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Exploring the Spatial Distribution of Toponyms and Its Correlation with Landscape Characteristics: A Case Study in Wuhan, China

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Abstract: Toponyms reflect the multifaceted relationship between humans and nature, recording and transmitting important cultural information. A toponymic cultural landscape (TCL) is the comprehensive embodiment of the cultural connotations and landscape significance carried by toponyms, reflecting various factors such as regional culture, historical memory, and social values. Wuhan, as the hinterland of Jing-Chu culture, carries a profound geo-culture and brings together numerous toponymic cultural heritages. Studying the spatial distribution characteristics of Wuhan's toponymic cultural heritage and their association with landscape elements is of great significance in promoting the inheritance of intangible cultural heritage and realizing the orderly continuation of local culture, and it also confers deeper cultural connotations and local characteristics to the process of landscape characterization. This study analyzes 3638 toponyms in Wuhan as the research objects, utilizing geospatial analysis methods, including kernel density analysis, standard deviation ellipse analysis, and average nearest neighbor analysis, to visualize the spatial distribution of Wuhan's TCL. It further combines these methods with the optimal parameter geographic detector (OPGD) model to explore the influence of landscape elements on the spatial distribution of different types of toponyms and their interaction effects. The results show the following: (1) The TCL of Wuhan is divided into two basic types, the natural landscape (61.16%) and the humanistic landscape (41.37%), of which hydrological-related toponyms occupy a significant proportion, reaching 35.02% of the total number of toponyms in Wuhan. (2) The distribution of Wuhan's TCL is characterized by aggregation, mostly in the core area of the city, with the Yangtze River as the main axis, and the density of the spatial distribution of humanistic landscape toponyms varies greatly. (3) The results of a single-factor analysis show that construction land (X2) is an important influencing factor in both natural and humanistic landscape toponyms, which indicates the central role of human activities in the formation of toponyms. (4) The explanatory power of the interaction effect of two factors on the spatial differentiation of Wuhan's TCL is stronger than that of the single factors, which suggests that the spatial differentiation characteristics of the TCL of Wuhan are formed under the joint influence of the respective variables.

Keywords: toponymic cultural landscape; toponyms; landscape characteristics; optimal parameter geographic detector; influencing factors

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1. Introduction

A landscape represents the cumulative expression of natural elements and cultural character within a certain geographical area, following certain patterns and processes [1]. As a cultural landscape with regional identity, a toponym serves as a linguistic imprint that people attach to the landscape. It reveals the deep cultural meanings embedded in regional character, offers insights into the human perception and cognition of natural landscapes, and becomes a unique link between natural geography and human activities [2]. The toponymic cultural landscape (TCL), as part of the world's intangible cultural heritage, holds extraordinary conservation significance in its own right and has non-negligible value for the sustainable development of landscapes and the promotion of cultural diversity [3]. In this study, to better elucidate the comprehensive characteristics of natural and cultural landscapes reflected by toponyms, we analyze toponyms from the perspective of the cultural landscape, thereby adopting a more holistic and integrated approach. The study of TCLs entails an in-depth exploration of the origin, evolution, and geographic distribution of these landscape elements, thereby establishing a link between nature and humanity, history, and modernity [4]. As a cultural phenomenon garnering increasing attention, TCLs have progressively become a focal point of both academic and policy discussions, recognized and actively supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO) for their distinctive cultural value and profound historical significance. The United Nations Conference on the Standardization of Geographical Names (UNCSGN) has emphasized that toponyms are important for the historical and cultural heritage of the country, urging countries to take action to protect them. However, along with the acceleration of the globalization process and the rise of the information society, TCLs are facing several challenges, including the problems of the irregular and non-standard management of toponyms and a general lack of public awareness of protection, which has led to confusion, obfuscation, duplication, anomalies, and the weakening of the cultural characteristics of toponyms [5]. TCL is increasingly facing the risk of homogenization. Systematically protecting, planning, and managing TCLs has become an urgent issue within the field of cultural heritage. In response to the increasingly pressing conservation dilemmas, a series of targeted strategies have been proposed and implemented, including the intensification of standardized management of toponyms, the promotion of scientific naming, and the formulation of plans for the conservation of TCLs [6]. Although both the government and academia have made notable progress in the protection of TCLs, more in-depth work remains necessary at multiple levels. These include advancing quantitative research, developing integrated management approaches, and ensuring the long-term preservation and sustainable utilization of TCLs.

The study of toponyms is typically conducted from disciplinary perspectives such as linguistics and geography, involving systematic classification, the interpretation of their origins, and analyses of their symbolic meanings [7]. TCLs are unique in their widespread and decentralized distribution, in contrast to cultural heritage, which is typically confined to specific geographical areas. This decentralization offers distinctive context for the application of visualization techniques. As a result, research methods have gradually shifted from early qualitative descriptions to quantitative approaches, with spatial analysis techniques such as GIS being widely applied [8]. Nonetheless, this type of quantitative analysis largely remains at the stage of the simple quantitative presentation of data and has yet to demonstrate significant practical application value. As academics deepen their understanding of and research on TCLs, toponymic studies have expanded from the traditional single perspective of etymology and taxonomy to a comprehensive analysis covering political, economic, social, and cultural dimensions [9], and have begun to pay attention to the interactions between toponyms and social, natural, and historical environments [10]. Fur-

ther explorations have focused on areas such as critical toponymy [11], toponymic origins and meanings [12], and toponymic classification and spatial distribution [13]. Despite significant progress in quantitative analytical methods within toponymic research, and a shift from early qualitative descriptions to quantitative analyses in exploring relationships between toponyms and the environment, existing studies remain limited in terms of integrating qualitative and quantitative approaches to comprehensively examine the causes of the spatial distribution patterns of toponyms, particularly the underlying mechanisms of their interactions with the environment. By conducting in-depth exploration and visualization analyses of the underlying meanings of toponyms, the spatial distribution characteristics of TCLs in different geographic regions can be revealed, and the extensive information on the history, culture, social life, and natural resources embedded in toponyms can be more intuitively presented [14], thus providing a scientific basis and decision-making support for the preservation and inheritance of toponymic cultural heritage.

Landscape Character Assessment (LCA), an important tool for interpreting the unique landscape of a region [15], involves the identification of distinctive qualities, patterns, and landscape elements that distinguish one region from another. Toponyms, serving as clear and concise textual symbols, conceptualize landscape elements through the lens of diverse regional cultures [16], thereby becoming a key descriptive factor in LCA. From this cognitive perspective, toponyms align with the goals of LCA and serve as an essential tool for identifying and revealing landscape character while also informing further landscape research. In addition, toponyms can also provide insights into human perception and understanding of the surrounding environment during the characterization process, thus effectively compensating for the limitations of LCA in the perceptual dimension. Currently, toponymic research related to LCA encompasses three main aspects. First, toponyms are used as important landscape indicators to help identify and locate landscape elements [17]. Second, changes in the landscape are revealed through the study of toponyms [18]. Third, research also explores the correlation between toponyms and the environment [19]. In this paper, our primary objective is to explore the factors affecting the formation and distribution of toponyms and to reveal the diverse information contained in toponyms by establishing the correlation between toponyms and landscape elements, which is of great significance for the protection of local culture and the inheritance of cultural heritage.

Wuhan, China, is a representative region with a rich historical and cultural heritage, where urban development and water systems coexist harmoniously. The long history of the Chu culture has shaped the city's unique cultural identity, while the intricate network of rivers, lakes, and harbors has fostered a diverse and vibrant natural environment. Over centuries, the interplay of these natural and human factors has culminated in the formation of a profound TCL. These landscapes not only highlight the uniqueness of culture but have also become an important carrier for the study and inheritance of regional culture. At present, there are limited studies on Wuhan's TCL; the studies that have been published mainly pertain to toponymic cultural connotations and characteristics [20], specific historical examinations and historical changes [21], and the protection and development of tourism resources [22], among others. Research on the overall distribution, spatial pattern, and regional differences in the TCL, as well as its relationship with the overall cultural and socio-economic background of cities, has not been in-depth and comprehensive. Given this, Wuhan was selected for this study, considering the city's notable geographic features, highly recognizable cultural characteristics, and continuity of cultural inheritance. Based on the unique geomorphologic and hydrological features of Wuhan, this study conducts a refined classification of its TCL, with a particular focus on the spatial distribution of the natural and cultural types of TCL. It further explores the relationship between the spatial distribution of the TCL and landscape elements. The aim is to contribute new perspectives

and insights to the study of the TCL in Wuhan, and then to provide a reference for the protection and inheritance of regional intangible cultural landscapes. The main objectives of this study are as follows: (1) to construct a classification framework for the TCL of Wuhan; (2) to quantitatively analyze the spatial distribution characteristics of various kinds of TCL in Wuhan from the perspective of geography; (3) to analyze the influencing factors of the spatial distribution of the TCL in Wuhan using the optimal parameter geographic detector (OPGD) model, and establish the correlation between the spatial distribution of the TCL and landscape elements.

2. Materials and Methods

2.1. Study Area and Data Sources

Wuhan, as the administrative center of Hubei Province, is located in the heart of central China (Figure 1) and is an important transportation hub connecting key regions, including Southwest China, East China, and the Central Plains. It is renowned as the "Thoroughfare of Nine Provinces". The confluence of the Yangtze River and the Han River (a major tributary of the Yangtze) has shaped Wuhan's unique urban pattern. The rivers, streams, and lakes not only nourish the land but also connect the economic, cultural, and social life along their banks, creating a distinctive river city landscape. Wuhan's advantageous geographical location and abundant water resources have created an urban fabric crisscrossed by rivers and dotted with hundreds of lakes, which, in turn, has brought about economic development and prosperity, while the 3500-year history of the Chu culture has given Wuhan unique cultural characteristics and urban charm, leaving behind a large amount of cultural heritage [23]. These factors provide Wuhan with rich natural and cultural landscape information, forming readable geographic features and distinctive urban cultural landscapes, thus shaping Wuhan's unique and richly connotative TCL.

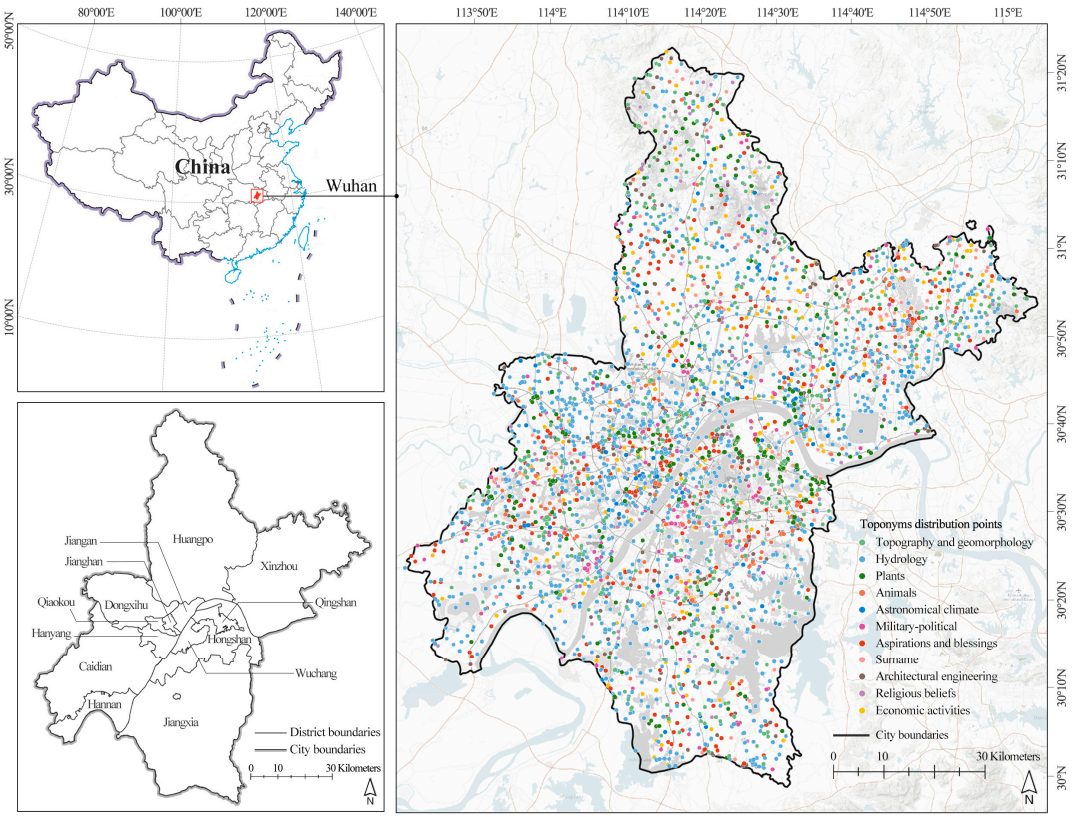


Figure 1. Research region.

Accordingly, this study selected Wuhan City, which has significant geographic features, high recognizability, and strong cultural continuity, as the spatial scope of this research. The study then focused on the TCL within Wuhan. The names, locations, and corresponding latitude and longitude coordinates of 4695 place names in Wuhan in 2017 were collected through open data platforms such as the National Geographic Information Resources Catalog Service System (http://www.webmap.cn/, accessed on 30 May 2025) and Gaode Maps. Subsequently, the data were carefully compared and analyzed with authoritative data sources such as the Wuhan Gazetteer, the Wuhan Toponymic Gazetteer, and the National Database for Geographical Names of China. After identifying and excluding 1057 toponymic data that could not be precisely located, were duplicated, or lacked reliable information support, 3638 toponymic data were finally selected for subsequent in-depth analysis. In addition, the Digital Elevation Model (DEM) data used in this study were obtained from the Geospatial Data Cloud of the Chinese Academy of Sciences (http://www.gscloud.cn/, accessed on 30 May 2025); the land-use data were derived from the China Land Cover Data (CLCD) (https://zenodo.org/records/5816591, accessed on 30 May 2025) released to the public by the team of Prof. Yang J and Prof. Huang X from Wuhan University [24]; the normalized difference vegetation index (NDVI) data were sourced from the MOD13A1.061 Terra Vegetation Indices dataset provided by NASA (https://ladsweb.modaps.eosdis.nasa.gov/, accessed on 30 May 2025); and the hydrographic data were obtained from OpenStreetMap (www.openstreetmap.org, accessed on 30 May 2025).

2.2. Research Methods

2.2.1. Classification of Toponymic Cultural Landscape

Toponyms are naturally characterized by different types of features, which provide different geographical, cultural, historical, and linguistic information [25]. A systematic classification can help researchers better identify and document the characteristic types of different toponyms and recognize the profound meanings behind them. However, as a carrier of regional culture, the diverse manifestations of TCLs, to a large extent, are significantly influenced and constrained by the natural conditions and humanistic background of the regions in which they are located. Given this diversity, the academic community has yet to form a universally applicable classification system for toponyms. With reference to previous research results [26], and in light of the specific conditions of Wuhan, this study divides the toponymic cultural landscape of Wuhan into two categories: the natural landscape and the humanistic landscape. In addition, as natural geographic phenomena tend to be universal and regular, their formation and characteristics have certain commonalities. Therefore, in the analysis of toponyms in the category of natural landscapes, the main focus is on the use of generic names to recognize the general nature of the geographical entities referred to by the names, while the human geographic entities are usually the result of human social activities, and have unique values and different expressions of significance, which need to be accurately identified and differentiated through specific names. Therefore, in the study of toponyms in the category of humanistic landscapes, emphasis is placed on the analysis of toponyms in terms of their specific names to reveal the links between toponyms and human social activities. Through this classification approach, this study aims to construct a systematic framework for the classification of toponyms to promote a deeper understanding of the natural and cultural information embedded in toponyms. Table 1 provides a detailed description of the definitions of various types of toponymic landscapes.

Table 1. The types and definitions of TCLs.

Type		Definition
Natural landscape	Topography and geomorphology	Toponyms describing topographical undulations
	Large surface water	Toponyms describing extensive and continuous surface water areas
	Small surface water	Toponyms describing small-scale and relatively independent surface water areas
	Waterfront	Toponyms describing waterfronts, riverbanks, coastlines, and other water–land interchanges
	Linear waters with high currents	Toponyms describing rapid and turbulent linear waters
	Linear waters with low currents	Toponyms describing slow and gentle linear waters
Humanistic landscape	Plants	Toponyms using the names or characteristics of plants
	Animals	Toponyms using the names or characteristics of animals
	Astronomical climate	Toponyms describing astronomical or climatic phenomena
	Military–political	Toponyms describing military activities or political events
	Aspirations and blessings	Toponyms expressing wishes for blessings
	Surname	Toponyms named after clan surnames
	Architectural engineering	Toponyms named after specific types of buildings (excluding military and political structures)
	Religious beliefs	Toponyms describing religious faith activities or venues
	Economic activities	Toponyms describing specific economic activities or venues

2.2.2. Kernel Density Estimation

Kernel Density Estimation (KDE) is a non-parametric method for estimating the probability density function [27], widely used for its flexibility and non-parametric assumptions about data distributions, including in fields such as cultural heritage conservation and cultural resource management [28]. In this study, KDE is used to visualize the concentration of heritage sites of the TCL, in order to reveal the spatial distribution characteristics of the TCL in Wuhan, and to identify the spatial distribution and morphological associations between the TCL and natural and humanistic environments. The calculation formula is

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \quad (1)$$

In Equation (1), f(x) represents the density value at the target point; indicates the number of points within the bandwidth range; $K\left(\frac{x-x_i}{h}\right)$ is the kernel function; $x - x_i$ denotes the distance between the estimation point x and the target point x_i; and h is the bandwidth, which determines the level of detail in the analysis results.

2.2.3. Standard Deviation Ellipse

The standard deviational ellipse (SDE) is a spatial statistical technique used to quantitatively describe the spatial distribution characteristics of geographical features [29]. In this study, the SDE method is employed to analyze the central tendency, directionality, and dispersion of toponymic heritage sites in Wuhan. The formula is as follows:

$$\text{Center-of-gravity model}: \ \overline{X}_w = \sum_{i=1}^{n} w_i x_i / \sum_{i=1}^{n} w_i; \overline{Y}_w = \sum_{i=1}^{n} w_i y_i / \sum_{i=1}^{n} w_i \quad (2)$$

$$\text{Azimuth angle}: \ tan\theta = \frac{\left(\sum_{i=1}^{n} w_i^2 \tilde{x}_i^2 - \sum_{i=1}^{n} w_i^2 \tilde{y}_i^2\right) + \sqrt{\left(\sum_{i=1}^{n} w_i^2 \tilde{x}_i^2 - \sum_{i=1}^{n} w_i^2 \tilde{y}_i^2\right)^2 + 4\sum_{i=1}^{n} w_i^2 \tilde{x}_i^2 \tilde{y}_i^2}}{2\sum_{i=1}^{n} w_i^2 \tilde{x}_i \tilde{y}_i} \quad (3)$$

$$\text{X-axis standard deviation}: \ \partial_x = \sqrt{\sum_{i=1}^{n} \left(w_i \overline{x}_i cos\theta - w_i \overline{y}_i sin\theta / \sum_{i=1}^{n} w_i^2\right.} \quad (4)$$

$$\text{Y-axis standard deviation}: \partial_y = \sqrt{\sum_{i=1}^{n}\left(w_i\overline{x}_i sin\theta - w_i\overline{y}_i cos\theta / \sum_{i=1}^{n} w_i^2\right.} \quad (5)$$

In Equations (2)–(5), (x_i, y_i) represents the spatial coordinates of toponyms; w_i represents their spatial weight; $(\overline{x}_w, \overline{y}_w)$ represents the weighted average center of each type of toponym; θ is the azimuth of the ellipse; $\hat{x}_i$ and $\hat{y}_i$ represent the deviation in the spatial coordinates of various toponyms from the average center; and ∂_x and ∂_y represent the standard deviations of the ellipse along the x-axis and the y-axis.

2.2.4. Nearest Neighbor Index

The Nearest Neighbor Index is used to calculate the average Nearest Neighbor Index R for each type of TCL, to assess its spatial distribution patterns [30]. This study method allows for the quantitative analysis of the spatial distribution patterns of toponyms and provides statistical evidence to validate the study's conclusions. The formula is as follows:

$$R = \frac{\overline{r_1}}{\overline{r_E}} = 2\sqrt{D} \quad (6)$$

In Equation (6), $\overline{r_1}$ represents the Actual Nearest Neighbor Distance, $\overline{r_E}$ represents the average Theoretical Nearest Neighbor Distance, and D is the point density. It is generally accepted that R < 1 represents a cohesive distribution, R = 1 represents a random distribution, and R > 1 represents a uniform distribution.

2.2.5. Parameter-Optimized Geodetector

Geodetector is a statistical method for detecting spatially stratified heterogeneity and revealing the driving factors behind it [31]. Traditional Geodetector uses subjective determination of the discretization of driving factors, which suffers from poor discretization and subjectivity.

Therefore, using the point data of 15 types of TCL as the dependent variables, and 7 types of landscape elements (elevation, slope, river density, etc.) as the independent variables, this study investigates the use of OPGD to discretize the spatial data [32]; in addition, it utilizes a factor detector to analyze the influence of each driving factor on the spatial heterogeneity of each type of toponym, and an interaction detector to assess whether the combined effect of the influencing factors would increase or weaken the explanatory power of the dependent variable. The aim is to explore whether there is a significant correlation between the spatial distribution patterns of the TCL in the study area and landscape elements.

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \quad (7)$$

In Equation (7), L is the stratification of dependent variables Y or factors X, N_h and N denote the number of units in stratum h and in the whole region, and σ_h^2 and σ^2 denote the variance in stratum h and dependent variable Y of the whole region, respectively. SSW is the sum of variance within the strata, and SSW is the total variance of the whole area. The q-value lies within the range [0, 1], where a higher q-value indicates a stronger explanatory power of the independent variable X on the dependent variable Y, and vice versa.

3. Results

3.1. Classification Results of Toponymic Cultural Landscape

This study divides the TCL of Wuhan into two types: the natural landscape and the humanistic landscape. The natural landscape includes topography and geomorphology, hydrology, plants, animals, and astronomical climate, while the humanistic landscape in-

cludes military–political, aspirations and blessings, surname, architectural engineering, religious beliefs, and economic activities. In addition, considering the unique hydrological conditions and diversified water body types in the study area, a more detailed categorization of hydrological toponyms is conducted to provide a more comprehensive and refined description and classification of the TCL in Wuhan. According to the area of the water, the size of water flow and the degree of association with human activities, they are further divided into five tertiary subcategories: large surface water, small surface water, waterfront, linear waters with low currents, and linear waters with high currents. Specific categorization and statistical data are shown in Table 2.

Table 2. Wuhan toponym classification table.

Type	Subtype	Tertiary Type	Words/Phrases That Occur More Frequently	Quantity	%
Natural landscape	Topography and geomorphology		Mountain (*山*), Ridge (*岭*), Knoll (*岗*), Hollow (*冲*), Recess (*墈*), Mound (*墩*), Rock (*石*), Peak (*岱*), Summit (*峰*), Soil (*土*), Hill (*丘*), Col (*坳*), Cliff (*陡*), Valley (*谷*)	420	11.54
	Hydrology	Waterfront	Shore (*岸*), Dam (*坝*), Waterfront (*滨*), Levee (*堤*), Ferry Crossing (*渡*), Mudflat (*沌*), Harbor (*港*), Estuary (*浦*), River (*泗*), Beach/Mudflat (*滩*), Bay (*湾*), Weir (*堰*), Sluice Gate (*闸*)	382	10.50
		Large surface water	Ocean (*洋*), Lake (*湖*), Sea (*海*), Sai (*赛*)	400	11.00
		Small surface water	Pond (*塘*), Spring (*泉*), Pool (*池*), Dangzi (*荡子*)	106	2.91
		Linear waters with low currents	Creek (*溪*), Gully (*沟*), Canal (*渠*), Point (*咀*), Ravine (*涧*), Distributary (*汊*)	172	4.73
		Linear waters with high currents	Chuan (*川*), River (*河*), Major River (*江*)	214	5.88
	Plants		Cedar (*柏*), Maple (*枫*), Osmanthus (*桂*), Lotus (*荷*), Locust Tree (*槐*), Orchid (*兰*), Lotus (*莲*), Willow (*柳*), Plum (*梅*), Persimmon (*柿*), Sandalwood (*檀*), Crabapple (*棠*), Peach (*桃*), Camphor Tree (*樟*), Bamboo (*竹*)	307	8.44
	Animals		Leopard (*豹*), Phoenix (*凤*), Crane (*鹤*), Tiger (*虎*), Oriole (*鹂*), Loong (*龙*), Deer (*鹿*), Horse (*马*), Lion (*狮*), Ostrich (*鸵*), Crow (*鸦*), Goose (*雁*), Sheep (*羊*)	132	3.63
Humanistic landscape	Astronomical climate		Sun (*阳*), Star (*星*), Cloud (*云*), Moon (*月*), Wind (*风*), Rain (*雨*)	92	2.53
	Military–political		Fort (*堡*), Prefecture (*府*), Workers and Peasants (*工农*), Official (*官*), Trench (*壕*), Army (*军*), First Uprising (*首义*), Patrol (*巡*), Vanguard (*先锋*), Hero (*英雄*), Post Station (*驿*), Leap Forward (*跃进*)	224	6.16
	Aspirations and blessings		Happiness (*福*), Morality (*德*), Rich (*富*), Sweet Dew (*甘露*), Glory (*光辉*), Light (*光明*), Peace (*和平*), Joy (*欢乐*), Diligence (*勤*), Dawn (*曙光*), Unity (*团结*), Future (*未来*), Happiness (*幸福*), Fulfill dreams (*圆梦*)	333	9.15

Table 2. *Cont.*

Type	Subtype	Tertiary Type	Words/Phrases That Occur More Frequently	Quantity	%
	Surname		Bao (*鲍*), Cai (蔡), Chen (陈), Deng (邓), Ding (*丁*), Dong (*董*), Fang (*方*), Feng (*冯*), Fu (*付*), Hu (*胡*), Liu (*刘*), Liao (*廖*), Pan (*潘*), Luo (*罗*), Peng (*彭*), Song (*宋*), Qiu (*邱*), Tu (*涂*), Yue (*岳*), Yao (*姚*), Tao (*陶*), Yuan (*袁*), Zhang (*章*), Ye (*叶*), Zhao (*赵*)	160	4.40
	Architectural engineering		Bridge (*桥*), Shed (*棚*), Pavilion (*亭*), Yard (*院*), Tile (*瓦*), House (*屋*), Building (*楼*), Gate (*门*), Room (*房*), City (*城*), Boat (*船*), Belvedere (*阁*), Alley (*巷*), Terrace (*台*), Station (*站*)	282	7.75
	Religious beliefs		Daoist Temple (*观*), Monk (*和尚*), Temple (*庙*), Hermitage (*茅*), Monastery (*寺*), Deity (*神*), Pagoda (*塔*), Buddha Hall (*堂*), Nunnery (*庵*), Zen (*禅*), Ancestral Hall (*祠*), Buddha (*佛*)	150	4.12
	Economic activities		Market (*市*), Farmland (*田*), Fishery (*渔*), Paper Industry (*纸*), Village (*庄*), Merchant (*商*), Garden (*园*), Fair (*集*), Cultivation (*稼*), Mine (*矿*), Grain (*粮*), Plot (*圃*), Farmer (*农*), Factory (*厂*), Shop (*店*), Workshop (*坊*) *	264	7.26

* Parentheses contain Chinese characters corresponding to English terms. For unique terms (e.g., surnames) and Wuhan dialect words, pinyin is used in translation.

The TCL of Wuhan is deeply influenced by its mountain–water environment. In the toponymic study of Wuhan, the statistical analysis of toponymic data (Figure 2) shows that 2225 toponyms fall under the category of natural landscapes (61.16%), accounting for the majority of all toponyms. Meanwhile, 1505 toponyms belong to the category of humanistic landscapes (41.37%), also representing a significant proportion. This distribution fully reflects both the natural characteristics and the profound cultural heritage of Wuhan as a 'mountain–water–city' city, and reveals the close correlation between Wuhan's toponyms and its local geographical and cultural features [33]. It is worth noting that the total number of hydrological toponyms is 1274, accounting for 35.02% of all toponyms in Wuhan and 57.26% of those within the category of natural landscapes. This significant proportion not only underscores the geographical characteristics of Wuhan as a city built on rivers with an extensive water system and abundant water bodies, but also reflects the profound influence of water culture on the region's cultural identity.

3.2. Spatial Distribution Characteristics of TCL

3.2.1. Spatial Distribution Characteristics of Toponyms in the Natural Landscape Category

Toponyms in the natural landscape category are mostly direct expressions of specific locations and their surrounding natural environments. They typically reflect the natural characteristics of the area and document how humans have adapted and transformed the natural environment [34]. Based on the three-level classification framework of Wuhan's TCL described in the previous section, the spatial distribution characteristics of natural landscape toponyms are further analyzed (Figures 3 and 4).

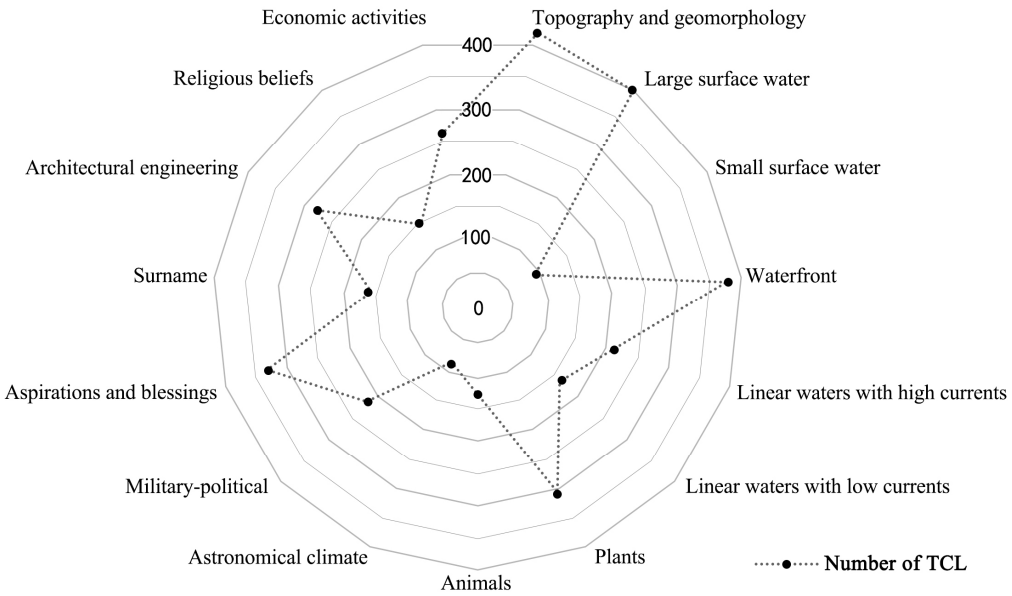


Figure 2. Proportion of various types of TCL.

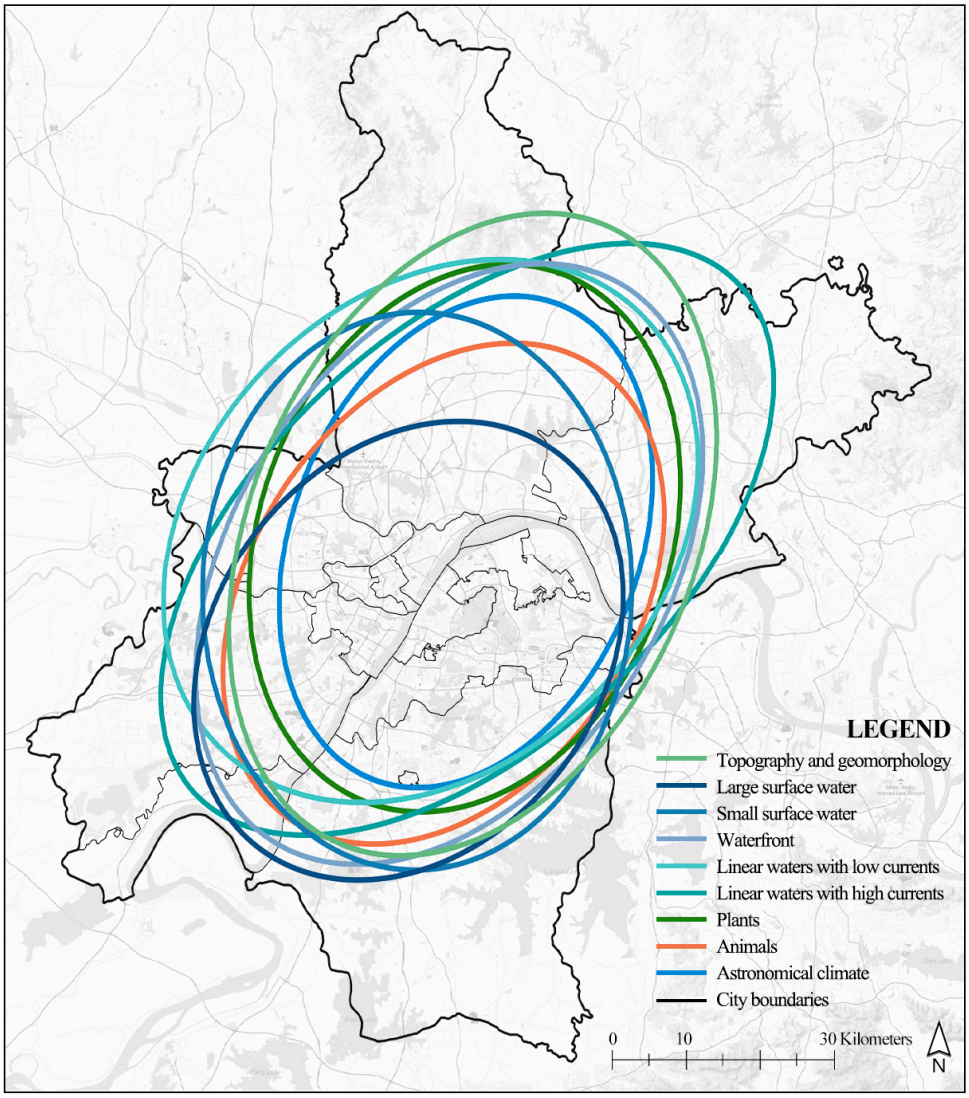


Figure 3. Results of standard deviational ellipse for toponyms in natural landscape category.

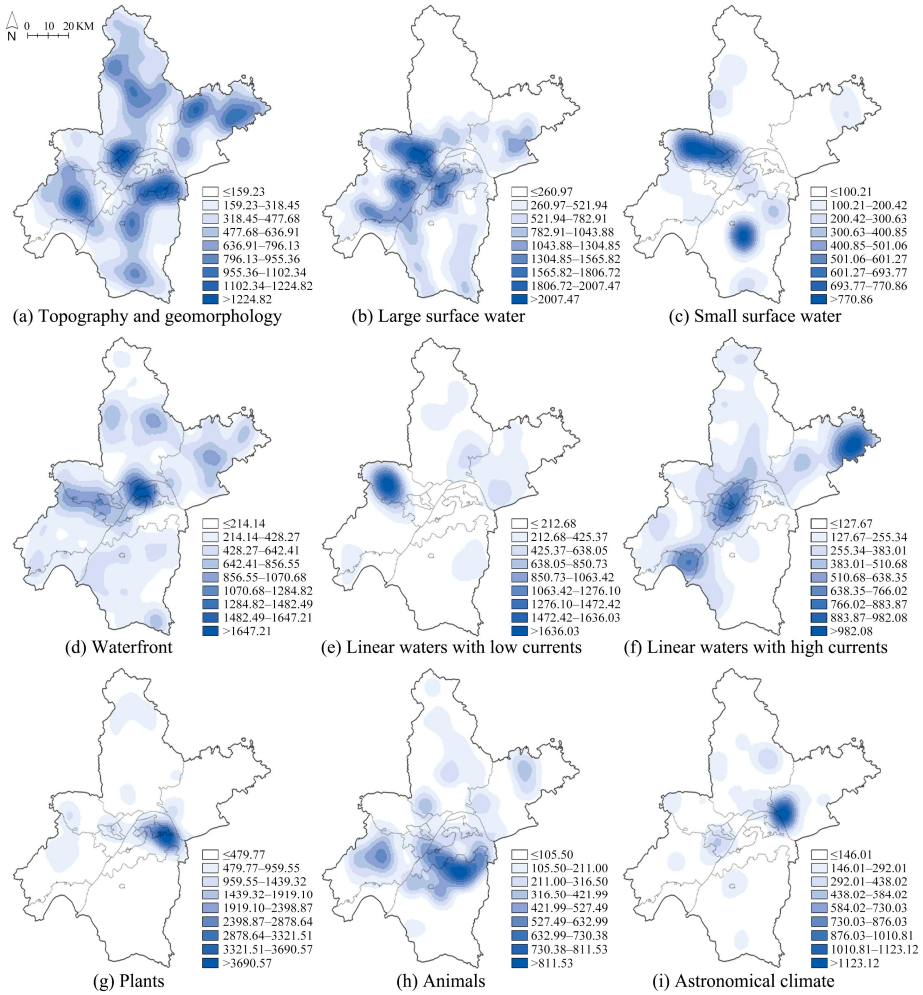


Figure 4. Distribution of kernel density for each type of toponym in natural landscape category.

When R < 1, it represents an aggregated distribution. The natural landscape toponyms in Wuhan are generally distributed in an aggregated pattern (as most R-values are less than 1) (Table 3), featuring widespread coverage with regionally concentrated clusters. This indicates that certain areas are more likely to have a concentration of specific types of toponyms [35].

The following results were obtained through an analysis using the SDE and KDE:

The spatial distribution of toponyms related to topography and geomorphology in Wuhan presents obvious directional characteristics, mainly along the northeast to southwest direction. Under this distribution pattern, five high-density core areas of toponyms have emerged across various administrative districts. Specifically, toponyms in the southern part of Hongshan District, Jiangan District, and Jianghan District of Wuhan show a high density of distribution, while the density of toponyms in the southwestern part of Xinzhou District and the northern and southern parts of Jiangxia District is relatively low.

Toponyms related to hydrology in Wuhan are distributed in the northeast–southwest direction. Wuhan has a well-developed water system throughout the city, and hydrological toponyms are therefore widely distributed, clustered in each administrative district. The distribution pattern varies according to the different forms, sizes, and flow characteristics of the waters. In addition, the spatial distribution of hydrological toponyms tends to cluster in specific geographical units, usually along urban lakes and rivers, rather than randomly. This distribution pattern partly reveals the close relationship between toponyms and natural water bodies.

Table 3. The spatial distribution of toponyms in the natural landscape category.

No.	Types	$\bar{r}_1$ (km)	$\bar{r}_E$ (km)	*R*	Z-Score	*p*-Value	Pattern
1	Topography and geomorphology	2.02	2.62	0.77	−9.06	0.00	Clustered
2	Large surface water	1.88	2.56	0.73	−10.22	0.00	Clustered
3	Small surface water	3.25	4.81	0.67	−6.41	0.00	Clustered
4	Waterfront	2.15	2.69	0.80	−7.49	0.00	Clustered
5	Linear waters with low currents	2.91	3.98	0.73	−6.74	0.00	Clustered
6	Linear waters with high currents	2.70	3.58	0.75	−6.91	0.00	Clustered
7	Plants	1.90	3.00	0.63	−12.35	0.00	Clustered
8	Animals	3.07	4.33	0.71	−6.38	0.00	Clustered
9	Astronomical climate	3.71	4.47	0.83	−3.09	0.00	Clustered

$\bar{r}_1$: Actual Nearest Neighbor Distance; $\bar{r}_E$: Theoretical Nearest Neighbor Distance; *R*: Nearest Neighbor Index.

The distribution of toponyms related to plants in Wuhan is primarily characterized by a northeast–southwest direction. The overall distribution is relatively dispersed, with a high-density cluster only between Yandong Lake and Yanxi Lake in the eastern part of Hongshan District. This may be because, although plants hold a prominent position in terms of quantity as natural elements, their identifying role is less noticeable. This is due to their relatively small individual size, with a single plant species often insufficient to become a representative feature of an area.

The spatial distribution of toponyms related to animals shows apparent regularity, with the northeast–southwest direction as the main distribution axis, and the distribution is relatively centralized, with a strong centripetal tendency. However, in spite of this clustering trend, the distribution of animal toponyms in other areas, such as the regions near Hou Lake and Wu Lake in Huangpi District, as well as Ju River and Zhangdu Lake in Xinzhou District, is more dispersed, and the density of toponyms is lower.

Toponyms related to astronomical climate in Wuhan are mainly distributed along the northeast–southwest direction, mainly clustered in the vicinity of Zhujia Lake in the southwest of Xinzhou District. These toponyms mostly originate from people's reverence and yearning for celestial phenomena and express their wishes. Due to the universality and randomness of celestial phenomena, they are not concentrated in certain areas like geographic features, so the related toponyms also show a more scattered distribution.

3.2.2. Spatial Distribution Characteristics of Toponyms in Humanistic Landscape Category

Toponyms in the humanistic landscape category are the projection of people's value orientations, cultural concepts, and spiritual pursuits on physical entities. They usually reflect the distinctive cultural characteristics of a region and record the process of human adaptation to and shaping of the environment. Based on the three-level classification framework of Wuhan's TCL, the spatial distribution characteristics of toponyms in the humanistic landscape category are further elaborated and visualized in Figures 5 and 6.

Compared with the distribution characteristics of the natural landscape category, the humanistic landscape in Wuhan shows an aggregated distribution in general (R > 1) (Table 4), and the high-density cluster areas of these toponyms are mainly located in the city center, which reflects the close connection between the humanistic landscape and human activities. In addition, in addition to the densely distributed central city, the surrounding areas of the city also show a widespread distribution, which reflects that this category of toponyms does not follow a specific geographical distribution, but has a certain degree of randomness.

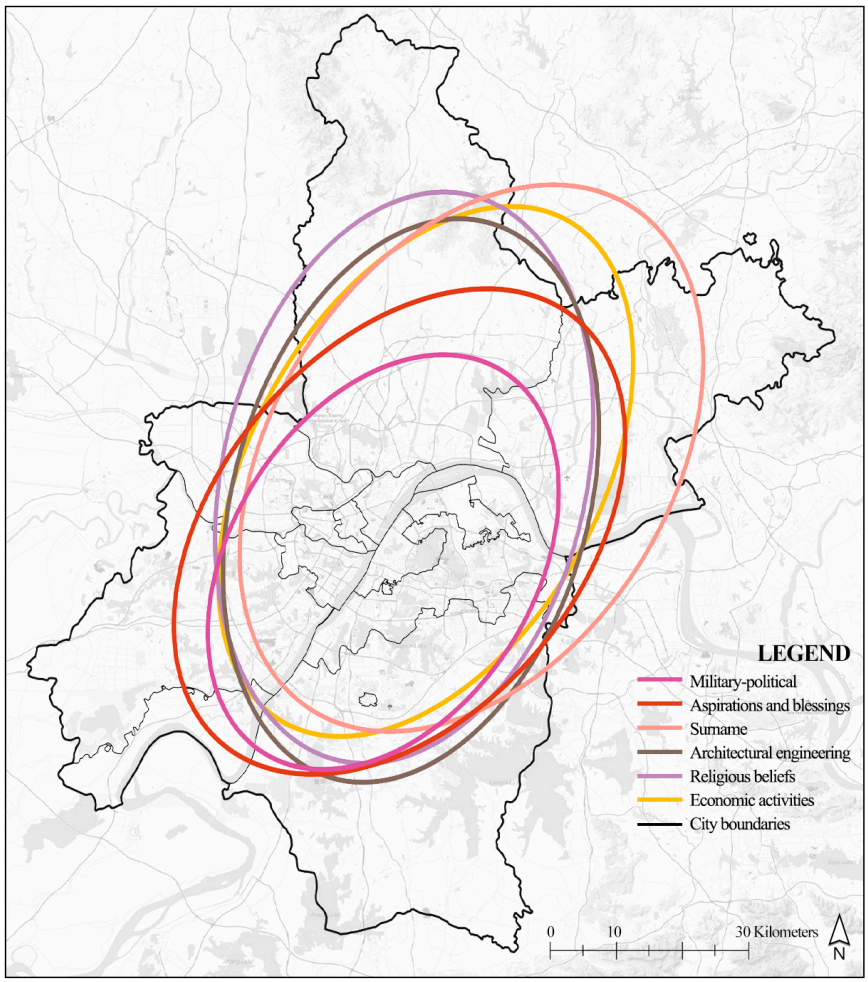


Figure 5. Results of standard deviational ellipse for toponyms in humanistic landscape category.

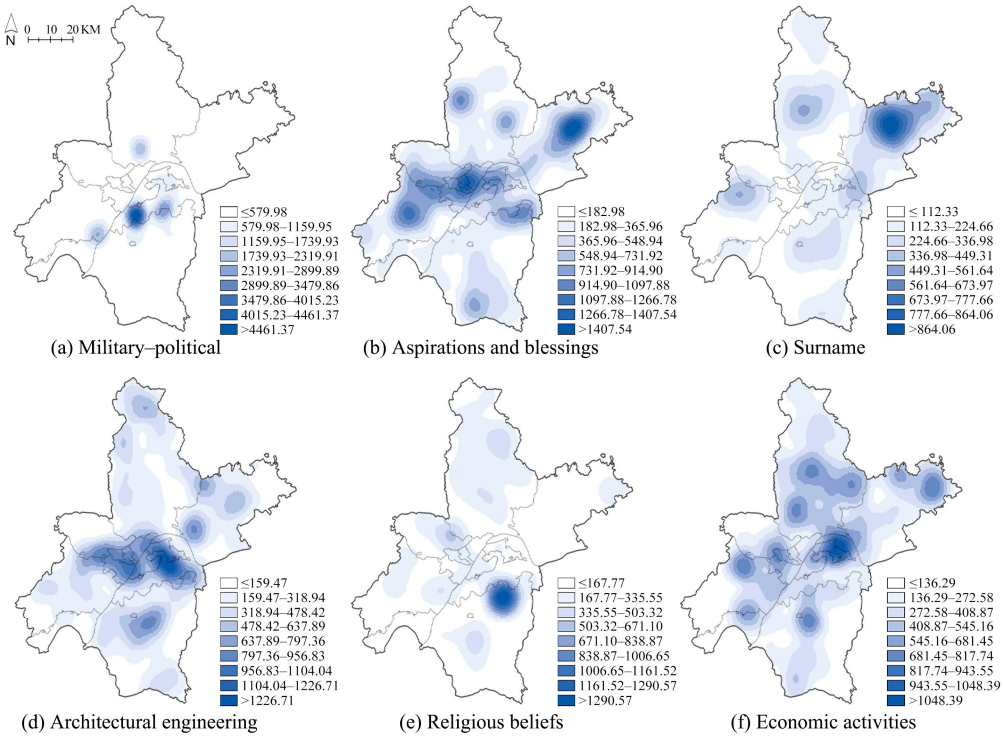


Figure 6. Distribution of kernel density for each type of toponym in humanistic landscape category.

Table 4. The spatial distribution of toponyms in the humanistic landscape category.

No.	Type	$\bar{r}_1$ (km)	$\bar{r}_E$ (km)	*R*	Z-Score	*p*-Value	Pattern
1	Military–political	2.27	3.55	0.64	−10.37	0.00	Clustered
2	Aspirations and blessings	2.08	2.85	0.73	−9.42	0.00	Clustered
3	Surname	3.09	4.00	0.77	−5.51	0.00	Clustered
4	Architectural engineering	2.09	3.18	0.66	−11.07	0.00	Clustered
5	Religious beliefs	2.89	4.40	0.66	−8.04	0.00	Clustered
6	Economic activities	2.51	3.12	0.80	−6.24	0.00	Clustered

$\bar{r}_1$: Actual Nearest Neighbor Distance; $\bar{r}_E$: Theoretical Nearest Neighbor Distance; *R*: Nearest Neighbor Index.

The following results were obtained through an analysis using the SDE and KDE:

Toponyms related to military and political themes in Wuhan are mainly distributed along the northeast–southwest direction. The distribution of the toponyms shows the characteristics of a continuous distribution in the center and a star-shaped distribution in the surroundings, mainly clustered and distributed in the vicinity of Shengli Park and Wuchang Institute of Technology in the southwest of Hongshan District, and in the vicinity of Zhongnan University of Economics and Law in the southeast. The formation of these toponyms mostly originates from historical military activities, as well as the remnants of military facilities such as communication and defense infrastructure.

Toponyms related to aspirations and blessings in Wuhan are mainly distributed along the northeast–southwest direction. The overall trend of its distribution is from northeast to southwest, forming a belt-like structure. With this belt as the core, the quantity and aggregation of aspirations-and-blessings toponyms gradually decrease toward the periphery. These toponyms are closely related to religious beliefs and historical events, reflecting the spiritual aspirations and value orientations of local residents, and are therefore mostly distributed in densely populated urban areas.

Toponyms related to surnames are mainly distributed in the northeast–southwest direction. The spatial distribution of such toponyms does not form a clear core of aggregation or an axis of distribution. This phenomenon may stem from the fact that such toponyms are often closely associated with human settlement, migration, and daily life, and their geographical distribution reflects the randomness and diversity of human activities more than a specific geographical distribution pattern.

Toponyms related to architectural engineering are mainly distributed in the northeast–southwest direction. In terms of spatial distribution, there is a contiguous high-density agglomeration in the central part of Wuhan city, while the rest of the city has a discrete distribution pattern. Combined with the frequent use of words such as reservoir, bridge, and rudder in architectural engineering toponyms, this shows that architectural engineering toponyms have a significant correlation with the density of Wuhan's water system. As a result, such toponyms are often distributed in the central urban area, where the water network is extensive and water conservancy is well developed.

The overall spatial distribution of toponyms related to religious beliefs is mainly along the south–north direction. The spatial distribution is characterized by the structure of local high values and a single core, with the high-density area radiating outwards from the vicinity of Fozuling in the northeastern part of Jiangxia District, and the distribution of such toponyms intuitively reveals the diversity of religious beliefs in Wuhan.

The spatial distribution of toponyms related to economic activities is characterized mainly by an extension along the northeast-to-southwest direction. The spatial distribution of such toponyms is relatively extensive, but the degree of aggregation is relatively low, forming several small but high-density clusters. Wuhan has been an economic center

in central China since ancient times, and the wide distribution of such toponyms maps the activity and prosperity of economic activities in the city.

3.3. Analysis of the Correlation Between Spatial Distribution of TCL and Landscape Characteristic Elements

3.3.1. Evaluation Index System of Influential Factors

Toponyms often visually reflect the salient features of a region's physical environment, reflecting the direct human perception of the natural environment, and thus serve as an important link between the natural landscape and human perception [36]. It is through the process of naming that the link between the natural environment and the cultural significance of the landscape becomes intertwined in toponyms [37]. By examining toponyms within the context of cultural landscapes, this study establishes a correlation between the spatial distribution of the TCL and landscape elements. The significance of the study lies not only in the simple identification and characterization of the cultural landscape, but also in its ability to reveal the complex and profound relationship between humans and the natural environment.

Toponyms are characterized by stability and durability and are typically preserved over a long period. Therefore, if inconsistencies are found between toponyms and current landscape character, it is most likely due to the landscape character itself having changed, and these inconsistencies provide an opportunity for research to explore potential factors contributing to the mismatch between toponyms and contemporary landscape character. Based on this recognition, to further explore the formation mechanisms and influencing mechanisms of the TCL in Wuhan, by integrating and analyzing the unique natural geographic features and cultural attributes of the study area, and based on the distinctive identifiers of different types of TCL, we filtered out landscape elements that are highly correlated and stable upon the formation of toponyms and their evolutionary process as the entry point for the study (Table 5). Due to the rapid advancement of urbanization in China, many socio-economic landscape elements, such as GDP, population density, road network density, etc., were not included in the indicator system of this study because of their high variability, which makes it difficult to keep them stable in a short period.

Table 5. Indicators of landscape elements.

Independent Variable	Factor Index
X1	Unused land
X2	Construction land
X3	Slope
X4	Aspect
X5	Elevation
X6	River density
X7	Normalized difference vegetation index (NDVI)

3.3.2. Analysis of Influencing Factors

(1) Analysis of Influencing Factors on Toponyms in the Natural Landscape Category

Based on the results of the single-factor detection, the q-value, indicating the influence of each indicator on the spatial distribution of natural landscape toponyms in Wuhan, was obtained (Table 6). To reveal the explanatory power of each factor more clearly, the study determined only the landscape elements that passed the significance test, which are shown in Figure 7. Overall, construction land (X2), elevation (X5), and NDVI (X7) are the three most common factors affecting the distribution of various types of natural landscape toponyms; the factor detection results of unused land (X1) in various types of natural land-

scape toponyms are not significant ($p < 0.05$), indicating that this factor does not have a significant driving effect on the spatial distribution of natural landscape toponyms. The results of the specific analyses are as follows:

Table 6. Single-factor detection results for natural landscape toponyms.

Type	Targets	X1	X2	X3	X4	X5	X6	X7
Topography and geomorphology	Q Value	0.032	0.138	0.066	0.071	0.217	0.087	0.043
	p Value	0.636	0.000	0.000	0.000	0.000	0.000	0.000
Hydrology	Q Value	0.051	0.293	0.091	0.082	0.209	0.090	0.206
	p Value	0.510	0.000	0.000	0.000	0.000	0.000	0.000
Plants	Q Value	0.001	0.143	0.012	0.032	0.027	0.105	0.059
	p Value	1.000	0.000	0.212	0.000	0.000	0.000	0.000
Animals	Q Value	0.020	0.287	0.036	0.046	0.087	0.081	0.132
	p Value	0.460	0.000	0.000	0.000	0.000	0.000	0.000
Astronomical climate	Q Value	0.011	0.108	0.043	0.022	0.041	0.022	0.063
	p Value	0.742	0.000	0.000	0.012	0.000	0.010	0.000

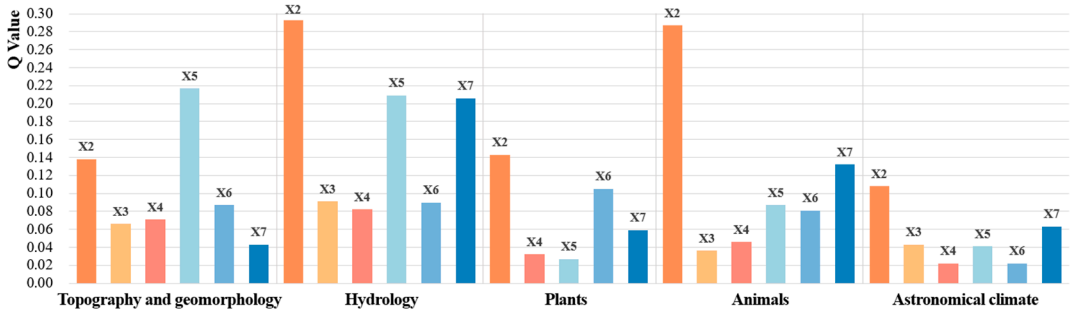


Figure 7. Single-factor detection results for natural landscape toponyms.

Elevation (X5) has the strongest explanatory power for the distribution of toponyms related to topography and geomorphology. This finding is highly consistent with the spatial distribution of such toponyms, which are concentrated in the hilly areas of Wuhan, reflecting people's intuitive cognition and naming habits of topographic features. For toponyms related to hydrology, the top three factors in the factor detection results are construction land (X1), elevation (X5), and vegetation cover (X7). This conclusion indicates that toponyms related to hydrology are not significantly correlated with river density. This is likely because such toponyms are not only distributed in areas adjacent to water bodies but are also widely found in human-inhabited areas. This phenomenon reflects the significant impact of human activities on the distribution pattern of hydrologic toponyms, which is no longer closely related to the distribution of natural water bodies but is intertwined with human settlement and construction activities. For toponyms related to plants, the factor detection results are ranked as follows: construction land (X2) > river density (X6) > NDVI (X7) > aspect (X4) > elevation (X5). The formation of such toponyms is often closely related to the species and uses of plants and their symbolic meanings, which is informative to a certain extent. However, since people's cognition and understanding of plants are often at a micro-level, the limitation of such micro-cognition leads to the fact that plant toponyms may only reflect the characteristics of plants in a small region, but cannot cover the plant diversity of the whole region, which results in the lack of a clear geographic pattern in the distribution of plant toponyms. Therefore, although their distribution is influenced by the NDVI factor, a direct correlation cannot be established; for toponyms related to animals, the factor with the strongest explanatory power is construction land (X2), followed by NDVI (X7) and elevation (X5). This is because animals are closely related to the

production and lives of human beings and play important roles in people's lives as prey, poultry, pets, etc. Therefore, the naming of animal toponyms is mostly distributed in areas where people live in groups. In addition, animal toponyms often contain the names of mythical beasts such as the "dragon" and "phoenix". The phoenix, as a mythological bird in traditional Chinese mythology, likes to live in high places, and using the word "phoenix" in a place name may be a metaphor for the existence of a certain mountainous and hilly terrain in this area, which is the reason why animal toponyms can be associated with such landscape elements as elevation. Toponyms related to astronomical climate have relatively weak explanatory power compared to other types of toponyms, as astronomical and climatic phenomena usually occur on a large spatial and temporal scale, such as seasonal changes and solar term variations, and it is difficult for these phenomena to form a clear and persistent geographic identity in a localized area. In addition, astronomical climate is more difficult to represent through specific geographic entities than other natural elements, which also makes it more difficult to establish a significant correlation with landscape elements in this category of toponyms.

(2) Analysis of Influencing Factors on Toponyms in Humanistic Landscape Category

Table 7 shows the results of the single-factor detection for different categories of humanistic landscape toponyms, and Figure 8 displays only the elements that passed the significance test. Overall, the influence of human activity factors on the formation of toponyms is more significant than that of natural geographic factors. Construction land (X2), elevation (X5), and NDVI (X7) are the three most common dominant factors affecting the distribution of various types of humanistic landscape toponyms. Compared with natural landscape toponyms, the formation of humanistic landscape toponyms is affected by a variety of factors (personal experience, cultural background, etc.), and the distribution is relatively random and lacks a geographical regularity. The results of the specific analyses are as follows:

Table 7. Single-factor detection results for humanistic landscape toponyms.

Type	Targets	X1	X2	X3	X4	X5	X6	X7
Military–political	Q Value	0.028	0.282	0.027	0.026	0.034	0.076	0.183
	p Value	0.062	0.000	0.000	0.001	0.000	0.000	0.000
Aspirations and blessings	Q Value	0.023	0.279	0.140	0.092	0.227	0.049	0.126
	p Value	0.604	0.000	0.000	0.000	0.000	0.000	0.000
Surname	Q Value	0.006	0.108	0.086	0.058	0.192	0.051	0.061
	p Value	0.893	0.000	0.000	0.000	0.000	0.000	0.000
Architectural engineering	Q Value	0.013	0.361	0.046	0.052	0.080	0.071	0.125
	p Value	0.922	0.000	0.000	0.000	0.000	0.000	0.000
Religious beliefs	Q Value	0.015	0.088	0.026	0.034	0.063	0.043	0.065
	p Value	0.589	0.000	0.005	0.000	0.000	0.000	0.000
Economic activities	Q Value	0.012	0.259	0.077	0.050	0.110	0.046	0.100
	p Value	0.991	0.000	0.000	0.000	0.000	0.000	0.000

The reason for the formation of military and political toponyms lies in the historical military activities and construction of facilities; these activities usually require specific land resources to establish camps, fortresses, official offices, and other related military buildings, and these buildings have gradually become representative of the region over time. Thus, the formation of military–political toponyms is closely related to construction land. The main influencing factors for the distribution of toponyms related to aspirations and blessings are construction land (X2) and elevation (X5). These toponyms symbolize people's values and spiritual pursuits, and most of them contain words such as "fortune", "peace", and "unity". Based on the desire for a better life and the worship of deities, peo-

ple often assign specific cultural and religious meanings to the surrounding natural environment, thus forming toponyms related to their wishes for blessings. Therefore, such toponyms are also mostly generated in communities, villages, and other areas where people gather. This kind of naming not only reflects people's spiritual needs, but also strengthens the community's sense of cultural identity and belonging, becoming an important way to strengthen social cohesion and transmit cultural heritage. Construction land (X2) is also the factor with the highest explanatory power in the distribution of toponyms related to surname. The naming format of "family name + village" (e.g., Li Village, Wang Village, etc.) is commonly adopted for this kind of toponym. This naming style is a reflection of the naming tradition of Chinese villages and is closely related to the structure of Chinese feudal society, in which the family was the basic social unit. Therefore, the distribution of such toponyms is mainly concentrated in villagers' residential areas; toponyms related to architectural engineering visually reflect the architectural characteristics or history of the region, and have a certain identifiability. As a result, this type of toponym is mostly located in built-up areas, transportation hubs, or areas with important architectural and historical significance. The overall explanatory power of factors related to religious belief toponyms is lower than that of other types of humanistic landscape toponyms. This is because this kind of toponym often has strong metaphorical and symbolic meaning; the cultural and spiritual connotation behind it is more abstract; it lacks regularity in its distribution; and it is more difficult to establish a direct correlation with the landscape elements. The factor detection results for toponyms related to economic activities are as follows: construction land (X2) > elevation (X5) > NDVI (X7) > slope (X3) > aspect (X4) > river density (X6). This is because human social interactions, economic activities, and cultural inheritance tend to be more frequent in areas where construction land is more concentrated, and people gather, live, and trade in these places, which triggers the naming of such toponyms.

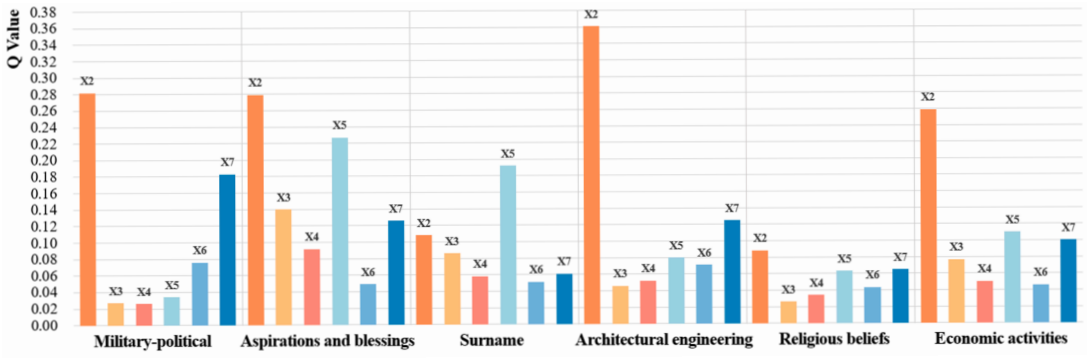


Figure 8. Single-factor detection results for humanistic landscape toponyms.

3.3.3. Analysis of Interaction Between Influencing Factors

The formation of the spatial distribution characteristics of the TCL in Wuhan is the result of the interweaving of multiple landscape elements. Because of this, this study used an interaction detector to quantitatively identify the interaction effects of the superposition of these factors on the spatial distribution of TCL in Wuhan. The results of the interaction detector (Figures 9 and 10) show that the pairwise interactions are mainly bi-enhancement or nonlinear enhancement, which suggests that a single factor does not drive the Spatial heterogeneity of the TCL in Wuhan, but rather, is formed through the combined effects of multiple factors.

(1) Natural Landscape Toponyms

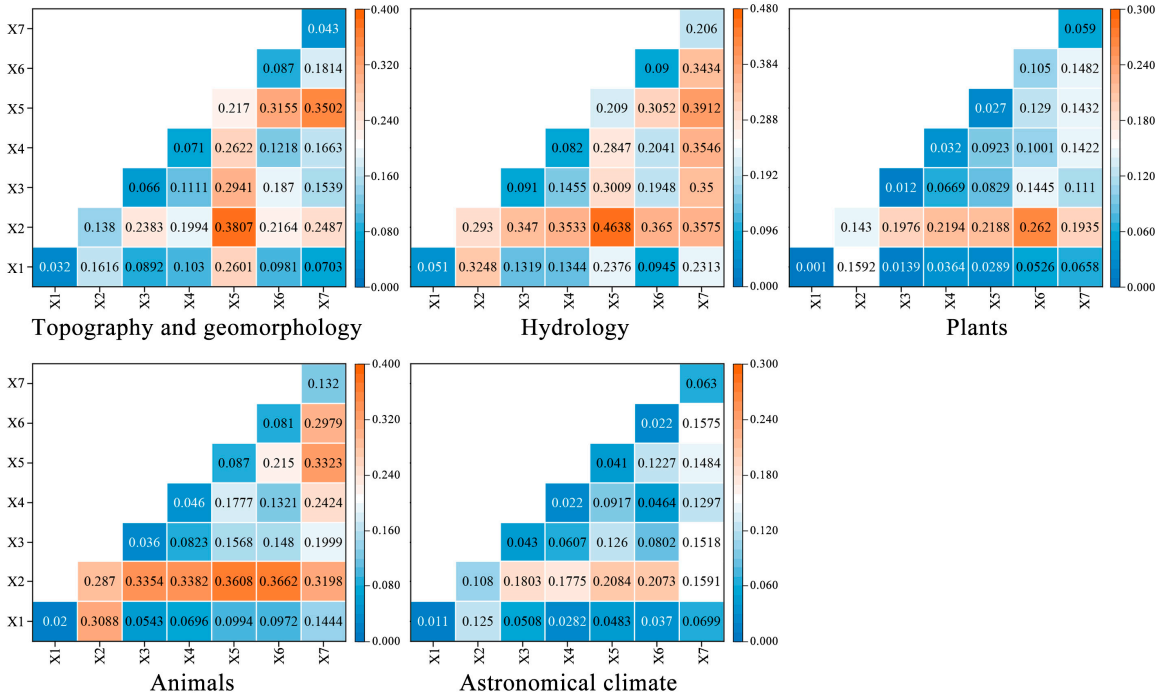


Figure 9. Results of bivariate interaction detection for natural landscape toponyms.

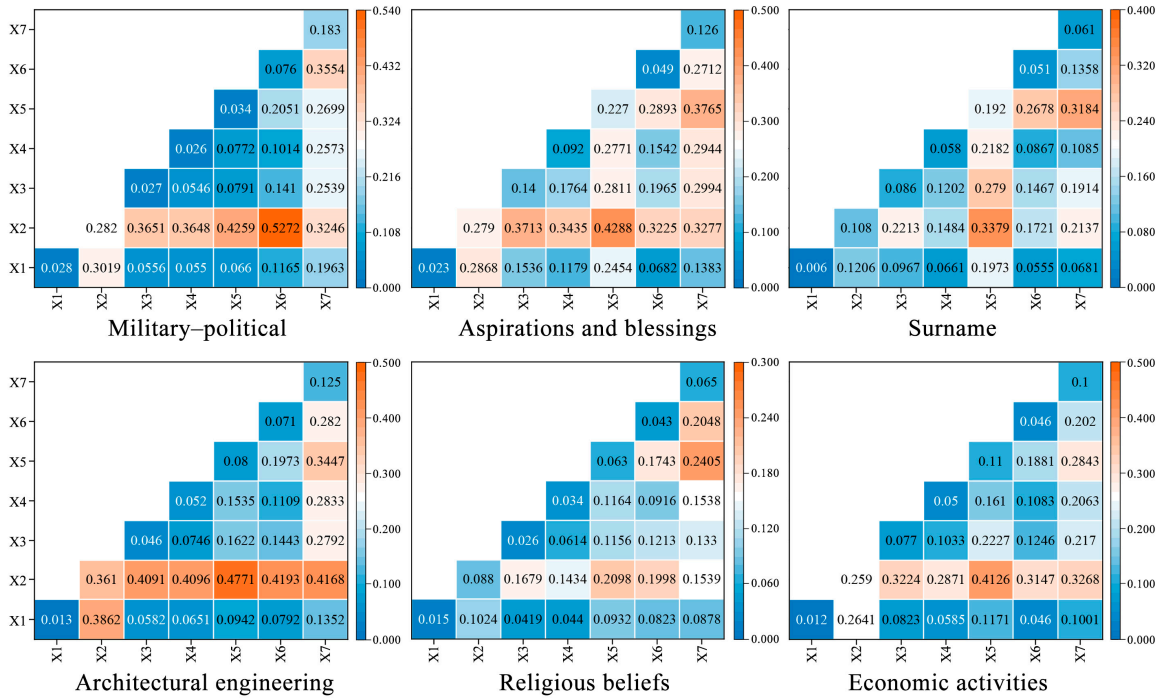


Figure 10. Results of bivariate interaction detection for humanistic landscape toponyms.

In the detection of toponyms related to topography and geomorphology, the interaction between elevation (X5) and construction land (X2) is the strongest, with an influence of 0.3807, followed by elevation (X5) and NDVI (X7), with an influence of 0.3502; in the detection of hydrologic toponyms, the interaction between aspect (X4) and NDVI (X7) is the strongest, with an influence of 0.3546, followed by river density (X6) and NDVI (X7); in the detection of toponyms related to plants, the interaction between construction land (X2) and river density (X6) is the strongest, with an influence of 0.262, followed by the interaction between construction land (X2) and aspect (X4); in the detection of animal toponyms, the

interaction between construction land (X2) and aspect (X4) is the strongest, with an influence of 0.3382, followed by the interaction between construction land (X2) and slope (X3), with an influence of 0.3354; in the detection of toponyms related to astronomical climate, the interaction between construction land (X2) and elevation (X5) is the strongest, with an influence of 0.2084, followed by the interaction between construction land (X2) and river density (X6).

(2) Humanistic Landscape Toponyms

In the detection of toponyms related to military–political history, the strongest interaction effect is found between construction land (X2) and river density (X6), with an influence of 0.5272, followed by construction land (X2) and elevation (X5), with an influence of 0.4259; in the detection of toponyms related to aspirations and blessings, the strongest interaction effect is found between elevation (X5) and NDVI (X7), with an influence of 0.3765, followed by slope (X3) and NDVI (X7), with an influence of 0.2994; in the detection of toponyms related to surname, the strongest interaction effect is found between construction land (X2) and elevation (X5), with an influence of 0.3379, followed by elevation (X5) and NDVI (X7), with an influence of 0.3184; in the detection of toponyms related to architectural engineering, the strongest interaction effect is between construction land (X2) and elevation (X5), with an influence of 0.4771, followed by construction site (X2) and slope (X3), with an influence of 0.4091; in the detection of toponyms related to religious beliefs, the strongest interaction effect is found between elevation (X5) and NDVI (X7), with an influence of 0.2405, followed by construction land (X2) and elevation (X5), with an influence of 0.2098; in the detection of toponyms related to economic activities, the strongest interaction effect is found in construction land (X2) and elevation (X5), with an influence of 0.4126, followed by construction land (X2) and river density (X6), with an influence of 0.3147.

4. Discussion

4.1. Analysis of Formation Origins of TCL in Wuhan

A TCL serves as a geographic paradigm for the coordinated development of human–land relations, with its formation intrinsically linked to the regional geographic environment and humanistic background [38]. Thus, the formation factors of Wuhan's TCL are mainly analyzed from both natural and humanistic dimensions [39].

4.1.1. Natural Factors

Natural geographic factors have the most overt and direct influences on the formation and distribution of TCLs. They shape urban space and provide the foundation upon which human activities and naming conventions are based. The spatial distribution characteristics of the TCL in Wuhan are deeply influenced by the natural environment, showing significant aggregation and directionality, especially concentrated in the area with the Yangtze River and its tributaries as the core. Wuhan is an important node in the middle reaches of the Yangtze River, and the Yangtze River and its tributaries, including the Han River, pass through the city; this remarkable natural geographic feature has deeply shaped the formation and distribution of toponyms. In the correlation analysis with landscape elements, we can see the influence of elevation, vegetation, hydrology, and other natural elements on the formation of toponyms, especially topographic and geomorphological toponyms, which are deeply influenced by the elevation factor; this result is closely related to the diverse topography of Wuhan. Overall, the natural geographical conditions not only constitute the environmental background for the formation of toponyms, but also influence the spatial distribution. This naming method reflects the wisdom of the Wuhan people of adapting to the local conditions and living in harmony with nature.

4.1.2. Humanistic Factors

The influence of humanistic factors on TCLs is often implicit and indirect, encompassing historical traditions, cultural practices, language habits, social structure, economic development, and people's values and belief systems [40]. In Wuhan, the formation of toponyms is profoundly shaped by social values and belief systems, as evidenced by the significant proportion (9.15%) of toponyms related to aspirations and blessings. Moreover, the significant impact of construction land (X2) on toponym formation highlights the close connection between human activities and socio-economic development. Wuhan's regional dialects, including terms like "Sai" and "Dangzi," further demonstrate the influence of local language on toponyms. These humanistic elements collectively reflect the historical memory, cultural inheritance, and social identity of Wuhan's people while also carrying the city's historical lineage and humanistic spirit.

4.2. Research Value of TCL in Wuhan

Applying qualitative and quantitative methods, statistically classifying toponyms based on their natural and humanistic characteristics, and quantitatively analyzing their spatial differentiation characteristics and influencing factors, with the help of Geographic Information System 10.8 (GIS) technology and the Geodetector method, has become a major paradigm in the study of cultural landscapes of toponyms [37,38]. However, no studies have yet comprehensively and systematically sorted out and carried out in-depth quantitative research on the TCL resources in Wuhan. Based on this research gap, 3638 TCL resources in Wuhan were counted and classified, and their spatial distribution and influencing factors were quantitatively analyzed. Additionally, this study confirms the potential value of toponyms in the identification and description of landscape character. By exploring the correlation between TCL and the landscape elements in Wuhan, the study offers a local perspective and cultural dimension that have not been fully explored and utilized for the characterization and description of landscapes, thus further enriching and perfecting the identification system for landscape character. This study provides a new perspective for understanding Wuhan's urban cultural landscape and effectively complements the valid information of Wuhan's TCL. The research results not only have important guiding value for current conservation practices, but also provide valuable insights for future sustainable development.

The study of the spatial distribution of toponyms and their formation mechanisms is an important foundation for establishing a comprehensive understanding and effective protection, and scientifically supporting the inheritance, of Wuhan's toponym landscapes and cultural heritage. The research results can be applied in the following ways: (1) Supporting community participation and public education in cultural landscapes. Toponyms not only describe the physical characteristics of a location, but also convey its social and cultural significance. Uncovering the historical origins and cultural connotations behind Wuhan's toponym landscapes can enhance people's sense of place identity and belonging, thereby encouraging diverse stakeholders to actively participate in the protection of toponymic cultural landscapes. (2) Providing a clear spatial framework for the protection and utilization of cultural landscapes. By systematically classifying toponyms, it is possible to accurately identify the core areas of different types of cultural landscapes and their associated nodal regions. For instance, centered around "Huanghe Tower", there are surrounding toponyms with significant historical importance, such as "She Mountain", "Yangtze River Bridge", and "Shouyi Square". These toponyms collectively outline the core area of Wuhan as a historical and cultural city. By preserving these clusters of toponyms, a more comprehensive picture of Wuhan's historical and cultural heritage can be presented, thus providing important references for cultural heritage protection and

sustainable urban development. (3) Facilitating the scientific monitoring and assessment of cultural landscapes. Toponyms describe the historical environment through linguistic mapping, indicating historical land-use categories, landscape patterns, and territorial boundaries, reflecting the local history of land use and traditions. In modern planning, these historical land-use patterns can be referenced and combined with modern technology to rationally plan land-use methods. This helps to arrange different functional areas, such as agricultural production, residential living, and ecological protection, in a more scientific manner.

4.3. Limitations and Future Work

Although the formation of toponyms is deeply influenced by natural landscapes and environments, the connection between toponyms and nature is not direct and obvious. The fundamental reason is that toponyms are the result of the human naming, writing, and recording of natural phenomena, a process that incorporates the rich perceptions and imaginations of humans and contains elements of sensibility and imagination. Therefore, the information carried by toponyms is often implicit rather than directly presented. This also means that it is difficult for this study to fully present the complex and diverse intrinsic correlation between toponyms and natural and humanistic landscapes in some aspects, which is worth further research in the future. In addition, due to the limitation of the length of this study, the consideration of the history dimension of TCL has yet to be explored. Future research can trace the origin and evolution of toponyms and the historical and cultural context behind them through a combination of historical documents, the analysis of archeological materials, and the recording of oral history, so as to provide a richer research background for research on the TCLs.

In terms of methodology, the framework adopted in this study can be adapted and applied to different spatial units. However, the following limitations and barriers need to be considered: (1) Cultural and linguistic differences between regions also require consideration, as the meanings and significance of toponyms may vary greatly across cultures. Accordingly, the interpretive framework used in this study may need to be adjusted. (2) Another potential barrier is the spatial scale of the research. While the methodology is suitable for local or regional scales, extending it to the national level may be challenged by the increased complexity of data management and analysis. The vast number of toponyms and the diversity of cultural contexts at the national scale require more robust and scalable approaches. In conclusion, although the methodology and results of this study demonstrate certain applicability, further research is needed to explore its wider application and address potential limitations and barriers. Future studies could focus on developing a more generalized framework for toponym analysis that is adaptable to different spatial scales and cultural contexts, thereby enhancing the practical application of such research in cultural heritage preservation, spatial planning, and related fields.

5. Conclusions

This study constructs a comprehensive three-level classification framework of the TCL in Wuhan, aiming to systematize and understand the unique toponymic cultural characteristics of the study area. Based on this framework, the study employed KDE, the NNI, and the SDE to quantify the spatial distribution characteristics of Wuhan's TCL and further reveal the intrinsic correlation between the spatial distribution of the TCL and landscape elements. The main conclusions of the study are as follows:

(1) Wuhan has a large number of toponyms and a rich TCL. Not only do they cover natural elements such as topography and geomorphology, hydrological features, and biological resources, but they also incorporate human elements such as military–

political history, economic activities, religious beliefs, and surname culture. In addition, there are 2225 (61.16%) more natural landscape toponyms than humanistic landscape toponyms (1505 (41.37%)) in Wuhan, a phenomenon that profoundly reflects the city's regional characteristics and historical origins, which are closely linked to the natural environment. Among them, there are 1274 hydrological toponyms in the natural landscape category, accounting for 35.02% of all toponyms, which reveals that the culture surrounding the water system, as an important basis for the development of Wuhan, has permeated the historical development of the city and had an important influence on the city's socio-economic activities.

(2) The spatial distribution of TCL shows a significant clustering trend, which is mainly distributed along the northeast–southwest direction, with only religious belief toponyms distributed along the south–north direction. This shows that under the combined effect of the natural environment and human activities, toponyms have a certain distribution pattern, which is not random: natural landscape and humanistic landscape toponyms are mainly distributed along the axis of the Yangtze River, which is an important water system in Wuhan, and show a high-density distribution pattern in the center of the city; humanistic landscape toponyms reflect the randomness and diversity of human activities, and their spatial distribution is more dispersed compared with that of natural landscape toponyms. The spatial distribution of humanistic landscape toponyms is more random and diverse than that of natural landscape toponyms, which are more decentralized. In addition, since these toponyms are mostly derived from human subjective feelings and associations with natural landscapes or social phenomena, the categories within the humanistic landscape toponyms (such as aspirations-and-blessings toponyms, religious beliefs toponyms, etc.) show a large difference in the density of spatial distribution.

(3) The results of single-factor detection are as follows: construction land (X2) has a significant influence on the formation of both natural landscape and humanistic landscape toponyms, which indicates that human activities play a central role in the formation of toponyms; the distribution of natural landscape toponyms is more influenced by natural elements (e.g., rivers, vegetation, topography) than that of humanistic landscape toponyms, which suggests that natural landscape toponyms not only represent human perceptions and expressions of the natural environment, but also reflect the natural environment of a geographical area. On the other hand, humanistic landscape toponyms are more often associated with areas of intensive human habitation and activity, and their distribution is influenced by a combination of factors, making it more difficult to establish a significant correlation with a single natural element.

(4) The results of bivariate interaction detection show that the spatial distribution of the TCL in Wuhan is influenced by a variety of factors rather than by a single factor, and the enhancement effects manifest as bi-enhancement and nonlinear enhancement, in which nonlinear enhancement is more significant than bi-enhancement in the interaction detection of humanistic landscape toponyms.

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