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Evaluation on the human settlements environment suitability in the Three Gorges Reservoir Area of Chongqing based on RS and GIS

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Abstract: To explore geographical differences in quantitative characteristics and spatial pattern of human settlements environmental suitability (HSES) in the Three Gorges Reservoir Area (TGRA), terrain, climate, hydrology, vegetation and other natural factors were selected to build the livable environmental evaluation, and the quantitative analysis was conducted through Remote Sensing(RS) and Geographic Informational System (GIS) to reveal geographical characteristics and spatial patterns of HSES. The results are obtained as follows: (1) inhabitants of the TGRA of Chongqing are concentrated in the area with moderate high HSES, which is 78% of the total population distributed in 48% of the study area; (2) the HSES is closely related to the terrain, and it forms an arc-banded spatial succession pattern: relatively low in the northeast and the southeast while comparatively high in the west and the south; (3) large numbers of people are distributed in the area with low suitability (with higher population density than the average of the western China), but economic development level in these areas is quite low. Moreover, these areas are ecological sensitive and fragile, many kinds of eco-environmental problems have been caused by human activities. Therefore, population migration and layout are reasonable options for the development of these areas.

Keywords: Three Gorges Reservoir Area of Chongqing; human settlements environment suitability; GIS; RS

1 Introduction

Human settlements environment is a surface space closely related to human activities. It is the combination of the natural, human, spiritual, political, and economic environment (Wu, 2001). The HSES does not only directly affect residents' physical and mental health, but also indirectly affect the development of human society. It fundamentally determines spatial distribution pattern of the population in a certain district. Since Greece scholar Doxiadis put

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forward the concept of "Science of Habitat Environment" in the 1950s (Doxiadis, 1968), habitat environment has been a hot issue in architecture, planning, geography and other subjects (Campbell, 1976; Choguill, 1996; Gilbert, 1998). At present, the researches on human habitation are mainly concerned on the studies and practices at national level, environmental impact assessment and the construction of GIS and RS database (Xiong *et al*., 2007). Many scholars mainly focused on the urban habitation environment, e.g., Ning *et al*. (1999) conducted a series of researches on the evaluation and optimization of habitation environment in Shanghai, Zhang *et al*. (2005) analyzed location dominance of habitation environment in Beijing, Liu *et al*. (2001) discussed the ecological design methods of urban habitation environment, and many other scholars worked on habitation environment in different cities (Li *et al*., 2005; Li *et al*., 1999; Li *et al*., 2002).

Although habitat environment is influenced by many factors and the research contents of habitation environment are comprehensive, the most fundamental factors are terrain and landforms, climate, hydrological conditions, land use/land cover etc., which play leading role in the habitat environment evaluation. Therefore, the research of the effect of natural factors on habitat environment and the analysis of HSES in typical areas are of great theoretical and practical significance. Some scholars have launched the evaluations of HSES so far. Emmanuel (2005) studied on the thermal comfort implications of urbanization in Colombo metropolitan region, a warm-humid city; Spagnolo *et al*. (2003) conducted a field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia; Zhang *et al*. (2005) analyzed the environmental change and its impacts on human settlement in the Yangtze Delta; other scholars also conducted a series of researches (Terjung, 1966; John, 1973; Wang *et al*., 2002; Li *et al*., 2003; Feng *et al*., 2008). These studies will undoubtedly enhance our awareness and understanding on HSES, but there are also some limitations of different levels as follows: (1) to evaluate the suitability under single natural factor, and lack comprehensive researches; (2) to limit in urban scale, and lack large-scale regional research; (3) lacking the studies on spatial distribution pattern of regional suitability of the habitation environment.

The Three Gorges Reservoir Area (TGRA), located at the end of the upper reaches of the Yangtze River, is the important ecological barrier of the Yangtze River Basin, playing a significant role in eliminating the economic disparity between the west and the east of China. The reasonable spatial population pattern directly influences not only the regional eco-environmental quality, the safety of the Three Gorges Project and the security of millions of immigrants, but also the ecological security of the entire Yangtze River Basin and the sustainable development of society and economy. In view of this, with reference to the "Technical Guidelines for the Population and Development Function Area" issued by the National People and Family Planning Commission of China, a human settlements environment suitability assessment model based on RS and GIS technology was developed to comprehensively research the natural suitability and quantitatively analyze the suitability and spatial distribution of habitation environment in the study area. The purposes are to analyze the spatial population distribution in the TGRA, and provide the basis for the formulation of effective policies and spatial population development strategy.

2 Study area

The TGRA of Chongqing is located at the end of the upper reaches of the Yangtze River

(105°49′–110°12′E, 8°31′–31°44′N). The southeastern and northeastern parts of the study area are the junction with Hubei, the southwest is bounded by Sichuan and Guizhou, and the northwest is adjacent to Sichuan and Shaanxi. The study area includes 22 districts and counties (autonomous counties) of Chongqing and covers 46,158.53 km^2 with a total population of 21,054,900 (14,435,900 agricultural population) at the end of 2007.

The study area is characterized by humid subtropical monsoon climate. Therefore the spring here comes early but the autumn comes late, and the winter here is warm but the summer is hot. The annual average temperature is 15 to 18℃, with high annual and daily range of air temperature, and the average annual precipitation is 1150.26 mm by uneven space distribution. The TGRA of Chongqing crosses three major tectonic units of Daba mountain fold belt, east Sichuan fold belt, and the uplift fold belt of Sichuan, Hubei, Hunan and Guizhou. The landforms are dominated by mountains and hills. The main types of soil are purple, yellow, yellow brown, brown, lime, alluvial, paddy soil etc. The subtropical evergreen broadleaved forest and warm coniferous forest are the zonal vegetation. The TGRA is the most special function area of ecological economy in China or even in the world. The TGRA of Chongqing accounts for 80% of the total TGRA, which is of great significance to the ecology and economy (Li *et al*., 2009) (Figure 1).

Figure 1 The location of the study area

3 Data and methods

3.1 Data collection

The research data consist of five major components: topographic data (DEM), land use/cover status data and vegetation cover data (Normal Differential Vegetation Index, NDVI), climatic data including the average annual temperature and relative humidity, hydrological data including average annual precipitation and water resources distribution, and other auxiliary data such as administrative division map, population density etc. Land use/cover map (2005), DEM data and water resources distribution maps are derived from the Chongqing Municipal Water Conservancy Bureau. The land use/cover data was interpreted from remotely sensed data by the joint effort of Chongqing Municipal Water Conservancy Bureau and the Institute of Mountain Hazards and Environment of Chinese Academy of Sciences in the soil erosion survey carried out in 2000 and 2005. The data have been checked and accepted by relevant departments and experts, and meet the study requirements after field calibration. The data of temperature, precipitation and relative humidity are collected from 34 meteorological sites data provided by the Chongqing Municipal Bureau of Meteorology. Based on meteorological site data, the spatial distribution maps of the annual average temperature, rainfall and humidity in the study area are generated using Kriging spatial interpolation method in ARCGIS. The NDVI data calculated from MODIS data is derived from the Chinese Earth System Science Data Sharing Network. Administrative maps and other auxiliary data come from the Geomatics Center of Chongqing. In order to conduct calculation, vector data are transferred to grid data and the size of all grid data units is consistent with the NDVI data (250 m× 250 m). In addition, all data are converted into the Albers Conical Equal Area projection before conducting the spatial computation.

3.2 Methods

3.2.1 The establishment of evaluation index system

Although there are many factors, such as regional geological conditions, atmospheric environmental quality and so on, which affect the HSES, yet the most fundamental factors are terrain and landforms, climate, hydrological conditions, land use/cover etc., which play leading roles in the HSES evaluation and these essential factors can to a certain extent reflect some other factors. So the paper analyzes the quantitative characteristics and spatial pattern of HSES in the TGRA of Chongqing from terrain, climate, hydrology and land use/cover based on the existing research results. The index of HSES is established to research the relationship between the population development and the regional natural environment according to the weight and relationship between the natural environmental factors and the population distribution (Figure 2).

(1) Relief degree of land surface (RDLS)

Relief is the reflection of regional terrain and can be characterized by the altitude and degree of the surface cutting. Using research achievements of Feng *et al*. (2007), for reference, the calculation formula of relief is

$$RDLS = AE/1000 + \left\{\left[Max(H) - Min(H)\right] \times \left[1 - P(A)/A\right]\right\}/500 \tag{1}$$

where AE is the average elevation (m) in certain window area centered around a grid cell; Max (H) and Min (H) are the region's highest and lowest elevation respectively; P (A) is the regional flatland area (km^2); A is the total area of window region (km^2), and in this paper the spatial calculation is produced with the window size of 5 × 5 (Tang *et al*., 2006) (Figure 3).

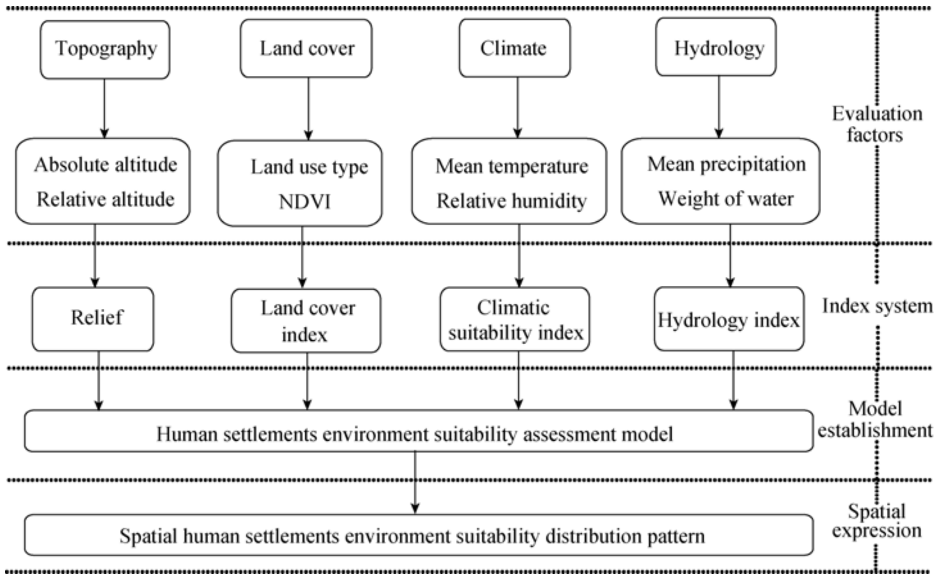

Figure 2 The technique flow chart of human settlements environment suitability assessment

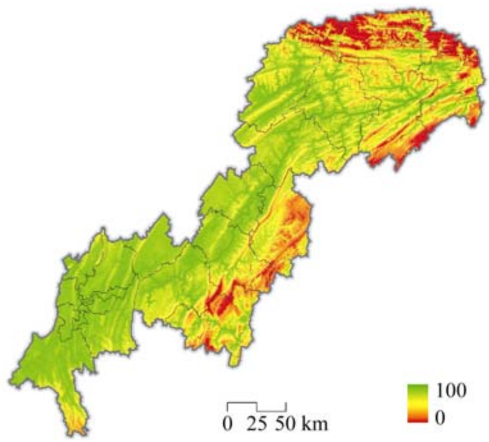

Figure 3 The standardized map of RDLS in the Three Gorges Reservoir Area

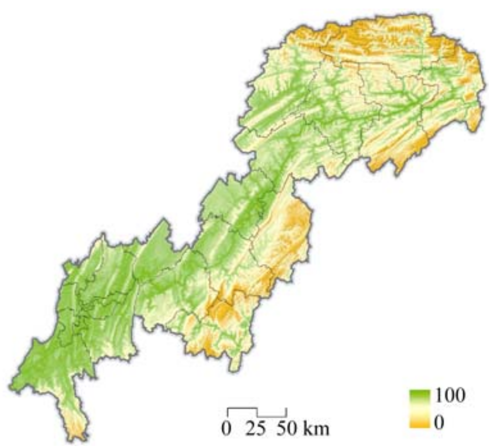

Figure 4 The standardized map of CSI in the Three Gorges Reservoir Area

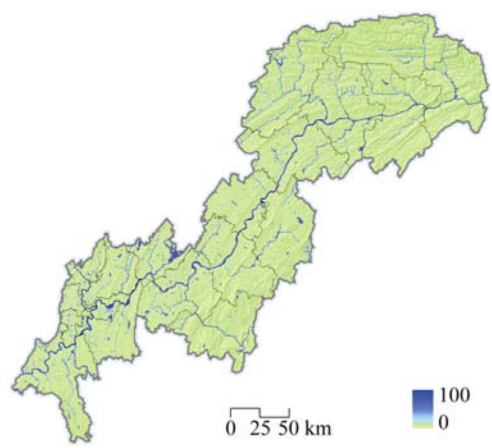

Figure 5 The standardized map of HI in the Three Gorges Reservoir Area

(2) Climatic suitability index (CSI)

Climatic suitability index can be expressed by the index of temperature and humidity which reflects climate suitability of the living environment (Feng *et al*., 2008; Tang *et al*., 2008), and its physical meaning is the temperature after humidity is revised (Thom, 1959).The calculation formula is:

$$CSI = 1.8t - 0.55(1-f)(1.8t-26) \tag{2}$$

where t is monthly mean temperature (℃); f is relative air humidity (%). Considering the stability of CSI, the monthly means for various meteorological elements of 34 meteorological stations covering nearly 30 years are calculated in the study area. The kriging interpolation is used to obtain the meteorological element maps. According to the criteria of human comfort (Feng *et al*., 1990; Lv *et al*., 1997; Wang *et al*., 1998), the grid maps of CSI are made with GIS. Then the spatial pattern of CSI in the TGRA is established (Figure 4).

(3) Hydrology index (HI)

Hydrology index uses the ratio of precipitation and water area to represent the abundance or deficiency of water resource. The precipitation embodies the capacity of water supply in natural state and the water area represents the catchment capacity in an area. The formula is given as follows:

$$HI = \alpha P + \beta Wa \tag{3}$$

where P is normalized precipitation; Wa is normalized waters area; α valued 0.8 and β valued 0.2 are the weight of precipitation ratio and water ratio respectively (Figure 5).

(4) Land cover index (LCI)

Land cover index is the comprehensive characterization of land use/cover. Its calculation formula is as follows:

$$LCI = NDVI \times LTi \tag{4}$$

where $NDVI$ is normalized difference vegetation index of a grid cell; LTi is the coefficient of various land use types (Table 1). Considering the stability of NDVI, the annual average maximum NDVI image is used in the paper. The process is implemented in ERDAS. The coefficient of land use types is determined according to Feng's research (2007) (Figure 6).

Table 1 Coefficient of land use types

Type	Farmland		Woodland				Grassland		
	Paddy field	Dry land	Forest land	Shrubbery	Scattered woodland	Others	High coverage	Medium coverage	Low coverage
Coefficient	1	0.7	0.6	0.6	0.4	0.4	0.6	0.6	0.6
Type	Water area						Construction land		
	River and canal	Lake	Reservoir and pond	Permanent glaciers and snowfield	Beach	Bottom land	Urban land	Rural residential land	Others
Coefficient	0.6	0.6	0.6	0.1	0.3	0.4	0.8	0.6	0.4

Type	Unused land						
	Sand	Gobi	Saline and alkali land	Swamp land	Bare land	Stone land	Others
Coefficient	0.1	0.1	0.2	0.5	0.2	0.1	0.3

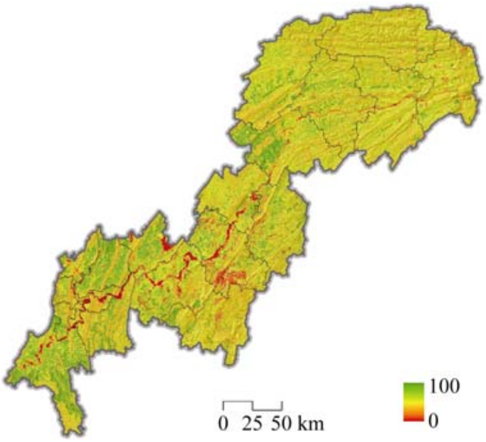

Figure 6 The standardized map of LCI in the Three Gorges Reservoir Area

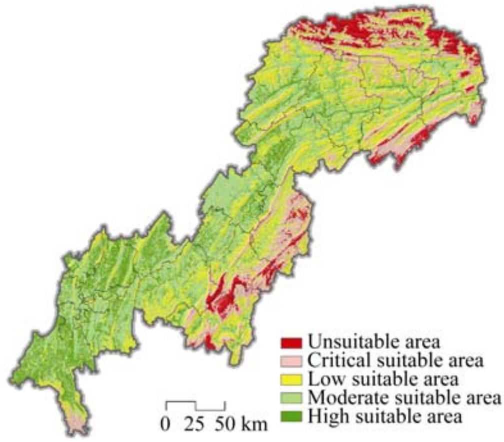

Figure 7 The evaluation map of habitat environment suitability in the Three Gorges Reservoir Area

3.2.2 The establishment of HSES assessment model

Based on the quantitative analysis of relief, climatic suitability, hydrology index and land cover index, the HSES assessment model was set up, and HSES index was calculated in the TGRA of Chongqing. The calculation formula is:

$$HEI = \alpha \times NRDLS + \beta \times NCSI + \chi \times NHI + \delta \times NLCI \tag{5}$$

where *HEI* is habitat environment index and value between 0 and 1; *NRDLS* is normalized relief; *NCSI* is normalized climatic suitability index; *NHI* is normalized hydrology index; *NLCI* is normalized land cover index; α, β, χ and δ are the weight of relief, climatic suitability index, hydrology index and land cover index respectively. In view of the relevant researches, the suitability index was calculated with the ratio of correlation coefficient of each single factor and the population density in the total correlation coefficient (Feng *et al*., 2007) (Table 2 and Figure 7).

Table 2 The weight and the coefficient of evaluation index and population density

Content	*RDLS*	*CSI*	*HI*	*LCI*
Correlation with population density	0.82	0.84	0.37	0.69
Weight	0.30	0.31	0.14	0.25

4 Results

Based on DEM data, land use data, NDVI data (calculated from MODIS data), average annual temperature, precipitation, relative humidity, and the HSES assessment model, the spatial distribution pattern of HSES were calculated in the study area with GIS. As the distribution pattern of calculated results is skewness and unsuitable for equidistant spacing grade method, the natural breaks grading method, frequently used to uneven data, was adopted to divide the HSES in the TGRA into five levels: the high suitable (73.2–100), the moderate suitable (62.2–73.2), the low suitable (50.8–62.2), the critical suitable (36.1–50.8) and the unsuitable (0–36.1) (Figure 8 and Table 3).

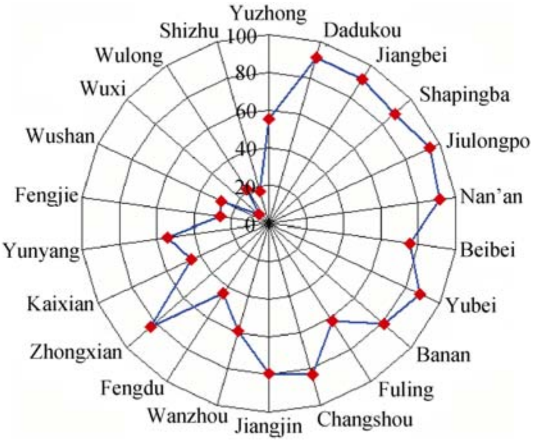

Figure 8 The area ratio radar map of moderate and high suitable area in various regions

Table 3 The table of the overall HSES characteristics in the TGRA of Chongqing

Classification of HSES	Land		Population			GDP		
	Area (km^2)	%	Amount (10^3)	%	Population density (person/km^2)	Total (10^6 yuan)	%	Per capita GDP (yuan/person)
High suitable area	5990.73	12.97	3360.4	19.35	561	8269.21	28.15	24608
Moderate suitable area	16380.88	35.46	8950.0	51.52	546	19293.93	65.68	21558
Low suitable area	12626.6	27.34	3725.3	21.45	295	5064.31	17.24	13594
Critical suitable area	7939.41	17.19	1149.5	6.62	145	1231.40	4.19	10712
Unsuitable area	3251.53	7.04	201.3	1.16	62	148.56	0.51	7378
Total	46189.5	100	17370.9	100	376	29375.20	100	16911

4.1 The analysis of the overall characteristic of HSES in the TGRA of Chongqing

Affected by natural factors such as topography, climate, hydrology and so on, about 51.57% of the TGRA of Chongqing (23,817.54 km^2), belonging to the low suitable, critical suitable and unsuitable area are of high restrict for human habitation. The rest areas are suitable for human habitation which are low restriction of various natural environmental factors (Tables 3 and 4). From unsuitable area to high suitable area, regional population density and per capita GDP show a regular increasing trend. The population density and per capita GDP in high suitable area are about 9 and 3 times as large as the unsuitable area. The feature fully reflects the socio-economic disparities in various regions. The HSES indicates an obvious spatial heterogeneity pattern. The northeast and southeast areas are of relatively low suitability, while the west and the south areas are of high suitability. It is an arc-banded spatial succession pattern on the whole (Figure 7). The spatial directivity of HSES in each county is obvious. The metropolitan areas and the neighbor counties locating in the west of Changshou-Fuling, putting Yuzhong, Fuling and Beibei aside, show highly suitability in which the area ratio of high suitable and moderate suitable area exceeds over 80%, especially, over 90% in Jiangbei, Nan'an, Dadukou and Jiulongpo. On the contrary, the HSES of the core areas of the TGRA of Chongqing in the east of Changshou-Fuling is apparently low where the area ratio of high and moderate suitable is almost less than 50% except Zhongxian,

Table 4 The result of HSES in various regions

District	Unsuitable area		Critical suitable area		Low suitable area		Moderate suitable area		High suitable area	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Yuzhong	0.00	0.00	1.13	6.12	7.15	38.56	7.64	41.22	2.61	14.10
Dadukou	0.00	0.00	0.13	0.12	8.39	8.16	74.35	72.31	19.97	19.42
Jiangbei	0.00	0.00	3.20	1.45	16.96	7.68	141.07	63.90	59.54	26.97
Shapingba	0.00	0.00	0.00	0.00	46.10	11.64	272.88	68.87	77.22	19.49
Jiulongpo	0.00	0.00	0.06	0.01	24.24	5.61	273.05	63.21	134.64	31.17
Nan'an	0.00	0.00	1.12	0.43	20.61	7.90	183.65	70.43	55.38	21.24
Beibei	0.00	0.00	13.68	1.81	171.59	22.73	359.99	47.68	209.74	27.78
Yubei	0.00	0.00	12.18	0.84	157.69	10.86	661.92	45.59	620.25	42.72
Banan	0.00	0.00	1.94	0.11	346.22	18.97	1097.63	60.14	379.21	20.78
Fuling	50.14	1.70	143.00	4.86	943.19	32.07	1450.12	49.30	355.01	12.07
Changshou	0.00	0.00	25.72	1.81	211.33	14.84	742.74	52.17	443.83	31.18
Jiangjin	2.14	0.07	275.88	8.57	386.37	12.00	1330.79	41.34	1223.83	38.02
Wanzhou	1.19	0.03	222.05	6.42	1186.69	34.33	1448.99	41.91	598.08	17.30
Fengdu	249.85	8.60	629.09	21.66	742.04	25.55	988.44	34.04	294.65	10.15
Zhongxian	0.31	0.01	15.27	0.70	348.42	16.01	1525.46	70.10	286.55	13.17
Kaixian	338.83	8.56	511.05	12.91	1322.16	33.40	1479.02	37.36	307.93	7.78
Yunyang	15.68	0.43	330.60	9.06	1328.35	36.40	1570.62	43.04	403.74	11.06
Fengjie	330.14	8.05	1145.51	27.95	1575.51	38.44	881.73	21.51	166.11	4.05
Wushan	354.97	12.00	876.04	29.63	898.79	30.40	720.99	24.38	106.21	3.59
Wuxi	1281.19	31.79	1433.71	35.58	1033.93	25.66	255.49	6.34	25.68	0.64
Wulong	361.86	12.47	993.70	34.25	931.60	32.11	478.81	16.50	135.34	4.66
Shizhu	265.22	8.81	1304.35	43.34	919.27	30.54	435.49	14.47	85.23	2.83

Wanzhou and Yunyang (Table 4 and Figure 8). In addition, the HSES is controlled by topography evidently, that is, the HSES is correspondence with the topographic distribution (Figure 7). Therefore, the dominant factor of HSES in the study area is topography.

4.2 The analysis of the subarea HSES characteristics in the TGRA of Chongqing

4.2.1 Unsuitable area

The unsuitable area is about 3251.53 km^2, accounting for about 7.04% of the study area. It ismainly distributed in the arc-like narrow belt along Guanmian Mountain, Daba Mountain, Wushan Mountain, Qiyao Mountain, Fangdou Mountain, Wuling Mountain and is located at the northeast and southeast of the study area. The unsuitable regions include northeastern Kaixian, southern Fengdu, northern Wuxi, eastern and southern Wushan, eastern Shizhu, and central Wulong. These areas have high elevation, steep slope, wide carbonate distribution and good vegetation cover, but high sensitivity ecological environment. The total population (about 201300) and density of population (62 person/km^2) in the unsuitable are the lowest, accounting for about 1.16% of the total population and 1/6 of the mean population density in the study area respectively. Moreover, the economic development level in the unsuitable area is also the lowest. The total GDP accounted for less than 1% of the total GDP of the study area in 2007 and the per capita GDP only 7378 yuan which was less than half of the average level in the study area. The unsuitable area is highly restricted by natural factors such as topography, climate, hydrology, and so on, and is unfit for human settlements. As the most important ecological barrier regions, the strategic priorities of the development in the region should focus on the construction of the important ecosystem service function areas, prohibiting the immigration of population, accelerating the organized ecological emigration and reducing the influence of human activities upon the ecological environment.

4.2.2 Critical suitable area

The critical suitable area, with a land area of 7939.41 km^2, accounting for 17.19% of the study area is mainly located in mountain area around the unsuitable area, including the central and northern parts of Kaixian, southern Wuxi, western Wushan, western Shizhu, eastern and western parts of Wulong, and the Simian Mountain in southern Jiangjin. The limitations to human life here are still high. The soil erosion and rocky desertification in the area are the most serious, and the ecological environment is very fragile and is unsuitable for a large habitation. The total population (about 1,149,500) and density of population (145 person/km^2) in the critical suitable area account for about 6.62% of the total population and less than half of the mean population density in the study area respectively. The economy here develops a little better than the unsuitable area. The total GDP was 12,313.98 million yuan accounting for 4.19% of the total GDP of the study area in 2007 and the per capita GDP was 10,712 yuan which was some what above half of the average level in the study area. The critical suitable areas are less restricted by natural factors than unsuitable areas and critical fit for living, which are transitional regions between suitable and unsuitable areas. As the more important ecological barrier regions, the strategic priorities of the development in the region should focus on the construction of the ecosystem; the alleviation of acute contradiction between human and nature; the implementation of active population policies to the promotion of the orderly emigration of people in the region. The favorable policies should be implemented to guide the people who still stay inside the region to concentrate in the core towns or villages.

4.2.3 Low suitable area

The low suitable area, with a land area of 12,626.60 km^2 (27.34%), is only less than moderate suitable area. These regions are mainly located in the northeast and southeast of the study area. In addition, a small proportion of the low suitable areas is also distributed on the top of the ridge in the equal ridge-valley region locating in the middle and west of the study area. In terms of geomorphologic types, low suitable areas are basically in the transitional regions where mountains gradually developed to plains including: central and southern Kaixian, eastern and southern Yunyang, a small proportion of southern Wuxi, central and northern Fengjie, some parts of central Wushan, southeastern Wanzhou, western Shizhu, central Fengdu, central Wushan, a small proportion of southeastern Wulong, western and southern Fuling, some parts of southern Banan and southern Jiangjin, and a few parts in other counties. The total population (about 3,725,300) and density of population (295 person/km^2) in the low suitable area account for about 21.45% of the total population and somewhat less than the mean population density in the study area respectively. Both the quantity and ratio of the population in the low suitable area are second only to the moderate suitable area. The total GDP was 50,643.13 million yuan accounting for 4.19% of the total GDP of the study area in 2007 and the per capita GDP was 13,594 yuan which was somewhat less than the average level in the study area. These areas, moderately restricted by topography, climate, hydrology and other natural factors, are generally fit for human settlements. The strategic priorities of the development in the region should focus on promoting the local people in the region orderly and voluntarily emigrating; developing the ecological industries and local special industries in the light of local conditions; and guiding the people still staying inside the region concentrate in the industrial parks or core towns by industrial agglomeration.

4.2.4 Moderate suitable area

The moderate suitable area, with a land area of 16,380.88 km^2 (35.46%), is the biggest one among various types. With Changshou-Fuling as a boundary, the moderate suitable area is concentrated in the flat areas north of the Yangtze River in the eastern side. In the western side, it is mainly located in the south of the Yangtze River and Jialing River of east of Jinyun Mountain. The southeastern part of the study area also belongs to the moderate suitable area. In terms of counties, the moderate suitable area accounts for a large proportion (over 50%) in Fuling, Changshou, Banan, Jiulongpo, Jiangbei, Shapingba, Nan'an, Dadukou and Zhongxian. The total population (about 8,950,000) and density of population (546 person/km^2) in the moderate suitable area account for about 51.52% of the total population and about 1.5 times as large as the mean population density in the study area respectively. Both the area and population of moderate suitable area are the first. The total GDP was 192,939.29 million yuan accounting for 65.68% of the total GDP of the study area in 2007 and the per capita GDP was 21,558 yuan which was 1.3 times higher than the average level in the study area. The moderate suitable area is slightly influenced by natural factors and moderate suitable for human settlements. The strategic priorities of the development in the region should focus on improving the quality of population urbanization; fostering regional economic centers; strengthening the capacity to absorb population; improving the social integration mechanism of floating population; encouraging the migrants settling, who have stable employments and accommodations; and guiding the people in the region emigrate to the adjacent high suitable area in order to guarantee the goal of the dynamic equilibrium of the total amount of the population in the region.

4.2.5 High suitable area

With a land area of 5990.72 km^2 (accounting for 12.97% of the land area of the study area), high suitable area is mainly located in the hilly regions and valleys in the metropolitan areas and the neighboring counties located in the west of Changshou-Fuling. Then, high suitable area is located in valleys of the Yangtze River and its tributary of the northwest study area as well, such as valleys along the Yangtze River in Wanzhou, valleys of Xiaohe River in Kaixian, valleys of Meixi River in Fengjie and valleys of Daning River in Wushan. With good natural conditions, the high suitable area is most suitable for human settlements. Although the water resources are shortage in some parts of high suitable area, it can be made up by diverting and storing water projects. The total population (about 3,360,400) and density of population (561 person/km^2) in the high suitable area account for about 19.35% of the total population and about 1.5 times as large as the mean population density in the study area respectively. The population density of the high suitable area is the highest. The total GDP was 82,692.10 million yuan, accounting for 28.15% of the total GDP of the study area in 2007 and the per capita GDP was 24,608 yuan which was 1.5 times higher than the average level in the study area. The high suitable area is free from the restriction of natural factors and thus is best for human habitation. The strategic priorities of the development in the region should focus on increasing the population density; and enhancing the construction of urban infrastructure and actively promoting the form of industrial cluster to strengthen the capacity to absorb and concentrate population; cleaning up all sorts of institutional obstacles of population flow to encourage and attract the migrants settling.

5 Conclusions and discussion

The TGRA of Chongqing accounts for about 80% of the entire Three Gorges Reservoir Area. Thus, a reasonable spatial distribution of population directly and indirectly affected the safety of the Three Gorges Project, the social stability, and the economic development as well. In view of the importance of ecological and geographical location and research limitations of the study area, this paper quantitatively evaluated the suitability in the TGRA of Chongqing and illustrated the spatial pattern and geographic features of HSES in the study area.

The results showed that: (1) The population of the TGRA of Chongqing is concentrated in the area with relatively high HSES, covering 22,371.610 km^2 (48.43%) and distributing 12.3104 million resident population (78.70%). That is, the area less than a half owns nearly 4/5 of the total population. (2) The geographical characteristics of HSES in the TGRA of Chongqing are obvious. Generally, the study area presents an arc-banded spatial succession pattern, relatively low in the northeast and the southeast while high in the west and the south. The HSES is closely controlled by the terrain. (3) A great number of people still live in the areas with low suitability and undeveloped economy where population density is much higher than the average population density in the areas with similar conditions in western China. Moreover, these areas are ecological sensitive and fragile districts and many kinds of eco-environmental problems are caused by human activities. Therefore, a reasonable population migration and layout are essential to the scientific development of these areas.

The HSES assessment model is established using GIS and RS, and can well reflect the natural suitability and limitation characteristics in various districts, and can quantitatively reveal the spatial pattern and geographic disparity of the habitat environment in the study area. Therefore, the research results in the paper can provide a scientific basis for the correct analysis of the spatial distribution of population in the TGRA of Chongqing, the formulation of effective policies, and sustainable development of society and economy. Moreover, the proposal of targeted measurements and patterns on migration will be more practical significance which is the direction for further study of this paper.

References

Campbell A, Converse P E, Rodgers W L, 1976. The Quality of American Life: Perceptions, Evaluations, and Satisfactions. New York: Russell Sage Foundation.

Choguill C L, 1996. Toward sustainability of human settlements. *Habitat International*, 20(3): 5–8.

Doxiadis C A, 1968. Ekistics: An Introduction to the Science of Human Settlements. Athens Publishing Center.

Emmanuel R, 2005. Thermal comfort implications of urbanization in a warm-humid city: The Colombo metropolitan region (CMR), Sri Lanka. *Building and Environment*, 40(12): 1591–1601.

Feng Dingyuan, Qiu Xinfa, 1990. Calculation and analysis of the apparent temperature in the four seasons over China. *Journal of Institute of Meteorology*, 13(1): 71–79. (in Chinese)

Feng Zhiming, Tang Yan, Yang Yanzhao *et al*., 2007. The relief degree of land surface in China and its correlation with population distribution. *Acta Geographica Sinica*, 62(10): 1069–1082. (in Chinese)

Feng Zhiming, Tang Yan, Yang Yanzhao *et al*., 2008. Establishment and application of human settlements environment index model (HEI) based on GIS. *Acta Geographica Sinica*, 63(12): 1327–1336. (in Chinese)

Gilbert A, 1998. An urbanizing world: Global report on human settlements. *Habitat International*, 22(1): 75–77.

John E O, 1973. Climate and Man's Environment: An Introduction to Applied Climatology. John Wiley & Son's Inc., 195–206.

Li Huasheng, Xu Ruixiang, Gao Zhonggui *et al*., 2005. Quality evaluation of human settlements in a city scale: A case study on Nanjing city. *Human Geography*, 20(1): 1–5. (in Chinese)

Li Wangming, Ye Xinyue, Sun Yu, 1999. The assessment of urban human settlements: A case study of Hangzhou. *Economic Geography*, 19(2): 38–43. (in Chinese)

Li Xueming, Jiang Bin, Yang Bo, 2002. Study on sustainable development of human settlement: In the case of Dalian. *China Populaion, Resources and Environment*, 12(6): 129–131. (in Chinese)

Li Xueming, Liu Jinghua, 2003. Preliminary research on the fuzzy comprehensive appraisal to environmental climate of the urban human settlements. *Economic Geography*, 23(Suppl.): 656–660. (in Chinese)

Li Yuechen, Liu Chunxia, Yuan Xingzhong, 2009. Spatiotemporal features of soil and water loss in Three Gorges Reservoir Area of Chongqing. *Journal of Geographical Sciences*, 19: 81–94.

Liu Ping, Wang Rusong, Tang Hongshou, 2001. Approach of the method of ecological design on the environment of urban human settlement. *Acta Ecologica Sinica*, 21(6): 998–1002. (in Chinese)

Lv Weilin, 1997. The apparent temperature and its calculation method. *Beijing Meteorology*, (4): 23–25. (in Chinese)

Ning Yuemin, Zha Zhiqiang, 1999. A study of evaluation and optimization for human settlement in the metropolitan areas: Take Shanghai for example. *City Planning Review*, 23(6): 15–20. (in Chinese)

Spagnolo J, Dear R D, 2003. A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. *Building and Environment*, 38(5): 721–738.

Tang Guo'an, Liu Xuejun, Fang Liang *et al*., 2006. The scales and scale effects of DEM and digital terrain analysis. *Geomatics and Information Science of Wuhan University*, 31(12): 1059–1066. (in Chinese)

Tang Yan, Feng Zhiming, Yang Yanzhao, 2008. Evaluation of climate suitability for human settlements in China. *Resources Science*, 30(5): 648–653. (in Chinese)

Terjung W H, 1966. Physiologic climates of the contentious United States: A bioclimatic classification based on man. *Annal A.A.G.*, 5(1): 141–179.

Thom E C, 1959. The discomfort index. *Weatherwise*, 12: 57–60.

Wang Jinliang, Wang Ping, Jiang Lianfang, 2002. Study on climate comfort degree of human settlements in Kunming. *Economic Geography*, 22(suppl.): 196–200. (in Chinese)

Wang Yuanfei, Shen Yu, 1998. The temperature-humidity effect and human comfort in Shanghai summer. *Journal of East China Normal University* (Natural Science), (3): 60–66. (in Chinese)

Wu Liangyong, 2001. Introduction to Human Settlements Environment Science. Beijing: China Architecture & Building Press. (in Chinese)

Xiong Ying, Zeng Guangming, Dong Lisan *et al*., 2007. Quantitative evaluation of the uncertainties in the coordinated development of urban human settlement environment and economy: Taking Changsha city as an example. *Acta Geographica Sinica*, 62(4): 397–406. (in Chinese)

Zhang Q, Zhu C, Liu C L *et al*., 2005. Environmental change and its impacts on human settlement in the Yangtze Delta, P.R. China. *Catena*, 60(3): 267–277.

Zhang Wenzhong, Liu Wang, Meng Bin, 2005. On location advantage value of residential environment in the urban and suburban areas of Beijing. *Acta Geographica Sinica*, 60(1): 115–121. (in Chinese)