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Spatial distribution regularity and influence factors of population density in the LRGR

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Combining GIS measures and statistic methods, this paper selects the physiographic factors and climatic factors to study the influencing strength and its functional forms of all factors on population density in the LRGR. In addition, this paper simulates the status of population density distribution in the LRGR with the factors influencing the population density distribution. The findings indicate the following circumstances: (1) All natural factors have influence on the spatial pattern of population density in the LRGR, but the influencing extent and forms are quite different. Physiographic factors and traffic network density have great influence on population density, while such factors as temperature and precipitation have little influence on population distribution. The relationship between the population density and the altitude and traffic network density assumes the negative and positive linear correlation trends, while the influence of water system density and slope appears to be the exponential function and logarithmic function separately. (2) The population is scattered throughout LRGR and takes on such features as integral scattering and local concentration because of the influence of natural conditions. Thus, a high population density belt has been formed in the middle of LRGR, and a high population density patch comes into being in the south of LRGR. (3) There is a good linear regression relationship between population density and human activity index (HAI) in the LRGR, which reflects that population density can present the artificial disturbance on natural ecosystem in the LRGR. (4) The increase of population density leads to the decrease of NDVI index.

population density, artificial disturbance, vegetation coverage, physiographic factor, LRGR

The LRGR is an area with the assembly of rich global species and a world-class biological gene bank[1]. It has become a hot spot in the academes of ecosystem succession and biodiversity protection. In these years, the population increases year by year greatly, which has violently influenced the succession process of regional ecosystem[2−5]. Therefore, it is of far reaching importance for studying the population density pattern in LRGR to discover the regional ecosystem succession rule, identify the key factors restricting spatial distribution and dynamic variation of the land system in LRGR, grope for a typical development model of mountainous resources in our country, and build up an evaluation system for regional ecological security.

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1 Database, fundamental hypothesis and research method

1.1 Data base

The data include the 1∶50000 DEM data, 1∶50000 land use map in 2000, 1∶250000 relief map (including 1173 residential areas), meteorological data, the distribution map of natural preserves and population statistics data of 88 administrative counties from *Yunnan Statistical Yearbook*.

1.2 Fundamental hypothesis

At the beginning of the primitive society, the human beings lived a congregative life, which developed gradually to form the present cities, and the cities and villages have become the major modes of people settlement. The people in the research area also live in concentrative inhabitation and the most residential areas can be found in 1∶250000 relief map, on which 1173 settlements include most population in LRGR, which is proved by field investigations for Xishuangbanna, Lijiang and Simao regions as well for the whole research area in 2004. Therefore, the influence of physiographic factors on main settlements in the research area can be analyzed so as to reflect the impact of such factors on population distribution.

1.3 Research method

The present paper simulates the population density[6−14] in LRGR with the distribution influence factors[15], and processes the database so as to produce seven physiographic raster factors, namely, temperature, precipitation, elevation, river density, slope, roughness, road and settlement map, thus converting the spatial data of villages into raster. Then, Arcgis8.3 is adopted to classify the physiographic factors into 32 levels by value so as to calculate the average value of various physiographic factors in different levels, extract the urban data in different-level physiographic factors, and count and finally calculate the numbers of cities in each level. In succession, the correlation and regression analysis will be carried out for the data on the basis of SAS9.0 system to determine the influence weight of each physiographic factor to population density. Finally, all physiographic factors are superposed with their weights and the areas without people, such as water area, natural reserves and steep slope, are masked and weeded out to obtain the coefficient of spatial population distribution. Based on vital statistics in each county collected in the *Yunnan Statistical Yearbook*, we control gross population of each administrative county to find the spatial distribution status of population density in the research area.

The human activity index (HAI) is calculated on the basis of land use. The process of land use is the one that the people change natural ecosystem. Different land use types embody different land use degrees and also reflect the artificial disturbance on natural ecosystem and land system, which has been studied by some scholars[16,17]. Shi et al.[17] summarized the HAI according to artificial disturbance on each land use type, and the results are listed in Table 1.

For a research area, the weight is the proportion occupied by different land use types and the HAI corresponding to various land use types is weighted to reflect the impact of human activity on regional land use. For the computing method, refer to the equation below:

$$\text{HAI}=\sum_{i=1}^{N} P_i \times A_i / A_{\text{T}}, \quad (1)$$

where HAI is human activity index, N the amount of landscape component types, A_i the area of landscape i, P_i the HAI reflected by landscape i (Table 1), and A_{T} the total area of landscape.

Based on population density simulation and HAI in LRGR, this paper studies the disturbance of population density on natural ecosystem from the viewpoint of land use. Firstly, we classified the simulated data of population density into 20 levels and calculated the average population density in each level. Then, we extracted the corresponding farm land, forest land, grass land, water area, residential land and unused land on the basis of spaces corresponding to population density in each level to count the areas of six land use types in each population density level space and then calculate the HAI in each level according to eq. (1). Please refer to ref. [18] for the detailed data construction. In this way, we obtained a group of variables, i.e. average population density and artificial disturbance intensity HAI in each level among 20 levels. In succession, we carried out the cor-

Table 1 The parameters of the influence degrees of human activities on land use types

Forest	Shrub	Orchard	High density urban land	Low density urban land	Farmland	Water area
0.1000	0.2300	0.4350	0.9500	0.6800	0.5500	0.1150

relation and regression analysis to judge the quantities relationship between population density and artificial disturbance intensity in LRGR. The integral technical flow of this paper is shown in Figure 1.

2 Results and analysis

2.1 Correlation analysis on physiographic factors and city density

The aim of correlation analysis is to deduce the influence of one factor on another by analyzing the interaction relationships of variable trends between two groups of variables or among many groups of variables. The results of correlation analysis could be expressed by correlation coefficient and significant degree. This paper selects Pearson correlation coefficient, which is most commonly used in correlation analysis, to present the impact of physiographic factors on city distribution (Table 2).

The influence of physiographic factors on spatial city distribution is very different in LRGR. Elevation, slope and roughness are negatively correlated with city numbers, which means that the above three factors are restrictive to city distribution. From the size of correlation coefficients and significance, we can see that restrictive effect of slope and elevation on city distribution is very significant, while that of the roughness is weak. The river density and road density show the most significant positive correlation with city distribution and the influence of both factors on city distribution is not quite different. Statistical analysis and field investigation indicate that traffic network is correlated with main river density to a certain extent, which indicates that the places with rich river system and traffic density in LRGR have high concentration of cities, and that human constructions, such as roads and residential areas with distinct surface relief in LRGR, are built along rivers. The correlation coefficient between the temperature and precipitation and the city density is close to zero, and those two factors have no significant effect on spatial distribution of cities.

2.2 Regression analysis between physiographic factors and city density

We select four factors, i.e. slope, river, road and elevation that have significant impact on city distribution, from the above seven physiographic features, and adopt the original data to further carry out the single-factor regression analysis so as to discuss the influencing modes of different physiographic factors on spatial distribution of cities.

The influence of the elevation on city distribution takes on an obvious linear relationship and the average density of cities descends stably (Figure 2) as the elevation zone rises gradually. The change of city density along with elevation is distinct. The average city density is about $1.36\times10^{-2}/\mathrm{km}^2$ at the average elevation of 216.64 m. When the average elevation increases to 4500.37 m, the city density decreases to $1.3\times10^{-3}/\mathrm{km}^2$ only, being one tenth of original density. Ge et al.[19]

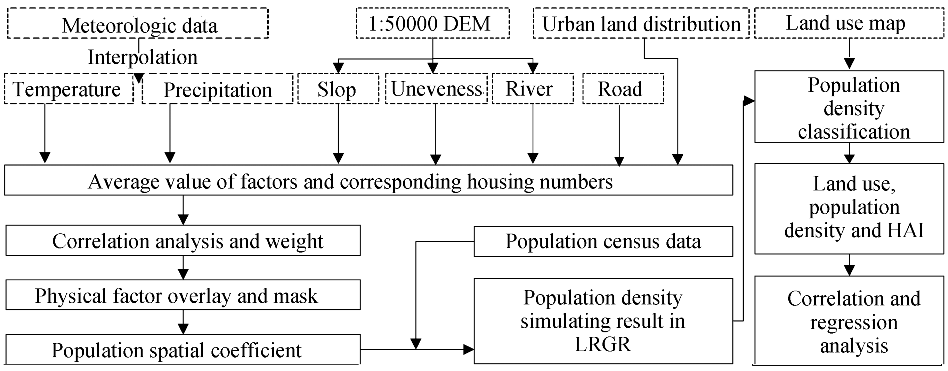

Figure 1 Work flow of population density study based on GIS.

Table 2 Correlation between physiographic factors and city distribution

Factors	Elevation	River density	Slope	Road density	Roughness	Precipitation	Temperature
Correlation coefficient	–0.9156	0.8734	–0.8071	0.7290	–0.5485	0.0324	0.3803
Freedom (*n*)	32	32	32	32	32	32	32
Significance ($P>r$)	<0.0001	<0.0001	<0.0001	<0.0001	0.0012	0.8602	0.0318

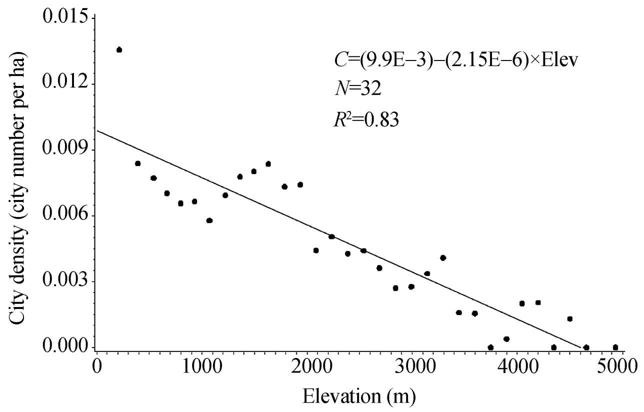

Figure 2 Relationship between city density and elevation.

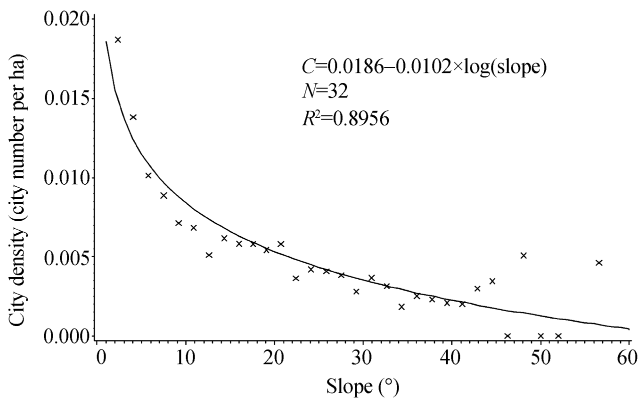

Figure 3 Relationship between city density and slope.

analyzed the relationship between countrywide population distribution and natural features, which indicates that four fifths population of China aggregates in the low-elevation areas accounting for about a quarter of Chinese land. The elevation change can lead to the corresponding changes of air pressure, temperature, precipitation and so on. Therefore it is impossible for people to live when the elevation is too high. And the maximum and minimum elevations in LRGR are 6740 and 76.4 m respectively with the relative elevation difference about 6600 m. Along with the continuous increase of elevation, the precipitation and air temperature generally take on a downtrend from southeast to northwest in LRGR, the ground roughness escalates, the traffic condition becomes worse and worse, the inhabited environment deteriorates gradually and the population decreases without intermission.

The function of slope on settlement distribution is expressed as logarithmic equation (Figure 3). The fitting curve shows that the response of city density to the change of slope is quite obvious at the beginning of slope increasing, and the slope of curve is very sharp. And then the influence of slope on city density becomes weaker and weaker when the slope increases to a certain degree, which is represented by a smooth curve. The area with gentle gradient in LRGR always concentrates near water areas and in intermountain basins, where natural resources are relatively superior, the farmland is concentrated and residential areas are dense. In course of relief changing from basin and valley to piedmont, hill, mesa and mountainous region, the ground slope increases gradually, the residential areas decrease, and the land use type also changes from original farmland predomination to the deserted grassland or forest, which leads to the annular landscape structure with river valley as the center, and mountainous area as fringes.

From Figure 4, we can see that the relationship between city density and river density is an exponential function. With the increase of river density, the number of cities becomes denser and the gradient of the fitting curve takes on an increasing trend.

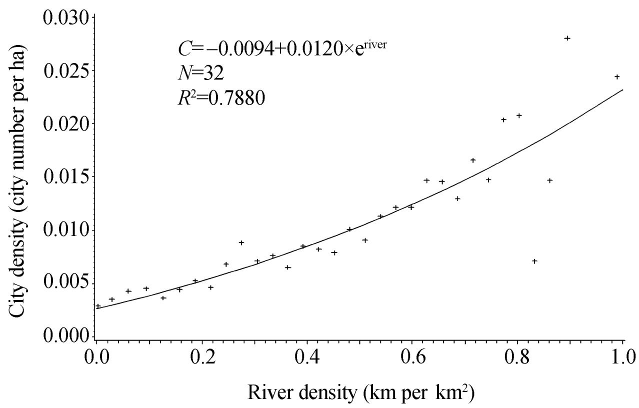

Figure 4 Relationship between city density and river density.

In LRGR, the gross amount of water resource is abundant because of rich river density. However, the spatial composing status of water resource and other resources, especially land resource, is not in good condition. The water-retaining capacity of soil is poor and the utilization of water resource is low, so that the bad phase is formed, that is, drought spreads when water is short and flood disasters happen frequently when water is excessive. Human absolutely relies on water resource, so water resource can reflect population density to some extent. The investigation by some scholars shows that precipitation in the south and east is more than that in the north and west of China, which to some extent results in that the population in the southeast coast is denser than that in the northwest and the relationship of the above two factors assumes a logistic function[20].

Compared with the whole country, the influence of surface water in LRGR on city distribution has special characteristics. Namely, the atmospheric precipitation can hardly influence the spatial distribution of cities with the correlation coefficient about 0.0324, while the surface water has a violent influence on city distribution with correlation coefficient about 0.8734 (Table 1). From the provincial scale, most water resource is from the development of river flow. The amount of water resource development from river flow is about 98.6 percent and the development amount of ground water is only about 1.4 percent[21]. This indicates that surface river network plays a positive role in relieving the water shortage in LRGR in Yunnan Province and improving the utilization efficiency of surface water. It also indicates that city distribution is subject to intensive influence from water resource from rivers and human being has been enjoying living along rivers for lots and lots of years.

From the relationship between traffic density and the number of cities (Figure 5), it is observed that the influence of the density of highway network on city distribution is less than that of water system, elevation and slope (Figures 1—3). The relation is that the fitting curve is even, the deviation between sampling points and the linearity is great and the model has a low interpreting extent for the relationship between "river network and city distribution", being merely 53.15 percent.

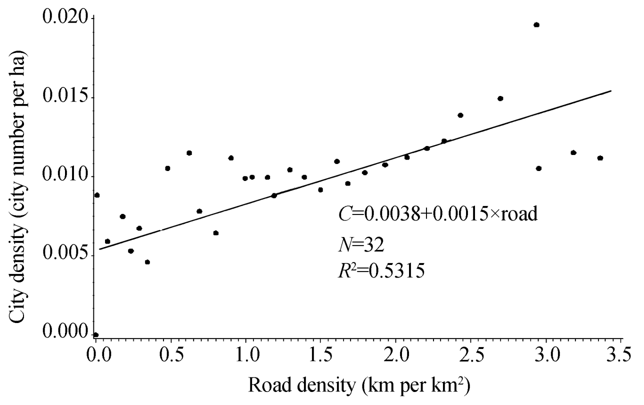

Figure 5 Relationship between city density and traffic density.

Furthermore, the correlation between road density and city density is weaker than that of river density, elevation and slope (Table 1). The phenomenon is closely related to the difference of traffic condition in the south and north of LRGR. The traffic condition in the south is relatively developed and the traffic network can be constructed by different roads at different levels, so that the vertical and horizontal connections among cities are relatively dense. However, in the central and northern LRGR, there are many great mountains and rivers intertwined together from west to east, including Gaoligong Mountain, Nujiang River, Nushan Mountain, Lancang River, Yunling Mountain, Jinsha River and so on, with obvious obstruction effect of mountains and rivers. Thus the traffic network becomes traffic line vertically going through the dams, indicating that the dams are distributed in the pinch-and-swell form along roads, however the west-east connections among large cities are quite weak. Therefore, the influence of the density of highway network on LRGR city density is relatively weak, mainly because of regional difference of "traffic-city" structural relationships.

Roads are the main traffic form between Yunnan Province and LRGR. Because of complicated relief, mountainous roads are always constructed along main rivers, so that the roundabout distance is long while the linear distance is short, the roads are of poor quality and traffic efficiency is low. The poor traffic condition has mainly restricted the regional resource exploration, local cooperation and urbanization.

2.3 Spatial pattern of population density

Based on the correlation analysis between physiographic factors and city density in LRGR (Table 1), the relative weights of all physiographic factors on city density are determined (Table 3).

According to Table 3, we have determined the influence weights of all factors on city distribution in LRGR. In order to make the simulated results become close to practical condition of population distribution in this area as far as possible, we have comprehensively considered the factors absolutely restricting population distribution in this area, such as water areas, mountain ridges, natural reserves and steep slopes, and eliminated them with masking analysis. In addition, we also took account of the attraction of cities on population distribution. Thus,

Table 3 Relative weights of physiographic factors on city density

Factor	Slope	Rough degree	Water system density	Road system density	Elevation	Precipitation	Temperature
Relative power	0.1883	0.1280	0.2038	0.1701	0.2136	0.0076	0.0887

we obtain the coefficient of spatial population distribution in LRGR and control the population in the county territory with the statistical data so as to realize the spatial distribution of vital statistics data and to obtain the spatial distribution of population in LRGR (Figure 6).

Mountain area accounts for about 84—94 percent of the total area of Yunnan Province. LRGR lies in the midwest of Yunnan Province with more obvious hilly country areas. The population density in LRGR is very greatly spatial with a characteristic that the population distributes sparsely in regional scale and concentrates together in local scale.

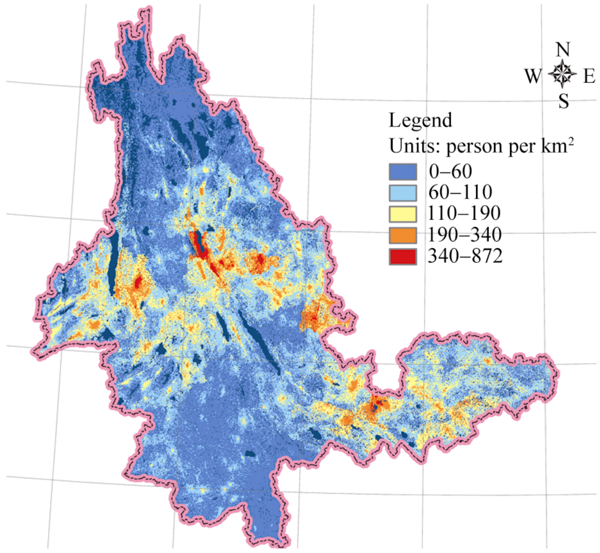

Figure 6 Spatial distribution of population in LRGR.

The average of population density is 79 persons/km^2 in LRGR, which is lower than 109 persons/km^2 in Yunnan Province[22], and lower than 133 persons/km^2 of the whole country[23]. Therefore the population is relatively sparse. Two regions with high population density are found, where the area is less than a half of the whole but with 80 percent of total population. One belt in the middle of LRGR is spanning from the west to east and another is the southeast of LRGR. The population in the middle transit belt is mainly concentrating in the east of Yunling Mountain-Ailao Mountain with relatively dense population gathered in Erhai Basin, Midu, Xiangyun, Yaoan, Yimen, etc. The area with maximum population density is Dali City in Erhai Basin with 870 persons/km^2, while in the west of Yunling Mountain-Ailao Mountain, Baoshan-Shidian-Luxi-Tengchong region has high population density. At latitude of 23°N, the area vale on two sides of Ailao Mountain-Yuanjiang and part of Yuanjiang, Mengzi, Gejiu, Jianshui, Yuanyang and Honghe, have high population density. Otherwise, persons are distributed at resident sites and along the highroads and vales in mountainous areas. Moreover, in the apparent mountainous areas with obvious height difference, most of the population mainly concentrates in settlements along roads and valleys.

2.4 Relationship between population density and HAI

Spatial heterogeneity of population density basically results from the spatial heterogeneity of physiographic factors and human activities are the main reasons on land use and land cover change. Therefore high population density affects LUCC intensively, which is outstanding in LRGR. By analysis, we found that the population density and human activity index (HAI) are most significantly correlated with each other and the relation coefficient is about 0.96 (n=20, P_r<0.0001) and the regression relation between population density and HAI is as follows:

$$\mathrm{HAI}=0.1736+0.0005\times\mathrm{POP}, \quad (2)$$

where R^2=0.9235, confidence level is 99%, and POP stands for population density (person/km^2).

It can be seen that HAI and population density have perfect linear regression relationship with regression coefficient larger than zero. That is to say, extent of artificial disturbance on land use is enhanced with the population increasing. Combining with the simulation results of population density in LRGR, we can see that the HAI is equal to 0.1736 when the population density equals zero. This reflects that the background of regional ecosystem is mainly constructed by original ecosystem including forest and shrub (Table 1). When population density reaches the maximum of about 870 persons/km^2, especially in Dali of Erhai Basin in the center of research area (Figure 6) with HAI equaling 0.6086, it reflect that the level of urbanization in LRGR is lower with low building density (Table 1).

2.5 Correlation between population density and vegetation cover changes

In order to analyze the influence of population density on vegetation cover, we adopt the map algebra method to calculate NDVI data accumulated in 2003, and make use of yearly accumulated value ($\mathrm{NDVI_a}$), average NDVI ($\mathrm{NDVI_m}$), standard deviation of NDVI ($\mathrm{NDVI_s}$) and the ratio of $\mathrm{NDVI_a}$ to $\mathrm{NDVI_s}$ ($\mathrm{NDVI_r}$).

Land use types in LRGR include farmland, forest, grassland, urban land, water area, orchard and unused land, and different land use types have different seasonal characters of vegetation cover, as well as different land cover characteristics. Farmland, forest and grassland are the main land use types with dominant areas in LRGR and the population concentrates mainly in urban land. Therefore, the above land use types determine the regional land cover condition. Among these land use types, forest and grassland are two types of original natural ecosystems with high vegetation cover presented by $NDVI_a$. Except for deciduous plants and annual herbaceous vegetation, forest and grassland use types mainly belong to evergreen vegetation, in which seasonal change is not obvious, and the monthly NDVI is close to $NDVI_m$, leading to a low $NDVI_s$. Therefore, the forest and grassland in LRGR have a higher $NDVI_r$. Comparing with forest and grassland, the farmland and urban land reflect a more disturbed condition created by human activity. The farming time in LRGR has apparent regional characteristics with various cropping modes including annual double cropping, two-year triple cropping and annual triple cropping. Therefore farmland has relatively high $NDVI_a$ covered by crop and higher $NDVI_s$ because of cropping by turns seasonally. Urban land is a direct result of population concentration with apparent artificial landscape and sparse natural vegetation covering. Comparing with original forest, urban land has relatively low $NDVI_a$, $NDVI_s$ and $NDVI_r$.

By calculating $NDVI_r$ and analyzing the seasonal changes for different land use types in LRGR, we can know that land use types with lower $NDVI_r$ are closely related to the intensity of artificial disturbance, namely crop land and urban land are correlated with each other spatially, while the urban is the area with high population density and artificial disturbance. The regression relationship between regional population density and vegetation coverage change can be seen from Figure 7.

In theory, $NDVI_r$ of LRGR is a decreasing function of population density. When population density is zero, $NDVI_r$ reaches the maximum 40.92. In the initial stage of population density increasing, the slope of the curve is steep with $NDVI_r$ decreasing rapidly. When population density increases to a certain level, the curve becomes plane and $NDVI_r$ decreases slowly. When population density tends to infinity, $NDVI_r$ trends to zero. The regression relation between $NDVI_r$ and population density clarifies that there is a tight relation between vegetation coverage change and population density.

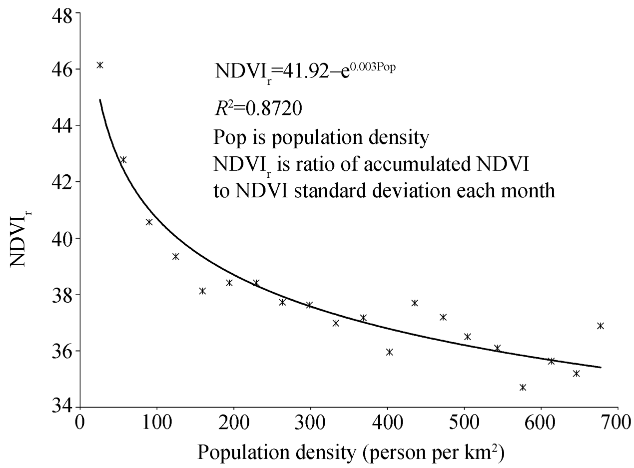

Figure 7 The regression relationship between regional population density and vegetation coverage.

With the population density increasing, artificial disturbance increases as well but $NDVI_r$ decreases. It illuminates that one of the important factors to promote land coverage change in LRGR is human activity in a congregating way (R^2=0.9235, eq. (2)).

3 Conclusion and discussion

This study simulates the population density in LRGR by factor-affecting method. The conclusion is as below. Mountain area amounts to 84—94 percent in LRGR, and all kinds of physiographic factors have influence on population density with different extent, different significance and different scales. Comparison shows that four factors including elevation, water system density, slop and traffic system have intense influence on population distribution, while the influence of population distribution by temperature and precipitation is mainly represented by temperature change along the elevation gradient, river density and productivity variation. From the function between natural factors and population, the linear relation is presented between the elevation or road density and population distribution. While the correlation between river density or slop and population is represented by an exponential function and a logarithmic function respectively. The simulation result of population density indicates that the population density in LRGR is sparse in integral scale and concentrated in local scale. Two areas with high population density are found. One is the belt with high population density spanning from east to west in the middle of LRGR, and the other is in the middle and lower reaches of the Yuanjiang Valley at about latitude 23°N. Settlement area mainly distributes along roads and rivers in apparent mountainous areas of LRGR.

During the process of simulating population density and analyzing the influence of physiographic factors and human activities on population density in LRGR, many factors are involved including many relief factors and climatic factors. The physiographic factors in this paper can be classified into two scales, namely, the factors in small scale including slope, roughness and road density, and the temperature and precipitation factors in large scale. The research area of this paper involves 88 counties. In such a scale, the middle-small scale factors influence population distribution violently, while temperature and precipitation in large scale can hardly influence the population distribution (Table 2). Moreover, difference of local elevation affects spatial redistribution of resources, leading to the different resource capacity in different geographic units[24]. It is apparent that people usually concentrate in broad area with low elevation and excellent allocation of water and soil.

Nowadays, global change has become a focus issue in the ecological and environmental field. Many study results indicate that rapid population increasing and natural resource exploitation are main reasons for global change. The biodiversity in LRGR is the most diverse in China, where population density and human activities have a great influence on ecosystem health and biodiversity in the research area. Therefore, the study on correlation between physiographic factors or human factors and region population density is very important for the study on the population density and land use change, regional ecology security and biodiversity conservation in the future. The results of this paper indicate that high population density results in an increasing human activity and decreasing vegetation coverage. Therefore the spatial distribution of population should be seriously considered when regional ecological security pattern and natural resource reserve system are established.

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