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# Transformation of agricultural landscapes under rapid urbanization: A threat to sustainability in Hang-Jia-Hu region, China

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A B S T R A C T

This paper analyzed the spatiotemporal dynamics of agricultural landscapes within Hang-Jia-Hu region (China) from 1994 to 2003 using a set of metrics that relate closely with sustainability. Considerable urban expansion was identified with the total built-ups increasing by 224.7% from $6.99 \times 10^4$ ha to $22.7 \times 10^4$ ha. The outcomes indicated that, at the whole region scale, agricultural landscapes became lost, fragmented, transformed and isolated as urbanization intensified. Global Moran's I statistics and Local Indicators of Spatial Association (LISA) analysis were employed to characterize the spatial dependence and hotspots for intra-level agricultural landscape changes at two grid scales. Generally, isolation of agricultural patches was a localized problem, while shape transformation of agricultural landscapes was a more regionalized problem; hotspots for lost, fragmentation and irregularity of agricultural landscapes concentrated around urban centers, while those for isolation of agricultural patches appeared in rural mountain areas. Spatial regression models further revealed that changes of agricultural landscapes showed diverging relationships with urbanization indicators for each landscape metric. The character and strength of relationships for each landscape metric were different and changed with scale. While our results of agricultural landscape changes consisted with some theoretical predictions in the literature, they also showed different spatiotemporal signatures of urbanization. Resolving these differences will certainly contribute to the ongoing landscape transformation and sustainability debate. This study demonstrated complexities of relationships between urbanization and agricultural landscape changes, and highlighted the importance of selected variables, spatial and temporal scales and incorporation of spatial dimensions when quantifying these relationships.



## Introduction

For many decades, centuries in some cases, cities have been spreading (Anas, Arnott, & Small, 1998; Taubenböck, Wegmann, Roth, Mehl, & Dech, 2009). Today almost half of the world's population lives in urban areas and the prospect is that 60% of the world's population will be urban by 2030 and the number of mega cities will reach 100 by 2025 (Avelar, Zah, & Tavares-Corrêa, 2009). One of the many problems resulting from this rapid urbanization is the environmental impact and the conversion of open or agricultural land into developed uses is among the major ones for most urbanized countries and regions (Batisani & Yarnal, 2009; OECD, 2001). This is the case in large parts of eastern coastal China and the problem is even more serious in Yangtze River Delta, where the average population density is above 1500 persons/km$^2$ and therefore three times the China level. Between 1992 and 1997, in Zhejiang Province for instance, the total provincial area of available agricultural land decreased by 4.7 percent, from 1.69 to 1.61 million ha (Skinner, Kuhn, & Joseph, 2001).

The high visibility of agricultural land conversion to developed uses in Yangtze Delta has motivated many policy makers, communities, and farmers to call for action to address this alarming issue (Ding, 2003; Long, Liu, Wu, & Dong, 2009; Skinner et al., 2001; Wu et al., 2009). The focus grows out of the concern that unlike other variations in agricultural land availability, it is unlikely that agricultural land converted to developed uses will ever become available again for agricultural production (Thompson & Prokopy, 2009). It thus has been considered to be

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one of the most serious problems affecting China's food security (FAO, 2002). Further, the accelerating urbanization also resulted in degradation of agricultural landscapes, which may influence a variety of ecological processes and finally pose threat to regional sustainability (Fu, Hu, Chen, Honnay, & Gulinck, 2006). Several reforms on land resources management and measures to preserve agricultural land have been carried out in China, but the Chinese government is still struggling with how to effectively deal with the agricultural land loss and its related problems (Lin & Ho, 2003; Tan, Beckmann, den Berg, & Qu, 2009). Foundation of successful land use policies relies upon answering the central question in the agricultural conversion-causes, impacts, and consequences. Great efforts have been devoted to characterize the agricultural land conversion in China. However, the spatio-temporal dynamics of agricultural landscapes under rapid urbanization has always been described without adequate quantitative measurement to show the implications for the existing land use planning and management with regards to sustainability.

Remote sensing (RS) and geographic information systems (GIS) have been recognized as powerful and effective tools for detecting the spatiotemporal dynamics of landscapes changes at various scales (DeGloria, 1985; Geri, Amici, & Rocchini, 2010; Serra, Pons, & Saurì, 2008). Landscape ecology offers theories and methods that can contribute to the formulation of sustainability strategies through a better understanding of landscape transformation processes (Ribeiro & Lovett, 2009). A key tool in landscape ecology is the use of metrics in the description, analysis, and modeling of the structure and pattern of landscapes (McGarigal, Cushman, Neel, & Ene, 2002). To investigate the dynamics of agricultural landscapes in response to rapid urbanization, for this study, we selected the Hang-Jia-Hu region as the study area, one of the most populated and fastest growing parts of Yangtze River Delta, eastern coastal China. This will be done by combining multiple research approaches: RS, GIS, spatial statistics and landscape metrics. More specifically, our objectives are to: (1) characterize intra-level agricultural landscape transformations within Hang-Jia-Hu between 1994 and 2003; (2) quantify relationships between agricultural landscape transformations and urbanization patterns at different grid scales; and (3) provide a frame of reference for policy makers to promote sustainability in the region.

## Study area

The "sister" cities of Hangzhou, Jiaxing and Huzhou are located in south of the Yangtze River Delta (Fig. 1). The region we now call Hang-Jia-Hu includes twelve districts and thirteen counties of Zhejiang province, and has a population of approximately 14 million. With a warm temperate, subtropical monsoon climate, the region enjoys four distinct seasons. Annual temperature averages 17.5 °C and rainfall averages 1139 mm. All of the natural conditions are beneficial for agricultural production, and Hang-Jia-Hu region is considered as one of the most important food bases in eastern coastal China.

During the first decade of market transition in China (1994–2003), Hang-Jia-Hu region had witnessed extensive urbanization and experienced significant social-economic changes. In the period between 1994 and 2003, it has tripled its Gross Domestic Product (GDP), with GDP increasing from RMB 1028 billion in 1994 to RMB 3502 billion in 2003. However, drawbacks also emerge: massive transference from agricultural land to constructive land associated with rapid urban sprawl; degradation of land productivity and farmland abandonment accompanied by large flows of young people into cities. Altogether, these processes resulted in widespread agricultural land conversion across this region. If this condition continues to worsen, it will become a major impediment to regional sustainable development. Considerable attention is required from the scientific and public policy communities to characterize the response of agricultural landscapes to urbanization in this region.

## Materials and methods

### *Data resources and processing*

According to the national basic terminology of land (GB/T 19231–2003), agricultural land refers to the land used to grow crops, including fallow land, grass and crop rotation land, land used

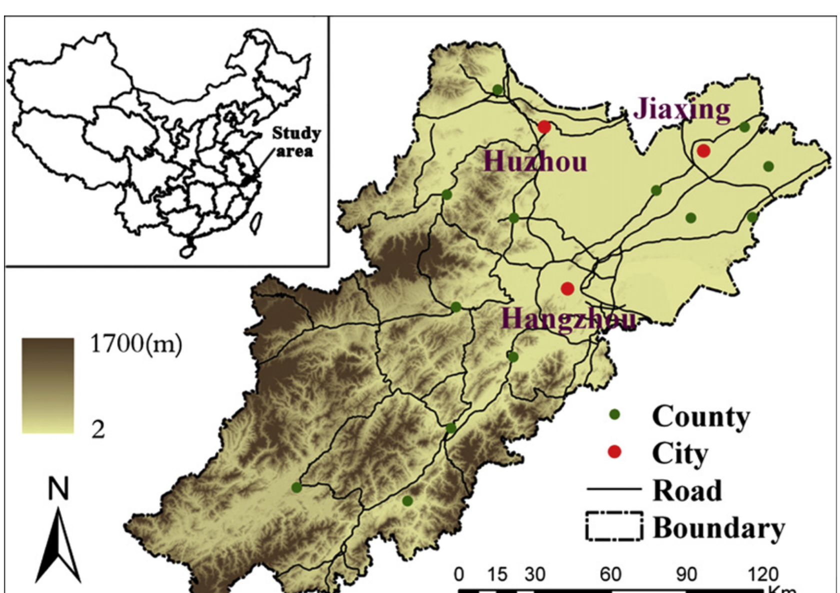


**Fig. 1.** Location of Hang-Jia-Hu region and spatial patterns of main roads, counties and cities.

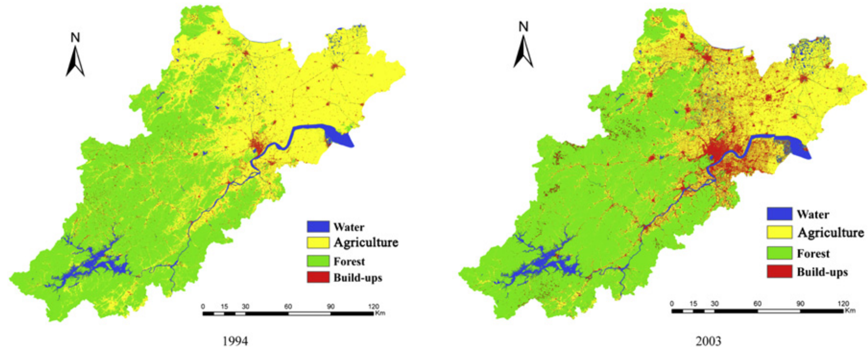


**Fig. 2.** Land use/cover of Hang-Jia-Hu region between 1994 and 2003.

to grow crops with scattered fruit trees, mulberry trees, or other trees, tideland and coastal land harvesting at least once each year, as well as trenches, drainage, roads and ridge (width: 1. 0 m, the South; 2.0 m, the North) between arable land. An assessment of landscapes change between 1994 and 2003 in Hang-Jia-Hu region was conducted using Landsat Thematc Map (TM) images. 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.

Due to the high spatial variability of landscape structure and fragmented land use patterns, mixed pixels are common in TM images covering China. Spectral mixture analysis (SMA), a technique better suited to heterogeneous environments, in particular, was used to interpret TM images in this study (For details, see Xiao et al., 2005). During the interpreting process, multi-temporal TM images, topography and soil datasets were used as the ancillary data. An accuracy assessment was performed following 3 × 3 majority filtering. Land cover fraction maps were then changed into thematic maps according to the fraction portion (Tooke, Coops, Goodwin, & Voogt, 2009). Land cover was classified into four categories: water, build-up, agricultural land, and forest (Fig. 2). Kappa statistics for classification were 0.86 (1994) and 0.83 (2003).

## Metric analyses

A large set of metrics for landscape composition and structure analysis has been proposed during the past three decades (e.g. Forman & Godron, 1986; O'Neill et al., 1988; Turner & Gardner, 1991). Many researchers have discussed possible relationships between landscape metrics and sustainability (e.g. Leitão & Ahern, 2002; Ribeiro & Lovett, 2009). To ensure comparability with previous studies, a set of landscape metrics was selected for this study, based on the research question and the set of metrics proposed by Leitão and Ahern (2002). The selected class-level metrics included total area (TA), patch density (PD), perimeter area ratio distribution (PARA), Euclidean nearest neighbour distance (ENND) and aggregation index (AI). The correlations between these metrics and sustainability were summarized in Table 1.

This study applied moving-window to combine with the spatial metrics for analyzing agricultural landscape transformations within the Hang-Jia-Hu region. Given that the results of metric analysis are sensitive to the input pixel size, a preliminary test of the effects of scale on metric analysis was carried out with pixel sizes of 1 km, 5 km, 10 km, 15 km, and 20 km. The pixel size of 5 km and 10 km was chosen because it retains more details of the landscape pattern than the larger pixel size does and at the same time it avoids the noise of landscape pattern captured by the smaller pixel size (For similar issues, see Weng, 2007). The grid landscape datasets for the entire Hang-Jia-Hu area were input into FRAGSTATS 3.3 (McGarigal et al., 2002) and 5 km × 5 km as well as 10 km × 10 km squares were used as basic units for moving-window analysis. Every central pixel of the output thematic map was recorded as the value of landscape metrics (Yeh & Huang, 2009). Transect analyses were also conducted again by using the 3D analysis tool in ArcGIS 9.2 based on the grid maps derived from the moving-window analysis to reveal the effects of size factor (Yeh & Huang, 2009).

## GIS analysis for urbanization indicators

The Urbanization Intensity Index (UII) reflects the dynamics of urban land expansion, which has been recognized as one of the main indicators involved in identifying the intensity of urbanization (Tate et al., 2005; Wang, Liu, & Ma, 2010; Xiao et al., 2006). We used the same sampling blocks for metric analysis (5 km × 5 km and 10 km × 10 km squares) to intersect with the temporal land use maps to group the input information into each block. The UII value

**Table 1**
Associations between landscape metrics and sustainability.[a]

| Metrics | Relations with ecological conditions |
|---|---|
| Total area (TA) | Indicator relates closely with food security and thus sustainability. |
| Patch density (PD) | Indicator for landscape fragmentation. A fragmented landscape provides less connectivity, greater isolation, and higher percentage of edge area in patches. |
| Perimeter area ratio distribution (PARA) | Indicator for shape transformation. Geometry patterns are indicators of human disturbance (roads, urban areas). |
| Euclidean nearest neighbour distance (ENND) | ENND measures the relative distance between patches of the same class and can be used as a surrogate for connectivity. The spread of disturbances such disease and fire are greater when ENND is higher. |
| Aggregation index (AI) | Indicator for change in landscape structure caused by urbanization. It provides information about specific aspects of landscape structure and thus is helpful to "guide" process of urbanization towards sustainability. |

[a] Source: Leitão & Ahern, 2002 & Ribeiro & Lovett, 2009.

for each block at different scales was then calculated using the following formula.

$$\mathrm{UII}_i = \frac{U_{i,t+n} - U_{i,t}}{n \times WA_i} \times 100 \quad (1)$$

In Eq. (1), $\mathrm{UII}_i$ represents an index of urbanization intensity for spatial unit $i$ during the time span $t$ and $t+n$; $U_{i,\,t+n}$ and $_{i,\,t}$ stand for the build-up area in the year $t+n$ and $t$ respectively; $WA_i$ is the total area of spatial unit $i$.

Proximity to urban centers or main roads parallels the intensity of urbanization and the changes of landscapes characteristics can reflect the degree of human influences on the environment. Therefore, distance to urban centers (Dis_urban) and distance to road (Dis_road) were frequently applied to reflect urbanization influence on landscapes (Gao & Li, 2011; Kromroy, Ward, Castillo, & Juzwik, 2007; Liu et al., 2008; Solon, 2009; Yeh & Huang, 2009). Maps of equal distance contours to urban centers and roads were generated by the DISTANCE module in ArcGIS 9.2 at two scales (5 km × 5 km and 10 km × 10 km squares).

### *Spatial analysis*

Global Moran's I statistics and Local Indicators of Spatial Association (LISA) analysis were employed to characterize the degree of spatial dependence on agricultural landscape pattern changes over time. Moran's I is a commonly used indicator of spatial autocorrelation and LISA measures the degree of spatial autocorrelation in each sample point by using local Moran's I. The value of Moran's I ranged from −1 to 1. A value of 1 means perfect positive spatial autocorrelation (high values or low values cluster together), a value of −1 suggests perfect negative spatial autocorrelation (a checkerboard pattern), and a value of 0 indicates perfect spatial randomness (For details, see Moran, 1950). Local Moran's I statistics for the landscape metrics were calculated and cluster maps were generated to identify the existence of hotspots. Hotspots, either spatial clusters or outliers, refer to the areas where there are higher degrees of landscape pattern changes than the surrounding areas. Maps obtained from moving-window analysis can help to identify hotspots visually, but not statistically. Contrarily, LISA index can capture hotspots both visually and statistically. Spatial clusters consist of two categories: (i) high–high clusters indicate high values of changes in landscape patterns are surrounded by high values; (ii) low–low clusters indicate clustering of low values of landscape metrics changes. The location under study is a spatial outlier when a high negative local Moran's I value is detected. Spatial outlier locates within the mix of low and high values of landscape metrics changes and includes low–high (a low value in a high value neighborhood) and high–low (a high value surrounded by low values) outliers. All the calculations were performed using GeoDa 0.9.5-i (Beta) analysis software (Anselin, Syabri, & Kho, 2006).

Spatial regression analysis was carried out to determine the relationships between urbanization indicators and agricultural landscape metrics. There exits three categories of spatial regression models: ordinary least square regression (OLS), spatial error model and spatial lag model. Compared to the OLS, the other two models incorporate spatial dependence in the form of lag or error dependence (Anselin, 1988). Spatial lag denotes a possible diffusion process while spatial error model gives weight the unexplained residuals by structural factors (Lacombe & Shaughnessy, 2004; Ye & Xu, 2011). Hence, the spatial lag model posits that agricultural landscape transformation rate depends on the rates observed in neighboring units and on a set of observed local independent variables. The spatial lag model's equation is given as:

$$y_i = \lambda \sum w_{ij} y_i + x_i \gamma + \mu_i + \epsilon_i \quad (2)$$

where $i$ represents spatial units at different scales. $\lambda$ is spatial autoregressive coefficient; $w_{ij}$ is an element of a spatial weights matrix $W$; $W$ describes the spatial arrangement of all the spatial units in the sample; $y_i$ is an observation on the dependent variable (landscape metric change rate) of $i$; $x_i$ is row vector of observed characteristics of spatial unit $i$; $\gamma$ is the matching vector of fixed but unknown parameters; $\epsilon_i$ is an independently and identically distributed error term for $i$ with zero mean and variance, which represents unobserved factors for observation $i$; $\mu_i$ denotes a spatial specific effect. The reason for consideration of spatial specific effects is that they exert significant impact on the space-specific variables whose omission could bias the estimates (Ye & Xu, 2011).

The spatial error model, on the other hand, implies that the dependent variable depends on a set of observed local indicators and that the error terms are spatially auto-correlated (Ye & Xu, 2011). The equation is expressed as follows:

$$\sigma_i = \lambda \sum w_{ij} \sigma_i + \epsilon_i \quad (3)$$

$$y_i = \gamma x_i + \mu_i + \sigma_i \quad (4)$$

where $\sigma_i$ reflects the spatially auto-correlated error term and $\sigma$ is spatial autocorrelation coefficient.

The spatial error model is consistent with a situation where determinants of agricultural transformation rate omitted from the model are correlated over space, and with a situation where unobserved factors follow a spatial pattern.

All spatial regressions were performed using GeoDa 0.9.5-i (Beta) analysis software (Anselin et al., 2006). The appropriate algorithm for spatial regression was selected based on the Lagrange Multiplier diagnostics (Anselin, 2005). 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 among urbanization indicators.

## Results

### *Synoptic agricultural landscape pattern changes*

The synoptic analysis of selected metrics provided a general representation of agricultural landscape patterns (Fig. 3). As evident from the results obtained, the total area of agricultural landscapes in Hang-Jia-Hu region had decreased by 28.5%, from

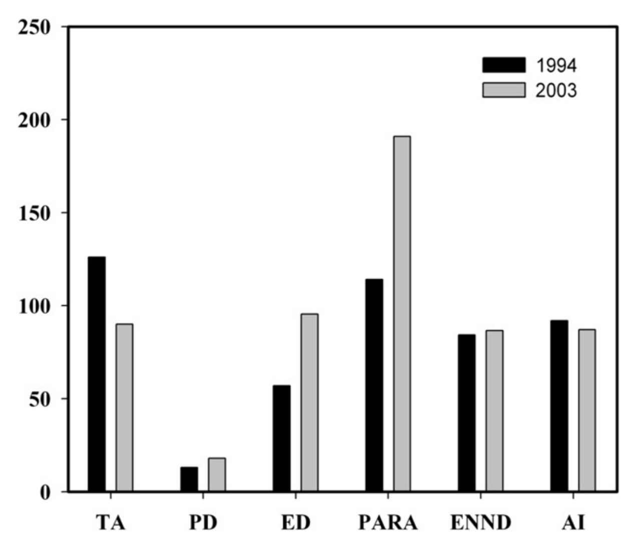


**Fig. 3.** Changes of metrics for agricultural landscapes at the whole region scale (unit for TA: $10^4$ ha).

1260665 ha in 1994–900914 ha in 2003. Fragmentation was also obvious characteristics of agricultural landscape changes with the patch density increased by 40.0%. The continuous decline of AI also indicated the fragmentation of agricultural landscapes. The increased PARA values denoted increases in the complexity and irregularity of patch shape. Such shapes are considered as very unstable and prone for further fragmentation. Additionally, the slight increase in ENND values suggested that the randomness and isolation of agricultural patches were intensified.

*Intra-level agricultural landscape patterns between 1994 and 2003*

The datasets of the metric analyses for every square block (5 km × 5 km and 10 km × 10 km) derived from FRAGSTATS were exported to become a set of attributes for the vector thematic maps of square polygons covering the Hang-Jia-Hu region. The thematic maps demonstrated the intra-level agricultural landscape patterns in Hang-Jia-Hu region (Figs. 4 and 5). These figures showed that the values of TA and AI in the northeastern area were higher than those in the counterpart. Opposite patterns were identified for PA, PARA and ENND. All these results indicated that agricultural landscapes mainly concentrated in the northeastern part, and the densely distributed landscapes presented relatively low patch density, more regular shapes and less isolated patterns. When comparing the figures in different years, we can see that agricultural landscapes in 2004 became less dominated, more fragmented and more irregular in shape. However, these maps are unsatisfactory for statistically determining the areas experiencing the most significant changes of landscape spatial patterns. Therefore, this study applied LISA index to further examine the hotspots for landscape pattern changes.

*Spatial autocorrelations of agricultural landscape pattern changes*

Maps of LISA are shown to describe the local autocorrelation of agricultural landscape changes (Fig. 6). The cluster maps in Fig. 6 for most landscape metrics showed several significant spatial clusters and clear spatial distribution patterns of the clusters at both scales. High–high clusters for TA, PD and PARA were concentrated around the three central cities, signifying that more urbanized areas always experienced more agricultural landscapes conversion and transformations. Differently, high–high clusters for ENND and AI appeared in southwestern region. On the contrary, these areas were low–low clusters for TA, PD and PARA. Such results may relate with the spatial variations of agricultural landscapes in Hang-Jia-Hu region. Though agricultural landscapes changes more significant in terms of TA and PD in the northeastern part, they may witnessed less changes in ENND and AI than its counterpart considering the densely distributed patterns of landscapes in the northeastern part. Low–high and high–low outliers were mainly individual sites within the areas between high–high and low–low clusters, some of which were the interfaces between urban and rural areas. There were changes in the patterns of LISA between the two scales. The low–low clusters in the southwestern area identified at the 5 km scale were not significant at the 10 km scale. In addition, high–high clusters of ENND in the central part occupied more area at 10 km scale than those at the 5 km scale.

The spatial dependence of landscape pattern changes, in terms of global Moran's I, across the study area are also displayed in Fig. 6. Great differences in spatial autocorrelation existed among the changes of the five metrics. Generally, ENND exhibited low spatial autocorrelation at both scales (Moran's I values ranging from 0.103 to 0.110), indicating that isolation of agricultural patches was a localized problem in Hang-Jia-Hu region. Conversely, shape transformation of agricultural landscapes was a more regionalized problem evidenced by the high Moran's I values at both scales. It has been widely recognized that landscape pattern is scale-dependent since it changes with the scale of observation or analysis. Our results showed that spatial autocorrelations of landscape pattern changes were more obvious at 5 km scale than those at 10 km scale. Specifically, TA and PD presented relatively high spatial autocorrelation at 5 km scale, while low spatial autocorrelation at 10 km scale. All these revealed that regionalized problems of conversion and fragmentation were easier to distinguish at 5 km scale than at 10 km scale.

*Spatial patterns of urban expansion*

Considerable urban expansion was identified for Hang-Jia-Hu region with the total built-ups increasing by 224.7% from 69909 ha in 1994–227003 ha in 2003. The most significant expansion occurred in the triangular-form plain area among the three main cities (Fig. 7c and d). On the contrary, hinterland areas westward witnessed little urban expansion (Fig. 7c and d). The aggregation of build-ups in the flat areas reflected residents' preferences for building sites, as few barriers exist to development across the landscape. Spatial autocorrelation of urban expansion was conspicuous for the whole region evidenced by the high Moran's I values at both scales (Fig. 7c and d). These results demonstrated that urbanization had become regionalized and also suggested that anthropogenic activities were dominated in this region. In addition, the spatial patterns of urban expansion also denoted the variations in urbanization intensity within the Hang-Jia-Hu region. As shown in Fig. 7a and b, Hangzhou was the most urbanized area in Hang-Jia-Hu region. Besides, urbanization level of the triangular-form area among the Hangzhou, Jiaxing and Huzhou was higher than the surrounding areas. It should be mentioned that area experiencing no expansion in the southwestern region is where the Lake Qiandao located. Land consolidation was frequently carried out around Lake Qiandao in response to tourism development. This contributed to the no expansion or even reduced build-ups in this area.

*Dynamics of agricultural landscape patterns in response to urbanization*

The plausible dynamics of agricultural landscape patterns in response to urbanization obtained from spatial regression are shown in Table 2 (5 km) and Table 3 (10 km). At 5 km scale, changes of TA, PD and PARA were significantly associated with all the three urbanization indicators. Changes of AI had close relationships with Dis_road ($R^2 = 0.58$) and Dis_urban ($R^2 = 0.53$). No significant correlations were identified between changes of ENND and any urbanization indicator (Table 2). More specifically, it can be seen that areas with high degree of urbanization, high proximity to urban centers or near distance to road always experienced more significant conversion, fragmentation and transformation in agricultural landscapes. At 10 km scale, Dis_road and urbanization intensity index only presented significant correlations with TA and PARA. Regarding the relationships between changes of agricultural landscape patterns and Dis_urban, the result revealed a linear correlation for TA ($R^2 = 0.57$), PD ($R^2 = 0.46$), PARA ($R^2 = 0.68$) and AI ($R^2 = 0.41$) (Table 3).

Comparing $R^2$ at two scales, changes of agricultural landscape patterns are better explained by urbanization indicators at the 5 km scale. In addition, spatial lag models, which take into account the weighted mean of the dependent variable for adjacent grids for predicting landscape metrics, was suited for most landscape metrics at both scales. This denoted that spatial autocorrelation might exist in landscape metrics changes of grid cells at grid scales.

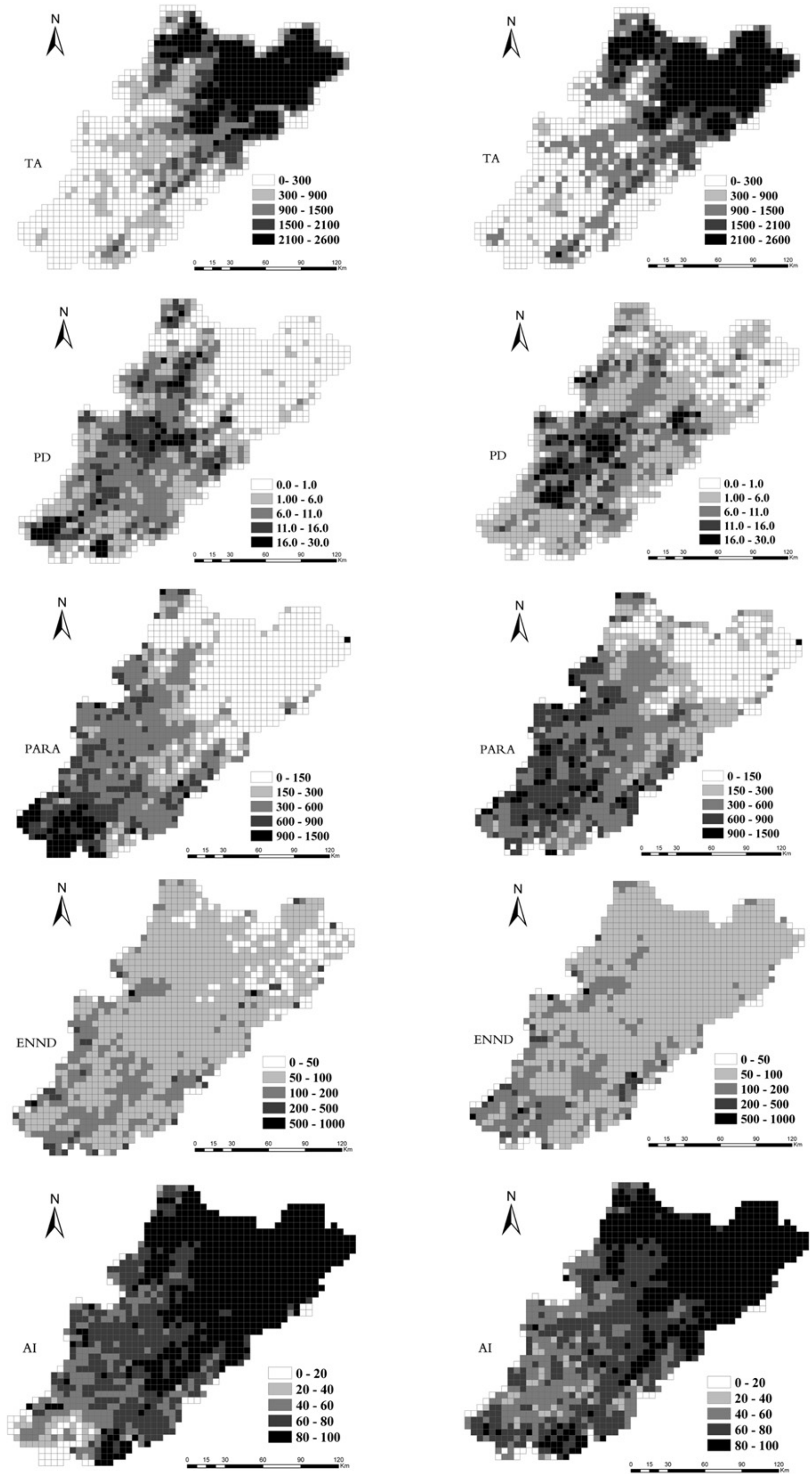


**Fig. 4.** Thematic maps showing the agricultural landscape patterns of Hang-Jia-Hu region at 5 km scale: 1994 in the left row and 2003 in the right row.

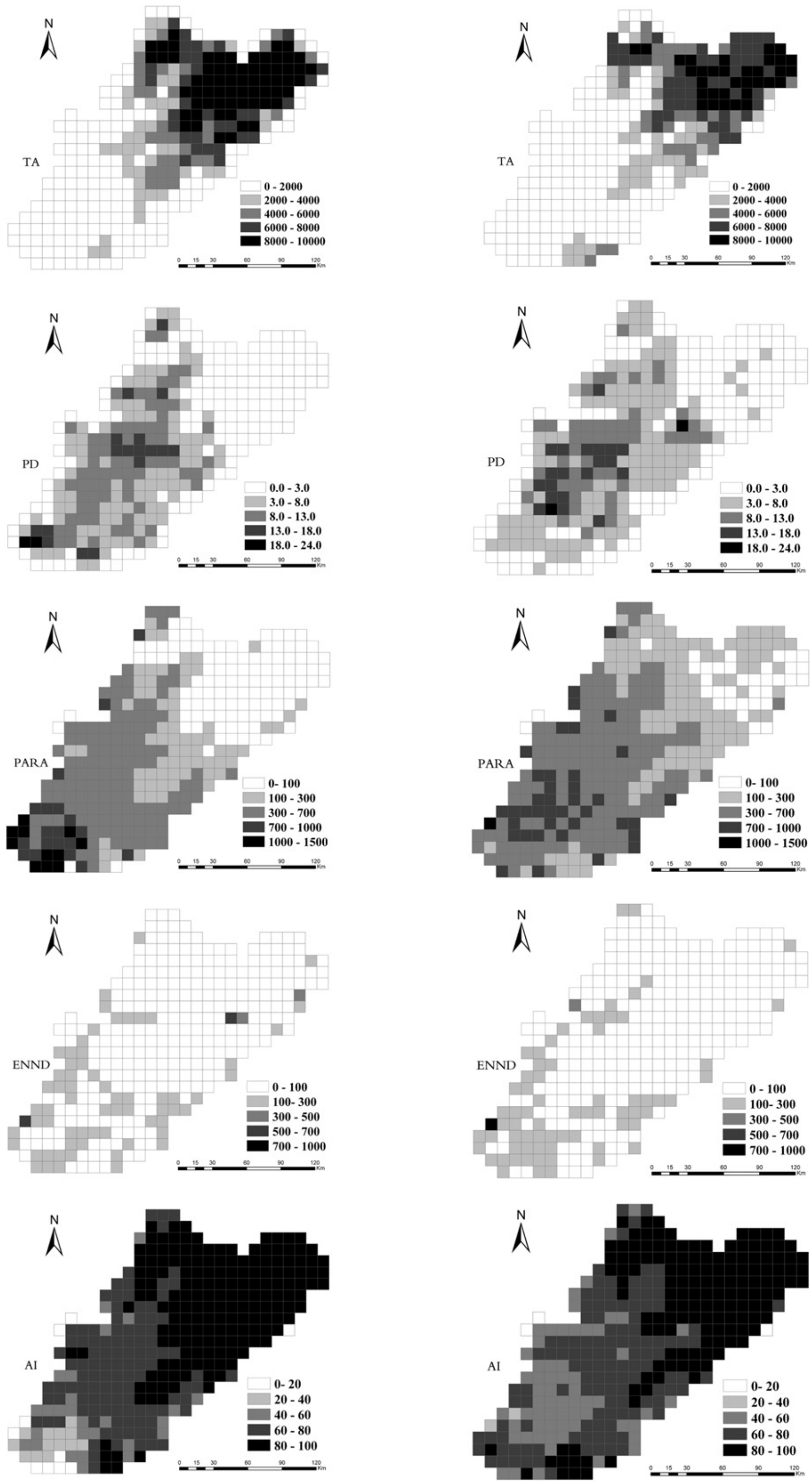


**Fig. 5.** Thematic maps showing the agricultural landscape patterns of Hang-Jia-Hu region at 10 km scale: 1994 in the left row and 2003 in the right row.

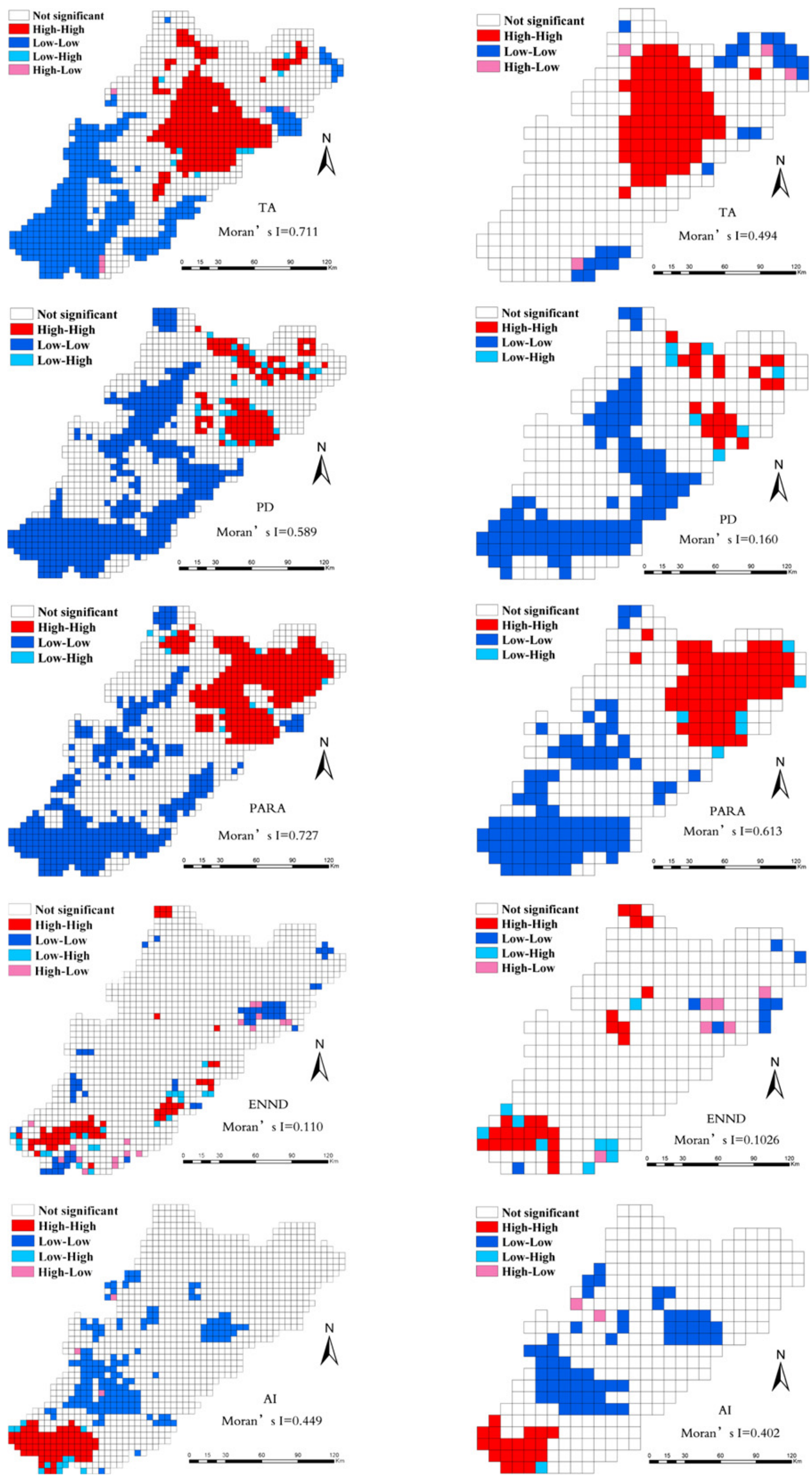


**Fig. 6.** Spatial patterns of hotspots for agricultural landscape transformations in Hang-Jia-Hu region: each block in the left row represents 5 km × 5 km and each block in the right row represents 10 km × 10 km.

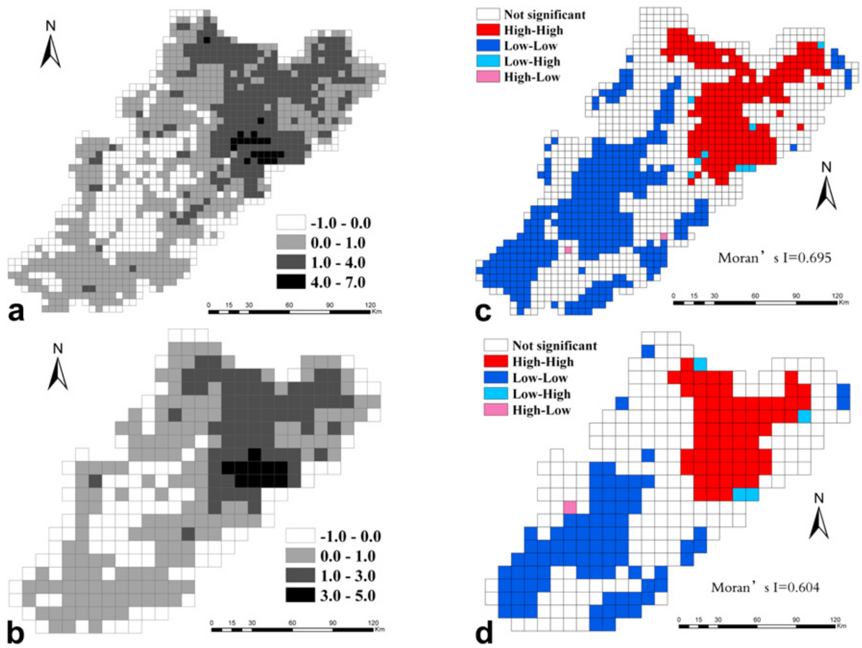


**Fig. 7.** a) spatial patterns of urbanization intensity at 5 km scale; b) spatial patterns of urbanization intensity at 10 km scale; c) hotspots of urban expansion in Hang-Jia-Hu region at 5 km scale; d) hotspots of urban expansion in Hang-Jia-Hu region at 10 km scale.

One grid cell may present more similar landscape pattern changes with adjacent cells than those far away given that nearer cells may receive similar human pressures and present natural characteristics such as soil, geology, land cover, and climate.

## Discussion and conclusions

### *Critical sustainability issue: rapid urbanization and impacts on agricultural landscapes*

Where high population density and wealth come together, demands for public infrastructure, housing, industrial and commercial uses increase and upcoming construction projects start to appear as "urban sprawl", or urbanization (Mann, 2009). Such urbanization imposes a new way of living and of organizing the environment and it thus creates new landscapes (Antrop, 2000). As urbanization intensified in Hang-Jia-Hu region from 1994 to 2003, agricultural landscapes were lost, fragmented, transformed and isolated. Loss of prime farmland was general indicator of urban sprawl (Hasse & Lathrop, 2003). The conversion of agricultural landscapes in Hang-Jia-Hu region is accorded with the CLUE-based simulation results of Verburg, Veldkamp, and Fresco (1999). Verburg et al. (1999) pointed that prominent increases in the area of farmland converted to residential and industrial construction would be found in the eastern region of China. Declines in the total area of agricultural landscapes would definitely result in lower self-supply abilities and threat to food security of this region accordingly. Fragmentation causes a reduction in patch size for the remaining habitat, increasing edge effects and isolation of patches through the destruction of connecting corridors (Leitão & Ahern, 2002). These fragmented agricultural landscapes are considered unsuitable or unavailable for urban development (Dredge, 1995). Fragmented agricultural landscapes can potentially decrease the operational efficiencies such as those associated with pest control and land supervision (Long et al., 2009). Consequently, they are left over after development and its distribution is neither planned

**Table 2**
Relationships between agricultural landscape changes and urbanization indicators at 5 km scale obtained by spatial regression.

| $X$ | $Y$ | Model | $R^2$ | Sig. |
|---|---|---|---|---|
| Distance to road | TA | $Y^a = 0.86 \times \text{WY} - 23506.19 \times X + 517{,}212.3$ | 0.71 | ** |
| Distance to road | PD | $Y^a = 0.69 \times \text{WY} - 0.06 \times X + 1.61$ | 0.59 | ** |
| Distance to road | PARA | $Y^a = 0.89 \times \text{WY} - 0.01 \times X + 0.19$ | 0.74 | ** |
| Distance to road | ENND | NS[c] | | |
| Distance to road | AI | $Y^a = 0.61 \times \text{WY} + 0.01 \times \text{X} - 0.06$ | 0.58 | ** |
| Urbanization intensity index | TA | $Y^b = 1{,}717{,}267 \times X + 1{,}466{,}664$ (Lambda = 0.87) | 0.82 | ** |
| Urbanization intensity index | PD | $Y^b = 3.74 \times X + 1.48$ (Lambda = 0.57) | 0.52 | ** |
| Urbanization intensity index | PARA | $Y^b = 0.43 \times X + 0.92$ (Lambda = 0.87) | 0.75 | ** |
| Urbanization intensity index | ENND | NS[c] | | |
| Urbanization intensity index | AI | NS[c] | | |
| Distance to urban centers | TA | $Y^b = 4{,}967{,}762 - 35{,}202.93 \times X$ (Lambda = 0.83) | 0.71 | ** |
| Distance to urban centers | PD | $Y^b = 8.97{-}0.07 \times X$ (Lambda = 0.64) | 0.53 | ** |
| Distance to urban centers | PARA | $Y^b = 2.58{-}0.02 \times X$ (Lambda = 0.86) | 0.73 | ** |
| Distance to urban centers | ENND | NS[c] | | |
| Distance to urban centers | AI | $Y^a = 0.62 \times \text{WY} + 0.002 \times X - 0.11$ | 0.53 | ** |

**Significant at the 99% confidence level.
[a] Spatial lag models; WY = weighted mean of water quality for adjacent stations.
[b] Spatial error models.
[c] No significant relationships were identified by spatial regression.

**Table 3**
Relationships between agricultural landscape changes and urbanization indicators at 10 km scale obtained by spatial regression.

| $X$ | $Y$ | Model | $R^2$ | Sig. |
|---|---|---|---|---|
| Distance to road | TA | $Y^b = 6{,}691{,}056 - 712{,}844.1 \times X$ (Lambda = 0.78) | 0.57 | ** |
| Distance to road | PD | NS[c] | | |
| Distance to road | PARA | $Y^a = 0.79 \times \mathrm{WY} - 0.01 \times X + 0.33$ | 0.68 | ** |
| Distance to road | ENND | NS[c] | | |
| Distance to road | AI | NS[c] | | |
| Urbanization intensity index | TA | $Y^b = 1.41 \times 10^7 {*} X - 5{,}871{,}241$ (Lambda = 0.78) | 0.70 | ** |
| Urbanization intensity index | PD | NS[c] | | ** |
| Urbanization intensity index | PARA | $Y^b = 0.71 \times X + 0.8$ (Lambda = 0.74) | 0.70 | ** |
| Urbanization intensity index | ENND | NS[c] | | |
| Urbanization intensity index | AI | NS[c] | | |
| Distance to urban centers | TA | $Y^b = 1.4e \times 10^7 - 183{,}209.5 \times X$ (Lambda = 0.79) | 0.57 | ** |
| Distance to urban centers | PD | $Y^a = 0.19 \times \mathrm{WY} - 0.06 \times X + 7.94$ | 0.46 | ** |
| Distance to urban centers | PARA | $Y^a = 0.74 \times \mathrm{WY} - 0.005 \times X + 0.67$ | 0.68 | ** |
| Distance to urban centers | ENND | NS[c] | | |
| Distance to urban centers | AI | $Y^a = 0.57 \times \mathrm{WY} + 0.003 \times X - 0.17$ | 0.41 | ** |

**Significant at the 99% confidence level.
[a] Spatial lag models; WY = weighted mean of water quality for adjacent stations.
[b] Spatial error models.
[c] No significant relationships were identified by spatial regression.

nor related to physical and environmental limitations, making little contribution to the amelioration of environmental impacts of urbanization (climatic changes, erosion, water pollution, etc) and does not further the integration of natural and built environments that is basic requirement of sustainability (Dredge, 1995). In addition, the more irregular shapes are considered as very unstable and prone for further fragmentation. All these evidences demonstrate that the sustainability of Hang-Jia-Hu had been greatly affected.

These agricultural landscape tendencies not only represent endogenous processes of the territory, but also some of most common and dynamic agricultural landscape patterns in eastern coastal China. In the Jing-Jin-Tang region, for example, of all the new urban land, about 74% was converted from agricultural land (Tan et al., 2005). Similar to Hang-Jia-Hu region, abandonment and transformation of agricultural landscapes posed threat to the sustainable development of Su-Xi-Chang region (Long et al., 2009). Further, places with a significant amount of agricultural lands near fast-growing urban areas of Taipei experienced the highest rates of agricultural landscape conversion (Huang, Wang, & Budd, 2009). These transformations in agricultural landscapes of these regions were subject to the economical focus of the government, given the fact that the economic development was regarded as political performance of the local government. Additionally, environmental protection consciousness at that time was not as high as it is today, so the values of the agricultural landscapes surrounding the cities have not been well appreciated. While doing so, the governments have lost track of the management of agricultural landscapes under rapid urbanization. Therefore, the balancing exercise has become more important for eastern coastal China as it undergoes urbanization and moves towards large-scale industrial construction.

### *Relating results with hypotheses on urbanization patterns*

Dietzel, Herold, Hemphill, and Clarke (2005) postulated the hypothesis that urbanization exhibited cyclic patterns in time and space driven by two alternating processes—diffusion and coalescence. Following this hypothesis, the threshold of landscape patterns in relationship to the degree of urbanization has been tested by several studies. For example, Weng (2007) found that there exited a threshold for the degree of landscape diversity and fragmentation as urbanization intensified temporally. This study of Yeh and Huang (2009) revealed the thresholds of the changes of landscape diversity while the degree of urbanization was increasing. However, the temporal data is generally insufficient to describe the whole process of urbanization due to issues related to initial and final conditions in studying urbanization (Dietzel et al., 2005). The analysis of correlation in this study provides an alternative way to relate with the theory of urbanization using the landscape data of blocks at different levels of urbanization. Our results denoted that all the significant relationships were monotonic and no thresholds were identified (Table 2 and Table 3). Two main factors may contribute to the discrepancies between our results and the urbanization hypothesis. For one thing, the land cover data of this study covered a very limited period and the urbanization process of the study area may still be in its early stage (i.e., dominated by diffusion). For another, differences in the spatial extent of the study landscapes often lead to differences in metric values (Wu, Jenerette, Buyantuyev, & Redman, 2011), and the urbanization pattern of large metropolitan region like Hang-Jia-Hu may differ from that of the small city in Dietzel et al. (2005).

### *Scale effects and methodology discuss*

Concerning the methods, comprehensive application of remote sensing, spatial analysis, landscape metrics and other indices, is demonstrated in this paper. This comprehensive approach proves to be helpful to develop applied geographic models of agricultural landscapes dynamics under human influences. The landscape metrics used in the study, revealing major trends of agricultural landscape transformations, may find application in the activities aiming at the protection of agricultural ecosystems. It has been widely recognized that spatial pattern is scale-dependent since it changes with the scale of observation or analysis (Wu & Hobbs, 2002). To advance our understanding of agricultural landscape patterns in response to urbanization, therefore, it is critically important and absolutely imperative to explore sensitivity to scale effects (e.g. grain size). We quantitatively analyzed the scale-specific associations between urbanization and agricultural landscape transformations via spatial lag/error regression. The results reflected that model fit and the strength of correlations between changes of landscape patterns and urbanization were both varied with the size of grid. Similarly, the study of Gao and Li (2011) found that relationships between urban landscape fragmentation and distance to main roads/urban centers were spatially non-stationary and scale-dependent. These finding can provide a scientific basis for policy-making to mitigate the negative effects of urbanization on landscape patterns. Temporal scale is another important factor that impacts relationships of change. The rate and metrics of agricultural landscapes are associated both with spatial scale and with the length of time over which it is measured. Urbanization also occurs in phases, with the measured rate dependent on many factors, including the interval of measurement (Kromroy et al., 2007). The studies of Doygun (2009) and Wu et al. (2009) signified the importance of temporal scale in the discussion of relationships between urbanization and agricultural landscapes. This study captured the relationships between agricultural landscapes change 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.

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