating their values from prominent decorative features and spatial archetypes (Li, 2002; Wang, 2009; Wang and Deng, 2001; Ye, 2010). However, these studies focus primarily on the religious character of the religious site itself, yet its comprehensive religious character is actually shaped by the site and surrounding terrain, natural, and social elements.

In response to this situation, Brace et al. (2006) introduced the concept of the religious landscape, which argues that archaeological research should focus not only on the religious features of the site itself, but also on the religious features it forms in conjunction with the surrounding geography. Similarly, Sauer (1925) advocates that the landscape of a religious site is a more integrated form of landscape

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superimposed on the physical landscape; Park (1996) considers geographical factors as one of the main components of the religious landscape; Atran and Norenzayan (2004) believe that religious landscape is a long-term product of human settlement, religious beliefs, and the adaptation of the geographical environment. As a religious landscape, the archaeological value of a religious site includes not only the site itself, but also its interaction with the surrounding human settlements and natural and geomorphological factors. In addition, due to the religious attributes, it is also subject to people's beliefs and worship. Hence, the religious landscape contains not only the objective geomorphological performance of religious sites, but also the way in which people subjectively perceive it.

To interpret the geomorphological context of the religious landscape, the archaeological predictive model was adopted. This model can reveal the influence of each selected geographic environmental factor on the site distribution (Muttaqin et al., 2019). In addition, to interpret the subjective perceptions of the religious landscape, with the prevalence of digital networking, the geo-tagged images posted online provide a visual representation of the human perception of religious landscapes by vast tourists. Therefore, the Fully Convolutional Neural Network (hereafter FCN) model, a deep learning model that can clearly segment the visual elements of an image, has also been applied to the study to quantitatively analyze religious landscapes' visual characteristics (He et al., 2020). Supported by the archaeological predictive model and FCN model, this paper raises four research questions: 1. How to delineate the classification groups of Tibetan Buddhist sites in Aba Prefecture to demonstrate the representative regional religious landscapes of each local area? 2. What geographical characteristics are performed by the religious sites in each classification group? 3. What visual characteristics

are performed by the religious sites in each classification group? 4. With the support of geographical characteristics and visual characteristics, what religious landscape does Aba Prefecture perform? This paper will be developed through a progressive response to the research questions.

2. Background

2.1. Overview of study area Aba Prefecture

Aba Prefecture is located in northwestern Sichuan, bordered by Qinghai and Gansu to the north, Chengdu Plain to the east, Ya'an City to the south, and separated from Tibet by the Garze Tibetan Autonomous Prefecture on the west (Fig. 1).

There were 899,300 people in Aba Prefecture at the end of 2019, of which the Tibetan population accounted for 59.5 % (Aba Tibetan and Qiang Autonomous Prefecture People's Government, 2020). The region is high in altitude, with profound types of landforms and rich hydrological resources (National Ethnic Affairs Commission of the People's Republic of China, 2022). Tibetan Buddhist culture has been in Aba Prefecture for nearly 1400 years, establishing many stupas, temples, and other religious places (Party History Research Office of the CPC Aba Prefecture Committee, 2018) and evolving into the religious sites of today.

2.2. Overview of religious sites in Aba Prefecture

The conservation of Tibetan Buddhist heritages in Aba Prefecture was carried out late – it was not until 1989 that the first list of state-level cultural heritage protection units was published (Party History Research

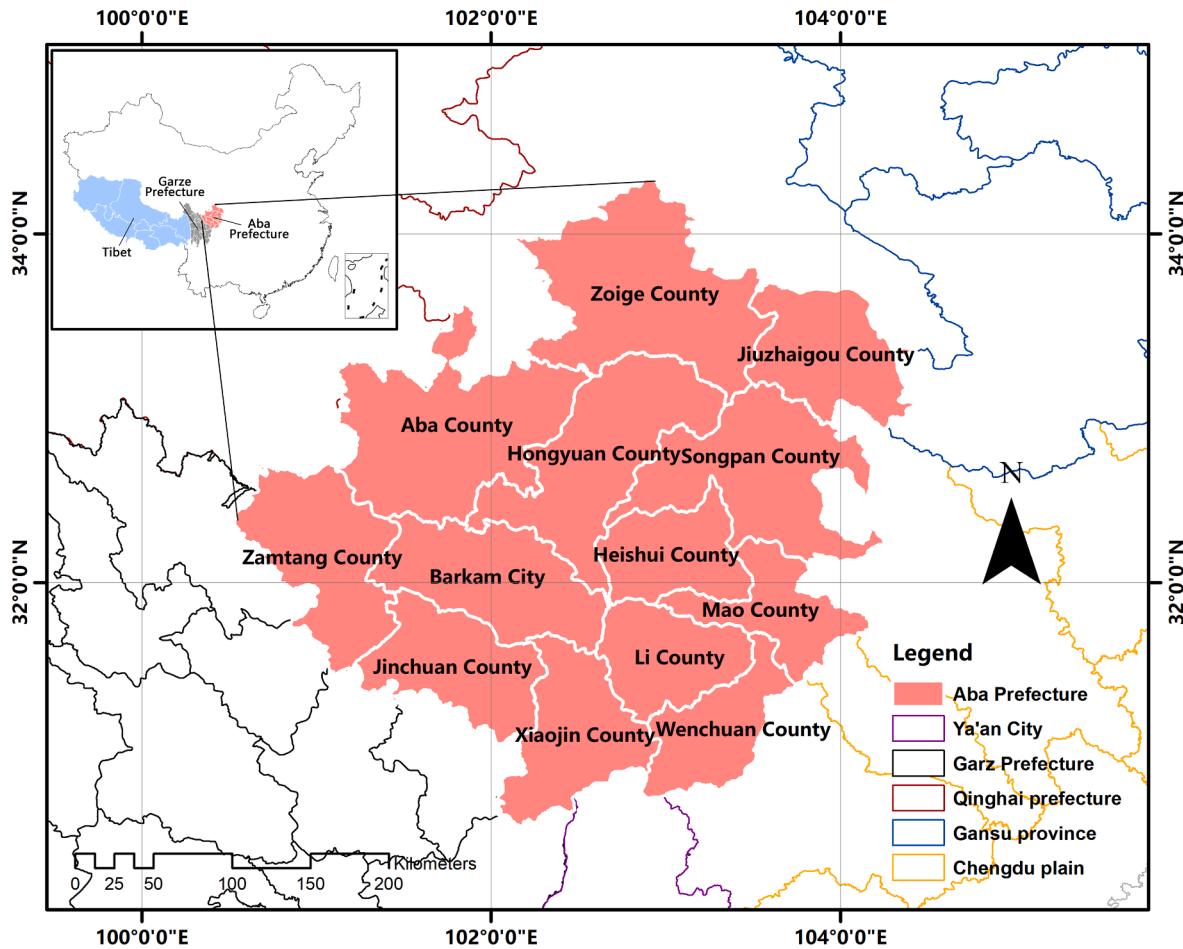


Fig. 1. Overview of the geographical location of Aba Prefecture.

[Office of the CPC Aba Prefecture Committee, 2018](#)). Tibetan Buddhism was introduced to Aba Prefecture at the end of the seventh century A.D. It gradually developed and grew in the middle of the tenth century, and remained under stable autonomous administration until the 20th century. Hence, this study focuses on the religious sites formed before the 20th century. By collating the above list with relevant academic papers and archaeological literature (Wang, 2008; Wang et al., 2011; Zhang, 2003; Zheng, 2020), this study finally selected a total of 40 well-preserved Tibetan Buddhist sites which cover 74.3 % of the religious sites recorded in the heritage lists. They are widely distributed in the western and northern parts of Aba Prefecture, due to the Tibetan nature of these areas and their proximity to Tibet. In eastern and southern Aba Prefecture, however, the aborigines include many Qiang and other pantheistic people, and the proximity of Han-ruled territories has hampered the spread of Tibetan Buddhism in these areas. The site samples of this study are all medium to large religious sites covering a site area of more than 500 m², thus making them stable for religious activities and ensuring that their religious landscapes are representative of the region. The information on their locations is summarized on the Arcmap platform in Fig. 2.

As shown in Fig. 2, the density of Tibetan Buddhist sites in Aba Prefecture decreases from west to east, bridging the Tibetan culture of the Ü-Tsang region in the west and the multi-ethnic culture in the east, which is consistent with the historical transmission path of Tibetan Buddhism, harvesting the uniqueness of its religious landscape.

3. Methods

3.1. KMeans clustering

Tibetan Buddhism in Aba Prefecture has a high autonomy in the site selection, which allows relevant religious groups in different regions to develop distinct landscape features that are appropriate to their religious culture and habitat demands (Wang et al., 2012). Therefore, a proper delineation of the study area can provide a comprehensive understanding of the representative characteristics of regional religious landscapes.

The archaeological prediction model requires regular and precise geographic data on a small scale to make predictions. Therefore, the KMeans clustering method was selected to delineate the classification groups of sites. The method is an unsupervised learning algorithm that groups samples by specifying the number of cluster centers, calculated as follows.

$$m_i = \frac{1}{N_i} \sum_{y \in c_i} y$$

$$J_e = \sum_{i=1}^c \sum_{y \in c_i} \|y - m_i\|^2$$

$$\rho_i = \frac{N_j}{N_j + 1} \|y - m_j\|^2 (j \neq i)$$

c is the number of clustering centers, i is the sampling sequence, j is

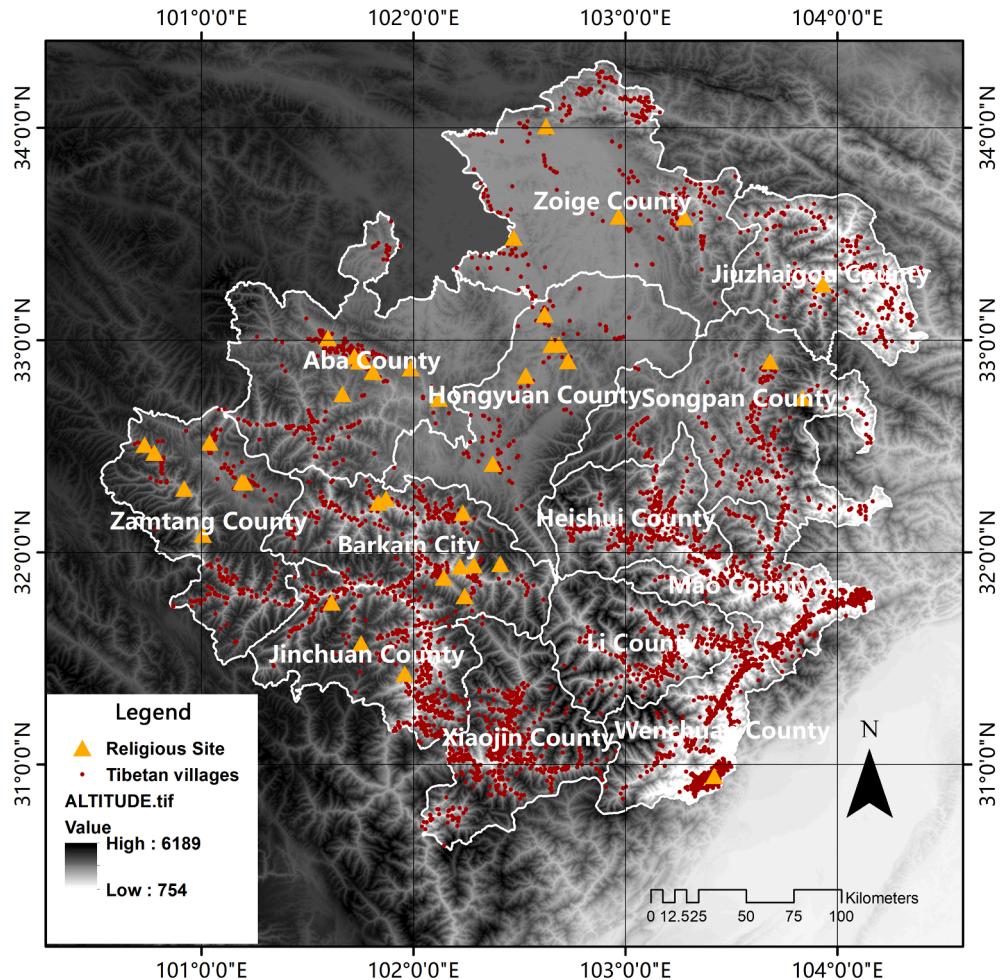


Fig. 2. Illustration of the geographical distribution of Tibetan Buddhist sites and Tibetan village.

the sequence of coordinates of the i -th samples, m_i is the mean value of each class, N_i is the number of iterations, y is the taken sample. If calculated $\rho_k < \rho_i$, then y is moved from c_i to c_k and the sum is recalculated, and if no change occurs through multiple iterations, the operation stops.

For a given number of clustering centers, Silhouette coefficient can evaluate the robustness of the clustering, with the larger value indicating a more reliable clustering result, which is calculated as follows:

$$S(i) = \frac{b(i) - a(i)}{\max\{a(i), b(i)\}}$$

For any point i , $a(i)$ is the mean value of its distance to other points in the belonging cluster, and $b(i)$ is the mean value of its distance to other points in non-belonging clusters.

Sites are grouped through KMeans method with a high Silhouette coefficient.

3.2. MaxEnt based archaeological prediction model

The applicability of archaeological prediction model at different geographical locations and scales has been carefully verified (Haber et al., 2011; Lansing and Fox, 2011; Zhang and He, 2021a). Xue and Zhu (2010) have studied that the model can further explore the human and social significance of sites in the surrounding environments. Zhang (2010) argued that this approach could promote geography archaeological research developing from morphological to cultural symbolism significance.

In this study, Maximum Entropy (hereafter MaxEnt) model, a machine-learning-based model, is applied to reveal the geographical characteristics of religious landscapes. In this model, the site coordinates and the corresponding raster of various environmental variables are input. Then, the gain parameter of each variable is adjusted by multiple training processes to maximize the randomness (i.e., entropy) of the site coordinate. When reaching the entropy maximization state, if the training gain of an environmental variable changed more than other variables, it had a more significant influence on the site distribution, suggesting that this variable was one of the leading environmental variables emphasized in the site construction. After training, the

distribution preferences of sites are also predicted by the model (Fig. 3).

Jackknife mode can parse the effect of each environmental variable on the site distribution. This mode calculates the training gain in three cases: 1. “Without variable”, i.e., the training gain obtained when the analyzed variable is removed; 2. “With only variable”, i.e., the training gain obtained when only the analyzed variable is used; 3. “With All variables”, i.e., the training gain obtained when all variables are used. This paper assesses the training gain in the “With only variable” case; the larger the gain, the greater the influence of this variable on the site distribution. Response curves are generated after training. The horizontal coordinate of the curve is the value of the environmental variable, and the vertical coordinate is the cloglog output, with higher values indicating a higher tendency for the sites to be distributed in the corresponding horizontal range.

The equations of MaxEnt model are: $H(p) = \sum_{x,y} -\tilde{p}(x)p(y|x)\log(p(y|x))$

$$p(y|x) = \operatorname{argmax}_p \sum_{x,y} -\tilde{p}(x)p(y|x)\log(p(y|x))$$

$p(y|x)$ is the conditional probability distribution. When $H(p)$ is maximum, the effect of the independent variable on the dependent variable is interpreted through the gain.

In this study, we take the three environmental variables with the greatest training gain as leading variables, which are the representation of the geographic characteristics of regional religious landscapes. The leading variables form the geographical features of the religious landscape that are the consequence of the religious activities of the local religious community.

3.3. FCN based image semantic segmentation model

FCN is a deeplearning-based image semantic segmentation model. The model has been widely applied in the built environment field (Dai et al., 2021). Zhang and He (2021b) applied this model to identify the visual characteristics of Kailash, Tibet, providing a practical basis for this study.

We take FCN-8s model for semantic segmentation in this paper. As in Fig. 4, the model extracts features through a VGG-16 network so that the size of the classification vector becomes 1/32 of the original image.

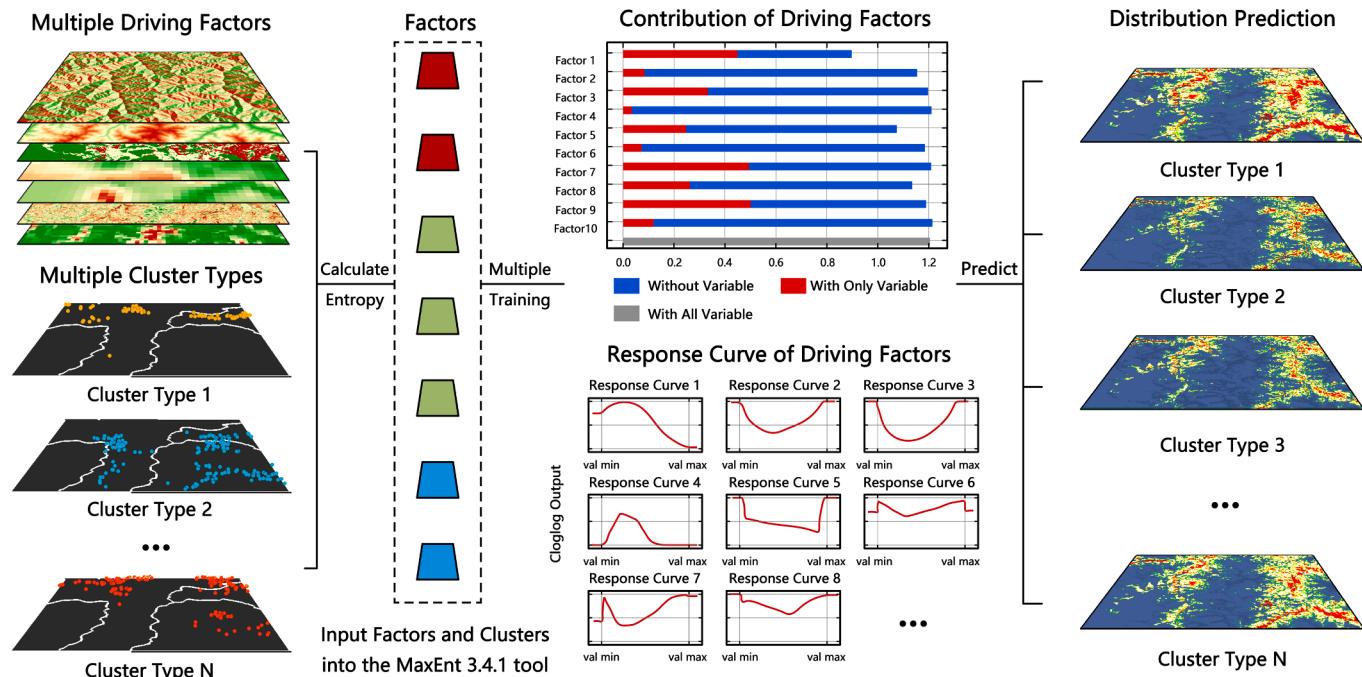


Fig. 3. Application diagram of MaxEnt model.

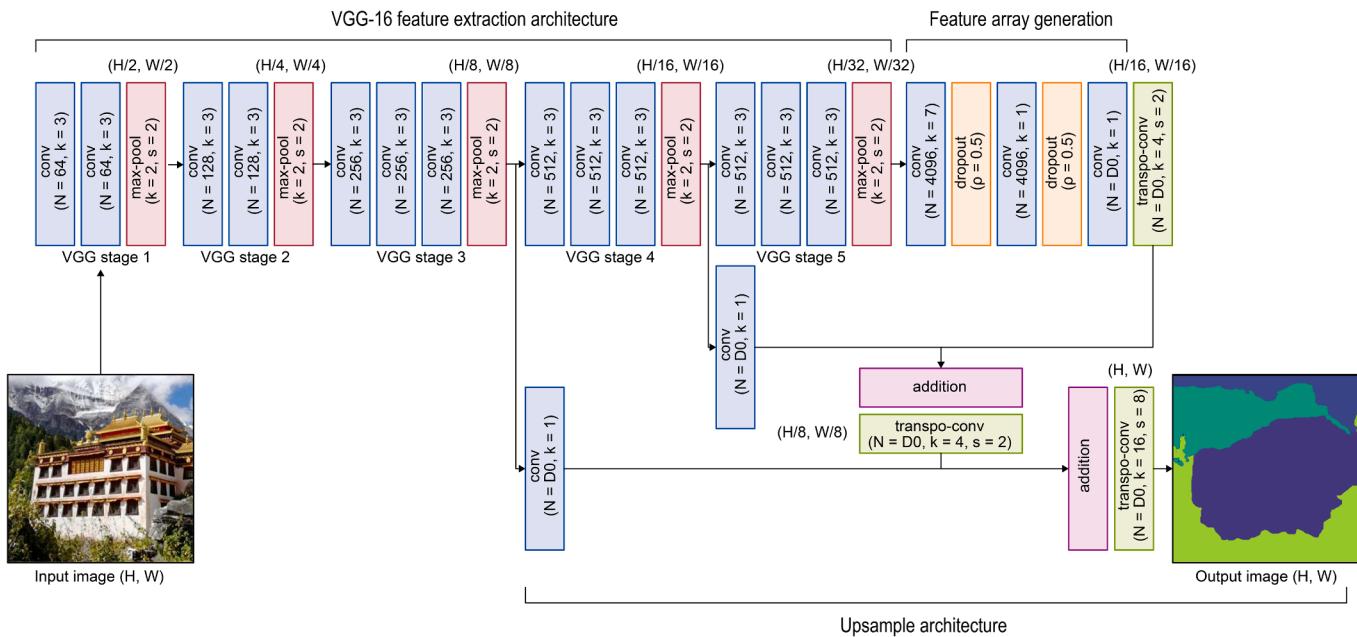


Fig. 4. Application diagram of FCN model.

Afterwards, the classification vectors are first upsampled (implemented by transposed convolution layer in this study) to double, and then a convolutional classification is performed with the result of the VGG-16 feature extraction stage 4 and is concatenated to a size of 1/16 of the original image. Repeat the double upsample and then perform a convolutional classification with the result of VGG-16 feature extraction stage 3 and concatenate them; the size of the vector becomes 1/8 of the original image. Finally, an eightfold upsample is performed to obtain the segmentation result.

The FCN was trained by ESM dataset (Gao, 2023). This dataset, which is manually labelled by our research group, is a semantic segmentation dataset compiled for live built heritage photo segmentation in Aba Prefecture, which achieves 84.7 % IoU (Intersection over Union) in the testdataset after the training of FCN-8s. The trained model can accurately segment elements of religious landscapes, such as greenery, sky, building, landform, etc.

Underpinned by research methods, the research framework of this paper is shown in Fig. 5.

3.4. Data sources

The research data is divided into three categories: 1) Site point and administrative boundary data, 2) Geographic environmental variable data, 3) Geo-tagged image data.

- 1) Site point and administrative boundary data: The data on Tibetan Buddhist sites are derived from the published lists of cultural heritage protection units, cultural heritage monuments, and national key cultural heritage protection units (Sichuan Local History Codification Committee, 1999a, 1999b; Sichuan Provincial Administration of Cultural Heritage, 2009). As shown in Fig. 2, 40 religious sites were selected. The administrative boundaries were downloaded from the Gscloud website (2022), as a reference for classification group naming.
- 2) Geographic environmental variable data: According to the research of Hultkrantz (1966) on religious phenomena, religious activities operate on the basis of three spaces, namely, physical space, spiritual space, and social space, based on which religious landscapes are developed. Following the previous description of religious preferences in Aba Prefecture, and the relevant literature (Sichuan

Editorial Group, 2009), three main factors – geomorphological factors, natural factors, and human settlement factors – were selected as the environmental variables. Geomorphological factors include five features of altitude, slope, aspect, waviness, and viewshed, which were calculated using ASTER GDEM V2 data (with a horizontal accuracy of 30 m) except for the viewshed element calculated by applying the cumulative viewshed analysis (Higuchi, 1985). Natural factors include the greenery feature measured by local NDVI and the hydrological accessibility feature measured by the shortest water spatial distance obtained through cost-surface analysis (Llobera, 2000). The human settlement factor was calculated by the shortest spatial distance to the surrounding Tibetan villages, which is also obtained through the cost-surface analysis (Wang et al., 2012). In this study, the water systems and Tibetan village sites of Aba Prefecture were obtained from the Gscloud (2023), and the DEM and NDVI data were obtained from the National Platform for Common Geospatial Information Services (2022). The local religious sites have not undergone significant relocation and destruction in history, and most of them have maintained stable activities with expansion and repair depending on the surrounding environment, as well as the human settlement locations (Ran and Liu, 2014). Therefore, contemporary geographic data can largely reflect the context harvesting the religious landscapes.

- 3) Geo-tagged image data: Geo-tagged images reflect the human perception of religious landscapes, so visual features extracted from a large number of geo-tagged images can more holistically portray the religious atmosphere and culture formed by religious sites in conjunction with their surroundings. Therefore, after delineating the classification groups, photographic images of each site were acquired from the popular Chinese Tourism Photography Website (2022). The website is a primary travel photo-sharing website with profound photographs of religious sites of many years taken by tourists for aesthetic and worship purposes, which excludes the alienation of the image subjected to other shooting purposes and simulates the observer's perception of the religious landscape. We downloaded 2710 images of religious sites with the keywords of their names. Since visual interactions between people and religious sites depend on human perspective, the study also filtered photographs of human perspectives from downloaded images (Fig. 6). This step trains the ResNet101 network with the Image Category Model dataset (Gao,

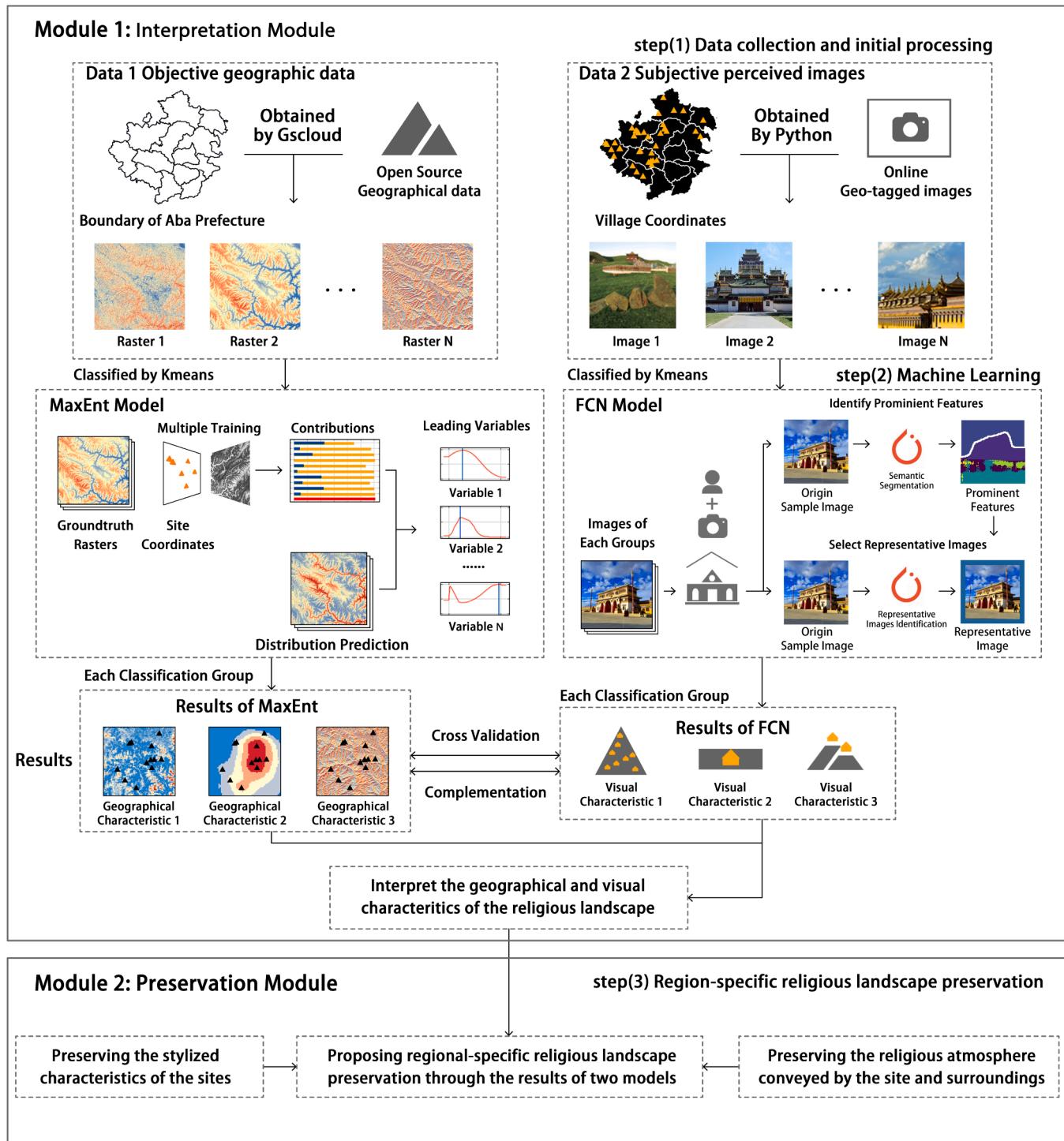


Fig. 5. The research framework.

2023), which was manually compiled by our research group. The model trained by this dataset can accurately categorize downloaded online images into five categories based on the content of the images, namely village whole (including a distant capture of the whole village), village part (including a distant capture of part of the village), building whole (including a close capture of the single building), building part (including a partial capture of the building), and others (Fig. 6(c)). The former three categories (e.g., the blue (left) cells in the figure) are images that record the interaction between the buildings and the surrounding landform from a human perspective, and are therefore, the target of filtering in this study.

The trained model achieved 93.36 % accuracy in the testdataset and can filter target images accurately (Fig. 6(a)). After filtering, all classification groups contained a sufficient number of images (more than 250, as shown in Fig. 6(b)) to help parse the visual characteristics of the religious landscapes in each classification group.

4. Result

4.1. Delineation of study areas

According to the research plan, the Silhouette coefficients were first



Fig. 6. Process and results of human perspective image filtering.

calculated according to various numbers of clustering centers (Fig. 7(b)). When the cluster number is 7–12, Silhouette coefficient is around the peak. To ensure that each area has more samples to optimize the archaeological prediction accuracy, this study delineated the sites into seven groups through the KMeans method (Fig. 7(a)).

As there is only one site in the Wenchuan area, the single case cannot accurately represent the religious landscape of the region and is too far from other classification groups. It was therefore excluded. Besides, in the delineation result, since the sites in Jinchuan & Barkam areas, as well as Songpan & Jiuzhaigou areas, are close, and the geographical conditions around the religious sites are similar, both groups are respectively combined to improve the prediction accuracy of MaxEnt training. One point to clarify is that the Aba area refers to the vicinity of Aba County, not the Aba Prefecture.

To determine MaxEnt evaluating range of each classification group for better cross-sectional comparison, the outer circle of each group is created in Arcmap. Then the circle is shifted by a buffer of 10 km, to ensure the training precision of the edge points. The buffered geometry is used as the MaxEnt evaluating range of the corresponding classification group (Fig. 8).

4.2. MaxEnt analysis of geographical characteristics of the sites

4.2.1. Correlation analysis of geographic environmental variables

MaxEnt model concerns the role of each environmental variable in

the distribution of the sites. If there is any strong correlation between the variables, it will pose an error weight to the prediction results (Yu and Zhao, 2019). Therefore, Spearman's rank correlation coefficient was applied to analyze selected environmental variables, as shown in Fig. 9.

There is an approximate covariance between slope and waviness variables, and that slope provides a more intuitive landform environment around the site, so the waviness is excluded.

4.2.2. MaxEnt training results

The training was conducted in MaxEnt 3.4.1 software. The training will be repeated 30 times to ensure the accuracy of the results. 25 % of the points are drawn to test the accuracy of the training results. The AUC (area under curve) training results demonstrate the accuracy of the prediction and take a value in the range [0,1], with a larger value indicating higher prediction accuracy (Zang et al., 2017).

The AUC values for each study area can be obtained (Table 1), where the AUC for the whole Aba Prefecture area is 0.862, with a high prediction accuracy. However, in the results of the local areas, although the majority of study areas have a high prediction accuracy (AUC values around 0.750), that for Songpan-Jiuzhaigou area is extremely low. According to information published by the [Songpan County People's Government \(2022\)](#), the two counties are multi-ethnic areas, where religious beliefs are dominated by local beliefs in mountain myths, and Tibetan Buddhism is not widely practiced in the area. As a result, the doctrines, activities, and worship objects of local religions are more

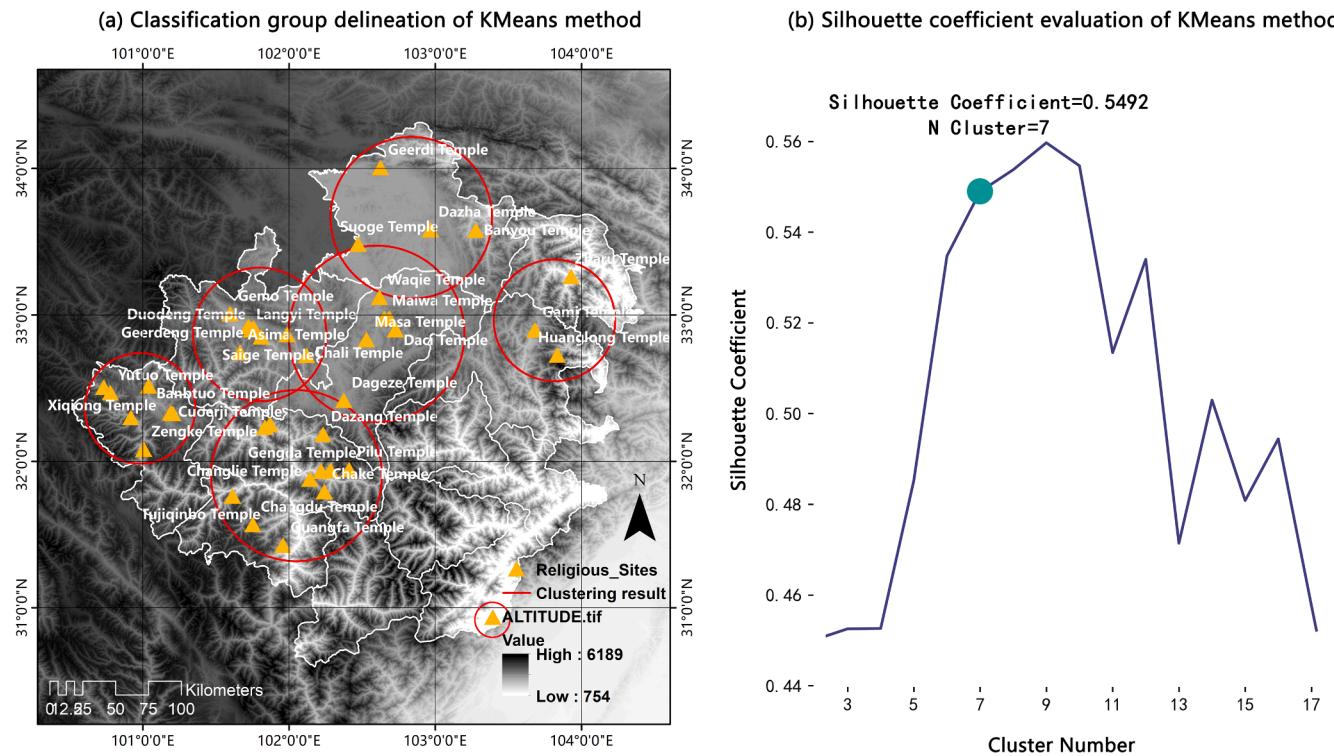


Fig. 7. Delineation results and Silhouette coefficient evaluation of KMeans clustering.

complex, making their religious landscapes neglect the unified expression of Tibetan Buddhism (Liu et al., 2017), so the area is excluded. Additionally, the religious landscapes of different classification groups form differentiated characteristics, and the study of the whole area range inevitably ignores the characteristics in the local area. Therefore, the subsequent analysis will be carried out in each local classification group, and the religious landscape of the whole area range will be analyzed by the correlation between the local religious landscapes of different classification groups.

MaxEnt evaluating results of each classification group are shown in Fig. 10. The training gains are normalized in Table 2.

4.2.3. Analysis of site distribution characteristics through MaxEnt results

Through MaxEnt analysis, the distribution preferences of religious sites in different classification groups exhibit significant differences (Fig. 11), where the red color represents the zones in which religious sites tend to be located. Table 3 summarizes the descriptions of the leading environmental variables of each classification group.

The main factor influencing the distribution of sites is the human settlement factor: sites close to western Aba Prefecture show a “close” or “keep a moderate distance” relationship with neighboring villages, which has been gradually developed over a long period of missionary role (Aba State People’s Government, 2011). In contrast, sites close to central and eastern Aba show a “distant” relationship with Tibetan villages due to the adjacency to areas inhabited by other ethnic groups, and religious sites in these areas were used more for preaching than worship (Aba State People’s Government, 2011). Geomorphological factors also strongly influence the distribution, and religious sites are sited in accordance with the leading environmental variables of each area, so that they are better suited to their landform environment. After satisfying the human settlement and geomorphological factors, religious sites tend to be built in proximity to natural resources, echoing green spaces, hydrology, etc., and creating a geographic distribution characteristic that is both locally appropriate and distinctive.

4.3. Deep learning-based interpretation of the visual characteristics of the sites

4.3.1. Validate the uniqueness of the visual characteristics of religious landscapes

To initially verify the uniqueness of the visual characteristics of the religious landscape in each classification group, we applied ResNet101 model of CNN model, a deep learning-based image recognition model. The model can understand distinct visual features of geo-tagged images in each classification group through multiple rounds of training, and output the test accuracy by fitting the predicted classification to the real classification. Each image processed by CNN generates a feature vector that is stored in the penultimate fully connected layer of CNN. Through the softmax operation on the feature vector, the probability of the image belonging to each category is obtained, and the image is predicted to the category with the highest probability. Thus, the better the model’s classification (i.e., the higher the test accuracy), the more distinctly the features of different categories are being distinguished. We randomly sampled 200 geo-tagged images from each classification group and took 160 of them as traindataset and 40 as testdataset to train the model. The test accuracy change is shown in Fig. 12(a). The trained model has a test accuracy of 84.25 %, indicating that the visual features of religious landscapes in different groups can be accurately distinguished.

After training, the uniqueness and relevance of the visual features of religious landscapes in different groups are visualized by T-SNE method. The method is a dimension reduction clustering algorithm that maintains the feature similarity of high-dimensional vectors and outputs them as low-dimensional vectors. Visual feature vectors at high dimensions can be preserved and expressed in low-dimensional vectors. The feature vector of all geo-tagged images was reduced to two dimensions and plotted in a planar coordinate system (Fig. 12(b)).

The scatters disperse significantly between five groups, indicating the regional uniqueness of the religious landscape of each group. Further, the discrete visual features of each group show a consistent distribution with their corresponding geographical distribution, further proving the strong correlation between the geographical features and

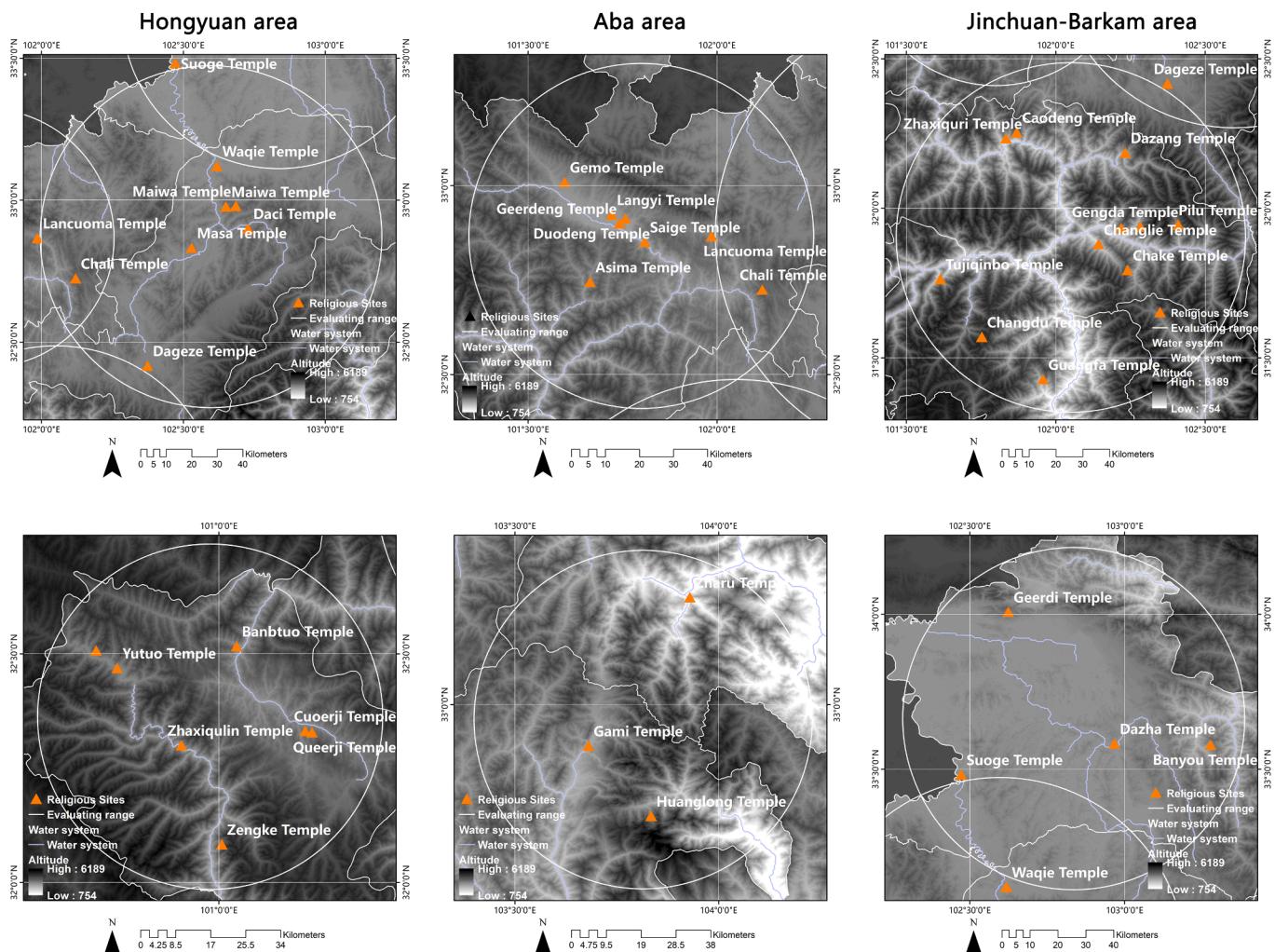


Fig. 8. Evaluating ranges of MaxEnt model.

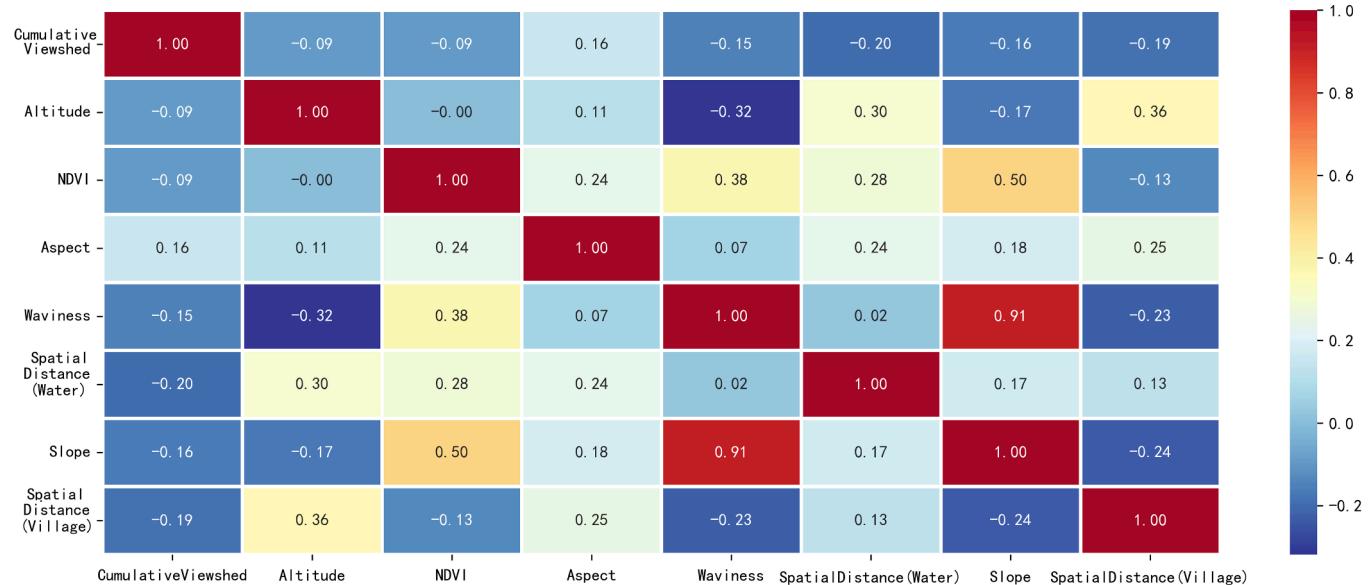
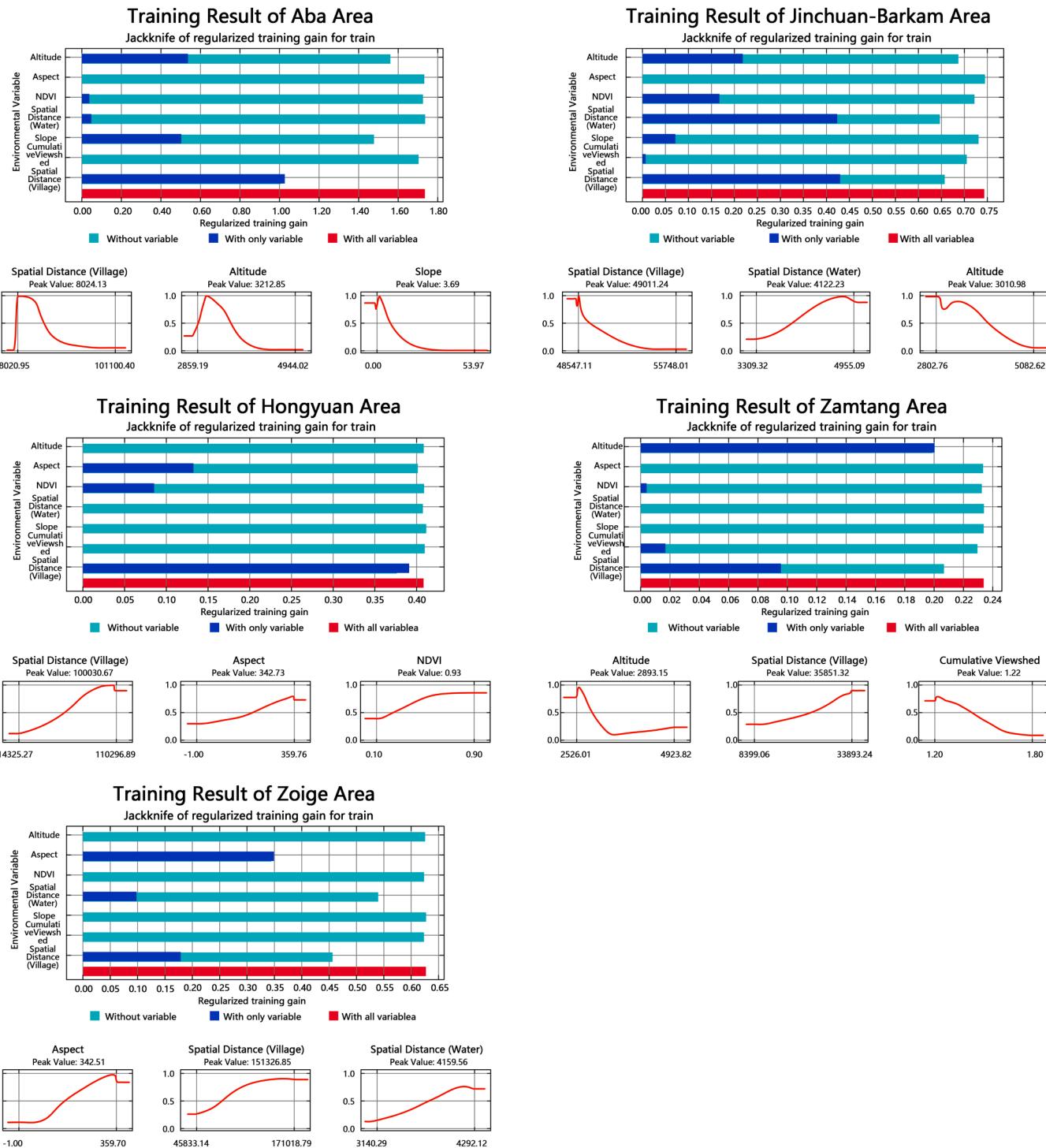


Fig. 9. Spearman rank correlation coefficient of environmental variables.

Table 1

The AUC training results.

Variable	Aba Area	Hongyuan Area	Jinchuan-Barkam Area	Zamtang Area	Zoige Area	Songpan-Jiuzhaigou Area	All Areas
AUC	0.796	0.750	0.773	0.736	0.739	0.105	0.862
Standard Deviation	0.070	0.069	0.052	0.033	0.066	0.036	0.035

**Fig. 10.** MaxEnt evaluating result of each classification group.

the visual features of the religious landscapes.

4.3.2. Semantic segmentation and classification of geo-tagged images

The geo-tagged images were first classified according to the classification group, and then the semantic segmentation of FCN-8s model

Table 2

Jackknife operation result (With only variable).

Variable	Aba Area(%)	Hongyuan Area(%)	Jinchuan-Barkam Area(%)	Zamtang Area(%)	Zoige Area(%)	Mean Value(%)
Spatial Distance (Village)	52.6	63.9	34.9	29.9	27.6	41.8
Altitude	17.6	0.1	14.9	63.4	0.0	19.2
Aspect	0.1	21.2	0.3	0.0	62.4	16.8
Spatial Distance (Water)	0.0	0.8	34.5	0.0	9.2	8.9
Slope	28.5	0.1	1.9	0.0	0.0	6.1
NDVI	0.7	13.9	9.5	0.0	0.7	5.0
Cumulative Viewshed	0.6	0.0	3.8	6.7	0.0	2.2

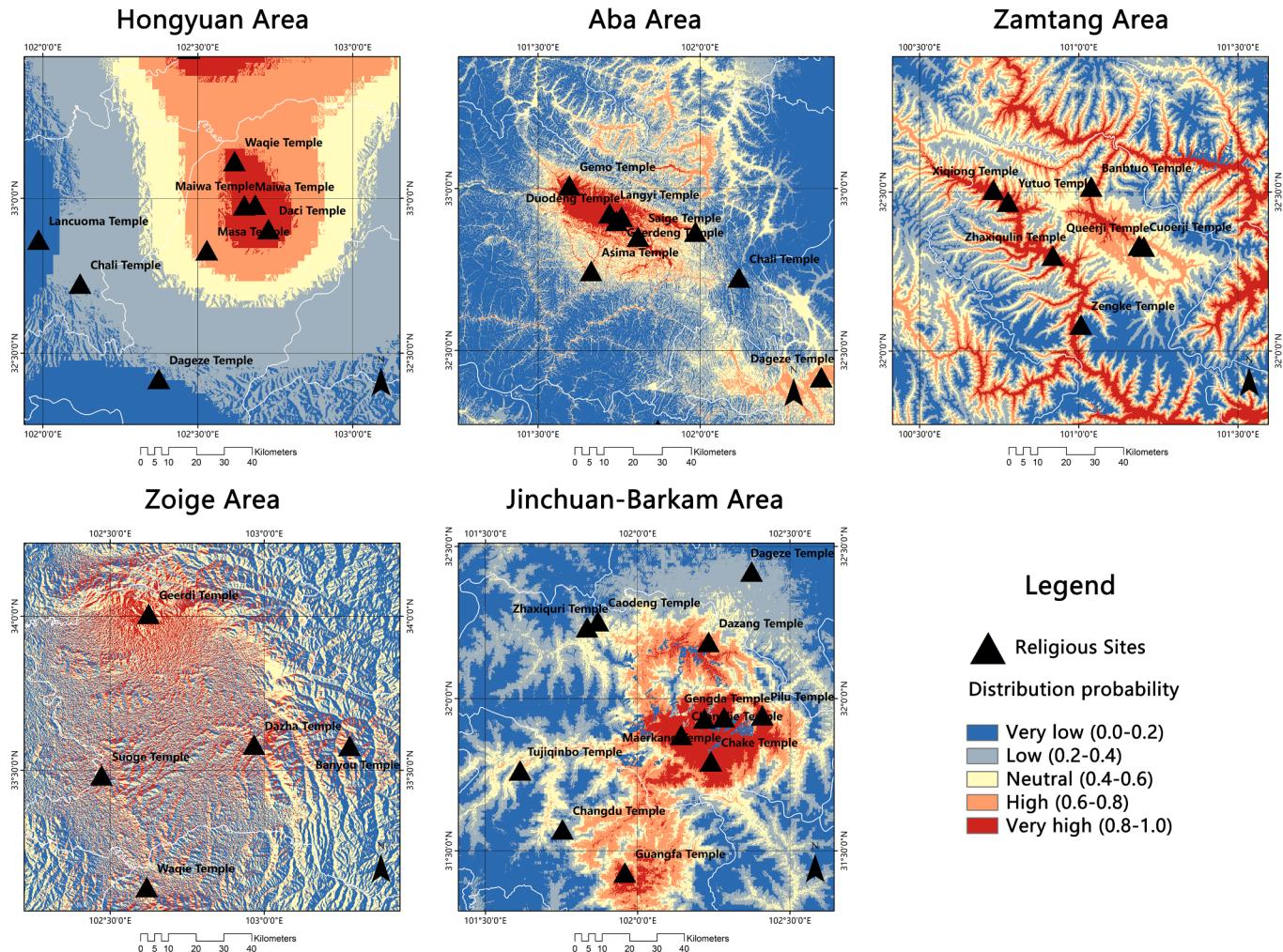


Fig. 11. The distribution preferences of religious sites of each classification group.

was conducted by the trained model by the dataset of Gao (2023). We count the proportion of four elements: landform, greening, sky, and building. Landform elements correspond to the geomorphological factor of MaxEnt environmental variables. Greening elements represent the natural context created by the local inhabitants around the religious sites. Sky element is chosen due to the Tibetan worship of the sky. Building element represents the buildings in the religious sites.

The proportion of sky elements is obtained from the "Sky" label, the proportion of landform elements is obtained by summing the "Ground" and "Mountain" labels, the proportion of green elements is obtained from the "Greening" label, and the proportion of building elements is obtained by summing all the labels within the main outline of the buildings. The specific proportion of each image element is shown in Table 4.

Based on the segmentation results, this study classified geo-tagged

images through the matplotlib module by the rule of identifying the visual element that accounts for the largest proportion in each image, and inlay the image with a border of corresponding colors. The segmentation samples and the classification process are shown in Fig. 13. Further, the study calculated the correlation between the landform and green elements and the corresponding environmental variable of each site by Pearson correlation coefficient, with a result of 0.6729, indicating that religious landscape of the sites can be interpreted from both geographical and visual perspectives. This result also verifies the credibility of the evaluated religious landscape by cross-validation of both models.

To present the representative visual characteristics of religious landscapes, the geo-tagged images in each classification group were first distinguished by the prominent features, then predicted by the trained ResNet101 model of landscape uniqueness validation step. The model

Table 3

Descriptions of MaxEnt evaluating results of environmental variables (NL in the table means that the variable is not the leading variable).

Variable	Aba Area		Hongyuan Area		Jinchuan-Barkam Area		Zamtang Area		Zoige Area	
	Peak Value	Describe	Peak Value	Describe	Peak Value	Describe	Peak Value	Describe	Peak Value	Describe
Spatial Distance (Village)	8024 m	Close	100030 m	Far away	49011 m	Medium distance	35851 m	Medium distance	151326 m	Far away
Altitude	3213 m	High altitude	NL	\	3011 m	Medium altitude	2893 m	Medium altitude	NL	\
Aspect	NL	\	342.73°	North	NL	\	NL	\	342.51°	North
Spatial Distance (Water)	NL	\	NL	\	4122 m	Close	NL	\	4160 m	Close
Slope	3.69°	Flat plain	NL	\	NL	\	NL	\	NL	\
NDVI	NL	\	0.93	Good farming land	NL	\	NL	\	NL	\
Cumulative Viewshed	NL	\	NL	\	NL	\	1.22	Medium visibility	NL	\

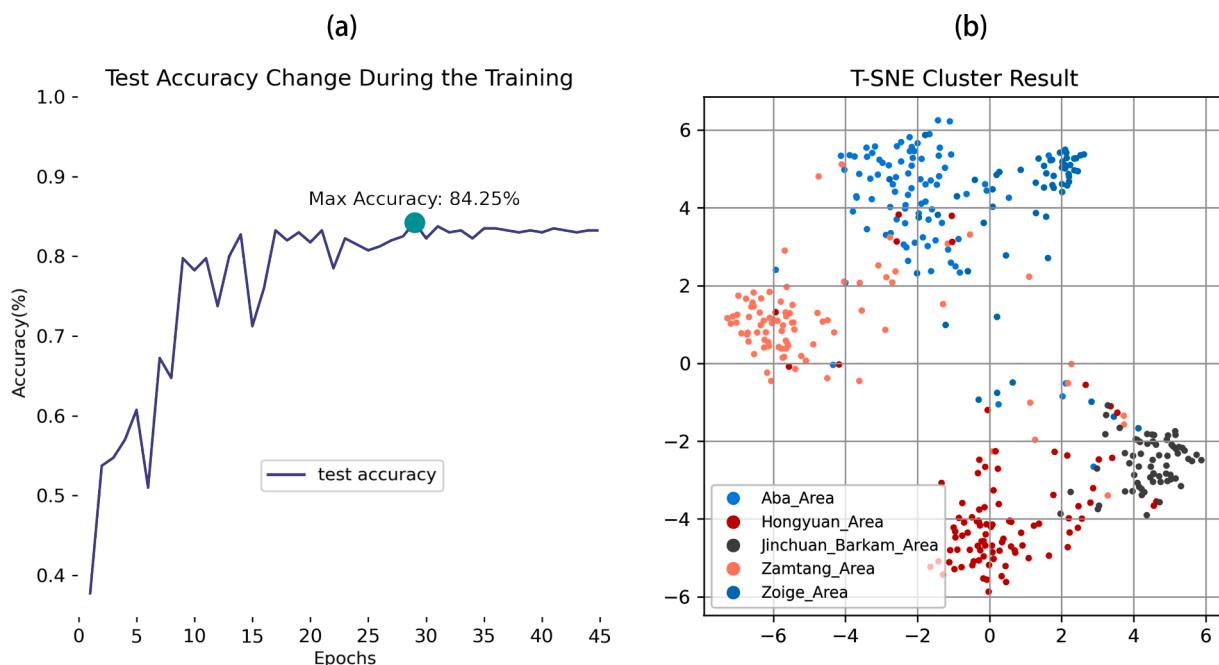


Fig. 12. The Resnet101 training process and T-SNE visualization result of the unique religious landscape of each classification group.

Table 4

The proportion of selected image element.

	Aba Area (%)	Hongyuan Area (%)	Jinchuan-Barkam Area (%)	Zamtang Area (%)	Zoige Area (%)
Green	7.08	15.26	9.40	8.04	5.02
Landform	25.09	13.92	29.17	14.28	23.04
Sky	25.02	33.45	15.61	23.16	20.35
Building	30.61	23.23	20.19	36.45	41.28

outputs a vector of the input image, which has the same dimensions as the classification group number in the last fully connected layer, representing the tendency of the visual feature to polarize towards each classification group by the magnitude of the values in each dimension. When this trend is extremely polarized to a certain classification, the image can representatively display the visual characteristics of the classification. This principle is used to filter out the representative images of religious landscapes in each classification group as follows:

$$V'_k = \frac{V_k - V_{\min}}{V_{\max} - V_{\min}}$$

$$T_r = (V'_{\max} - V'_{\min}) \times 100\%$$

V_k represents the value of the vector in the k th dimension. k takes the value 1–5 according to the number of classification groups, V_{\min} and V_{\max} represent the minimum and maximum values of all dimensions. V'_{\max} is the maximum value of the normalization result, and V'_{\min} is the second largest value of the normalization results. The larger the T_r , the more the visual feature is polarized towards the representative features of the belonging classification.

Finally, five images were sampled due to their top T_r values in each classification group. The sampled images are shown in Fig. 14, and the V'_k results of the images are shown in Table 5.

4.4. Interpretation of religious landscape through MaxEnt and FCN models

The joint analysis of MaxEnt and FCN model can illustrate religious landscape of each classification group:

- 1) Aba area: According to MaxEnt, religious sites in Aba area are mostly located on flat grounds at a high altitude and near Tibetan villages.

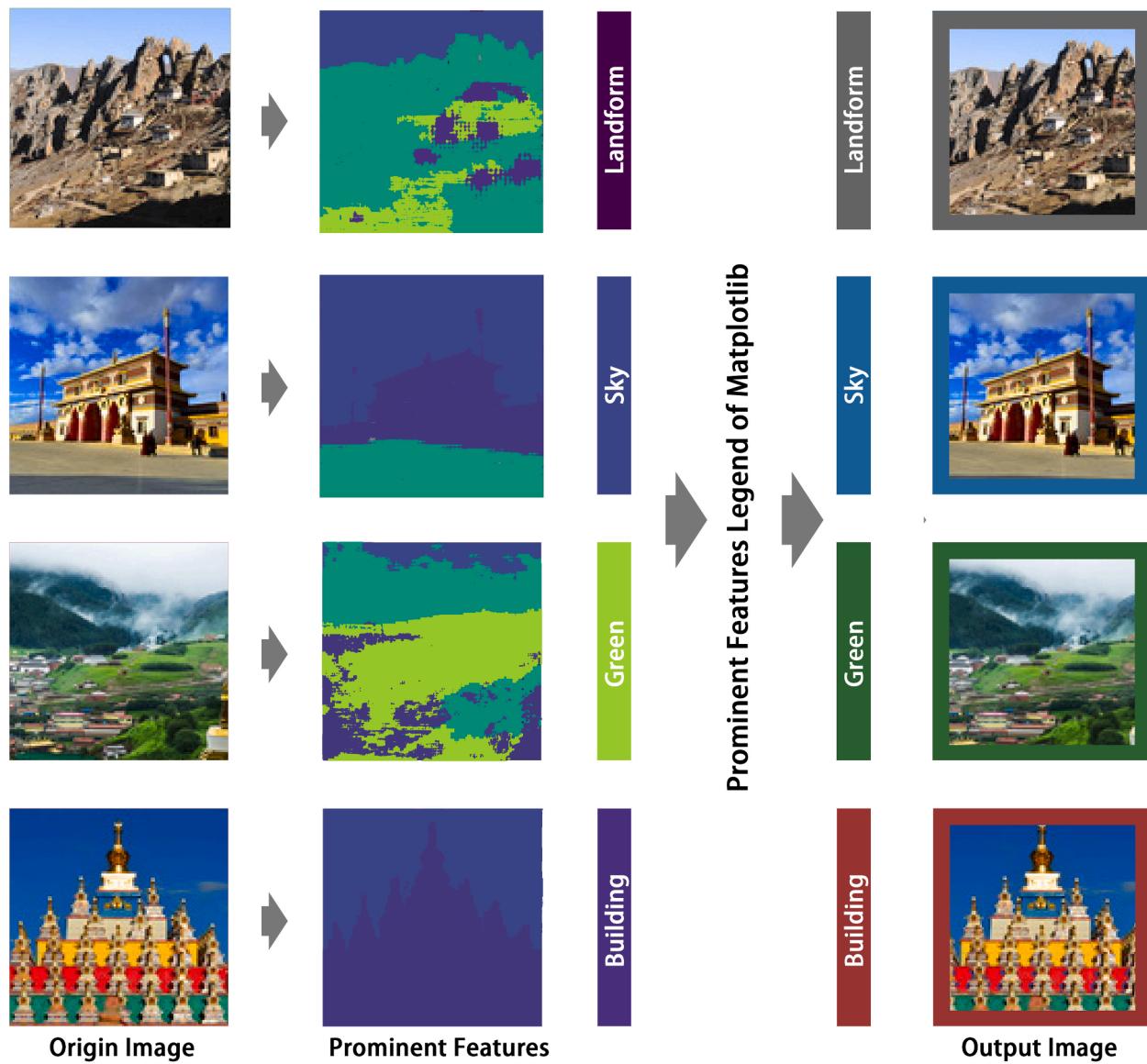


Fig. 13. The classification process by FCN and matplotlib module.

According to FCN, geo-tagged images are dominated by buildings, which are accented by the surrounding montane landform and exhibit an imagery of approaching the sky. Under the joint analysis, Aba area exhibits a religious landscape of “conforming the landform, worshipping the sky and thriving on religious pilgrimage”.

- 2) Hongyuan area: According to MaxEnt, religious sites in Hongyuan area are mostly located in the plateau plains with good greenery and sunlight, and far from Tibetan villages. According to FCN, geo-tagged images focus on the natural scenario of surrounding greenery and sky, with buildings integrated into the landscape and partly designed as monumental stupas, creating a transcendental visual characteristic. Under the joint analysis, Hongyuan area exhibits a religious landscape of “separated from the secular and perching alone on the plain”.
- 3) Jinchuan-Barkam area: According to MaxEnt, religious sites in Jinchuan-Barkam area are mostly located halfway up the mountain, a medium distance from the Tibetan villages and close to the water. According to FCN, geo-tagged images show that the buildings were built in small masses in the mountainous terrain. This area is located at the border between Tibetans and other ethnic groups. Religious sites were rarely accessed due to the treacherous terrain, so the

scattered buildings and the daily missionaries in them present a discreet, humble showcase for other ethnic groups and also make the site easier to observe from a distance. The treacherous terrain also allowed the site to be built close to the water sources. Under the joint analysis, Jinchuan-Barkam area exhibits a religious landscape of “showcasing the religious practice and embracing potential devotees of other ethnic groups”.

- 4) Zamtang area: According to MaxEnt, religious sites in Zamtang area are mostly located around the hills with good visibility and at a medium distance from Tibetan villages. According to FCN, geo-tagged images are dominated by buildings, which exhibit distinctly religious monumental style. The proportion of sky is the second to the building element. The geographical topography of the area is complex and can hardly be habitat, so the building forms are more monumental than functional, allowing Tibetan devotees to worship from a distance. Under the joint analysis, Zamtang area exhibits a religious landscape of “dominating the plain around the mound and performing distinctive monumental significance”.
- 5) Zoige area: According to MaxEnt, religious sites of Zoige area are mostly found in areas with good daylight orientation, close to the water and far from Tibetan villages, where geomorphological factors



Fig. 14. The representative images in classification groups.

have less influence on their distribution. According to FCN, geo-tagged images vary in geomorphological features, in line with the MaxEnt results. This area is close to the multi-ethnic Songpan County, with mixed ethnic and religious cultures. Hence, the building elements of rich forms have become the dominant part of the images, while other visual elements depend on the surrounding geomorphological features. Under the joint analysis, Zoige area

exhibits a religious landscape of “adapting to the complex terrain and incorporating the habitat culture of local groups”.

In summary, the religious landscapes in Aba Prefecture show a preference for “conformity” rather than “subjugation” to the geographical environment. The mountainous areas in the western and southern parts tend to hold religious sites that are close to Tibetan villages, showing distinctive building features of stupas and temples, and

Table 5The V'_k predicting results of representative images in each classification group.

Classification Group	Image index	Resnet101 Predicting Results					
		V'_k of Aba Area	V'_k of Hongyuan Area	V'_k of Jinchuan-Barkam Area	V'_k of Zamtang Area	V'_k of Zoige Area	T _r Value
Aba Area	Image 1	1.00	0.08	0.02	0.05	0.00	92.49 %
	Image 2	1.00	0.00	0.01	0.07	0.08	91.61 %
	Image 3	1.00	0.10	0.00	0.08	0.05	89.77 %
	Image 4	1.00	0.06	0.00	0.10	0.07	89.61 %
	Image 5	1.00	0.09	0.10	0.11	0.00	88.92 %
Hongyuan Area	Image 1	0.04	1.00	0.03	0.02	0.00	95.54 %
	Image 2	0.00	1.00	0.03	0.05	0.07	93.37 %
	Image 3	0.06	1.00	0.00	0.07	0.06	93.29 %
	Image 4	0.06	1.00	0.08	0.04	0.00	92.12 %
	Image 5	0.00	1.00	0.08	0.00	0.08	91.55 %
Jinchuan-Barkam Area	Image 1	0.00	0.05	1.00	0.08	0.03	92.45 %
	Image 2	0.04	0.08	1.00	0.06	0.00	92.13 %
	Image 3	0.08	0.02	1.00	0.00	0.09	90.95 %
	Image 4	0.05	0.10	1.00	0.03	0.00	89.72 %
	Image 5	0.12	0.09	1.00	0.04	0.00	88.15 %
Zamtang Area	Image 1	0.03	0.08	0.08	1.00	0.00	91.83 %
	Image 2	0.09	0.05	0.00	1.00	0.08	90.52 %
	Image 3	0.00	0.11	0.06	1.00	0.08	89.21 %
	Image 4	0.00	0.12	0.10	1.00	0.06	88.31 %
	Image 5	0.05	0.00	0.14	1.00	0.14	86.50 %
Zoige Area	Image 1	0.01	0.00	0.00	0.02	1.00	98.32 %
	Image 2	0.04	0.03	0.05	0.00	1.00	95.25 %
	Image 3	0.09	0.00	0.00	0.00	1.00	91.13 %
	Image 4	0.06	0.09	0.01	0.00	1.00	91.07 %
	Image 5	0.00	0.09	0.10	0.03	1.00	90.10 %

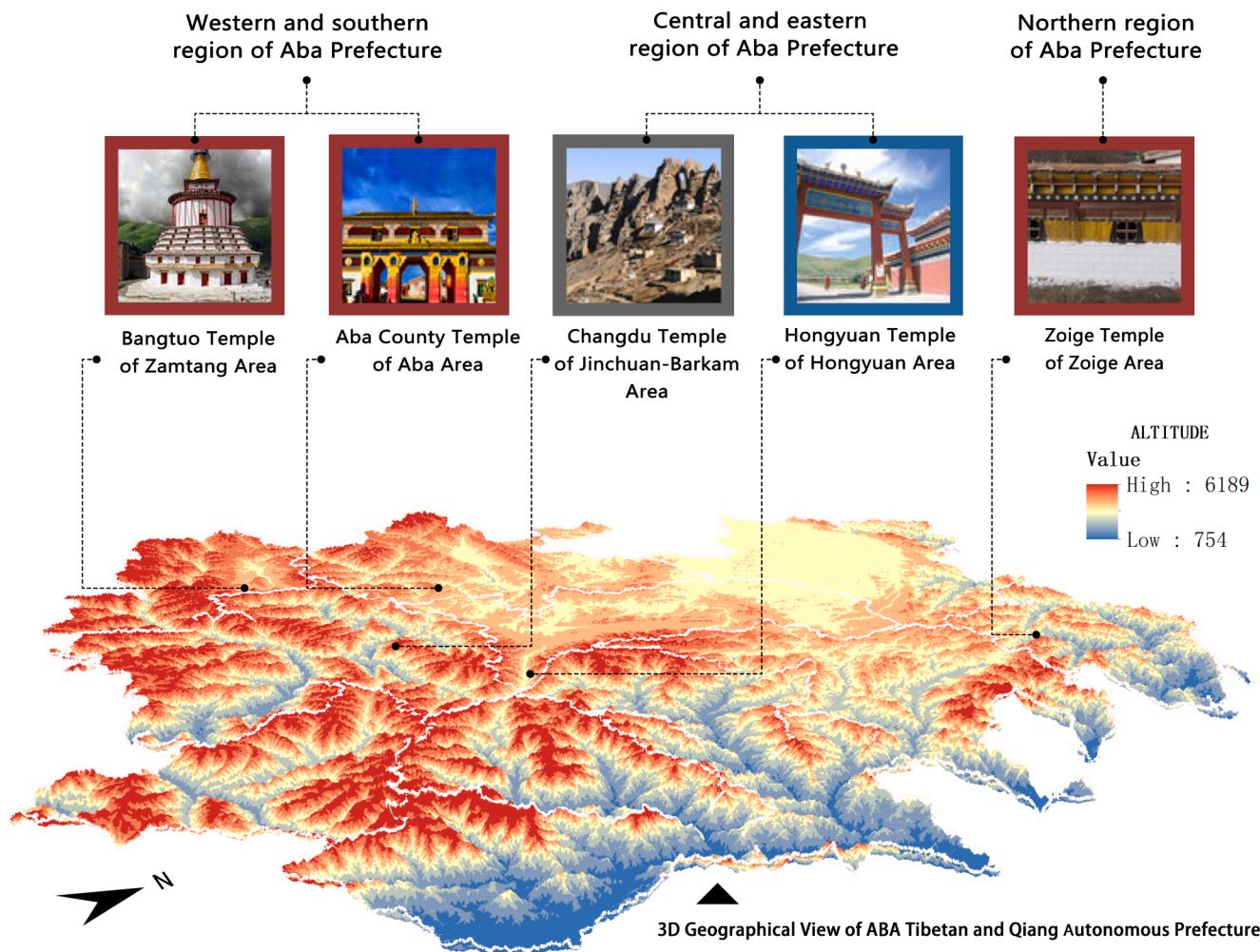


Fig. 15. The illustration of religious landscapes of Aba Prefecture.

consolidating the dominance of local beliefs. In contrast, the central and eastern parts tend to hold more symbolic religious sites with composite structures, compact massing, and scattering layouts and keep a long distance from the Tibetan villages, highlighting their preaching function.

Fig. 15 provides a general illustration of religious landscape of each classification group.

4.5. Preservation of religious landscape of Aba Prefecture

Through the above analysis, we propose religious landscape preservation recommendations for each classification group:

1) Aba area: The sites should be preserved in original building form, while supporting religious activities. In addition, the site should not be moved, and the surrounding mountainous landscape should be

left intact, preserving the sacred image of the site and the landform together, as well as its humble incorporation into the environment and worship to the sky.

- 2) Hongyuan area: The stupas and wooden temples need to be protected, and in the time that the site must be moved, it needs to be moved over the vast plateau plain as much as possible. Remote observation spots should be set up to fit the viewpoint of other ethnic groups, so that its image of independence and sanctity can be perceived by believers and tourists.
- 3) Jinchuan-Barkam area: Two typical building types in different landforms need to be protected, and observation spots located in other ethnic groups should be set for observing the scattered houses to restore their missionary character. The preaching conditions within the houses and the transportation conditions to other villages should be improved to guarantee the frequent travel of the Tibetan missionary people.

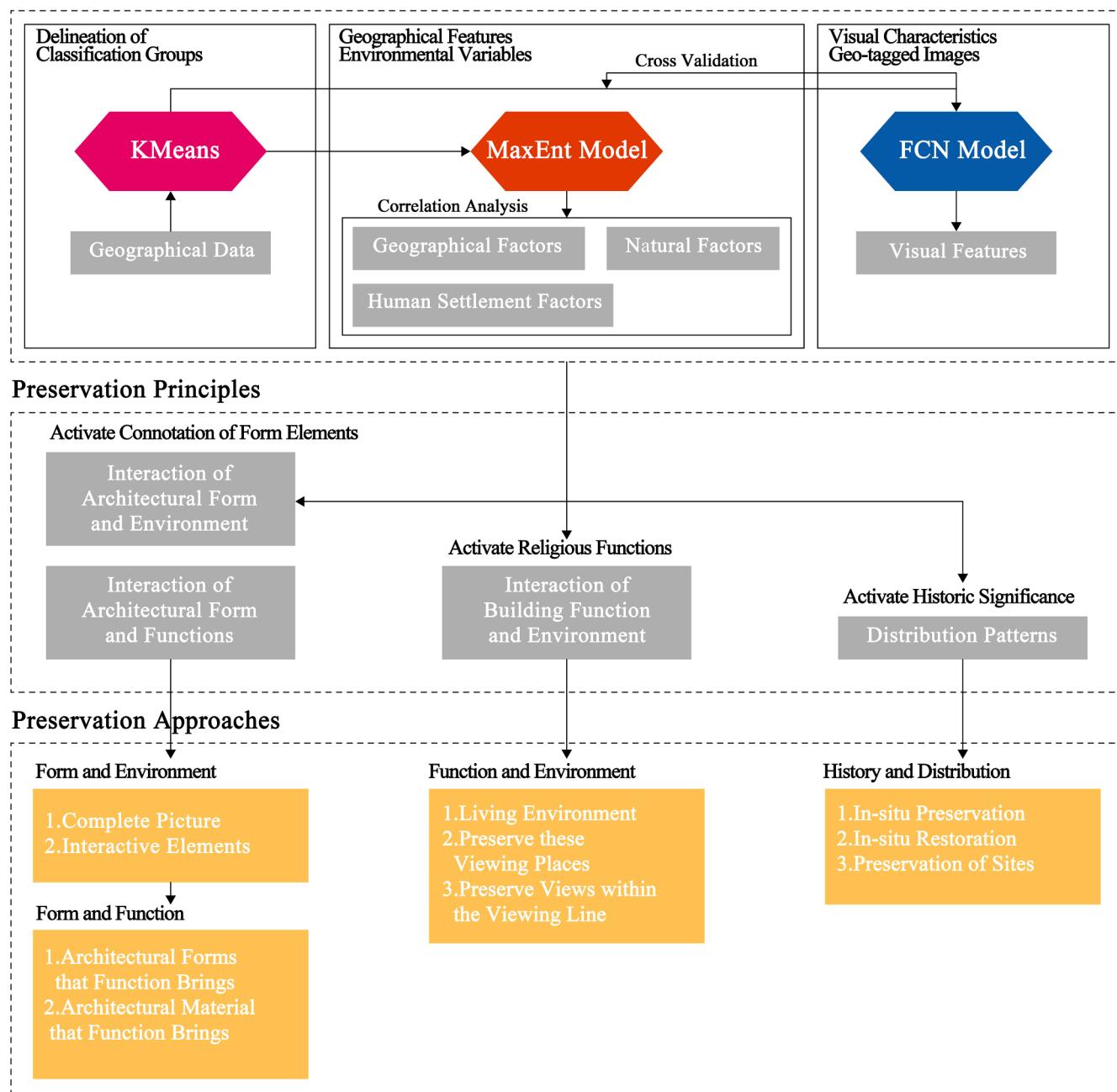


Fig. 16. Religious landscape preservation framework.

- 4) Zamtang area: The Tibetan Buddhist style of the local buildings needs to be preserved in its original form, and their locations should be left intact, with observation spots set up on the surrounding hills. If the site location needs to be moved, it should be moved to the top of the hills, where it can be more easily observed to visually display its distinctive monumental feature.
- 5) Zoige area: The preservation of representative sites from the various architectural styles should be done to highlight their tendency to integrate other ethnic cultures. If sites need to be moved, it is necessary to correspond their style to the landform in which they are located, to preserve the environmental-specific image.

In general, the preservation strategy for religious landscapes in Aba Prefecture encourages preserving the overall atmosphere conveyed by the site together with the surrounding. The specific results of MaxEnt and FCN models can also guide the further operation of the sites.

5. Religious landscape preservation framework

The results further suggest that the image of religious sites is conveyed by the interaction between the site and the surrounding environment. In addition, religion is a human activity, so the subjective perception of the site, whether in the process of preaching, worshipping or visiting, is another significant value conveyed by religious sites. The term “landscape” refers to “living space”, encompassing the physical features of the natural landscape, the social and cultural spaces within it, and the importance that residents place on both (Cecil, 2020; Mitchell, 1994). Therefore, by interpreting the environmental embeddedness of the site while analyzing people’s subjective feelings about it, its role as heritage becomes more stereoscopic, and it also illustrates the necessity and effectiveness of preserving religious sites through the religious landscape perspective (Hoelscher and Alderman, 2004).

Through the study of Aba Prefecture, we summarize a framework for religious site preservation based on the religious landscape perspective, which can be a reference for other regions, as shown in Fig. 16.

1. Activating the connotations of form elements. The communication of essential connotations defines which elements cannot be removed or replaced, and which can be replaced by homogeneous elements. This includes a). The interaction of architectural forms with the environment, for example, the spire and roof of the pagoda with the sky suggest sky worship. The complete picture formed by the building and its environment requires that the interaction of these important elements cannot be altered. b). The interaction of architectural form and function, for example, the layout and materials of the building should be protected in the process of conservation and restoration based on the functions it carries, such as the allocation of the building for residential use or puja activities, the display function of the magnificent pagoda details, and the reinforcement in which the wooden structure should be maintained to showcase with the stylistic characteristics of ethnic fusion.
2. Activating religious functions. As religious landscapes, especially buildings and environments that still perform religious functions, preserving these functions is essential to maintaining the vitality of local religion. One point is the interaction between architectural functions and the environment, such as the living environment of missionary residents; the landscape needs to be viewed or worshipped from a distance. The way of life of the monastery residents should be preserved, including the means of production, such as the food and water sources provided by the surrounding landscape. Conservation should be concerned that viewpoints and view corridors are not destroyed, and that if residential improvements or accessibility are required, care is taken not to disrupt the original landscape pattern.
3. Activating historical significance. The temporal and spatial elements have shaped the religious landscape, so restoring its place in history

gives it an accumulation of deeper cultural connotations. The distribution patterns need to be kept, which include the distribution of religious sites as well as the relationship between the religious sites and human settlements. This allows for the removal of religious buildings that are badly damaged and in need of restoration, but in situ reproduction is the best option, or at least the remains of these sites should be protected to preserve the overall pattern.

The framework is an extension of the traditional preservation strategy for stylistic characteristics of religious sites, which further interprets and protects the value of religious sites in terms of distribution, landscape, and the visual scenes they convey to observers.

6. Conclusion

After analyzing with MaxEnt and FCN models, the geographical and visual features of the religious landscape of Aba Prefecture are interpreted.

The joint analysis of both models indicates that the spatial relationship between Tibetan village sites and religious sites shows a trend of gradually distancing from west to east within the Aba Prefecture, making the religious sites on the east side mostly used to consolidate local religious beliefs, while the sites on the west side primarily used for preaching. Geography environment also poses a significant effect on the distribution of religious sites, which has led to a landform-specific characteristic of sites, allowing them to be located and constructed adapting to the environmental factors of the region. In more detail, visual features of the environment reveal that in the treacherous terrain, the atmosphere formed by the monumental building style and the surrounding landform with the sky is the prominent characteristics of the local religious landscape, while in the relatively flat terrain, the site tends to incorporate the local building style to construct a large-volume building to host religious activities and practices.

The cross-validation of two models can verify the consistency of the religious landscapes precipitated by geographical characteristics and visual characteristics. Besides, the deficiencies of MaxEnt model in analyzing the building style and religious atmosphere can be filled by the FCN model, and the geographical features expressed in the FCN results can be quantified and demonstrated by MaxEnt evaluating results. Through the complementation of the two models, the religious landscape is presented in a multi-perspective manner.

Then, the protection strategies and framework are concluded. They are not only preservation approaches for the religious landscape in Aba Prefecture, but also for other regions with rich religious heritage.

However, there are still factors of this study that can be optimized. The accuracy of site locations and selection of influencing factors can be further improved; the changes in historical and current landforms will add a temporal dimension to the religious landscape; in the complex mixed-beliefs religious landscape, for instance, Songpan-Jiuzhaigou area in this study, with the update of the dataset, it should be able to screen out the photographs representing the Tibetan Buddhist religious landscape in this area. In addition, more image sources should be included to expand the geo-tagged images and improve the reliability of the FCN evaluation result.

The preservation framework and methodology concluded by this study can provide a promising path for research on religious heritage protection, and hopefully, the findings will inspire more attention to the religious landscape.

CRediT authorship contribution statement

Xiaoyi Zu: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Chen Gao:** Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation,

Conceptualization, Writing – review & editing. **Yi Wang**: Conceptualization, Project administration, Resources, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data used are claimed in the paper.

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