Dynamic Pattern of Agricultural Landscapes in Response to Urbanization across Hangzhou Metropolitan Region: A Remote Sensing Approach

Zou Dongdong[1], Jiang Zhi[2], Zhang Qi[3], and Zhang Yuan[4]

[1] Oujiang College Wenzhou University Wenzhou, China
[2] Physics & Electronic Information Engineering College Wenzhou University Wenzhou, China
[3] College of Environmental & Resources Sciences Zhejiang University Hangzhou, China
[4] Research Center of Remote Sensing & Geoscience
Northeast Institute of Geography & Agroecology of CAS Changchun, China
jsj_zdd@163.com, jsj_jz@wzu.edu.cn,
zhangqi.j@hotmail.com, yuan.zhang75@gmail.com

Abstract. This paper applied multiple endmember spectral mixture analysis (MESMA) to interpret Landsat satellite imageries and then analyzed the spatiotemporal dynamics of agricultural landscapes within Hangzhou metropolitan region. Between 1994 and 2003, this region has witnessed accelerated urbanization based on four indicators: total population, percentage of non-agriculture population, GDP per capita, and area of impervious surface. Meanwhile, conversion, fragmentation, irregularity and isolation of agricultural landscapes were also captured according to four class-level metrics: total area, patch density, area-weighted mean shape index, and Euclidean nearest neighbor distance. Statistics showed that increased impervious area was significantly correlated with declined area and configuration of agricultural landscapes. Growth in GDP per capita was also correlated with increased irregularity of agricultural landscapes. Changes of total population and percentage of non-agriculture population were weakly associated with all the agricultural landscape metrics, denoting that the two indicators did not have direct influences on agricultural landscape patterns. Further, distance to the nearest road was also a good indicator of how the cultivated land was lost and transformed. Our results demonstrated complexities of relationships between urbanization and agricultural landscapes, and highlighted the importance of selected variables, spatiotemporal scales and land-use classification when quantifying these relationships.

Keywords: urbanization, agriculture, indicator, landscape pattern change, remote sensing.

1 Introduction

The global accelerating urbanization has significantly altered ecological environment [1]. In the context of urban regions, changes in landscape patterns are believed to significantly influence the maintenance of ecological integrity [2], and the processes

L. Jiang (Ed.): International Conference on ICCE2011, AISC 111, pp. 467–474.
springerlink.com

and functions are tightly interrelated with the mosaic of landscape elements resulting from urbanization [3]. Consequently, one systematically effective approach to analyze the ecological effects of urbanization is to study landscape pattern changes and assessment of space suitability for chosen species on the basis of habitat distribution and landscape connectivity [4].

Agricultural landscapes play a driving role in social advancement and economic progress at regional, national and even international scale. Meanwhile, the rapid urbanization has transformed traditional agricultural landscape patterns and resulted in degradation of agricultural landscapes, which may influence a variety of ecological processes and finally pose treat to regional sustainability [5]. Great efforts have been devoted to characterize the dynamic pattern of agricultural landscapes under rapid urbanization. However, most related studies were carried out in developed countries. We are unaware of landscape-level studies regarding the problems of China, since related studies merely focus on the quantitative changes of agricultural land in China.

Remote sensing (RS) and geographic information systems (GIS) have been recognized as powerful and effective tools for detecting landscape changes. Spatial metrics are critical in the description, analysis, and modeling of land cover and its changes [6]. To investigate the dynamics of agricultural landscapes associated with the rapid urbanization in China, for this study, we selected the Hangzhou metropolitan region as the study area, one of the most populated and fastest growing parts of Yangtze Delta, eastern coastal China (Fig.1). This region has witnessed extensive urbanization and experienced significant social-economic changes in the last decades. However, the rapid urbanization also exerted negative impacts on agricultural landscapes across this region. If this condition continues to worsen, it will become a major impediment to regional sustainable development. This paper addresses this concern and our objectives are to: (1) characterize the patterns of agricultural landscapes across Hangzhou metropolitan region using a set of landscape metrics between 1994 and 2003; (2) quantitatively quantify relationships between changes urbanization and agricultural landscapes; and (3) provide some references for developing sustainable development strategies in this region.

Fig. 1. Location and administrative division of Hangzhou metropolitan region as well as spatial distributions of roads

2 Materials and Methods

2.1 Agricultural Land Mapping

Landsat satellite imageries (TM) were used to assess agricultural landscape change between 1994 and 2003 in Hangzhou metropolitan region. The geometric registration was done using the quadratic method. The specification for image to image registration was 0.5 pixel in both directions and this precision requirement was met for both two years. Multiple endmember spectral mixture analysis (MESMA), which allows the number and type of endmembers to vary on a per pixel basis, given the high degrees of spectral heterogeneity exhibited by the complex land cover patterns in the study area, was applied to interpret images [7]. An accuracy assessment was performed following 3×3 majority filtering. The average classification accuracy was 87.4%.

2.2 Urbanization Indicators

Indicators used in our study to quantify change in urbanization over time were: area of impervious surface (AIS), GDP per capita (GDP_{per}), total population (POP), urbanization rate or percentage of non-agriculture population (UR) and proximity to the nearest road (DIS). MESMA was applied to estimate impervious surface distribution in our study [8]. The average classification accuracy was 92.8%. GDP and population data were obtained from Zhejiang Statistics Bureau. Buffer analysis was used to characterize the association between proximity of roads and changes in agricultural landscape patterns. Distance of 1000m was divided into ten equal intervals for buffer analysis.

2.3 Landscape Metrics Selection

A set of landscape metrics was selected for this study, based on the research question and comparability with previous studies. The finally selected landscape metrics were: total area (TA), patch density (PD), Area-weighted mean shape index (AWMSI), and Euclidean nearest neighbor distance (ENND).

2.4 Statistical Analyses

Associations between agricultural landscape metrics and urbanization indicators were determined by Pearson's correlation analysis. Where appropriate, regression was applied to further analyze the relationships. All statistics were calculated using SPSS 16.0. All regression models were performed using one landscape metric as dependent variable and one urbanization indicator as independent variable in order to avoid the potential multicollinearity.

3 Results

3.1 Urbanization Process

During the period between 1994 and 2003, Hangzhou metropolitan region had witnessed extensive urbanization and social-economic change. As shown in Table 1, total population for the whole region increased by 6.34%. Compared to population growth, economic development was more significant, given the more than doubled increase in GDP per capita. Area of impervious surfaces doubled during the ten years, signifying the intensive urban sprawl in this region.

At the administrative level, the fastest growth in total population was particularly observed in Hangzhou city. Rate of population growth of Hangzhou city reached 12.6%, while that of the other city/county was less than 3.4%. All these figures reflected that regional population were prone to concentrated in the central city of metropolitan region. The highest increases in urbanization rate were identified in Lin'an (67.4%) and Anji (61.7%), denoting the significant changes of population structure. Economic development rates, in terms of GDP per capita, were high for all the cities/counties. Hangzhou, Chun'an, Tonglu, Fuyang and Jiande all doubled their GDP per capita. Regarding urban growth, Huzhou experienced the highest growth of impervious surfaces (508.9%), followed by Tongxiang (472.2%), Deqing (372.5%), Hangzhou (314.8%) and Anji (224.0%).

Table 1. Changes of urbanization indicators and agricultural landscape metrics between 1994 and 2008

	AIS	GDP	POP	UR	TA	PD	AWMSI	ENND
Hangzhou	314.8	226.3	12.6	24.2	-37.7	144.0	13.1	5.0
Fuyang	108.3	248.3	3.4	37.8	-44.0	21.6	-51.7	2.7
Lin'an	21.0	175.3	2.1	67.4	-51.4	76.2	-73.4	9.4
Jiande	115.1	212.4	3.1	32.3	-43.2	13.7	-53.0	4.4
Tonglu	91.6	252.9	1.6	47.7	-40.3	80.2	-49.8	-3.3
Chun'an	-20.1	268.7	1.3	50.5	-72.0	111.0	-46.1	14.7
Anji	224.0	186.1	0.7	61.7	-33.8	15.2	-8.3	2.5
Deqing	372.5	159.3	3.3	38.0	-31.9	57.9	97.2	6.0
Huzhou	508.9	167.3	3.0	202.6	-26.5	70.2	85.5	5.4
Changxin	152.3	134.9	1.6	44.5	-19.0	-36.5	85.7	2.9
Tongxiang	472.2	179.2	2.9	29.9	-12.7	681.2	244.8	12.5

3.2 Agricultural Landscape Patterns

The agricultural land cover maps for 1994 and 2003 were presented in Fig. 2. As evident from the results obtained, the total area of agricultural landscapes in Hangzhou metropolitan region has drastically decreased. Fragmentation is also obvious characteristics of agricultural landscape changes with the patch density increased by 26.6% (Table Ⅰ). The increasing AWMSI value for the entire region indicated more complex shape of agricultural landscape. Such shapes are considered as very unstable and prone for further fragmentation. Additionally, the slight rise in ENND value, whose net change was 4.6%, suggested that the randomness and isolation of agricultural patches were intensified.

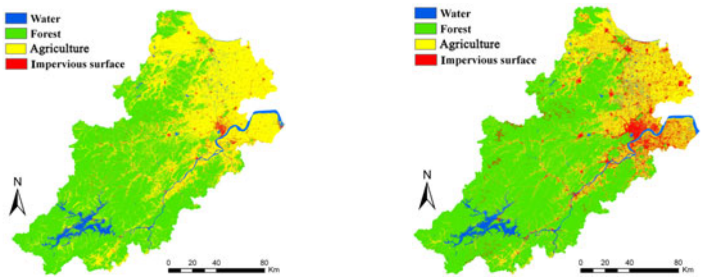

Fig. 2. Land use/cover patterns of Hangzhou metropolitan region in 1994 (left) and 2003 (right)

Obvious spatial variations in agricultural landscape pattern changes were also detected. Hangzhou and Chun'an are hotspots for agricultural landscape conversion and fragmentation. In contrast to the other cities/counties, PD value for Changxing presented a declining trend. As the typical intensive agricultural base, land consolidation was frequently carried out in Changxing and many scattered agricultural areas were merged into large patches. During the ten years, developed cities/counties, such as Hangzhou, Huzhou, Deqing, Changxing and Tongxiang, witnessed increases in AWMSI. Conversely, relatively less developed areas experienced declines in AWMSI. All the results implied the negative impact of economic development on agricultural landscapes. In addition, the problem of isolation in agricultural patches was serious for Chun'an, Tongxiang and Lin'an (Table 1).

3.3 Relationships between Urbanization and Agricultural Landscapes

When change was expressed as percentage, loss of agricultural landscapes was significantly associated with increases in impervious surface and GDP per capita (Table 2). In addition, impervious surface was also significant correlated with AWMSI. No statistically significant correlations were identified between urbanization indicators and PD/ENND. Specifically, total population and urbanization rate did not have significant correlation with any agricultural landscape parameters. This may be due to it that population factors exerted indirect impact on agricultural landscape patterns. Regressions were further applied to reveal the relationships between urbanization and agricultural landscapes. As shown in Table 3, AIS presented an inverse U-shape relationship with TA, and linear association with AWMSI. A linear correlation was also identified between TA and GDP per capita.

Table 2. Pearson correlation analysis between urbanization indicators and agricultural landscape metrics

	AIS	GDP_{per}	POP	UR
TA	.756**	-.706*	.070	.124
PD	.480	-.025	.113	-.165
AWMSI	.813**	-.527	.055	.094
ENND	.055	.013	-.019	-.016

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 3. Relationships between urbanization and agricultural landscapes explored by binary regression

Y	X	Equation	R^2	Sig.
TA	AIS	$Y=0.336X -0.001X^2-62.209$	.784	.010
TA	GDP_{per}	$Y=14.973-0.261X$	.498	.015
AWMSI	AIS	$Y=0.44X-72.282$	.660	.002
TA	DIS	$Y=0.573+58.775/X$	.986	.000
PD	DIS	$Y=0.176+404.825/X$	.940	.000
AWMSI	DIS	$Y=-0.36-15.738/X$	.902	.000

Changes of TA and PD exhibited regular patterns along the distance to the nearest road (Fig.3). Differently, ENND displayed an oscillatory behavior. Changes of AWMSI values increased with the growing distance from road and dropped suddenly at the 800 m distance. Statistically significant relationships between agricultural landscapes and distance to road were explored by binary regression (Table 3). Results denoted that relationships between TA/PD/AWMSI and distance to the nearest road could be described using a distance decay function.

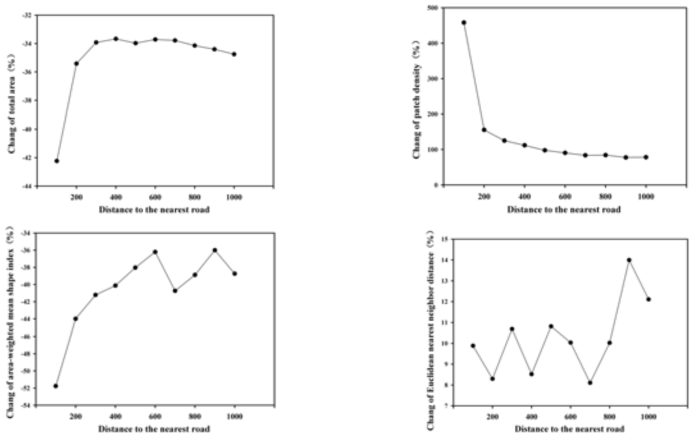

Fig. 3. Changes of agricultural landscape metrics with growing distance to the nearest road.

4 Discussion and Conclusions

Our results indicated that urban sprawl, in terms of imperative surfaces increase, contributed to agricultural landscape conversion and configuration. Because lands most suitable for growing crops also tend to be most suitable for "growing houses" (being flat and historically near human settlements), a disproportionate amount of agricultural landscapes were converted to impervious surfaces. While direct loss of agricultural landscapes is a primary concern, configuration issues also assume a vital significance in the context of maintaining the 'natural' variability in the size, shape and distribution of agricultural patches. In China, the attempts are been made to maintain the total amount of agricultural landscapes. But based on our results, we argue that there is an urgent need to check the increasing configuration problem associated with urban sprawl, since the irregularity in shape could also increase the potential to further agricultural landscape loss.

Significant correlation was identified between GDP_{per} and TA. In China, compared to food crops, production efficiency of economic crops is much higher. In seek of high GDP growth rate and good political performance, governments encouraged farmers to adjust their agricultural structure. Besides, living standards of residents rose and the demand for fruits, fish and other food increased correspondingly. As a consequence, a number of cropland had being converted into orchards, fish ponds and nurseries. In addition, economic advancement paved the way for the increase of living space per capita, transportation land per capita, common green belt per capita, and so on [9]. A number of industrial areas, infrastructures, service facilities and residential houses were largely constructed in the urbanization process. All these contributed to the rapid disappearance of agricultural landscapes.

Three relationships were straightforward in this study—agricultural landscape loss and distance to the nearest road, fragmentation and distance to the nearest road, as well as irregularity and distance to the nearest road. Distance measures can be proxies for other process related variables like transportation cost and travel time to the field [10]. When people select their home and work locations, they try to optimize their time and monetary resources in reaching those activities [11]. Consequently, agricultural landscapes close to transportation lines are more likely to be occupied by build-ups. The increased build-ups are characterized by strongly fragmented, situated relatively close to one another, but they are, at the same time, poorly interspersed among the patches of other types of land cover [4]. Such patterns would finally result in the fragmentation and configuration of agricultural landscapes.

Population factors provided very different information from impervious surface. POP and UR were not correlated with any agricultural landscape metric. These results reflected that population factors may impact agricultural landscape patterns in an indirect way. Therefore, these two parameters were not good indicators of changes of agricultural landscapes in our study.

The most interesting discovery of this study was the variability among the relationships between urbanization and agricultural landscapes. They varied with both agricultural landscape metrics and the urbanization indicators. Several factors may contribute to the variability among the relationships between urbanization and agricultural landscapes: the accuracy of GDP and population statistical data, the spatiotemporal scale, and methodological factors (land-use classification, raster size, sampling method and metric selection). Specifically, issues of scale are central to geospatial analysis of relationships between urbanization and agricultural landscapes. It would be expected that with a finer spatial scale and the resultant increase in data points, the variation among the various urbanization measures of change would decrease [12]. We selected the administration as our spatial unit, because statistical data were collected at this scale in China. We accounted for differences among the administrative divisions in spatial pattern of agricultural landscape, but the limited number of administrative divisions could impact the accuracy of regression models. Urbanization occurs in phases, with the measured rate dependent on the interval of measurement [12], and temporal scale is thus another important factor that impacts relationships of change. This study captured the relationships between agricultural landscapes and urbanization during a ten-year time interval. Lag-time analysis approach may be appropriate for more information about relationships of change within different intervals.

Acknowledgment. This work was supported by National Natural Science Foundation (No.41001202) and the Emerging Talent Project of Zhejiang Province (No. 667140).

References

1. Napton, D.E., Auch, R.F., Headle, R., Taylor, J.L.: Land changes and their driving forces in the Southeastern United States. Reg. Envir. Chang. 10, 37–53 (2010)
2. O'Neill, R.V., Hunsaker, C.T.: Monitoring environmental quality at the landscape scale. BioScience 47, 513–519 (1997)
3. Alberti, M., Marzluff, J.M., Shulenberger, E., Bradley, G., Ryan, C., Zumrrunnen, C.: Integrating humans into ecosystems: opportunities and challenges for urban ecology. BioScience 53, 1169–1179 (2003)
4. Solon, J.: Spatial context of urbanization: Landscape pattern and changes between 1950 and 1990 in the Warsaw metropolitan area, Poland. Landsc. Urban Plan. 93, 250–261 (2009)
5. Fu, B.J., Hu, C.X., Chen, L.D., Honnay, O., Gulinck, H.: Evaluating change in agricultural landscape pattern between 1980 and 2000 in the Loess hilly region of Ansai County, China. Agric. Ecosyst. Environ. 114, 387–396 (2006)
6. McGarigal, K., Cushman, S.A., Neel, M.C., Ene, E.: FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps (2002)
7. Xiao, X.M., Boles, S., Liu, J.Y., Zhuang, D.F., Frolking, S., Li, C.S., Salas, W., Moore, B.: Mapping paddy rice agriculture in southern China using multi-temporal MODIS images. Remote Sens. Environ. 95, 480–492 (2005)
8. Wu, C.S., Murray, A.T.: Estimating impervious surface distribution by spectral mixture analysis. Remote Sens. Environ. 84, 493–505 (2003)
9. Tan, M.H., Li, X.B., Xie, H., Lu, C.H.: Urban land expansion and arable land loss in China-a case study of Beijing-Tianjin-Hebei region. Land Use Pol. 22, 187–196 (2005)
10. Overmars, K.P., Verburg, P.H.: Analysis of land use drivers at the watershed and household level: Linking two paradigms at the Philippine forest fringe. Int. J. Geogr. Inf. Sci. 19, 125–152 (2005)
11. Kucukmehmetoglu, M., Geymen, A.: Urban sprawl factors in the surface water resource basins of Istanbul. Land Use Pol. 26, 569–579 (2009)
12. Kromroy, K., Ward, K., Castillo, P., Juzwik, J.: Relationships between urbanization and the oak resource of the Minneapolis/St. Paul Metropolitan area from 1991 to 1998. Landsc. Urban Plan. 80, 375–385 (2007)