Chin. Geogra. Sci. 2011 21(6) 695–707
doi: 10.1007/s11769-011-0477-x
www.springerlink.com/content/1002-0063

Measurement and Spatio-temporal Distribution of Urbanization Development Quality of Urban Agglomeration in China

WANG Deli[1, 2], FANG Chuanglin[1], GAO Boyang[1, 2], HUANG Jinchuan[1], YANG Qingshan[3]
(*1. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; 2. Graduate University of Chinese Academy of Sciences, Beijing 100049, China; 3. School of Urban and Environmental Sciences, Northeast Normal University, Changchun 130024, China*)

Abstract: Urbanization development quality (UDQ) of urban agglomeration (UA) is one of the important indexes to evaluate if the UA urbanization speed is reasonable, if the population urbanization process is sound, if the economic urbanization process is efficient, if the social urbanization process is harmonious and fair, which is generally composed of three parts, including economic urbanization development quality, social urbanization development quality and spatial urbanization security quality. With the research of evolution rules of UDQ, through the analysis on the interactive coordination relation between UDQ and urbanization level, the paper proposes three dimensional index ball and standard value of comprehensive measures of UDQ, which is composed of three categories of indexes. By introducing Atkinson model, this paper constructs the sub-element measure model and segmental measure model of UDQ, and further makes an overall evaluation on the characteristic of UDQ of UAs in China. Results show that: 1) UDQ of UAs lied at optimization and upgrading phase during 1995–2008 and the quality was low. Population urbanization level did not reflect the UDQ of UAs; 2) the improving speed of the spatial urbanization security quality was higher than the social urbanization development quality, and the improving speed of economic urbanization development quality was the lowest; 3) the coordination between UDQ and urbanization level was not so good; 4) there was a weak correlation relation between UDQ and UA scale, and it was not true that the bigger the UA was, the better the UDQ was.
Keywords: urbanization development quality (UDQ); urbanization speed; comprehensive measure model; urban agglomeration (UA)

Citation: Wang Deli, Fang Chuanglin, Gao Boyang, Huang Jinchuan, Yang Qingshan, 2011. Measurement and spatio-temporal distribution of urbanization development quality of urban agglomeration in China. *Chinese Geographical Science*, 21(6): 695–707. doi: 10.1007/s11769-011-0477-x

1 Introduction

Urban agglomeration (UA) has become the principal geographic unit for countries to participate in the global competition and the international division of labor. The development of UA has profound impacts on the country's international competitiveness, and it also shows great significance for sustainable and stable economic development of the country (Allen, 2001). China is now in the rapid development period of urbanization (Zheng *et al.*, 2009), and the increasing speed of the urbanization level rises up to 1.4% annually (Chen *et al*., 2004). Many governments expedited development of urbanization process, which has become the main objective of governments at all levels. However, whilst pursuing the development speed of urbanization, they neglect the improvement of urbanization development quality (UDQ) which shoud be placed at the foremost position. The speed of urbanization development and UDQ are a contradiction. How to improve the UDQ and secure the consistent development of quality and speed of urbanization while ensuring the rapid improvement of urbanization is becoming an urgent scientific subject which should be focused on.

Received date: 2010-10-10; accepted date: 2011-03-10
Foundation item: Under the auspices of National Natural Science Foundation of China (No. 40971101), Key Direction in Knowledge Innovation Programs of Chinese Academy of Sciences (No. KZCX2-YW-321-05)
Corresponding author: FANG Chuanglin. E-mail: fangcl@igsnrr.ac.cn
© Science Press, Northeast Institute of Geography and Agroecology, CAS and Springer-Verlag Berlin Heidelberg 2011

The studies on UDQ problem mainly focused on the aspects of connotation, comprehensive measurement, influencing factor and improvement strategy of UDQ. Many scholars illustrate the connotation of UDQ from varying views according to their own subject backgrounds but have not reached a consensus (Chen and Hao, 2005). Methods of evaluating model of UDQ mainly include weighting method (Zhao, 2004), standard value method (Ye, 2001), factor analysis method (Yuan *et al*., 2008), entropy means method (Han and Liu, 2009) and mathematical statistics analysis method (Zheng, 2006). However, different scholars study different regions and have difficulties at various levels in acquiring index data; therefore, there are many differences in the aspect of index selection and its focus point. There are also various kinds of computational methods to adopt and there is no recognized UDQ evaluation model in China (Gu *et al*., 2008). The studies on UDQ improvement strategies are divided into comprehensive study on UDQ improvement strategies (Lu *et al.*, 2007), single aspect study on UDQ improvement strategies (Zhu *et al.*, 2008) and study on regional UDQ improvement strategy (Liu *et al.*, 2007), *etc*. Studies on UDQ mainly include urban development quality (Lynch, 1981), healthy city (Vlahov and Galea, 2002), and urban sustainability (Li *et al*., 2001; Moussiopoulos *et al*., 2008), comprehensive measurement on urbanization level (Chang and Brada, 2006), and urban comprehensive strength (Li *et al.*, 2001), urban modernization (Zhu *et al.*, 2000) and single factor evaluation, such as studies on quality of life (Diener and Suh, 1997; Shafer *et al.*, 2000), environmental quality (Jasch, 2000) and economic quality (Gafni and Birch, 1995). In the aspect of urbanization development speed, three clear opposing viewpoints of ′rapid urbanization′ (Deng, 1999), ′under-urbanization′ (Hu, 2004) and basic coordination (Chang and Brada, 2006) have been formed in China, and many scholars adopt ′correction method′ (Zhou, 2002), ′model method′ (Chen and Zhou, 2001) and ′characteristic method′ (Bai *et al.*, 2004) based on actual conditions of China to make correction studies on urbanization development speed of China. However, the united viewpoint has not been formed on urbanization development speed in domestic academic circles.

Based on the domestic and international researches on UAs and UDQ, finding no results on UDQ of UAs, this is the first attempt in China to establish a comprehensive set of indicators covering the whole scope (economic, social and spatial) of UDQ of UAs. This paper aims at building the three dimensional comprehensive measurement index system and UDQ model, analyzing the system evolution characteristics and spatial and temporal variation law of UDQ, judging the speed and level of urbanization development of UAs based on UDQ, and providing references for decision-making for promoting the sound development of UA′s urbanization.

2 Evolution Rules of UDQ

The development of UDQ is actually an improving process of population, social, and economic development quality, as well as spatial urbanization security capacity. Social and economic subsystems have infinite growth trend in the process of urbanization, however, spatial urbanization security capacity is limited. Therefore, the development of population, economy and society are constrained by spatial urbanization security capacity. Over time, the development of UDQ will eventually be like a stretched ′S′ curve. But it is the description of development principles of UDQ in which the development of economy and society is constrained by the limitation of spatial urbanization security capacity in a relatively closed system. The UDQ evolution curve under the influence of human element is a big ′S′ shape evolution curve include more than one ′S′ curve and it can be divided into four phases including preliminary stage (O-A), optimization and upgrading stage (A-B), late-perfect stage (B-C) and sustainable development stage (C-D) (Fig. 1), which correspond to the urbanization development stages of initial stage, medium term stage, late stage and terminal stage (Fang *et al*., 2008a). O-A stage is a low speed and low quality development stage, which means the UDQ is low and the increasing speed of urbanization is slow. A-B stage is a high speed and below average quality development stage. The improving speed of UDQ is not enhanced significantly. However, the economic and social urbanization capability is still far less than the spatial urbanization security capability. Economic and social urbanization have large space for improving. B-C stage is an above average speed and above average quality development stage. The UDQ continue to ascend with high speed. Eco-

nomic and social urbanization development is close to the threshold of spatial urbanization security capability gradually. In C-D stage, the economic, social, and spatial urbanization will keep a dynamic equilibrium on a certain development level, which does not exclude the pursuit of economic development exceeded threshold of spatial urbanization capability. If the exceeding level is under the control of human technology, it will become equilibrium with dynamic fluctuation eventually (C-D). If the exceeding level is beyond the spatial urbanization security threshold which cause system crashes and beyond retrieval, the regional UDQ will drastically decrease and the system will be ruined (C-E) (Fig. 1).

3 Measurement Objects and Methods

3.1 Measurement objects

Currently, great dispute over the concept and definition standard of UA still exists in China. Based on the domestic research results about structural system of UA in China, restricted by the statistic data, 23 UAs are selected as the measurement objects (Qi *et al*., 2008) (Fig. 2).

3.2 Indices of UDQ

According to the connotation of UDQ and the principles of comparability, measurability, availability and feasibility, we take urbanization speed as regulation valve to establish a three dimensional index ball of UDQ comprising 12 indexes of three categories, i.e., economic urbanization development quality (*EUDQ*), social urbanization development quality (*SUDQ*) and spatial urbanization security quality (*SUSQ*) (Fig. 3). According to Fig. 3, *EUDQ* is represented by five indexes including economic efficiency index (*EEI*), economic structure index (*ESI*), economic development cost index (*ECI*), economic linkage index (*ELI*) (Fang *et al*., 2008b) and economic growth force index (*EFI*). *SUDQ* is represented by five indexes including human development index (*HDI*), social service facilities development index (*SSI*), infrastructure development index (*IDI*), urban-rural integration index (*URII*) and traffic accessibility index (*TAI*) (Fang *et al*., 2008b). *SUSQ* is represented by five indexes including water resource security index (*WSI*), land quality security index (*LSI*), power security index (*PSI*), air quality security index (*ASI*) and spatial compactness index (*SCI*) (Fang *et al*., 2008b). Each index is calculated from several relevant original indexes, and the quantification details can be seen from Table 1.

3.3 Dynamic assessment standard values and weight coefficients

Standard value for assessment index of UDQ shall be determined by four methods as follows: 1) apply the standard value specified in relevant international or national research report; 2) refer to current status value in leading national or international areas; 3) determine the standard value according to current computation result; and 4) refer to current authoritative documents for determination. With reference to revised division of urbanization development stages in China (Fang *et al*., 2008a) and evolution rules of UDQ, we choose four key

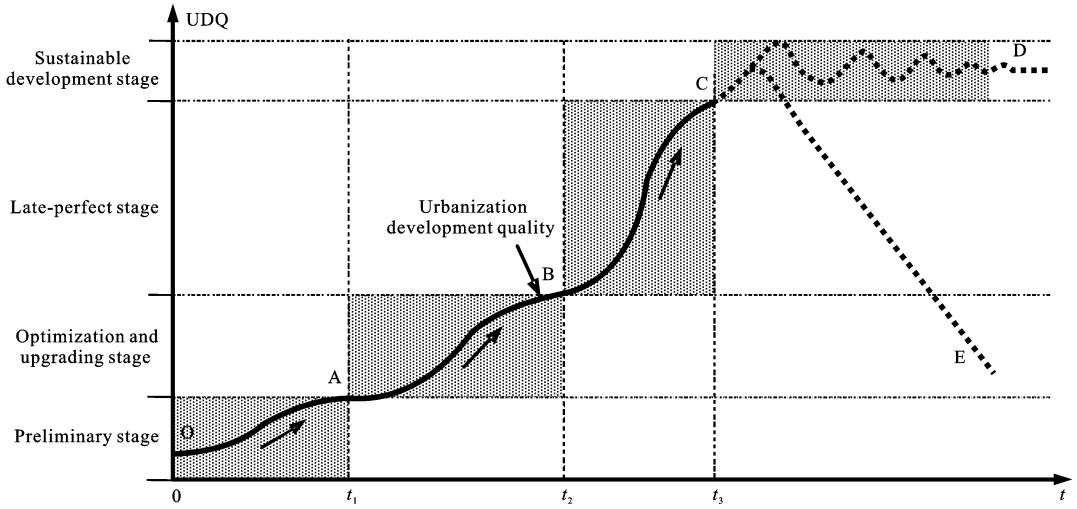


Fig. 1 Evolution rules of urban development quality (UDQ)

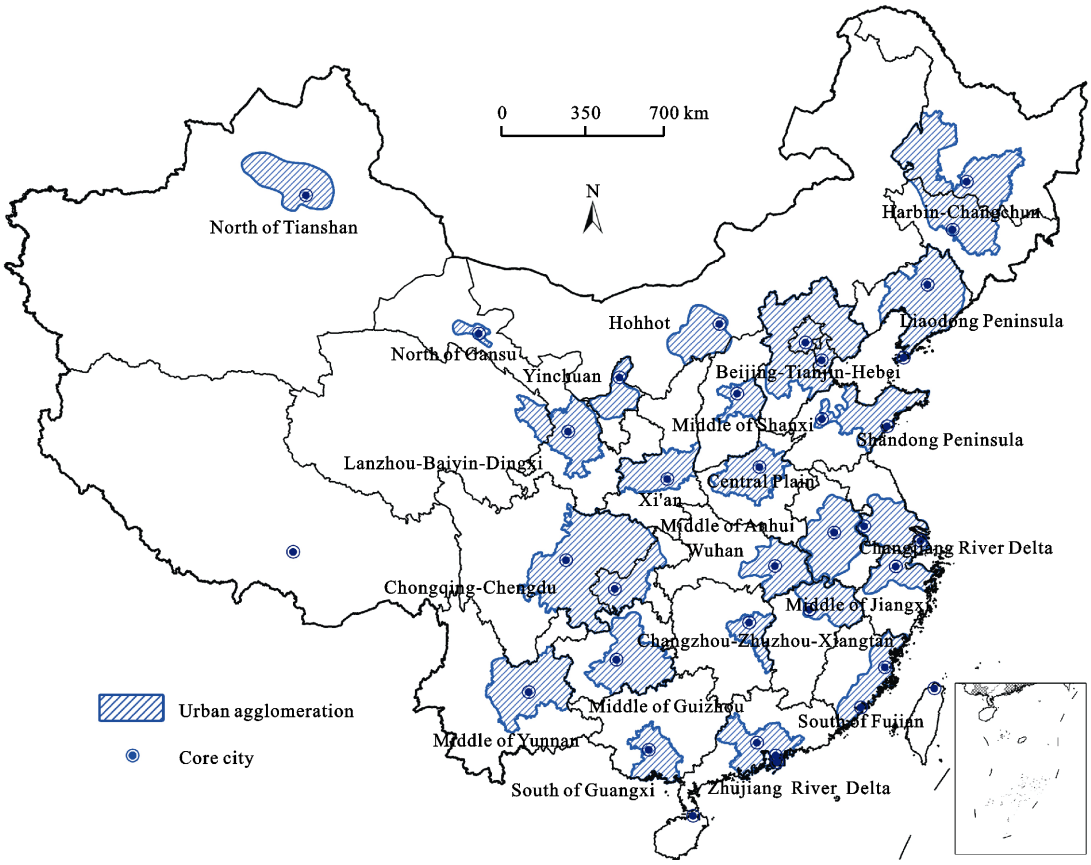


Fig. 2 Spatial distribution of UAs in China

turning points including 30%, 60%, 80% and 100% of urbanization development level related to UDQ and speed. Then according to standard converted value when urbanization level reaches 100%, we determine the corresponding standard values for 30%, 60% and 80% of urbanization development level. We revised them according to actual conditions to get dynamic standard values for UDQ assessment (Table 2). We used AHP model supported by entropy technology to calculate 15 measurement indexes and related weight coefficients (Fang, 2000).

3.4 Measurement models

3.4.1 Sub-element measurement model for UDQ

According to the elements forming comprehensive measurement of the *UDQ*, we use α_i, β_i and γ_i to represent *EUDQ*, *SUDQ* and *SUSQ* weighted influence coefficients respectively. Hence the equation to calculate *UDQ* is:

$$UDQ = EUDQ \times \alpha_i + SUDQ \times \beta_I + SUSQ \times \gamma_i \quad (1)$$

$$EUDQ = \sum_{m=1}^{5} (EUDQ)_m \omega_m = EEI \times \omega_1 + ESI \times \omega_2 + ECI \times \omega_3 + ELI \times \omega_4 + EFI \times \omega_5 \quad (2)$$

$$SUDQ = \sum_{k=1}^{5} (SUDQ)_k \delta_k = HDI \times \delta_1 + SSI \times \delta_2 + IDI \times \delta_3 + URII \times \delta_4 + TAI \times \delta_5 \quad (3)$$

$$SUSQ = \sum_{n=1}^{5} (SUSQ)_n \rho_n = WSI \times \rho_1 + LSI \times \rho_2 + PSI \times \rho_3 + ASI \times \rho_4 + SCI \times \rho_5 \quad (4)$$

where ω_1, ω_2, ω_3, ω_4 and ω_5 represent weight coefficients of *EEI*, *ESI*, *ECI*, *ELI* and *EFI*; δ_1, δ_2, δ_3, δ_4 and δ_5 represent weight coefficients of *HDI*, *SSI*, *IDI*, *URII* and *TAI*; and ρ_1, ρ_2, ρ_3, ρ_4 and ρ_5 represent weight coefficients of *WSI*, *LSI*, *PSI* , *ASI* and *SCI*.

3.4.2 Sectional measurement model for UDQ

Former researchers used standard value method to study UDQ (Ye, 2001) when the actual value is higher

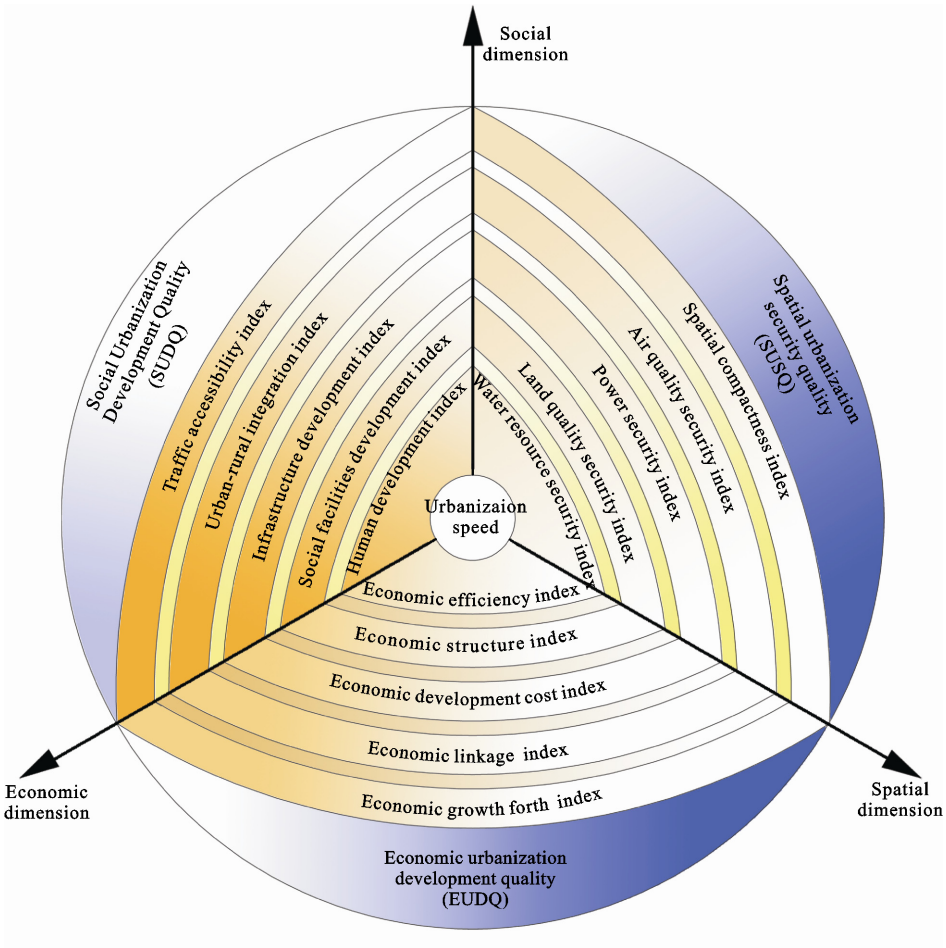


Fig. 3 Three dimensional index ball for comprehensive measure of UDQ of UAs

than the standard one. It will be marked as ′1′ or ′0′, meaning the part exceeding standard value does not work on UDQ, namely no ′contribution′, which is inconsistent with actual situation. Here we build an Atkinson Model for sectional measurement of urbanization development quality to calculate the ′contribution′ made by the part exceeding standard value by sections. The equation is as follows:

$$W(x_i) = \frac{1}{1-\xi} \times (x_i)^{1-\xi} \tag{5}$$

where x_i is the actual value of index of certain UA, $W(x_i)$ is the contribution rate to UDQ. When actual value is higher than standard value, we shall calculate the contribution to UDQ made by the part exceeding standard value by sections. x_i should be placed in an interval among $[0, S_{xi}]$, $[S_{xi}, 2S_{xi}]$, $[2S_{xi}, 3S_{xi}]\cdots[nS_{xi}, (n+1)S_{xi}]$. S_{xi} is standard value of certain index. When $nS_{xi} < x_i \leq (n+1)S_{xi}$, we make $\xi = n/(n+1)$. It is obvious that as a parameter, the value of ξ is among the half-open interval [0, 1]. If $\xi = 0$, then $W(x_i) = x_i$. Normal situations are as follows:

$$\begin{aligned} W(x_i) &= x_i \quad (0 < x_i < S_{xi}) \\ &= S_{xi} + 2(x_i - S_{xi})^{1/2} \quad (S_{xi} < x_i \leq 2S_{xi}) \\ &= S_{xi} + 2(S_{xi})^{1/2} + 3(x_i - 2S_{xi})^{1/3} \quad (2S_{xi} < x_i \leq 3S_{xi}) \\ &\cdots \\ &= S_{xi} + 2(S_{xi})^{1/2} + \cdots + (n+1)(x_i - nS_{xi})^{1/(n+1)} \\ &\quad (nS_{xi} < x_i \leq (n+1)\,S_{xi}) \end{aligned} \tag{6}$$

3.4.3 Coordination measurement model between UDQ and urbanization level

Based on the above analysis about the evolution rules of UDQ, we found that the more synchronous urbanization level and UDQ are, the better the coordination is. Thus the ideal urbanization level under certain UDQ can be inversely deduced.

Table 1 Quantification explanation for three dimensional index ball of UDQ of UAs

Index (Level I)	Subgroup (Leve II)	Calculation method	Explanation of calculation method
EUDQ	*EEI*	$\begin{cases} EEI = \theta \\ \sum_{j=1}^{k} x_{jl}\lambda_j + s^- = \theta x_l^n \quad l = 1, 2, \cdots, L \\ \sum_{j=1}^{k} y_{jm}\lambda_j - s^+ = y_m^n \quad m = 1, 2, \cdots, M \\ \lambda_j \geq 0 \quad j = 1, 2, \cdots, K \end{cases}$	We use labor force and fixed capital inventory of UA as independent variables, and total regional GDP of UA as dependent variable. θ ($0 < \theta < 1$) is efficiency index of comprehensive technical scope and is shortened as comprehensive efficiency index; x_{jl} is the observed amount of input; y_{jm} is the amount of output. The x_l^n and y_m^n represent the amounts of inputs (l = 1, 2, ..., L) and outputs (m = 1, 2, ···, M) associated with DMUs (Decision Making Units). λ_j ($\lambda_j \geq 0$) is weight variable; S^-($S^- \geq 0$) is slack variable; S^+($S^+ \geq 0$) is surplus variable. j= 1, 2, ···, K indexes the set of DMUs (Decision Making Units) which are of interest. If θ is closer to 1, economic efficiency of the nth area will become higher; otherwise, economic efficiency will become lower
	ESI	$ESI = \frac{t_i}{s_i}$	t_i is the proportion of added value of tertiary industry in GDP; s_i is the standard value of t_i; i represents a specific UA
	ECI	$ECI = \frac{1}{3}\left(\frac{r_i}{s_1} + \frac{w_i}{s_2} + \frac{l_i}{s_3}\right)$	r_i is power consumption per 1×10^4 yuan (RMB); w_i is water consumption per 1×10^4 yuan; l_i *is* land consumption per 1×10^8 yuan; i represents a specific UA, and s_1, s_2 and s_3 are standard values of r_i, w_i *and* l_i
	ELI	$ELI = \frac{\sum_{i,j=1}^{n} \frac{\sqrt{p_i GDP_i} \times \sqrt{p_j GDP_j}}{D_{ij}^2}}{1 + 2 + \cdots + (n-1)}$	p_i and p_j are the total population of city i and j in a urban agglomeration; GDP_i and GDP_j are the total GDP of city i and j; D_{ij} is the distance between city i and j; n is the number of the cities in urban agglomeration
	EFI	$EFI = \frac{Y - \alpha K - \beta L}{YS_i} \times 100\%$	We use modified Solow surplus value algorithm to calculate the rate of contribution to economic growth by science development. The rate of contribution can represent the economic growth force. Y is the average annual growth rate of total output; K is the average annual growth rate of investment; β is the average growth rate of labor input; s_i is standard value. i represents a specific UA; $\alpha + \beta = 1$ ($\alpha = 0.6$, $\beta = 0.4$) (Yuan and Hu, 2010)
SUDQ	*HDI*	$HDI = \frac{1}{3}\left(\frac{\log y - \log y_{\min}}{\log y_{\max} - \log y_{\min}} + \frac{S - S_{\min}}{S_{\max} - S_{\min}} + \frac{a - a_{\min}}{a_{\max} - a_{\min}}\right)$	y is GDP per capita; s is number of students in higher school per 1×10^4 people; a is registered unemployment rate in urban areas; $y_{\max}$ and $y_{\min}$ are the highest and lowest of GDP per capita; $s_{\max}$ and $s_{\min}$ are the highest and lowest of number of students in higher school per 1×10^4 people; $a_{\max}$ and $a_{\min}$ are the highest and lowest of registered unemployment rate in urban areas
	SSI	$SSI = \frac{1}{2}\left[\left(\frac{d_i}{s_1}\right) + \left(\frac{t_i}{s_2}\right)\right]$	d_i is the number of doctors serving per 1×10^4 people; t_i is the number of basic education teachers serving per 100 people; i represents a specific UA; s_1, s_2 are standard values of d_i and t_i
	IDI	$IDI = \frac{1}{5}\left(\frac{r_i}{s_1} + \frac{b_i}{s_2} + \frac{g_i}{s_3} + \frac{w_i}{s_4}\frac{f_i}{s_5}\right)$	r_i is per capita road area; b_i is the number of buses serving per 1×10^4 people; g_i is park green area per capita; w_i is coverage rate of water supply; f_i is gas popularization; i represents a specific UA, and s_1, s_2, s_3, s_4 and s_5 are standard values
	URII	$URII = \frac{c_i}{u_i s_i}$	c_i is rural per capita net income; u_i is urban per capita disposable income; i represents a specific UA; s_i is standard value of c_i
	TAI	$TAI = \sqrt{\sum_{i=1}^{n}(xi - \bar{x})^2 \Big/ (n-1)} \times \frac{\sum_{i-1}^{n-1} T_{ij}}{n(n-1)}$	x_i is the corresponding index values of city i; $\bar{x}$ is the average index values; n is the number of cities in the urban agglomeration; T_{ij} is the shortest travel time between city i and j (The average speed on highway is 100 km/h, and the average speed on national road is 80 km/h)
SUSQ	*WSI*	$WSI = \frac{WT_i}{s_i}$	WT_i is sewage treatment rate; i represents a specific UA, and s_i is standard value of WT_i
	LSI	$LSI = \frac{1}{2}\left(\frac{ISW_i}{s_1} + \frac{DGT_i}{s_2}\right)$	ISW_i is ratio of industrial solid wastes utilized; DGT_i is harmless treatment processing rate of household garbage; i represents a specific UA; s_1, s_2 are standard values of ISW_i and DGT_i
	PSI	$PSI = \frac{P_r}{C_r \times s_i}$	P_r is the total UA output of primary energy in certain period; C_r is the total energy consumption; s_i is the standard value of P_r; i represents a specific UA
	ASI	$ASI = \frac{1}{2}\left(\frac{SD_i}{s_1} + \frac{IF_i}{s_2}\right)$	SD_i is so_2 processing rate; IF_i is soot processing rate; i represents a specific UA; s_1, s_2 are standard values of SD_i and IF_i
	SCI	$SCI = \frac{n\sum_{i=1}^{n} L_{Ni}}{\sum_{i=1}^{n} A_i \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n}(x_{ij} - \bar{x})^2 \Big/ (n-1)}}$	L_{Ni} is the number of external direct connection lines of city node i; n is the number of city nodes in the urban agglomeration; A_i is the area of city i; x_{ij} is the straight-line distance between two city nodes; $\bar{x}$ is the average straight-line distance between city nodes

Table 2 Dynamic standard values and weight of UDQ of UAs

Index (Level I)	Weight	Subgroup (Leve II)	Weight	Index	Unit	Dynamic standard value			
						30%	60%	80%	100%
EUDQ	0.40	*EEI*[1)]	0.263	Economic efficiency	—	0.25	0.74	0.80	1.00
		ESI	0.232	Proportion of value-added of tertiary industry in GDP	%	15	45	60	75
		ECI[2)]	0.228	Power consumption per unit GDP	kWh/(1 × 10^4 yuan)	1500	1000	800	550
				Water consumption per unit GDP	m^3/(1 × 10^4 yuan)	200	66	50	30
				Land consumption per unit GDP	km^2/(1 × 10^8 yuan)	20	5.0	1.0	0.5
		ELI	0.176	Economic linkage index	—	0.3	0.6	0.8	1.0
		EFI[3)]	0.101	Contribution rate brought by science development	—	17	50	70	80
SUDQ	0.35	*HDI*	0.291	GDP per capita (Sagar and Najam, 1998)	(1 × 10^4) USD	1.5	2.5	3.2	4.0
				Students in higher school per 1 × 10^4 people	Person	300	600	800	1000
				Registered unemployment rate in urban areas	%	6.0	4.6	3.5	2.8
		SSI	0.200	Number of doctors serving per 1 × 10^4 people	Person	0.9	2.8	3.8	4.8
				Number of basic education teachers serving per 100 people	Person	0.5	1.5	2.0	2.5
		IDI	0.200	Per capita road area	m^2	4.0	9.6	13.0	15.0
				Number of buses serving per 1 × 10^4 people	—	8.0	20	30	35
				Park green area per capita	m^2	15	20	25	30
				Urban water access rate	%	50	90	100	100
				Gas popularization	%	50	90	100	100
		URII	0.170	Income gap between urban and rural	—	4.8	1.6	1.2	1.0
		TAI	0.139	Traffic accessibility	—	0.3	0.6	0.8	1.0
SUSQ	0.25	*WSI*	0.200	Sewage treatment rate	—	50	90	100	100
		LSI	0.200	Ratio of industrial solid wastes utilized	%	40	72	90	100
				Harmless treatment processing rate of household garbage	%	40	84	100	100
		PSI[4)]	0.200	Power security level	—	1	1	1	1
		ASI	0.200	So_2 processing rate	%	40	75	100	100
				Soot processing rate	%	40	75	100	100
		SCI	0.200	Spatial compactness index	—	0.3	0.6	0.8	1.0

Notes: 1) At the end of 2008, benchmark of economic efficiency in Shanghai was 1; DEA model is used to calculate the economic efficiency in China and all provinces, thus the standard value is determined to be 1. 2) Due to the lack of data of administrative region of city, we use data of urban area. In 2008, China's GDP water consumption was 234m^3/(1 × 10^4 yuan), Beijing had the lowest—33m^3/(1 × 10^4 yuan), Japan had 25m^3/(1 × 10^4 yuan), and standard value is determined to be 30m^3/(1 × 10^4 yuan) in this paper. According to calculations, standard values of power consumption per unit GDP, land consumption per unit GDP are 550kWh/(1 × 10^4 yuan) and 0.5km^2/(1 × 10^8 yuan). 3) According to the measurement, the contribution rate of scientific and technical advancement in China is 39% at present, while such contribution rates in major developed countries such as USA and Japan are around 80%. Standard contribution rate is determined to be 80% in this paper. 4) For making energy production satisfy energy needs during urbanization development process, standard value in this paper is determined to be 1

$$E_{(t)} = \begin{cases} \dfrac{Z_t - V_t}{|Z_t - V_t|}\left[1 - \dfrac{\min\{Z_t, V_t\}}{\max\{Z_t, V_t\}}\right] & (Z_t \neq V_t) \\ 0 & (Z_t = V_t) \end{cases} \quad (7)$$

where $E_{(t)}$ is the coordination index of urbanization level and quality, $E_{(t)} > 0$ means the UDQ is ahead of the urbanization level, $E_{(t)} < 0$ means the UDQ lags behind the urbanization level, $E_{(t)}$ being closer to 0 means better coordination of UDQ and level. Z_t is the UDQ index in year t or region t, V_t is the urbanization level index in year t or region t as shown below:

$$Vt = \begin{cases} \dfrac{v_t}{v_0} & (v_t < v_0) \\ 1 & (v_t > v_0) \end{cases} \quad (8)$$

where V_t is the urbanization level index in year t or region t, v_t is the actual urbanization level in year t or region t, v_0 is the target value of urbanization level. We

can use Equation (7) to calculate ideal urbanization level of year t or region t by its UDQ.

3.5 Data sources

According to *Urban Statistical Yearbook of China*, *China Urban Construction Statistical Yearbook*, *China Statistical Yearbook for Regional Economic* and *Cities China*: *1949–1998* (Huang, 1999; National Bureau of Statistics of China, 1996; 2009; Ministry of Construction of China, 2008; Department of Comprehensive Statistics National Bureau of Statistics, 2009), this paper calculated *EUDQ*, *SUDQ* and *SUSQ* and then employed Equation (1) to calculate *UDQ* of UAs.

4 Results

4.1 Spatio-temporal distribution of UDQ of UAs

Spatial differentiations obviously existed between the UDQ and urbanization level. From 1995 to 2008, the UDQ of UAs gradually decreased from the eastern part to the middle and western part of China. UAs in the coastal region maintained a relatively higher UDQ. Among the 23 UAs in China, UDQ of the top five UAs (Zhujiang River Delta, Changjiang River Delta, Changzhou-Zhuzhou-Xiangtan, Middle of Jiangxi and South of Fujian) were above 0.40 in 1995. Most of them were in the eastern region. In 2008, the UDQ of most costal UAs were above 0.40, within which the UDQ of Zhujiang River Delta was 0.639 and that of Changjiang River Delta was 0.584. The medium quality UAs were mostly located in the old industrial bases in Northeast China and Middle China in 2008. Universally low quality UAs distributed in Southwest China. This tendency corresponded with the overall level of economic development in those three areas. In view of the temporal evolution characteristics, UDQ of UAs showed a gradually increasing tendency from 1995 to 2008. Calculation based on the UDQ comprehensive measurement model showed that from 1995 to 2008, the UDQ of UAs increased from 0.30–0.45 to 0.40–0.70, which was the optimization and upgrading phase (Fig. 4). The UDQ was not positively correlating with the urbanization level as we could tell from Fig. 4. In 2008, the urbanization level of North of Tianshan, Yinchuan and Hohhot agglomeration were 69.23%, 58.82% and 59.66% respectively, while the UDQ were 0.431, 0.424 and 0.455. The UDQ of these UAs were low comparing with Changzhou-Zhuzhou-Xiangtan where the UDQ was 0.561, however, the urbanization level in Changzhou-Zhuzhou-Xiangtan was 38.9% only. There was a weak correlation relation between UDQ and urbanization level.

4.2 Sub-element characteristics of UDQ of UAs

Economic urbanization development quality, social urbanization development quality and spatial urbanization security quality reflect the quality of urbanization development. As what we can see from Table 3, the improving speed of these three aspects is at different degrees. The improving speed of the spatial urbanization security quality is higher than the social urbanization development quality, and the improving speed of economic urbanization development quality is the lowest. The economic urbanization quality improved from 0.10–0.30 to 0.20–0.40 during 1995–2008; however, it was still far behind the quality of spatial urbanization, which was around 0.40–0.70. At the same time, the social urbanization quality in most UAs was around 0.35–0.45. The gap among economic, social and spatial urbanization quality was diminishing from 1995 to 2008. The high-cost development mode make the social urbanization quality was higher than the economic urbanization quality. The relationship between economic urbanization development quality and social urbanization development quality was tight. This was probably because spatial change was less discernable in the short run, and economic and social developments were closely related with each other. In addition, in this study the correlation between economic urbanization development quality and spatial urbanization security quality was closer than the relationship between social urbanization development quality and spatial urbanization security quality. This can be explained partly by the effects of pollution control, which was closely related to the economic conditions of UAs. UAs with greater economic achievements can afford better facilities which will help control the pollution (Table 3).

4.3 Coordination relation between urbanization level and UDQ of UAs

Based on the calculations of the coordination relations between urbanization level and UDQ from 1995 to 2008, we divide the coordination coefficient into five types, including over under-quality type ($-1 < E_{(t)} < -0.5$), under-quality type ($-0.5 \le E_{(t)} < -0.1$), coordination type ($-0.1 \le E_{(t)} \le 0.1$), under-urbanization type ($0.1 < E_{(t)} \le$

Table 3 Sub-element characteristics of UDQ of UAs in 1995 and 2008

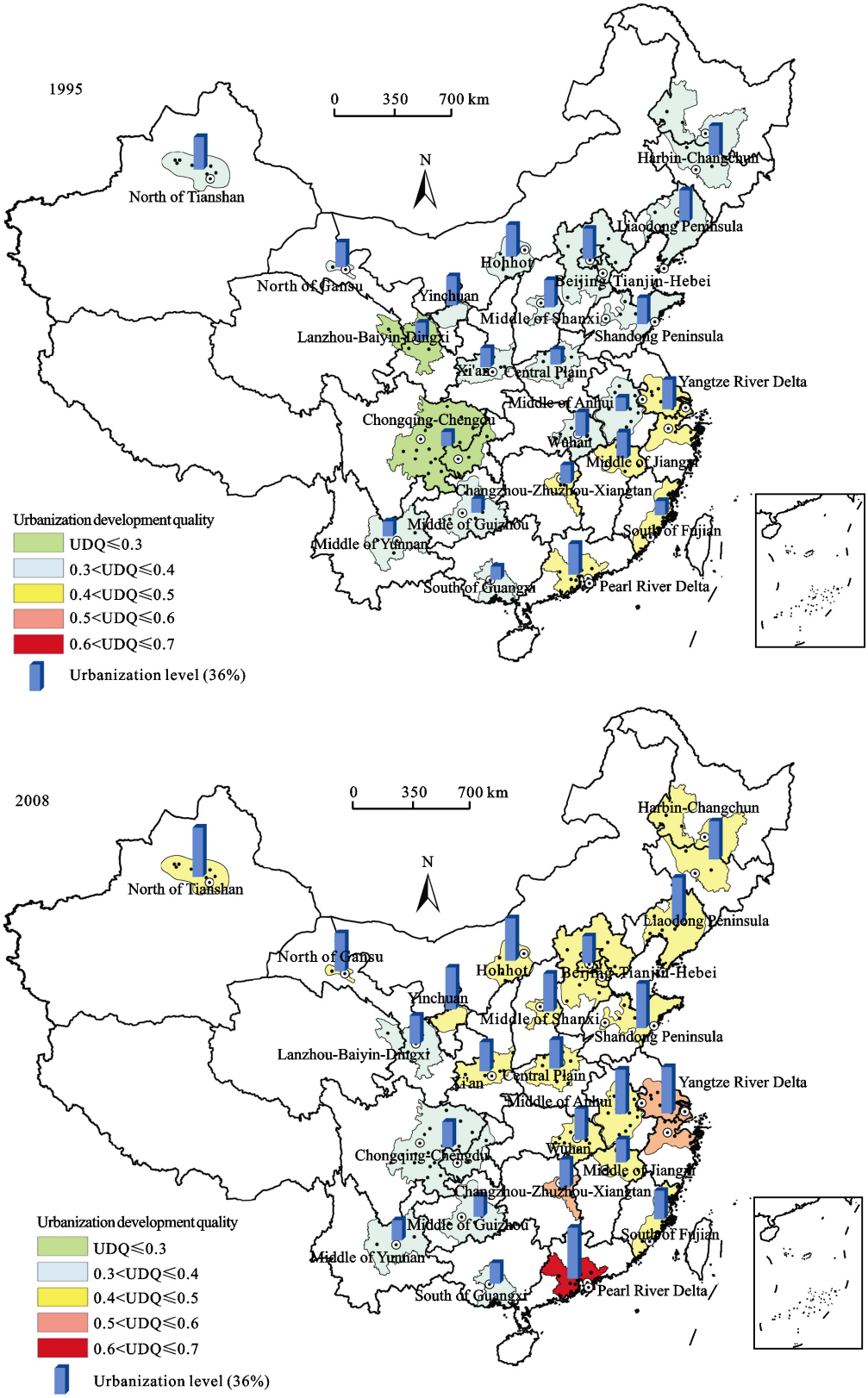
Urban agglomeration	1995			2008		
	EUDQ	SUDQ	SUSQ	EUDQ	SUDQ	SUSQ
Zhujiang River Delta	0.381	0.473	0.691	0.593	0.622	0.719
South of Fujian	0.326	0.447	0.515	0.423	0.539	0.518
South of Guangxi	0.242	0.371	0.355	0.313	0.422	0.453
Middle of Yunnan	0.254	0.379	0.430	0.348	0.433	0.402
Middle of Guizhou	0.229	0.388	0.422	0.345	0.437	0.424
Chongqing-Chengdu	0.217	0.316	0.385	0.306	0.377	0.496
Changzhou-Zhuzhou-Xiangtan	0.391	0.460	0.622	0.485	0.582	0.652
Wuhan	0.216	0.428	0.508	0.295	0.509	0.593
Middle of Anhui	0.195	0.417	0.514	0.288	0.553	0.560
Middle of Jiangxi	0.272	0.389	0.578	0.295	0.485	0.538
Changjiang River Delta	0.395	0.458	0.687	0.516	0.567	0.717
Lanzhou-Baiyin-Dingxi	0.161	0.366	0.356	0.300	0.415	0.422
North of Gansu	0.141	0.448	0.439	0.288	0.545	0.544
Yinchuan	0.177	0.457	0.403	0.236	0.540	0.561
Central Plains	0.176	0.432	0.495	0.278	0.514	0.589
Middle of Shanxi	0.198	0.362	0.398	0.310	0.454	0.516
Hohhot	0.157	0.379	0.462	0.444	0.471	0.450
Xi'an	0.248	0.505	0.432	0.281	0.562	0.441
Beijing-Tianjin-Hebei	0.254	0.426	0.627	0.369	0.520	0.652
Shandong Peninsula	0.229	0.412	0.573	0.396	0.539	0.568
Liaodong Peninsula	0.223	0.412	0.515	0.301	0.472	0.552
Harbin-Changchun	0.163	0.368	0.432	0.398	0.443	0.517
North of Tianshan	0.188	0.434	0.439	0.338	0.525	0.449

0.5) and over under-urbanization type ($0.5 < E_{(t)} < 1$). There were enormous differences in the types of urbanization of UAs. In 1995, coordination UAs were North of Gansu, Middle of Shanxi and Shandong Peninsula, *etc*. In 2008, UAs of coordination were Changjiang River Delta, Central Plain, *etc*. The coordination between urbanization level and UDQ of UAs in the coastal region was getting worse and worse from 1995 to 2008. More and more UAs in the coastal regions were moving towards under-quality type, and only South of Fujian remained in an under-urbanization condition. Most of UAs from middle part to southwest part of China were under-urbanization type. The highest UA of under-quality type was North of Tianshan agglomeration, where the actual urbanization level was 43.1% while the ideal urbanization level was 69.23%. The highest UA of the under-urbanization type was Changzhou-Zhuzhou-Xiangtan agglomeration, where the actual urbanization level was 38.8% and the ideal was 56.1% (Fig. 5).

4.4 Relationship between UA development level and UDQ

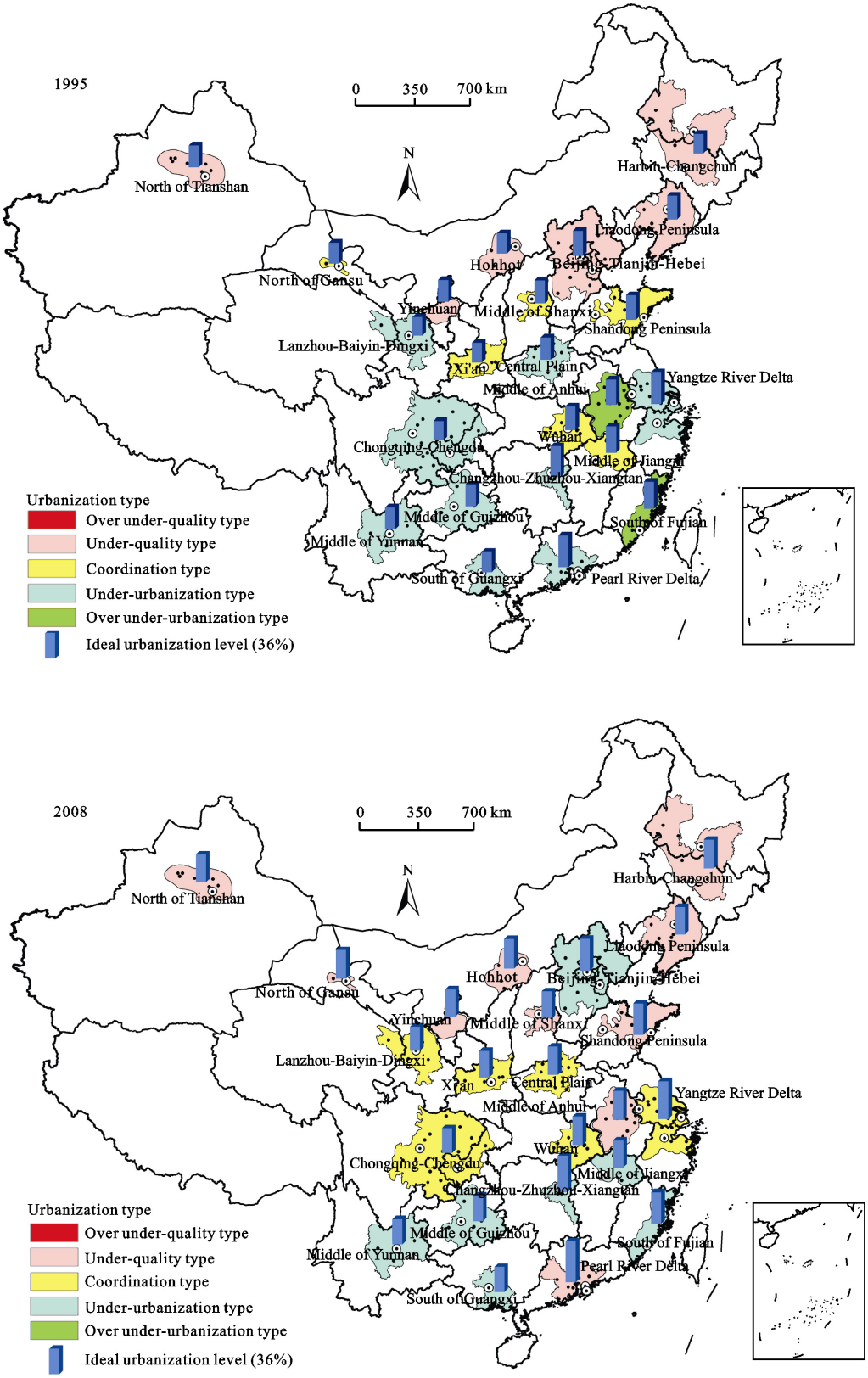
Correlation between UA compactness, development degree and UDQ is not high. According to the research of Chinese UA development degree (Fang *et al.*, 2010) and UA compactness (Fang *et al.*, 2008b), we analyze the correlations between UA compactness, development degree and UDQ. The result shows that there is not remarkable positive correlation among them. Correlation coefficient of UA development degrees to UDQ was 0.553 and UA compactness to UDQ was 0.527 in 1995. In 2008, correlation coefficient of UA development degree to UDQ was 0.512 and UA compactness to UDQ was 0.329 (Table 4). This indicates that the connections of UAs within China are not close.

We used population size, urban completed area and urban economic scale from 1995 to 2008 to represent urbanization development scale of UAs, and represented by urban population, urban completed area and GDP so



The legend, automatically generated by ArcGIS, shows that urbanization level reaches 36%

Fig. 4 Spatio-temporal analysis on quality and level of urbanization of UAs in 1995 and 2008



The legend, automatically generated by ArcGIS, shows that urbanization level reaches 36%

Fig. 5 Urbanization types and ideal urbanization levels of UAs in China in 1995 and 2008

that we can study the relation between scale and UDQ of UAs. Correlation coefficients of UDQ to population size, urban completed area and urban economic scale of UAs are among 0.320–0.550 from 1995 to 2008. This indicates that there is a weak correlation among them. Larger UA does not mean higher UDQ (Table 5).

Table 4 Correlation analysis on UA compactness, development degree and UDQ in 1995 and 2008

	1995		2008	
	UA development degrees	UA compactness	UA development degrees	UA compactness
UDQ	0.553	0.527	0.512	0.329

Table 5 Correlation analysis on urbanization scale and UDQ of UAs in 1995 and 2008

	1995		
	Population size	Urban completed area	Urban economic scale
UDQ	0.336	0.320	0.473
	2008		
	Population size	Urban completed area	Urban economic scale
UDQ	0.394	0.426	0.533

5 Conclusions

UDQ benchmarking can be useful for policymakers, but when UA development is understood mainly as economic development, this narrow understanding generates problematic policy implications. This study highlights the usefulness of a sustainable development perspective to the study of UDQ of UAs and employs data from 1995 to 2008. The results can serve as a baseline for further decision-making. Since 1996, Chinese urbanization has entered a new period of rapid growth. In order to sustain UA′s urbanization, it should achieve not only good economic performance, but also satisfactory social and spatial development. By examining how the quality of UA is in all three dimensions including economic, social and spatial, government can stay alert to achieving balanced UA development. By constructing relevant models and analyzing the selected 23 UAs, this paper drew the following conclusions:

(1) From 1995 to 2008, the UDQ of UAs gradually decreased from the eastern part to the middle and the western part of China. UAs in the coastal region maintained a relatively higher UDQ. There was a weak correlation relation between UDQ and urbanization level.

(2) The improving speed of the spatial urbanization security quality was higher than the social urbanization development quality, and the improving speed of economic urbanization development quality was the lowest.

(3) There were enormous differences in the types of urbanization of UAs. The coordination between urbanization level and quality of UAs in the coastal region was getting worse and worse from 1995 to 2008. More and more UAs in the coastal regions were moving towards under-quality type.

(4) There was a weak correlation relation between UDQ and urbanization development scale, and it was not true that the larger the UA was, the better the UDQ was.

References

Allen J S, 2001. *Global City-regions*: *Trends*, *Theory*, *Policy*. Oxford: Oxford University Press.

Bai Xianchun, Ling Kang, Guo Cunzhi, 2004. The level measure and the international comparison of urbanization in China. *Urban Problems*, (2): 23–26. (in Chinese)

Chang G H, Brada J C, 2006. The paradox of China's growing under-urbanization. *Economic Systems*, 30(2): 24–40. doi: 10.1016/j.ecosys.2005.07.002

Chen Bochong, Hao Shouyi, 2005. Research on the impact of natural resources on urbanization level of china. *Journal of Natural Resources*, 20(3): 394–399. (in Chinese)

Chen Bochong, Hao Shouyi, Yang Xingxian, 2004. The dynamic mechanism of the rapid development of urbanization in china. *Acta Geographica Sinica*, 59(6): 1068–1075. (in Chinese)

Chen Yanguang, Zhou Yixing, 2001. Researches in models of algometric analysis of urban systems and forecast of urbanization level based on RS data of urban area. *Acta Scientiarum Naturalium Universitatis Pekinensis*, 37(6): 819–826. (in Chinese)

Deng Yupeng, 1999. On China′s hidden superurbanization. *Contemporary Finance & Economics*, (6): 20–23. (in Chinese)

Department of Comprehensive Statistics National Bureau of Statistics, 2009. *China Statistical Yearbook for Regional Economic*. Beijing: Science Press. (in Chinese)

Diener E, Suh E, 1997. Measuring quality of life: Economic, social, and subjective indicators. *Social Indicators Research*, 40(2): 189–216. doi: 10.1023/A:1006859511756

Fang Chuanglin, 2000. *Planning of Regional Development*. Beijing: Science Press. (in Chinese)

Fang Chuanglin, Liu Xiaoli, Lin Xueqin, 2008a. Stages correction and regularity analysis of urbanization course of China. *Arid Land Geography*, 31(4): 512–523. (in Chinese)

Fang Chuanglin, Qi Weifeng, Song Jitao, 2008b. Researches on comprehensive measurement of compactness of urban agglomerations in China. *Acta Geographica Sinica*, 63(10): 1011–1021. (in Chinese)

Fang Chuanglin, Song Jitao, Lin Xueqin, 2010. *Theory and Practice of China's Urban Agglomerations Sustainable Development*. Beijing: Science Press. (in Chinese)

Gafni A, Birch S, 1995. Preferences for outcomes in economic evaluation: An economic approach to addressing economic problems. *Social Science & Medicine*, 40(6): 767–776. doi: 10.1016/0277-9536(94)E0109-6

Gu Chaolin, Yu Taofang, Li Wangming, 2008. *Pattern, Process and Mechanism of Urbanization in China*. Beijing: Science Press. (in Chinese)

Han Zenglin, Liu Tianbao, 2009. Analysis of the characteristics and spatial differences of urbanization quality of cities at prefecture level and above in China. *Geographical Research*, 28(6): 1508–1515. (in Chinese)

Hu Aihua, 2004. World urbanization and general practice of China. *Inquiry Into Economic Issues*, (9): 115–118. (in Chinese)

Huang Langhui, 1999. *Cities China*: *1949–1998*. Beijing: Xinhua Publishing House. (in Chinese)

Jasch C, 2000. Environmental performance evaluation and indicators. *Journal of Cleaner Production*, 8(1): 79–88. doi: 10.1016/S0959-6526(99)00235-8

Li Xiaojian, Peterson J, Liu Gangjun, 2001. Assessing regional sustainability: The case of land use and land cover change in the Middle Yi Luo catchment of the Yellow River Basin. *China Applied Geography*, 21(21): 87–106. doi: 10.1016/S0143-6228(00)00020-5

Liu Yanjun, Li Chenggu, Dong Huihe, 2007. Urbanization response of industrial structure evolvement in Northeast China: Process, mechanism and tendency. *Economic Geography*, 27(3): 433–437. (in Chinese)

Lu Dadao, Yao Shimou, Li Guoping, 2007. Comprehensive analysis of the urbanization process based on China's conditions. *Economic Geography*, 27(6): 883–887. (in Chinese)

Lynch K, 1981. *Good City Form*. Cambridge: Massachu-setts Institute of Technology Press.

Ministry of Construction of China, 2008. *China Urban Construction Statistical Yearbook 2008*. Beijing: China Architecture & Building Press. (in Chinese)

Moussiopoulos N, Achillas C, Vlachokostas C *et al.*, 2008. Environmental, social and economic information management for the evaluation of sustainability in urban areas: A system of indicators for Thessaloniki, Greece. *Cities*, 27(5): 377–384. doi: 10.1016/j.cities.2010.06.001

National Bureau of Statistics of China, 1996. *Urban Statistical Yearbook of China 1996*. Beijing: China Statistics Press. (in Chinese)

National Bureau of Statistics of China, 2009. *Urban Statistical Yearbook of China 2009*. Beijing: China Statistics Press. (in Chinese)

Qi Weifeng, Fang Chuanglin, Song Jitao, 2008. Measurement and spatial distribution of urban agglomeration industrial compactness in China. *Chinese Geographical Science*, 18(4): 291–299. doi: ZDKX.0.2008-04-001

Sagar A D, Najam A, 1998. The human development index: A critical review. *Ecological Economics*, 25(3): 184–187. doi: 10.1016/S0921-8009(97)00168-7

Shafer C S, Lee B K, Turner S, 2000. A tale of three greenway trails: User perceptions related to quality of life. *Landscape and Urban Planning*, 49(3): 163–178. doi: 10.1016/S0169-2046(00)00057-8

Vlahov D, Galea S, 2002. Urbanization, urbanicity, and health. *Journal of Urban Health*, 79(4): s_1–s_{12}. doi: 10.1093/jurban/79.suppl_1.S1

Ye Yumin, 2001. Approach on China′s urbanization quality. *China Soft Science*, (7): 27–31. (in Chinese)

Yuan Jing, Hu Lei, 2010. The empirical analysis of the contribution rate of scientific and technological progress to Shandong Province economic growth. *Journal of Shandong Institute of Commerce and Technology*, 10(1): 90–93. (in Chinese)

Yuan Xiaoling, Wang Xiao, He Weiyue, 2008. Synthetic evaluation for urbanization quality of Shanxi Province. *Urban Studies*, 15(2): 38–45. (in Chinese)

Zhao Xueyan, 2004. Urbanization quality evaluation in northwest area of China. *Journal of Arid Land Resources and Environment*, 18(5): 69–73. (in Chinese)

Zheng Y T, Chen T, Cai J M *et al.*, 2009. Regional concentration and region-based urban transition: China′s mega-urban region formation in the 1990s. *Urban Geography*, 30(3): 312–333. doi: 10.2747/0272-3638.30.3.3 12

Zheng Yaping, 2006. Research into evaluation of the quality of China's provincial wide urbanization level. *Chongqing Technology Business University*, 16(6): 95–98. (in Chinese)

Zhou Yixing, 2002. The suggestion of amending china urbanization level based on the results of the fifth population census. *Statistical Studies*, (4): 44–47. (in Chinese)

Zhu Chuangeng, Sun Shanshan, Li Zhijiang, 2008. The influencing factors and spatial distribution of population urbanization in China. *Geographical Research*, 27(1): 13–22. (in Chinese)

Zhu Yingming, Yao Shimou, Li Yujian, 2000. Research about problems related urban modernization of our country. *Human Geography*, 15(4): 16–19. (in Chinese)