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Comprehensive Assessment of Urbanization Coordination: A Case Study of Jiangxi Province, China

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Abstract: In order to make assessment on urbanization coordination, we developed a comprehensive model by integrating entropy weight method (EWM), coupling degree model (CDM), coupling coordination degree model (CCDM), multi-index grading method (MIGM) and Remote Sensing & Geographic Information System (RS & GIS) technology. Then we applied this integrated model to a case study in Jiangxi Province, China. Our study finds that: 1) EWM, CDM and CCDM can evaluate the temporal dynamic of urbanization. Urbanization process of Jiangxi Province can be divided into three periods, the stable development period (1990–2001), the accelerated development period (2002–2009) and the rapid development period (2010–2015). Coordinated development of urbanization in Jiangxi Province can be divided into two phases, an increasingly coordinated phase (1990–2003) and an increasingly incongruous phase (2003–2015). The state transition was due to low development rate of population urbanization. 2) RS & GIS technology is an effective tool for detecting urban growth. Urban construction land area of Jiangxi Province increased from 615.8 km^2 in 1990 to 2896.8 km^2 in 2015, and the per capita urban construction land area (PCUCLA) reached 122.9 m^2, with the maximum value of 343 m^2 in Gongqingcheng City. 3) MIGM and RS & GIS technology can analyze spatial difference of urbanization. There is a significant spatial difference in socioeconomic development at county scale, with the maximum value six times the minimum value for both PCUCLA and per capita GDP in 2015. Population urbanization lag and excessive land use are the main reasons for uncoordinated urbanization. There were 15 counties with a lag in demographic urbanization and 33 counties where PCUCLA exceeded the national standard in 2015, among which 20 exceeded the national standard of PCUCLA by 50% ($\geq$165 m^2). Since there are significant spatio-temporal differences in urbanization, it is necessary to carry out a comprehensive assessment to facilitate differential urbanization strategy making.

Keywords: urban construction land; coupling degree model; entropy weight method; multi-index grading method; Remote Sensing & Geographic Information System Technology

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1 Introduction

Urbanization is one of the most significant transformations occurring in contemporary human society; however, uncoordinated urbanization has caused lots of urban problems in many developing countries (Chen et al., 2013a; Mulligan, 2013; You, 2015). As the largest developing country, China suffers a range of problems caused by rapid urbanization, including environmental pollution (Chen et al., 2013b; Wang et al., 2013; Ren et

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al., 2014; Ameen et al., 2015), wastage of land resources (Ameen et al., 2015; Chen et al., 2016; Liu et al., 2017), and widened urban-rural gap and regional disparities (Chen et al., 2014; Zhou et al., 2015). Therefore, the coordinated development of China's urbanization has attracted considerable attention from policy makers and scholars (Bai et al., 2014; State Council of China, 2014; Chen et al., 2016).

Urban development is a complex system, so we need to focus on the main issues in the study of urbanization. The three most important aspects of urbanization include population, land and economy. In the process of urbanization, people are the central and leading aspect, while economic activities serve as the driving force, and land or geographic space is the stage—the physical or material setting as well as the product (Sun et al., 2013). Healthy urban development depends on the coordinated development in all respects, but that is not the case in most developing countries (Mulligan, 2013; Chen et al., 2014; You, 2015). *Hukou* (an official residency status) and land finance are the root causes of population urbanization lag and excessive land use in China's urbanization (Sun et al., 2013; Bai et al., 2014; He et al., 2016; Hu, 2016).

There are extensive researches on the coordinated development of China's urbanization, which can be divided into two categories. First, many studies have evaluated coordinated development of urbanization over time, including the coordination among urbanization subsystems (Chen et al., 2013a; You, 2015; Zhou et al., 2015), or coordination between urbanization with resource environment (Ren et al., 2014; Ameen et al., 2015; Chen et al., 2016; Liu et al., 2017). Second, there are many studies on spatial difference of urbanization level (Chen et al., 2014, 2016; Zhou et al., 2015). Temporal evolution research is helpful to analyze the process of urbanization and predict its development tendency, but it can not show the spatial differences of urbanization. Thus, a distinguishing development strategy can not be developed. Similarly, spatial difference studies fail to consider process and development tendency of urbanization. Therefore, it is necessary to carry out a spatio-temporal dynamic comprehensive research on coordinated development of urbanization (Li, 2013; Tan et al., 2016).

Index system has important influence on the evaluation result of urbanization. Single index methods are simple and clear (Chen et al., 2014, 2016; He et al., 2016), but they can not indicate the complexity of urbanization processes. Comprehensive index assessment methods involve more information on urbanization (Wang and Cai, 2008; Ren et al., 2014; Wang et al., 2014; You, 2015; Zhou et al., 2015), however, the indexes may have impact on each other and affect the significance of their real relationship. Furthermore, the evaluation results of different index system can not be compared directly (Tan et al., 2016). Sometimes, differences in indexes and methods could even lead to opposite result. For example, for the relationship between urbanization level and economic development level, some studies compare urbanization rate with economic growth rate, and suggest that China is under-urbanized (Chang, 2002; Chang and Brada, 2006; Bai et al., 2014; Lu and Wan, 2014). In contrast, other studies propose that China is confronting over-urbanization, based on the evidence that dramatic increase in the number of rural-urban migrants and the amount of urbanized land (Lu et al., 2007; Chen et al., 2013a). Therefore, it is necessary to establish a comparable and operable index system, to realize the spatial difference analysis of urbanization.

Excessive occupation of land resources is an important feature of China's urbanization. In the year 2016, there were more than 3500 new urban areas at the county level or above, and the planned population in these new areas reached 3400 million (Zheng and Zheng, 2017). Some studies indicate that one third of the development zones are left unused in China (Liu et al., 2014). However, the urban construction land area (UCLA) indicator has been neglected in most research on urbanization (Chang and Brada, 2006; Chen et al., 2013a; He et al., 2016). Some studies only choose urban built-up area index as an alternative (Sun et al., 2013; Wang et al., 2014; You, 2015; Chen et al., 2016). Urban built-up area matches poor with the urban population data which have been used for many years, meanwhile, urban built-up area neglects the heterogeneity of urbanization level at county level (Wang et al., 2012). In recent years, the integration of RS & GIS technology has provided a range of effective tools for detecting urban growth (Hu et al., 2015; Hegazy and Kaloop, 2015; Kamusoko, 2017). Therefore, it is necessary to use RS & GIS technology to monitor the spatio-temporal dynamic of urban construction land.

In this study, Jiangxi Province was chosen as a case study. Jiangxi Province is backward in social and economic development, however, its per capita industrial and mining land area has reached 148 m^2 (People's Government of Jiangxi Province, 2016). With the implementation of major national economic and social development programs, such as the 'Su District Revitalization Plan' and 'Poyang Lake Eco-economic Region', there will be new challenges in urbanization of Jiangxi Province. In order to realize the comprehensive evaluation of Jiangxi Province's urbanization, we have developed a spatio-temporal dynamic assessment model of urbanization by integrating EWM, CDM, CCDM, MIGM and RS & GIS technology. This study intends to obtain three primary objectives: 1) to make a spatio-temporal dynamic comprehensive evaluation of urbanization; 2) to establish a new index system for spatial difference analysis of urbanization, which is comparable and operable; 3) to accurately detect the spatial and temporal dynamics of urban construction land by RS & GIS technology.

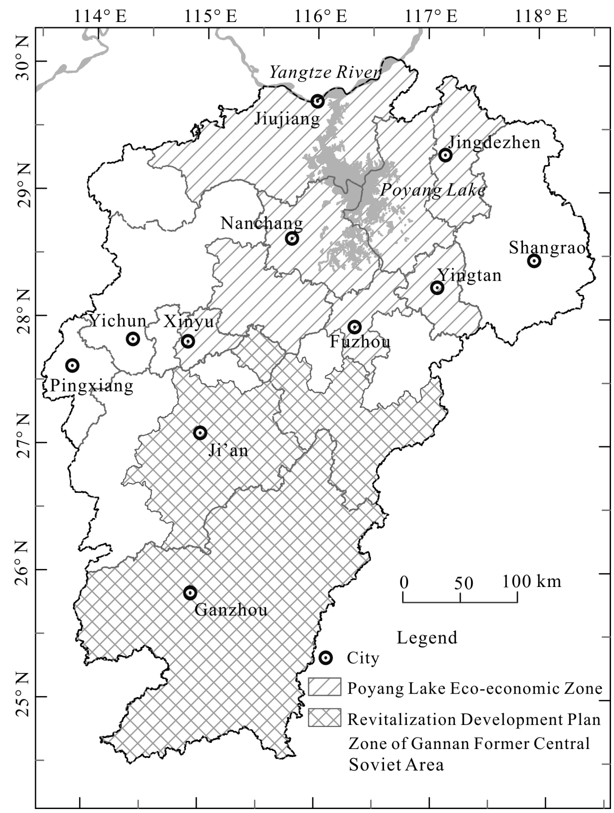

Fig. 1 Location of Jiangxi Province, China

2 Data and Methods

2.1 Study area

Jiangxi Province is situated in central China on the southern bank of the middle and lower reaches of the Yangtze River. It is located at latitude 24°29′N–30°04′N, longitude 113°34′E–118°28′E (Fig. 1). The total area of Jiangxi Province is 166 900 km^2. Jiangxi Province is backward in social and economic development; however, the gap has narrowed in recent years. Studies showed that urbanization in Jiangxi Province has been basically coordinated (Chen et al., 2014), however, the land urbanization has been faster than the demographic urbanization in recent years (Li, 2013). Construction land resource of Jiangxi Province was deficient during the 12th Five-year Plan period, with the annual construction land gap reaching 9400 ha. However, land resources have been seriously wasted in Jiangxi Province. In the year 2015, the per capita urban industrial and mining land area was 148 m^2, and the per capita rural residential area reached 260 m^2 (People's Government of Jiangxi Province, 2016). With the implementation of major national economic and social development programs, such as the 'Some opinions of the State Council on support Gannan former Soviet central development' and 'Poyang Lake Eco-economic Region', there will be new challenges in urbanization of Jiangxi Province.

2.2 Datasets

The cities, towns and administrative division data of Jiangxi Province were derived from the Atlas of Jiangxi Province. Municipal districts were merged into county administrative units, forming a total of 92 county-level units. Urban construction land data were obtained from six periods of Landsat satellite images (1990, 1995, 2000, 2005, 2010 and 2015). Paths and rows of these images are 120/040-041, 121/039-043, 122/039-042 and 123/040-041. A total of 84 winter or spring images were used, including Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI). The data format is Collection 1 and all images were downloaded from United States Geological Survey (USGS: https://landsat.usgs.gov/).

Statistical data used in this study were collected from Jiangxi Statistical Yearbook (1991–2016) (Statistics Bureau of Jiangxi Province, 1991–2016). Some statistical data on cities were collected from China's City Statistical Yearbooks (1991–2016) (China's National Bureau of Statistics, 1991–2016). County-scale statistical data in 2015 were collected from Jiangxi Statistical Yearbook (2016) and the statistical yearbooks (2016) of 11 prefecture-level cities in Jiangxi Province.

2.3 Methods

In this study, a comprehensive model was used to evaluate the coordination of urbanization. Different submodels and index systems were selected for different targets. First, area and location information of urban construction land were extracted from remote sensing images. Second, EWM, CDM and CCDM were used to evaluate the evolution of urbanization at provincial scale. Third, MIGM and RS & GIS technology were used to realize spatial difference analysis of urbanization at county scale. The structure of the comprehensive model is shown in Fig. 2, and the detailed algorithm is detailed below.

2.3.1 Urban construction land extraction

Urban construction land was extracted from remote sensing image by manual digitization. Urban construction land is composed of e.g., residential land, industrial land, road transportation land and green space, so it is difficult to extract urban construction land from remote sensing images automatically. In this study, urban construction land was distinguished from rural residential by the location of towns and streets. First, we used manual digitization to extract urban construction land in 2015, and then revised it with high resolution images from Google Earth. Second, we used the data digitized and corresponding Landsat satellite images to extract urban construction land in 2010, 2005, 2000, 1995 and 1990. Finally, urban construction land data were allocated to 92 counties by location in ArcGIS software, and area data of other years were generated through linear interpolation.

2.3.2 Temporal dynamic assessment of urbanization

In this study, temporal dynamic assessment of urbanization was carried out at provincial scale, which included temporal evolution of urbanization level and urbanization coordination. The urbanization level was evaluated by comprehensive index model of EWM, and the urbanization coordination was evaluated by methods of

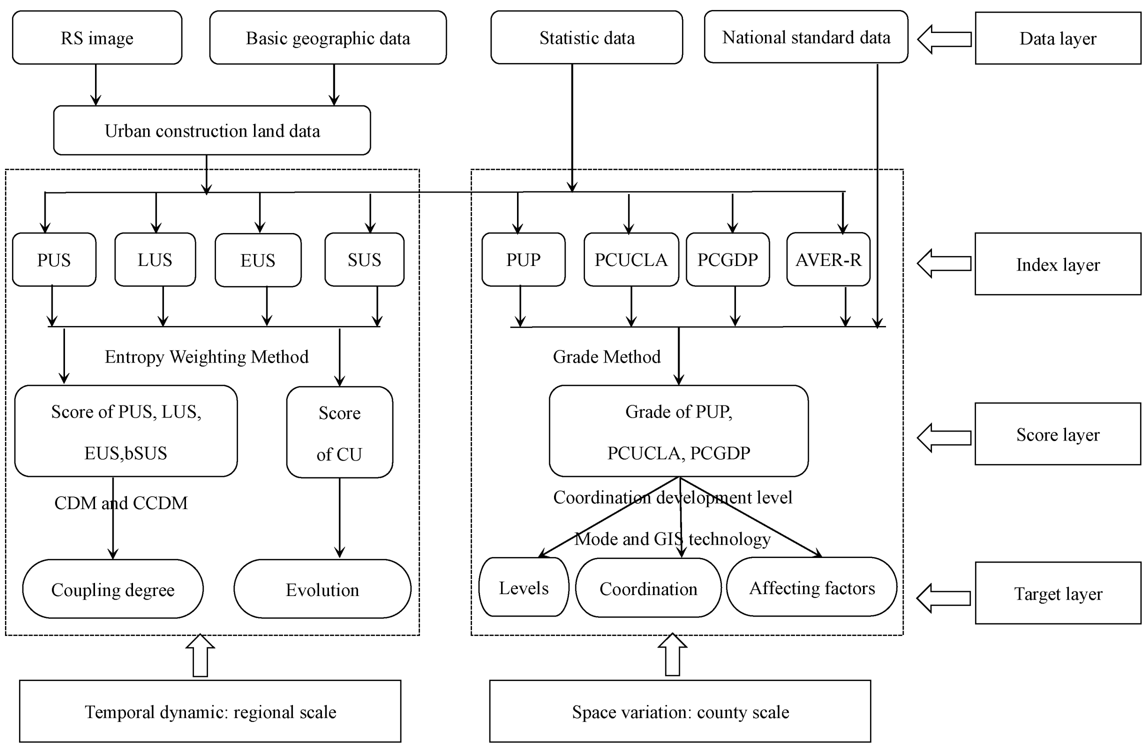

Fig. 2 Structure diagram of urbanization's comprehensive evaluation model. PUS: population urbanization subsystem; LUS: land urbanization subsystem; EUS: economic urbanization subsystem; SUS: social urbanization subsystem; CU: comprehensive urbanization; PUP: proportion of urban population; PCUCLA: per capita urban construction land area; PCGDP: per capita gross domestic product; AVER-R: regional average of PUP, PCUCLA and PCGDP; CDM: coupling degree model; CCDM: coupling coordination degree model

CDM and CCDM, details will be shown below.

(1) Entropy weight method

Indicator's weight measures the relative importance of each element in terms of its contribution to the overall system. EWM determines the indicator's weight based on the effect size of each indicator, so it is not disproportionally influenced by experts' subjective knowledge (Li and Li, 2014). EWM has been widely used in urbanization assessment (Wang et al., 2015; You, 2015). The main steps are as follows (Chen et al., 2010).

Data standardization: To avoid zero values, we standardize all data using Equation (1) and Equation (2) (Shen et al., 2015).

Positive indicators:

$$X'_{ij} = \frac{X_{i,j}}{\max_j (x_{i,j})} \tag{1}$$

Negative indicators:

$$X'_{ij} = \frac{\min_j (X_{i,j})}{X_{i,j}} \tag{2}$$

Calculating the proportion of index j in year i:

$$Y_{ij} = X'_{ij} / \sum_{i=1}^{m} X'_{ij} \tag{3}$$

Calculating the information entropy of the index:

$$e_j = \frac{1}{\ln m} / \sum_{i=1}^{m} (Y_{ij} \times \ln Y_{ij}) \qquad 0 \le e_j \le 1 \tag{4}$$

Calculating the redundancy of information entropy:

$$d_j = 1 - e_j \tag{5}$$

Calculating the weight of the index:

$$w_j = d_j / \sum_{j=1}^{n} d_j \tag{6}$$

Calculating the value of a single index evaluation:

$$S_{i,j} = w_j \times X'_{ij} \tag{7}$$

Calculating the value of the comprehensive evaluation in year i:

$$S_i = \sum_{j=1}^{n} S_{i,j} \tag{8}$$

where X_{ij} represents the value of index j in year i, $\min_j(X_{ij})$ and $\max_j(X_{ij})$ expresses the minimum and the maximum of index j, respectively, m is the number of years and n is the number of indexes, Y_{ij} represents the proportion of index j in year i, e_j represents the information entropy of index j, d_j represents the information entropy's redundancy of index j, w_j represents the weight of index j, S_{ij} represents the evaluation value of index j, S_i represents the comprehensive evaluation value in year i.

(2) Coupling degree model and coupling coordination degree model

Coupling describes the phenomenon by which two or more systems influence each other through interactive mechanisms (Li et al., 2012). The concept has been widely applied in research on urbanization coordination, the coupling degree among elements of urbanization can be defined by the following standard expression (He et al., 2017):

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

The coupling degree model for two, three and four elements of urbanization can be written as:

$$C_2 = \left\{ (U_i \times U_j) / \left[\left(\frac{U_i + U_j}{2} \right) \left(\frac{U_i + U_j}{2} \right) \right] \right\}^{1/2} \tag{10}$$

$$C_3 = \left\{ (U_1 \times U_2 \times U_3) / \left[\left(\frac{U_1 + U_2}{2} \right) \left(\frac{U_1 + U_3}{2} \right) \left(\frac{U_2 + U_3}{2} \right) \right] \right\}^{1/3} \tag{11}$$

$$C_4 = \left\{ (U_1 \times U_2 \times U_3 \times U_4) / \left[\left(\frac{U_1 + U_2}{2} \right) \left(\frac{U_2 + U_3}{2} \right) \left(\frac{U_3 + U_4}{2} \right) \left(\frac{U_4 + U_1}{2} \right) \right] \right\}^{1/4} \tag{12}$$

where U_i represents the urbanization level of subsystem i, n is the number of urbanization subsystem, C represents the coupling degree of urbanization subsystem, and the minimum value of C is 0, while the maximum value is 1.

Although the coupling degree model can characterize the degree of intersystem coupling, it is not able to distinguish between low level coupling and high level coupling. The coupling coordination degree model (CCDM) has been developed to solve this problem (Sun et al., 2013; He et al., 2017). This model was defined as follows:

$$T = aU_1 + bU_2 + cU_3 + dU_4 \quad (13)$$

$$D = \sqrt{C \times T} \quad (14)$$

where U_i represents the urbanization level of subsystem i, T represents the level of comprehensive urbanization, a, b, c, and d denote the contribution of U_1, U_2, U_3 and U_4 to the comprehensive system, respectively. C represents the coupling degree of U_1, U_2, U_3 and U_4, D is the coupling coordination degree between U_1, U_2, U_3 and U_4.

2.3.3 Spatial difference analysis of urbanization

In this study, spatial difference of urbanization was evaluated at county scale, which also includes two aspects: spatial difference of urbanization level and driving factor difference of uncoordinated urbanization. The three most important aspects of urbanization relate to population, land and economy (Sun et al., 2013), furthermore, population urbanization lag and excessive land use are the most important issue of China's urbanization (Bai et al., 2014; State Council of China, 2014), so we chose the proportion of urban population (PUP), per capita urban construction land area (PCUCLA) and per capita gross domestic product (PCGDP) to represent demographic urbanization, land urbanization and economic urbanization respectively. The analysis method is shown below in details.

(1) Multi-index grading method for urbanization level evaluation

When there is no clear standard, comparison based on the average value is a common method for urbanization level evaluation (Wang et al., 2012; Chen et al., 2013a, 2014). In this study, based on the average of Jiangxi Province and current national standards of PCUCLA (Ministry of Housing and Urban-Rural Construction of the People's Republic of China, 2012), the indicators of urbanization level were divided into five grades. Classification parameters of the three indicators are shown in Table 1. Given that demographic urbanization and economic urbanization often lag behind land urbanization in China, 130 m^2 is set as the maximum value for middle level, middle-high level and high level of PCUCLA, which is about 1.2 times the national standard.

(2) Multi-index grading method for urbanization coordination evaluation

Healthy urbanization depends on the coordinated development of population, land and economy. To facilitate the comparison between these variables, we converted the levels of urbanization subsystems to digital values, with 1 representing the low level and 5 representing the high level. We chose 145 m^2 and 165 m^2 as two cut-off points of PCUCLA, respectively about 1.3 and 1.5 times the national standard of PCUCLA (110 m^2). When PCUCLA was between 130 m^2 and 145 m^2, we assigned 6 to land urbanization level, which represent that the land urbanization slightly exceeds the national standards of PCUCLA. Correspondingly, 7 and 8 were assigned when PCUCLA was between 145 m^2 and 165 m^2, and over 165 m^2, which represent that the land urbanization moderately and severely exceeds the national standards of PCUCLA respectively. In this study, urbanization coordination was divided into four classes: high coordination, basic coordination, slight incongruity and serious incongruity. The classification process is shown in Fig. 3.

Table 1 Classification parameters of PUP, PCUCLA and PCGDP

Level	PUP (%)	PCGDP (10^4 yuan (RMB))	PCUCLA (m^2)
High level	80.0≤PUP<100.0	PCGDP≥5.0	90.0≤PCUCLA <130.0
Middle-high level	55.0≤PUP<80.0	3.8≤PCGDP <5.0	90.0≤PCUCLA <130.0
Middle level	48.0≤PUP<55.0	3.0≤PCGDP <3.8	90.0≤PCUCLA <130.0
Middle-Low level	40.0≤PUP <48.0	2.0≤PCGDP <3.0	70.0≤PCUCLA <90.0
Low level	PUP <40.0	PCGDP <2.0	PCUCLA <70.0
Provincial average	51.6	3.40	122.9

Notes: when PCUCLA is greater than 130 m^2, it has exceeded the normal range of fluctuation and does not represent a higher level of land urbanization; PUP: proportion of urban population; PCUCLA: per capita urban construction land area; PCGDP: per capita gross domestic product, when PCUCLA is greater than 130 m^2, it has exceeded the normal range of fluctuation and does not represent a higher level of land urbanization

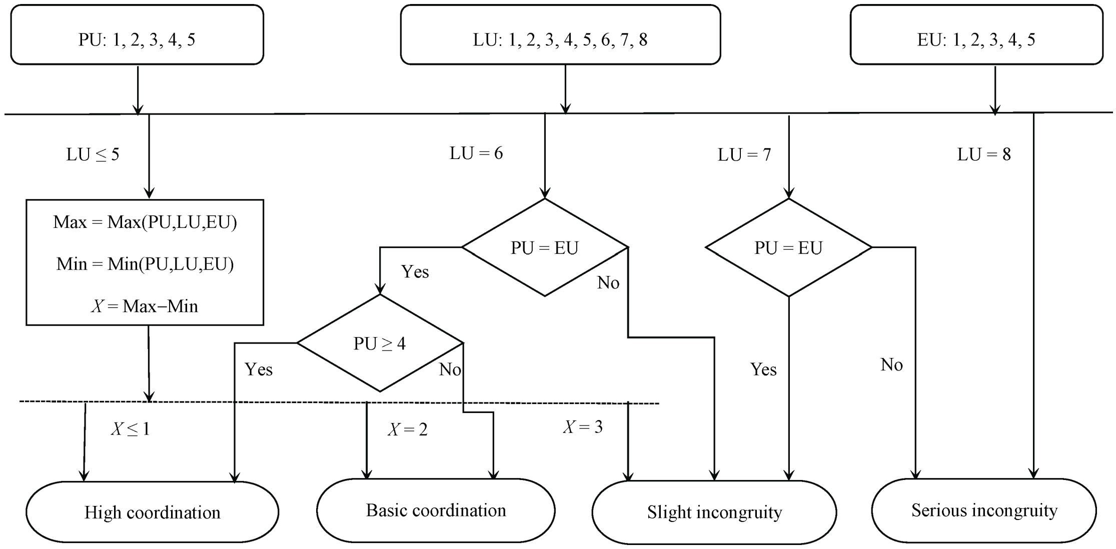

Fig. 3 Decision flow chart for coordinated development degree of urbanization. PU, LU, EU indicate population urbanization, land urbanization and economic urbanization

3 Results

3.1 Temporal evolution of urbanization level

Multi-dimensional systems for urbanization typically incorporate four dimensions: demographic, economic, spatial and social (Guo et al., 2015; You, 2015). In this study, we chose 16 indicators in temporal evolution evaluation of urbanization level at province scale in 1990–2015. The weights of these indicators were calculated by EWM in Excel. Per capita total government revenue has the highest weight of 0.1526 (Table 2), followed by fixed investment density (0.1218) and per capita GDP (0.1067), indicating that economic growth and fixed investment were the most important driving forces of urbanization. Economic urbanization (0.3416) and land urbanization (0.2958) were the main characteristics of urbanization in 1990–2015, demographic urbanization was the slowest (0.1243).

Table 2 Index systems and weights for urbanization comprehensive evaluation

Subsystem	Weight (%)	Variable (unit)	E-value	Weight (%)
U_P	0.1243	U_{P1} Urban population size (10^4 person)	0.9579	0.0336
		U_{P2} Proportion of urban population (%)	0.9601	0.0319
		U_{P3} Proportion of labor force in non-agriculture (%)	0.9672	0.0262
		U_{P4} Population density in built-up area (person/km^2)	0.9591	0.0326
U_L	0.2958	U_{L1} The built-up area (km^2)	0.9375	0.0499
		U_{L2} Public green area (km^2)	0.9397	0.0481
		U_{L3} Fixed investment density (10^4yuan/km^2)	0.8474	0.1218
		U_{L4} Area of paved roads in city (km^2)	0.9047	0.0760
U_E	0.3416	U_{E1} Per capita GDP (yuan/person)	0.8662	0.1067
		U_{E2} Proportion of GDP in non-agriculture (%)	0.9662	0.0270
		U_{E3} GDP density of non-agriculture (10^4yuan/km^2)	0.9307	0.0553
		U_{E4} Per capita total government revenue (yuan/person)	0.8087	0.1526
U_S	0.2383	U_{S1} Per capita disposable income of urban residents (yuan/person)	0.9005	0.0794
		U_{S2} Enrollment of undergraduate and graduate students (person)	0.8861	0.0909
		U_{S3} Proportion of urban population participating in pension and unemployment insurance (%)	0.9609	0.0312
		U_{S4} Hospital beds per ten thousand people	0.9539	0.0368

Note: U_P, population urbanization; U_L, land urbanization; U_E, economic urbanization; U_S, social urbanization; E-value: information entropy

The temporal evolution of urbanization level is shown in Fig. 4, from which we can see that urbanization level improved gradually in Jiangxi Province from 1990 to 2015. Based on the scores of comprehensive urbanization, the urbanization process in Jiangxi Province can be divided into three periods: the stable development period (1990–2001); the accelerated development period (2002–2009) and the rapid development period (2010–2015). In the stable development period, the scores of comprehensive urbanization increased steadily from 0.1510 to 0.2795 with an annual growth of 0.0117. In the accelerated development period, the scores increased from 0.2795 to 0.5982 with an annual growth of 0.0398. In the rapid development period, the scores increased from 0.5982 to 1.0 with an annual growth of 0.0670.

Fig. 4 also shows the temporal evolution of urbanization subsystems in 1990–2015. The urbanization level of four subsystems continued to grow in 1990–2015, but the leading components varied over time. From 1990 to 2001, population urbanization was ahead of the other three, and social urbanization topped from 2002 to 2008, briefly led by land urbanization in 2009, and then economic urbanization became dominant after 2010. Population urbanization had the slowest growth, and the gap between demographic urbanization and others gradually increased after 2003, indicating that the process of urbanization has changed from a population-leading type to a population-lagging one.

3.2 Temporal dynamic of urbanization coordination

Based on the scores of urbanization subsystems, we calculated the coupling degree between two, three and four elements by Equations (10), (11) and (12) respectively. At the same time, coupling coordination degree of the four elements was calculated by the CCDM (Equations 12–14), then we got eleven coupling degree curves and one coupling coordination degree curve (Fig. 5). According to Fig. 5, we can divide the temporal dynamic of coupling degree into two phases, the first phase was from 1990 to 2003, during which the coupling degree among urbanization subsystems increased gradually, and the second phase was from 2003 to 2015, during which the coupling degree among urbanization subsystems decreased gradually. On the whole, coupling degree between population urbanization with others was the worst. The coupling coordination degree increased gradually from 0.382 in 1990 to 0.980 in 2015.

3.3 Urbanization classifications

County's urbanization level took the median value of the three indicators (Table 1), so they were also made up of five grades: low level, middle-low level, middle level, middle-high level and high level. County's urbanization coordinated development grade was calculated according to Fig 3. The classifications of county's urbanization in 2015 are shown in Table 3, and the statistical information on the classifications is shown in Table 4.

Table 4 shows that 68.48% of the counties are highly coordinated or basically coordinated, and 23.91% of the counties are seriously incongruous. Urbanization of most highly coordinated counties are of low-level or middle-low level, and that of most seriously incongruous counties are above middle level. There are 22 and

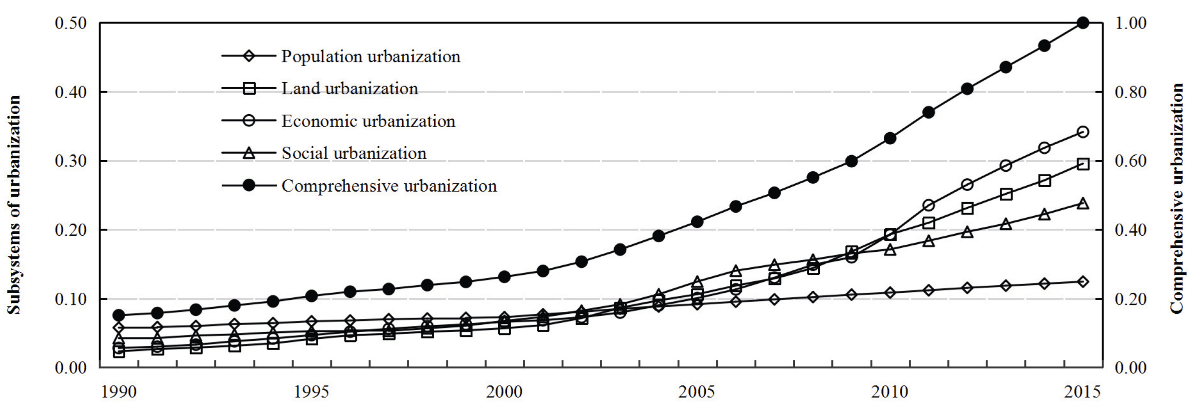

Fig. 4 Temporal evolution of urbanization level for Jiangxi Province in 1990–2015

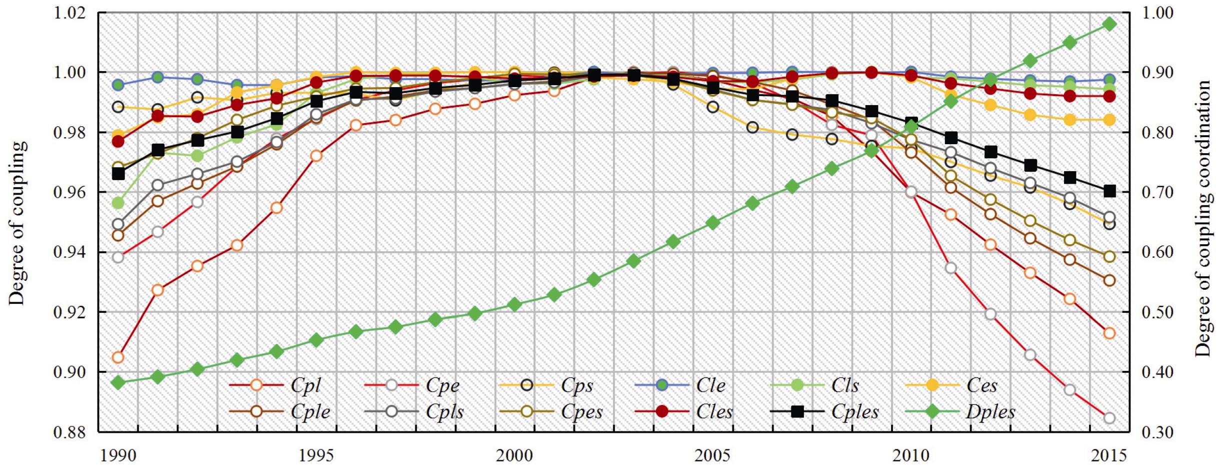

Fig. 5 Temporal dynamic of urbanization coordination development degree for Jiangxi Province in 1990–2015. *Cpl*, coupling degree between population urbanization and land urbanization; *Dples*, degree of coupling coordination between population urbanization, land urbanization, economic urbanization and social urbanization; *C*, coupling degree; *p*, population urbanization; *l*, land urbanization; *e*, economic urbanization; *s*, social urbanization

Table 3 Classification results of county-level urbanization in 2015

Urbanization level	Coordination level	Counties and municipal districts
High level	High coordination	Jingdezhen municipal district, Nanchang municipal district, Pingxiang municipal district
	Basic coordination	Fenyi
	Slight incongruity	Zhangshu, Guixi, Xinjian
	Serious incongruity	Xinyu municipal district, Gongqingcheng, Jiujiang municipal district, Yingtan municipal district, Nanchang, De'an
Middle-high level	High coordination	Jinggangshan, Shangrao municipal district, Dexing
	Basic coordination	Jinxian
	Slight incongruity	Ji'an municipal district
	Serious incongruity	Longnan, Hukou, Anyi, Shanggao, Ganzhou municipal district
Middle level	High coordination	Zixi, Anfu, Wanniang, Hengfeng, Xiajiang, Nancheng, Fengxin, Luxi
	Basic coordination	Fuzhou municipal district, Yongxiu, Nanfeng, Guangfeng, Leping
	Slight incongruity	
	Serious incongruity	Yichun municipal district, Xin'gan, Yifeng, Xingzi, Ruichang, Jiujiang, Ji'an, Fuliang, Dingnan
Middle-low level	High coordination	Wan'an, Huichang, Yongxin, Ganxian, Quannan, Yanshan, Yiyang, Jishui, Xinfeng, Yongfeng, Lianhua, Chongyi, Dayu, Chongren, Wuyuan, Tonggu, Jing'an, Shangrao, Taihe, Pengze, Guangchang, Dongxiang, Nankang
	Basic coordination	Shangli, Yushan, Ruijin, Wanzai, Yujiang, Wuning
	Slight incongruity	Fengcheng, Lichuan, Gao'an
	Serious incongruity	Jinxi, Yihuang
Low level	High coordination	Duchang, Poyang, Yudu, Ningdu, Yugan, Xunwu, Xingguo, Shicheng, Suichuan, Xiushui, Shangyou, Le'an, Anyuan

Table 4 Statistical information of county-level urbanization classifications in 2015

	Serious incongruity	Slight incongruity	Basic coordination	High coordination	Total	Percentage (%)
High level	6	3	1	3	13	14.13
Middle-high level	5	1	1	3	10	10.87
Middle level	9	0	5	8	22	23.91
Middle-low level	2	3	6	23	34	36.96
Low level	0	0	0	13	13	14.13
Total	22	7	13	50	92	100.00
Percentage (%)	23.91	7.61	14.13	54.35	100.00	–

34 counties with middle level and middle-low level, respectively, accounting for 60.87% of the total. High level, middle-high level and low level account for 14.13%, 10.87% and 14.13% of the total respectively.

3.4 Spatial differences of urbanization

Spatial difference of socioeconomic development is obvious in Jiangxi Province (Table 5). In the year 2015, the PUP in Jingdezhen was as high as 93.65%, while that in Duchang was only 33.62%. For PCUCLA and PCGDP, their maximum values were more than six times their minimum values respectively.

To analyze spatial difference of urbanization level, we have made an overview map of Jiangxi Province (Fig. 6). The map includes terrain, railways and Poyang Lake, which are closely related to the spatial difference of urbanization level. According to the classification results of urbanization level (Table 3), we produced a spatial difference map of urbanization level (Fig. 7). Fig. 6 and Fig. 7 show that spatial difference of urbanization level is closely related to terrain and transportation. There are 23 counties which have a high level or middle-high level of urbanization, twenty of which are located in flat areas, except Jinggangshan (tourist city), Dexing (resource-based city) and Longnan. Counties with high level of urbanization are almost located in the central and northern part of Jiangxi Province, along the Beijing-Kowloon and Zhejiang-Jiangxi railways. Counties with low level of urbanization are almost located in mountainous or flood-prone areas around Poyang Lake.

Based on Table 3, a spatial difference map of urbanization coordination was made (Fig. 8a), Fig. 8a shows that counties with uncoordinated urbanization are all located in the central and northern regions of Jiangxi Province except for Ganzhou, Longnan and Dingnan. Fig. 8b shows that population urbanization lag and excessive land use are the main reasons for the uncoordinated develment of urbanization. There are 15 counties with a lag in demographic urbanization, while Zhangshu

Table 5 Information of PUP, PCUCLA and PCGDP in 2015

Indicators	PUP (%)	PCUCLA (m^2)	PCGDP (10^4 yuan)
Provincial average value	51.62	122.91	3.40
Maximum value	93.65	343.03	8.64
Minimum value	33.62	51.18	1.30

Note: PUP: proportion of urban population; PCUCLA: per capita urban construction land area; PCGDP: per capita gross domestic product

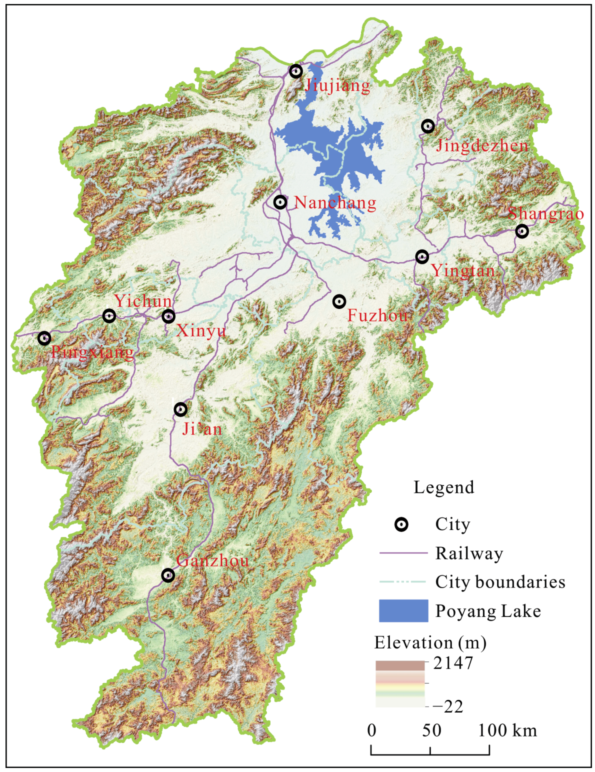

Fig. 6 Overview map of Jiangxi Province

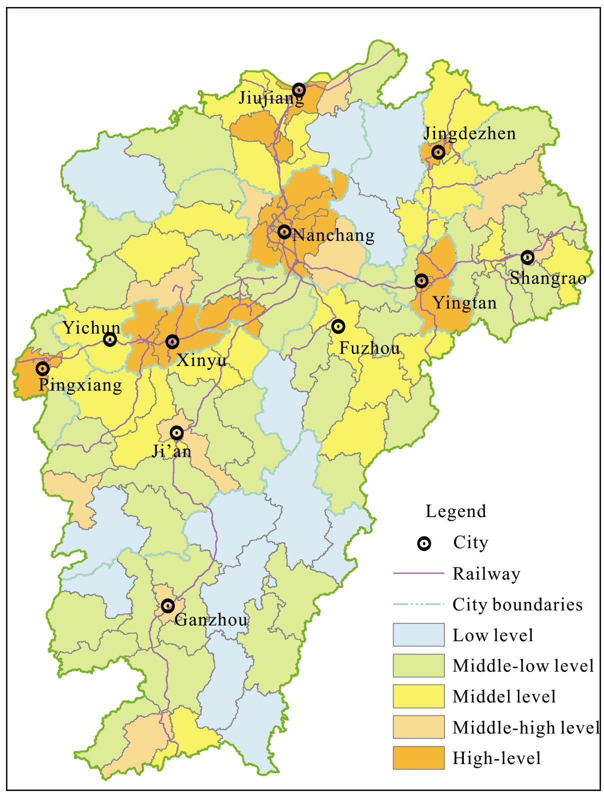

Fig. 7 Spatial difference map of urbanization level in 2015

Table 6 Classification result of uncoordinated urbanization factors in 2015

Type	Number	Counties
Land lagging	4	Shangli, Yushan, Guangfeng, Leping
Economy lagging	1	Ruijin
Population lagging	4	Wanzai, Nanfeng, Jinxian, Fenyi
Population seriously lagging	2	Zhangshu, Guixi
Land mildly exceeding standard	6	Yujiang, Wuning, Yongxiu, Fuzhou municipal district, Jingdezheng municipal district, Nanchang municipal district,
Land moderately exceeding standard	5	Gaoan, Longnan, Yichun municipal district, Ji'an municipal district, Lichuan
Land severely exceeding standard	13	Yifeng, Xingzi, Ruichang, Jiujiang, Ji'an, Fuliang, Dingnan, Shanggao, Gongqingcheng, Yingtan municipal district, Jiujiang municipal district, Xinyu municipal district, Ganzhou municipal district
Land mildly exceeding standard and population lagging	2	Fengcheng, Xinjian
Land severely exceeding standard and population lagging	7	Jinxi, Yihuang, Xingan, Hukou, Nanchang, Dean, Anyi

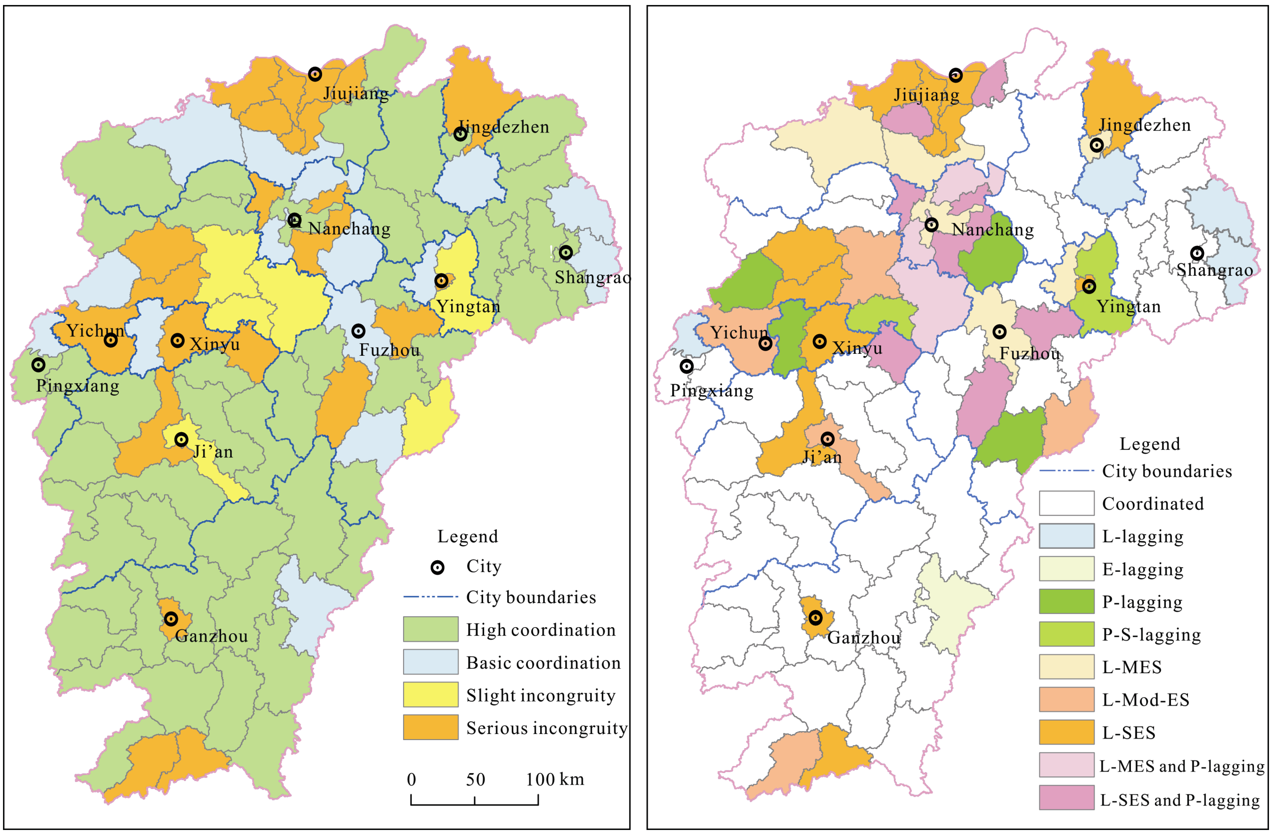

Fig. 8 Spatial difference map of urbanization coordination level (a) and uncoordinated factor (b) in 2015. In Fig. 8b, L-lagging: Land urbanization lags behind; E-lagging: Economic urbanization lags behind; P-lagging: Population urbanization lags behind; P-S-lagging: Population urbanization seriously lags behind; L-MES: Land urbanization mildly exceeds standard; L-Mod-ES: Land urbanization moderately exceeding standard; L-SES: Land urbanization seriously exceeds the standard; L-MES and P-lagging: Land urbanization mildly exceeds standard and population urbanization lags behind; L-SES and P-lagging: Land urbanization seriously exceeds the standard and population urbanization lags behind

and Guixi have a serious lag in demographic urbanization (Table 6). There are 33 counties where the PCUCLA exceed the national standard, 20 of which exceed the national standard of PCUCLA by 50% (≥165m^2). Gongqingcheng and De'an have the largest PCUCLA, with values of 343 m^2 and 256 m^2 respectively.

4 Discussion

4.1 Urbanization process

Urbanization process shows an obvious staged characteristic. In our study, urbanization process of Jiangxi Province was divided into three periods: the stable development period (1990–2001); the accelerated development period (2002–2009) and the rapid development period (2010–2015). These periods are obviously related to local development strategies. Previous studies have shown that since the beginning of this century, China has experienced a shift from industrialism to urbanism in political legitimacy and policy discourse (Qian, 2012). Jiangxi Province has launched an accelerating development strategy of industrialization and urbanization since the year 2001, and achieved significantly accelerating urbanization from 2002 (Liu, 2007). The rapid development period (2010–2015) is associated with the implementation of national major economic-social development programs, such as ‘Poyang Lake Eco-economic Region’ (approved in 2009), ‘Some opinions of the State Council on support Gannan former Soviet central development’ (approved in 2012) and the ‘Integration of Jiujiang and Nanchang’ (started in 2013).

4.2 Dynamics of urbanization coordination

Coordinated development of urbanization in Jiangxi Province was divided into two phases: an increasingly coordinated phase (1990–2003) and an increasingly incongruous phase (2003–2015). The state transition of urbanization coordination was due to low development rate of population urbanization. Urbanization process has changed from a population-leading type to a population-lagging one, which is consistent with the results of previous research (Sun et al., 2012; Research Group of China Population and Development Research Center, 2012). In Jiangxi Province, the state transition of urbanization coordination happened in 2003, which is different from the time found in previous studies. Chen et al. (2013a) indicated that China’s urbanization process has progressed faster than economic growth since 2004 (Chen et al., 2013a). Sun et al. (2013) pointed out that the non-coordination overall level of China’s urbanization declined during 2000-2008 (Sun, et al., 2013). You (2015) revealed that urbanization coordination of Shanghai City increased from 1970 to 2000, but slowed down after the 2000s (You, 2015). It can be seen that urbanization coordination has a staged characteristic, but the demarcation points are different when it is investigated from different perspectives or in different regions.

4.3 Spatial difference of urbanization level

There is a significant spatial difference on urbanization level at county scale in Jiangxi Province. In the year 2015, the maximum values of PCUCLA and PCGDP were more than six times their minimum values, respectively. There were 23 counties with a high level or middle-high level of urbanization, 19 of which were located in the central and northern part of Jiangxi Province. Like the spatial characteristics of county urbanization in China (Liu and Yang, 2012), counties with low level of urbanization level were almost located in mountainous area. The counties with a high level or middle-high level of urbanization were almost located in flat areas along the Beijing-Kowloon and Zhejiang-Jiangxi railways.

4.4 Heterogeneity of urbanization coordination

This study finds that 68.48% of counties in Jiangxi Province are highly coordinated or basically coordinated, which is consistent with the results in previous research (Chen et al., 2014). However, there are 15 counties with a lag in demographic urbanization, and 33 counties where PCUCLA exceed the national standard. Population urbanization lag and excessive land use are the main reasons for uncoordinated development of urbanization in Jiangxi Province, which is consistent with the uncoordinated development of China’s urbanization (Bai et al., 2014; He et al., 2016). We have also found that, in counties where urbanization level are above middle level, 44% are of serious incongruity, while in counties with low level and middle-low level, only 4.3% are of serious incongruity. This finding suggests that, with the improvement of urbanization level, the urbanization coordination declines, which are consistent with the practice of provincial difference in China’s urbanization (Li, 2013).

5 Conclusions

This study has developed a comprehensive evaluation model on urbanization coordination, which integrates EWM, CDM, CCDM, MIGM and RS & GIS technology, and then the authors have conducted a case study of Jiangxi Province, China. The following conclusions can be safely drawn.

We have found significant spatial and temporal differences in urbanization processes of Jiangxi Province. Urbanization process of Jiangxi Province can be divided into three periods: the stable development period (1990–2001), the accelerated development period

(2002–2009) and the rapid development period (2010–2015). According to the variation trend of coordination, urbanization in Jiangxi Province can be divided into two phases, an increasingly coordinated phase (1990–2003) and an increasingly incongruous phase (2003–2015). The state transition is due to low development rate of population urbanization. From a spatial perspective, there is a significant spatial difference of urbanization level at county scale in Jiangxi Province. Population urbanization lag and excessive land use are the main reasons for uncoordinated development of urbanization. There are 15 counties with a lag in demographic urbanization, and 33 counties where PCUCLA exceed the national standard in 2015. With the improvement of urbanization level, the coordination has gradually reduced.

EWM can evaluate temporal evolution of urbanization level. CDM and CCDM can evaluate temporal evolution of urbanization coordination, but they need to be used jointly. RS & GIS technology can provide support of data and spatial analysis technology in urbanization research, combined with MIGM, which are all effective tools for analyzing spatial differences of urbanization, and the evaluation result is comparable and operable. In a word, urbanization is a comprehensive process, which includes aspects of time, space, level, coordination and so on. Since there are significant spatio-temporal differences in urbanization, it is necessary to carry out a comprehensive assessment to facilitate differential urbanization strategy making.

There still are some limitations in this study. First, in the spatial difference analysis of urbanization coordination, we selected PUP, PCUCLA and PCUCLA as the index system, although they have clear meaning and comparability, yet they can not fully express the rich connotation of urbanization. Second, due to the lack of reference standards, the grading parameters are somewhat arbitrary in the MIGM, so the results are of a relative value. Despite these shortcomings, the results of this research are of great significance to the development of differentiated urbanization strategies. According to the research results of this paper, we propose three suggestions for the coordinated development of China's urbanization. First, population urbanization lag and excessive land use are the main reasons for uncoordinated development of China's urbanization, therefore, in the areas with rapid urbanization, it is necessary to accelerate the establishment of laws and regulations to match the size of urban population and the scale of land use. Second, there are obvious regional differences in development levels and uncoordinated development factors of urbanization, so it is necessary to develop differentiated urbanization strategies. Third, major function-oriented zone planning is the guiding and prospective planning of spatial development in China, therefore, in the future work, we should pay more attention to the coordinated distribution of population, economy and urban construction land from the perspective of major function-oriented zone planning.

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