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Applying WUDAPT Product into the Spatial-Temporal Analysis of Land Use Change in the Pearl River Delta Region from 1988 to 2009

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Abstract: The Pearl River Delta (PRD) region has experienced significant land use change since the putting forward of reform and opening policy in 1978. This paper analyses the spatial-temporal pattern of land use change in the PRD region with the help of a remote sensing based land use classification method—the World Urban Database and Access Portal Tool (WUDAPT), in the selected year 1988, 1999 and 2009. Land use transformation matrix was used to specify the quantity and transferring direction of each land use type in the PRD region. Moran' I was used to detect the spatial correlation of different land use types in this region. The results show that the area of urban built-up types is continuously increasing and natural land cover types (such as mixed forest, wetland/ fish pond and water bodies) is decreasing from 1988 to 2009. Moreover, cropland/ grassland, mixed forest and water bodies are the dominate land use types which were converted into urban built-up types in this period. Last but not least, the spatial distribution pattern of land use types has a decreasing gathering trend from 1988 to 2009. This paper also examines that WUDAPT is efficient and effective for analysing land use changing issue.

Keywords: Land Use Change, World Urban Database and Access Portal Tool (WUDAPT), Land Use Transformation Matrix, Spatial Autocorrelation Analysis

Introduction

Researches on Land Use and Land Cover (LULC) change have become an important scope of studying global climate change in recent decades, since the issue of LULC change not only affects the local urban environment and life quality of local residents, but also inevitably influences environmental problems of the rest of the world (López et al., 2001, Aguilar et al., 2003). The Pearl River Delta (PRD) region in China has been experiencing fast urbanization and land use changing since the early 1980's. Looking into the spatial-temporal changing pattern of land use in the PRD region will help local urban planners and government officials obtain in-depth understanding of land use changing issue and make scientific planning decisions in this region for future development.

However, land use data, especially the historical one are not easily accessible in China and usually with rough categories as well as unsatisfied resolution. The World Urban Database and Access Portal Tool (WUDAPT) is a global initiative to generate urban morphology data and land use data for various applications (Bechtel et al., 2015). It is based on the Local Climate Zone (LCZ) classification system, which aims to connect urban climatology and urban morphology together (Stewart and Oke, 2012). It provides a standardized and quantitative way to describe different land use types and reveals their corresponding thermal properties (Stewart and Oke, 2012). Taking advantages of free satellite images and standardized classification procedure, WUDAPT can provide land use data to look into urban development.

Study area

Geographically, the Pearl River Delta (PRD) located within Guangdong province, which is at the southeast of China, close to the South China Sea (Fig. 1). The PRD region was put forward as economic and industrial zone which had attracted a large population of new immigrants to move in during the twentieth century. This region includes Guangzhou, Shenzhen, Zhuhai, Dongguan, Zhongshan, Jiangmen, Foshan, Huizhou and Zhaoqing (Fig. 1). The total areas are about 55,000 km^2, covering one third of the whole Guangdong province (Liang and Chen, 2012). At the end of 2008, permanent residents of the PRD are a half of that of the whole Guangdong province (Statistics Bureau of Guangdong Government, 2009). Economically, the PRD region has become one of the most prosperous economic zones in China after the putting forward of reform and opening policy in 1978. With economic development, urban expansion was an on-going phenomenon. In 2008, the urbanization rate of the PRD region was up to 80.5%, the average population density was 863 people/km^2; the coverage of built-up types reached 8790 km^2, taking up 16% of the entire area of the PRD region (Government of Guangdong Province, 2010). From 2000 to 2010, the urban expansion area increased by 2615 km^2 (Statistics Bureau of Guangdong Government, 2001; Statistics Bureau of Guangdong Government, 2011).

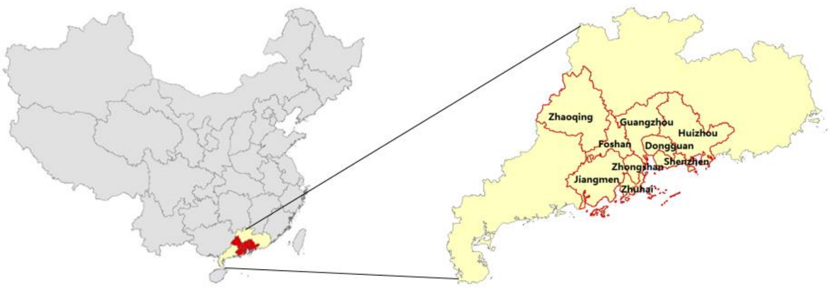

Fig. 1 Location and Main Cities Included in Pearl River Delta (PRD) Region

Method

Land use classification

Data

Landsat satellite images were used as input data to produce land use classification data by using WUDAPT (Mills et al., 2015), because of its free accessibility and satisfied resolution (30m). To check the urbanization procedure in the PRD region, selected Landsat-5 images in different times (1988, 1999 and 2009) were collected as origin input to develop and mapping out LCZs. The reasons why chose these three years were because that, on one hand, data availability of Landsat images limits the earliest year, since the first Landsat satellite was launched in 1972 (Belward et al., 2008); on the other hand, the reform and opening policy took effect from the year 1978 and the fast urbanization also started around the same year. Therefore, images of every ten-year beginning from 1988 were chosen to analyse land use changing pattern of the PRD.

Research steps

WUDAPT follows a standardized workflow to generate LCZ classes to represent different land use and land cover types (Bechtel et al., 2015). The whole classification algorithm is developed as a tool in an open-source GIS software, called SAGA GIS. It contains three major steps:

Firstly, pre-processing of Landsat images: Landsat images were mosaicked into one image to cover the study area. Next, this image was resampled from 30m to 100m resolution and clipped to fit the range of the PRD region.

Secondly, selection of training samples: training samples acted as learning samples for random forest classifier to classify LCZs. They were polygons digitized from Google Earth based on local expertise. In this paper, each type of LCZ contains around 100 training samples, selected from Guangzhou, Shenzhen, Zhaoqing, Jiangmen, Zhongshan, Foshan, Dongguan, Zhuhai, Huizhou, Hong Kong and Macau.

Thirdly, classification by LCZ Classification tool in SAGA GIS: the pre-processed Landsat image and selected training samples were input LCZ classification tool in SAGA GIS. The core of LCZ classification is the random forest algorithm, a kind of machine learning algorithm. Taking advantages of spectral features contained in each training sample, the random forest classifier generated the classification rule and applied it to identify each LCZ type.

Land use transformation matrix

In this study, land use transformation matrix was selected to analyse land use and land cover changes in the PRD region in selected year 1988, 1999 and 2009. Land use transformation matrix was developed from system analysis (Xu and Zhao, 1993). It reveals the mutual conversion area of different land use types during a certain period. Land use transformation matrix can analyse the quantity and direction of regional land use changing systematically and comprehensively (Deng et al., 2009). Thus, such kind of matrix has been used commonly in the field of land use changing analysis (Liu et al., 2003, Li and Yeh, 2004, Li and Yeh, 2002, Verburg and Overmars, 2009). The form of land use transformation matrix is shown as below (Deng et al., 2009).

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \dots & \dots & \dots & \dots \\ S_{n1} & S_{n2} & \dots & S_{nn} \end{bmatrix}$$

S represents the area of certain land use type, n represents total number of land use types, i is the land use type at the beginning and j represents the land use type at the end of transformation; S_{ij} shows the change area from land use type 'i' to land use type 'j'. Apart from the changing quantity between different land use types, this matrix also illustrates the changing directions. Values in every row show the transferring information of land use type 'i' to different land use types during the land use changing period, on the other hand, values in every column show, at the end of the study period, the transferring direction of different land use types to land use type 'j'.

Moran's I index

Moran’s I index was also employed to examine the spatial autocorrelation of land use types in the PRD region. According to the first law of geography put forward by Tobler, it is noted that everything is related to each other, but much more related to things nearby than things in distant locations (Tobler, 1970). Spatial autocorrelation usually examines the correlation of spatial variables in different geographical locations (Overmars et al., 2003, Seto and Kaufmann, 2003). Moran’ I is the mostly common index to describe spatial autocorrelation. Its expression is as follows (Cliff and Ord, 1981):

$$I=\frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}(X_i-\overline{X})(X_j-\overline{X})}{(\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij})\sum_{i=1}^{n}(X_i-\overline{X})^2}$$

X_i and X_j refers to the attribute value of spatial variable X at location i and j, $\overline{X}$ represents the average value of X, W_{ij} is the spatial weight function, n is the total number of geographical locations.

The range of Moran’s I is between -1 and 1. When Moran’s I is smaller than 0, it indicates that the spatial variable has a negative spatial correlation, showing a dispersed pattern; when Moran’s I equals to 0, it indicates that there is no spatial correlation among the spatial variables, the variables are distributed randomly; when Moran’ I is between 0 and 1, it illustrates that the spatial variable has a positive spatial correlation, showing a cluster pattern.

This paper chose Moran’s I to analyse the spatial autocorrelation among different land use types in the PRD region in selected year 1988, 1999 and 2009.

Result and Discussion

Overall analysis of Land use change

After obtaining the LCZ classes of the PRD region (Fig. 2) generated by using WUDAPT method, the original seventeen LCZ classes with the added subclass ‘Wetland/ Fish Pond’ were converted into land use types defined by U. S. Geological Survey (USGS) with 1 km resolution (Table 1). Table 2 shows the overall changing trend of each land use type in the PRD region from 1988 to 2009. It is found that the area of urban built-up types in 2009 is 3.4 times than that of 1988. During this period, all three types of urban built-up types have an increasing trend. While, the areas of cropland/ grassland, mixed forest, wetland/ fish pond and water bodies shrink.

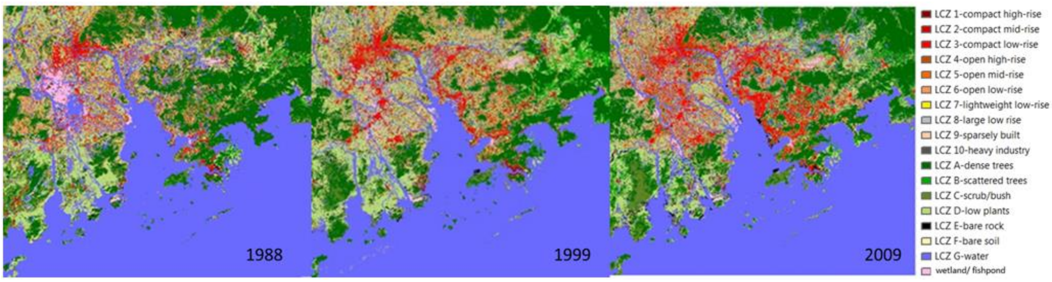

Fig. 2 LCZ Maps of the PRD Region in the Year of 1988, 1999 and 2009

Table 1. Conversion between Local Climate Zone Classes and USGS Land Use Categories

	Local Climate Zone Categories		USGS Land Use Categories
Urban Types	LCZ Category	Land Use Description	Land Use Description
	LCZ 1	Compact High-rise	Urban (High-rise)
	LCZ 4	Open High-rise	
	LCZ 2	Compact Mid-rise	Urban (Mid-rise)
	LCZ 5	Open Mid-rise	

	LCZ 3	Compact Low-rise	Urban (Low-rise)
	LCZ 6	Open Low-rise	
	LCZ 7	Lightweight Low-rise	
	LCZ 8	Large Low-rise	
	LCZ 9	Sparsely Built	
	LCZ 10	Heavy Industry	
Land Covers	LCZ A	Dense Trees	Mixed Forest
	LCZ B	Scattered Trees	
	LCZ C	Bush, Scrub	Shrub land
	LCZ D	Low Plant	Cropland/Grassland Mosaic
	LCZ E	Bare Rock or Paved	Barren or Sparsely Vegetated
	LCZ F	Bare Soil or Sand	
	LCZ G	Water	Water Bodies
	Wetland/ Fish Pond		Wetland/ Fish Pond

Table 2. Change of Different Land Use Types in PRD Region from 1988 to 2009

	Urban (Low-rise)	Urban (Mid-rise)	Urban (High-rise)	Cropland /Grassland	Shrub land	Mixed Forest	Barren/ Sparsely Vegetated	Wetland/ Fish Pond	Water Bodies
1988	3.45%	0.31%	0.30%	19.72%	2.96%	21.25%	0.42%	1.79%	49.81 %
1999	7.05%	0.49%	0.65%	23.46%	1.94%	18.80%	0.33%	0.88%	46.38 %
2009	13.46%	0.74%	3.61%	18.50%	3.28%	17.28%	0.56%	0.77%	41.80 %

Land use transferring analysis

Table 3. Land Use Transformation Matrix of PRD Region during 1998 to 1999 (km^2)

Land Use Type		1999									
		Urban (Low-rise)	Urban (Mid-rise)	Urban (High-rise)	Cropland/ Grassland	Shrub land	Mixed Forest	Barren or Sparsely Vegetated	Wetland/ Fish Pond	Water Bodies	Total Area (1998)
1988	Urban (Low-rise)	1142	35	12							1189
	Urban (Mid-rise)		95	13							108
	Urban (High-rise)			103							103
	Cropland/ Grassland	494	7	23	4939	78	530	43	55	636	6805
	Shrub land	23	2	5	363	178	394	13	2	40	1020
	Mixed Forest	342	8	19	1209	331	5141	19	8	257	7334
	Barren or Sparsely Vegetated	6			59	14	31	15	2	18	145
	Wetland/ Fish Pond	71	1	3	316		12		141	72	616
	Water Bodies	356	22	46	1210	70	380	24	96	14982	17186
	Total Area (1999)	2434	170	224	8096	671	6488	114	304	16005	34506

From Table 3, it is noted that the added areas of urban low-rise types were mainly converted from cropland/ grassland, mixed forest and water bodies. For urban mid-rise types, its area increased mostly due to the transformation from urban low-rise type. For urban high-rise type, its total area increased by 117% from 1988 to 1999. Transformation of cropland/ grassland, mixed forest and water bodies contributed to 40% of the urban high-rise area in 1999. The area of cropland/ grassland increased by 19% in the PRD region from 1988 to 1999. The reason behind it was that mixed forest and water bodies of 1988 transferred into cropland/ grassland in 1999. For mixed forest, its area decreased by 12% during 1988 to 1999. The decreased area is mainly converted into the area of urban low-rise type and cropland/ grassland. For wetland/ fish pond, during 1988 to 1999, its area decreased by a half. Its decreased area is mainly converted into the area of urban low-rise and cropland/ grassland. The area of water bodies also went down from 1988 to 1999 because of the increasing construction area and enlargement of cropland/ grassland.

Table 4. Land Use Transformation Matrix of PRD Region during 1999 to 2009 (km^2)

Land Use Type		2009									
		Urban (Low-rise)	Urban (Mid-rise)	Urban (High-rise)	Cropland/ Grassland	Shrub land	Mixed Forest	Barren or Sparsely Vegetated	Wetland/ Fish Pond	Water Bodies	Total Area (1999)
1999	Urban (Low-rise)	2188	60	186							2434
	Urban (Mid-rise)		151	19							170
	Urban (High-rise)			224							224
	Cropland/ Grassland	1610	17	561	4845	221	704	65	73		8096
	Shrub land	14	5	5	68	361	216	2			671
	Mixed Forest	302	5	76	785	464	4839	13	4		6488
	Barren or Sparsely Vegetated	9	4	1	28	7	34	30	1		114
	Wetland/ Fish Pond	58		46	58	1			141		304
	Water Bodies	463	12	128	599	78	171	84	47	14423	16005
	Total Area (2009)	4644	254	1246	6383	1132	5964	194	266	14423	34506

From Table 4, in 2009, the areas of urban low-rise types were mainly converted from cropland/ grassland, mixed forest and water bodies. For urban mid-rise type, its area was mainly converted from low-rise types. For urban high-rise, the sprawling was converted from cropland/ grassland, mixed forest and water bodies. During this period, the area of cropland/ grassland had decreased by 21%. Around 27% of cropland/ grassland in 1999 had been converted into urban types. Total area of mixed forest in the PRD region had also decreased. The transferring directions of mixed forest consisted of three ways. One was transferring from mixed forest to urban low-rise type, covering approximately 5% of the total area of mixed forest in 1999; the second was around 12% of mixed forest in 1999 transferred into cropland/ grassland; the third one was converting into shrub land with a coverage of 7% of the total area for the original mixed forest. During 1999 to 2009, areas of wetland/ fish pond and water bodies decreased mainly due to the construction of urban built-up types.

To conclude, from Table 3 and Table 4, the main reason of continuously increasing areas for urban built-up types is the construction projects on the previous cropland/ grassland, mixed forest and water bodies from 1988 to 2009. After the putting forward of reform and opening policy, the PRD region has a tremendous economic growth, therefore the demand for building construction keeps increasing. Correspondingly, a large number of natural land covers are occupied for construction projects during 1988 to 2009. The increasing rate of urban types during 1999 to 2009 is much higher than that from 1988 to 1999, especially for urban high-rise type. This is because, with much rapid economic development and urbanization rate from 1999 to 2009, the demand for transportation facilities and residential buildings increases a lot. At the same time, soaring population into the PRD region intensifies the development of real estates, contributing to enlargement of urban built-up types' area. This indicates that the demand for urban built-up types enlarges with the rapid economic development and urbanization.

For mixed forest, its area keeps decreasing during 1988 to 1999. The reduced area is mainly converted into urban low-rise type and cropland/ grassland. For wetland/ fish pond and water bodies, they mainly transfer into urban built-up types. The reason behind the decreasing area of mixed forest, wetland/ fish pond and water bodies is the rapid urban construction.

Spatial autocorrelation analysis of land use change

The value of Moran's I indicates the spatial convergence of different land use types. After calculation, the value of Moran' I of 1988, 1999, 2009 is 0.477, 0.482 and 0.452 respectively. It is noted that Moran's I of each year is a positive value, revealing that the land use distribution pattern of the PRD region has a significantly positive spatial autocorrelation. Different land use types are not distributed randomly in the PRD region, instead, they have an apparent spatial cluster. More specifically, each land use type tends to gather around the same type—urban types are clustered in their own group and non-urban types tend to form different clusters. However, looking into the value of Moran' I for each selected year, the spatial clustering pattern of different land use types is not a continuous trend. From the year 1988 to 1999, the value of Moran' I increased, indicating that the spatial convergence of land use types was strengthened. While, the value decreased from 2009. Spatial convergence of land use types in the PRD region become weaker compared to 1988 and 1999. The reason behind it might be urban sprawl in this region. The sprawling development mode in the PRD region contributes to increasing area of mixed urban built-up types and rural types, which weakens the clustering of the same land use type.

Conclusion

This paper analyses the spatial-temporal land use changing pattern of the PRD region from 1988 to 2009 with the help of the popular land use classification method WUDAPT. WUDAPT has the advantages of free data source, standardized procedure and easy comparison among different cities. It accuracy was proved to achieve around 80% in some Chinese cities (Cai et al., 2016). Results of this study reveal that, during 1988 to 2009, the area of urban built-up types increased significantly, while the area of cropland/ grassland, mixed forest, wetland/ fishpond and water bodies decreased a lot. Urban expansion of the PRD region mainly relies on occupying rural areas to construct residential buildings, offices, factories and public facilities. At the same time, although there are significant clusters of different land use types, the clustering trend has been weakened due to the extensive urban sprawl mode. This paper examines the application of WUDAPT product in land use changing analysis, illustrating the potentials of WUDAPT product for different applications, apart from urban heat island studies. In next study step, based on the developed land use and land cover data in this study, future land use change detection will be conducted.

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