Open Journal of Applied Sciences, 2023, 13, 1967-1981
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Research on Spatial Distribution of Settlements in the Upper Reaches of the Minjiang River

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How to cite this paper: Song, L.J., Tian, S.J., Yang, L. and Fan, N. (2023) Research on Spatial Distribution of Settlements in the Upper Reaches of the Minjiang River. *Open Journal of Applied Sciences*, **13**, 1967-1981.
https://doi.org/10.4236/ojapps.2023.1311154

Received: October 7, 2023
Accepted: November 14, 2023
Published: November 17, 2023

Abstract

Under the background of the uplift of the Qinghai-Tibet Plateau, the settlements in the upper reaches of the Min River are significantly affected by the mountain environment, and their spatial distribution is typical and representative. In this study, the relationship between settlements and topography, rivers and transportation, and the spatial distribution patterns of settlements, such as the aggregation and orientation characteristics of settlements, have been studied. The main conclusions include: 1) The settlement density decreases with the increase of elevation, slope, and distance from rivers and roads; 76.25% and 63.17% of the settlements are distributed in the range of elevation 1500 - 3000 m and slope 6˚ - 25˚, the upper reaches of the Min River are mostly alpine valley terrain, the bottom of the river has a low altitude, the landscape is undulating. The warm and humid climate is suitable for farming, conducive to agricultural production, and an ideal living environment for mountain residents. 2) The nuclear density of the settlement is distributed in strips along the axis of the river, and the closer to the river, the greater the nuclear density value. 3) Mathematical statistical methods were applied for the first time to realize the quantitative expression of the coupling of settlement and river direction. The influence of topographic conditions in different watersheds on the coupling degree of settlement extension and river flow direction was revealed. The slope of the fitted straight line between the settlement and river direction was 0.897, and the two directions were consistent. Except for the mainstream of the Min River, the larger values of the standard deviation ellipse flattening of settlements in each basin appeared in the upper reaches of the bay, and the overall trend showed a gradual decrease from the upstream to the downstream, which was consistent with the topographic change characteristics of the basin.

Keywords

Settlement, Spatial Distribution, Agglomeration, Alpine Valleys, The Upper

Reaches of the Minjiang River

1. Introduction

Settlements are the closest spatial and temporal units between people and the environment. The study of the spatial distribution pattern of settlements plays a significant role in revealing the characteristics of the emergence and evolution of settlements. It is the critical foundation and way to implement the rural revitalization strategy and the method of urban-rural integration [1]. The development of "3S" technology has expanded the depth and breadth of the research on the spatial distribution law of settlements, and different theories and methods have been continuously applied to the research on the spatial regulation of settlements [2]. For example, the integration of fuzzy mathematics and neural network methods is used to explore the spatial distribution patterns of geographic phenomena [3]; mathematical and statistical methods for characterizing the evolution of natural environmental factors on settlement distribution patterns [4]; the spatial autocorrelation method and Moran's index for revealing the characteristics of the spatial distribution of clusters and optimizing the practice [5]; Geoprobes for studying the mechanism of coupled hydrological-environmental topographic features on the distribution of mountain settlements [6]. ArcGIS spatial analysis method was used to study the correlation between human activities and settlement sitting. The above theories and practices are primarily based on the research object of flat topographic settlements, and their results are difficult to apply to mountainous settlements. At the same time, mountainous areas account for more than two-thirds of the country's total area, and the complex topography of the mountainous regions significantly impacts settlement [7]. Therefore, research on the spatial distribution pattern of mountain settlements is of great theoretical and practical significance in revealing the characteristics of the emergence and evolution of mountain settlements [8].

A combination of natural and social factors forms the spatial characteristics of settlements, where biological factors are the root cause of the spatial distribution of settlements, social factors are the core driving force of the spatial distribution of settlements [9]. These factors have significant differences in the way they work and the extent to which they influence the emergence and development of settlements. This study takes the mountainous settlements in the upper reaches of the Minjiang River as its object of study and statistically and analytically analyzes the relationship between the settlements and factors such as topography, rivers, and transportation. As well as examining the factors affecting the spatial distribution characteristics of settlements in the upper reaches of the Minjiang River, revealing the spatial distribution pattern of settlements in the upper reaches of the Minjiang River. More importantly, it can provide a reference and basis for optimizing and reconstructing spatial patterns of settlement and rural revitalization in the upper Minjiang River and similar mountainous areas.

2. Regional Overview and Data Sources

2.1. Overview of the Study Region

The upper reaches of the Minjiang River are located in the transition zone from the Sichuan Basin to the eastern edge of the Qinghai-Tibetan Plateau, with a steep change in elevation from 700 to 5000 meters within a horizontal range of 40 to 50 kilometers. Among them, the rivers are deeply cut, and there is a significant difference in surface undulation, typical of the alpine canyon area (Figure 1(a)) [10]. The dramatic elevation change characterizes the vertical band

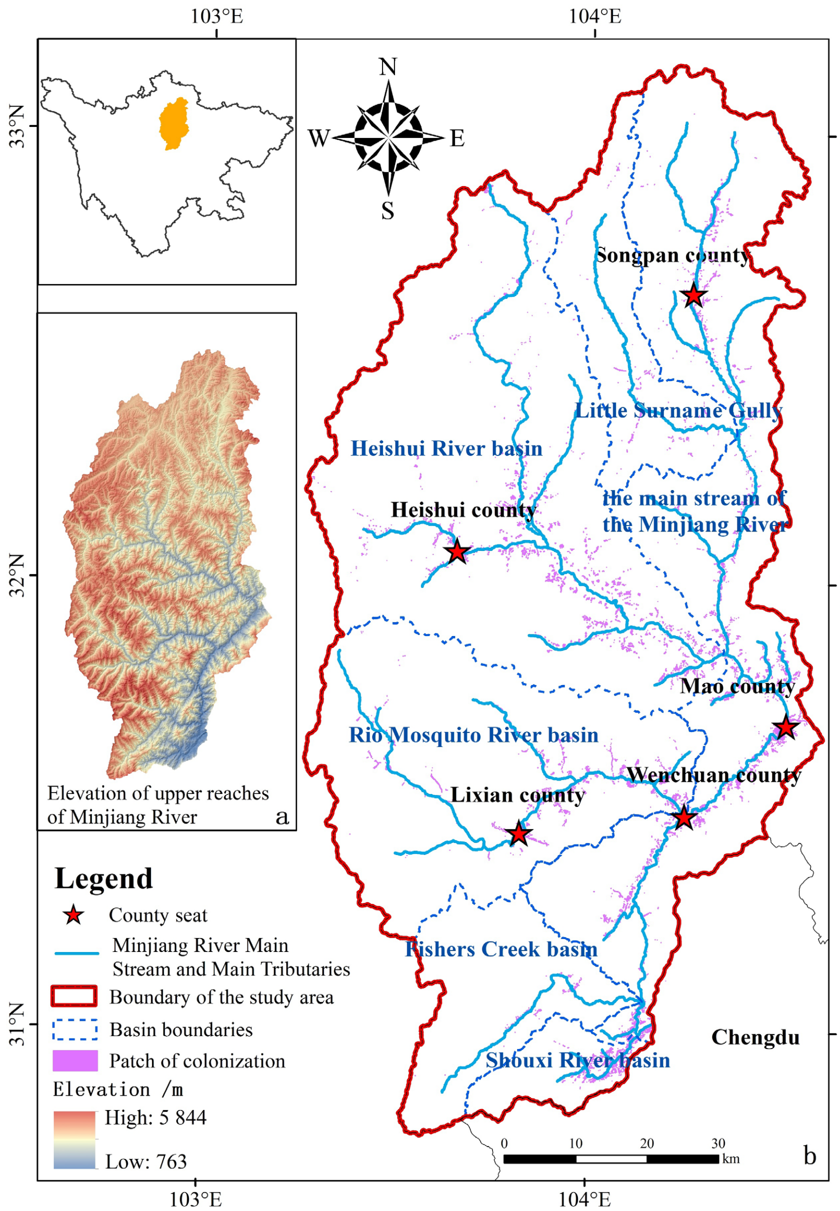

Figure 1. The study area.

spectrum of its mountains. At the same time, the upper reaches of the Minjiang River is a multi-ethnic settlement area of Tibetan-Qiang-Hui-Hispanic-Chinese origin, forming a critical ethnic corridor in the southwest region [11]. Influenced by history, culture, and industrial methods, the distribution pattern of different ethnic groups clustered along the upper Minjiang River along the elevation corresponds to the natural vertical belt spectrum of the mountains. In short, it forms a particular mountain genuine vertical belt spectrum-colonial ecological niche ethno-type map [12].

The upper reaches of the Minjiang River consist of five counties: Songpan County, Li County, Heishui County, Wenchuan County, Mao County, and parts thereof, with a watershed area of about 22,400 km^2. It mainly includes the tributary watersheds of the Mixed Valley Brain River, Fishers Creek, Little Surname Gulch, Blackwater River, and Shou Creek. The mainstream of the Minjiang River flows from north to south and is 355 km long. In conclusion, the distribution of settlements in the upper reaches of the Minjiang River is significantly affected by the topography, and they are mainly distributed in the lower elevation and relatively flat river banks (**Figure 1(b)**) [13] [14].

2.2. Data Sources

In conjunction with field surveys, collect and organize data on the upper Minjiang River settlements concerning environmental factors such as topography, rivers, and transportation, mainly:

1) Settlement data: Based on the acquisition of high-definition remote sensing images (resolution of 0.5 m) of the sky map, the settlement building data were vectorized using visual interpretation, and a total of 86,814 settlement building patches were obtained.

2) Topographic data: DEM digital elevation images (12.5 m resolution) were obtained from the NASA Geoscience Data website, cropped and spliced, and topographic data such as elevation and slope of the study area can be obtained through ArcGIS;

3) Other vector data: The spatial vector data of the upper Minjiang River, such as administrative boundaries, rivers, and traffic, come from the National Platform for Shared Services of Scientific and Technological Resources-National Earth System Science Data Center.

3. Research Methodology

3.1. Average Nearest Neighbor Analysis

There are three forms of spatial distribution of clusters: random, agglomerated, and homogeneous, which can be determined using the average nearest neighbor index [15]. The average distance value of all these most relative neighbor distances was calculated by measuring the distance between the center of each cluster site and its nearest cluster site. This was then compared with the average distance values under a hypothetical random distribution of cluster sites to determine the type of cluster distribution. The formula for this method is as follows:

$$\mathrm{ANN}=\frac{\bar{D}_o}{\bar{D}_e}=\frac{\sum_{i=1}^{n} d_i/n}{\sqrt{n/A}/2}=\frac{2\sqrt{\lambda}}{n}\sum_{i}^{n} d_i \quad (1)$$

In the formula: $\lambda = n/A$; $\bar{D}_o$ is the observed mean value of a clustered site to its nearest clustered location; $\bar{D}_e$ Is the expected mean distance of a clustered site assuming a randomized form; n is the total number of clustered sites; d is the distance; and A is the area of the study area. Taking one as the critical value for determination, if ANN > 1, it means that the cluster is a uniform distribution; if ANN < 1, it means that the collection is an agglomerative distribution; if ANN = 1, it means that the group is a random distribution. The average nearest neighbor has a Z-value, which indicates the degree of dispersion, and the results can be tested for significance using the Z-value.

3.2. Kernel Density Analysis

The kernel density method generates a density convergence surface by calculating the number of clusters within a radius using the cluster point as a statistical sample. Kernel density estimation represents the degree of density in the spatial distribution of colonies [16]. It's more of a statistical nonparametric density imputation. The larger the kernel density value, the denser the distribution of settlements will be. The expression is as follows:

$$f(x,y)=\frac{1}{nh^2}=\sum_{i=1}^{n} k\left[\frac{d_i}{n}\right] \quad (2)$$

In the formula: $f(x, y)$ is the value of the kernel density at point (x, y); n is the number of clustered points; h is the bandwidth or threshold; k is the kernel function, and d_i is the distance from the position of a point (x, y) to the part of the i-th observation point.

3.3. Standard Deviation Ellipse Analysis

The standard deviation ellipse analysis represents the cluster's spatial distribution characteristics, explaining the cluster's center location, degree of dispersion, and directional trend [17]. Where the long axis of the ellipse represents the directional tendency in the spatial distribution of clusters, and the short axis expresses the degree of dispersion.

$$C=\frac{\operatorname{var}(x)\operatorname{cov}(x,y)}{\operatorname{cov}(y,x)\operatorname{var}(y)}=\frac{\sum_{i=1}^{n} X_i^2 \sum_{i=1}^{n} X_i Y_i}{\sum_{i=1}^{n} Y_i X_i \sum_{i=1}^{n} Y_i^2} \quad (3)$$

In the formula: x, y are, the coordinates of variable i; $\{x; y\}$ denote the mean center of the variable; n is the total number of variables.

4. Spatial Distribution Patterns of Settlements in the Upper Reaches of the Minjiang River

4.1. Characterization of the Spatial Distribution of Settlements along the Terrain

At intervals of 500 m above sea level, the slopes of the upper reaches of the Minjiang River were categorized into five classes based on land slope: flat (≤2˚), balanced and gentle pitches (2˚ to 6˚), gentle slopes (6˚ to 15˚), steep slopes (15˚ to 25˚) and sharp and steep slopes (≥25˚). The number and density of colonies in different elevation ranges and slope classes were counted separately on the ArcGIS platform, and the results are shown in **Figure 2**.

The colonies are mainly distributed in the altitude range of 1500 - 3000 m and the slope range of 6˚ - 25˚, accounting for 76.25% and 63.17% of the total number of colonies, respectively. The density of colonies decreased with the increase of elevation and slope. The areas with low height and gentle slopes are ideal for the inhabitants of the upper reaches of the Minjiang River. Still, they are limited by the topographic and geomorphological characteristics of the upper reaches of the Minjiang River. Therefore, the residents mainly live in the high semi-mountainous section of 1500 - 3000 m, which belongs to the warm temperate semi-arid river valley climate and mountain temperate climate zone. The precipitation in the area is about 600 - 900 mm, the average annual temperature is about 10˚C, and the slopes are gentle between 6˚ and 15˚. The site is suitable for growing crops, and there is a wide distribution of gardens, arable land, and forested land while the climate is relatively humid and warm, so mountain people tend to live in this area. The subalpine section at an altitude of >3000 m belongs to the mountainous climate zone, where the height and slope constrain the development of arable land. This range is more suitable for developing forestry and animal husbandry, but not for human habitation, and the distribution of settlements is sparse. The vertical differentiation of settlement distribution in the upper reaches of the Minjiang River is apparent and closely related to the climate and topographic conditions. This is consistent with the characteristics of the mountain natural vertical belt spectrum-colony ecological niche ethno-type mapping by related scholars studying the environmental niche of the upper Minjiang River.

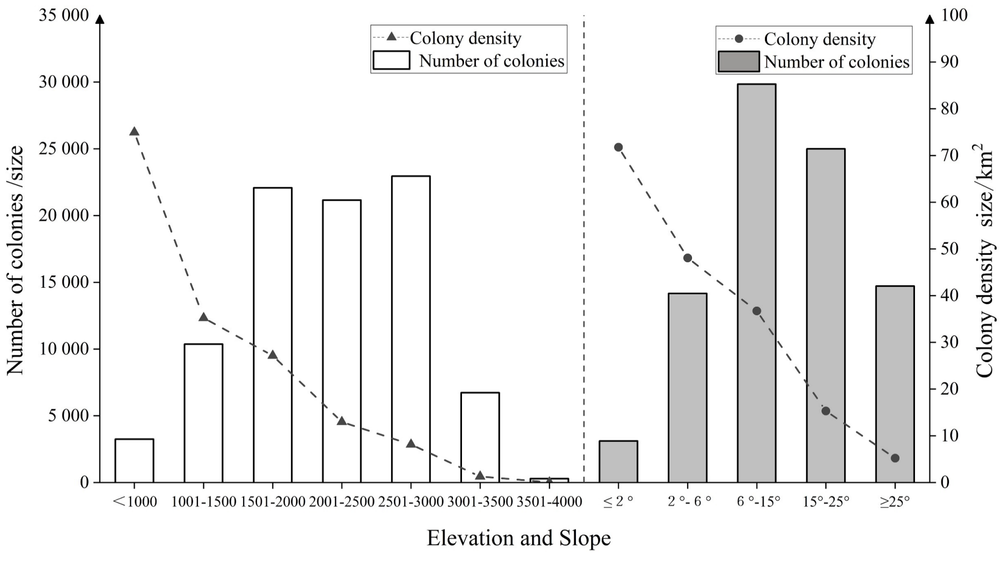

Figure 2. The relationship between settlement number & density and elevation & slope.

4.2. Characteristics of Spatial Distribution of Settlements along Rivers and Transportation

The number of colonies at different distances from the river and the road were counted separately, and their densities were calculated and the results are shown in **Figure 3**.

The number and density of settlements decrease as the distance from rivers and roads increases, with the number of accommodations in the range of 0 - 500 m accounting for more than 50% of the total number of settlements and the density being 3.5 times that of 500 - 1000 m. This distribution reflects the significant influence of mountain rivers on the distribution of payments. Because the upper reaches of the Minjiang River are mostly high mountain canyon terrain, the river elevation is low, and the banks are relatively flat. At the same time, there are broad terraces on both sides of the river, the soil is more fertile, and the water and heat conditions are balanced and suitable for the growth of crops. Settlements built along the river are convenient to get water, which is conducive to agricultural production. At the same time, due to topographic conditions, roads are generally built along both sides of the river. This has led to the same trend and characteristics of the settlement as the distance from the river and the road changes.

4.3. Spatial Aggregation Characteristics of Settlements

The cluster vector data were converted to raster data (4 m × 4 m). The average nearest neighbor analysis (Equation (1)) and kernel density analysis (Equation (2)) were used to calculate the average most comparative neighbor index (ANN), Z-value, and kernel density values of the upper reaches of the Minjiang River, respectively, and the results are shown in **Figures 4-6**. The ANN values of the 80 townships in the upper reaches of the Minjiang River range from 0.03 to 0.36,

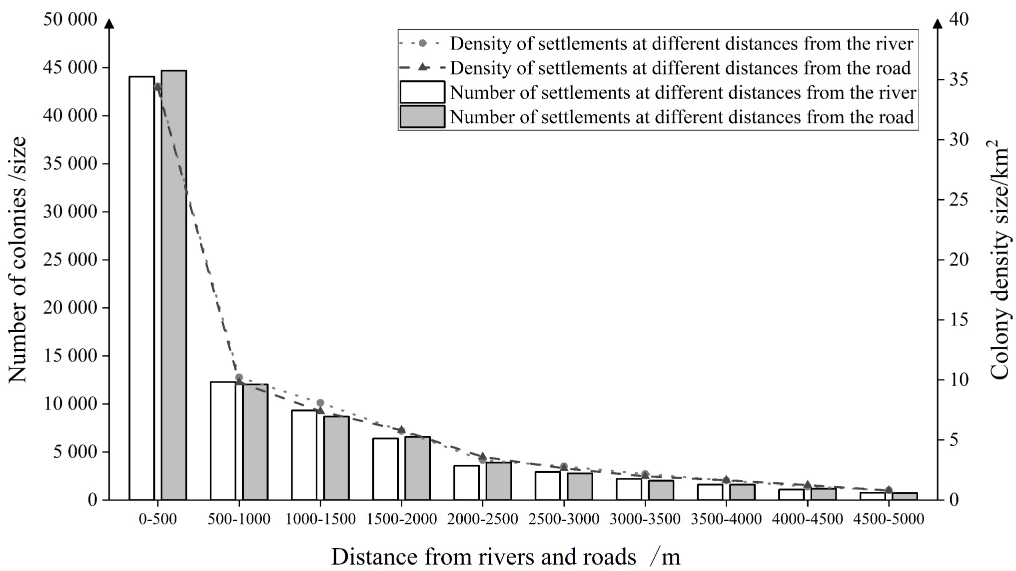

Figure 3. The relationship between settlement number & density and rivers & roads.

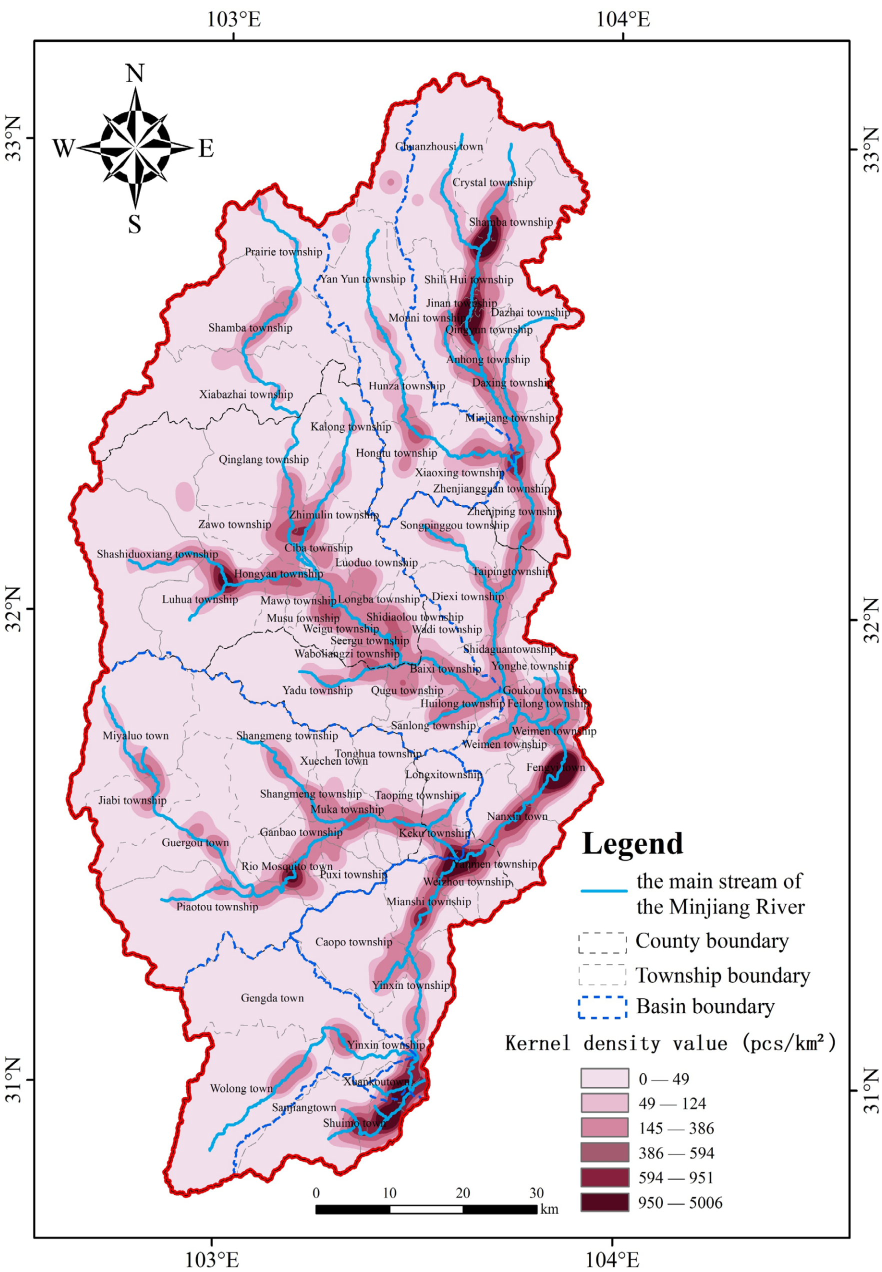

Figure 4. Distribution of the kernel density of settlement.

and their Z-values are smaller than the critical value of −2.58 at the confidence level of 0.01. This indicates a confidence level of more than 99%, which suggests that the clusters in the upper reaches of the Minjiang River are all clustered distributions.

Kernel densities are mainly distributed in strips within 2 km of the river on the axis of the river. The closer to the river, the greater the value of nuclear density. In the study area, there are 16 agglomeration centers with nuclear densities more fabulous than 1000, and except for Wenchuan County, the atomic density of the county towns is the maximum value in their counties. Among them, Fengyi Town, the county town of Mao County, has the most significant nuclear

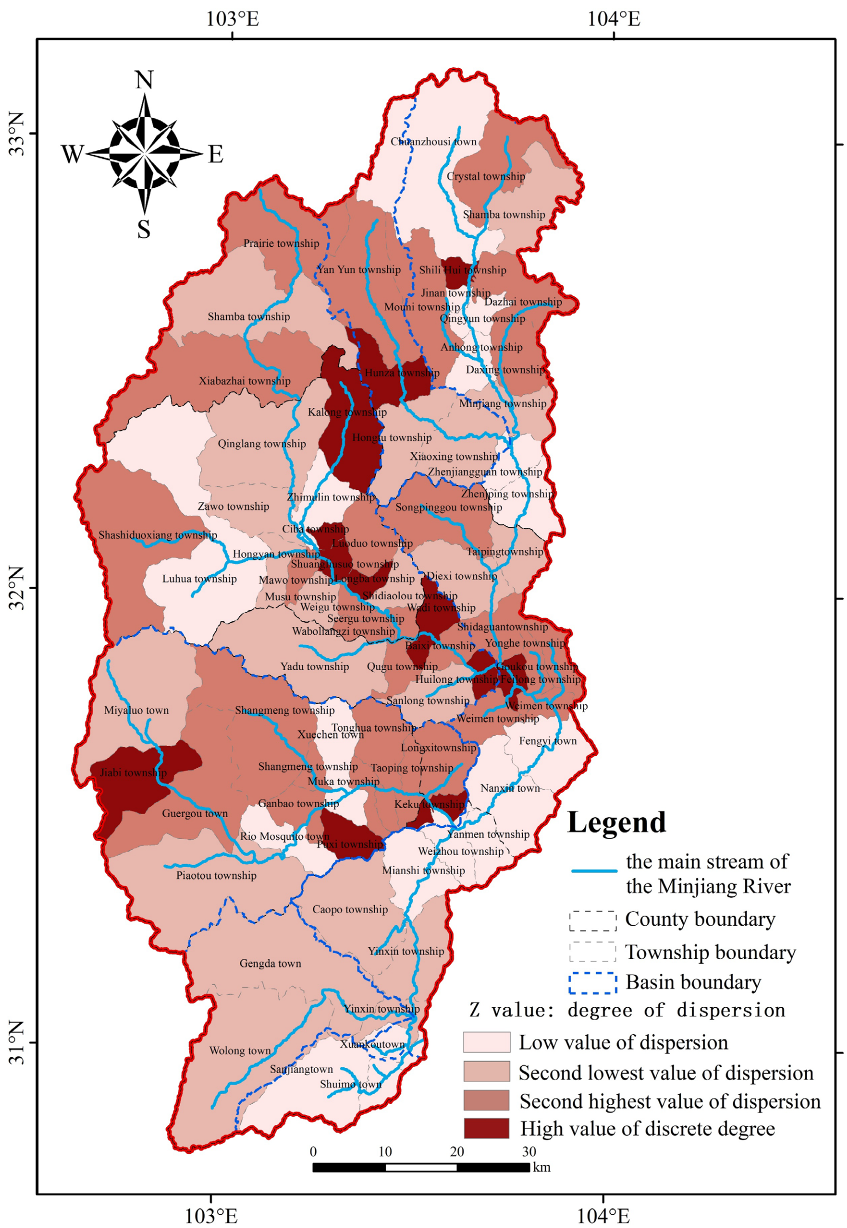

Figure 5. Distribution on the degree of dispersion of settlement.

density, much larger than the other agglomeration centers. Mao County, Heishui County, and Li County are all single agglomeration centers, and Wenchuan and Songpan are multiple agglomeration centers (**Figure 4**). The natural breakpoint method was used to classify the Z values into discrete levels, and most of the high discrete values were distributed in the Heishui River and the Zaogu Brain River. This indicates that the clusters in the mainstream of the Minjiang River are more clustered than the tributaries **Figure 5**), and there are 12 clustering centers in the mainstream of the Minjiang River. A comparison of kernel density values and Z-values shows that high kernel density values generally correspond to low Z-values. This shows the consistency of using kernel density and Z-value to express the degree of accumulation (**Figure 6**).

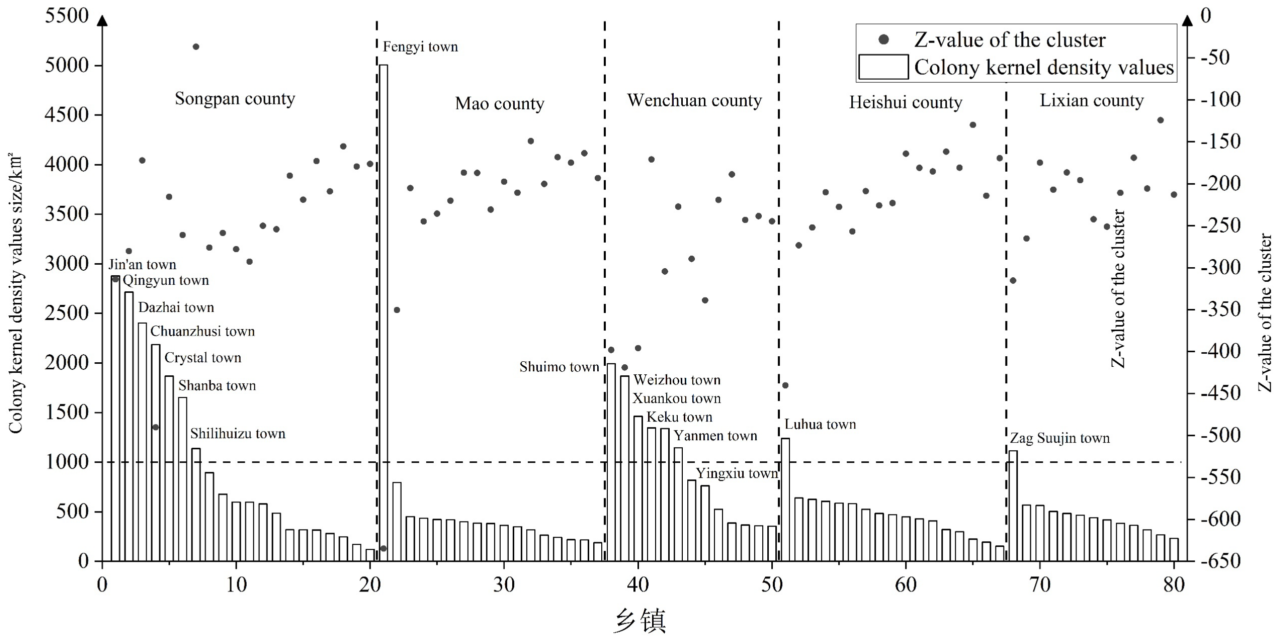

Figure 6. Analysis of the relationship between settlement Z-value and kernel density.

As described in Sections 3.1 and 3.2, the influence of the upper Minjiang River on the distribution of settlements is significant due to the effect of topography. Accommodations are generally clustered along both sides of the rivers with better topographic conditions. For example, Fengyi Township, the county seat of Mao County, is located in the Maowen Fracture Fault Basin, with open river valleys and flat topography, where 43% of the total population of Mao County is clustered. As Wenchuan County is close to the Chengdu metropolitan area, its economy is relatively developed and subject to Chengdu's socio-economic radiation, so its population is concentrated in areas close to Chengdu (such as Shuimo Town and Xuankou Town). The basins of the Heishui River and the Zaogu Brain River, tributaries of the Minjiang River, are areas where the Tibetan and Qiang ethnic groups gather, and their mode of industry is based on animal husbandry, leading to a lower degree of aggregation.

4.4. Spatial Orientation Characteristics of Settlements

According to the area of cluster distribution, the river sections of the basin were divided and numbered according to the direction from upstream to downstream, as shown in Figure 7. The standard deviation ellipse analysis method (Equation (3)) was used to calculate the length and direction degrees of different river section settlements' long and short axes to make the standard deviation ellipse of their payments. The long axis direction and river direction degrees of the river segment colonies in the upper Minjiang River and its tributary basins were linearly fitted, respectively, and the results are shown in Figure 8. Based on the lengths of the long and short axes of different river segment colonies, their flatness (ratio of the long and short axes) was calculated, as shown in Figure 9.

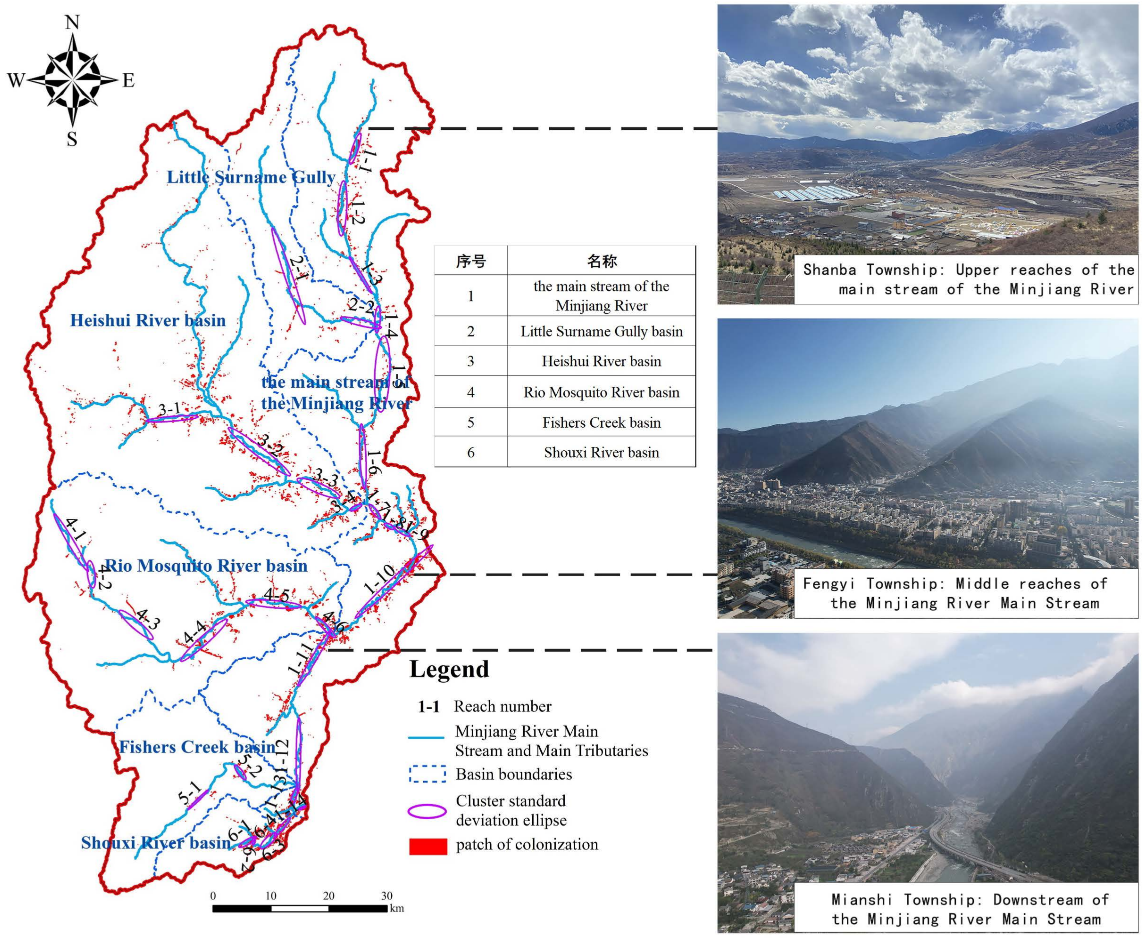

Figure 7. Division of river basin section and standard deviation ellipse flattening of settlements of the upper reaches of the Minjiang River.

The standard deviation ellipse of clustering in different river sections of the upper Minjiang River is centered on the river and extends in the same direction as the river (**Figure 7**). When the direction of the long axis of the standard deviation ellipse is closer to the direction of the river, *i.e.*, the slope of the two linearly fitted lines is closer to 1, it indicates that the approach of the two is more consistent (**Figure 8**). The slopes of the straight lines of the long axis of the standard deviation ellipse of the upper reaches of the Minjiang River and the direction of the river are 0.897, which indicates that the two approaches are more consistent. The consistency of different river basins was shown as Minjiang River main stream > Yuuzi River > Heishui River > Xiaoshuigou > Maogu brain River > Shouxi River. If the direction of the long axis of the standard deviation ellipse of the settlement is better consistent with the law of the river, the larger the standard deviation ellipse flatness is. It indicates that the greater the influence of rivers on the spatial distribution of settlements. Except for the mainstream of the Minjiang River, the larger values of the flatness of each basin appeared in the upper part of the basin and generally showed a trend of gradual decrease from the upper part to the lower leg (**Figure 8**).

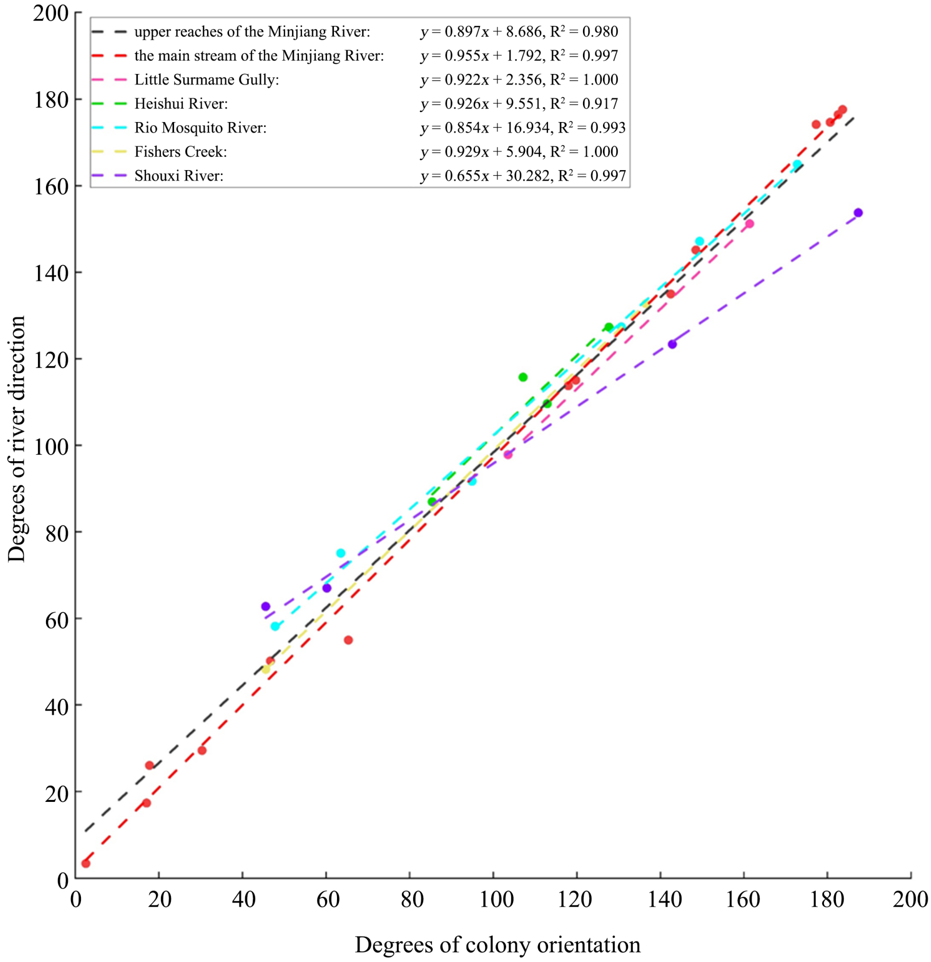

Figure 8. The extension of settlements and rivers of the upper reaches of the Minjiang River.

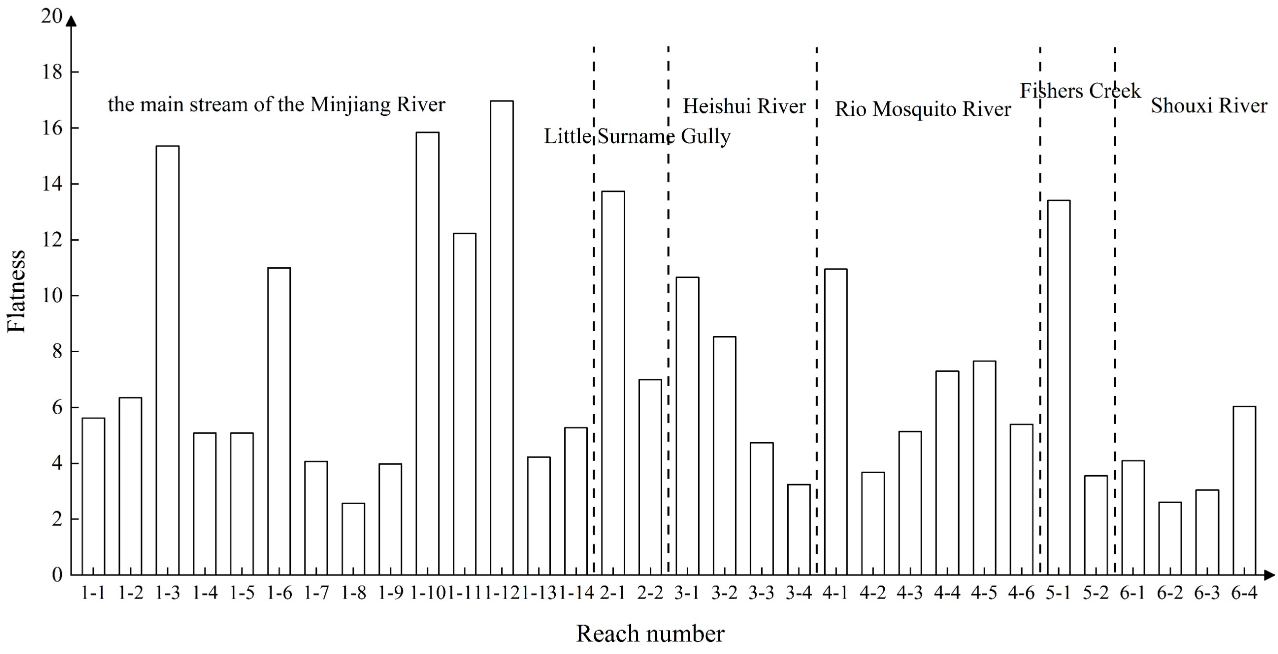

Figure 9. Distribution of standard deviation ellipse flattening of settlements in different watersheds.

The upper reaches of the Minjiang River are characterized mainly by high mountain and canyon terrain, and except for the mainstream of the Minjiang River, the upper reaches of the various basins have significant differences in height and slope. At the same time, the topography on both sides of the river on the valley floor is relatively flat, with a high degree of agglomeration of settlements along the river's flow. So, it makes its standard deviation elliptic oblateness larger, and the effect of the river on the accumulation of the accommodation is weakened in the middle and lower reaches. Influenced by the tectonic uplift of the Qinghai-Tibetan Plateau, the mainstream of the Minjiang River has entered a new round of fluvial geomorphic development. However, the anadromous erosion has not yet been transmitted to the middle and upper reaches, making its downstream elevation and undulation high, while the middle and upper reaches have relatively low elevation and undulation, and its flattening rate is more significant in the lower reaches (**Figure 9**).

5. Conclusions

In this study, the relationship between settlements and topography, rivers and transportation, as well as the spatial distribution patterns of settlements, such as the aggregation and orientation characteristics of the settlement, has been studied. The main conclusions are as follows:

1) The distribution of settlements in the upper reaches of the Minjiang River is closely related to topography and rivers. The density of settlements decreases with the increase of altitude and slope; 76.25% and 63.17% of the accommodations are distributed in the range of 1500 - 3000 m above sea level and in the field of 6˚ - 25˚ in slope; the number and density of settlements decrease with the increase of distance from the rivers and roads, and more than 50% of the accommodations are distributed in the range of 500 m from the rivers and roads; the upper reaches of the Minjiang River are mainly in the terrain of high mountains and canyons, and the rivers on the bottom of the valley are low in altitude and relatively flat on both sides, which is suitable for agricultural production. The upper reaches of the Minjiang River are mostly high mountain canyon terrain, with low elevation and relatively flat banks, a warm and humid climate, and suitable for cultivation, which is favorable for agricultural production and is an ideal living environment for mountain residents.

2) The clusters in the upper reaches of the Minjiang River have prominent characteristics of clustering along the river. Kernel density is distributed in a strip-like manner with the river as the axis, and the closer to the river, the larger the value of kernel density is. The high value of kernel density generally corresponds to the low value of Z value, which is consistent with the degree of aggregation of settlements expressed using kernel density and Z value.

3) The river significantly influences Upper Minjiang River settlements. The slope of the linearly fitted straight line between the extension direction of the payments and the river direction is 0.897, indicating that the two approaches are

in good agreement. Except for the mainstream of the Minjiang River, the more considerable value of the flat rate of each basin appeared upstream of the bay, and the overall trend decreased from upstream to downstream. This is due to the high difference in topography and slope upstream of the tributary basin. In contrast, the topography of both sides of the river at the bottom of the valley is relatively flat, and the degree of aggregation of colonies along the river flow is high. The degree of river influence on the settlements is high.

Through analysis and research, this thesis has only analyzed the spatial distribution characteristics of the cluster in the study area, and lacked temporal discussion. And it fails to implement into the specific implementation plan, so it needs to make further optimization plan development and discussion.

Funding

Foundation Project: Supported by the National Natural Science Foundation of China (41971214, 41401195).

Acknowledgements

We thank the National Science and Technology Resources Sharing Service Platform-National Earth System Science Data Center (http://www.geodata.cn) for providing data support.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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