ISSN: 1648-6897 / eISSN: 1822-4199

VILNIUS TECH
Vilnius Gediminas Technical University

JOURNAL of ENVIRONMENTAL ENGINEERING & LANDSCAPE MANAGEMENT

2025
Volume 33
Issue 3
Pages 322–334
https://doi.org/10.3846/jeelm.2025.24538

LANDSCAPE CHANGE AND PERCEPTION ALONG HISTORICAL RAILWAY: THE CASE OF YUNNAN-VIETNAM RAILWAY, CHINA

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Highlights:

- quantify the landscape changes by historical GIS method;
- integrate historical maps with remote sensing data and questionnaire, the study provides a comprehensive analysis of landscape evolution over time;
- explore the interplay between landscape change and human perception through fsQCA.

Article History:

- received 11 February 2025
- accepted 27 March 2025

Abstract. Against the background of environmental change, this study investigates the relationship between landscape changes and perceptions along the historical railway using a combination of Historical Geographic Information Systems (HGIS) and Fuzzy-set Qualitative Comparative Analysis (fsQCA). After quantifying the changes by GIS, the research aims to understand how different types of landscape changes affect physical, psychological, and cultural perceptions among locals. By integrating historical maps with remote sensing data and questionnaire, the study provides a comprehensive analysis of landscape evolution over time. The findings reveal that cropland and urban areas both showed significant increases along the railway; forest and water body both decreased over 70 years. The presence of forest change led to significant cultural perceptions and cropland change influenced the psychological perceptions of landscape. This research contributes to the understanding of the interplay between landscape change and human perception, offering valuable insights for sustainable landscape management and heritage conservation.

Keywords: historical GIS, historical landscape, historical images, Yunnan-Vietnam Railway.

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1. Introduction

The earth is undergoing some fast alterations in terms of landscape (Seto et al., 2012). The concept of "landscape change" refers to the structural and functional transformation of a landscape over time, driven by climatic shifts, ecological succession, urbanization, and infrastructure development, etc. (Li et al., 2021). For instance, dam construction in China has altered hydrological regimes, triggered upstream inundation, and disrupted ecosystem integrity (Zhao et al., 2012). Such changes critically influence biodiversity, ecosystem services, and land-use sustainability under climate stressors (Yang et al., 2024). Consequently, nations like Malaysia have institutionalized landscape governance through frameworks such as the National Landscape Policy (NLP), which prioritizes balanced development and ecological stewardship. From a social perspective, how people perceive and interpret changes in the landscape is also influenced by a variety of factors, including shaped by sociocultural contexts, individual lived experiences, and environmental values, etc. (Półrolniczak & Kolendowicz, 2023). Empirical studies confirm that landscape perception directly informs environmental attitudes and health outcomes, underscoring its role in conservation policy design (Cao et al., 2020, 2025). Further, understanding how people perceive landscape changes can inform more effective land conservation and sustainable management strategies.

Among all the factors, transport infrastructure, like railway construction, is a significant driver of landscape change, as well as human-nature interdependencies. Railway projects, especially cross-border corridors, can lead to substantial alterations. Zhao et al. (2024) highlighted the multifaceted impacts of railway construction on landscapes, such as urban expansion, land fragmentation, etc., which provided valuable insights for policymakers and urban planning. Except for the concern about high speed railway, historical railways (constructed in the 19th and early 20th centuries) have left lasting impacts on both natural and built environments. Romania's Transylvanian Railway–have indelibly shaped urban morphologies and spatial connectivity (Purcar, 2007). The Konkan Railway in India further demonstrates that legacy rail systems can coexist with natural landscapes, balancing agricultural conversion with forest preservation (Navalkar et al., 2023). Despite their socioecological significance, historical railways remain understudied compared to other contemporary projects (Martín et al., 2021; Yin et al., 2024). Historical railways are regarded as significant remnants of industrial civilization and contributed to global transportation, economic progress, and cultural exchange (Merciu et al., 2022; Wang et al., 2024). Figuring out landscape change and perception along these old railways offers multiple benefits: sustainable tourism revenue and community identity preservation. Initiatives like the Yunnan–Vietnam Railway (YVR) industrial heritage framework (Wang et al., 2024) and the U.S. Rails-to-Trails movement (Rizk & Salvo, 2025) exemplify strategies to repurpose rail landscapes while enhancing ecological and recreational value.

The relationship between landscape change and perception is multifaceted. Existing studies lack systematic analyses of how heterogeneous landscape changes along historical railways correlate with public perceptions. This study addresses this gap by integrating GIS-based spatial analysis with fuzzy-set Qualitative Comparative Analysis (fsQCA) to: 1) quantify landscape changes along historical rails; 2) Identify causal configurations of landscape changes that influence perception shifts; 3) Propose adaptive management strategies for heritage conservation and sustainable tourism.

2. Literature review

2.1. Landscape change and perception

Landscape changes, whether anthropogenic (e.g. urbanization and conservation) or biophysical (e.g. ecological succession), fundamentally reshape human-environment interactions. Previous studies about landscape changes are abundant, such as analyzing the factors (socio-economic activities) influencing landscape fragmentation (Li et al., 2025), integrating ecology and design methods to enhance the landscape sustainability (Musacchio, 2025), studying landscape pattern and ecological network (Zhou et al., 2024), etc. The changes also impact human society from multiple perspectives, like degradation in ecosystem services (Zhang et al., 2024) and human survival and wellbeing (Jia et al., 2023). From people's perception, vegetation, diversity, green openness, etc. are the landscape parameters that perceived and monitored frequently (Wang et al., 2017). And social dimensions including age, profession, background, culture, and expertise may influence the visual perception of a landscape (De Val et al., 2006). Emerging research links landscape transformations to mental health and cultural outcomes. For example, Vanhöfen et al. (2025) stated that perceived naturalness and biodiversity in recreational landscapes correlate with human emotional well-being. Landscape also plays a significant role in shaping various conditions, such as adjusting the level of stress, depression, and anxiety (Liang et al., 2024). And place attachment and cultural identity are strongly linked to the restorativeness of an area. Yoon et al. (2023) suggested that landscapes that promote a sense of connection to nature can have long-term benefits for humans. But urbanization-induced loss of traditional landscapes reduced the sense of place identity in East Asian contexts (Wang, 2015).

The factors that influence the relationship between landscape change and human perceptions are complex. Zube et al. (1989) started to use GIS to analyze the differences between physical change and perceived changes. They stated that respondents thought that the changes improved or had no effect on local landscape quality. Aretano et al. (2013) defined the subjective and objective assessment of landscape change, finding that physical changes led to the awareness of landscape and ecosystem service dynamics among local communities. Hedblom et al. (2020) further explained that physical landscape and human perception are closed linked. They applied photos into questionnaire for a landscape perception survey, adding to physical monitoring data. More key factors have been emphasized by scholars, like naturalness and biodiversity (Vanhöfen et al., 2025), characteristic variations (Duan et al., 2024), and landscape aesthetics and preferences (Ning et al., 2024).

Current scholars recognize perception as a multidimensional construct. Recently, Han et al. (2021) applied the Maslow's Hierarchy of Needs and Landsense theory to analyze the landscape change perception. As previous studies stated, landscape perception can be physical (such as feelings about housing, convenient location and transportation and natural spaces) (Lovejoy et al., 2010) or cultural (sense of belonging, cultural education, etc.) (Mohit & Azim, 2012; Hwang et al., 2019). Previous studies only addressed single factor, and few studies evaluated perceptions from multiple perspectives. This research follows Han et al. (2021), studying the landscape change perception from three perspectives, namely, along the railway landscape, the landscape perceptions include 1) physical perceptions of surrounding environment; 2) psychological perception, namely subjective judgments formed during the cognitive process; 3) cultural perceptions related to identity and education. And this paper will further test how different kinds of landscape changes influence the three perceptual dimensions along railways.

2.2. Historical landscape

The flexibility and practicality of GIS have established it as a powerful methodological tool for social scholars, historians, and archaeologists. The concept of HGIS emerged as part of a "spatial turn" in the humanities (Knowles et al., 2015; Robertson, 2016). Digitized historical data offer advantages such as openness and continuity, overcoming limitations of paper documents, including physical storage demands, revision complexity, and degradation risks (Huang, 2017). As an interdisciplinary approach, HGIS has been applied to: historical land use and spatial economies (McLeman et al., 2010); past landscapes and environmental morphology (Algeo et al., 2013); open-source public platforms (Knowles et al., 2008). More and more research is focusing on the 3D heritage reconstruction using LiDAR and historical photographs (Li et al., 2019), georeferencing methods, smart digitalization of maps (Uhl et al., 2017), etc. But some related issues remain unresolved and 19th-century maps exhibit positional errorsn (Zhu et al., 2021). Landscape remains a central focus in HGIS studies (Statuto et al., 2015). As a product of human-nature interactions, historical landscapes provide continuity for historical development and inform future planning (Antrop, 2005). The analysis of historic landscape is usually based on a variety of sources, such as historical maps and aerial photographs, geodetic survey maps, digital elevation models, cadastral maps, and other archival documents in form of texts and images (Bender et al., 2005). A common method involves comparing digitized historical maps and aerial photos with remote sensing imagery to analyze land-use/cover evolution (Wu et al., 2015; Kull, 2005).

Then, historical maps are critical for reconstructing past landscapes. They reflect historical geographic perspectives and mapping techniques (Rumsey & Williams, 2002) and can be categorized as regional maps (depicting administrative boundaries and territorial changes) and thematic maps (documenting landscapes, place names, and natural phenomena like soil erosion or deforestation) (Pindozzi et al., 2016). But historical maps often include ambiguous descriptions, uncertain sources, or obsolete projections, complicating feature georeferencing. Historical photos vividly capture phenomena such as landscapes, conflicts, and cultural preferences. They are also used to make the visual assessment and perception of landscape (Steen Jacobsen, 2007) and the 3D reconstruction of historical views (Dewitz et al., 2019). For historical railways, HGIS has been used to analyze relationships between rail development, population dynamics, and territorial changes (Martí-Henneberg, 2013; Gregory & Schwartz, 2009). The activity of constructing railways have left lots of historical documents and maps, especially in the 20th century when the mapping technique became more mature. However, limited HGIS studies quantified socio-cultural perceptions previously (Thompson, 2012). And landscape perception along historical railways has been seldom studied quantitatively (Meng et al., 2024).

2.3. FsQCA

FsQCA is a methodological approach for analyzing causal complexity in social sciences. It combines qualitative and quantitative techniques to identify condition configurations leading to specific outcomes (Kumar et al., 2024). It has emerged as a methodological tool in landscape studies, particularly in addressing complex issues related to environmental management, sustainability, and human-environment interactions. For example, Lai et al. (2024) used fsQCA to study the tourism ecological security. It concluded that financial support from the government is an indispensable role in achieving tourism ecological security; Zhang et al. (2022) applied fsQCA to analyze farmers' willingness to protect arable land, identifying key conditions such as perceived economic benefits, policy subsidies, and government outreach; Rao et al. (2022) integrated fsQCA with structural equation modeling to study environmental behavior in rural tourism, identifying conditions like destination image, satisfaction, trust, and relationship quality; For the case of tourism entrepreneurship in rural destinations, Guo et al. (2023) identified the key factor by fsQCA, such as human and physical capitals of entrepreneurs. FsQCA has also been combined with more analytic tools,such as Necessary Condition Analysis (Zang & Guo, 2024), GIS, partial least squares (Foroughi et al., 2024), etc. As is seen, fsQCA has proven effective for analyzing complex causal configurations in landscape studies. By identifying the necessary and sufficient conditions for various outcomes, it provides an overall understanding of the interplay between different factors, offering valuable insights for both academic and practical applications in landscape management and sustainability.

In summary, according to the literature review, some shortcomings can be seen: comprehensive evaluations from multiple perspectives, socio-cultural perceptions in the context of historical railways, complex causal configurations between landscape change and perceptions. Based on the discussion above, and facing with the problem between landscape change and human perceptions, this study innovatively integrates HGIS with fsQCA, combining historical maps and questionnaires to analyze landscape changes along railway corridors, focusing on the case of YVR. While environmental factors like biodiversity and soil erosion have been analyzed via repeat photography (Dearing, 2008), social dimensions of landscape change remain overlooked (Dearing, 2008). This research demonstrates how HGIS and fsQCA can advance railway landscape studies by developing a method to digitize historical maps, visualize landscape changes through spatiotemporal comparison, and explore the key factors between landscape change and perception.

3. Materials and methods

3.1. Study area

YVR was constructed in the early 20th century under French Indochina's colonial administration. The whole railway system starts from Kunming in the southwest of China, extending to Hanoi (Vietnam's capital) and terminating at Haiphong, a northern Vietnamese seaport. Because of the limited data in the Vietnamese section, only the Yunnan section (Kunming to Hekou, 468 km) is analyzed. As the first international railway in China, its multiple value and meaning have been widely acknowledged by scholars from various aspects such as technology, history, culture, art, heritage, and tourism (Che, 2013; Hu & Matsubara, 2023). Though originally built to expand French colonial influence, the railway catalyzed socioeconomic changes–reshaping ideologies, cultural norms, and religious practices–while accelerating modernization (Yan & Zhuang, 2014). Railway construction in Yunnan generated thousands of historical photographs from corporate and personal archive, but lots of original historical maps and photos conserved in the archives have been seldom studied by scholars (Pholsena, 2015). Due to the significance and historical value of the railway, this research selected the counties passed by YVR in Yunnan as study area (Figure 1), which covered an area of nearly 25,000 km^2 with 13 administrative bodies. Integrating HGIS and fsQCA in YVR regions advances understanding of anthropogenic landscape modifications and regional development in this railway area, which helps assess the degree and type of landscape changes along the railway, provide insights into the cultural and railway landscapes, informing future land management, conservation measures, and heritage preservation/redevelopment.

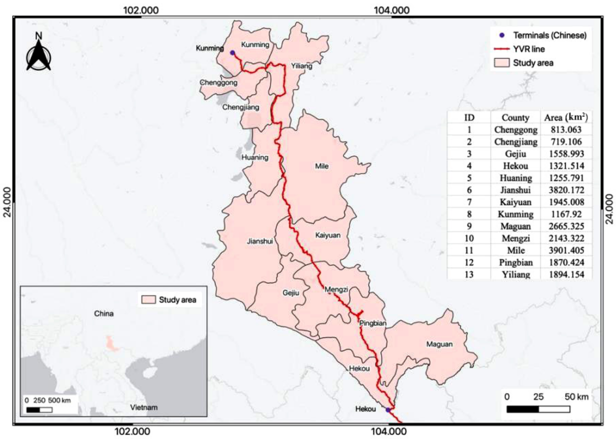

Figure 1. Study area of YVR

3.2. Workflow

This research applied HGIS and fsQCA as the principal methodology to analyze the historical landscape data of YVR. The workflow included: Collecting historical photographs and current land-use data; Georeferencing and digitizing historical maps; Processing raster data; Analyzing historical landscape changes using landscape metrics; Testing relationships via fsQCA; Explain the results through coverage and consistency (Figure 2). The software tools included Quantum GIS (QGIS), an open-source GIS platform, and fsQCA 4.1 (University of California, Irvine).

3.3. Data acquisition

YVR documents are preserved in several institutions: the Mulhouse Archives, French National Overseas Archives (Provence), and Guimet Museum (Paris). The University of Texas Libraries holds a series of 1954 U.S. Army Map Service topographic maps (Series L500). Historical photos were sourced from the YVR Company Album (Mulhouse Archives), while 1954 maps served as the primary cartographic sources. Then, modern spatial data were derived from MODIS imagery (United States Geological Survey), with 500-meter resolution land cover datasets from 2001 and 2021 used for temporal comparison (Friedl & Sulla-Menashe, 2022).

3.4. Georeferencing

Scanned historical maps lack spatial coordinate systems, requiring coordinate assignment and correction. The georeferencing process involved: Selecting Open Street Map as the base map; Identifying projections and coordinate systems; Choosing stable features (road intersections, stations, bridges) as control points; Applying a first-order polynomial transformation with nearest-neighbor resampling (Kiraly et al., 2008; Baiocchi et al., 2013; Piovan, 2019). The 1954 U.S. Army maps used Universal Transverse Mercator (UTM 48N) projection at 1:250,000 scale (Figure 3a), aligning with the study area's longitudinal range (102°E–108°E). Five old maps were georeferenced using eight control points per section (railway stations/cities), yielding a final average root mean square error (RMSE) of 12.163 (Figure 3b). Georeferenced outputs were integrated into QGIS for further analysis (Figure 3c).

The georeferenced historical maps in GIS serve as valuable sources for extracting spatial information into new vector layers, such as historical buildings and monuments (represented as points) and historical landscape areas (delineated as polygons). Once digitized, these geographic features can be analyzed and compared with modern GIS datasets. In this study, the digitization process primarily focused on vectorizing four landscape types: forests,

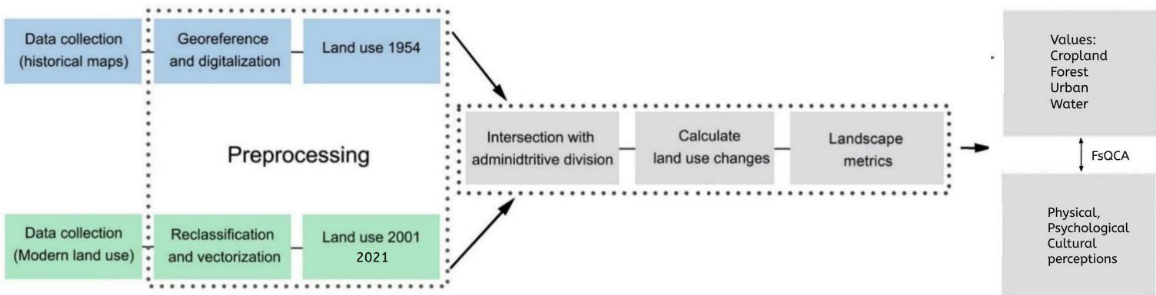

Figure 2. The workflow

Figure 3. Georeferencing process: a) basic information in the 1954 map; b) georeferencing parameters; c) mapping results

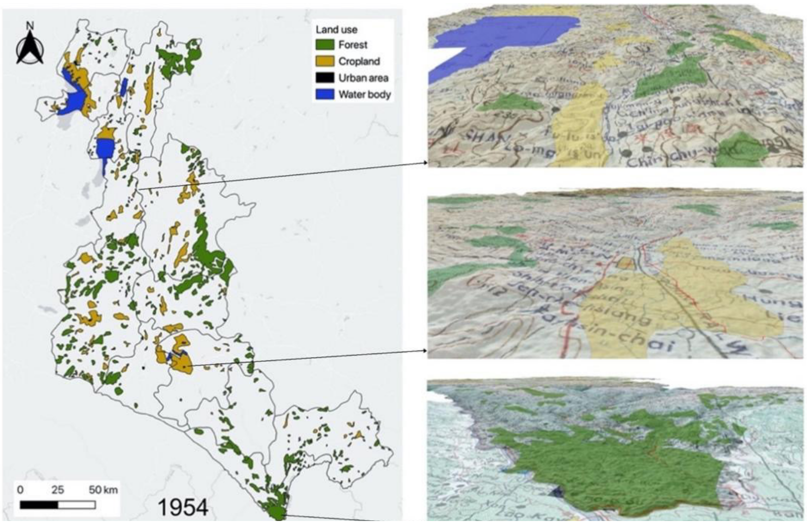

Figure 4. Digitization of historical map

croplands, water bodies, and urban areas (Figure 4). Following the digitization of 1954 landscapes, subsequent analyses were conducted to quantify changes between the 1950s and 2021.

3.5. Quantify landscape changes

Following raster data collection, the datasets required clipping and reprojection to align with the study area's UTM zone 48N coordinate system. The MCD12Q1 raster dataset includes 17 land classes, but only four categories relevant to historical land use were retained. Reclassification and vectorization were applied to harmonize these data with historical maps. The reclassification criteria and outcomes are summarized in Figure 5. Both reclassified rasters were vectorized using QGIS's Polygonize tool, enabling landscape change rate calculations at the county level for visualization. Post-vectorization, the areal coverage of each

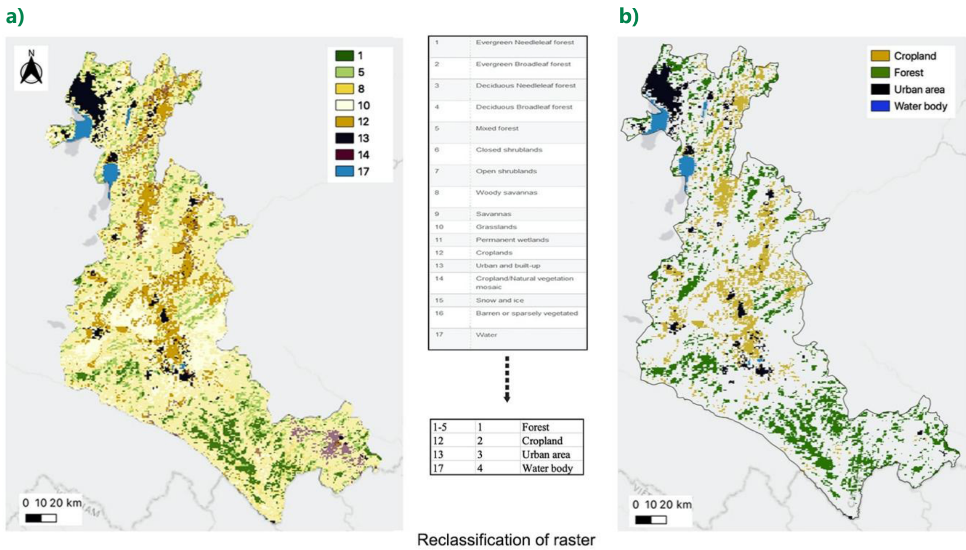

Figure 5. Reclassification of raster: a) MODIS image; b) reclassified raster data

land use type was computed via the vector layer's Field Calculator. These vectors were then intersected with administrative boundaries to quantify land use proportions within individual counties.

At last, landscape metrics were selected to reflect the landscape change: edge, patch, and core. The Landscape Ecology Statistics tool (LecoS) was used in QGIS, which contained several analytical functions for landscape analysis. Among them, the edge metric (edge density – ED) describes the configuration of the landscape. It is calculated as followed (Eq. (1)):

$$ED = \frac{E}{A} \times 10\,000. \quad (1)$$

In this equation, E means the total landscape edge in meters and A is the total landscape area in square meters. Then, patch metrics (patch density – PD) describes the composition of the landscape. It is calculated by Eq. (2):

$$PD = \frac{N}{A} \times 10\,000. \quad (2)$$

In this calculation, N is the number of patches and A is the total landscape area in square meters. And Core area metric (CA) measures the shape of core landscape elements, if the cell has no neighbor with a different value than itself. When the patch is large and compact, it has a higher value. Then, it can be calculated by Eq. (3):

$$CO = a_{ij}^{CO}. \quad (3)$$

The CO means core area in square meters. And ij means the number of cores.

4. Research results

4.1. Comparisons of landscape type

Table 1 summarizes the landscape change rates across counties. The key findings include: about water bodies, higher change rates occurred in Mile and Hekou, while Kaiyuan, Gejiu, and Maguan exhibited the lower changes. For forest cover, dramatic changes were observed in Kun-

Table 1. Landscape changes

Landscape type	County	Area (km^2)			Change rate	
		1954	2001	2021	1954–2001	2001–2021
Cropland	Chenggong	105.63	75.02	14.00	–0.29	–0.81
Forest		1.53	41.88	62.31	26.37	0.49
Urban		0.00	101.06	120.21	+	0.19
Water		144.81	130.73	129.85	–0.10	–0.01
Cropland	Chengjiang	91.25	135.18	73.11	0.48	–0.46
Forest		12.23	33.94	62.83	1.77	0.85
Urban		0.56	31.57	37.48	55.38	0.19
Water		135.50	122.84	121.09	–0.09	–0.01
Cropland	Gejiu	72.86	109.81	96.38	0.51	–0.12
Forest		76.00	136.30	150.08	0.79	0.10
Urban		1.58	60.32	61.63	37.17	0.02
Water		5.65	1.13	1.13	–0.80	0.00
Cropland	Hekou	0.00	10.88	17.48	+	0.61
Forest		292.48	184.03	319.14	–0.37	0.73
Urban		0.00	3.88	3.88	+	0.00
Water		0.00	0.00	0.54	0.00	+
Cropland	Huaning	90.36	271.34	106.83	2.00	–0.61
Forest		66.26	119.93	118.85	0.81	–0.01
Urban		0.75	25.44	25.87	32.91	0.02
Water		19.46	14.54	13.66	–0.25	–0.06
Cropland	Jianshui	224.15	551.09	410.94	1.46	–0.25
Forest		527.53	504.66	518.90	–0.04	0.03
Urban		1.78	45.41	50.94	24.51	0.12
Water		4.17	1.32	0.88	–0.68	–0.33
Cropland	Kaiyuan	78.87	425.75	442.38	4.40	0.04
Forest		270.58	162.18	166.79	–0.40	0.03
Urban		0.96	64.28	66.46	65.96	0.03
Water		1.43	0.00	0.00	–1.00	0.00

End of Table 1

Landscape type	County	Area (km^2)			Change rate	
		1954	2001	2021	1954–2001	2001–2021
Cropland	Kunming	163.66	61.86	23.04	–0.62	–0.63
Forest		36.83	135.79	179.46	2.69	0.32
Urban		4.87	357.62	391.23	72.43	0.09
Water		60.06	18.68	16.93	–0.69	–0.09
Cropland	Maguan	40.28	19.31	9.83	–0.52	–0.49
Forest		161.41	263.79	535.12	0.63	1.03
Urban		0.00	10.97	16.68	+	0.52
Water		0.67	0.00	0.00	–1.00	0.00
Cropland	Mengzi	202.67	274.09	177.90	0.35	–0.35
Forest		51.18	117.66	157.24	1.30	0.34
Urban		0.96	76.17	86.70	78.34	0.14
Water		16.87	10.72	9.84	–0.36	–0.08
Cropland	Mile	219.86	939.89	872.83	3.27	–0.07
Forest		408.32	217.76	303.87	–0.47	0.40
Urban		1.69	43.44	47.83	24.70	0.10
Water		0.70	2.63	3.07	2.76	0.17
Cropland	Pingbian	6.64	15.70	277.42	1.36	16.67
Forest		84.74	412.30	454.67	3.87	0.10
Urban		0.00	3.07	3.07	+	0.00
Water		0.00	0.00	0.00	0.00	0.00
Cropland	Yiliang	124.57	672.22	386.19	4.40	–0.43
Forest		289.69	170.81	254.50	–0.41	0.49
Urban		0.47	55.72	57.96	117.56	0.04
Water		15.44	8.62	8.62	–0.44	0.00

ming, Chenggong, and Pingbian, whereas Yiliang, Mile, and Kaiyuan showed minimal fluctuations. For urban areas, significant expansion occurred in Chenggong, Yiliang, and Maguan, contrasting with stable patterns in Mile, Jianshui, and Pingbian. And for cropland, the most changes were happened in Yiliang, Hekou, and Kaiyuan, while Kunming, Chenggong, and Maguan experienced relatively stable conditions.

Landscape metrics (Table 2) reveal the following trends over the 70-year period (1954–2021): edge density and patch density remained consistently low (<0.001), reflecting minimal fragmentation along the railway; Cropland and urban areas exhibited significant increases in core-area, signaling sustained expansion. Forests displayed a notable rise in core area from 1954 to 2001, followed by a decline by 2021; Water bodies showed an increase in core area between 1954 and 2001, but with a reduction by 2021.

4.2. Fuzzy set comparisons

According to Pappas and Woodside's (2021) guidelines, the fsQCA procedure involves: (1) data collection, (2) data calibration, (3) generating a truth table of all causal condition configurations and their consistency via the fsQCA algorithm, and (4) interpreting solutions. This study tests the relationship between landscape change rates (causal conditions) and perceptions (outcomes). The causal conditions are set as the average change rates (1954–2021) of four landscape types: cropland, forest, urban area, and water bodies.

Table 2. Landscape metrics

Types	Edge density	Patch density	Core area	Edge density	Patch density	Core area	Edge density	Patch density	Core area
	1954			2001			2021		
Cropland	<0.001	<0.001	2.99	<0.001	<0.001	318.08	<0.001	<0.001	471.76
Forest	<0.001	<0.001	2.99	<0.001	<0.001	810.05	<0.001	<0.001	324.63
Urban	<0.001	<0.001	0.00	<0.001	<0.001	306.28	<0.001	<0.001	350.41
Water	<0.001	<0.001	7.98	<0.001	<0.001	172.15	<0.001	<0.001	170.83

The outcomes are three perceptual dimensions: physical (green space, air freshness, public facilities, housing quality, convenience), psychological (comfort, esteem, security, social harmony, belonging), and cultural (educational functions, cultural identity). A Likert-scale questionnaire (Linwei et al., 2021) was administered in eight high-population-density counties along the railway: Chenggong, Hekou, Jianshui, Kaiyuan, Kunming, Mengzi, Pingbian, and Yiliang. Purposive sampling was applied and participants were filtered by the criteria: have resided locally for >10 years in this area. The data collection period was between July 2023- October 2023 for three month. Within 900 distributed questionnaires, 813 were valid (90.3% validity rate). Data collection adhered to ethical standards (privacy, voluntariness, etc.), and reliability was confirmed by Statistical Product and Service Solutions (SPSS) (Cronbach's $\alpha > 0.8$). Perception values were calculated from averaged scores per dimension. After preprocessing, data were transformed into fuzzy sets using thresholds (0.95, 0.55, 0.55). The transformed variables are detailed in Table 3.

Using fsQCA 4.1, the paper analyzed configurations of landscape change and perceptions (Table 4). Configurations with low frequency (<0.8) were excluded. Physical perception results were omitted due to low consistency and coverage rates, leaving only cultural and psychological perceptions for interpretation. Key Parameters were used to check the results, such as consistency: measuring how reliably a configuration predicts the outcome; and Coverage: indicating how much of the outcome is explained by a configuration (Pappas & Woodside, 2021). For cultural perceptions, two configurations stood out: Water change + Forest change + Low urban change + Low cropland change (Coverage: 0.34; Consistency: 0.96); and Low water change + Forest change + Urban change + Low cropland change (Coverage: 0.35; Consistency: 0.96). These combinations explain 55% of cases (solution coverage: 0.55) with high stability (consistency: 0.96). For psychological perceptions: the configuration Water change + Forest change + Low urban change + Cropland change showed unique coverage (0.22) and near-perfect consistency (0.98). Overall, these conditions explain 58% of cases (coverage: 0.58) but with lower reliability (consistency: 0.93).

The parsimonious solution simplifies the intermediate solution by focusing only on core factors–conditions that cannot be removed without losing explanatory power. Two core conditions were identified: cultural perceptions rely on the presence of forest change, while psychological perceptions depend on the presence of cropland change (Table 5).

Table 3. Fuzzy set of variables

ID	Areas	Water change	Forest change	Urban change	Cropland change	Physical perception	Psycho-perception	Culture perception
1	Chenggong	0.71	0.98	0.05	0.05	0.04	0.31	0.94
2	Hekou	0.98	0.12	0.05	0.5	0.91	0.12	0.08
3	Jianshui	0.05	0.07	0.15	0.41	0.82	0.03	0.16
4	Kaiyuan	0.05	0.03	0.63	0.68	0.25	0.58	0.56
5	Kunming	0.14	0.56	0.73	0.04	0.97	0.12	0.96
6	Mengzi	0.5	0.51	0.8	0.16	0.06	0.88	0.75
7	Pingbian	0.77	0.92	0.05	0.99	0.44	0.98	0.11
8	Yiliang	0.5	0.08	0.98	0.65	0.52	0.83	0.04

Table 4. FsQCA results

Parsimonious solution (Cultural perception)		Parsimonious solution (Psychological perception)	
forest*~crop	Raw coverage: 0.62 Unique coverage: 0.62 Consistency: 0.96	crop	Raw coverage: 0.68 Unique coverage: 0.68 Consistency: 0.75
Solution coverage: 0.62	Solution consistency: 0.96	Solution coverage: 0.68	Solution consistency: 0.75
Intermediate solution (Cultural perception)		Intermediate solution (Psychological perception)	
water+forest+~urban+~crop	Raw coverage: 0.34 Unique coverage: 0.20 Consistency: 0.96	~water+~forest+urban+crop	Raw coverage: 0.36 Unique coverage: 0.26 Consistency: 0.89
~water+forest+urban+~crop	Raw coverage: 0.35 Unique coverage: 0.21 Consistency: 0.96	water+forest+~urban+crop	Raw coverage: 0.31 Unique coverage: 0.22 Consistency: 0.98
Solution coverage: 0.55	Solution consistency: 0.96	Solution coverage: 0.58	Solution consistency: 0.93

Table 5. FsQCA conditions

Cultural perception	Solution 1	Solution 2	Psychological perception	Solution 1	Solution 2
Cropland	x	x	Cropland	●	•
Forest	●	•	Forest	x	•
Urban	x	•	Urban	•	x
Water	•	x	Water	x	•

Notes: big circle means core conditions, small circle means peripheral conditions; x means missing condition.

5. Discussion

5.1. Methodological construction

To address the problem of landscape change and perception, this research proposes a new workflow and combination of technologies from both natural and social perspectives. Specifically, it utilizes GIS for mapping and spatial analysis, questionnaires for obtaining public opinions, and fsQCA for identifying complex factors in the relationships. The study examines the multiple influences from cropland, water, forest, and urban changes on physical, psychological, and cultural perceptions. The research demonstrated that fsQCA could identify complex causal relationships in landscapes where multiple factors interact between stimuli and reactions. The spatial analysis capabilities of GIS were shown in mapping changes, examining spatial patterns of landscapes, and enhancing decision-making in landscape planning and management by providing detailed data. The questionnaire method from social science has the advantage of quickly obtaining data from a large scale. The constructed method addresses the research question and provides a reference for future landscape studies. Further studies are needed to validate its efficiency in different cases and backgrounds. More improvements can be considered, such as introducing participatory GIS in studying landscape perceptions (Álvarez & McCall, 2019).

5.2. Relationship between landscape change and perception

The study reveals how landscape changes along the Yunnan-Vietnam Railway influence how people perceive their surroundings. Especially, shifts in forests, urban areas, and farmland did not just alter the environment, they also affected how communities feel about their land. For example, areas with forest changes consistently tied to cultural connections. Forest was the landscape that displayed a notable change along the railway (decreasing). Previous research further explained the reasons (Liang et al., 2024; Yoon et al., 2023). Residents who perceived preserved or restored green spaces may report greater feeling in local traditions and a clearer sense of identity. This aligns with earlier work showing nature's role in mental health and community bonds. Conversely, new infrastructure and improved access to services, rapid urban expansion can leave some feelings disconnected from historic landscapes (Wang, 2015).

Besides, the study illustrates that changes in cropland are intricately linked to psychological perceptions, indicating that the transformation of agricultural landscapes impacts residents' sense of comfort, security, belonging, etc. Previous studies have emphasized that shrinking farmland correlated with anxiety about food security and lost livelihoods, echoing studies on emotional ties to agricultural landscapes (Mohit & Azim, 2012; Hwang et al., 2019). For the reasons why landscape changes not significantly lead to physical feelings, Berrang-Ford et al. (2021) found that individuals can adapt to environmental changes over time, which may reduce their sensitivity to changes. However, some other research also stated that citizens can clearly sense the physical changes about landscape using semi-structure interview (Solecka et al., 2022). More research needs to be done to solve this issue in the future. Effective landscape planning must balance ecological and human needs. By addressing physical changes and their emotions, policymakers can focus on the strategies that protect both ecosystems and community well-being.

5.3. Relationship between railway and landscape change

Railway is one of the key factors that can drive landscape change, a fact widely acknowledged by scholars. Previous studies have found that railways may lead to the conversion of agricultural land and grasslands into urban land, as seen in the case of the Longhai Railway in China (Gu & Zhang, 2024). However, vegetation cover can be recovered in other cases, such as along the Qinghai-Tibet Railway (Zou et al., 2024). In the case of the Yunnan-Vietnam Railway, results show that cropland and urban areas increased significantly, while forest and water bodies decreased. These results are basically consistent with previous research (Gu & Zhang, 2024). However, a notable difference is that cropland increased as the railway developed. The reasons for these differences among railways may be due to the type of railways. For example, the Qinghai-Tibet Railway is a mountainous railway, and during its construction, the local government emphasized ecological security for the Tibetan Plateau. In contrast, the Yunnan-Vietnam Railway was a colonial railway, aimed at extending economic and political influence (Altan, 2022), with less consideration given to ecological factors during construction. And the increase in cropland can also be influenced by local policies. For example, China has proposed regulations to protect farmland with high production potential and has emphasized the reform of land allocation systems (Lichtenberg & Ding, 2008).

5.4. Limitation and future research

The landscape change data obtained from the historical maps are meaningful for future land management and land policy-making. They can also be associated with other socio-economic data, such as population, economic growth, and tourism data, to study further the relationship between railway, land, and other socio-economic factors in history. The historical maps collected in this paper focus on mainly a period (70 years) in the history. More historical maps and data need to be gained to cover the blank period of the development of YVR, especially before the railway construction. There are also thousands of historical photos waiting for further analysis. And more methods of analyzing historical photos can be discussed and introduced in the future, such as the building of a virtual 3D model of historical landscape, require GIS or other digital techniques. In order to acquire the current land use/cover data with higher accuracy, the technique of Unmanned Air Vehicle (UAV) can be introduced. As a kind of remote sensing data, the imageries and digital surface models derived from the UAV usually have higher resolutions, which can generate precise land use/land-cover maps for studying regional landscape and environment by GIS techniques. However, for observing the large-scale railway landscape like YVR, it needs more long-term and cooperative research (Iizuka et al., 2018).

Meanwhile, in more geographic studies, the Volunteered Geographic Information has brought more possibilities to collect many real-time imageries, which is an integration of social media and web mapping (Zaccomer & Grassetti, 2017). For example, the geotagged photos loaded on Flickr or other social media can be used for observing the landscape changes along the YVR, which saves time for the process of re-photography. Furthermore, the landscape is a comprehensive system involving both natural and cultural environments and human activities. Various landscape indicators are discussed and used in previous studies. For analyzing the landscape changes, more landscape indicators should be used for an overall landscape assessment. At the same time, railway landscape is also a complex entity related to both landscape factors and railway heritage elements. Assessing railway landscape by indicators still needs further studies (Uuemaa et al., 2013).

6. Conclusions

6.1. Theoretical and practical implications

This study advances the theoretical understanding of landscape-perception dynamics by bridging historical geography with human perception analysis. Unlike traditional studies that often isolate ecological or social factors, the integration of HGIS and fsQCA) reveals how spatial transformations interact with cultural factors and emotional well-being. For example, by reconstructing historical landscape patterns through HGIS, the paper identified that rapid urbanization along the Yunnan-Vietnam Railway after 1954 disproportionately altered water bodies and forests–changes linked via fsQCA to residents' cultural perception and psychological feelings. This methodology offers a reference for future studies aiming to quantify relationship between intangible human experiences, such as place attachment or heritage loss, within spatially evolving contexts. Practically, these findings challenge conventional landscape management frameworks over community perspectives. In areas, where forest conservation efforts aligned with cultural preservation initiatives, residents may have stronger emotional ties to their environment. Conversely, in areas with urban expansion disrupted historic landscapes, leading to community pushback despite more economic gains. Such cases underscore the need for policies that treat cultural heritage and ecological integrity as interconnected assets. For instance, zoning laws could mandate buffer zones around heritage sites to limit urban encroachment while promoting green corridors that enhance both biodiversity and cultural connectivity.

6.2. Conclusions

This research reconstructs over 70 years of landscape evolution along the YVR using historical maps, revealing stark contrasts in how counties adapted to the railway's influence. While urban areas exploded near areas like Kunming and Hekou, water bodies deceased, mainly due to agricultural and industrial demands. Cropland and forest changes, however, followed diverse situations: some regions intensified farming, others reforested, or reflecting urban development priorities. These physical shifts are inseparable from their human dimensions. Communities with preserving forests can be associated these spaces with traditions and identities. But regions with rapid cropland change may generate more psychological feelings, such as anxieties over security. Such patterns highlight that landscape change is not merely an ecological process but a driver for cultural and psychological perceptions. By merging HGIS's spatial method with fsQCA's capacity to model participants responses, this study provides a framework for analyzing environment-perception linkages in other contested landscapes, from post-industrial regions to climate-vulnerable areas. Future work could deepen these insights by pairing historical maps with archival photography or oral histories, capturing not just what changed but how communities memorize or value those transformations. For policymakers, prioritizing participatory planning—such as co-designing green spaces with residents—could mitigate the alienation wrought by top-down development, ensuring that progress honors both ecological and cultural resilience.

Funding

This work was supported by the Xiamen University Malaysia Research Fund under Grant: XMUMRF/2024-C13/IART/0023 & Fujian Social Science Research Fund (FJ2024C128).

Conflicts of interest

The authors declare no conflict of interest.

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