CHINESE GEOGRAPHICAL SCIENCE
Volume 15, Number 3, pp. 219–226, 2005
Science Press, Beijing, China

SCENARIOS SIMULATION OF COUPLING SYSTEM BETWEEN URBANIZATION AND ECO-ENVIRONMENT IN JIANGSU PROVINCE BASED ON SYSTEM DYNAMICS MODEL

LIU Yao-bin[1], LI Ren-dong[2], LI Chun-hua[3]
(1. School of Management, China University of Mining and Technology, Xuzhou 221008, P. R. China; 2. Institute of Geodesy and Geophysics Research, Chinese Academy of Sciences, Wuhan 430077, P. R. China; 3. Institute of Resource, Beijing Normal University, Beijing 100875, P. R. China)

ABSTRACT: By means of ISM (Interpretative Structural Modeling) and SD (System Dynamics) methods, this paper made a system dynamics model of urbanization and eco-environment coupling in Jiangsu Province according to the implication and PSR (Pressure State Response) framework of urbanization and eco-environment coupling. Moreover, five typical scenarios during 2000–2015 have been simulated and analyzed based on the time serial statistical data during 1990–2003 in Jiangsu, which indicates: firstly, there are significant differences between the results and the scenarios, and the five coupling models all have comparative advantages and drawbacks; secondly, in terms of the characteristics and regional development disparities of Jiangsu and the general rule of world urbanization process, this paper reveals that only when either population urbanization model or social urbanization model to be correspondingly adopted, the sustainable development among population, economy, urbanization and eco-environment can be realized.
KEY WORDS: urbanization; eco-environment; system dynamics model; simulation; Jiangsu Province

CLC number: F061.3; N941.3 Document code: A Article ID: 1002-0063(2005)03-0219-08

1 INTRODUCTION

Urbanization and eco-environment coupling is unique and complex, and its mechanisms and rules have provoked much scholarship (BRENNA, 1999). More than 100 years ago, HOWARD (1898) published *Garden Cities of Tomorrow* to reveal the interrelationships between city growth and its eco-environment, and he tried to deal with the issue with rational planning way, but he failed (BOURNE and SIMMONS, 1978). However, only since the 1920s had the topic specially been intensified. After the Chicago school had evidently succeeded in urban health, land use and social segregation by social ecology approaches (GRIMM *et al*., 2000), some problems concerning urbanization and human settlement environment had once been listed in the subprojects of MAB (Man and Biosphere) (WCED, 1987), so the work brought world scholars to attend (MACLAREN, 1996). The relative issues had deeply been probed and involved in some quantitative calculations and evaluations. For example, with IPAT (Impact=Population×Affluence×Technology) formula and econometric method, some environmental economists (COMMONER *et al*., 1971; GROSSMAN and KRUEGER, 1993) checked up the relationship between urban economic growth and environmental degradation and put forward a hypothesis that urban environment press took on a inversed U-shape with economic growth (GROSSMAN and KRUEGER, 1995). By energy model, system dynamics (SD) and sensitivity model, some ecologists (ODUM and ELISABETH, 2000; FORRESTER, 1971; VESTER and VON HESLER, 1980) analyzed the subjects and revealed the inner mechanisms of urbanization and eco-environment coupling. Moreover, in terms of systemic optimization and geometric models, BRAAT and VAN LIEROP (1986), SUKOPP and WEILER (1988) analyzed the issues, and they succeeded, too. In China, similar studies and reports can be found as well. With econometric model, some scholars (LING *et al*., 2001; WU *et al*., 2002; LIU and LI, 2003) individually revealed some

Received date: 2005-05-09
Foundation item: Under the auspices of Knowledge Innovation Program of Chinese Academy of Sciences (No. KZCX2-SW-415)
Biography: LIU Yao-bin (1970–), male, a native of Macheng of Hubei Province, Ph.D. candidate, specialized in urban and regional planning and management. E-mail: liuyaobin2003@163.com

characteristics of economic development and environment change in Nanjing, Beijing and Wuhan. By means of SD, some scholars (WANG, 1988; YANG, 1992; SONG and WANG, 1991; YANG, 2003) respectively simulated the scenarios of city evolution, such as Tianjin, Beijing and Changxingdao. In terms of numeric model and grey correlation method, HUANG *et al*. (2004) and LIU *et al*. (2005) individually calculated the coupling degrees of the Three Gorges area and the whole China. However, in general, urbanization level indicates urban population growth and its economic development in a country or region, and it has less been used to calculate the single city (ZHOU, 1999). As the above literatures shown, most research contents were about single city or some sides of cities, and there was not a special and systemic involvement in the coupling system between urbanization and eco-environment in provinces or regions, thus the paper takes Jiangsu Province as a case to analyze the coupling mechanism between urbanization and eco-environment by SD, and to dynamically simulate the scenarios, which aims at providing some suggestions for Jiangsu's urbanization strategy and eco-environment construction.

2 CONNOTATION AND FRAMEWORK OF URBANIZATION AND ECO-ENVIRONMENT COUPLING

Urbanization is a major trend in recent years all around the world (WEBER and PUISSANT, 2003). The concept of urbanization can vary from author to author; here, it is defined as a territorial and socio-economic process that induces a general transformation of land use/cover categories. Referring to China census, urbanization process deals with concentrations of population and human activities. It creates aggregations of urban areas that shelter hundreds of and thousands of inhabitants. From an economic point of view, these structures are more and more linked with international activities, becoming an interface between local and national scales, and the international one. So urbanization has many contents that mainly include urban population growth, economic development, spatial expansion and welfare improvement (LIU *et al*., 2005). Eco-environment is one of ecological and environmental terms that are frequently used in the fields, but its concept also varies from scholar to scholar. In terms of different studied body, the connotation of eco-environment extremely varies: if life beings is referred as main body, eco-environment is a habitat that affects the growth, development, reproduction, behavior and distribution of living beings. As famous ecologist WHITTAKER (1973) defined, from the perspective of species, a unit where they evolve is just an ecotope. On the contrary, if humankind is referred as main body, eco-environment is an integrative surroundings where humankind exists and develops, including some environmental factors, such as water, land, gas, resources, energy sources, etc. Because most environmental problems are induced by humankind actions, the latter concept is prevalently applied.

With humankind being a focus of the world, urbanization is a process of utilizing and transforming natural resources and environment. Therefore, if the scale of human action is too big or living expectation is higher, it sometimes leads to the disharmony between humankind and geographical environment under the limitation of technologic level, which is called eco-environmental problems. The coupling relationship between urbanization and eco-environment is nonlinear interaction in four aspects from urbanization and five factors from eco-environment, and the coupling action can be concluded: on the one hand, eco-environment is intimidated by urban population growth, economic development, energy consumption and traffic outspread, by which original eco-environment is transformed to artificial environment and environmental degradation is induced; on the other hand, urbanization is restrained through urban population repulsion, capital reprobation and polices regulation, which lead to environmental maintenance and improvement. Fig. 1 shows PSR model in which urbanization interacts with eco-environment, in the model, some factors reciprocate and feed back between urbanization and eco-environment, and the best condition is an efficient complex ecological system where they can coordinate and interject.

3 SD OF COUPLING SYSTEM BETWEEN URBANIZATION AND ECO-ENVIRONMENT IN JIANGSU PROVINCE

3.1 SD Design

3.1.1 Systemic structure

3.1.1.1 ISM build-up

SD theory considers that systemic actions result from the systemic structure, and effects that come from exterior environment must be passed on by interior structure (FORRESTER, 1971), so to make systemic borderline sure and to analyze the systemic structure reasonably are keys to build up SD model. According to PSR framework (Fig. 1), with interpretative structural

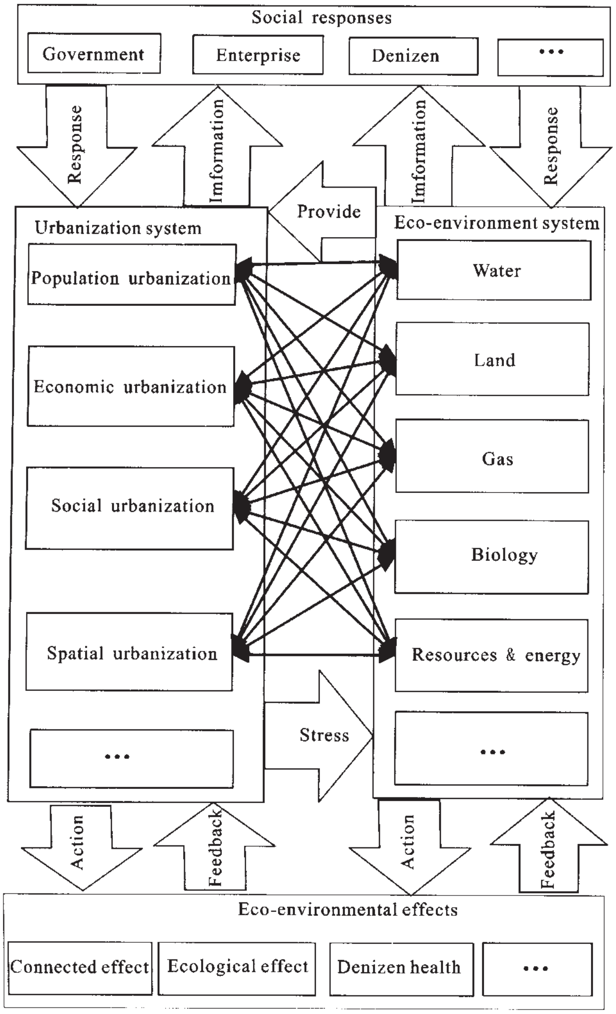

Fig.1 PSR framework of urbanization and eco-environment coupling

modeling (ISM), the structure of the coupling system in Jiangsu Province has been simplified. ISM is an available approach to deal with social-economic complex system (PARASURAMAN *et al*., 1985), by which the coupling system can be decompounded before SD model is designed. With the attainable matrixes calculated, the 58 factors have been selected and the ISM of the coupling system has been built up, in which the ISM can be divided into four levels and eight subsystems. As the ISM model showed, the coupling system can be reduced to a simple structure where the relationship is clear, and it can be applied to design the SD model.

3.1.1.2 Systemic structure analysis

According to the ISM model and present situation of Jiangsu Province, the coupling system can be classified as four subsystems, i.e. population, economy, eco-environment and urbanization subsystems. In terms of the levels structure that the ISM model provides, the subsystems can be further divided into 14 model blocks, which are total population, primary industrial output, secondary industrial output, tertiary industrial output, waste water pollution, waste gas pollution, solid waste pollution, cultivated land, population urbanization, urban house, urban built-up area, scientific-technological level, educational level and medical & healthy level, and the causal loops can be concluded as follows:

(1) Population subsystem. Total population (TP) is assigned to level variable, and its accumulative number depends on birth rate (BR) and death rate (DR). Total population is relatively affected by population policies and other factors including pollution, food and congestion, the influences from family planning policies, etc. are widely taken into account, and by feedback the total population can be linked with economic subsystem, scientific-technological subsystem and urbanization as well. As an important state variable, population deeply affects the provincial social economy development, urbanization process and eco-environment, etc. Meanwhile, it is restrained by eco-environment capacity, economic development level and urbanization level. In the model, the resources character and population structure are considered. That is to say, through linking social labor force to "three industries", the resources character of population can affect industrial outputs; and through determining the difference between agricultural and non-agricultural population, urban subsystem has been emphasized.

(2) Economic subsystem. It is explained by three industries outputs, manufacture industry, GDP and social productive investment. In the subsystem, primary industrial output (PIO), secondary industrial output (SIO), tertiary industrial output (TIO) are designed as level variables, and the social capital investment and labor force are appointed as auxiliary variables to connect other subsystems. By Cobb-Douglass (CD) production function, the transformation mechanism between input and output is expressed, where capital is defined as interior factor and labor force as exterior factor. At the same time, the positive and negative influence is calculated and it in turn acts on CD function outputs. Among three industries, secondary industry as a critical material production department, and through linking with manufactory industry value (MIV), can affect the environmental subsystem. The total economic block is represented by GDP and social productive investment (SPI), and they are considered as auxiliary variables and controllable variables to reveal the dynamic connection relationship among investments, industrial structure and environmental management. When GDP is connected to total population, the per capita GDP (PGDP) can further

act on urbanization subsystem.

(3) Eco-environment subsystem. In the subsystem, cultivated land (CL), wastewater accumulation (WWA), waste gas accumulation (WGA), solid waste accumulation (SWA) are selected as level variables. Through linking built-up areas (BUA), the decreasing of cultivated land (CLD) can influence cultivated land accumulation and further affects food yield (FY) and the total population. The accumulations of waste water, waste gas and solid waste depend upon the discharges and disposes of the wastes from industries and inhabitants and environmental protection investment (EPI), and they further influence other subsystems.

(4) Urbanization subsystem. Urbanization is a transformation process of urban economy, population, space and society. Here, population urbanization is expressed by population urbanization rate (PUR), and it is affected by increasing of population urbanization rate (PURI). As a key indicator, on the other hand, PUR is also affected by pollution, house, scientific-technological level, educational level, medical & healthy level and urban greenbelt. As an important indicator, BUA is considered as state variable and it is converted by CD function with urban population (UP) and nonagricultural output (NOV), and it can in turn promote total population and economic development. Social urbanization is showed by scientific-technological level (STL), educational level (EL), medical & healthy level (MHL), and they directly behave on economic subsystem and eco-environment subsystem by feedbacks, so the block is more considered.

The flow chart of the SD is shown in Fig. 2.

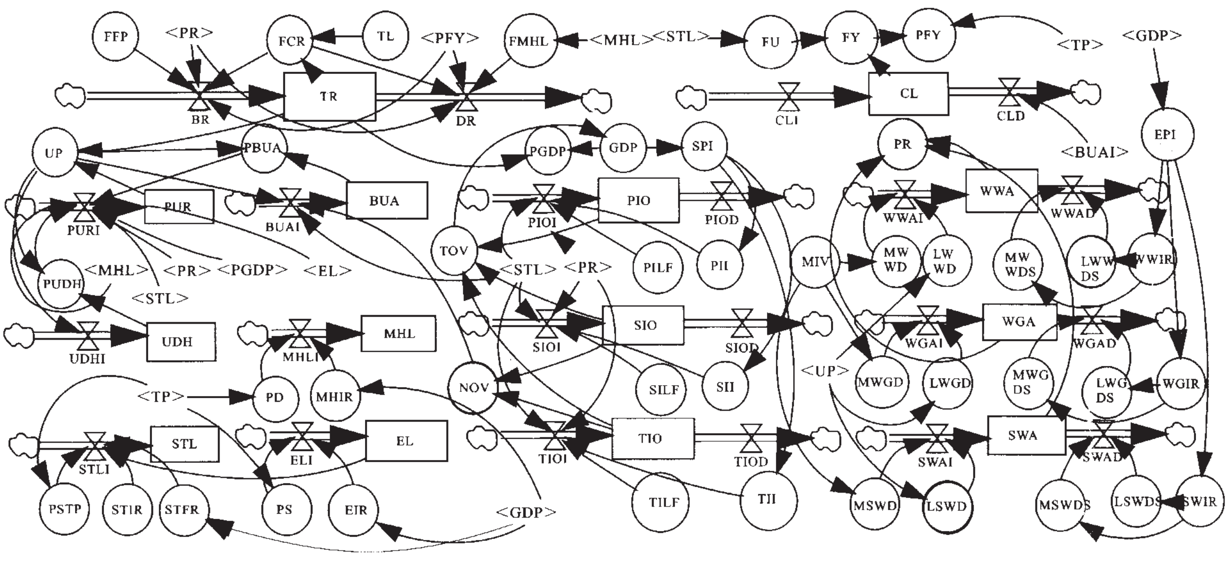

Fig. 2 Flow chart of SD

Note: TP: total population, BR: birth rate, DR: death rate, FFP: factors of family planning policies, PR: pollution rate, FCR: factor of congestion rate, TL: total land area, PFY: per capita food yield, FMHL: factor of medical & healthy level, PUR: population urbanization rate, PURI: increasing of population urbanization rate, UP: urban population, BUA: built-up areas, BUAI: increasing of built-up areas, PBUA: per capita built-up areas, UDH: house of urban denizen, UDHI: increasing of house of urban denizen, PUDH: per capita house of urban denizen, MHL: medical & healthy level, MHLI: increasing of medical & healthy level, STL: scientific-technological level, STLI: increasing of scientific-technological level, PSTP: per capita number of scientific-technological personnel, STIR: scientific-technological investment rate, STFR: scientific-technological foreign rate, EL: educational level, ELI: increasing of educational level, PS: per capita number of students, EIR: educational investment rate, GDP: gross domestic product, PGDP: per capita GDP, SPI: social productive investment, PIO: primary industrial output, PIOI: increasing of primary industrial output, PIOD: decreasing of primary industrial output, PII: primary industrial investment, PILF: factor of primary industrial labor, SIO: secondary industrial output, SIOI: increasing of secondary industrial output, SIOD: decreasing of secondary industrial output, SII: secondary industrial investment, SILF: factor of secondary industrial labor, TIO: tertiary industrial output, TIOI: increasing of tertiary industrial output, TIOD: decreasing of tertiary industrial output, TII: tertiary industrial investment, TILF: factor of tertiary industrial labor, TOV: total output value, NOV: nonagricultural output, CL: cultivated land, CLI: increasing of cultivated land, CLD: decreasing of cultivated land, FY: food yield, FU: food yield of per unit cultivated land, EPI: environmental protecting investment, MIV: manufactory industrial value, WWA: waste water accumulation, WWAI: increasing of waste water accumulation, WWAD: decreasing of waste water accumulation, WWIR: waste water investment rate, MWWD: discharge of manufacturing waste water, LWWD: discharge of living waste water, MWWDS: dispose of manufacturing waste water, LWWDS: dispose of living waste water, WGS: waste gas accumulation, WGAI: increasing of waste gas accumulation, WGAD: decreasing of waste gas, WGIR: waste gas investment rate, MWGD: discharge of manufacturing waste gas, LWGD: discharge of living waste gas, MWGDS: dispose of manufacturing waste gas, LWGDS: dispose of living waste gas, SWA: solid waste accumulation, SWAI: increasing of solid waste, SWAD: decreasing of solid waste, SWIR: solid waste investment rate, MSWD: discharge of manufacturing solid waste, LSWD: discharge of living solid waste, MSWDS: dispose of manufacturing solid waste, LSWDS: dispose of living solid waste

3.1.2 Systemic parameters calculation

According to some references (FANG and YU, 1999; TANG *et al*., 2000), some methods are employed to calculate the parameters: 1) Arithmetic averages of historical statistical data. They are average birth rate (0.00908), average death rate (0.00679), proportion of public greenbelt to built-up areas (0.37500), coefficient of environment protection investment (0.10000), coefficient of primary industrial investment (0.03200), coefficient of secondary industrial investment (0.47900), coefficient of tertiary industrial investment (0.48900), etc. 2) Trend extrapolation. They include impact factor of family planning (0.85000), growth coefficient of primary industrial output (0.03266), growth coefficient of secondary industrial output (0.14786), growth coefficient of tertiary industrial output (0.13108), growth coefficient of population urbanization rate (0.04087), growth coefficient of built-up areas (0.15233), growth coefficient of urban house (0.06085), growth coefficient of scientific-technological level (0.02300), growth coefficient of educational level (0.37406), growth coefficient of medical & healthy level (0.01000), etc. 3) Calculation by table functions. They are factors of pollution affecting birth and death, factors of medical & healthy level affecting birth and death, factors of food affecting birth and death, factors of congestion affecting birth and death, factor of scientific-technological level affecting population urbanization rate, factor of medical & healthy level affecting population urbanization rate, factor of educational level affecting population urbanization rate, factor of pollution affecting primary industrial output, factor of pollution affecting secondary industrial output, factor of pollution affecting tertiary industrial output, etc. 4) Calculation by regressions. With SPSS software, to determine social labor forces, labor forces of primary industry, labor forces of secondary industry, labor forces of tertiary industry, coefficient of social productive investment, etc.

3.1.3 Model check up

Firstly, with Vensim PLE software, the reality check is completed. Secondly, with historical data during 1990–2003, historical check is also done. From the simulated results, the relative errors range from −5.2% to 9.8%, which indicates the SD model is reliable, and to a certain extent it can reveal some complex behaviors of the coupling system and evaluate the potential effects that urbanization intimidated eco-environment, accordingly, it can be applied to simulate and forecast scenarios simulation of the coupling system between urbanization and eco-environment in Jiangsu Province.

3.2 Scenarios Simulation and Analysis of Coupling System

There are stages of world urbanization. However, because of different situation of a country and its development goal, the process and result of urbanization are obviously different, which bring about "overurbabization" and "underurbanization", thus the different eco-environmental problems are induced. According to the general rule, the five models of natural urbanization, economic urbanization, population urbanization, spatial urbanization and social urbanization are introduced and the five scenarios are simulated from 2000 to 2015 (Table 1).

Table 1 Scenarios simulation of the five coupling models in Jiangsu Province

Variable	2000	2005					2010					2015				
		I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
TP ($\times 10^6$ person)	73.27	74.51	74.51	74.51	74.49	74.53	75.35	75.33	75.37	75.26	75.47	75.99	75.92	76.08	75.79	76.25
GDP ($\times 10^9$ yuan)	478.3	907.3	1033.1	941.2	907.2	867.7	1533.4	1890.5	1627.3	1531.5	1431.0	2255.2	2862.1	2414.7	2247.2	2098.5
PGDP (yuan)	6561	12177	13866	12632	12179	11642	20349	25095	21591	20349	18962	29679	37698	31740	29649	27520
PUR (%)	41.52	51.21	51.67	53.18	51.50	51.08	61.81	62.48	63.90	62.05	61.63	66.70	67.08	68.34	66.85	66.63
PHD (m^2)	12.15	12.98	12.87	12.57	12.92	13.01	14.22	14.12	13.97	14.20	14.23	16.97	16.97	16.86	17.00	16.91
GPD (m^2)	8.1	10.15	10.25	9.80	10.87	10.1	13.20	13.40	12.10	14.34	13.03	14.08	14.38	12.67	15.35	13.83
GRBA (%)	33.24	37.70	37.81	37.71	38.12	37.66	40.01	40.11	39.78	40.36	39.95	40.60	40.69	40.29	40.90	40.54
BUA (km^2)	1383	2740	2784	2745	2917	2723	4097	4194	3906	4424	4046	4689	4799	4361	5071	4621
WBALA (%)	1.35	2.67	2.71	2.68	2.84	2.66	3.99	4.09	3.81	4.31	3.94	4.57	4.68	4.25	4.94	4.50
STL	2.70	2.76	2.76	2.76	2.76	2.78	2.85	2.86	2.86	2.85	2.89	2.94	2.94	2.94	2.94	2.99
MHL	1.2	1.26	1.26	1.26	1.26	1.30	1.33	1.33	1.33	1.33	1.40	1.39	1.39	1.39	1.39	1.50
WWA ($\times 10^9$t)	3.24	5.40	5.47	5.45	5.40	5.37	8.57	8.89	8.83	8.59	8.42	12.28	13.40	12.67	12.31	12.09
WGS ($\times 1015 m^3$)	11.5	17.6	17.9	17.7	17.6	17.4	26.0	27.7	26.6	26.0	25.3	37.1	39.4	38.3	37.0	35.6
SWA ($\times 10^6$t)	48.3	68.6	69.5	67.0	68.6	67.9	93.2	98.7	95.0	93.3	91.0	127.8	137.2	131.8	127.8	122.5
CL ($\times 10^3$ha)	5008	4728	4720	4728	4693	4731	4464	4445	4500	4402	4471	4351	4330	4413	4278	4360

Note: TP—total population (TP), GDP—gross domestic product, PGDP—per capita GDP, PUR—population urbanization rate, PHD—per capita house of denizens, GPD—greenbelt of per denizen, GRBA—green rate of built-up area, BUA— built-up area, WBALA—weight of built-up area accounting for land areas, STL—scientific-technological level, MHL—medical & healthy level, WWA—waste water accumulation, WGS—waste gas accumulation, SWA—solid waste accumulation, CL—cultivated land

3.2.1 Natural urbanization model (Ⅰ)

Supposing that the initial parameters do not change, and in the light of the represent model in Jiangsu Province, the future scenario is simulated. As Table 1 showed, the subsystems all vary, and the result can be characterized as follows: 1) Economic growth is relatively quick. GDP and per capita GDP will individually reach 2252.2×10^9 and 29 679 yuan (RMB) (in 1990 fixed price) in 2015, and growth rate in the future 15 years will respectively arrive at 10.9% and 10.6% that can approach to the low scheme of Jiangsu long-term planning, but there is a significant distance to the high scheme (ZHANG *et al*., 1997). 2) The growth of urbanization level is also quicker. In 2010 and 2015, the population urbanization respectively attains 61.80% and 66.75%, which will attain the goal of Jiangsu long-term planning ahead of schedule. Meanwhile, accompanying with urban population rapid increment, the built-up areas also take on rapid expansion in which annual average rate reach 8.48%, and in 2015 WBALA will be 4.57%. 3) The scientific-technological level, medical & healthy level respectively increase by 1.67% and 1.27% with population urbanization and social urbanization. 4) The eco-environmental pressures will appear seriously, and in 2015 the waste water accumulation, waste gas accumulation and solid waste accumulation will individually reach 12.28×10^9t, $37.1\times10^{15}m^3$ and 128×10^6t, with their annual average increase rates of 9.3%, 8.1% and 6.7%. 5) In cultivated land block, the areas is continuously decreasing and its annual decrease rate attains 0.93%, and there will be only 4350.65×10^3ha of cultivated land in 2015.

3.2.2 Economic urbanization model (¢ò)

If economic growth is rapider than the natural urbanization model, it can be assigned as economic urbanization. The annual economic growth rate of Jiangsu was 13.3% during 1990–2003. Supposing the trend can be extrapolated, the annual economic growth rate will maintain 12%, which corresponds with the high scheme of Jiangsu long-term planning. In order to attain the goal, some parameters are adjusted: 1) Productive investment is much emphasized and coefficient of social production investment is heightened from 0.35 to 0.40. 2) Because the manufactory industry may still be a main driving department in the future, coefficient of secondary industrial investment is adjusted from 0.479 to 0.600. The scenario is simulated and the results show that the economic growth is the most rapid, and in 2015 GDP and per capita GDP will respectively reach 2862.1×10^9 and 37 698 yuan. At the same time, population urbanization level, denizen house and greenbelt also advance, but the pollution discharges are the most serious, in 2015 the waste water accumulation, waste gas accumulation and solid waste accumulation will respectively exceed 1.12×10^9t, $0.23\times10^{12}m^3$, 9.43×10^6t and 1.30×10^9t, $0.38\times10^{12}m^3$, 14.7×10^6t than model¢ªand model¢ñ. On the other hand, the occupancy of cultivated land is very serious and is the second among the five urbanization models. It is obvious that the pressure of eco-environment is very serious though economic urbanization can more rapidly accelerate economic growth and population urbanization, so this model can only be applied in primary stage of urbanization.

3.2.3 Population urbanization model (Ⅲ)

If urban population growth is emphasized, the scenario is also debugged. Because the annual growth rate of urbanization in Jiangsu Province was 1.94 percent point during 1990–2003 and was 0.85 percent point higher than the whole country average level in the same period, the growth speed was extremely rapid and it is impossible to be further accelerated. Therefore, we suppose that urbanization growth rate can be kept at 1.8 percent point and take steps to attain the goal. The simulated results reveal: 1) The model can rapidly promote both economic growth and population urbanization, in which the growth rate of GDP and per capita GDP is 11.4% and 11.1% during 2000–2015 and both are 0.5 percent point higher than model Ⅰ. 2) The increasing of population urbanization is the most quick and it can achieve the urbanization scheme of Jiangsu's long-term planning than other models ahead of schedule. 3) Because efficiency of land use is improved, the decreasing of cultivated land becomes slow. 4) Urban population gradually becomes excessive so that the living pollution discharges becomes excessive, and in 2015 the simulated waste water accumulation, waste gas accumulation and solid waste accumulation respectively reach 12.67×10^9t, $38.3\times10^{15}m^3$ and 131.8×10^6t, which range the second in the five model. Meanwhile, to the degree, denizen house, greenbelt and infrastructure become relatively lack with the urban scale compared. It can be seen that the model can be applied for the middle stage of urbanization, i.e. rapid increasing phase.

3.2.4 Spatial urbanization model (Ⅳ)

The model attempts to push up urbanization by spreading urban spatial scale. For the annual increasing rate of built-up areas in Jiangsu Province was 8.6% during 1990–2003 and was 0.23 percent point higher than the whole country average level in the same period, the increase speed is extremely rapid and it must not be further accelerated, otherwise, the contradiction between humankind and natural environment will be more serious. However, with nonagricultural development and urban population increment, the demand of urban residents for living space is very great, so the average increasing rate of built-up area can be supposed as 9% with the factors considered and other parameter do not be modified. The simulated scenario can be summed up: 1) The contradiction between humankind and nature environment is provoked while the built-up areas rapidly expand, thus the total population and economic growth are extremely affected. In this scenario, there will be only 75.7939×10^6 persons in 2015, and 193.9×10^3 and 461×10^3 persons less than model Ⅰ and model Ⅴ. 2) The economic growth is slower and in 2015 its GDP and per capita GDP will be only 2247.21×10^9 and 29 649 yuan. Its growth rates are only higher than model Ⅴ. 3) Because the built-up areas rapidly spread, the denizen house, greenbelt and infrastructure are superior, which is the best favorite in the five models. The waste water accumulation, waste gas accumulation and solid waste accumulation are heavily discharged, which is similar to model Ⅰ. Obviously, from the perspective of sustainable development, the model cannot be advocated.

3.2.5 Social urbanization model (Ⅴ)

The aim of the model is to promote soft environment, such as urban culture, science and technology, medical treatment and health, etc. As some scholars pointed out (ZHOU, 1999), urbanization process in developed areas can be divided into two stages, the former period of which is a course of population convergent along with industrialization and the latter period is a socialization course with efficient production and living, scientific management and high technology, and good welfare. In 2003 per capita GDP of Jiangsu Province reached 9642 yuan and population urbanization rate was 44.8%, which indicates the whole province has stepped into rapidly increasing stage of urbanization, thus people's demands for culture, scientific-technology, education, medical treatment and health must increase. It is available to suppose that socialization level be kept up with economic growth and urban population increment. To attain the goal, first of all, the proportion of culture, scientific-technology, education and health to finance is adjusted from 0.02 to 0.05; secondly, the coefficient of tertiary industrial investment is arranged from 0.489 to 0.500 so that tertiary industry can coordinate to the whole society, and other initial parameters isn't be modified. The simulated results show that: both economic growth, population urbanization and environmental pressure are relatively low, which is the lowest one in the five models, but the scientific-technological level, educational level and medical & healthy level are the most rapid improvement than other model. It can be seen that the social urbanization model can be applied for the last stage of urbanization, i.e. high urbanization level period.

4 CONCLUSIONS

The coupling system between regional urbanization and eco-environment is a kind of system with lots of feedback loops and many interfaces, and what urbanization interacts eco-environment is a complex integration between four aspects of urbanization and five factors of eco-environment. The five scenarios have been simulated and analyzed, and the results can be concluded as follows:

(1) It is available for SD to be applied to studying the coupling system between urbanization and eco-environment. With the SD of Jiangsu Province designed and historical data checked, it is showed that the relative errors range from −5.2% to 9.8%, which indicates the SD model is reliable, and to a certain extent it can reveal some complex behaviors of the coupling system and evaluate the potential effects that urbanization intimidated eco-environment.

(2) There are both marked advantages and evident drawbacks among the five models. Firstly, economic growth is the most rapid among the five models but the environmental pollution pressure is also the most serious in economic urbanization. Secondly, although population urbanization can rapidly attain the goal of urbanization and effectively promote economic growth, the environmental pressure is bigger and urban infrastructure supply is not superior. Thirdly, spatial urbanization can availably satisfy demands of urban space expansion and urban infrastructure construction, but the model excessively occupies cultivated land so as to provoke the contradiction. Lastly, social urbanization can rapidly improve the scientific-technological level, educational level and medical & healthy level and effectively protects environment, but the economic growth rate is too slow.

(3) The different development models must be selected corresponding with the urbanization stages and spatial urbanization disparities so as to realize urbanization sustainable development. From the perspective of time, urbanization is stepping into the rapid increasing stage, to in turn select population urbanization and social urbanization can ensure rapid economic growth, urbanization and socialization process. From the perspective of space, there is evident regional disparities among the

southern, the middle, the northern parts of Jiangsu Province, and in 2003 their per capita GDP and population urbanization rate were respectively 35 278, 12 871, and 8480 yuan, and 64.60%, 44.74%, and 37.98%£¬which indicates there are different urbanization stages and economic development levels in Jiangsu Province. Therefore, to select social urbanization model in the southern part, to select population urbanization model in the northern part and the two models in the middle part, the sustainable development among population, economy, urbanization and eco-environment in Jiangsu Province can be realized.

REFERENCES

BOURNE L S, SIMMONS J W, 1978. *Systems of Cities* [M]. New York: Oxford University Press.

BRAAT L, VAN LIEROP W, 1986. Economic-ecological modeling: an introduction to methods and applications [J]. *Ecological Modelling*, 31: 33–44.

BRENNA E M, 1999. Population, urbanization, environment, and security: a summary of the issues [J]. *Environmental Change & Security Project Report*, 5: 4–23.

COMMONER B, CORR M, STAMLER P J, 1971. The causes of pollution [J]. *Environment*, 13(3), 2–19.

FANG Chuang-lin, YU Dan-lin, 1999. Study on optimal-control experiment of the resources development and corresponding development between economy and eco-environment in the Qiadam basin [J]. *Acta Ecologica Sinica*, 19(6): 767–774. (in Chinese)

FORRESTER J W, 1971. *Urban Dynamics* [M]. Cambridge, Mass: The MIT Press.

GROSSMAN G, KRUEGER A, 1993. Environmental impacts of a North American free trade agreement [A]. In: GARBER P (ed.). *The Mexico-US Free Trade Agreement* [C]. Cambridge, MA: MIT Press.

GROSSMAN G, KRUEGER A, 1995. Economic growth and the environment [J]. *Quarterly Journal of Economics*, 110 (2): 353–377.

HOWARD E, 1898. *Garden Cities of Tomorrow* [M]. London: Feber and Faber.

HUANG Jin-chuan, FANG Chuang-lin, FENG Ren-guo, 2004. Quantitative research on the relationships between urbanization and eco-environment¡"case of the Three Gorges area [J]. *Resources and Environment in the Yangtze Basin*, 13 (2): 153–158. (in Chinese)

LING Hang, WANG Huan-chen, LIU Tao, 2001. A statistical analysis on urban economic development and environment pollution¡"taking Nanjing as a case [J]. *Statistical Research*, 10: 46–52. (in Chinese)

LIU Yao-bin, LI Ren-dong, 2003. Exploring on environmental Kuznets characteristics of wastewater, waste gas and solid wastes and their causes in Wuhan city [J]. *Urban Environment and Urban Ecology*, 16(6): 44–45. (in Chinese)

LIU Yao-bin, LI Ren-dong, SONG Xue-feng, 2005. Grey associative analysis of regional urbanization and eco-environment coupling in China [J]. *Acta Geographica Sinica*, 60(2): 237–247. (in Chinese)

MACLAREN V W, 1996. Urban sustainability reporting [J]. *Journal of the American Planning Association*, 62(2): 185–202.

GRIMM J, MORGAN G, STEWWARD T A *et al*., 2000. Integrated approached to long-term studies of urban environment system [J]. *BioScience*, 50(7): 289–293.

ODUM H T, ELISABETH C, 2000. *Modeling for All Scales: An Introduction to System Simulation* [M]. San Diego: Academic Press.

PARASURAMAN A, ZEITHAML V A, BERRY L L, 1985. A conceptual model of service quality and its implications for further research [J]. *Journal of Marketing*, 49(3): 234–248.

SONG Yong-chang, WANG Yong, 1991. *Study on Changxingdao Island Complex Ecosystem* [M]. Shanghai: East China Normal University Press. (in Chinese)

SUKOPP H, WEILER S, 1988. Biotope mapping and nature conservation strategies in urban area of the Federal Republic of Germany [J]. *Landscape and Urban Planning*, 47(15): 39–58.

TANG Wan-jin, GAO Lin, WU Gang *et al*., 2000. Simulation and adjustment of system dynamics on sustainable development in the mining area [J]. *Acta Ecologica Sinica*, 20(1): 20–27. (in Chinese)

VESTER F, VON HESLER A, 1980. *Ecology and Planning in Metropolitan Areas Sensitivity Model* [M]. Berlin: Federal Environmental Agency.

WANG Ru-song, 1988. *Great Efficiency and Coordination: the Principles and Approaches of Urban Ecological Regulation* [M]. Changsha: Hunan Education Press. (in Chinese)

WCED, 1987. *Our Common Future* [M]. Oxford: Oxford University Press.

WEBER C, PUISSANT A, 2003. Urbanization pressure and modeling of urban growth: example of the Tunis Metropolitan Area [J]. *Remote Sensing of Environment*, 86: 341–352.

WHITTAKER R H, LEVIN S A, ROOT R B, 1973. Niche, habitat, and ecotope [J]. *American Naturalist*, 107: 321–338.

WU Yu-ping, DONG Suo-cheng, SONG Jian-feng, 2002. Modeling economic growth and environmental degradation of Beijing [J]. *Geographical Research*, 21(2): 239–246. (in Chinese)

YANG Bang-jie, 1992. *Decision Support System for Urban Ecological Regulation* [M]. Beijing: China Science and Technology Publishing House. (in Chinese)

YANG Shi-hong, 2003. *Urban Ecological Environment* [M]. Beijing: Science Press. (in Chinese)

ZHANG Feng, YUAN Feng, CHEN Jian-qing, 1997. *Development Strategies of Jiangsu during 1996–2020* [M]. Nanjing: Jiangsu People's Press. (in Chinese)

ZHOU Yi-xing, 1999. *Urban Geography* [M]. Beijing: The Commercial Press. (in Chinese)