Suitability evaluation of urban terrain in China

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Abstract. To clarify the terrain characteristics of Chinese cities, three terrain parameters that altitude, relief and slope are selected to be analysed. Based on these factors, we make a classification of urban landforms and then compare the differences of urban terrain using the classification results. In conclusion, firstly, it is in a micro scale that the terrain of built-up areas has similar characteristics. Secondly, a method to evaluate the suitability of urban terrain in China is proposed and the suitability evaluation of terrain around built-up areas is realized. Finally, statistical data shows that Chinese urban expansion potentials are all considerable except for urban areas in high altitude mountain.

1. Introduction

A city is the center of politics, economics, technology, culture and education in a country or district, where the human activity is focus and the natural environment is the most intense affected. Although urban areas account for less than 3% of the world’s land, the impact of urban expansion on ecological environment is global. Urban expansion is a concentrated expression of urban spatial distribution and structural changes, which has become a hot spot in the research of urban development both at home and abroad. Domestic and foreign research about urban expansion mainly focused on monitoring, mechanism, influence, simulation prediction and optimal adjustment, etc. (Batty, 2013; Zhang & Zhang, 2012; Zhang, et al., 2014; Xu, Zhao & Min, 2014). Some scholars take terrain as one of the important factors to restrict urban expansion and make researches to clarify how much influence the topographic does (Diao, 1990; Zhang, 2008; Zhao, et al., 2015). During the process of urban expansion, terrain from macro aspect control the shape, structure and extension direction of a city (Verstappen, 1983). From the above all, the terrain is mainly restricting the intense and direction of urban expansion. Analysis on urban topography may help to estimate and forecast the city extension status in the future, which is of great significance in urban planning decision and suitable terrain selection. Moreover, research on urban terrain influence is an important factor when we study urban expansion mechanism. And the relationship between urban scope change and terrain can provide rule and data basis to simulation prediction and optimal regulation of urban expansion.

From the perspective of formation and development of a city, gentle terrain is one of the most favorable external conditions for the development of the city (Diao, 1990). And from the aspect of the overall construction of the city, gentle open terrain is more favorable (Tongji university, 1991). However, for urban terrain, what mentioned “gentle open” above is only a kind of qualitative description, and transferring it to quantitative characterization is more meaningful. From low to high, plain to mountain, there exist cities. The landform types in traditional landform classification system, restricted by use and division basis, are mainly based on macro landform factors. Traditional system has an important limitation. It is unable to distinguish suitable urban terrain for its classification rule is based on a macro scale. Less micro scale terrain factor is necessary to evaluate the suitability of urban terrain. In this research, to compare the similarities and differences of different topographic parameters,
more than two hundred cities are analyzed. At last, a method named neighborhood relief is proposed to
distinguish micro terrain characteristics. Experiments show that neighborhood relief is not only
accordant with urban terrain, but has a good universality in different landform types in China.

There are great differences of urban topographic distribution characteristics between the east and
west sides of "Hu Huanyong Line". And these differences directly restrict the distribution of
population and buildings, which is a key factor to answer whether or not the line can be broken
through in the strategy of "new urbanization" in China. Meanwhile, related problems derived from the
strategy such as “how much geomorphology controls the temporal and spatial evolution of urban
expansion” become increasingly concerned in the field of city geomorphology, and it is true that the
research on urban topography is the foundation of study on potential evaluation of urban expansion.

In this paper, we take Chinese urban peripheral terrain as the research object. To find out how to
depict the urban built landform with some universal terrain parameter, we analyze the characteristics
of different terrain factors and different scales of topographic relief features in the scope of Chinese
288 urban areas using 2010 land use database of China, nearly 40 years of Chinese urban expansion
database and the second edition of the Aster DEM Terrain Data. As a result, a topographical statistical
rule named neighborhood relief method is built, and the suitability evaluation of Chinese urban terrain
is realized at last.

2. Basic characteristics of urban terrain in China

As a human gathering place, the city’s landscape environment is generally open and flat. And urban
landform has a distinctive feature in the complex environment of China. In this paper, we extract the
terrain information in the build-up area of Chinese prefecture-level city based on land use data in 2010
and the second edition of the ASTER DEM data. Finally, the characteristics of China city landform are
described by analysis of landform factors, such as elevation, slope and topographic relief. In order to
further clarify the terrain features in the East and west sides of "Hu Huanyong line", all the statistical
analysis of China will be divided into three parts, the western part is located in the west of "Hu
Huanyong line", and the central part and the eastern part are located in the east of "Hu Huanyong
line"(Fig. 1).

2.1. Altitude Characteristics of Chinese Cities

Altitude is a basic parameter of terrain. It is the vertical distance from the sea level of a region. The
altitude characteristics of Chinese cities are as followings. As a whole, the altitude of built-up areas in
Chinese single prefecture-level city is between 9m and 3664m, and the average value is 202m. There
are 79.61% areas at an altitude of 200m below, and 88.17% areas are 500m below. But there are only
7.56% areas at 1000m above, 0.14% areas at 3000m above. Specifically, the regional difference of
altitude in Chinese cities is obvious. The altitude of built-up areas in the eastern region is between 9m
and 1248m, and the average value is 77m. The middle region, as located in the second step in Chinese
topographic step distribution, is distinctly higher than the eastern region. And the altitude of built-up
areas in this region is between 12m and 2407m, and the average value is 588m. Cities in the western
region of China are mainly located in the central and western regions of the Tibetan Plateau, the Loess
Plateau and the Inner Mongolia Plateau. It is the highest in the three parts of China. The altitude of
built-up areas in this region is between 390m and 3664m, and the average value is 1265m.
2.2. **Slope Characteristics of Chinese Cities**

Slope is the ratio of vertical height and horizontal distance, and it also refers to the inverse trigonometric tangent function when showed by degree. The essence of slope is to show its steep. The slope characteristics of Chinese cities are as followings. As a whole, in 2010, the slope of built-up areas in Chinese cities is between $0.47^\circ$ and $14.28^\circ$, and the average value is $2.65^\circ$. About 55.19% city areas have an average slope of $2^\circ$ below, the city proportion will rise to 91.84% when the slope is increased to $6^\circ$ below, 98.68% city areas have an average slope of $15^\circ$ below, and 99.83% city areas have an average slope of $25^\circ$ below, but only 0.17% city areas have an average slope of $25^\circ$ above. Specifically, the difference of slope is small among the three parts of China. The slope of built-up areas in the eastern cities is between $0.46^\circ$ and $10.29^\circ$, and the average value is $2.40^\circ$. The middle region with broken terrain is mainly located in the Yunnan-Guizhou Plateau, and the slope of built-up areas in the middle cities is between $1.41^\circ$ and $14.36^\circ$, and the average value is $4.43^\circ$. The central region has the most rugged terrain in the three parts of China. The slope of built-up areas in the western cities is between $1.16^\circ$ and $10.67^\circ$, and the average value is $2.98^\circ$. It is a little more than the eastern region, but less than the central region.

2.3. **Topographic Relief Feature of Chinese Cities**

The relief reflects the maximum height in a certain area. It is an important index to quantitatively describe the geomorphology and to divide the type of landform. According to the theory of landform development, with the increase of the statistical range, the relief becomes larger and larger, and tends to be stable after reaching a certain value. To analyze the topographic relief of Chinese cities, the best statistical unit result $13\text{km}^2$ based on the analysis of Chinese typical urban terrain is used in this study. As a whole, in 2010 the relief of built-up areas in Chinese cities is between 23m and 881m, and the average value is 104m. About 11.94% built-up areas are located at a relief valued 30m below, 87.59%
areas are at 200m below, and more than 80% areas are at 153m below. Specifically, Regional differences of relief in Chinese cities are obvious. In the east, the relief is between 23m and 443m, the average value is 93m, and it is the smallest relief in the three parts of China. In the middle areas, the relief is between 40m and 667m, and the average value is 164m, which is the biggest in the three parts of China, where there is large range, typical developed karst landform, broken terrain and steep surface. At last, the relief in the west is between 33m and 887m, and the average value is 153m.

2.4. Classification of Urban Terrain in China Based on Topographic Relief and Altitude

Topographic relief and altitude are important parameters for the classification of regional terrain in a macro scale and the quantification of topographic features, which is widely used in basic terrain classification. The Chinese urban terrain classification in this paper is based on the morphological classification system proposed by Zhou Chenghu et al(Zhou et al., 2009). Chinese urban terrain is divided into six types based on the average topographic parameter of its outline circle. By the relief, there are three types of cities called plain city, hilly city and mountain city. And according to altitude, urban terrain is divided into low altitude city, middle altitude city and high altitude city. More than 200 prefecture-level cities have been divided into different types(Table. 1 and Table. 2). As a result, the most types of cities in China are located in low altitude hill, and the ratio is 71.69%. The other city proportion show a descending tendency as low altitude mountain cities, low altitude plain cities, medium altitude mountain cities and high altitude mountain cities, and the proportion of the high altitude mountain cities is the least in the six types of landform, which is only 0.14%.

Table 1. Terrain classification of Chinese cities.

| Altitude range | Relief range | Landform          | Proportion |
|----------------|--------------|-------------------|------------|
| <1000m         | <30m         | low altitude plain| 8.97%      |
| 1000~3500m     | 30~200m      | low altitude hill | 71.69%     |
| >3500m         | >200m        | low altitude mountain| 11.82%     |

Table 2. Terrain characteristics of Chinese cities.

| Landform                  | Altitude (m) | Relief (m) | Slope(°) |
|---------------------------|--------------|------------|----------|
| low altitude plain        | 10           | 31         | 1.12     |
| low altitude hill         | 92           | 90         | 2.40     |
| low altitude mountain     | 220          | 195        | 4.52     |
| medium altitude hill      | 1263         | 123        | 4.83     |
| medium altitude mountain  | 1564         | 243        | 3.40     |
| high altitude mountain    | 3664         | 417        | 3.24     |

The cities in different types of landform in China have distinct differences in topographic features. Above all, compared to the surrounding areas, cities tend to distribute in the low and flat terrain areas. The topographic parameters of urban built-up areas are mostly in the low value of terrain classification criteria. Taking altitude as an example, the average altitude of low altitude plain is only 10m, the value of medium altitude hill is 1263m, and the value of high altitude mountain is 3664m. Secondly, the difference of average slope among single city is small in China. Urban topography has a strong commonality in a more microscopic scale. For example, the average slope of all types of built-up areas is less than 5°(Table. 2).

3. The topographic constraints of urban expansion in China

The analysis of the terrain limitation of urban expansion is helpful to find out the suitable terrain areas of a city in the future, and it is the basis of further study on potentiality of urban expansion. According to statistics of neighborhood relief, the terrain requirement of urban expansion will be proposed in this study.
3.1. Terrain restriction parameter setting for urban expansion

The topographic restriction parameter of urban expansion should give full consideration to the terrain requirements for houses. Compared with the relief mentioned above, the neighborhood relief is more restrictive to the housing construction. Topographic relief should be analyzed based on a much closer area. Based on this, resolution of 100m pixel is used to analyze the terrain restriction condition in this paper, and the parameter is called neighborhood relief mainly due to avoiding confusion of concept understanding.

3.2. The range of urban neighbouring relief and its statistical regulation

After less than 0.01% discrete pixel value being rejected, the statistical results show that the range of urban neighbouring relief in China is from 0m to 129m, and the average value is 18m. Urban neighbouring relief with the largest proportion is 11m, its range is from 7m to 16m, and the cumulative proportion is up to 49.52%. The region where neighbouring relief is lower than 10m accounts for 32.20%, 74.50% region lower than 20m, 89.34% region lower than 30m, and 98.91% region lower than 80m(Fig. 2). In addition, the neighbouring relief range of each single city is from 3m to 79m, and there is a small regional difference(Table. 2). In the east, where there are 83.80% cities, the neighbouring relief range of each single city is from 3m to 59m, and the average value is16m. In the middle, where there are 10.06% cities, the neighbouring relief range of each single city is from 10m to 79m, and the average value is28m. In the middle, where there are 10.06% cities, the neighbouring relief range of each single city is from 10m to 79m, and the average value is28m. In the west, there are 6.14% cities, the neighbouring relief range of each single city is from 9m to 59m, and the average value is 20m.

![Figure 2. Scatter distribution of neighbouring relief in 288 urban built-up areas.](image)

To find out the suitable terrain requirement of built-up areas, the first consideration is to ensure that most of the areas are in the range of built-up neighbouring relief. Taking into account the possible extreme cases that a sharp, steep, cliff terrain in the city have been packed into the neighbouring relief range, the upper height limit of neighbouring relief cannot be set as the maximum value. According to the statistical result and above analysis, 80m is chosen as the upper height limit of neighbouring relief. When the neighbouring relief is less than 80m, there exist two kinds of upper height limit. One is 30m, the neighbouring relief in these areas are less than 30m. From the statistical characteristics of neighbouring relief, the landform with this kind of height limitation is more suitable for construction of built-up areas. The other one is 80m, about 10% in proportion, here average neighbouring relief of each single city is imported to help further choosing. When the value is more than 30m, the limitation is adjusted to 80m(Fig.3).
Figure 3. The extraction process of suitable terrain in urban built-up areas.
4. The distribution regularities of suitable terrain for built-up areas around Chinese cities

According to terrain limitation of urban expansion analyzed above, suitable terrain of built-up areas (hereinafter referred to as the suitable terrain) can be found out by the elimination of the areas beyond the terrain limitation. Based on the built-up areas of 288 prefecture-level cities in China in 2010, the buffer radius is set to 2 times of the radius of each city circle, a buffer region of about 25 times of the existing urban built-up areas produces. The buffer region is the first choice for the future development of the city. The reason lies that compared with the other areas there are more regional contact and larger impact by the city in these regions. As a whole, the terrain suitability in the buffer regions around the build-up areas of Chinese cities is evaluated by the method proposed above.

4.1. Regional difference of suitable terrain around Chinese cities

In the buffers based on 2 times of the radius of Chinese cities, about 65.51% terrain is suitable for built-up areas. The proportion in the eastern, central and western parts of China is showed as 66.19%, 69.08% and 53.70%, respectively. The difference among them is not large. The proportion of urban suitable terrain in the central and west are both more than a half, and moreover, the value in the central area is even more than that in the eastern region. In conclusion, the potential of urban development in the central and west is huge from a view of microscopic scale. Otherwise, judging from the absolute amount of suitable terrain, the amount in the eastern region is still far greater than the central and western regions. And this is mainly due to the current city proportion in the eastern region of China is far greater than that in the western region (Fig. 4).

4.2. Distribution of suitable terrain of built-up areas in different landform environment

The distribution difference of suitable terrain around Chinese cities is significant in different types of landform. There is a common descending tendency of suitable terrain proportion as the altitude rises. And it shows a descending order as low altitude hill, low altitude mountain, low altitude plain, medium altitude hill and medium altitude mountain (Fig. 5). This is consistent with the current proportion of built-up areas in various types of landform. That is to say, greater the proportion of the built-up areas surrounding the city is, the greater proportion of suitable terrain land the type of landform has. The most prominent is the low altitude hill city, the suitable terrain areas in this type of landform are 2.45 times the total areas of the other types. From the view of the proportion of suitable terrain for built-up areas in various types of landform (called relative proportion in abbreviated form following), low altitude plain is the most suitable type of landform for built-up areas, which relative proportion is up to 78.57%. Besides, medium and low altitude hill are suitable for built-up areas, too, the relative proportion of these two types of landform are high as 71.04% and 69.22%. Moreover, each has about a half suitable terrain land in low and medium altitude mountain, the relative proportion is 50.90% and 47.37%. The terrain environment surrounding built-up areas in high altitude mountain city is the most severe, which is obviously restricted by the terrain environment, and the suitable terrain proportion is only 13.16%. In conclusion, the suitable terrain proportion of the six types of landform
except for high altitude mountain is equal to or more than a half, the potential development of Chinese cities is huge.

5. Conclusions

Terrain characteristics of Chinese cities are analysed by a method of landform classification. Based on the terrain characteristics analysed above, suitable terrain requirement of urban expansion is built with the statistical regulation of neighbouring relief. At last, urban terrain suitability contrast in different parts of China is made. In conclusion,  

1) Chinese urban areas are tend to distribute in low and gentle plain or hill, and the terrain characteristics show more unsuitable for urban areas in the west than in the east. There is a huge difference in altitude and relief but a small difference in slope among different urban areas. It is in a micro scale that the terrain in urban areas has similar characteristics. The average altitude, slope and relief in Chinese urban areas are 202m, 2.65° and 104m, and the average range of these terrain factors in individual urban areas are 9 ~ 3664m, 0.47 ~ 14.28° and 23 ~ 881m respectively, and mainly concentrated in less than 500m, 6° and 200m.

2) Neighbouring relief is selected as a micro scale factor to make quantitative analysis of Chinese urban terrain characteristics. Neighbouring relief in more than 98.91% Chinese urban areas is lower than 80m, and 89.34% is lower than 30m, and the neighbouring relief range of individual urban areas is 3 ~ 79m, therefore, the upper limitation of neighbouring relief that 30m and 80m is statistically applicable to evaluate suitability of urban terrain in China.

3) In the buffers based on 2 times radius of Chinese cities, about 65.51% terrain is suitable for built-up areas. The potential of urban development in the central and west is huge from a view of microscopic terrain scale.

4) The suitable terrain around Chinese urban areas show a decline order as low altitude hill, low altitude mountain, medium altitude mountain, low altitude plain and high altitude mountain. And in the six types of landform except for high altitude mountain, the potential development of the cities is huge.

Acknowledgments

Authors wishing to acknowledge assistance from Project of National Key Technologies R&D Program of China, “Potential evaluation and scenario analysis of hollow rural settlement renovating” (No. 2014BAL01B01C).

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