Interaction Relationship Between Built-Up Land Expansion and Demographic-Social-Economic Urbanization in Shanghai-Hangzhou Bay Metropolitan Region of Eastern China

Rui Xiao, Xin Huang, Weixuan Yu, Meng Lin, and Zhonghao Zhang

Abstract

Employing coupling coordination degree model (CCDM), this research attempts to reveal the interaction relationships between built-up land expansion (BLE) and demographic-social-economic (DSE) urbanization in Shanghai–Hangzhou Bay (SHB) Metropolitan Region. It first compared the development trends of four elements, including built-up land expansion level, demographic urbanization, social urbanization, and economic urbanization from 1994 to 2015 through descriptive statistics. Then CCDM was used to identify the spiral escalation trend relationships between built-up land expansion and demographic/social/economic urbanization, respectively. The findings revealed that the degree of coupling coordination between BLE and DSE urbanization had the trend to ascend in SHB, and Shanghai has a more superior balanced development tendency than other cities. It concludes that CCDM can be implemented as an effective approach to evaluate the coupling relationship, and the related agencies in SHB can strengthen the coordination to provide suggestions and make decisions for the coordinated development of urban agglomeration.

Introduction

China has been experiencing a rapid urbanization process, which is characterized by strong built-up expansion, extreme urban population growth, and unprecedented social-economic development since the 1990s. During the last several decades, urbanization emerged in the developed areas, where urban construction and development were vigorous, and land use in these regions experienced significant changes and restructuring. Under the force of administrative measure and land finance, China's urbanization is in a stage of fast-forward and uncontrolled spatial sprawl, leading to illusory high population urbanization (Qi *et al.* 2016), high housing prices (Wang *et al.* 2017a; Li *et al.* 2017), disorder expansion of built-up lands (Li *et al.* 2014), environmental degradation (Wang *et al.* 2017b), huge farmland encroachment (Chien 2015), increasing conflicts between human and land (Ma *et al.* 2016), and so on. Especially the cities in the coastal economic zone, which are the preferred destination for millions of internal migrants and overseas investors, have been the locomotives in propelling China's economic growth (Chen *et al.* 2000; Wu and Zhang 2012). However, the unbalanced disposition of human and land in coastal zones may threaten the healthy development of urbanization. How to coordinate the relationships among built-up land expansion, population growth, and social-economic development is one of the most important issues that China should face during the new urbanization process.

Urbanization involves an array of interactive processes such as demographic, social, and economic. How China's urbanization has been influenced by the built-up land expansion in the eastern coastal region is certainly a significant issue that needs to be explored and addressed. Related existing research is largely dedicated to identifying the urbanization's impacts through the aspects of spatiotemporal changes of built-up land expansion (Chuai *et al.* 2015; Ianos *et al.* 2016) and driving forces and their interactions of built-up land expansion during the urbanization process (Ju *et al.* 2016; Liu *et al.* 2017). Others built models to analyze the interaction relationship between population growth and urban expansion (Marshall 2007; Deng *et al.* 2008). However, comprehensive studies on the coupling coordination relationships among expansion of built-up land, planning policies, and demographic-social-economic urbanization in the metropolitan regions are relatively scarce.

The concept of coupling coordination is oriented from physics, which refers to two or more systems that may influence one another through a variety of interactions (Li *et al.* 2012). Coupling coordination degree was employed to analyze the interaction within systems, since it can reflect to what extent the development of systems is coherent and harmonious when comparing its value of two different subsystems. Coupling coordination model has been applied in geographic studies, such as urbanization and environment (Fang and Wang 2013; Guo *et al.* 2015; Wang *et al.* 2014), eco-economics (Lu *et al.* 2017), tourism and environment (Tang 2015), urbanization and population (Tang *et al.* 2017), and so on. The interaction between the two systems can promote a regional coupling coordination degree, which shows a spiral escalation trend (Lu *et al.* 2017).

Taking the Shanghai-Hangzhou Bay Metropolitan Region (SHB), a region covering the most developed cities in

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eastern China as an example, this study explores the status and process of built-up land expansion there, as well as its correlations to demographic, social, and economic urbanization through the coupling coordination degree model. It first compared the development trends of four elements— "built-up land expansion", "demographic urbanization", "social urbanization", and "economic urbanization"— in SHB across the past 21 years (from 1994 to 2015) through descriptive statistics. Then coupling coordination degree model was employed to identify the interactive effects of built-up land expansion and demographic-social-economic (DSE) urbanization. Specifically, this research focuses on (1) spatiotemporal patterns of built-up land expansion (BLE) and DSE urbanization from 1994 to 2015; (2) coupling coordination degree of BLE and DSE urbanization; and (3) implications for coordinated development in SHB.

Study Area

The SHB metropolitan region consists of one core megacity, Shanghai, as well as five cities (Hangzhou, Ningbo, Shaoxing, Jiaxing and Huzhou) in the Zhejiang Province (Figure 1). The SHB covers a total land area of more than 50 000 km^2 with a total population of more than 38 million (2016 Statistical Yearbook of China). SHB is located on the southern part of Yangtze River Delta, which is the first pole of China's economic growth. Its climate is humid, subtropical, characterized by short cold dry winters and long, hot, rainy summers. The average annual temperature is 16.4°C, with annual rainfall of 1460 mm. Landforms are diverse, including hills, plateaus, basins and plains.

Figure 1. Locations of Shanghai-Hangzhou Bay.

As one of the most important components in the southern part of world-class city groups in the Yangtze River Delta, SHB is a pivotal economic development benchmark in China's southeast coastal area, as well as a typical manifestation of the rapid development of urbanization in China. China's market transition since 1994 has pushed SHB into a stage of rapid growth. It has experienced unprecedented economic development and population growth in recent decades. Gross Domestic Product (GDP) per capita was 55 840 renminbi (RMB) in 1994, and reached about 660 890 RMB in 2015, which increased more than 11-fold. In addition, its population density amounted to 683 and 750 persons per km^2 in 1994 and 2015, respectively, making it one of the most densely populated regions in China. The demand for built-up lands increased rapidly with the population explosion and economic inflation. Therefore, scientific evidence was needed to inform the local government about the relationship between DSE and BLE, and the subsequent rational utilization of built-up lands. SHB was used as a case to evaluate the interactive effects between DSE and BLE in this study.

Materials and Methods

Data Preprocessing

Built-Up Land Detection

Time series of satellite data, including the datasets of multispectral Landsat Thematic Mapper (TM)/Enhanced Thematic Mapper Plus (ETM+) (Path 120, Row 38–40; Path 119, Row 38–40; Path 118, Row 38–40) imagery acquired on 1994, 2003, 2009, and 2015, were selected for this study. Prior to interpretation, all images were standardized to the same reference spectral characteristics by atmospheric correction. Then, the images were geometrically rectified to Universal Transverse Mercator (UTM) 50 World Geodetic System 1984 (WGS 84) coordinate system using the quadratic method. All the images were resampled to 30 m using the nearest neighbor algorithm to maintain the unchanged original brightness values of pixels, and the root mean squared error (RMSE) were both calculated within 0.5 pixels. The image processing and data manipulation were conducted using Data Preparation Module supplied with the Environmental Systems Research Institute (ESRI) ERDAS IMAGINE 2014 image processing software. The methods for visual interpretation were adapted from Herold *et al.* (2003) and Munsi *et al.* (2010). The working window was set at a 1:50 000 scale and then built-up boundaries were delineated. Google Earth was used to check the accuracy of image interpretation. For each image, 300 samples were randomly selected to check the accuracy of the built-up land maps. The overall accuracy of built-up land maps between 1994 and 2015 was determined to range from 82.6% to 86.4% with an average of 84.5%, and the Kappa coefficient ranged from 0.81 to 0.84 with an average of 0.82. Then the overlay module in *ARCGIS* 10.1 was used to map built-up land expansion from 1994–2015 (Figure 2).

Statistical Indicators

A database of three important aspects of urbanization—demographic urbanization, social urbanization and economic urbanization was established based on data from statistical yearbooks (Shanghai and Zhejiang Municipal Bureau of Statistics, 2016), China's urban statistical yearbook (China National Bureau of Statistics, 2016), official websites of local governments, and other statistical outlets (1990–2016), spatially regarding city-level administrative bodies of the SHB region as a basic statistical unit. We standardized the data using Equations 1 and 2 and eliminated the influence of dimension, magnitude, and positive and negative orientation:

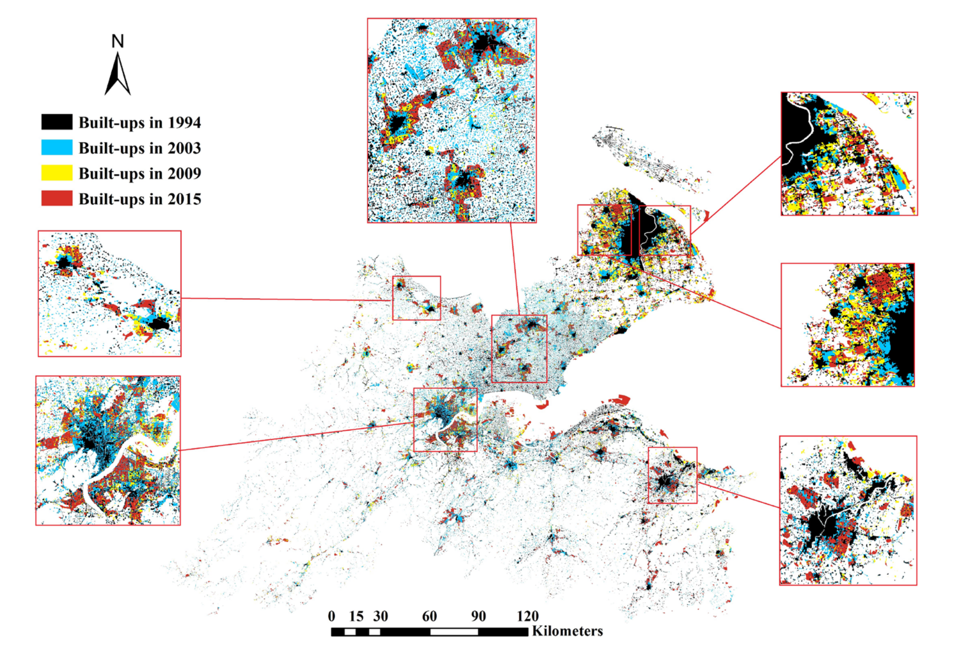

Figure 2. Built-up land expansion from 1994–2015 in Shanghai-Hangzhou Bay.

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Positive indicator: $$r_{ij}=\frac{\left(x_{ij}-\min\left(x_j\right)\right)}{\left(\max\left(x_j\right)-\min\left(x_j\right)\right)} \tag{1}$$

Negative indicator: $$r_{ij}=\frac{\left(\max\left(x_j\right)-x_{ij}\right)}{\left(\max\left(x_j\right)-\min\left(x_j\right)\right)} \tag{2}$$

where x_{ij} denotes the value of indicator j in year i; max(x_j) and min(x_j) are the maximum value and minimum value of j indictor in all years, respectively. Thus, all the index value will be ranged in [0,1].

Methods

Index System for BLE and DSE Urbanization

Referring to previous conducted studies (Qiao and Fang 2006; Bao and Fang 2007; Li *et al.* 2012), a set of indices focusing on different aspects of demographics, society and economy were initially selected considering of the data integrity, accuracy and availability. Subsequently, three-round Delphi Process and correlation analysis were performed, and a total of 12 indices were generated. Besides, area and percentage of built-up land were used to indicate the built-up land in each year (Table 1).

Evaluation of BLE and DSE Urbanization

The built-up land expansion rate was used to evaluate the spatio-temporal process of built-up land expansion. The expansion rate describes the growth of built-up land area as a percentage of the total built-up land area for a given period. The built-up land expansion annual rate (km²/year) is given as (Xu and Min 2013):

$$R=\frac{UA_{n+i}-UA_i}{UA_i}\times\frac{1}{n}\times 100\% \tag{3}$$

where R is the urban expansion rate, UA_{n+i} and UA_i are the built-up land area in different time periods $n+i$ and i, respectively, and n is the interval of the whole period (years).

Weighting coefficients of all indicators are obtained through mean square error (MSE) decision methods:

Here the normalized data is used to calculate the MSE of random variables of each indicator, which are then normalized for weighting coefficients (Tang *et al.* 2017).

The average value of x^i is given as:

$$F(x_i)=\frac{1}{n}\sum_{j=1}^{n}r_{ij} \tag{4}$$

The MSE of indicator x_i is given as:

$$\xi\left(x_i\right)=\sqrt{\sum_{j=1}^{n}\left[r_{ij}-F\left(x_i\right)\right]^2} \tag{5}$$

The weighting coefficient of indicator x_i is given as:

$$\omega_i=\frac{\xi\left(x_i\right)}{\sum_{i=1}^{n}\xi\left(x_i\right)} \tag{6}$$

Table 1. Index system used for evaluation of BLE and DSE urbanization.

Subsystem	First Grade Index	Basic Grade Indices
The integration value of BLE	Built-up land expansion level	Area of built-up land (km²) Percentage of built-up land (%)
The integration value of DSE urbanization	Demographic urbanization level	Number of total population Percentage of non-agricultural population (%) Number of social industry employment Number of primary industry employment
	Social urbanization level	Number of academic school students per 10 000 people Number of hospital/clinic beds per 10 000 people Number of libraries per 10 000 people
	Economic urbanization level	Output value of the primary industries (Yuan) Total investment in fixed assets (Yuan) Per capita income of rural residents (Yuan) Total retail sales of consumer goods (Yuan) Total power of agricultural machinery (kilowatt)

The evaluation of a single indicator is given as:

$$S_{ij} = \omega_i \times r_{ij} \quad (7)$$

The comprehensive level in year *i* is given as:

$$S_i = \sum_{j=1}^{n} S_{ij} \quad (8)$$

where r_{ij} is the value of each indicator after standardization, $F(x_i)$ is the average value of indicator x_i, $\xi(x_i)$ is the MSE of indicator x_i, ω_i is weighting coefficient of indicator x_i, S_{ij} is the evaluation of a single indicator, and S_i is the comprehensive level in year *i*.

Coupling Coordination Degree Model (CCDM)

Coupling coordination degree model (CCDM) was employed in this study to reveal the interaction relationship between demographic-social-economic urbanization and built-up land expansion. The variable values were defined as U_0, U_1, U_2, and U_3, which refer to built-up land expansion level, demographic urbanization, social urbanization, and economic urbanization, respectively.

The CCDM is given as (Illingworth 1996):

$$C = n\left\{\left(U_0 \cdot U_1 \cdot U_2 \cdots U_n\right) / \left[\prod\left(U_i + U_j\right)\right]\right\}^{1/n} \quad (9)$$

where U_i represents the contribution of sub-system *i* to the total system. *C* is the coupling degree and the value of *C* ranges from 0 to 1, which reflects the strength of mutual influences among systems from U_1 to U_n. The coupling coordination degree model can further reflect to what extent the development of systems is coherent and harmonious. In this study, we calculated the coupling coordination degree of two sub-systems U_a and U_b, and the formula is given as:

$$D = (C \times T)^{1/2} \text{ and } T = \alpha U_a + \beta U_b \quad (10)$$

where *C* represents the coupling coordination degree between U_a and U_b, and *T* reflects the overall effect and level of U_a and U_b, whereas α and β denote undetermined coefficients, which are 0.5 in this study because U_a and U_b are equally important. The coupling coordination degree D ranges from 0 to 1, whereas higher value indicates higher coherence level among subsystems. The coupling coordination periods was divided into four distinct stages according to the previous references on coupling coordination division standard (Tang 2015; Sun *et al.* 2016; Ai *et al.* 2016), including low level coupling, antagonistic period, running-in period, and high-level coupling. When $0 \le D < 0.2$, the coordination of BLE and DSE is in the low-level coupling stage, in which there is little influence between each other. When $0.2 \le D < 0.5$, the coupling coordination of BLE and DSE is in the antagonistic period, in which built-up land expansion would restrict the DSE urbanization. When $0.5 \le D < 0.8$, the coordination of BLE and DSE is in the running-in period, in which the relationship between BLE and DSE gradually become more optimized. When $0.8 \le D \le 1.0$, the coupling coordination of BLE and DSE is in the high-level coupling stage, in which the relationship between BLE and DSE is coordinated optimization, and each aspect would propel the development of the other aspect. Besides, there are two kinds of relationship between BLE and DSE in different stages: BLE development is ahead of or lags behind DSE urbanization. Therefore, the four stages were divided into eight intervals according to the relationships between BLE and DSE in different stages (Figure 3). The explanation of all the intervals are shown in Table 2.

Results

Evaluation of BLE and DSE Urbanization

Table 3 shows the expansion patterns of the built-up land of the SHB during different periods, which can be described as three stages. (1) During 1994 and 2003, Shanghai had the lowest built-up land expansion rate, whereas the cities in Zhejiang Province had a rapid expansion in this time, especially for Hangzhou, Jiaxing and Shaoxing, which witnessed an expansion rate increase more than 15%. In this stage, the built-up land areas in Shanghai reached from 1350 km² to

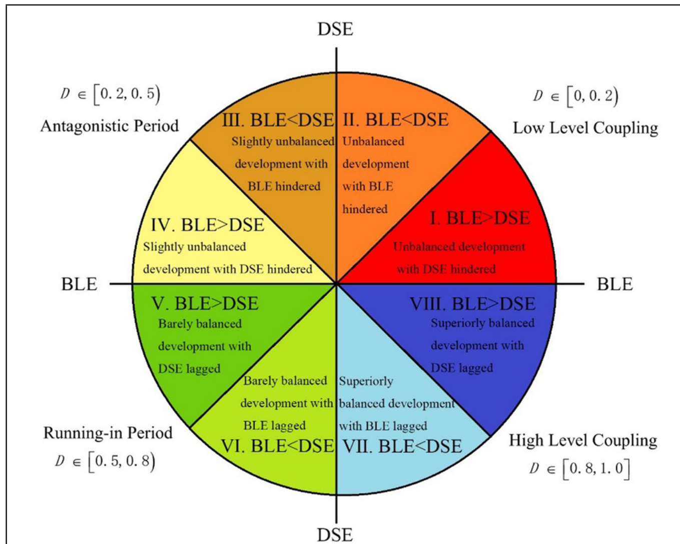

Figure 3. Coupling coordination division for BLE and DSE.

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Table 2. Explanation for coupling coordination division.

D Value	Division	U_{BLE} and U_{DSE}	Stage	Interval	Features
[0,0.2)	Unbalanced Development	$U_{BLE} > U_{DSE}$	Low level coupling	I	Unbalanced development with DSE hindered, in which the DSE has little influence on the BLE development.
		$U_{BLE} < U_{DSE}$	Low level coupling	II	Unbalanced development with BLE hindered, in which the BLE has little influence on the DSE development.
[0.2,0.5)	Slightly Unbalanced Development	$U_{BLE} < U_{DSE}$	Antagonistic Period	III	Slightly unbalanced development with BLE hindered, in which the BLE would restrict the DSE development.
		$U_{BLE} > U_{DSE}$	Antagonistic Period	IV	Slightly unbalanced development with DSE hindered, in which the DSE would restrict the BLE development.
[0.5,0.8)	Barely Balanced Development	$U_{BLE} > U_{DSE}$	Running-in Period	V	Barely balanced development with DSE lagged, in which DSE has ample room for development in a relatively stable subsystem.
		$U_{BLE} < U_{DSE}$	Running-In Period	VI	Barely balanced development with BLE lagged, in which BLE would develop more rapidly to catch up with the DSE development.
[0.8,1.0)	Superiorly Balanced Development	$U_{BLE} < U_{DSE}$	High Level Coupling	VII	Superiorly balanced development with BLE lagged, in which DSE urbanization is in a mature stage that can propel built-up land expansion in a stable subsystem.
		$U_{BLE} > U_{DSE}$	High Level Coupling	VIII	Superiorly balanced development with DSE lagged, in which built-up land expand ahead that can provide great room for DSE development in a stable subsystem.

Table 3. Built-up land expansion rate in the SHB (Unit: %).

Period	1994–2003	2003–2009	2009–2015	1994–2015
Shanghai	3.5	6.3	3.1	5.5
Hangzhou	15.9	3.4	5.4	13.7
Ningbo	5.4	1.9	5.8	5.9
Jiaxing	16.2	1.5	2.8	10.1
Huzhou	13.1	3.4	5.1	11.5
Shaoxing	16.6	1.6	4.9	12.1
Shanghai-Hangzhou Bay	8.6	3.5	4.1	8.0

1770 km^2, and the percentage increased from 20% to 26%, lagged behind Jiaxing, which saw the percentage increased from 11% to 28% (Figure 4). (2) During 2003 and 2009, Shanghai revealed highest values in built-up expansion rate, which displayed a new sprawl boom in this period. However, the cities in Zhejiang Province slowed the pace of expansion, with the percentage fluctuating between 1% and 3% (Figure 4). (3) During 2009 and 2015, Hangzhou, Ningbo, Huzhou, and Shaoxing had an expansion rate around 5%, almost as the same value as in Shanghai, showing that these cities begun a new growth under the influence of Shanghai. For the whole Shanghai-Hangzhou Bay, built-up land increased by 5320 km^2, from 3208.4 km^2 to 8528.4 km^2, at an annual increase rate of 253.3 km^2 during the period from 1994 to 2015, which is lower than the period during 1994 and 2003 and higher than the other two periods, indicating that the expansion of built-up land in the SHB mainly occurred in the first stage. Built-up lands increased slower during 2003–2009 than the other two stages in SHB, resulting from that the built-up lands in cities of Zhejiang Province expanded slowly in this period. Synthetically, SHB reached at 8% annual increase from 1994 to 2015, whereas Shanghai and Ningbo lagged behind the whole study area, increasing by 5.5% and 5.9%, respectively.

There was a significant spatial variability between BLE and DSE urbanization. Shanghai and Ningbo saw a lower annual rate of built-up land expansion, suggesting that these two cities had controlled the expansion of built-up lands during 1994 and 2015. Hangzhou and Shaoxing had a higher increase of built-up land expansion with annual rate of more than 12.1%, which indicated that these two cities had a great demand for built-up lands and this need converted large amounts of land into built-up lands, promoting the rapid growth of urban built-up areas.

Demographic urbanization resulted that Jiaxing and Shaoxing had an annual increase rate of more than 1.5%, while Shanghai and Hangzhou followed this number (0.81%–1.50%). Huzhou and Ningbo had demographic urbanization annual rate lower than 0.80%. The results of social urbanization showed that Shaoxing witnessed the highest average annual rate more than 50%, while Shanghai and Hangzhou had the lowest average annual rate less than 30%. In addition, Hangzhou and Ningbo were in the first rank of economic urbanization annual rate more than 50%, while Shanghai had the lowest number less than 30%.

Overall, Shanghai saw a lower annual rate in all the aspects of built-up land expansion and demographic-social-economic urbanization than most of the cities in Zhejiang Province, which indicated that on the one hand Shanghai had a bigger radix number than other cities and on the other hand the Shanghai government had a good control in urbanization. Shaoxing had a higher annual rate in built-up land expansion, demographic and social urbanization, displaying a rapid development during the two decades. Hangzhou and Ningbo were the two strong economic cities in Zhejiang Province and also showed the dominant economic positions during 1994 and 2015 (Figure 5). Jiaxing and Shaoxing had the highest annual rate of demographic urbanization, representing that people would consider the factors of urban construction and social urbanization when they decided to migrate to other cities. Especially for Shaoxing, which had the most rapid development rates of built-up lands and social urbanization, and accordingly absorb most people to move into the city for urban construction.

Comprehensive Levels in the BLE and DSE Urbanization

Demographic urbanization in Shanghai witnessed the most rapid development, while the built-up land expansion rate cannot catch demographic and social urbanization. It indicates that more built-up lands should be developed to satisfy the demands of housing and social activities for human beings. There was a steady increasing trend for all the aspects during 1994 and 2003 in Hangzhou, and an enormous increasing trend for economic and social urbanization from 2009 to 2015, both reaching more than 0.8. Ningbo saw the most rapid development in economic urbanization, far ahead of other aspects, which demonstrated that built-up land expansion should be emphasized on economic construction. Jiaxing had a larger range of built-up land expansion, while other aspects were in a steady developing trend. It suggested that there existed enough built-up land areas for DSE urbanization in Jiaxing. Levels of built-up land expansion in Huzhou lagged behind demographic-social-economic urbanization in 1994 and 2015, suggesting that built-up lands cannot meet the demand of DSE urbanization. Shaoxing had the most development of economic urbanization and the least development of built-up land expansion, indicating that Shaoxing focused more on the economic development and ignored the construction for built-up lands.

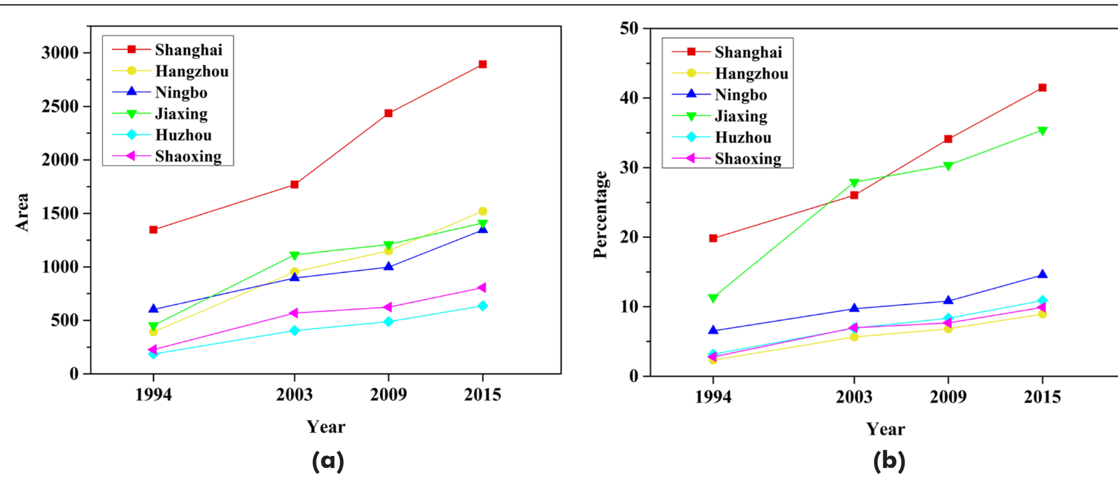

Figure 4. Area (a) and percentage (b) of built-up land in each city during 1994 and 2003.

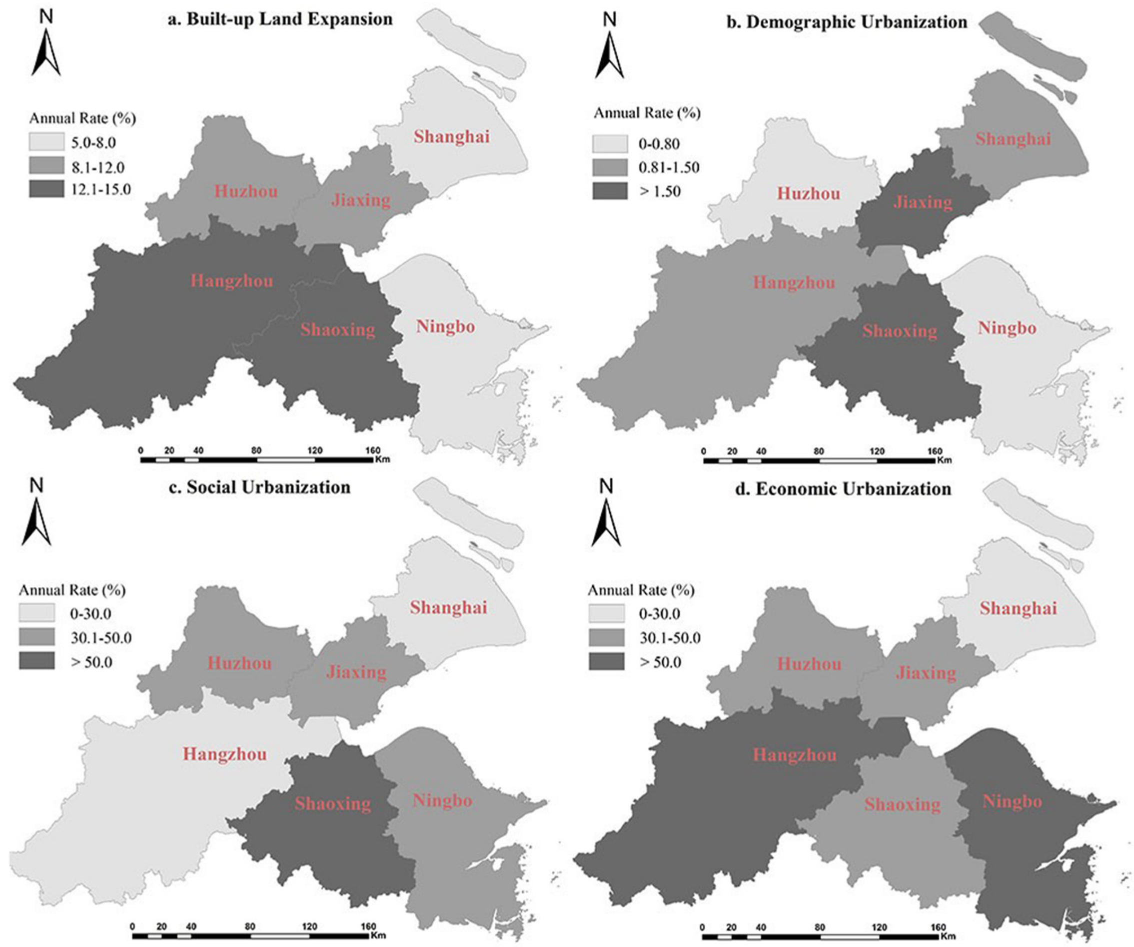

Figure 5. The distribution of average annual rate of built-up land expansion (a), demographic urbanization (b), social urbanization (c), and economic urbanization (d) in the SHB region during 1994 and 2015.

Coupling Coordination Degree of BLE and DSE Urbanization

Figure 6a shows that many cities are in III and IV intervals for the coupling coordination of BLE and demographic urbanization in 1994, which means a slightly unbalanced stage. Most cities reached barely balanced stage in 2015, which are V and VI Intervals, respectively. The development of Shanghai was ahead of other cities, reaching VI interval in 1994 and 2003 and VII interval in 2009 which is a stage of superiorly balanced development with BLE lagged. It indicated that the built-up expansion in 2015 provided sufficient space for demographic urbanization development; in other words, Shanghai has plenty of built-up land areas for more immigrants. This result was related to the population policy management issued by Shanghai, where there were many restrictions for people to obtain the household registration. Therefore, as the first-tier city and one of the fastest economically growing cities in China, Shanghai witnessed a nonrapid growth of the population. This well explained the reason that built-up lands provided enough spaces for population growth. Jiaxing lagged behind other cities in the coupling coordination of BLE and demographic urbanization, which was in barely balanced development with demographic urbanization lagged in 2015. Jiaxing had more intensity of built-up land expansion than demographic-social-economic urbanization (Figure 7), but the coupling-coordination result reported that Jiaxing had not attracted enough people to balance the coupling development of built-up land expansion and demographic urbanization. Hangzhou and Ningbo had a similar development trend, which was in IV interval at the beginning, and then came into the V interval and VI at last. It displayed that these two cities had a stable development for coupling coordination of BLE and demographic urbanization.

Figure 6b shows the coupling coordination of BLE and social urbanization. Shanghai was still ahead of other cities. The development was from V interval in 1994 to VI interval in 2003 and finally to VII interval in 2009 and 2015, which was in the stage of superiorly balanced development with BLE lagged, indicating that the built-up land had already provided enough space for social urbanization in 2009. Hangzhou, Ningbo and Jiaxing were in IV interval in 1994, which is slightly unbalanced. Among these three cities, Hangzhou had a stable increasing trend in the latter stages of development, reaching VI interval in 2009 and 2015. While Ningbo and Jiaxing were in V interval in 2015, which is barely balanced development with social urbanization lagged, displaying a weak social development in these two cities. Huzhou and Shaoxing had similar developing trend, which were in II and I intervals in 1994, respectively, representing an unbalanced coordination. However, they developed from IV interval in 2009 to VI interval in 2015, skipping the V interval. It indicated that these two cities had emphasized on coordination development between social urbanization and built-up land expansion.

Figure 6c shows that Shanghai changed from IV interval in 1994 to V interval in 2003 and changed from V interval in 2009 to VIII interval in 2015 (skipping the VI and VII intervals), which was in the stage of superiorly balanced development with economic urbanization lagged. It displayed that Shanghai had developed into a very high stage that built-up

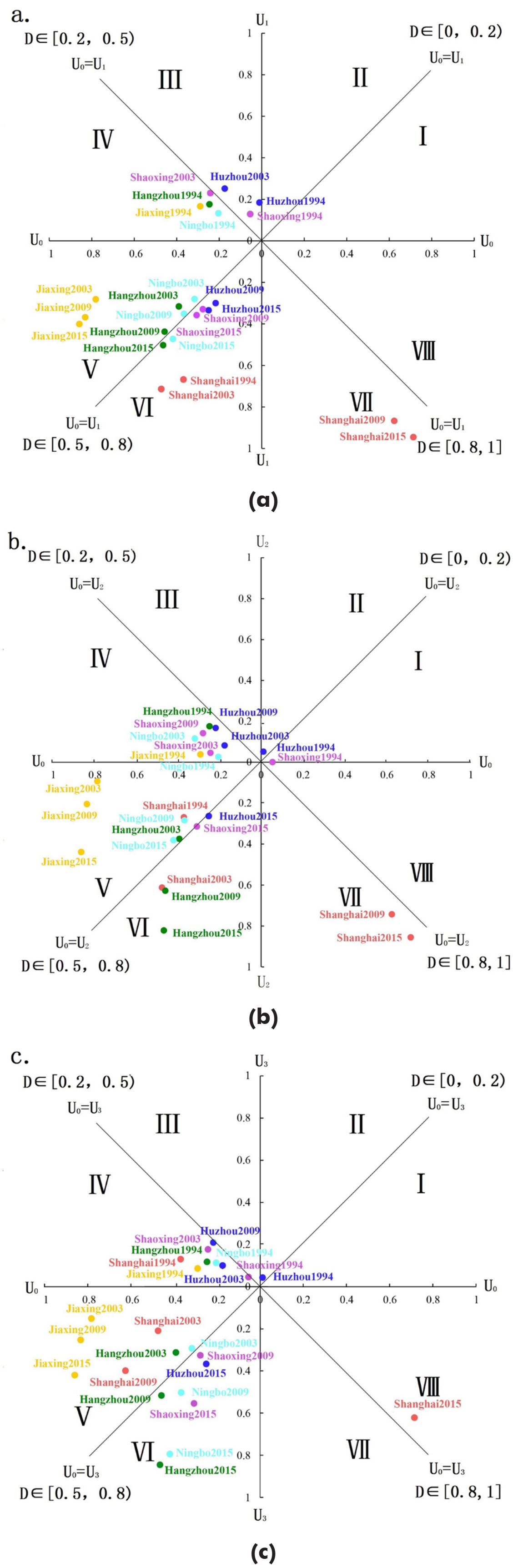

Figure 6. Coupling Coordination Degree of BLE(U_0) and demographic urbanization (U_1) (a), BLE and social urbanization (U_2) (b), BLE and economic urbanization (U_3), (c) in the cities of SHB during 1994 and 2015.

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land areas were able to provide enough room for the economic urbanization, showing an emphasis from the government on the coordination development between BLE and economic urbanization. Jiaxing had a similar BLE-Economic Urbanization developing trend as BLE-Social Urbanization, which reached V interval in 2015, indicating a weak coordination of built-up land and social urbanization as well. Hangzhou and Ningbo had similar changing trend during 1994 and 2015, reaching the VI interval at last, which is barely balanced development with BLE lagged. Huzhou had a rapid growth of development during 1994 and 2015. It grew from the unbalanced development stage in 1994 to IV interval in 2003, and from IV interval in 2009 to VI interval in 2015, which showed that the Huzhou government had emphasized on the coordination development between built-up land expansion and economic urbanization.

Discussion

The results of the coupling coordination degree are essential for cities in SHB in their future development planning. It is important to monitor the coupling coordination process and use the coupling coordination model to understand sustainable development between BLE and DSE urbanization in the SHB region. Demographic increase could surely improve social and economic benefits. In turn, the increase benefits of society and economy could absorb more people to move in (Hasan *et al.* 2017). During the cycling process, the expansion trend of built-up lands has been pushed forward. Besides, a great amount of young immigrant population from rural to urban would ask for more houses to live. And with social development, more and more public basic facilities, such as healthy communities, cultural facilities, schools, recreational facilities, art museums, gymnasiums, etc., were needed to satisfy people's demands of material culture and spiritual culture. Besides, rapid development of economy also brings increases in investment in urban construction, which leads to urban area to expand at an accelerated rate (Xu *et al.* 2000). All these aspects account for the constant expansion of built-up lands. In addition, built-up land expansion provides strong basic support and construction space for the development of demographic-social-economic urbanization. In another word, when the built-up lands cannot satisfy the demands of socio-economic development, the former would have an inhibitory effect on the latter to some extent. With the population increase, people have great demands for land resources and the land prices increase accordingly, which make the fringe areas become one of the best choices for investors. Developers choose suburbs as residential areas, and factories and schools move to the surrounding areas of the city, all of which lead to the construction of a serious of supporting facilities in these areas such as housing, schools, hospitals, transportation and service facilities (Tian *et al.* 2017). Moreover, the investment of financial business and improvement of social public service facilities can absorb more outlanders pouring into the urbans, and accordingly these people would contribute to the development and construction of those cities, and to cause the built-up land expansion year after year.

The increasing rate of built-up lands in Shanghai lags behind that of other cities in Zhejiang Province; it results from this city having had rapid development in the early 1990s, when some New Districts such as Pudong and Jiading were established in 1992 (Shi *et al.* 2009), so Shanghai displayed a low increasing rate value during after 1994. Then, due to China's Development Zone Policy, which was successful in attracting foreign direct investments and promote regional economic development (Zhang 2011), land price in central urban grows rapidly. This impelled many medium-sized and small enterprises to open factories in villages or towns, which may absorb the rural people who were restricted by the household

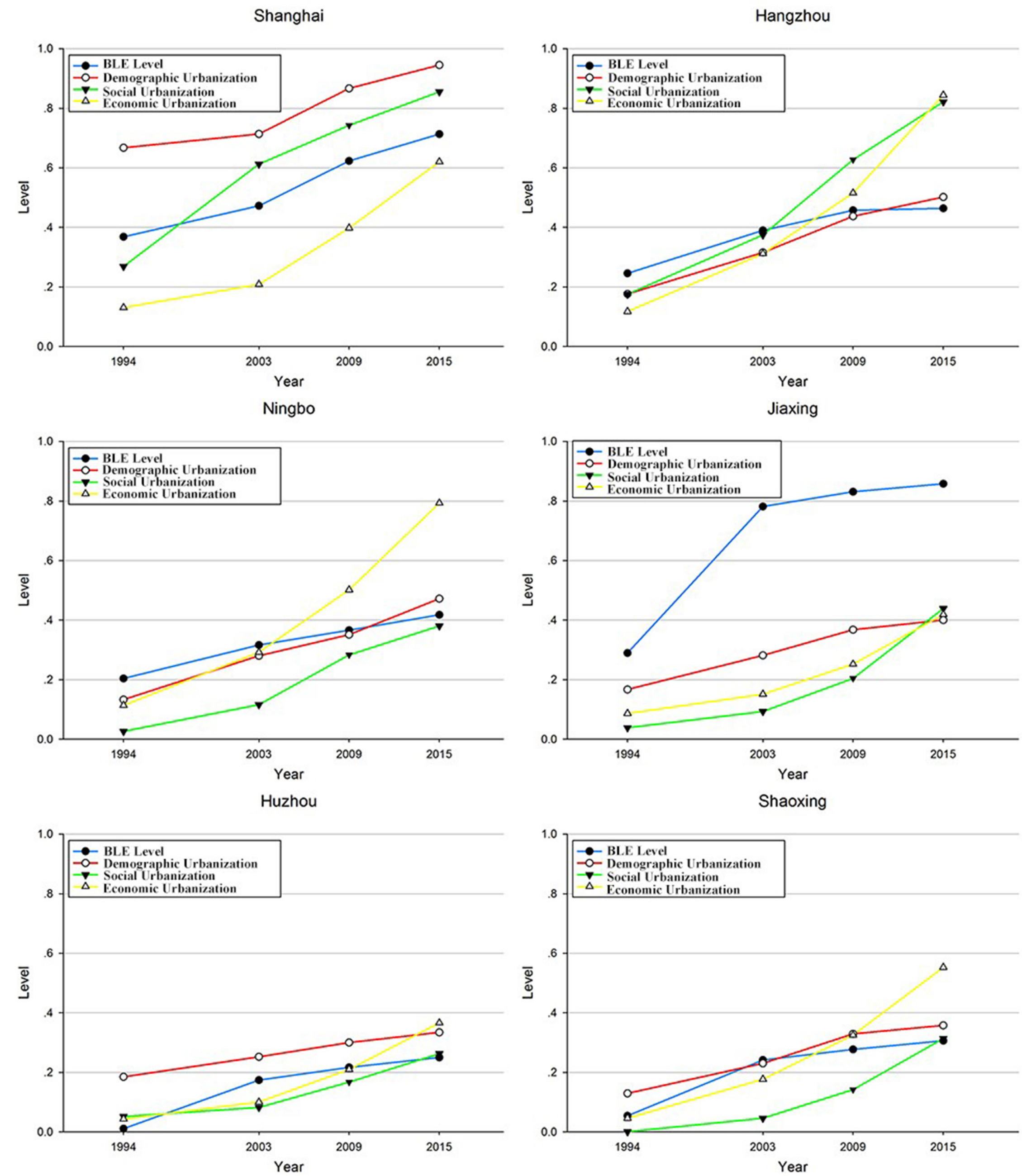

Figure 7. Trends of comprehensive levels in the BLE and DSE urbanization subsystem.

registration or cannot afford the cost living in central urban. Therefore, it significantly resulted in the accelerated population migration from rural or other remote areas to the developed villages or towns near the cities and sped up the built-up land expansion as well (Wu and Zhang 2012). Under these policies, built-up land expansion showed a rapid development from 1994–2003. Then in 2004, the central government issued a policy on strict land management system, aiming to control construction land growth and prevent cultivated land loss, in order to restrain the excessive land expropriation in the urban fringe to avoid or mitigate farmland degradation (Liu *et al.* 2015). Therefore, in our research, SHB displayed the lowest annual increase rate during 2003–2009 than other two stages.

Propelled by industrialization and urbanization, there is a great need of land resources for socio-economic development, pushing forward the built-up land expansion and absorbing a great amount of population to accumulate. Nevertheless, because of the certain lag comparing urban construction to population attraction and the restriction by the household registration system, the expansion rate of built-up lands would show faster trend than population growth. With the implementation of China's Yangtze River Economic Belt strategy, the social and economic development of urban agglomeration centered on Shanghai and Hangzhou will continue to be in the steady development trend. In addition, since urbanization was a key national development strategy (Bloom *et al.* 2008; Siciliano 2012), the urbans still demand for enormous land resources, which brings great challenges to the coordinated development of city, people and land.

Currently, the high speed of expansion of built-up lands and development of demographic-social-economic urbanization attracts a great deal of attention due to the extreme population boom, severe environmental damage and scarcity of land resources. By collaboration with adjacent cities, governments introduced a series of policies to monitor land use and urban planning, as well as a great number of decisions, such as household registration policy (Tyner and Ren 2016), housing restriction measures (Zhou 2016), agricultural tax reform (Takeuchi 2013), etc. to limit the freedom of rural population migration into urbans, aiming at avoiding uncontrolled demographic urbanization and built-up land expansion which may cause adverse social, land and environmental issues (Henríquez *et al.* 2006; Dewan and Yamaguchi 2009; Abu Hammad and Tumeizi 2012; Siciliano 2014). Since built-up land expansion will inevitably occupy large number of natural and seminatural lands, which can be the most intensive disturbance to natural ecosystems (Qin *et al.* 2017). Shen *et al.* (2017) found that megacities such as Beijing and Shanghai experienced increases in particulate matter (PM) 2.5 exposure due to migrants swarming into cities and rapid urbanization. Cao *et al.* (2017) pointed out that urbanization would cause haze pollution, which could further enhance urban heat. Xie *et al.* (2017) reported that land use change, especially urban expansion, has caused lake degradation and water pollution in the middle and lower Yangtze floodplain. Besides, built-up land expansion can also lead to soil sealing (Xiao *et al.* 2013), soil degradation (Tesfaye *et al.* 2015; Khaledian *et al.* 2017), green space reduction (Chan and Vu 2017; Liang *et al.* 2017), agricultural abandonment and intensification (Detsis 2010) and so on. These impacts on the eco-environment should all be seriously considered in the future in SHB region. Obviously, the interaction of different cities in urban metropolitan areas will become more and more frequent, and the population, society and economy will be closely connected. The environmental and ecological impacts by the built-up land expansion in one city are likely to cause harm to the environment and ecology in neighboring cities, which would indirectly influence social and economic development. Therefore, coordination among the neighboring governments in SHB should be strengthened to balance the conflicts between built-up land expansion and social-economic development.

The objective results could help identify contributions of BLE and DSE urbanization in subsystems and understand the complicated coupling coordination relationship, and then implement the coupling development policies to better balance built-up land expansion and demographic-social-economic urbanization. Obviously, with China's economy entering the new normal and China's strategic planning of the Yangtze River Economic Belt, the social and economic development of the Yangtze River Delta is swift and intense. The urban construction is still urgent for land resources in the future, which will promote further expansion of built-up lands, causing serious challenges to coordinated development of people and land. Consequently, further studies are essential to establish dynamic simulation for coordinated development of built-up land expansion and population growth, when considering how to change the mode of land resources exploitation and utilization, to control the excessive urban land expansion effectively and absorb the demographic accumulation reasonably.

Conclusions

Using SHB as an example, this study employed CCDM to analyze the changing trend of six cities, and to identify their developing process during 1994–2015 for providing suggestions for the future development. The harmonious development of BLE and DSE urbanization system is a dynamic process, which can be quantitatively evaluated by coupling coordination degree model. At different stages, built-up land expansion could produce push or pull forces toward demographic-social-economic urbanization. In turn, urban development also has feedback influences on built-up land expansion at the same time. This is a nonlinear interaction that can be identified through CCDM. As the above result shows, Shanghai witnessed a lower annual rate of built-up land expansion and social-economic urbanization, while this city has a superior coupling coordination degree due to its successfully implemented policies and land planning. In addition, the degree of coupling coordination between BLE and DSE had the trend to ascend in general during 1994 and 2015, indicating that most cities in SHB emphasized the coordinate development between BLE and DSE, while there are still some cities such as Jiaxing that ignored this issue. Consequently, the government and decision makers should pay particular attention to monitoring the coupling subsystems and understanding the factors influencing the degrees of coupling coordination between built-up land expansion and demographic-social-economic urbanization. Besides, taking advantage of superiorly balanced development of Shanghai, all the governments should strengthen the coordination to provide suggestions for the development of urban agglomeration in SHB.

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