# GIS-Based Analysis of Spatial Distribution Characteristics of Toponymic Landscapes in Semi-Agricultural and Semi-Pastoral Areas of Inner Mongolia (Postprint)

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## Abstract

Zhalute Banner is situated in the northern part of the transition zone from the Xing' anling Mountains to the Liaohe Plain, spanning the second and third topographic steps of China. Constrained by various natural conditions, it has formed a farming-pastoral ecotone characterized by agriculture in the south, animal husbandry in the north, and interlaced farming-pastoral activities in the central region. By taking 3,349 place names in Zhalute Banner, Inner Mongolia as the research object, this study employs kernel density estimation, geographic concentration index, and hot-cold spot analysis to examine the spatial distribution patterns and characteristics of toponymic landscapes. The findings reveal: (1) Natural landscape toponyms are primarily concentrated in the western and northern hilly regions and medium- and small-mountain areas. Topographic and geomorphic toponyms cluster in topographic transition zones, i.e., areas with significant terrain undulations. Hydrological toponyms are mainly distributed in relatively low-altitude areas, showing no obvious correlation with river size and exhibiting a uniform north-south distribution, which reflects the distribution characteristics of toponyms in water-scarce arid and semi-arid regions; (2) Cultural landscape toponyms are predominantly distributed in the central and southern regions. In terms of distribution characteristics, cultural settlement toponyms exhibit the closest relationship with natural hydrological toponyms, displaying a banded distribution along rivers in the central region. Moreover, due to agriculture' s dependence on water resources, they concentrate in relatively low-altitude areas and riparian zones where surface water and groundwater are enriched, which also represents a characteristic of settlement distribution in semi-farming and semi-pastoral regions. (3) Cultural toponyms have undergone a transformation from random distribution in the early Qing Dynasty to concentrated distribution today, with most cultural toponyms formed within

the last century. Settlement toponyms evolved from small settlements in the early Qing Dynasty to initial scale following the land reclamation in Mongolian areas in the late Qing Dynasty, and subsequently developed into relatively large-scale concentrated settlements. Economic, transportation, and architectural toponyms have gradually clustered since the 1980s in conjunction with industrialization and urbanization. (4) Regarding the overall distribution of toponyms in the study area, the primary factors influencing natural toponyms include geomorphology, hydrological conditions, meteorology and climate, and toponymic cognition, whereas the distribution of cultural toponyms is influenced not only by natural factors but also by policies, population activities, urbanization, and economic development levels.

## Full Text

# Spatial Distribution Characteristics of Toponymic Landscapes in the Semi-Agricultural and Semi-Pastoral Areas of Inner Mongolia Based on GIS: A Case Study of Jarud Banner

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### Abstract

Jarud Banner is situated in the transitional zone from the foothills of the Greater Khingan Range to the northern Liaohe Plain, spanning China's second and third topographic steps. Constrained by various natural conditions, the region has formed a distinctive farming-pastoral ecotone characterized by agriculture in the south, pastoralism in the north, and mixed land use in the central area. This study examines 3,349 place names in Jarud Banner, employing kernel density estimation, geographic concentration index, and hot spot analysis to investigate the spatial distribution patterns and characteristics of toponymic landscapes. The findings reveal: (1) Natural landscape toponyms are predominantly concentrated in the western and northern hilly areas and medium-low mountain regions. Landform-related names cluster in terrain transition zones with significant relief, while hydrological names are mainly distributed in relatively low-altitude areas, showing no clear correlation with river size and exhibiting a uniform north-south distribution pattern that reflects water scarcity characteristics of arid and semi-arid regions. (2) Human landscape toponyms are primarily distributed in central and southern areas. Settlement names demonstrate the closest relationship with natural hydrological names, displaying zonal distribution along rivers in the central region. This pattern reflects the concentration of settlements in relatively low-altitude and riparian areas rich in surface and groundwater resources, driven by agriculture' s dependence on water—characteristic of settlement distribution in farming-pastoral regions. (3) Human toponyms have evolved from random distribution in the early Qing Dynasty to concentrated distribution today, with most forming within the last century. Settlement names developed from small settlements in the early Qing period to initial scale after land reclamation in the late Qing Dynasty, and further to relatively large concentrated settlements today. Economic, transportation, and architectural toponyms have gradually clustered since the 1980s with industrialization and urbanization. (4) Overall, natural toponym distribution is primarily influenced by geomorphology, hydrology, climate, meteorology, and toponymic cognition, while human toponym distribution is additionally affected by policy, population activities, urbanization, and economic development level.

**Keywords:** GIS; place names; kernel density estimation; hot and cold spot analysis; Jarud Banner

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**Introduction**

Place names are proper nouns assigned to natural or human geographical entities at specific spatial locations [ ]. Foreign toponymic research has experienced qualitative development in classification, origins, evolution, and language types [ ]. Hua Linfu [ ] systematically compiled toponymic works and achievements from various Chinese dynasties and periods, summarizing the origins, naming conventions, interpretations, and changing patterns of geographical names. Gu Yong [ ] reviewed modern scholars' research on geographical names, while Niu Ruchen [ ] analyzed and statistically examined place names in northern ethnic regions during the Qing Dynasty. Research on Mongolian region toponyms has seen initial development, with scholars such as Jin Feng and Na Shundalai conducting in-depth investigations into the evolution of historical geographical names, directional cognition in Mongolian regions, and place names in ancient documents [ ]. Studies on the origins of Chinese place names have a long history, with early works focusing on etymology, origins, and textual research [ ].

In recent years, Chinese scholars have begun using spatial information technology to transform traditional toponymic research approaches. For instance, Wen Pengling and Xu Jianguo [ ] shifted toponymic studies toward more quantitative and spatially visualized styles, overcoming previous shortcomings of subjectivity and advancing the field toward informatization and quantification. Additionally, spatial and statistical analyses have been applied to study the classification and spatial distribution patterns of Beijing' s toponymic landscapes [ ], spatial smoothing methods have explored Chengde' s rural toponymic cultural landscapes [ ], and "toponymic time layers" have been used to create thematic maps for Guangdong place names [ ].

While previous scholars have enriched toponymic research in content and methodology, studies on ethnic region toponyms based on spatial analysis and statistical methods remain limited. This research builds upon these new methods by incorporating topographic relief analysis and overlay analysis of relative terrain maps with place names to explore underlying patterns. Jarud Banner represents a typical semi-agricultural and semi-pastoral area in Inner Mongolia, and studying its toponymic landscape distribution characteristics contributes to understanding the natural environment and ethnic culture of eastern Inner Mongolia.

[Figure 1: see original paper] Sketch map of study area

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### 1.1 Study Area Overview

Jarud Banner is located in northeastern Inner Mongolia, within the map extent of 119°14 -117°06 E and 43°50 -45°50 N. It lies in the transitional zone from the southern foothills of the Greater Khingan Range to the Liaohe Plain and Horqin Sandy Land, with terrain transitioning from northern mountains to central low hills and then to southern low sand dunes and plains. This makes it one of Inner Mongolia' s typical semi-agricultural and semi-pastoral banners. The climate is temperate semi-arid monsoon, with an average annual temperature of 6.7°C and average annual precipitation of 382.5 mm. The frost-free period is relatively long in central and southern areas (approximately 130–147 days) and shorter in the north (91–114 days).

Following administrative adjustments, the region now comprises 15 township-level administrative divisions (sumu/towns). Among them, Ar Kunduleng Town, Bayartuhushuo Town, Wulanhada Sumu, Gerichulu Sumu, and others constitute the pastoral-dominated zone, while central Lubei Town, Xiangshan Town, Jurihe Town, Bayanta 拉 Sumu, and Huanghuashan Town form the agricultural-dominated zone. The remaining divisions are semi-agricultural and semi-pastoral areas [ ]. The total population is 306,000, with higher population density in agricultural areas and lower density in pastoral areas.

Administrative boundary data were obtained from the Geographic National Condition Monitoring Cloud Platform. Statistical data on industrial levels and population were sourced from the *Jarud Banner Statistical Yearbook*, *Tongliao City Statistical Yearbook*, and *Jarud Banner Gazetteer*.

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### 1.2 Data Sources

This study uses the *1:10,000 Place Name Map of Inner Mongolia Autonomous Region* as the basic spatial vector data. Textual materials including the *Place Name Gazetteer of Inner Mongolia Autonomous Region: Jirem League Volume* [ ], *Jarud Mountain and River Place Names*, and geographical name information from the China National Geographical Names Information Database were consulted to identify place names related to secondary and tertiary economic activities and functional cultural zones. Coordinates were determined through Google Earth and field investigations. After eliminating names with unverifiable origins or undeterminable coordinates, 3,349 place names were selected for analysis.

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#### 1.3.1 Kernel Density Estimation Method

Kernel density estimation can be understood as setting a density value window with a specified radius to calculate the density of point or linear geographical features within the spatial extent. The natural breaks method is then used to divide the data into different value ranges for analyzing spatial distribution patterns. The mathematical expression is: f(x) = ···[formula placeholder]. In this method, h represents the specified search distance of the density window, and n is the total number of place names within the defined spatial extent.

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#### 1.3.2 Geographic Concentration Index

The geographical significance of this model is to define the spatial concentration or dispersion degree of spatial elements (or phenomena). The formula is: $G = 100 \times \Sigma(Xij/T)$, where G is the geographic concentration index of toponymic landscapes in different agricultural-pastoral zones of Jarud Banner; Xij is the number of j-type landscape names in the i-th agricultural-pastoral zone; and T is the total number of landscape names. The index ranges between [0, 100], with values closer to 100 indicating higher concentration of j-type landscape names in the i-th zone.

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#### 1.3.3 Local Spatial Autocorrelation (Getis-Ord G*)

This method is primarily applied to determine whether geographical entities in the study area are spatially correlated and the positive or negative nature of such correlation. The Hot Spot Analysis tool in ArcGIS is typically used to identify spatially distributed hot spots and cold spots. The standardized formula is: G*i = ···[formula placeholder], where Wij represents spatial weights; E denotes mathematical expectation; and $\sigma$ represents variance. If the Z-score is significant and greater than 0, it indicates that the value in that region is higher than in neighboring regions, representing a significant clustering area (hot spot). Conversely, it represents a non-significant spatial dispersion area (cold spot).

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## 2 Classification and Statistics of Jarud Banner Place Names

Place names in Jarud Banner are classified into two major categories based on geographical attributes: natural landscape toponyms and human landscape toponyms. Natural landscape toponyms are further subdivided into three subcategories: landform, hydrological, and flora-fauna types. Human landscape toponyms are divided into five subcategories: settlement, functional, economic activity, and transportation-architecture types (Table 1).

Landform toponyms account for the highest proportion of natural landscape names, totaling 1,372 entries (40.97% of the total), reflecting the prevalence of mountain and river names in Mongolian regions. Common generic terms include "Ula" (mountain), "Zhalage" (floodplain), "Tala" (meadow), "Shan" (mountain), "Gou" (gully), and "Dianzi" (meadow). Hydrological toponyms rank second with 466 entries (13.91%). Frequently occurring generic terms include "Bulege" (spring), "Gol" (river), "Nur" (lake), "Haga" (a type of lake), "Arshan" (spring), and "Usu" (water).

Flora-fauna toponyms are the least common among natural landscape names, with only 46 entries. Common generic terms include "Mod"(tree), as in "Jumode" meaning "one hundred trees." "Tai" and "Tu" (or "Tu" ) are frequent generics for flora-fauna toponyms on the Mongolian Plateau, indicating the presence of certain animals or plants. In Qing Dynasty maps, such toponyms were used for wild animal or plant locations.

Settlement toponyms appear 1,187 times. Mongolian generics include "Ail" (village) and "Qagaan"(village), while Chinese generics include "Zhen"(town), "Cun" (village), "Tun" (hamlet), "Yingzi" (settlement), "Bao" (fort), and "Yao" (kiln). Mongolian settlement toponyms typically use local natural features as specific names, such as "Erdunbolgo Qagaan" (precious spring) and "Bayanjalaga Qagaan" (rich floodplain). Chinese specific names, however, predominantly reflect human elements, such as Bao' an Tun (Peace Fort), Anle Cun (Peaceful Village), Zhongxin Tun (Central Hamlet), and Zhixing Cun (Prosperity Village).

Functional cultural zones form naturally without social change, representing spatial distributions of cultural traits influenced by political, economic, or social functions [ ]. Functional toponyms derive from these divisions and typically represent officially supported service types such as education, healthcare, legal systems, and management. This category appears least frequently with only 34 entries, mainly using terms like "Fu" (government office), "Ju" (bureau), "Xiao" (school), "Yuan" (institution), and "Yuan" (garden).

Economic activity toponyms appear most frequently among human landscape names, totaling 458 entries. Main terms include "Taobu" (herdsman' s hut), "Dian" (shop), "Pu" (store), "Bao" (fort), "Cheng" (city), "Fang" (workshop), and "Fang" (house). Transportation and architecture toponyms number 306 entries. Mongolian generics include "Oboo" (cairn), "Zhao" (temple), "Sum" (temple), and "Hudag" (well), which have existed in Mongolian regions since historical times. Chinese generics mainly include "Si" (temple), "Miao" (shrine), "Lou" (building), "Qu" (district), "Yuan" (courtyard), and "Yuan" (garden). Except for some religious and garden landscape buildings, most reflect urbanization-generated structures.

Classification, quantity, and percentage of word use in Jarud Banner place names

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### 3.1 Spatial Characteristics and Causes of Jarud Banner Place Names

Spatial analysis has been widely applied in recent years to vegetation dynamics, precipitation spatiotemporal variation, scenic areas, and economic zone patterns [ ]. Spatial analysis of toponyms can not only intuitively reflect regional physical geographical features but also reveal human cognition of the natural environment. Human landscape toponyms typically demonstrate local regional culture, economic development, land use patterns, urbanization, and distribution of educational and medical resources, representing a spatial manifestation of human social phenomena.

Figure 2 shows that natural landscape toponyms have the highest kernel density values in the north and west (2,389.41–2,986.76), approximately twice that of central-southern and southern areas, indicating greater distribution in the north and west. Conversely, human landscape toponyms are more concentrated in central and southern areas, with fewer in the north. Hot spots with the highest Gi Z-scores are predominantly in central and southern regions (1.85–14.36), while most northern administrative villages belong to cold or sub-cold spots.

Comparing both toponym types with population density distribution reveals that human landscape toponyms in high-density agricultural areas show zonal distribution, while natural landscape toponyms are more distributed in low-density pastoral areas. The geographic concentration index for natural landscape toponyms in the three agricultural-pastoral zones follows the order: pastoral-dominated zone (53.88) > semi-agricultural/semi-pastoral zone (41.27) > agricultural-dominated zone (25.48), related to lower overall population density and less human impact in pastoral and semi-pastoral areas.

Hydrological toponyms are relatively evenly distributed, with peak kernel density values of 785.42–981.77 concentrated in the northwest and southeast. The northwest contains numerous small lakes and streams, while the southeast has the highest concentration of lakes in the entire banner. In this water-scarce arid region, hydrological toponyms do not concentrate in major river basins but rather along small tributaries and minor lakes. Northern hydrological toponyms frequently use terms like "Usu," "Arshan," and "Bulege," while the southeastern high-density area with more lakes commonly uses "Nur" and "Haga." The geographic concentration index order is 19.98 > 15.63 > 5.06, consistent with the pattern of more hydrological toponyms in the north and south than in the center.

Flora-fauna toponyms show the highest kernel density in the southeast (1.85–14.36), with scattered distribution in the north and minimal distribution in the center. The geographic concentration index order is 4.07 > 3.53 > 2.10. Plant toponyms show no significant variation in terminology, mostly representing common Mongolian Plateau species such as "Burgastai" (Achnatherum splendens) and "Delesutai."

Topographic relief is the primary factor influencing landform toponym distribution. Further focal statistics on elevation data using raster calculator yielded topographic relief values (Figure 4). Landform toponyms mainly appear at edges of different relief values, with sparse distribution in areas of low relief, related to human activity and toponymic cognition.

[Figure 2: see original paper] Distribution of kernel density for natural landscape place names and cold-hot spots for human landscape place names
[Figure 3: see original paper] Spatial distribution of kernel density for various natural place names
[Figure 4: see original paper] Topographic and geomorphological place names and topographic fluctuation values

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### 3.2 Spatial Characteristics and Causes of Natural Landscape Toponyms

As shown in Figure 3, landform toponyms have the highest kernel density values in the north and southeast (1,614.03–2,017.54), where terrain relief is significant. The lowest values appear in the southeast and northwest (below 1,614.03). Based on the agricultural-pastoral zone division in Figure 2, the geographic concentration index for natural landscape toponyms follows the order: pastoral-dominated zone > semi-agricultural/semi-pastoral zone > agricultural-dominated zone.

Landform toponyms in the northern mountainous area primarily use generics reflecting large mountains such as "Ula," "Ondor," "Oroin," "Zhalaga," "Hada," and "Chulu," while the southern plain and sand dune areas with gentler terrain use generics like "Hua," "Hushuo," "Dob," "Shorong," "Tolgoi," "Tala," "Mangh," and "Dianzi." This distribution pattern and generic variation relate to crustal movements. The Greater Khingan Range formed as a fold system from plate collision and compression during the Late Paleozoic orogeny (see *Atlas of China Geography*, Geology Section), with rock types dominated by granite and andesite that extruded during tectonic movements, resulting in numerous rock-related toponyms like "Hada" and "Chulu" in the northern Khingan foothills.

[Figure 5: see original paper] Kernel density distribution of different types of human landscape place names

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### 3.3 Spatial Characteristics and Causes of Human Landscape Toponyms

Settlement toponyms are more abundant in central and western areas, with kernel density values of 958.90–1,198.62 in some central-western regions, and relatively sparse distribution in the south and north (Figure 5). The geographic concentration index for human landscape toponyms follows the order: agricultural-dominated zone > semi-agricultural/semi-pastoral zone > pastoral-dominated zone. For settlement toponyms specifically, the order is 18.32 > 15.49 > 5.33.

Natural factors influencing this pattern include topography and frost-free period length. The northern pastoral zone has greater terrain relief and a shorter frost-free period (91–114 days), causing agricultural settlements to concentrate in the longer frost-free central and southern regions. Human factors primarily include population migration, land development since the late Qing Dynasty's "immigration to strengthen border regions" and "invitation to reclaim land" policies, the "village consolidation" policy during the puppet Manchukuo period, and the household contract responsibility system since the reform and opening-up era.

The geographic concentration index for functional toponyms follows the order: 6.39 > 2.55 > 0.10, reflecting large gaps in urbanization levels and economic, educational, and medical development among zones. Economic activity toponyms are most abundant in agricultural-dominated zones, with peak kernel density values reaching 958.90–1,198.62, fewer in semi-agricultural/semi-pastoral zones, and minimal in the north. The geographic concentration index order is 36.64 > 17.36 > 5.30.

According to 2017 statistics by national economic sector, Lubei Town in the agricultural zone alone had 12,000 tertiary industry employees and 8,000 secondary industry employees, while in the pastoral zone only Gerichulu Sumu had over 1,000 tertiary industry employees (including those engaged in services and retail in other towns). The agricultural zone's more developed secondary and tertiary industries are reflected in toponyms using characters like "Bao" (fort), "Pu" (store), "Dian" (shop), "Cheng" (city), and "Fang" (workshop), whereas the semi-agricultural/semi-pastoral zone, still dominated by primary industry, retains many names like "Taobu" (individual contracted pasture), "Mapu" (horse station), and "Nongpu" (farm station). In Qing Dynasty maps, transportation toponyms in Mongolian areas mainly comprised military post stations and heavily guarded passes, while architectural toponyms commonly featured temples and oboo cairns.

Transportation and architectural toponyms are also concentrated in central areas, with kernel density values of 377.68–472.09 in the central region—4–6 times those in the northern pastoral zone. The geographic concentration index order is 11.74 > 6.64 > 5.07. Major roads and garden buildings converge in central and southern areas, while the pastoral zone retains only a few newly built rural roads and stations alongside ancient oboo and temple structures.

Settlement toponyms, as the most fundamental and typical category of human landscape toponyms, reflect production patterns, residential customs, and human-land relationships. They concentrate in relatively low-altitude areas, a pattern that becomes more pronounced from south to north with increasing elevation, as higher-altitude settlements tend to locate in river and stream valleys. Settlement toponyms in Jarud Banner are most abundant in medium-altitude areas because sandy land in the south is unfavorable for agriculture (Figure 6).

[Figure 6: see original paper] Overlapping map of settlement place names and relative altitude topography

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## 4 Discussion

Toponyms are not only living fossils of history and culture but also record traces of human cognition of the objective world. Landform toponyms represent human cognition of elevation differences. Contrary to the common assumption that landform toponyms are abundant in high mountains, this study finds they concentrate in terrain transition zones with obvious relief—transitions from plain to hill, low mountain-high plain to high mountain, and valley lowland to low mountain-high plain—forming four belt-like and two block-like kernel density zones (Conclusion 1). Moreover, toponymic naming exhibits directionality, arising from visual cognition when people view higher elevations from their residential plains or low-altitude areas (Figure 4).

Toponym concentration is related to feature size but not in the expected way. Small landform toponyms are denser than large ones. Similarly, major river basins have fewer hydrological toponyms than small river basins. For example, the Liaohe River basin has fewer hydrological toponyms than its northern and southern small river basins. This demonstrates not only the capacity of features per unit space but also the "scarcity increases value" principle of water resource distribution in arid regions (Conclusion 2), resulting in multiple hydrological toponym kernel density zones.

Spatial analysis technology offers many possibilities for toponymic research. This study builds on previous work by analyzing spatial patterns of toponymic cultural landscapes in under-researched semi-agricultural and semi-pastoral areas of Inner Mongolia. However, due to limitations in academic accumulation and knowledge preparation, aspects related to toponymic cognition and spatial perception may have shortcomings, and the research may remain at the spatial information level—these are issues for future in-depth investigation.

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## 5 Conclusions

Toponyms reflect a region' s natural conditions, historical culture, ethnic structure, and socioeconomic information [ ]. Based on landscape classification and statistical analysis of Jarud Banner place names, combined with GIS kernel density analysis and geographic concentration index modeling, this study reveals the following characteristics:

(1) As a farming-pastoral ecotone in a semi-arid region, the study area shows a higher proportion of natural landscape toponyms than agricultural-dominated areas, with more diverse terminology. Natural landscape toponyms have the highest kernel density values in the north and west, related to greater terrain relief, reflecting lower dependence on terrain conditions in pastoral-dominated areas. Human landscape toponym hot spots appear mainly in central areas, followed by eastern and southern areas—opposite to natural landscape toponyms—concentrating in low-relief, long frost-free period, high population density agricultural zones.

(2) From the perspective of geographic concentration indices across the three agricultural-pastoral zones, natural landscape toponyms decrease in the order: pastoral-dominated > semi-agricultural/semi-pastoral > agricultural-dominated. Landform toponyms are concentrated in transition zones between northern high mountains, western and central medium mountains, and high plains, while being sparse in central-southern and southern plains. Hydrological toponyms are more abundant in the northwest and southeast, matching river system characteristics. Flora-fauna toponyms are few and scattered in southwestern and northern areas, representing common Mongolian Plateau species. Analysis reveals that landform toponyms and large landform generics mostly appear where terrain relief is significant, related to the fold structure and rock formation of the southern Greater Khingan Range and human toponymic cognition.

(3) Human landscape toponyms show geographic concentration indices in the order: agricultural-dominated > semi-agricultural/semi-pastoral > pastoral-dominated for all subcategories. Economic activity and transportation-architecture toponyms concentrate in central areas, while settlement high-density zones are relatively western. These spatial distribution differences result from gaps in economic, medical, educational, and transportation resources among the three agricultural-pastoral zones. As typical human landscape toponyms, settlement names show clear patterns of water dependence and concentration in relatively low-altitude areas.

(4) Analysis of historical maps and local gazetteers reveals that human landscape toponyms were scarce while natural landscape toponyms predominated until the late Qing Dynasty. Settlement names only began forming during the land reclamation period of the late Qing and early Republic, with economic, transportation, and architectural toponyms emerging gradually since the 1980s due to socioeconomic development and infrastructure expansion.

In summary, the spatial characteristics of Jarud Banner' s toponymic landscapes reflect human-land relationships in arid and semi-arid regions and faithfully record the socio-cultural transformation process in eastern Inner Mongolia' s semi-agricultural and semi-pastoral areas.

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*Note: Figure translations are in progress. See original paper for figures.*