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ORIGINAL RESEARCH ARTICLE

Population distribution characteristics and its relationship with natural factors in karst mountainous areas of Northwest Guangxi

Shana Shi[1,2], Bingkang Xie[1], Baoqing Hu[2,3*], Chuanyong Tang[4], Yan Yan[2,3], Xiaoqing Li[1]

[1]*College of Resources and Environmental Sciences, Hunan Normal University, Changsha 410081, Hunan Province, China.*
[2]*Key Laboratory of Environment Change and Resources Use in Beibu Gulf, Ministry of Education, Nanning Normal University, Nanning 530001, Guangxi Province, China. E-mail: Bq_XHu288@163.com*
[3]*Guangxi Key Laboratory of Surface Processes and Intelligent Simulation, Nanning 530001, Guangxi Province, China.*
[4]*School of Geography and Planning, Nanning Normal University, Nanning 530001, Guangxi Province, China.*

ABSTRACT

The smallest administrative unit of the sixth national census-township (town) is selected as the basic unit, the population spatial distribution characteristics at the township (town) level in karst mountainous areas of northwest Guangxi are analyzed by using Lorenz curve and spatial correlation analysis method, and the influence intensity of natural factors on regional population spatial distribution is detected by using geographic detector method. The results show that: 1. the spatial distribution of population at the township (town) level has the characteristics of imbalance, showing generally significant positive correlation and certain aggregation; 2. There are significant differences in the impact of the spatial distribution of various natural factors on the population distribution. For the towns without karst distribution in the northwest and central south of the study area, the population density increases with the increase of factors conducive to human residence, but the average population density is only 79 people/km^2. In the towns with karst distribution in the East and south, the spatial distribution of population density and natural factors is not a simple increase or decrease relationship, but fluctuates with the change of karst distribution area. 3. The factor detection results of the geographic detector show that the altitude has the greatest impact on the spatial distribution of population. The interactive detection results show that the impact intensity of any two natural factors after superposition and interaction presents nonlinear enhancement and two factor enhancement. It can be seen that the karst mountain area in northwest Guangxi is similar to other areas. Altitude is one of the main factors affecting the spatial distribution of population, but the river network density and unique geological landform of karst mountain area have a strong catalytic effect on the spatial distribution of population. The superposition and interaction with other factors can further strengthen the impact on population distribution.

Keywords: Karst Mountain Area; Population Distribution Characteristics; Geographic Detectors; Northwest Guangxi; Guangxi

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1.Introduction

Population, resources, environment and development are the most important global issues[1]. The number of population and its spatial distribution characteristics reflect the difference of natural conditions and the level of economic development in a region to a certain extent. Therefore, it is of great significance to reveal the regional characteristics of population spatial distribution[2]. The number and distribution of population are mainly affected by the level of social and economic development, but no matter what degree of social and economic development, human survival and development are inseparable from the

natural environment. Its process and combination type are affected by various natural environmental factors, showing distinct regional differences[3]. China's diversified natural environment leads to regional differences in population distribution. Clarifying the relationship between population spatial distribution pattern and natural environment plays an important role in improving the understanding of man land relationship and realizing the sustainable management of population, resources and environment[4].

At present, scholars at home and abroad have carried out a lot of research on population change and spatial distribution, population distribution data statistics and simulation methods, and the relationship between population distribution and influencing factors[5–18]. The research scale is involved from the world, the country to the city and county level, and the research accuracy is becoming more and more precise. In recent years, some studies have also been carried out on the township level research scale[19–26]. In 2015, Bai Zhongqiang and others analyzed the population distribution characteristics and influencing factors of the township level research scale in 25 provinces (cities and districts) in China, and pointed out that the population distribution research from the township level research scale can more objectively and finely describe the spatial pattern of population distribution. However, due to the lack of data and the availability of data, Guangxi, Sichuan and other provinces and regions are not within the scope of their research. In addition, some scholars have studied the population spatial distribution characteristics and influencing factors of different landforms such as plateau and mountainous areas.

The similarities and differences between the population distribution of different geomorphic types such as plateau and mountainous areas and other regions are analyzed[27–30]. Due to the special terrain, landform and geological conditions, the population distribution and natural influencing factors in karst areas are different from those in other regions. There is relatively little research on the population distribution and related aspects in karst areas. The research units are mainly counties and cities (districts)[31–33]. The research content is to explore the relationship between the population distribution and various natural factors in karst areas. The zonal characteristics of various factors are the main factors, while the impact differences of various natural factors on population distribution in karst areas are discussed. The research on the impact intensity of population distribution after the superposition of various natural factors is relatively rare.

Karst mountainous area is the largest karst landform type area. Its basic feature is the vicious cycle of poverty and ecological environment, which is the epitome of China's sustainable development[34]. For a long time, unreasonable farming and the increase of population pressure have led to serious soil and water loss and the continuous expansion of rocky desertification, resulting in a vicious circle of ecological environment damage in karst mountainous areas. Taking the karst mountainous area in northwest Guangxi as the research area and the township as the research unit, this paper uses the spatial correlation analysis method to study the population spatial distribution characteristics of Karst mountainous area, and selects the main natural factors affecting the population spatial distribution of Karst mountainous area, The influence of different natural factors on population spatial distribution in Karst mountainous areas and the comprehensive influence intensity after the superposition and interaction of various factors are quantitatively analyzed by using geographic detectors, so as to provide scientific reference for sustainable development, ecological resettlement and optimal layout of urban system in karst mountainous areas.

2. Overview of the study area

Northwest Guangxi is located at the southeast edge of Yunnan Guizhou Plateau and the west of Liangguang hills. It is located at 104 ° 29' ~ 109 ° 09'E and 23 ° 41' ~ 25 ° 37'N. The total land area is 6.97 × 104 km^2, including Baise City and Hechi City, governing 23 counties (cities, districts) and 276 townships (**Figure 1**). In 2010, the total population was 6.836 million (data from the sixth national census). The terrain in Northwest Guangxi fluctuates greatly, and the altitude is distributed between 100

~ 2000 m, showing the characteristics of low in the southeast and high in the northwest. Mountainous areas account for more than 80% of the total land area. The karst landform in this area is widely developed, and the main karst landform type is mountainous, accounting for more than 80%. The carbonate rocks in the area are mainly composed of continuous limestone, limestone and dolomite, accounting for more than 70%. In addition, this is the main distribution area of rocky desertification in Guangxi (2 / 3 of the rocky desertification area in Guangxi is distributed in this area)[35]. The regional rocky desertification area accounts for more than 60% of the total land area, and the ecological environment is extremely fragile. The study area has a subtropical and mid subtropical monsoon climate, with an annual average temperature of 15 ~ 25 ℃ and an average annual precipitation of 1000 ~ 1600 mm, decreasing from southeast to northwest. Rivers mainly include Youjiang River, Hongshui River, Longjiang River and their tributaries.

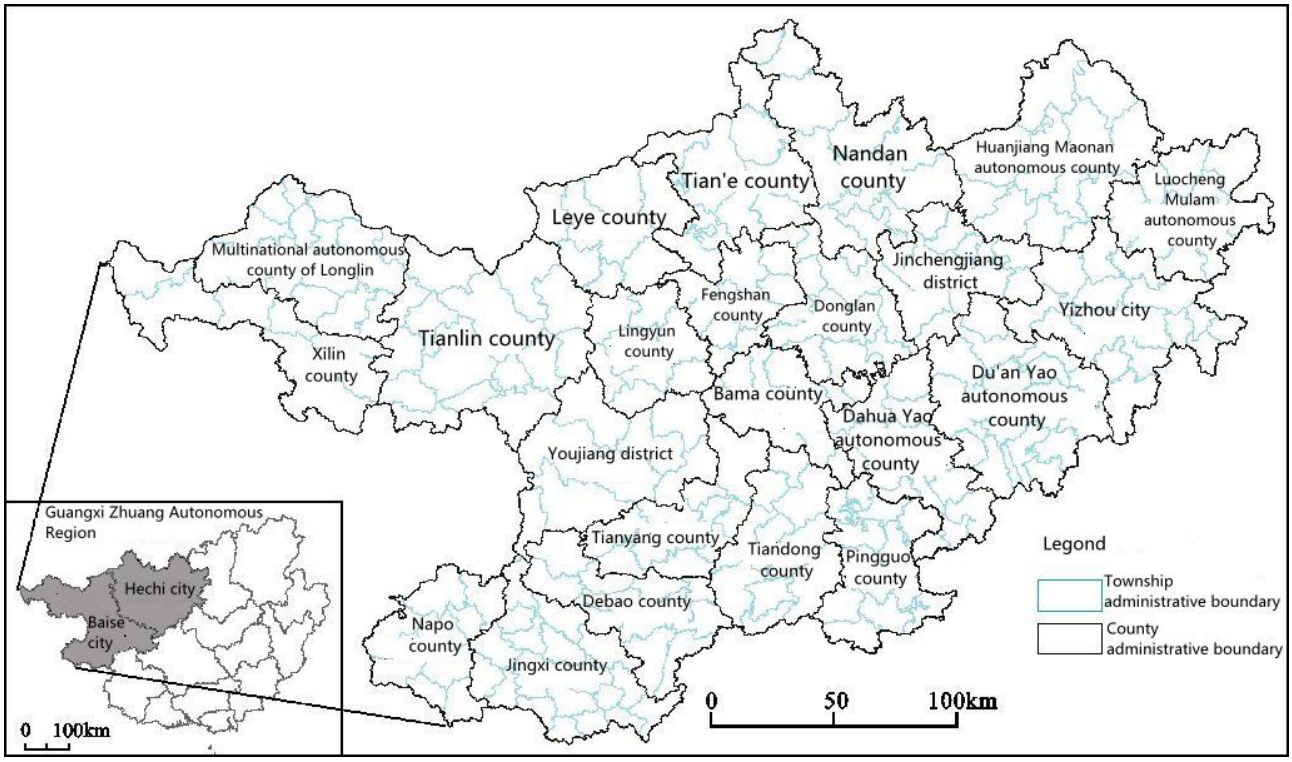

Figure 1. Location and scope of the study area.

3. Data sources and research methods

3.1 Data sources

The data of township population comes from the data of China's 2010 census by township, town and street published by China Statistics Publishing House[36]; Digital elevation model (DEM), 30 m × 30 m) the data of land use status and administrative division are from the data cloud website of the Chinese Academy of Sciences (http://www.csdb.cn/); Meteorological data comes from the national meteorological science data sharing service platform (http://data.cma.cn/); the data of karst landform comes from the geomorphic Atlas of the People's Republic of China (1:1 million) prepared by the Chinese Academy of Sciences[37]; the karst geological data is derived from the 1:1 million digital geological map of the People's Republic of China.

3.2 Research methods

3.2.1 Analysis method of population spatial distribution

1) Lorenz curve method. In this paper, Lorenz curve is used to analyze the balance of population spatial distribution. The drawing method of Lorenz

curve is as follows: according to the ranking of average population density of townships from small to large, calculate the cumulative proportion of population and land area of each township, take the cumulative proportion of population as the horizontal axis and the cumulative proportion of land area as the vertical axis, and draw the Lorenz curve of population distribution in the study area[38]. The curvature of Lorenz curve represents the balance of population distribution.

2) Spatial autocorrelation analysis. In this paper, the spatial autocorrelation analysis method is used to analyze the spatial correlation of population distribution. Spatial autocorrelation includes global and local spatial autocorrelation. Global spatial autocorrelation is the distribution of a phenomenon or attribute value in the whole region to judge whether the phenomenon or attribute value has aggregation characteristics in space. Local spatial autocorrelation is to reveal the distribution of the phenomenon or attribute value in local spatial units.

3.2.2 Geographic detectors

Geographic detector is a group of statistical methods to explore spatial differentiation and reveal its driving force[39]. Factor detection in geographic detector can identify influencing factors, and interactive detection can explain the interaction of influencing factors on dependent variables. It is an effective tool to study the driving mechanism of complex geographic factors[40].

1) Factor detection can detect the extent to which a certain influence factor explains the spatial differentiation of geographical elements and whether the changes of a certain influence factor and geographical elements have significant consistency in space. The calculation formula is as follows:

$$Q_{DY} = 1 - \frac{\sum_{i=1}^{L} n_{D,i}\sigma_{Y_{Di}}^2}{n\sigma_Y^2} \quad (1)$$

In this formula, Q_{DY} is the detection force value of detection factor D to geographical element Y; i = 1,... L, is the stratification of detection factors, i.e. classification or zoning; N is the number of units; n_D, i is the number of units in the detection factor layer i; σ_Y^2 and $\sigma_{Y_{Di}}^2$ is the variance of Y values of the whole region and layer i respectively. If $\sigma_{Y_{Di}}^2 \neq 0$, then the model is established and the value range of Q_{DY} is [0,1]. When Q_{DY} = 0, it indicates that the geographical elements are not driven by the influencing factors. The larger the Q_{DY} value, the greater the impact of the factor on the geographical elements. By comparing the factor detection force value Q_{DY}, the main influencing factors of the spatial distribution of geographical elements are detected.

2) Interaction detection can analyze the interaction between different influencing factors and evaluate whether their interaction will enhance or weaken the impact on the spatial differentiation of geographical elements. For example, to detect the interaction between factors A and B affecting the spatial distribution of geographical elements, first calculate the Q values of the two factors, and then overlay layers A and B to form layer C to obtain their interactive Q values. By comparing the influence values Q_a, Q_b and Q_c of layers A, B and C, we can evaluate the impact of the interaction of the two factors on the spatial differentiation of geographical elements and the impact of a single factor. There are five types of interaction between the two influencing factors on the spatial distribution of geographical elements. When Q (A ∩ B) < min [Q (A), Q (B)] is nonlinear weakening, min [Q (A), Q (B)] < Q (A ∩ B) < Max [Q (A), Q (B)] is single linear weakening, Q (A ∩ B) > Max [Q (A), Q (B)] is double factor enhancement, Q (A ∩ B) > Q (A) + Q (B) is nonlinear enhancement, and Q (A ∩ B) = Q (A) + Q (B) is independent.

4. Characteristics of population spatial distribution

4.1 General pattern of population spatial distribution

In 2010, the total population and population density of Karst Mountainous townships in Northwest Guangxi were quite different in space (**Figure 2**). Qingyuan town with the largest population had a total population of 155,900, and Sannong Yao Township with the least population was only 3,991 people, with an extreme value ratio of 39.06. Jinchengjiang

street with the highest population density is 5,377 people/km^2, while Baile Township with the lowest population density is only 21 people/km^2, 256 times of the latter. Overall, the spatial distribution of population in Karst Mountainous Areas in Northwest Guangxi shows the following characteristics: 1. The total population is more in the southeast and less in the northwest. The population is mainly distributed in counties (cities) in the East and south, and the population in the west, especially Tianlin county and Leye County in the northwest, is less. 2. The population density gradually decreases from southeast to northwest, and the relatively densely populated areas are Luocheng County, Yizhou city, Du'an county, Dahua County, Pingguo County and other places in the East and South; The population density in the west is low, and the population density in most areas is less than 60 people/km^2. 3. The total population and population density of the townships streets where the county (city, district) government is located are the highest in the county (city). For example, Qingyuan town is the seat of Yizhou district Party committee and Yizhou district government, with a population density of 494 people/km^2. Tianzhou town is the seat of Tianyang County, with a population density of 802 people/km^2.

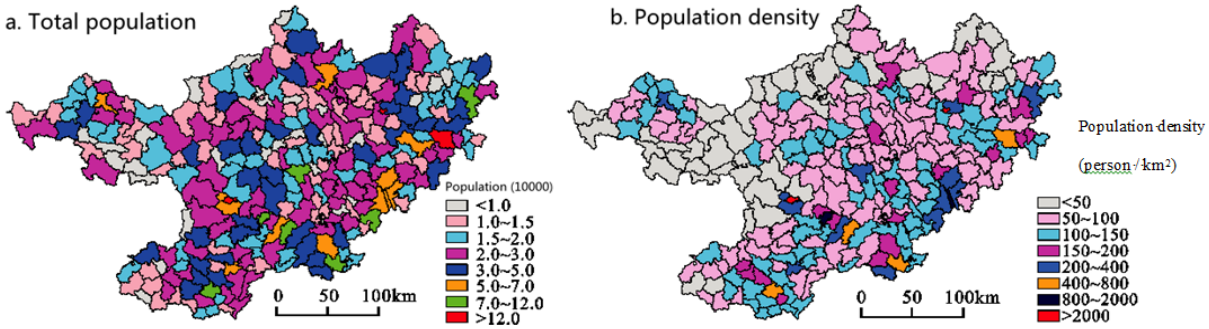

Figure 2. Spatial distribution of total population and population density in the northwestern Guangxi in 2010.

4.2 Balance of population spatial distribution

Lorenz curve is highly curved (**Figure 3**) and deviates from the absolute average, indicating that the spatial distribution of population is extremely uneven. The proportion of population and land area in different density levels is obviously unbalanced. In 2010, 10% of the population in Northwest Guangxi was distributed on more than 25% of the total regional area, and its population density is less than 50 people/km^2. When the cumulative population proportion is close to 70%, the total land area occupied by them is close to 90%, and the population density is less than 150 people/km^2. It can be seen that the population density in most areas of Northwest Guangxi is low. The area with a population density of more than 400 people/km^2 accounts for only 1.62% of the land area, but 12.94% of the population is distributed, indicating that a large number of people are gathered in some small areas in Northwest Guangxi, and the spatial distribution of population in the study area is extremely uneven.

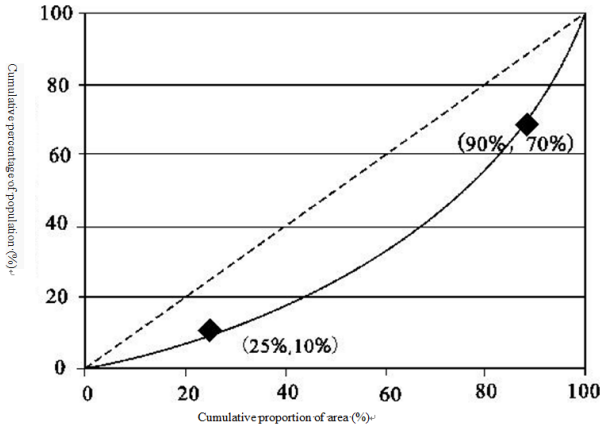

Figure 3. Lorenz curve of population distribution in the northwestern Guangxi in 2010.

4.3 Spatial autocorrelation of population distribution

The results of global autocorrelation analysis show that Moran's I of population density in Northwest Guangxi in 2010 is 0.027 (**Figure 4a**). After significance test, the Z value is 1.900, $P < 0.03$, showing a spatial positive correlation, indicating that the spatial distribution of population density in

Northwest Guangxi in 2010 is not completely random, but shows that the adjacent regional units in some spatial locations have the same attribute values. The results of local spatial autocorrelation analysis (**Figure 4b**) show that the high–high concentration areas of population density are mainly scattered in the central cities or key towns of Hechi and Baise, such as Baiyu town and Xin'an town. These townships have good natural conditions, relatively flat terrain, mainly plains and hills, relatively convenient land and water transportation, and high population density; the low oligomeric concentration areas with population density are mainly distributed in villages and towns far away from the central city, such as most townships in Tianlin county, Tian'e county and other counties. These townships have relatively poor natural conditions, more mountains and less regional population; the low high population density gathering areas are distributed in the townships around the two downtown areas, such as Yongle Town and Liuwei Town, whose population density is much lower than that of the surrounding central towns; the high oligomeric concentration area with population density is distributed in the central town far away from the central city, just like Le town. Although the township has the same high terrain as the surrounding township, it is rich in natural resources and convenient transportation. As the seat of the county, its population density is much higher than that of the surrounding towns.

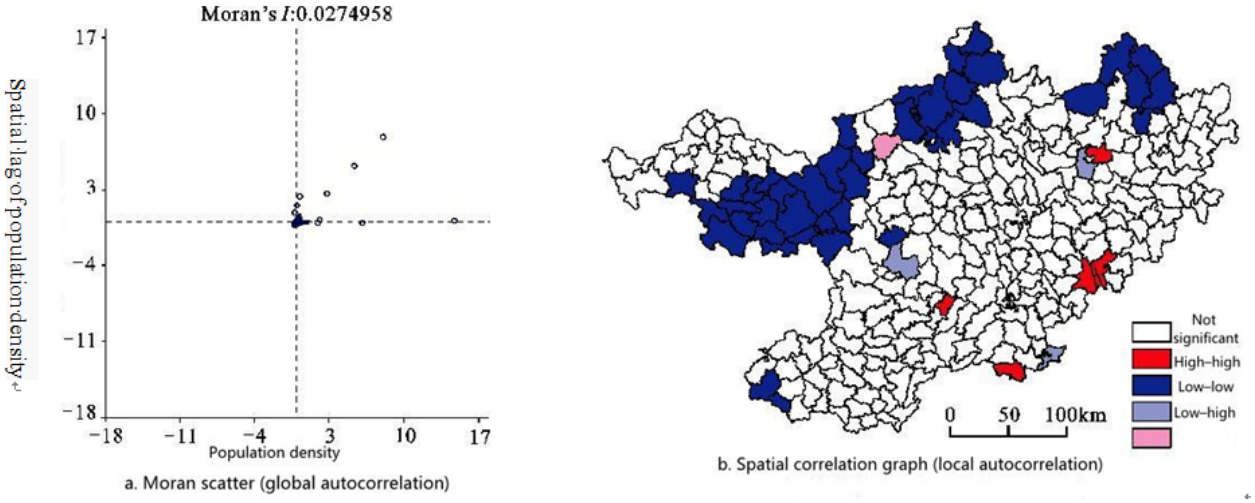

Figure 4. Moran scatter plot (global autocorrelation) and spatial correlation map (local autocorrelation) of population density in the northwestern Guangxi in 2010.

5. Influence of natural factors on population distribution in karst area of Northwest Guangxi

5.1 Relationship between natural factor distribution and population distribution

Altitude, ground slope, climate, hydrology and vegetation among natural factors are considered to be the main factors affecting population distribution, and altitude and karst geological conditions are considered to be the two main factors affecting population distribution in Karst Areas[34–43]. Based on the available research results and data, the natural influence factors selected in this paper are altitude (H), ground slope (SL), annual average temperature (Ta), river network density (Rn), forest coverage (Tr), karst distribution area ratio (Kr), karst physiognomy type (Km) and karst geological type (Ca).

5.1.1 Population density and altitude

Towns with an altitude of less than 200 m have the highest population density High, 541 people/km^2, about a township with an altitude of more than 900 M 6.5 times the population density, about 200 ~ 500 m above sea level 4 times the mouth density. Villages and towns with an altitude of 200 ~ 500 m are the main population gathering areas (**Table 1**), with a population density of 136 people/km^2, divided into It is distributed in most towns in the southeast of

Table 1. The relationship of natural factors and spatial distribution in the Northwestern Guangxi in 2010

Impact Factors	Classification	Proportion in total population(%)	Proportion in total land area (%)	Impact factors	Classification	Proportion in total population (%)	Proportion in total land area (%)	Impact factors	Types	Proportion in total population (%)	Proportion in total land area (%)
Altitude (m)	<200	4.35		River network density	0	5.20	5.40	Type of karst	Mountainous region	34.08	42.98
	200~500	45.04	32.51		0~0.01	61.30	71.34		hills	1.45	0.31
	500~700	15.56	23.14		0.01~0.02	20.47	15.02		Upland plain	18.56	15.11
	700~900	20.30	26.31		0.02~0.03	5.36	4.76		Mountain plain hills	15.58	11.58
	>900	14.74	17.25		>0.03	7.68	3.48		Mountain plain and hilly platform	6.09	2.66
Ground slope (°)	<15	8.60	2.93	Forest coverage (%)	<30	14.77	9.34		Others	7.72	6.87
	15~20	18.67	11.75		30~50	23.59	16.93		Non-karst	16.52	20.49
	20~25	51.99	59.59		50~60	19.84	15.20	Combination mode of karst geological types*	b	4.45	2.21
	25~30	19.36	24.52		60~70	20.08	23.70		ad	6.03	4.05
	>30	1.39	1.21		>70	21.71	34.84		abc	9.10	7.52
Average temperature of the year （℃）	<18	6.66	10.53	Karst distribution area ratio （%）	0	16.52	20.49		abd	18.67	17.15
	18~19	15.07	18.06		0~40	21.23	26.44		abcd	33.46	37.88
	19~20	26.26	31.51		40~60	14.81	12.16		Others	11.76	10.70
	20~21	25.02	24.22		60~80	11.76	11.89		Non-karst	16.52	20.49
	>21	26.99	15.68		>80	35.69	29.03				

the study area. Overall, the population is the characteristics of low altitude aggregation (**Figure 5a**).

5.1.2 Population density and ground slope

The townships with a ground gradient of less than 15 ° have the highest population density of 287 people/km^2. They are distributed in Toutang town in the south of the study area and Qingyuan town in the East (**Figure 5b**), which is 3.7 times the population density of townships with a ground gradient of 25 ° ~ 30 ° and 2.6 times the population density of townships with a ground gradient of more than 30 °. Villages and towns with a ground slope of 20 ° ~ 25 ° are the main population gathering areas (**Table 1**), but the population density is only 85 people/km^2. On the whole, the population density decreases with the increase of ground slope, and the population tends to gather in towns with small ground slope.

5.1.3 Population density and annual average temperature

The villages and towns with annual average temperature above 21 ℃ have the highest population density of 169 people/km^2, which is mainly distributed in some villages and towns in Tianyang county, Pingguo county and other counties in the south of the

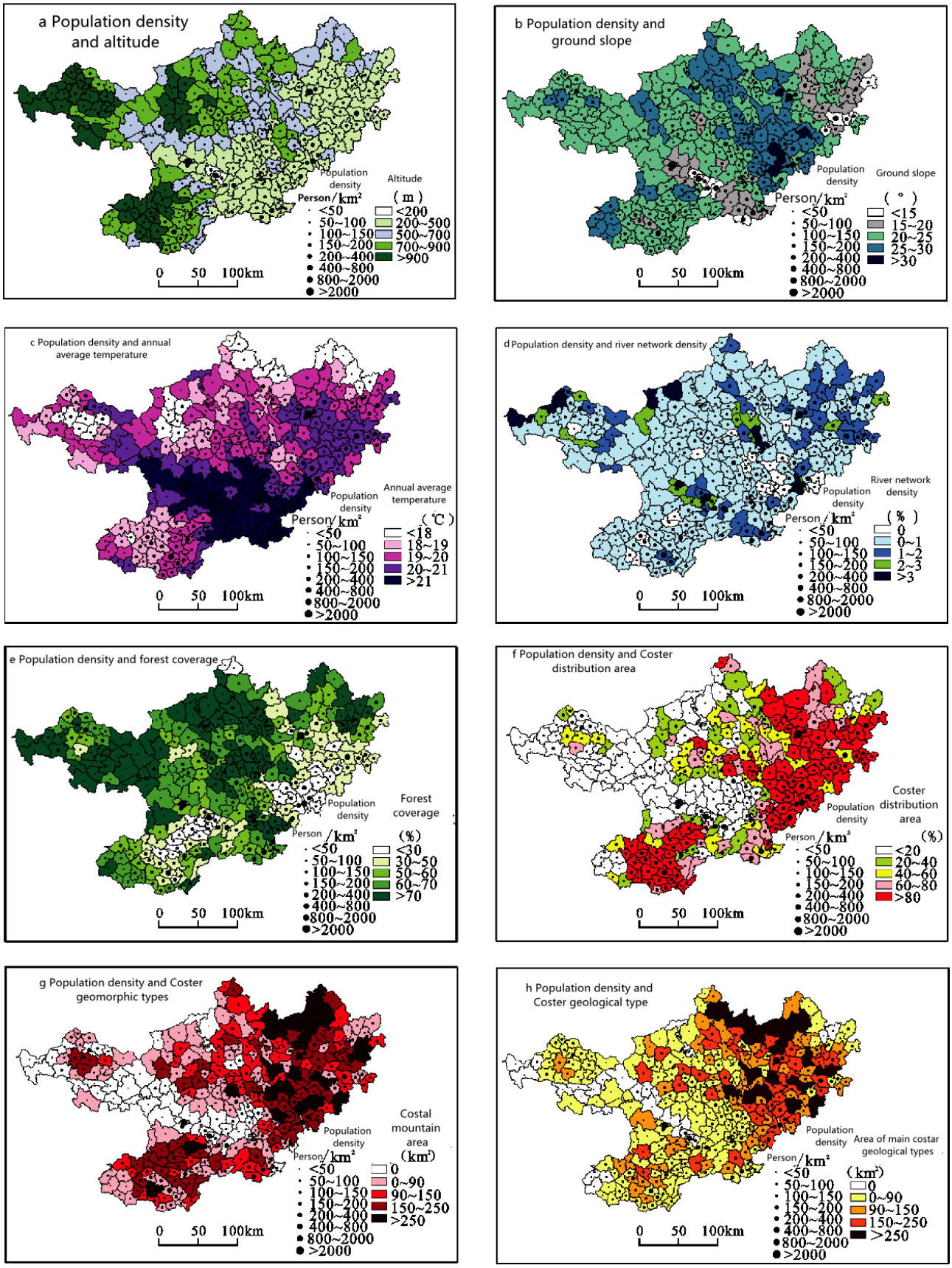

Figure 5. Spatial distribution of natural factors and population density in the northwestern Guangxi in 2010.

study area (**Figure 5c**), which is 2.7 times the population density of villages and towns with annual average temperature below 18 ℃. Villages and towns with annual average temperature above 20 ℃ are the main population gathering areas (**Table 1**), which are distributed in the research area In the South and east of the study area, the population density is more than 100 people/km^2. On the whole, with the increase of annual average temperature, the population density increases gradually.

5.1.4 Population density and river network density

Towns with river network density greater than 3% have the highest population density of 216 people/km^2, distributed in Youping Township, Yachang Township and other towns (**Figure 5d**), which is 2.3 times the population density of towns without rivers. Villages and towns with river network density of 0 ~ 1% are the main population gathering areas (**Table 1**), but the population density is only 84 people/km^2. On the whole, with the increase of river network density, the population density shows an increasing trend.

5.1.5 Population density and forest coverage

Villages and towns with forest coverage of less than 30% have the highest population density of 155 people/km^2 and the population proportion is 14.77% (**Table 1**). They are distributed in some villages and towns in the north and northwest of the study area (**Figure 5e**), which is 2.5 times that of villages and towns with forest coverage of more than 70%, and the population density of villages and towns with forest coverage of more than 70% is only 61 people/km^2. On the whole, with the increase of forest coverage, the population density decreases gradually.

5.1.6 Population density and karst distribution area

Villages and towns with karst distribution area greater than 80% have the highest population density, reaching 120 people/km^2. They are the main gathering area of population (**Table 1**), distributed in the east and south of the study area (**Figure 5f**), which is 1.5 times that of villages and towns without karst distribution and with karst distribution area less than 40%. The population density of villages and towns without karst distribution is 79 people/km^2, which is distributed in the West and Central South of the study area. On the whole, with the increase of karst area, the population density first increases, and then decreases and then increases.

5.1.7 Population density and karst landform type

The karst landform in the study area is mainly mountainous. The areas with karst mountainous area greater than 150 km^2 are mainly concentrated in most towns in the northeast and south of the study area, and the areas with karst mountainous area less than 90 km^2 are scattered in the study area (**Figure 5g**). Other geomorphic types include karst hills, platforms and plains. There are 8 combination modes in towns and townships. Here, the 5 combination types accounting for a large proportion of the population are mainly analyzed (**Table 1**). In the villages and towns with no Karst Mountains and only karst hills, the population density is the largest, reaching 460 people/km^2. There are villages and towns of all four geomorphic types, with a population density of 224 people/km^2, mainly distributed in Beiya Yao Township, Huaiyuan town and other villages and towns in the East, which is 2.84 times the population of villages and towns without karst distribution. The villages and towns only distributed in karst mountainous areas, with a population density of 78 people/m^2, are the main population gathering areas, distributed in a small number of villages and towns in the East, South and North. On the whole, the towns with only Karst Mountains and no karst landform have the lowest population density. Except for the towns with only karst hills, the population density shows an increasing trend with the increase of the number of karst landform types, and the landform type with the greatest impact is Karst Mountains.

5.1.8 Population density and karst geological types

The karst geological types in the study area are mainly continuous limestone assemblage (a) and limestone and dolomite assemblage (b). Areas with

an area of major karst geological types greater than 150 km^2 are distributed in most towns in the East and southeast of the study area, and areas with an area of major karst geological types less than 90 km^2 are distributed in most towns in the west of the study area (**Figure 5h**). Other karst geological types include limestone plus clastic rock combination (c), limestone, dolomite and clastic rock combination (d), continuous dolomite (e), dolomite plus clastic rock combination (f). There are 22 combinations of 6 geological types in villages and towns. Here, the first 5 combination types accounting for a large proportion of the population are mainly analyzed. It is found that only the first type (b) has the highest population density, reaching 205 people/km^2, which is 2.3 times that of the fifth combination type (abcd combination) and 2.5 times that of the towns without karst distribution. The towns of the fifth combination type (abcd combination) are the main population gathering areas, but the population density is only 90 people/km^2, mainly distributed in Liuwei town, Changlao township and other towns in the east of the study area. Without karst distribution, the population density of villages and towns is at a medium and low level. On the whole, with the increase of the number of karst geological type combinations, the population density gradually decreases, among which the most influential are continuous limestone combination (a) and limestone and dolomite combination (b).

5.2 Analysis on influence intensity of natural factors on population distribution

The influence intensity of various natural factors and the increase and decrease relationship of influence intensity after the superposition of different natural factors can be quantitatively explored by using geographic detectors. Because it is impossible to directly quantify the combination of all karst landforms and geological types for geographic exploration and analysis, according to the situation of the study area, finally, the area of karst mountain and the area of main karst geological types are selected to replace, and the natural breakpoint method is used to divide the eight natural factors into different levels, and then discretized and analyzed by geographic detectors.

1) The results of geo detector analysis show that the 8 natural factors alone have a certain influence on the spatial distribution of population density, and the comprehensive influence of each natural factor after coupling and superposition is significantly enhanced (**Table 2**). The factor detection results show that the

Table 2. Interaction of natural factors in the spatial distribution of population in the northwestern Guangxi

A∩B=C	A+B	Comparison	A∩B=C	A+B	Comparison
H∩Kr=0.22	0.17+0.01=0.18	C>A+B	Km∩Ca =0.021	0.01+0.01=0.02	C>A+B
H∩Km=0.24	0.17+0.01=0.18	C>A+B	Km∩Rn =0.20	0.01+0.16=0.17	C>A+B
H∩Ca=0.24	0.17+0.01=0.18	C>A+B	Km∩Sl=0.05	0.01+0.02=0.03	C>A+B
H∩Rn=0.65	0.17+0.16=0.33	C>A+B	Km∩Ta=0.11	0.01+0.06=0.07	C>A+B
H∩Sl=0.85	0.17+0.02=0.19	C>A+B	Km∩Tr=0.20	0.01+0.05=0.06	C>A+B
H∩Ta=0.26	0.17+0.06=0.23	C>A+B	Ca∩Rn =0.22	0.01+0.16=0.17	C>A+B
H∩Tr=0.34	0.17+0.05=0.22	C>A+B	Ca∩Sl=0.05	0.01+0.02=0.03	C>A+B
Kr∩Km=0.08	0.01+0.01=0.02	C>A+B	Ca∩Ta=0.09	0.01+0.06=0.07	C>A+B
Kr∩Ca=0.05	0.01+0.01=0.02	C>A+B	Ca∩Tr=0.11	0.01+0.05=0.06	C>A+B
Kr∩Rn=0.46	0.01+0.16=0.17	C>A+B	Rn∩Sl=0.26	0.16+0.02=0.18	C>A+B
Kr∩Sl=0.07	0.01+0.02=0.03	C>A+B	Rn∩Ta=0.50	0.16+0.06=0.22	C>A+B
Kr∩Ta=0.17	0.01+0.06=0.07	C>A+B	Rn∩Tr=0.43	0.16+0.05=0.21	C>A+B
Kr∩Tr=0.08	0.01+0.05=0.06	C>A+B	Sl∩Tr=0.12	0.02+0.05=0.07	C>A+B
Ta∩Tr=0.23	0.06+0.05=0.11	C>A+B	Sl∩Ta=0.07	0.02+0.06=0.08	C>Max(A, B)

Note: H is the natural influence factor, altitude, SL is the ground slope, Ta is the annual average temperature, Rn is the river network density, Tr is the forest coverage, Kr is the karst distribution area ratio, Km is the karst landform type, and Ca is the karst geological type.

influence of various natural factors on population spatial distribution is altitude (0.17), river network density (0.16), annual average temperature (0.06), forest coverage (0.05), ground slope (0.02), karst distribution area (0.01), karst mountain area (0.01) and main karst geological types (0.01).

2) The interactive detection results show that except that the interaction between ground slope and annual average temperature is enhanced by two factors, the interaction of other factors is enhanced nonlinearly (**Table 2**). Among them, the intensity of superposition of altitude and various factors is large, especially after superposition with ground slope, its value is the largest, and the increase rate reaches more than 70%, mainly because northwest Guangxi is located in mountainous areas with great altitude difference, and other geographical elements are inevitably affected by altitude. When the river network density is superimposed with karst geological and geomorphic conditions, the impact intensity of population spatial distribution increases by more than 90%. It is mainly due to the poor water storage and retention capacity in karst areas, and human beings have a stronger tendency to river network and water system.

3) After the superposition of karst geological and geomorphic factors and other factors, the increase is large, most of which are more than 80%. It is mainly because the karst area in Northwest Guangxi is located in the subtropical zone, with good climatic conditions such as water and heat, and has natural conditions suitable for human habitation. Therefore, the influence intensity of karst geological and geomorphic factors on population spatial distribution is not obvious. However, the dissolution of carbonate rocks is strong, which will show higher sensitivity and vulnerability after superimposing natural factors such as uplift height and ground slope. For example, the elevation of sea level and the increase of slope can lead to the strengthening of dissolution, and the soil is easy to be lost along the slope. Finally, the soil layer may become thinner and even the bedrock may be exposed, which is not suitable for crop growth and human habitation. After the superposition of the unique geological and geomorphic factors in karst area and other natural factors, the impact intensity on the spatial distribution of population in karst mountain area will increase significantly.

6. Conclusion and discussion

6.1 Conclusion

1) The population spatial distribution at the township scale in the karst mountainous area of Northwest Guangxi is extremely uneven. The population quantity and density in the southeast are higher than those in the northwest, and the population density gradually decreases from southeast to northwest

The total population and population density of the township (town, street) where the (municipal) government is located are the highest in the county (city). The population distribution shows a certain aggregation. The high-value areas and low-value areas of population density are not completely random distribution. The radiation capacity of high-value areas is weak, and the radiation capacity of low-value areas is relatively strong.

2) The population distribution in karst areas of Northwest Guangxi shows obvious differences with the spatial distribution of different natural factors. The population density of towns without karst distribution in the northwest and Central South of the study area is low on the whole; the population density of villages and towns with high altitude, ground slope and forest coverage is relatively low, and the population density of villages and towns with high annual average temperature and river network density is relatively high. In the eastern and southern villages and towns with karst distribution, in addition to karst geological and geomorphic factors, the population density increases with the increase of natural factors suitable for human habitation, but shows a trend with the increase of karst area wave type variation characteristics. In addition, in villages and towns with single karst geological type or diverse geomorphic type, the population density is relatively high, and vice versa.

3) The greatest influence intensity of each factor on the spatial distribution of population is altitude,

and the smallest is karst geological and geomorphic factors. However, the superposition of any two natural factors can enhance the impact on population spatial distribution, and the strengthening methods are nonlinear enhancement and Gemini enhancement. The spatial distribution of population is affected by the spatial distribution of various natural factors. The change of any factor may affect the change of population spatial distribution. Although the impact intensity of karst geological and geomorphic elements on population spatial distribution in the study area is low when acting alone, the impact on population spatial distribution is significantly enhanced after their superposition with any natural factors, and most of the increase rate is more than 90%. In the karst area of Northwest Guangxi, the spatial distribution of population does not completely depend on the most influential factor among the natural factors, and the role of karst geological and geomorphic factors cannot be ignored.

6.2 Discussion

1) The area with karst distribution area of more than 80% in Northwest Guangxi has the largest population density and gathers a certain number of people. Although there are a wide range of karst landforms in the northwest of Guizhou Karst Plateau Area in Li Xudong and other documents, it also gathers a large number of people. This research conclusion has some similarities[42]. However, the population density of villages and towns with no karst distribution in Northwest Guangxi is close to that of villages and towns with only karst mountain distribution. The relationship between population spatial distribution and karst geological and geomorphic conditions is not a simple linear relationship, but is jointly affected by a variety of natural factors such as altitude.

2) Whether in karst areas or non karst areas, the spatial distribution of population is affected by both natural and economic factors. Natural factors also affect the distribution of economic factors. However, the natural ecological environment in karst areas is more fragile, and the influence of natural factors must be different from that in non karst areas, and further affect the spatial distribution of population through influencing economic factors. Compared with non karst areas, what is the difference in the extent to which population growth can break through the limitations of natural factors, how much impact can change the natural conditions of karst areas have on population spatial distribution, and how to reasonably carry out population spatial layout on the basis of protecting the ecological environment and ensuring economic development in karst areas.

Conflict of interest

The authors declare that they have no conflict of interest.

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