

Influential Intensity of Urban Agglomeration on Evolution of Eco-environmental Pressure: A Case Study of Changchun, China

LIU Yanjun, ZHANG Jing, LI Chenggu, ZHOU Guolei, FU Zhanhui, LIU Degang

(School of Geography Sciences, Northeast Normal University, Changchun 130024, China)

Abstract: In this paper, we study the interactive relationship between the agglomeration of urban elements and the evolution of eco-environmental pressure. We build an index system for evaluating the agglomeration of urban elements and eco-environmental pressure. Using the entropy method and response intensity model, we analyze how urban elements agglomeration influenced eco-environmental pressure in Changchun from 1990 to 2012, eliciting the changing features and influential factors. Ultimately, we conclude there is a significant interactive relationship between the agglomeration of urban elements and the evolution of eco-environmental pressure in Changchun. This is inferred from the degree of this agglomeration in Changchun having increased since 1990, with the degree of eco-environmental pressure first decreasing and then increasing. Alongside this, the impact of urban elements agglomeration on eco-environmental pressure has changed from negative to positive. The main reasons behind this shift are arguably the rapid growth of urban investment and ongoing urbanization.

Keywords: urban elements agglomeration; eco-environmental pressure; influential intensity; response index; Changchun, China

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1 Introduction

In recent years, the deterioration of the ecological environment through rapid urbanization has been one of the most difficult challenges faced by big cities worldwide. The accelerating spatial expansions of big cities cause the mass consumption of water and soil resources, triggering an urban eco-environmental crisis. Paying attention to such environmental problems in the urbanization process should, therefore, be considered urgent. In this study, we focus on the interactive relationship between the urban expansion of elements agglomeration and eco-environmental pressure.

The spatial agglomeration of urban elements, and the eco-environmental problems that emerge alongside it, have been highly topical research areas in recent studies.

Many scholars have studied the relationships between different elements of urban development, e.g., industrial allocation, population migration, land utilization, etc. (Frenkel, 2001; Bolton and Breau, 2012; Cassiers and Kesteloot, 2012). In addition, Zhou and Yan (2005), Chen *et al.* (2008), and Xiu *et al.* (2011; 2013) widely studied the relationships between urban elements agglomeration and changes to the urban spatial structure. Krugman (1996) argued that the external economy, urban congestion, and environmental pollution are important factors affecting the agglomeration of urban elements. Beardsley *et al.* (2009), Tu *et al.* (2007), and Hasse and Lathrop (2003) paid close attention to the eco-environmental influence on urbanization progress, conducting part of their research on the eco-environmental problems of big cities worldwide.

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Corresponding author: ZHANG Jing. E-mail: zhangj888@nenu.edu.cn

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Nonomura *et al.* (2009), Jenerette and Larsen (2006), and Wu *et al.* (2009) evaluated the effects of urban constructions on the ecological environment. Boschken and Herman (2013) showed how urban development around the world has severely jeopardized the coastal ecological environment. Naeema and Carolien (2015) suggested that the process of urbanization would inevitably exacerbate environmental degradation. Arunprakash and Giridharan (2014), Mansour and Nazrul Islam (2013), Daniel A *et al.* (2014) and Daniel S *et al.* (2014) studied the negative effects of urbanization with regard to a city's water environment, climatic change, biological species distribution, *etc.* Puay and Abdul (2014) studied Singapore's urban ecosystem development between 1991 and 2012. Emmanuel and Loconsole (2015) suggested that green infrastructures exerted a positive effect on urban development in the context of global warming. Beal (2015) discussed European urban policy and urban environmental strategy. Roland *et al.* (2013) proposed some key management goals for the environmental improvement of coastal cities. Yigitcanlar and Teriman (2015) studied sustainable development methods from the perspective of urban development, ecological planning, *etc.* Wang *et al.* (2015) conducted a statistical analysis of 74 Chinese cities to study the effects of economic growth and population agglomeration on the urban environment. Lin and Fang (2008) discussed the eco-environment effects of industrial agglomeration in city-agglomeration areas. As this extensive list of studies indicates, the relationship between urban development and eco-environmental influence is becoming an increasingly focal point of research interest. Overall, previous studies have focused on the impacts of urban development, externality of urban spatial expansion, and eco-environmental influences of urbanization. However, more systematic study of the influences of comprehensive, essential urban elements on eco-environmental evolution is required.

Urban elements agglomeration refers to the process and state of the relative concentration of various elements, such as population, material, capital, information, technology, *etc.*, within an urban area, owing to rapid urbanization and the attraction of big cities. An interactional relationship exists between the agglomeration of these elements and the evolution of eco-environmental pressure. The eco-environmental system is not only the foundation of urban development and the ag-

glomeration of urban elements but also constrains the latter. Urban spatial agglomeration is an important cause of eco-environment evolution, while the extent of the agglomeration of urban elements determines the pressure effects on the eco-environmental system. As shown in Fig. 1, in the early stages of urban development, there is generally little pressure on resource consumption and environmental pollution, given the small agglomeration of such elements as population, industry, *etc.* With rapid urban development, however, the city subsumes an increasing number of regional elements, and expands its size continuously. Both the consumption of resources (such as water and land) and environmental pollution increase significantly during this process, which may even exceed the carrying capacity of the eco-environment. In this case, the eco-environment plays an increasingly important role in constraining the process of urban spatial agglomeration, ultimately engendering the phenomenon of diseconomy, slowing down the agglomeration of regional elements, and potentially causing spatial diffusion that may relieve ecological pressure. Alongside this, the enhancement of environmental governance and investment, as well as the improvement of pollution control technology, is likely to induce the degree of pressure on the eco-environment to gradually decline once over the vertex P shown in Fig 1. The pressure and constraint relationship between space agglomeration and the eco-environment thus eases, and a more benign interaction gradually forms.

In this logical frame, we focus on the agglomeration of urban elements to conduct an empirical research, aiming to further discover the correlations and influencing factors between spatial agglomeration and the evolution of eco-environmental pressure. In this paper, by

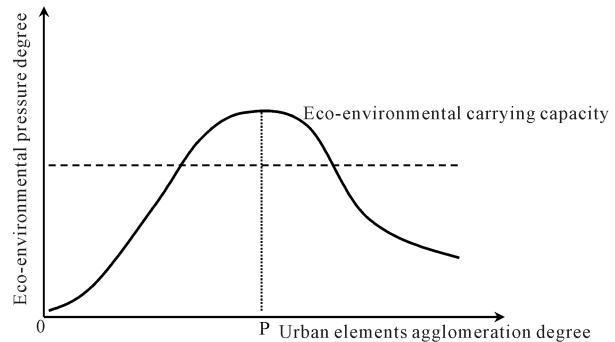


Fig. 1 Curve of interactive relationship between urban elements agglomeration and eco-environmental pressure

building index system and using quantitative method, we try to testify the logical frame above and find out more details about the relationship between urban development and eco-environment influence.

2 Materials and Methods

2.1 Study area

For our study, we choose the major city of China, Changchun, as a typical case (Fig. 2). Changchun is located in the middle of Northeast China and is the capital of Jilin Province. Changchun covers an area of 20 571 km² (inner city area: 3673 km²), with a total population of 7.57×10^6 . In 2012, the population of the inner city was 3.63×10^6 (2.11×10^6 in 1990), the urbanization rate was 45.3% (36.6% in 1990), and its GDP was 4.46×10^{12} yuan (RMB), while its per capita GDP reached 58 691 yuan (35.2 times that in 1990). The agglomeration of various elements in the inner city is highly evident from the rapid increase in Changchun's population, industry, and spatial development. However, such expansive urban economic development has involved huge resource consumption and caused extensive environmental pollution, resulting in eco-environmental crisis. For example, the per capita emission of industrial wastewater has increased 39.07% since 1990. All of the aforementioned factors make Changchun highly representative of typical major cities in China, for which reason it was chosen as our case study.

2.2 Data sources

The original data were mainly collected from: 1)

Changchun Statistical Yearbooks (Changchun Statistical Bureau, 1991–2013); 2) *Chinese Urban Statistical Yearbooks* (National Bureau of Statistics of China, 1991–2013); and 3) *Jilin Statistical Yearbooks* (Jilin Statistical Bureau, 1991–2013). To compensate for missing data for particular years, we used the mean value of the adjacent years before and after for interpolation purposes. To ensure the continuity of data analysis, we also incorporated Shuangyang County into Changchun City Proper, thereby excluding the impact of local administrative adjustments on the analysis results.

2.3 Indicators system

We developed two operable and effective evaluating indicator systems to represent the degree of urban elements agglomeration and eco-environmental pressure, respectively, based on the principles of systematization, representativeness, and availability (Table 1). We take full consideration of the intension of the urban elements agglomeration and the eco-environmental pressure in Changchun to choose the indicators. The system level of urban elements agglomeration comprises four sub-system levels: population agglomeration (UD_a), substance agglomeration (UD_b), capital agglomeration (UD_c), and information agglomeration (UD_d); and includes 15 indicators at the indicator level. The system level of eco-environmental pressure comprises three sub-system levels: eco-environmental pressure (EP_a), the eco-environmental safety (EP_b), and eco-environmental health (EP_c); and includes 16 indicators at the indicator level.

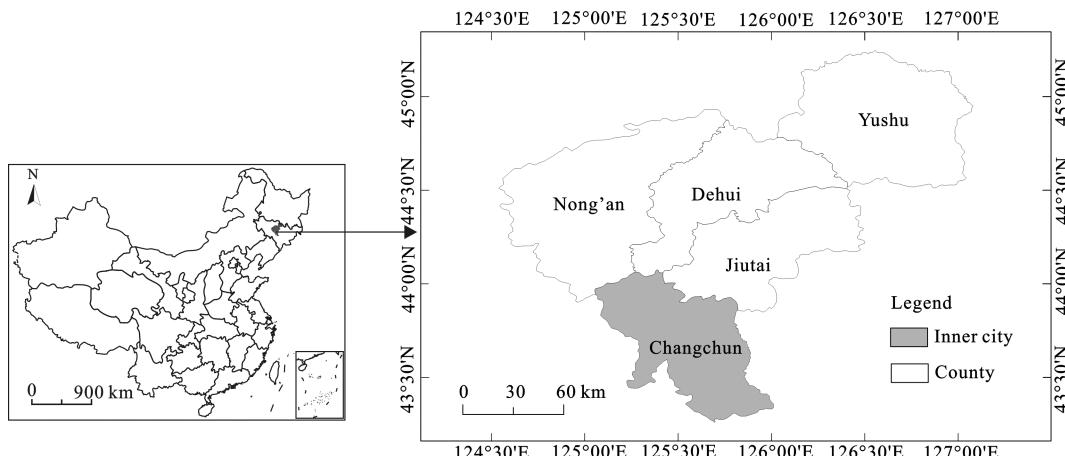


Fig. 2 Location of Changchun City

Table 1 Evaluating indicator systems of urban elements agglomeration (UD) and eco-environmental pressure (EP)

System	Sub-system	Indicator	Information entropy	Redundancy	Weight
Urban elements agglomeration (UD)	Population agglomeration (UD_a)	UD_{a1} Proportion of population in urban area (%)	0.8842	0.1158	0.1136
		UD_{a2} Proportion of urban population in urban area (%)	0.9084	0.0916	0.0898
		UD_{a3} Proportion of non-agricultural industrial employed persons in urban area (%)	0.9585	0.0415	0.0407
		UD_{a4} Proportion of passenger traffic in urban area (%)	0.9484	0.0516	0.0506
	Substance agglomeration (UD_b)	UD_{b1} Proportion of built-up areas (%)	0.8093	0.1907	0.1870
		UD_{b2} Proportion of freight traffic in urban area (%)	0.9771	0.0229	0.0225
		UD_{b3} Proportion of electricity consumption in urban area (%)	0.9329	0.0671	0.0658
		UD_{b4} Proportion of non-agricultural industrial GDP in urban area (%)	0.9796	0.0204	0.0200
	Capital agglomeration (UD_c)	UD_{c1} Proportion of fixed assets investment in urban area (%)	0.9343	0.0657	0.0644
		UD_{c2} Proportion of total retail sales of consumer goods in urban area (%)	0.9519	0.0481	0.0472
		UD_{c3} Proportion of total amount of foreign capital actually used in urban area (%)	0.9715	0.0285	0.0279
		UD_{c4} Proportion of business volume of postal and telecommunication services in urban area (%)	0.9463	0.0537	0.0527
	Information agglomeration (UD_d)	UD_{d1} Proportion of telephone subscribers in urban area (%)	0.9464	0.0536	0.0526
		UD_{d2} Proportion of technological activities human resource in urban area (%)	0.9675	0.0325	0.0318
		UD_{d3} Proportion of scientific research expenditure in urban area (%)	0.8638	0.1362	0.1335
		EP_{a1} Per capital living area (m^2 /person)	0.8476	0.1524	0.1082
Eco-environmental pressure (EP)	Eco-environmental safety (EP_a)	EP_{a2} Per capital tap water supply in urban area (t/person)	0.9439	0.0561	0.0398
		EP_{a3} Per capital electricity consumption in urban area (kWh/person)	0.9097	0.0903	0.0641
		EP_{a4} Per capital residential use of coal gas in urban area (m^3 /household)	0.9209	0.0791	0.0562
		EP_{a5} Per capital industrial wastewater discharge (t/person)	0.9354	0.0646	0.0459
		EP_{a6} Per capital industrial SO ₂ discharge (t/person)	0.9146	0.0854	0.0607
	Eco-environmental health (EP_c)	EP_{b1} Per capital area of cultivated land in urban area (hm^2 /person) [*]	0.9223	0.0777	0.0552
		EP_{b2} Per capital water resource supply in urban area (m^3 /person) [*]	0.9726	0.0274	0.0194
		EP_{b3} Forest coverage rate in urban area (%) [*]	0.9672	0.0328	0.0233
		EP_{b4} Green coverage rate in built-up area (%) [*]	0.9248	0.0752	0.0534
		EP_{b5} Area in up-to-standard noise-control zones (km^2) [*]	0.9332	0.0668	0.0475
	Eco-environmental	EP_{c1} Compliance rate of industrial wastewater discharge (%) [*]	0.8373	0.1627	0.1156
		EP_{c2} Handing rate of municipal sewage (%) [*]	0.9478	0.0522	0.0371
		EP_{c3} Rate of sulphur dioxide removed (%) [*]	0.9333	0.0667	0.0473
		EP_{c4} Rate of industrial solid waste utilized (%) [*]	0.7550	0.2450	0.1740
		EP_{c5} Wastes treatment rate (%) [*]	0.9263	0.0737	0.0523

Note: * represents negative indicator

2.4 Evaluation method

We use the entropy method to reflect the weight of different variables and eliminate subjective bias. The calculation procedures are as follows (Wang *et al.*, 2014; Chen *et al.*, 2009).

Data normalization: among the indexes, if the greater the value of the index (X_{ij}) is, the better the system will develop, then we use the positive indexes and calculate $X_{ij}^* = (X_{ij} - \min\{X_j\}) / (\max\{X_j\} - \min\{X_j\})$. Conversely, if the smaller the value of the index (X_{ij}) is, the better the system will develop, then we use the negative

indexes and calculate $X_{ij}^* = (\max\{X_j\} - X_{ij}) / (\max\{X_j\} - \min\{X_j\})$. Here X_{ij} represents the value of indicator j in year i ; X_{ij}^* is the normalized value of X_{ij} ; $\max\{X_j\}$ is the maximum value of indicator j ; $\min\{X_j\}$ is the minimum value of indicator j ;

The proportion of the value of indicator j in year i (Y_{ij}):

$$Y_{ij} = X_{ij}^* \left/ \sum_{i=1}^m X_{ij}^* \right. \quad (1)$$

The entropy of the indicator e_j :

$$e_j = -k \sum_{i=1}^m (Y_{ij} \ln Y_{ij}), k = \frac{1}{\ln m}, \text{ in which } 0 \leq e_j \leq 1 \quad (2)$$

The redundancy of entropy d_i :

$$d_i = 1 - e_j \quad (3)$$

Weight of indicator ξ_i :

$$\xi_i = d_i / \sum_{j=1}^n d_i \quad (4)$$

Then, the comprehensive level score in year i (η_i):

$$\eta_i = \sum_{j=1}^n (\xi_i \times X_{ij}^*) \quad (5)$$

where m is number of year, and n is the number of indicators. Based on Equation (5), we subsequently calculate the indexes of urban elements agglomeration (UD) and eco-environmental pressure (EP), respectively. A higher UD value indicates a higher degree of the agglomeration of urban elements, while a lower UD value indicates a lower degree thereof. A higher EP value demonstrates higher eco-environmental pressure, while a lower EP value points to lower pressure. In this paper, we use UD_v and EP_v to respectively represent the indexes of urban elements agglomeration and eco-environmental pressure in Changchun.

2.5 Response intensity model

We constructed a response index model and response

intensity index model to represent the degree of influence exerted by urban elements agglomeration on eco-environmental pressure. The response index model can be expressed as follows (Liu *et al.*, 2008):

$$H = \frac{dEP}{dUD} \cdot \frac{UD}{EP} \quad (6)$$

where H is the response index of eco-environmental pressure to the agglomeration of urban elements; and $\frac{dEP}{dUD}$ is the derivative of the eco-environmental pressure index (EP) to the elements agglomeration index (UD). Using Equation (6), we define the response intensity (L) of eco-environmental pressure to spatial agglomeration, where the L value is equal to the absolute value of H (Liu *et al.*, 2013):

$$L = |H| \quad (7)$$

In theory, the higher the L value, the higher the influence degree of spatial agglomeration on eco-environmental pressure, and vice versa. Table 2 provides the implications of specific variations of the H and L values used in this study.

2.6 Influential factors model

In order to further analyze the factors influencing the change of the response index (H_v) of eco-environmental pressure to the agglomeration of urban elements, we use the linear multiple regression model. We set H_v as the dependent variable(y), and selected many related indicators as the independent variables. The model is:

Table 2 Response types of eco-environmental pressure to elements agglomeration

H value	Response types	Relationship between H and L	H value variation	Implication
$H > 0$	Positive response	$L = H$	Increase	Influence of urban elements agglomeration on eco-environmental pressure increases, and the influence intensity strengthens
			Unchanged	Influence strength of urban elements agglomeration on eco-environmental pressure does not change
			Decrease	Influence of urban elements agglomeration on eco-environmental pressure increases, but the influence intensity weakens
$H = 0$	No response	$L = H = 0$	–	There is no influence of urban elements agglomeration on eco-environmental pressure
			Increase	The influence of urban elements agglomeration on eco-environmental pressure decreases, and the influence intensity weakens
$H < 0$	Negative response	$L = -H$	Unchanged	The influence strength of urban elements agglomeration on eco-environmental pressure does not change
			Decrease	The influence of urban elements agglomeration on eco-environmental pressure decreases, but the influence intensity strengthens

$$y = \lambda_0 + \lambda_1 x_1 + \lambda_2 x_2 + \lambda_3 x_3 + \lambda_4 x_4 + \lambda_5 x_5 + \omega \quad (8)$$

where y is the calculated estimate according to independent variable x ; λ_0 is the constant term. $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ and λ_5 are partial regression coefficients of y corresponding to x_1, x_2, x_3, x_4 and x_5 ; and ω is a random disturbance term. SPSS19.0 was used to carry out the regression analysis, form the regression model, and obtain the explanatory variable parameters.

3 Results and Analysis

3.1 Agglomeration of urban elements and evolution of eco-environmental pressure

Using the above-mentioned evaluation systems and models, we find that the index of urban elements agglomeration in Changchun has increased from 0.2491 to 0.6902 over the period 1990–2012, generally indicating a rising trend. This, in turn, suggests that the degree of the agglomeration of urban elements has been steadily increasing since 1990. Specifically, the indexes of population agglomeration and material agglomeration show a clear upward trend, indicating that the population and material elements clustered quickly in the central area of Changchun. However, the capital agglomeration index and information and technology index are found to have grown slowly and fluctuated, arguably indicating a state of capital and information-technology agglomeration that is unstable. Generally, therefore, these results indicate that the rising degree of the agglomeration of urban elements in Changchun may have

derived from the city's rapid accrual of population and material elements.

The eco-environmental pressure index is found to exhibit a fluctuating trend, first showing a downward pattern and then an upward one (Fig. 3). This index reached 0.3464 in 2012, after dropping from 0.5805 to 0.2859 during the period 1990–2004. Specifically, the ecological pressure index increased significantly, the ecological security index declined dramatically, and the ecological health index shows a clearly decreasing tendency. Combined, these results convey that ecological environmental pressure has been increasing under the influence of Changchun's spatial agglomeration, and that the ability of the city to cope with environmental pressure has also been growing. Overall, the increasing ecological pressure that appears in the process of spatial agglomeration can be said to result in volatile rising of eco-environmental pressure.

3.2 Change in response intensity of eco-environmental pressure to agglomeration of urban elements

We calculate the response indexes and response intensity indexes of eco-environmental pressure to urban elements agglomeration from 1990 to 2012. We selected the best response functional equation of EP_v and UD_v by using the method of curve estimation: $EP_v = 0.701 + 0.055UD_v - 3.416UD_v^2 + 3.788UD_v^3$ ($R^2 = 0.555$, $F = 7.893$, $P = 0.001$). The response function used is a cubic equation (Fig. 4) that passed significance testing and has good curve-fitting. We place this result into Equation (6), and obtain the response index (H_v) and response intensity (L_v) of eco-environmental pressure to the

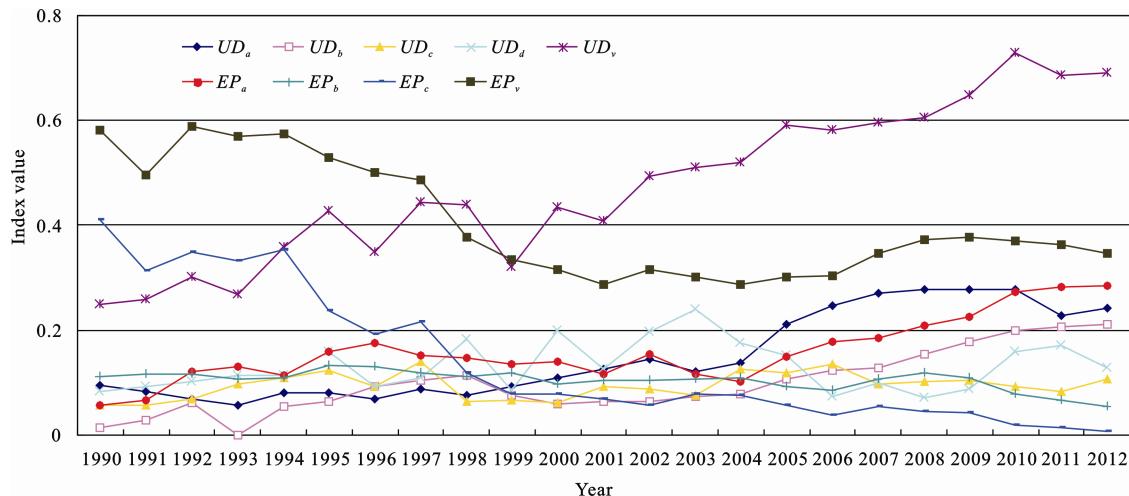


Fig. 3 Tendency and features of elements agglomeration index (UD_v) and eco-environmental pressure index (EP_v)

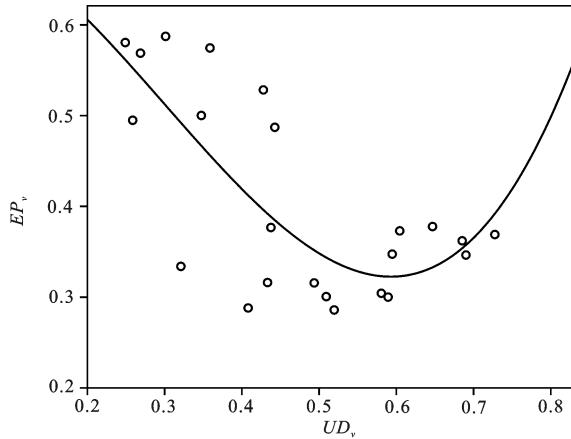


Fig. 4 Response function of eco-environmental pressure (EP_v) to elements agglomeration (UD_v) in Changchun

agglomeration of urban elements in Changchun in 1990–2012.

Fig. 5 shows that H_v increased from -0.9417 to 0.7531 during 1990 to 2012, proving that the influence of EP_v on UD_v shifted from negative to positive. The figure also shows two phases of H_v , which grew slowly in 1990–2001 and then grew rapidly in 2001–2012. At the same time, L_v showed a rise after a drop. According to Table 2, this indicates that the influential degree of urban elements agglomeration (UD_v) on eco-environmental pressure (EP_v) first decreased and then increased. Consequently, as various elements cluster rapidly in the central city, they have an increasing impact on urban eco-environment.

3.3 Factors influencing the impact of elements agglomeration on eco-environmental pressure

Based on general theory and practice analysis, the important factors causing response index (H_v) to increase include the intensity of urban development, rate of urbanization, industrial economic development and industrial structural change, resource use efficiency, environmental governance, and regional development policy. By constructing index systems, we further validated and measured the key characteristics influencing H_v and L_v , and the degree to which this influence occurred, by synthetically setting H_v as the dependent variable (y). The GDP per unit of construction land in the urban area (x_1), the rate of urbanization of the urban area (x_2), the second industrial output share of GDP of the urban area (x_3), the waste utilization value share of GDP of the urban area (x_4), and fixed assets investment per unit area of the urban area (x_5) are used to reflect, respectively, urban development intensity, urbanization rate, industrial economic development and industrial structural change, resource use efficiency, environmental governance, regional development policy, and institutionalization. Following this, we use the linear regression model (Equation 9) to obtain the explanatory variable parameters which are showed in Tables 3 and 4.

The five models, as outlined in Table 3, use x_1 , x_2 , x_3 , x_4 and x_5 respectively as separate independent variables, performing a unitary linear regression analysis with y (H_v). Each model passed the test of significance. H_v is

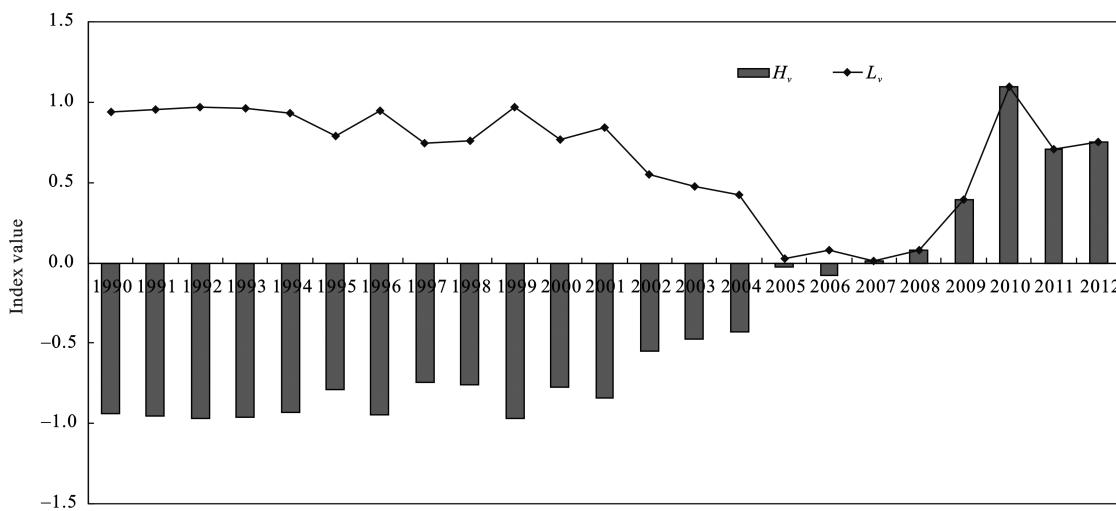


Fig. 5 Variation tendency and stage characteristics of response index (H_v) and response intensity (L_v)

Table 3 Unitary regression model of response index (H_v) (1990–2012)

Item	Dependent variable		$y (H_v)$		
	Model 1	Model 2	Model 3	Model 4	Model 5
λ_0	-1.354 (-8.23)**	-14.941 (-3.76)**	-10.205 (-11.41)**	-0.983 (-3.64)**	-0.887 (-18.93)**
x_1	0.822 (6.61)**				
x_2		0.624 (3.66)**			
x_3			0.923 (10.99)**		
x_4				0.468 (2.43)*	
x_5					0.964 (16.60)**
R^2	0.675	0.389	0.852	0.219	0.929
F	43.68	13.39	120.82	5.90	275.54
P	0.000	0.001	0.000	0.024	0.000

Notes: **and * represent coefficients statistically significant at the 0.01 and 0.05 level, respectively. The numbers in parentheses are t statistics

found to be positively correlated with x_1 , x_2 , x_3 , x_4 and x_5 , which is consistent with the theoretical assumptions. Among them, the correlation coefficient between the fixed assets investment per unit area of the urban area (x_5) and H_v (along with the applicable t statistic) is significantly higher than the other indices. These findings indicate that the growth of fixed assets investment in Changchun during 1990–2012 is highly relevant to explaining the increase in H_v , without necessarily considering other factors. In addition, industrial structural change, the increase in urban development intensity, and the promotion of urbanization are also found to exert a significant influence on the increase in H_v .

To further investigate the dominant factors driving the increase in H_v , we use x_1 , x_2 , x_3 , x_4 and x_5 as the common independent variables to perform a multiple stepwise linear regression analysis with $y (H_v)$. For this purpose, and considering the phase change characteristics of H_v and L_v , the time period was divided into three stages: 1990–2012, 1990–2001, and 2001–2012. We

then examine the main factors responsible for changes in H_v and L_v at different stages; the detailed analysis results are shown in Table 4.

The results show that the regression models applied to the three time phases all passed the significance test. The significant factors driving the increase in H_v in 1990–2012 were the fixed assets investment per unit area of the urban area (x_5) and the rate of urbanization of the urban area (x_2), while other factors were relatively insignificant. The result further indicates that the rapid growth of fixed assets investment is arguably the most important factor behind the increase in H_v , with the promotion of urbanization also a relatively important factor. More specifically, the rate of urbanization of the urban area (x_2) was found to be the main factor encouraging the increase in H_v during 1990–2001, meaning that the promotion of urbanization had an important effect on the slow growth of H_v , while fixed assets investment of per unit area of the urban area (x_5) was the main factor behind the rapid growth of H_v during 2001–2012.

Table 4 Multiple regression model of H_v

Time scale	Regression model	F	R^2	P
1990–2012	$y = -4.805 + 0.170x_2 + 0.876x_5$ (2.92)** (15.03)**	191.26	0.950	0.000
1990–2001	$y = -3.308 + 0.579x_2$ (2.244)*	5.03	0.335	0.049
2001–2012	$y = -0.709 + 0.947x_5$ (9.355)**	87.52	0.897	0.000

Notes: ** and * represent coefficients statistically significant at the 0.01 and 0.05 level, respectively. The numbers in parentheses are t statistics corresponding to the independent variables

Overall, the influential degree of urban elements agglomeration (UD_v) on eco-environmental pressure (EP_v) first decreased and then increased since 1990. The main factors of this change are the growth of fixed assets investment and the promotion of urbanization rate. This is consistent with the actual development of Changchun: for example, fixed assets investment in Changchun has continued to accelerate in recent years (the rate of investment growth increased from 19.0% in 1990 to 44.9% in 2012). Moreover, the steady development of urbanization has brought urban population growth, industrial agglomeration, and large-scale land development. The rapid growth of urban investment and the development of urbanization have, in turn, engendered the promotion of urban spatial agglomeration and also, to some extent, exerted significant pressure on the urban ecological environment. Under the support of government policy, especially since the implementation of the Northeast China Revitalization Strategy, many capital and non-capital elements have been combined in Changchun's spatial constructions. To some extent, the extensive constructions of industries and infrastructures increased the pressure on environmental resources. Through further calculation, it was found that fixed assets investment and the rate of urbanization showed a significant positive correlation during 1990–2012, thus proving that the interaction between the rapid growth of urban investment and the development of urbanization jointly promotes growing urban spatial agglomeration and fluctuating trends in the resulting urban eco-environmental pressure. Arguably, these results also posit this interaction to be the major factor affecting the evolution of eco-environmental pressure in response to urban agglomeration in Changchun.

4 Conclusions and Recommendations

The relationship between the agglomeration of urban elements and the evolution of urban eco-environmental pressure in a major city has been found to be significant. The degree of such agglomeration in Changchun increased continually from 1990 to 2012 due to the rapid clustering of population and production factors. During this period, the eco-environmental pressure fluctuated under the pressure of urban elements agglomeration. The influential intensity of urban elements agglomeration on eco-environmental pressure in 1990–2012

showed its defining stage characteristic that, first the urban development could ease the eco-environmental pressure, and then along with the more urban elements agglomeration, the eco-environmental pressure increased again. In recent years, various urban elements have accrued rapidly in Changchun, with the pressure they exert on the ecological environment increasing accordingly. According to the general theories of urbanization, Changchun is still in the stage of elements clustering, with high eco-environmental pressure.

The main urban elements that induced the shifting impact of urban elements agglomeration on eco-environmental pressure are arguably growing fixed assets investment and ongoing urbanization development. The coactions of these two elements could obviously accelerate the change of influential intensity of urban agglomeration on eco-environmental pressure.

Based on the correlation between urban agglomeration and eco-environmental evolution discovered in the current study, and in line with the requirements of urban sustainable development, it can be argued that Changchun should proceed with ordered urbanization to appropriately control the speed and scale of urban development, to avoid excessive spatial expansion, and to reduce the amount of construction land occupying agricultural, especially cultivated land. In addition, this paper's findings imply that the local government should further adjust the industrial layout, quicken the transfer of polluting industries to the region, and constantly optimize the structure of the urban space. Infrastructure construction needs to be improved to provide an attractive investment environment, leading the investment and capital factors to the high-tech and ecological industries. Moreover, the local government should strengthen the conservation and intensive use of water, land, and other resources; adjust and optimize the coal-based energy structure; further increase investment in environmental protection; improve environmental infrastructure construction; and further improve the institutional construction of eco-environment protection.

References

- Arunprakash M, Giridharan L, 2014. Impact of urbanization in groundwater of south Chennai City, Tamil Nadu, India. *Environmental Earth Sciences*, 71(2): 947–957. doi: 10.1007/s12665-013-2496-7
- Beal V, 2015. Selective public policies: sustainability and neolib-

- eral urban restructuring. *Environment and Urbanization*, 27(1): 303–316. doi: 10.1177/0956247814549153
- Beardsley K, Thorne J H, Roth N E et al., 2009. Assessing the influence of rapid urban growth and regional policies on biological resources. *Landscape and Urban Planning*, 93(3–4): 172–183. doi: 10.1016/j.landurbplan.2009.07.003
- Bolton K, Breau S, 2012. Growing Unequal? Changes in the distribution of earnings across Canadian cities. *Urban Studies*, 49(6): 1377–1396. doi: 10.1177/0042098011410335
- Boschken, Herman L, 2013. Global cities are coastal cities too: paradox in sustainability? *Urban Studies*, 50(9): 1760–1778. doi: 10.1177/0042098012462612
- Cassiers T, Kesteloot C, 2012. Socio-spatial inequalities and social cohesion in European cities. *Urban Studies*, 49(9): 1909–1924. doi: 10.1177/0042098012444888
- Chen Gangqiang, Li Xun, Xu Xueqiang, 2008. Spatial agglomeration and evolution of urban population in China. *Acta Geographica Sinica*, 63(10): 1045–1054. (in Chinese)
- Chen Mingxing, Lu Dadao, Zhang Hua, 2009. Comprehensive Evaluation and the Driving Factors of China's Urbanization. *Acta Geographica Sinica*, 64(4): 387–398. (in Chinese)
- Daniel A, Jason P E, Lluís F et al., 2014. Temperature response to future urbanization and climate change. *Climate Dynamics*, 42(7–8): 2183–2199. doi: 10.1007/s00382-013-1789-6
- Daniel S, Alessia S, Marco C, 2014. Urbanization effects on shoreline phytoplankton: a multiscale approach at lake extent. *Aquatic Sciences*, 76(1): 17–28. doi: 10.1007/s00027-013-0307-6
- Emmanuel R, Loconsole A, 2015. Green infrastructure as an adaptation approach to tackling urban overheating in the Glasgow Clyde Valley Region, UK. *Landscape and Urban Planning*, 138(SI): 71–86. doi: 10.1016/j.landurbplan.2015.02.012
- Frenkel A, 2001. Why high-technology firms choose to locate in or near metropolitan areas? *Urban Studies*, 38(7): 1083–1101. doi: 10.1080/00420980120051666
- Hasse J E, Lathrop R G, 2003. Land resource impact indicators of urban sprawl. *Applied Geography*, 23(2–3): 159–175. doi: 10.1016/j.apgeog.2003.08.002
- Jenerette G D, Larsen L, 2006. A global perspective on changing sustainable urban water supplies. *Global and Planetary Change*, 50(3–4): 202–211. doi: 10.1016/j.gloplacha.2006.01.004
- Krugman P, 1996. Urban concentration: the role of increasing returns and transport costs. *International Regional Science Review*, 19(1–2): 5–30. doi: https://doi.org/10.1177/016001769601900202
- Lin Xueqin, Fang Chuanglin, 2008. Research progress on the eco-environmental effect of industry agglomeration in city group. *Progress in Geography*, 27(3): 110–118. (in Chinese)
- Liu Yaobin, Chen Fei, Zhou Jiewen, 2008. Responsive model of eco-environment to urbanization and its application. *Arid Land Geography*, 31(1): 122–128. (in Chinese)
- Liu Yanjun, Liu Jing, He Cui et al., 2013. Evolution of the coupling relationship between regional development strength and resource environment level in China. *Geographical Research*, 32(3): 507–517. (in Chinese)
- Mansour A M, Nazrul Islam P D J, 2013. Urbanization effects on the air temperature rise in Saudi Arabia. *Climatic Change*, 120(1–2): 109–122. doi: 10.1007/s10584-013-0796-2
- Naeema J Z, Carolien K, 2015. Future trends in urbanization and coastal water pollution in the Bay of Bengal: the lived experience. *Environment, Development and Sustainability*, 17(3): 531–546. doi: 10.1007/s10668-014-9558-1
- Nonomura A, Kitahara M, Masuda T, 2009. Impact of land use and land cover changes on the ambient temperature in a middle scale city, Takamatsu, in Southwest Japan. *Journal of Environmental Management*, 90(11): 3297–3304. doi: 10.1016/j.jenvman.2009.05.004
- Puay Y T, Abdul R A H, 2014. Urban ecological research in Singapore and its relevance to the advancement of urban ecology and sustainability. *Landscape and Urban Planning*, 125(2): 271–289. doi: 10.1016/j.landurbplan.2014.01.019
- Roland G, Tim D J, Alexander B et al., 2013. Megacities and large urban agglomerations in the coastal zone: interactions between atmosphere, land, and marine ecosystems. *AMBIO*, 42(1): 13–28. doi: 10.1007/s13280-012-0343-9
- Tu J, Xia Z G, Clarke K C et al., 2007. Impact of urban sprawl on water quality in eastern Massachusetts, USA. *Environmental Management*, 40(2): 183–200. doi: 10.1007/s00267-006-0097-x
- Wang Changjian, Zhang Xiaolei, Du Hongru et al., 2014. Quantitative analysis of the dynamic relationship between urbanization and ecological environment in Urumqi, Xinjiang. *Arid Land Geography*, 37(3): 609–619. (in Chinese)
- Wang Xingjie, Xie Gaodi, Yue Shuping, 2015. Impact of economic growth and population aggregation on urban environmental quality and Its Regional Differentiation: a case study of 74 cities implemented the new standard for air quality during the first stage. *Economic Geography*, 35(2): 71–76, 91. (in Chinese)
- Wu Yongjiao, Ma Haizhou, Dong Suocheng et al., 2009. Modelling the interaction of urbanization and eco-environment. *Scientia Geographica Sinica*, 29(1): 64–70. (in Chinese)
- Xiu Chunliang, Cheng Lin, Song Wei et al., 2011. Vulnerability of large city and its implication in urban planning: a perspective of intra-urban structure. *Chinese Geographical Science*, 21(2): 204–210. doi: 10.1007/s11769-011-0451-7
- Xiu Chunliang, Sun Pingjun, Wang Qi, 2013. Residence-employment structure analysis on spaces of geography and flows in Shenyang City. *Acta Geographica Sinica*, 68(8): 1110–1118. (in Chinese)
- Yigitcanlar T, Teriman S, 2015. Rethinking sustainable urban development: towards an integrated planning and development process. *International Journal of Environmental Science and Technology*, 12(1): 341–352. doi: 10.1007/s13762-013-0491-x
- Zhou Suhong, Yan Xiaopei, 2005. The relationship between urban structure and traffic demand in Guangzhou. *Acta Geographica Sinica*, 60(1): 131–142. (in Chinese)