Analysis of the division of the urban-rural ecotone in the city of Zhuhai

Nan Cui¹, Sulong Zhou², Luo Guo*.

¹ College of Life and Environmental Sciences, Minzu University of China, Beijing 100081, China
² University of Wisconsin-Madison Center for Sustainability and the Global Environment, University of Wisconsin-Madison Madison, United States of America

*Corresponding author: Luo Guo. Email: guoluo@muc.edu.cn

Abstract. In this study, a high-resolution remote sensing image of downtown Zhuhai (2010) was used to analyze the division of the urban-rural ecotone. Based on the information entropy theory, the study analyzed the characteristics of the ecotone's land use and entropy value distribution, the break entropy values of the inner and outer boundary, as determined by mutation detection, were 0.51 and 0.46, respectively, providing a range for the rough classification of the rural-urban ecotone. The results showed that the boundaries of the ecotone were dynamic and the landscape turbulence of the urban fringe in the section between rural and urban areas was greater than that of the core area and imagery area of Zhuhai city. We concluded that this study provided technical support for urban planning and administration in the city of Zhuhai.

1. Introduction

Urbanization, along with an increase in urban population, is the expansion and evolution of a city’s complex ecosystem and its geographic space. With the rapid development of China’s economy, urbanization is an inevitable result. In this case, urban ecological patterns, processes and the maintenance of stability mechanisms are under enormous pressure. The resulting complex ecological and environmental consequences have affected regional and even global sustainable development [1-4]. The continuous reforms of the economic system, coupled with accelerating urbanization, have led to the expansion and emergence of many new urban areas which were previously rural land. An intermediate zone, serving as a transitional space between rural and urban areas, is called an ecotone. [5-7] Rapid urban development has led to a rapid encroachment of farm land, which has already resulted in land use conflicts, landscape pattern disorder and a fragile ecological environment, any of them impedes not only urban construction but also rural development. Thus, it is necessary to quantify the geographic range of the urban-rural ecotone [8-12].

Zhuhai city is located in the southeast of Guangdong province, close to the South China Sea. It shares a border with Macao in the south and faces Hong Kong and Shenzhen across the sea to the east. In 1980, Zhuhai was identified as a special economic zone and its urbanization was accelerated inevitably. In 2003, Zhuhai’s long-range plan (2001-2020) was approved by the State Council, the plan put forth a multilevel and grouped urban pattern consisting of “center downtown-second center downtown-external new town-center town.” The ecological environment of Zhuhai was undoubtedly impacted by its rapid urbanization, in addition, landscape fragmentation had led to serious issues concerning the sustainable development of Zhuhai. The lack of knowledge about the structures,
function features and evolvement law of the Zhuhai urban-rural ecotone, coupled with the lack of attention to the local ecology, had limited the improvement of Zhuhai’s urban construction and management.

Through a quantified analysis and the rational classification of the urban-rural ecotone, this study provided valuable data to support the need to implement a scientific and environmentally friendly policy for the sustained development and utilization of Zhuhai’s resources.

Figure 1. (a) Landscape classification and (b) the information entropy distribution map of study area.

2. Study area and methods

2.1. Study area overview
Zhuhai is located in the southern portion of Guangdong province, west of the Pearl River estuary, (21° 48’-22° 27’ N, 113° 03’-114° 19’ E). The total area encompassed by Zhuhai is 7653 km², 1687 km² of which is land area. Zhuhai is made up of 3 districts, Xiangzhou, Doumen and Jinwan, 15 towns and 8 subdistricts. Zhuhai, located 140 km away from Guangzhou City, is bordered by the South China Sea and is connected by waterway with Hong Kong in the east and by land with Macao in the south. Zhuhai is also bordered by Xinhui and Jiangmen City to the west and Zhongshan City to the north. It includes a mountainous region as well as 144 scattered off shore or open-sea islands. For this reason, Zhuhai is also known as the “city of islands.” The central downtown area is Xiangzhou district, measuring 252 km², and includes the towns of Shishan, Meihua, Cuixiang, Jida, Qianshan, Gongbei, Xiangwan, Wanzai subdistrict, Tangjiawan and Nanping. The above ten towns are known as town administrative units. The government of Zhuhai is located in the Shishan subdistrict, and the administrative center of Xiangzhou district is in the Meihua subdistrict. The central downtown area of Zhuhai is also its economic, cultural and political center. The climate type is subtropical maritime, means that it is humid most of time. Evergreen monsoon forest and monsoonal evergreen broad-leaf forest are the dominant flora types. The elevation changes from the northwest to the southeast. The predominant land use types are low mountainous regions and hills. The general mountain range lies in the south of the downtown area. Phoenix Hills, South Hills and Wugong Hills are located on the north of the downtown area. The eastern and southern parts of Zhuhai border the South China Sea, where the climate is warm and moist with abundant precipitation and thermal energy.

2.2. Data
The data used for this study was drawn from Quick Bird high resolution remote sensing images in February 2010. To acquire adequate imagery for the interpretation of training area information, we
carried out a field study with GPS between March and April 2011. We used Erdas8.6 to preprocess the images (radiometric correction, geometric rectification, clipping and resampling) by adding elements that could reflect the process of urbanization and by reducing data redundancy and detail interferences resulting from meticulous division. Based on the similarity of the natural character and the convergence of human use patterns, we identified 8 first-level landscapes and 14 second-level types as the following Fig.1(a): urbanized land (including urban land, rural settlements and industrial land), forest, shrubs, grasslands, street trees(arbor and shrub), bare land, water (including lakes, ponds and rivers), farmland and roads. The classification result of the image has been checked for accuracy.

2.3. Division of rural-urban ecotone

"Entropy" was originally a concept of thermodynamic, it was used to represent the degree of molecular irregular movement in statistical physic, but it was defined as a random variable in information theory\(^{[13-14]}\). The concept of information entropy is used to carry out the quantitative analysis of the complex urban geography system structure, in this study, it was used to describe the diversity of urban land use types. Assuming the total area of a city’s construction land is S, the land use type of the city can be divided into m according to its function, the S means area of each kind of land use type according to its function, it is given by:

\[
S = \sum_{i=1}^{m} S_i (i=1,2,3,\ldots,m)
\]

The proportion of land areas of occupied by various types of land functions is:

\[
P_i = \frac{S_i}{S} (\sum_i P_i = 1)
\]

According to the principle of information theory, and refer to Shannon-Weaner index, the information entropy of land use structure is defined as:

\[
H = -\sum_{i=1}^{m} P_i \cdot \log P_i
\]

Where H is the information entropy and it can be seen that H\(\geq 0\), The level of information entropy can reflect the equilibrium degree of urban land use. The higher the entropy, the more the function of land use, the smaller the difference in the area of each function.

**Figure 2.** The entropy change curve from City Hall in North direction

According to Fig. 2 and the continuity and integrality of the area, we created the range of the rural-urban ecotone in downtown of Zhuhai. In the entropy figure, City Hall was set as the starting point.
We set entropy cross section line along the north, and then obtained the entropy change curve in this direction. From City Hall to the peripheral area, the first break of entropy from low to high is approximately 0.51, which reflected the land use type changed from complete urban construction to mixed urban and rural ecotone. Thus, we used 0.51 as the inner boundary break entropy value. The second break value is approximately 0.46, which reflected a change of land use types from the mixed rural-urban ecotone to completely rural areas. We used 0.46 as the outer boundary break entropy value.

3. Results and analysis

3.1. Rural-urban ecotone

According to the boundary standard, we created the rural-urban ecotone as shown in Fig. 3 (a). In Fig. 3(a), some regions were supposed to be classified as urban area instead of classified as being within the ecotone. This mainly occurred in downtown natural landscapes, including mountain land, forest, and reservoir. These regions are not seriously disturbed by human activity because of protection policies, while the areas around these regions are highly urbanized centers of Zhuhai. There are both natural landscapes and urban landscapes in this connected area, so it was also classified as being part of the ecotone. Based on the actual situation, we corrected the figure by removing the intersected area from the ecotone, and obtained the rural-urban ecotone as shown in Fig. 3 (b).

3.2. Analysis of the information entropy

The entropy of each unit in the map distinctly varies from one unit to another with the smallest at 0 to the largest at 1.0435 (Fig. 1(b)). This shows how the various regions were located in different levels of urbanization. Zero, the value of highly urbanized areas, stands for a uniform and stable urban landscape. A distribution of 0.95 or greater in the rural-urban ecotone reflected a rivalry between the rural and urban landscape, with the latter gradually replacing the former. At the microcosmic level, some of the different entropy units are crossed, namely low within high and high within low.

It indicates that the development of city does not completely follow the trend from the center to the periphery and that the process was influenced by a series of policies, such as the formation of a high-tech development district, forest reserves and other regions supported by special policies. In such cases, a pattern contrary to the development trend had formed.
4. Conclusion and discussion
Based on information entropy theory and the extraction of land use information from remote sensing classification and combined with RS and GIS, we had roughly identified the range of the urban-rural ecotone from a quantitative perspective, which allowed us to adequately classify the position of the ecotone based on spatial analysis and the break entropy value. In this case, with the topography of the study area in mind, we refined the ecotone by tailoring a high entropy area that resulted from natural factors in the center of the city. Moreover, the ecotone is a transitional area between urban and rural areas so that no definite geological line exists. In conclusion, the classification of the urban-rural ecotone presented in this study needs further refinement.

Acknowledgments
The work presented in this paper was supported by the National Natural Science Foundation of China (31370480) and the key research project of Chinese Ministry of science (2017YFC0505601)

References
[1] Li JX, Wang YJ, Shen XH, et al.(2004)Landscape pattern analysis along an urban-rural gradient in the Shanghai metropolitan region. Acta Ecologica Sinica, 24(9):1973-1980.
[2] Zeng H,TangJ,Guo QH(1998)Landscape changing research of small town in eastern part of Zhujiang delta area——A case study of Changping Town, Dongguan City.Journal of Basic Scienceand Engineering, 6(2):125-133.
[3] Sun J, XiaHP, Lan CY, et al.(2006)A gradient analysis on the buffer zones of urban pattern of the constructed area in Guiuguang City, Guangxi, China. Acta Ecologica Sinica,26(3): 655-662.
[4] Guo L, Du SH, Sun HM, Ding C(2013)Study on gradient variation of landscape spatial pattern in the urban area of Zhuhai City, Journal of Geo-information Science,159(2):307-313.
[5] Witoñ, A., & Krzysztof Wach, ,. H. (2013). Economic effects of the urbanization process in china. Entrepreneurial Business & Economics Review, 1(3), 57-69.
[6] Dong, C., Man-Chun, L. I., Chen, Z. J., Wei, W., & Wei, H. U. (2010). A method of division of urban fringe based on message entropy——a case study in nanjing city. Science of Surveying & Mapping, 35(3), 106-109.
[7] Shi, H. P., Yu, K. Q., & Feng, Y. J. (2013). [ecological risk assessment of rural-urban ecotone based on landscape pattern: a case study in daiyue district of tai' an city, shandong province of east china]. Ying yong Sheng tai Xue bao, 24(3), 705.
[8] Ma T,YangFH,Li B, et al.(2004)City-country interlocking belt——Special ecology zone. Urban Environment & Urban Ecology,17(1): 37-39.
[9] Zhang WB,Fang XQ (1999) Method to identify the urban-rural fringe by TM images. Journal of Remote Sensing,3(3):199-202.
[10] Cai D,LiMC,Chen ZJ, et al. (2010)A method of division of urban fringe based on message entropy—A case study in Nanjing City. Science of Surveying and Mapping,35(3):106-108.
[11] Le Drew, Holden E F, H, Wulder, M, et al. (2004)A spatial statistical operator applied to multi-date satellite imagery for identification of coral reef stress. Remote Sensing of Environment, (91):271-279.
[12] Wu JG(2002) Landscape ecology——pattern, process, scale andhierarchy. Beijing: Higher Education Press, 2-6.
[13] Yan, C., & Ji, L. (2001). An index of equilibrium of urban land-use structure and information dimension of urban form. Geographical Research, 20(2), 146-152.
[14] White, R., & Engelen, G. (2008). Cellular automata and fractal urban form: a cellular modelling approach to the evolution of urban land-use patterns. Environment & Planning A, 25(8), 1175-1199.