Geo-Visualization of Cultural Landscape Values via Theme Behavior Model: A Case of Lo Manthang, Upper Mustang, Nepal

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Abstract

As a living heritage that connects nature and culture, cultural landscape gradually emerges as a key paradigm in global heritage conservation practices. However, researches on cultural landscape heritages in non-urban environments, on a large scale, and across regions still face challenges at present. As a UNESCO tentative heritage site inscribed in 2019, Lo Manthang in Upper Mustang, Nepal, has rich and diverse cultural landscapes. It is required to pay attention in future World Heritage nominations, holding significant value for empirical research. Taking it as a case, this paper designs a framework for the geo-visualization of cultural landscape values. It integrates archaeological evidence and geographical environment to conduct an integrated assessment of cultural landscape values and achieve spatial visualization, emphasizing the role of human behaviors influenced by local culture in shaping cultural landscapes. Based on a GIS analysis tool (thematic behavior model, TBM), this study simulates the spatial probabilities of different behaviors, thereby reflecting the spatial distribution patterns of various cultural landscape values. Driven by data patterns, this paper interprets the value distribution, interactions, and potential causes of the cultural landscapes near Lo Manthang. The goal is to excavate the heritage value of Lo Manthang and its surrounding areas, and discuss potential conservation zoning schemes.

1. Introduction

Since being incorporated into the World Heritage Convention system in 1992, cultural landscape is recognized as "a joint work of nature and humanity", and gradually emerges as a key paradigm for global heritage conservation practices. This perspective highlights the significance of cultural heritage as a carrier of historical information and comprehensively considers the relationship between heritage sites and nature (Shan, 2010). By 2024, 129 cultural landscape heritage sites worldwide have been inscribed on the World Heritage List, encompassing diverse types ranging from sacred religious sites to agricultural systems. These inscriptions have provided a new perspective for interpreting the value of heritage sites and inspired discussions on topics such as cultural diversity, living heritage, authenticity, integrity, outstanding universal value, and historic urban landscapes (Liu, 2015). However, researches on cultural landscape heritages in non-urban environments, on a large scale, and across regions still face challenges at present. Their values are difficult to analyze and visualize using traditional methods, which constrains the scientific formulation of heritage conservation strategies.

As a linear heritage representing cross-civilizational dialogue, the Silk Roads is a key point in international heritage studies in recent years (Figure 1). Currently, UNESCO and ICOMOS are advancing transnational nomination efforts for "The Silk Roads in South Asia". This corridor traverses the Himalayan region, connecting Tibet (China), Nepal, and India. Among its segments, Section 41, the "Lumbini-Mustang" corridor, has been designated a priority nomination node due to its potential heritage value (Williams, 2014 and 2016). Located in the core zone of Section 41, Lo Manthang (also called Lo) is the capital of Mustang Kingdom, Nepal from the 15th century until the 20th century. In 2008, it was inscribed on the Tentative List of World Heritage under the designation "medieval earthen-walled city". Yet its heritage value extends beyond the architectural artistry of the city walls, embodying a living testimony to the convergence of highland river valley civilization and Tibetan Buddhist culture. Archaeological discoveries (Massa, et al., 2019; Helman-Wany, 2020) and abundant Tibetan Buddhist remains (Henss, 1993) further reveal the significance of Lo and its surrounding areas. The Nepalese government emphasizes the need to move beyond the understanding of individual heritage conservation, and the value of the broader area around Lo should be considered from the perspective of cultural landscape in future heritage nomination efforts.

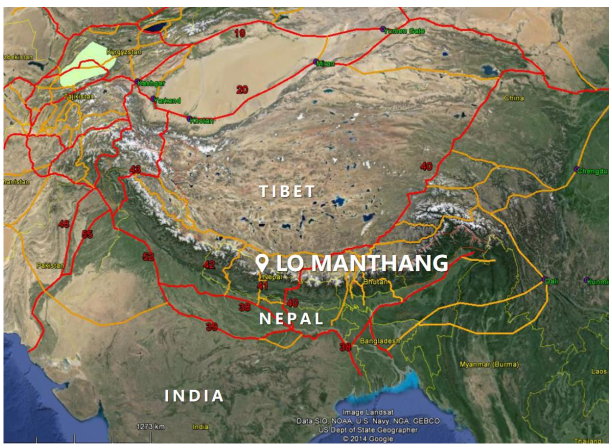

Figure 1. The Silk Roads delimited by ICOMOS, with the base map provided by Williams (2016).

When advancing international heritage nomination efforts, research on Lo's cultural landscape has been endowed with special significance. However, the current researches face multiple challenges: slow progress and fragmented research outcomes due to transportation constraints and geopolitical factors; heritage archaeology that has primarily focused on individual sites; limitations in recording methods and analytical approaches for regional archaeological surveys; insufficient consideration of the relationship between sites and their environment, leading to structural gaps in cultural landscape research. For advancing research progress, this study explores a method for analyzing cultural landscape value of Lo. It explores the geo-visualization of heritage values and attempt to achieve a paradigm shift in relative research through data-driven approaches.

2. Literature Review

Researches on cultural landscapes discuss the interactions between human societies, activities and their geographical settings (Yang and Mei, 2001). Decision-making behavior is one of the most critical aspects in these studies, typically focused on environmental influences. When destinations are predetermined, human path selection adheres to specific principles, including minimizing distance, time, cost, or reducing directional changes; these spatial choices are shaped by diverse constraints such as economic rationality, spatial rationality, bounded rationality, maximized satisfaction, or minimized regret (Golledge and Stimson, 1999). It reveals the logic of behavioral decision between spatial alternatives, facilitating the identification of optimal spatial schemes. By integrating many geographical constraints into a platform, Geographic Information System (GIS) serves as the analytical support tool of behavioral decision-making.

Landscape archaeology conceptualizes landscape as cumulative records of persistent human social activities and cultural traditions inscribed upon surface features, and the scholars utilize limited archaeological evidence to infer conditions of ancient societies (Barrett, 1991; Zhang, 2014; Daniels, 2023). They investigate the relationship between human behavior and geographic elements such as archaeological sites, enabling GIS to play a leading role in constructing archaeological interpretive models. As one of the commonly used methods, cost analysis bases on the geographical factors to set horizontal/vertical coefficients or other potential obstacles, and calculates the cumulative cost consumption from a starting point on the raster surface to other grids. The applied cases include: invasion routes toward the capital before and after the Great Wall's construction (He and Zou, 2010), human migration paths from the East African Rift into the Levant (Beyin, et al., 2019), and the seasonal transhumance movement in Northern Neuquén (D' Abramo, 2021).

3. Methodology

3.1 Framework

Cultural landscape is a form of human activity overlaid on natural landscape (Sauer, 1963), and its value intrinsically linked to human behaviors. Cultural landscape value analysis must integrate both the idiographic orientation of local cultural studies (characterizing local cultural uniqueness), and the nomothetic orientation of geographical analysis (predicting patterned regularities in spatial distributions).

This paper analyzes cultural landscape values by simulating different types of behaviors with local characteristics. We propose a framework of cultural landscape value analysis (Figure 2). It bases on the theme behavior model (TBM), leveraging the geospatial data platform GIS which integrates multisource datasets. The TBM is a spatially analytical model selected according to behavioral patterns, which simulates diverse cultural behaviors through GIS and outputs the corresponding probability raster (TX). Next, the framework identifies high-value space ($\triangle TX$) of cultural landscape by cross-referencing TBM results with other evidences. Driven by data phenomena, the assessments of cultural landscape value will be formed finally.

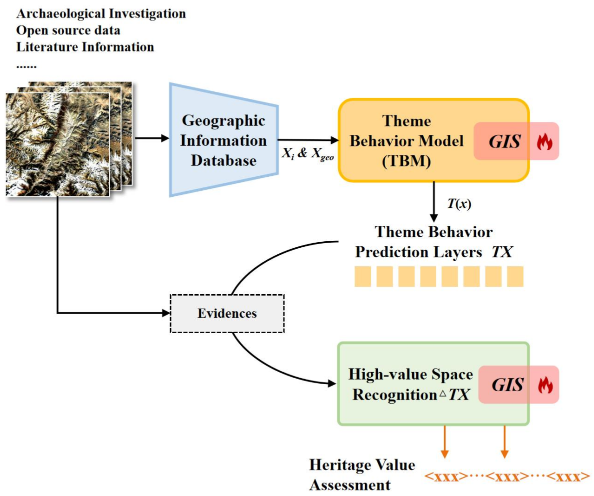

Figure 2. The Framework of Cultural Landscape Value Analysis.

3.2 Thematic Behavioral Model (TBM)

3.2.1 Model Program: TBM is a calculation program that analyzes natural elements and site evidence through a certain or some specific instructions. It is suitable for the value analysis of multiple types of landscapes in a certain area.

Figure 3 shows the TBM program applied to a certain type of landscape: For the corresponding theme landscape, select pre-set operation instructions based on behavioral decision-making principles, and input the corresponding behavioral trigger factors X_i and environmental impact factors X_g. The former refers to sampling points or sites corresponding to behaviors, and the latter includes geographical impact factors represented by topographic complexity and hydrological networks. Next, according to the specificity of each behavior, the calculation formula x is constructed on the model operation panel, and adaptive model parameters are set. The probability conversion function $T(x)$ is used to map the calculation results to the 0-1 interval, aiming to eliminate potential impacts of differences in result ranges. Finally, the model outputs a behavioral probability raster TX, which reflects the distribution of cultural landscape value. Each component of this model program incorporates region-adaptive design considerations to address the challenges posed by complex and unique regional cultural landscapes.

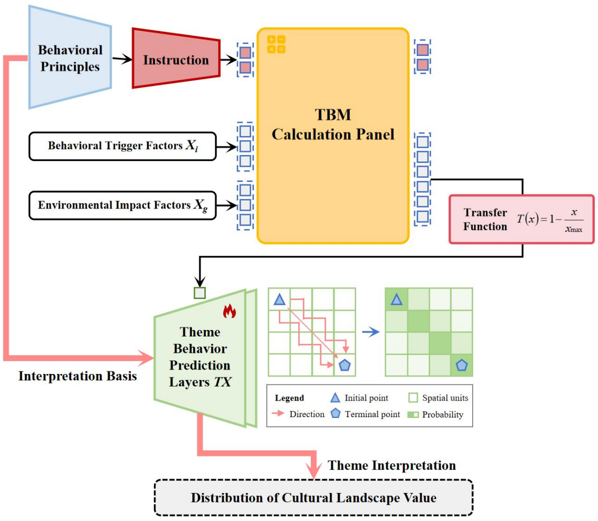

Figure 3. TBM and landscape value analysis program.

3.2.2 Model Instruction: Based on the spatial decision-making principle that actors select optimal behavioral path from trigger points, this study proposes a TBM operation instruction. It modifies the model of Minimum Cumulative Resistance (MCR) (Knaapen, et al., 1992), aiming to calculate the cumulative behavioral cost $C_X(i)$ of each behavioral trigger factor X_i:

$$C_X(i) = \int \sum_{j=m}^{i=n} (D_{Xij} \cdot \vec{R}(i)) \quad (1)$$

Where, D_{Xij} is the diffusion distance from factor X_i to the grid j; $\vec{R}(i)$ is the resistance coefficient experienced at grid j along the direction of movement of the actor; and $R(i)$ is determined by topographic slope, river features, and the settlement attraction coefficient:

$$R(i) = r(\theta) \cdot (\alpha \cdot g(t) + \beta \cdot f(d) + \lambda) \quad (2)$$

Where, α, β, and λ are constant coefficients set based on the geography of Upper Mustang, with α = 0.3, β = 0.1, and λ = 0.6. The topographic slope resistance r employs a piecewise function to enhance resistance in steep slope areas, where θ denotes the slope corresponding to grid j:

$$r(\theta) = \begin{cases} 1+0.1\theta & \theta \leq 10° \\ 6+0.3(\theta-10) & 10° < \theta \leq 30° \\ 15+0.5(\theta-30) & \theta \geq 30° \end{cases} \quad (3)$$

$g(t)$ is the probable resistance coefficient corresponding to river hierarchy t for grid j:

$$g(t) = \begin{cases} 1 & t=4 \\ 0.8 & t=3 \\ 0.6 & t=2 \\ 0.4 & t=1 \\ 0.1 & t=0 \end{cases} \quad (4)$$

$f(d)$ is the coefficient of settlement attraction while a behavior processing, associated with the set of settlement sites; and d is the cutoff distance for the attraction generated by the set of settlement sites (S_i):

$$f(d) = \begin{cases} -1 & d \leq 1000\,\text{m} \\ -0.5 & 1000\,\text{m} < d \leq 2000\,\text{m} \\ -0.1 & d > 2000\,\text{m} \end{cases} \quad (5)$$

Based on the preset instruction $C_X(i)$, the TBM panel can achieve rapid calculations and obtain the accumulated cost raster x_X. For instance, Equation 6 is the formula for the cumulative behavioral cost raster of a specific site type X, which shows optimal spatial area chose by actors moving from X_i under the influence of the resistance raster $R(i)$. Equation 7 defines the corresponding cost corridor model, representing the cumulative cost of movement from site X to Lo.

$$x_X = \sum_{i \to n}^{n} C_X(i) \quad (6)$$

$$x_X = \sum_{i \to n}^{n} (C_X(i) + C_{Lo}) \quad (7)$$

Where, X is the category of behavioral trigger points; n is the number of behavioral trigger points; $C_X(i)$ is the cumulative cost of movement across the surface raster starting from a single behavioral trigger point X_i; and C_{Lo} is the cumulative cost of movement across the surface raster with Lo as the source location.

3.3 Study Area

As the capital of the Mustang kingdom, Lo's cultural landscape is situated within an extensive area closely associated with its territory. This study area focuses on Upper Mustang (Figure 4), which is characterized by alpine river valley landforms in the Himalayan region, where most areas exhibit mountain steppe or desert steppe landform. The Kali Gandaki River and its tributaries constitute the hydrological network there. The royal city, Lo Manthang, is located on a plain at an altitude of approximately 3,800 meters along the upper reaches of this river.

The economic, political, and religious history of Mustang Kingdom has been deeply intertwined with Tibet. In 676 AD during the Tang Dynasty, it was occupied by the Tibetan Empire, and the South Asian corridor traversing China and Nepal already existed at that time, with caravans, monks, and travelers flowing along the Kali Gandaki River valley. Historical record indicates that Guru Rinpoche (the master who introduced Buddhism to Tibet), as well as figures such as Lama Sangye and Lhato Marpo, were once active in Lo and its surrounding area (Kadro, 2013; Dawa and Tsering, 2020). Thereafter, various local regimes alternately controlled Mustang, and constructed various dzongs for defense. In the mid-15th century, Ame Pal, a descendant of a general dispatched by the Guge Kingdom, established Lo Manthang city and ascended to kingship. He led the people to leave the caves and settle on the plain. Gradually, the settlements formed and agriculture was developed. The earliest generations of kings controlled the trade routes between Tibet and South Asia (Dhungel, 2002), and used the substantial tax revenues generated by these trade routes to built many monasteries. The kingdom gradually flourished and expanded its domain to the lower reaches of the Kali Gandaki River valley. The kings constructed palaces in key villages, which served as summer palaces or residences for local leaders.

Mustang was not conquered by the Gorkha Kingdom until 1775, and lost its autonomy in 1990.

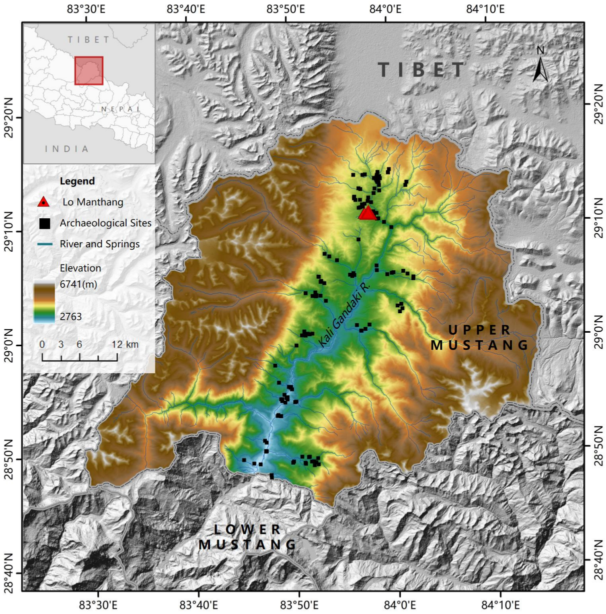

Figure 4. Map of the study region in Upper Mustang, Nepal, and the location of archaeological sites.

3.4 Data acquisition and processing

Based on ArcGIS, this study establishes a geographic information database of Upper Mustang for data processing. The database includes Digital Elevation Model (DEM), high-precision remote sensing imagery WorldView-3 (WV3), and the geographic information data of archaeological site.

3.4.1 DEM: The DEM used for the study is a 30m spatial resolution Digital Surface Model (DSM) as shown in Figure 5(a), obtained from the open-source website Geospatial Data Cloud (https://www.gscloud.cn). In ArcGIS, It is processed and converted into three geographical impact factors calculable by TBM:

1. Slope & Aspect: As critical factors for simulating spatial behavioral processes in landscape archaeology, slope and aspect serve as environmental bases for behavioral decision-making in complex terrains. Using GIS, slope and aspect are mapped as Figures 5(b) and (c).

2. Hydrological Network: Previous studies have established a consensus regarding the potential influence of land cover on behavioral decision-making in species spatial migration (Knaapen, et al., 2013; D’Abramo, et al., 2021). Due to the plateau location and sparse vegetation cover of Upper Mustang, this study mainly focuses on the significant impact of rivers on behavioral patterns. River networks are extracted by the Hydrology module in GIS, and the network hierarchy (t) classified into four levels. Referring to the actual width of different rivers in WV3, river buffer zones of 30m, 60m, 120m, and 300m were generated respectively, as shown in Figure 5(d).

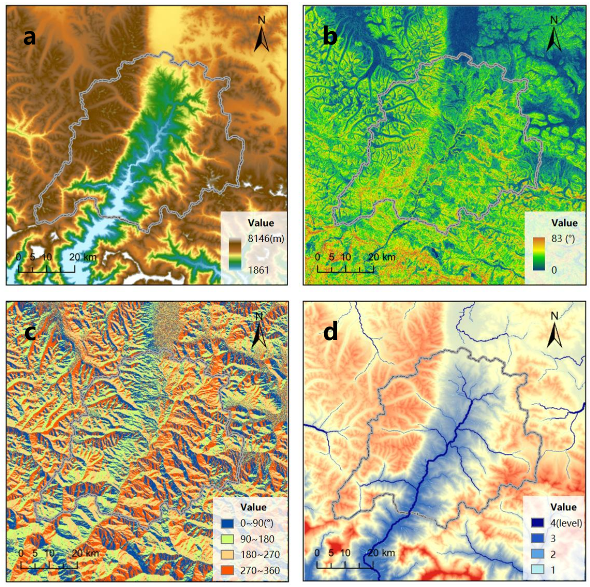

Figure 5. Geographic impact factors of the TBM.

(a) DEM; (b) Slope; (c) Aspect; (d) River buffer zones.

3.4.2 Archaeological Sites: The site data are obtained from the field surveys in Upper Mustang conducted by our team from 2018 to 2024, with the supports from ICOMOS (China), OCHSPA, and the Department of Archaeology, Nepal. These site data are organized into ArcGIS, and presented in point format. There are 356 possible sites data in total. Next, descriptive information of the sites, which is collected from the ethnography, surveys and researches, is supplemented into the data table.

Based on the surveys and materials, this study codes site types with tags. It meets the needs of multi-theme spatial analysis by classifying the attributes of the site. These tags include four basic types (settlement, palace, dzong, and monastery), and three extended types (commercial settlement, agricultural settlement, and religious site) (Figure 6). A tag of sites is a kind of behavioral trigger factor X_i (where X represents the initial letter of the corresponding site, and i is a continuous positive integer). A site may include multiple tags. For example, Lo has three functions, which is labeled as S (settlement), CS (commercial settlement), and AS (agricultural settlement). Also, The Lo Gekar Monastery, built by Guru Rinpoche, is labeled as M (monastery) and RS (religious site). Finally, 160 sites are effectively labeled and obtained to the study database (Figure 4).

Figure 6. Types of Upper Mustang sites.

(a) Settlement; (b) Palace; (c) Dzong; (d) Monastery; (e) Commercial Settlement; (f) Agricultural Settlement; (g) Religious Site

4. Spacial Value Analysis of Cultural Landscape

4.1 Spatial distribution of Cultural Landscape

Four typical types of cultural landscapes, including commerce, politics, religion, and agriculture, are developed TBM to reflect the distribution of value. The results are shown in Figure 7.

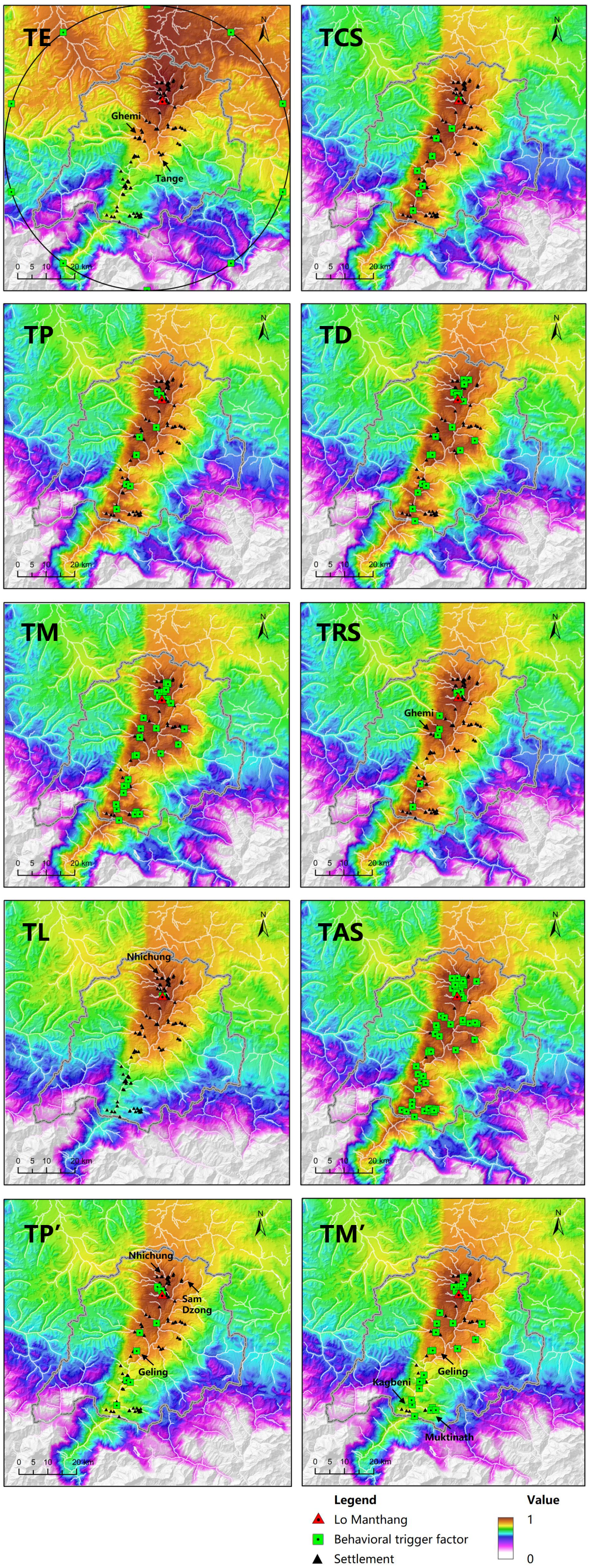

Figure 7. Distribution of cultural landscape value.

4.1.1 Commercial Landscape: This study analyzes two potential commercial landscape behavior scenarios. In Scenario 1, a caravan is simulated to arrive at Lo from outside the Kingdom of Mustang for material exchange. Ten trade behavior entry points are randomly and equidistantly generated along the edge of a circle, centered on the centroid of Upper Mustang and the radius is 50km. Subsequently, the cost corridor modeling was applied to sets E_i and Lo. In Scenario 2, a caravan is simulated to transport goods along commercial routes between settlements, and the cumulative cost is calculated by the commercial settlements (CS) recorded in ethnography.

As shown in the results TE and TCS, a probable trade corridor is represented. It is constrained within the Kali Gandaki River valley in its southern section, expanding toward the central regions like Ghemi and Tange. The commercial landscape extends northward to the depths of tributaries like Nhichung Khola and Sam Dzong Khola, and reaches extensive areas of Tibet, China. TE also indicates a higher probability of foreign merchant activities in northern Upper Mustang, suggesting historically intensive commercial interactions between Upper Mustang and Tibet.

4.1.2 Political Landscape: This study selected palace and dzong sites for political landscape modeling, yielding results as TP and TD. The distributions of them are similar, primarily aligned along the Kali Gandaki River valley. High-value areas largely converge with settlement distributions. TP values demonstrate higher concentrations on the western valley slopes, particularly at tributary confluences. TD shows a more dispersed pattern, with significant values also emerging along eastern tributaries. It reveals the political control of Mustang's royal authority over its territory.

This study further analyzes the other political landscape, aiming to reconstruct scenarios of royal inspection tours from Lo to subordinate settlements based on cost corridor modeling between palaces and Lo. The result (TP') shows that potential concentrations of royal inspection activities is situated in the north of Geling, and penetrates into valleys such as Nhichung and Sam Dzong.

4.1.3 Religious Landscape: This study selected monastery sites for modeling under the religious theme. The result (TM) demonstrates the distribution of religious landscapes, predominantly located within the tributary valleys of the Kali Gandaki River, manifesting extensive spatial dispersion. This pattern attests to the pervasive and profound influence of Tibetan Buddhism across Upper Mustang.

Based on the monastery sites, this study also reconstructs the behavioral pathways of Buddhists traveling from monasteries to the religious center Lo for participation in collective religious affairs. The result (TM') reveals stronger religious connectivity between Lo and the monasteries to its east and north, while connections diminish progressively with the south of Geling. Significantly weaker linkages are observed with key southern settlements, Kagbeni and Muktinath.

Another religious landscape focuses on the missionary activities of foreign religious masters, including Guru Rinpoche, Tenpai Gyaltsen, and Kunzang Longyang et al. These religious sites (RS) in ethnography are selected as behavioral trigger factors for TBM. The result (TRS) reveals potential activity areas of these masters along the Kali Gandaki River valley between Lower Mustang and Tibet. In the lower reaches of the Kali Gandaki River, high-value landscape is concentrated in the valley, shifting westward in the central-northern regions and notably clustering in the fluvial plains between Ghemi and Lo.

4.1.4 Agricultural Landscape: First, TBM was conducted for Lo to examine the agricultural landscape value distribution revealed by the result TL. The agricultural landscape of Lo exhibits lower probability of distribution in the southern area, primarily manifesting in the valley plain regions north of the urban center. Continuous variation in TL values reflects potential close agricultural linkages between Lo and Nhichung.

Next, cumulative behavioral costs were calculated for all agricultural settlements across Upper Mustang. The result (TAS) shows a spatial pattern with regional characteristics based on natural topography and water sources: a linear agricultural landscape running north-south was formed, with high-value landscape areas highly dependent on the favorable terrain along the Kali Gandaki River and its tributaries.

4.2 Discussion

4.2.1 The Relationships between Landscapes: The landscapes shown in Figure 7 are interrelated with one another, illustrating potential scenarios of cultural behaviors among the people and reflecting the organizational relationships of multiple cultural functional spaces in Lo. The conduct of diverse cultural activities within the limited river valley area has fostered closely interconnected relationships among these landscapes in this region. For example, the concentrated distribution of the trade and commerce landscape (TCS) along the river valley exhibits a high degree of overlap with the high-value areas of the political landscape (TP, TD) at tributary confluences, which demonstrates the functional link between the economy and politics in the Kingdom. By controlling trade routes through key nodes in the Kali Gandaki River valley, the kingdom derived economic benefits, then utilized these resources to reinforce political power spaces. The establishment of palaces or dzongs at tributary confluences further reflects the logic of state governance. The results of Tsarang, Ghemi, Geling, Chursang, and Kagbeni support this point.

The distribution of landscape value also reflects spatial extension characteristics centered on Lo. The commercial landscape (TE) reflects the possibility of connections from Lo to the northern Tibet region; and TCS illustrates the internal trade and commerce system of the kingdom, revealing potential trade routes from Lo to the southern areas. Similarly, the high-value regions of political, religious, and agricultural landscapes are all located in the valley plain from Lo to Nhichung.

4.2.2 The Integrity of Landscapes: To understand the overall distribution of cultural landscape values in Lo Manthang, this study calculated the average of the six results (TCS, TP, TD, TM, TRS, TAS) in Figure 7.

The result shows that the overall landscape exhibits an aggregated distribution characteristic converging toward the Kali Gandaki River valley (Figure 8). In the downstream, the landscape corridor is relatively narrow; except for Muktinath, other regions are largely and closely concentrated along both banks of the river valley. The corridor extends northward to the vicinity of Geling and expands east-west. The high-value areas of the landscape are no longer concentrated along the Kali Gandaki River but are dispersed across its tributary. The plain between Lo and Nhichung, as well as the areas near Tsarang and Ghemi, demonstrate notable landscape values. In comparison, the landscape value on the eastern bank of the river are generally slightly lower than those on the western bank.

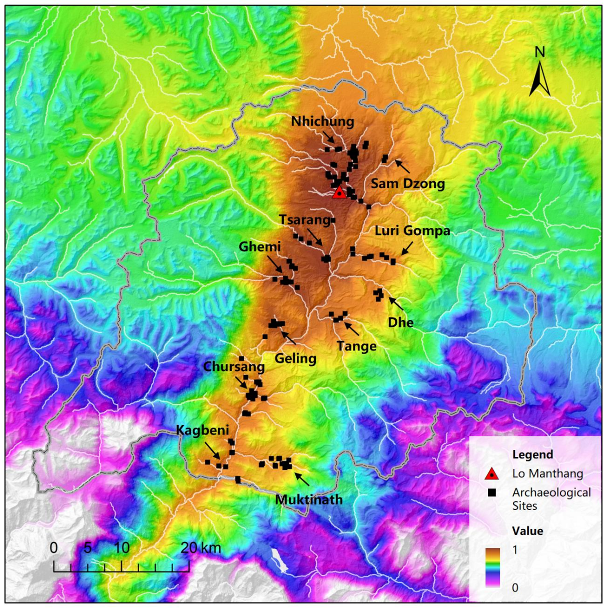

Figure 8. The overlay of TBM results.

4.2.3 Explanations for the Landscape Values: This study employed an alternative method, Kernel Density Estimation (KDE), to analyze the distribution characteristics of sites in Upper Mustang (Figure 9). The result reveals five main clusters: Lo to Nhichung, Geling to Tsarang, the river valley west of Luri Gompa, Chursang, and Kagbeni to Muktinath.

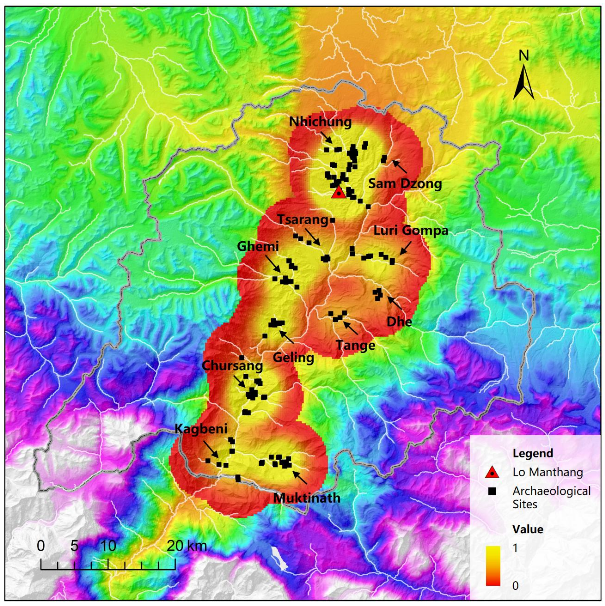

Figure 9. Kernel density estimation of archaeological sites.

Overall, the value distributions of KDE and TBM exhibit similarities: both show a north-south distribution pattern along the Kali Gandaki River. In areas with densely clustered sites such as Lo, Ghemi, and Geling, the results of the two models are similar, showing relatively high values. It reflects the influence of site density on the assessment of cultural landscape values. However, TBM value is not entirely determined by site density. For instance, while KDE value is high in Chursang and Muktinath, TBM value is relatively low. More specifically, TBM value is higher in the tributary valley between Ghemi and the Kali Gandaki River than the near highland. In contrast, the value of these areas is homogeneous in the KDE results.

The difference between these two results is mainly due to the discussion of geographical impact factors in TBM. The complex topography of Upper Mustang leads to the concentration of people's lives in the limited space of river valley plains, which can be clearly observed in Lo Manthang, Tsarang, Luri Gompa, and Chursang (Figure 10). It is evident that TBM can reflect the potential influences of the natural environment on cultural activities there, particularly the action orientation along the river valleys.

Figure 10. Remote sensing images of cultural landscapes in the valleys of Kali Gandaki River and its tributary.

(a) Lo Manthang; (b) Tsarang; (c) Luri Gompa; (d) Chursang

4.2.4 Heritage Value Assessment: The cultural landscape of Lo is diversity and synergy, reflecting the creative adaptation of highland civilizations in trans-Himalayan countries to achieve survival and development through spatial organization under extreme geographical environments. This study interprets the cultural landscape heritage values of Lo from three scales and visualizes them using spatial mapping methods (Figure 11).

1. Cultural Route: Zone I with TBM value ranging from 0.845 to 0.9, presents a trans-regional, high-value landscape corridor along the Kali Gandaki River Valley. Extending southward from Tibet to Lower Mustang, this corridor reconstructs the action trajectory of material exchange, religious dissemination, and political interaction between Tibetan and South Asian civilizations via the river valley corridor, thereby revealing the cultural functions of the Mustang section of the "South Asian Silk Road". Many locally characteristic sites are located along the river valley, contributing to the distinctive sense of place and embodying the corridor identity of the "South Asian Silk Road".

2. Mustang Kingdom: Zone II with TBM value ranging from 0.9 to 0.975, exhibits a potential territory of the Mustang Kingdom. This area constitutes a high-value zone for both political landscapes (TP, TD) and agricultural landscapes (TAS), encompassing major settlements and sites. The region aligns with the high-value areas of religious landscapes (TM), reflecting the profound integration of Tibetan Buddhism with the daily lives of local people.

3. Core Area: Zone III is the highest TBM values area (0.975 to 1), including the plain area near Lo, Tsarang, and Ghemi. The vicinity of Lo features a dense distribution of various types of sites, where the values of commercial, political, religious, and agricultural landscapes simultaneously exhibit high levels. This indicates that the area near the royal capital Lo, has developed multiple cultural functions, holding significant value for the livelihoods and cultural continuity of local residents. Meanwhile, Tsarang and Ghemi, as key nodes along the Kali Gandaki River, also exhibit extremely high comprehensive landscape values. These areas form a core landscape associated with Lo, potentially serving as a critical factor in the demarcation of the heritage core area.

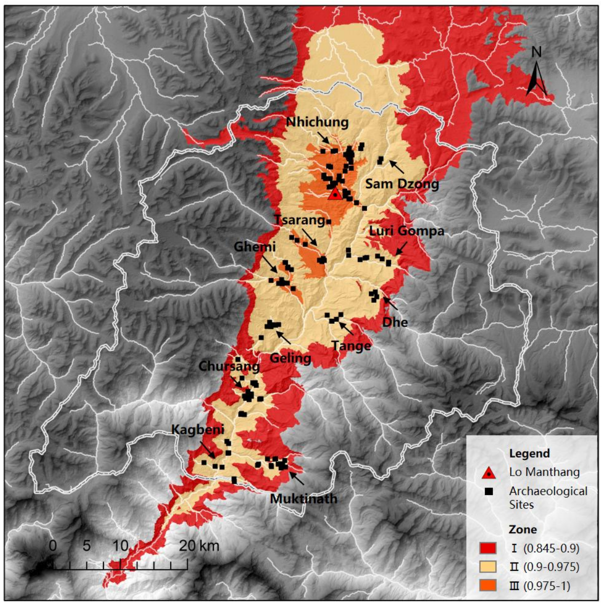

Figure 11. Cultural landscape zones with high heritage value.

Therefore, the protection of the cultural landscape heritage of Lo can be carried out from three dimensions. First, the Kali Gandaki River and its tributaries have provided favorable living environments for the people of Mustang, including flat river buffer zones and rare water sources on the high plateau. Heritage conservation should emphasize the critical role played by the river valley and advocate for cultural exchanges in the new era within Zone I. Second, Zone II is dedicated to maintaining the characteristic landscape features of the Mustang Kingdom, including Tibetan Buddhist monasteries and other sites, to highlight the authenticity of the heritage. Zone III serves as the core area for heritage preservation and restoration. It is recommended to carry out site rehabilitation work in a planned manner. Meanwhile, community participation should be encouraged to sustain the vitality of the cultural landscape through living practices.

5. Conclusion

The cultural landscape of Lo Manthang is not only a testimony to the long-standing history of the Mustang Kingdom but also one of the South Asian cases in the world cultural landscape heritage. Based on GIS, this study analyzes the value distribution of four thematic cultural landscapes and revealed its potential heritage value. The research findings indicate:

1. The cultural landscape distribution of Lo shows the characteristic of multi-functional synergy. The four types of cultural landscapes are interconnected and converge toward the valleys of the Kali Gandaki River and its tributaries. This constitutes a creative practice through which highland civilizations have achieved survival and development via spatial organization under extreme geographical environments.

2. Possibly, the core of the heritage value of Lo's cultural landscape lies in the unique cultural spatial system formed by the long-term interaction between the natural environment and human activities. It has the significance of heritage conservation across three scales: cultural routes, the Mustang Kingdom, and the areas near Lo, Tsarang and Ghemi.

3. To a certain extent, TBM is capable of analyzing the potential connections between sites, as well as between sites and the environment, based on limited site survey data and geographical conditions. It visualizes the value distribution of Lo's cultural landscape in complex terrain, thereby revealing the distribution characteristics of cultural landscapes under the influence of highland culture.

This research framework aims to serve as a tool supporting spatial decision-making in accordance with the Operational Guidelines for the Implementation of the World Heritage Convention. It is worth noting, however, that the parameters of TBM are primarily based on the regional characteristics of Upper Mustang, and its universality requires further validation in other highland cultural landscape cases. Additionally, constrained by site survey data, the simulation accuracy of cultural behaviors in the model still has room for improvement. Future research may optimize the model by integrating multi-source data like ethnography and oral history. extend this framework to other regions of the Himalayas, deepen comparative studies on trans-regional cultural landscapes, and provide more empirical support for global cultural heritage conservation.

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