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Prediction and coordination of the man–environment system —- a case study in Jiaozuo City

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Abstract—In this paper, the new systematical theory and methodology have been applied to the research on the structure, development and coordination of man–environment system in Jiaozuo City. It has been proved that the application of self–organization theory of synergism is successful. Furthermore, on the basis of self–organization theory, a series of mathematical models have been established. The prediction of the status of man–environment system in Jiaozuo City by the year 2010, was made, and the trend of population growth, industrial development, environmental pollution were given. Finally, suggestions for the future development of Jiaozuo City were mentioned.

Keywords: man–environment system; self–organization theory; dynamic and coupling; coordination.

INTRODUCTION

The man–environment system is an nonequilibrium, complex and open macrosystem. With the increasing human effect on the environment, the contradiction between man and environment becomes more and more conspicuous. This contradiction is reflected in today's worldwide environmental pollution. Environmental problem, mixed with population, energy and natural resources problems, becomes the main issue that the world is facing with.

The fundamental way for solving environmental problems, especially industrial pollution, is not a simple treatment course, but a comprehensive process of coordination and control. We should start with the structure of the polluted man–environment system and the process of occurrence and diffusion of pollution, then seek after the coordinative and control countermeasures for solving environmental pollution finally, implement the reorganization of man–environment system. For this purpose, according to the basic circumstances and environmental problems in Jiaozuo City, the author has made some prediction and coordination of man–environment system in Jiaozuo City.

THE BASIC CIRCUMSTANCE OF JIAOZUO CITY

Jiaozuo City is located in the northwestern of Henan Province. It is situated at the north of the Yellow River and the south of Shanxi Province. The area of Jiaozuo City is 370 square kilometers. The altitude of landform increases successively from south to north.

Water resources in Jiaozuo City are richer than in other areas of northern China. The available flow of natural water sources (mainly underground water) is 20.9 m^3/s. At the present time, the usage rate is 7.7 m^3/s (not including the water discharged from coal mining).

Jiaozuo is rich in mineral resources. By the end of 1984, the population in Jiaozuo City was 0.495 million, the natural growth rate was 0.59%. In 1984, the total industrial output value was 1.144 billion yuan. The agricultural output value is 0.109 billion yuan and the grain yield was 65 million kilograms.

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THE STRUCTURAL CHARACTERISTICS OF INDUSTRIES AND ENVIRONMENTAL PROBLEMS

characteristics of the industrial structure

At present, the leading industries in Jiaozuo City are the coal mining, power, chemical, building material and metallurgical industries. The mechanical engineering is of fair size. The above industries account for more than 70% of the total industrial value. They represent the developing level of industries and the economy in Jiaozuo City. Meanwhile, they are also the main sources of pollutant, the discharge volume of pollutants makes up 85–90% of the total in this city.

The common structural characteristcs of these industries have made a high consumption of energy and natural resources and serious pollution. There are very close connection among these industries. On one hand, they depend on each other; on the other hand, they condition each other. The relations among them are from of a " coupling circulation " .

Main environmental problems

The main environmental problem in Jiaozuo City is air pollution. It is even more serious in Jiaozuo City than in other areas. The main pollutants are SO_2, total suspended particulates (TSP) and dust. In dense traffic areas, the pollution of NOx is also serious. As the industry developing, the pollutions of surface water, underground water and noise will also become serious.

POPULATION DISTRIBUTION, INDUSTRIAL DEVELOPMENT AND ENVIRONMENT IMPACT

Analyzing the information previously mentioned, we have found that the future development in Jiaozuo City is closely related to population growth and distribution, to the consumption of energy and natural resources and also to environmental pollution. How to coordinate the population distribution with economic development and environmental protection, so as to acquire an optimal industrial development (rate and structure) is the crucial problem which will be dealt with in this paper. As a research topic, we take the Jiaozuo City as a man–environment system, an open and nonequilibrium system. The structure of the system and the coupling relations among the elements are shown in Figure 1. In order to resolve the crucial problem described above, we use the concepts and methods of self–organization theory of synergism.

The model of structure and development

A mathematical model consisting of the following series of equations has been established.

1. models of population growth

(1) model of total population

$$\frac{dP_1}{dt} = \varepsilon(\lambda P_1 + M^{in} - M^{out}) \tag{1}$$

$$M^{in} = \alpha \sum_{m \neq 1} N_m \frac{A_{1m}}{A_{lm}}, \qquad M^{out} = \beta \sum_{m \neq 1} N_1 \frac{A_{m1}}{A_{l1}} \tag{2}$$

$$A_{1m} = \left(\psi_1 \frac{Z_1}{Z_m} + \psi_2 \frac{F_1}{F_m} + \psi_3 \frac{W_1}{W_m} + \psi_4 \frac{H_1}{H_m} + \psi_5 \frac{J_1}{J_m} \right) e^{-d1m} \tag{3}$$

where

P_1—total population in Jiaozuo City;

λ—natural increasing rate of population;

M^{in}, M^{out}—the amount of people who move in or from Jiaozuo City;

$\varepsilon, \alpha, \beta$—the parameters to be defined;

N_1, N_m—the number of persons who can move freely within Jiaozuo City and city m, respectively;

A_{1m}—attraction potential from Jiaozuo City to city m;

d_{1m}—the distance between Jiaozuo and city m.

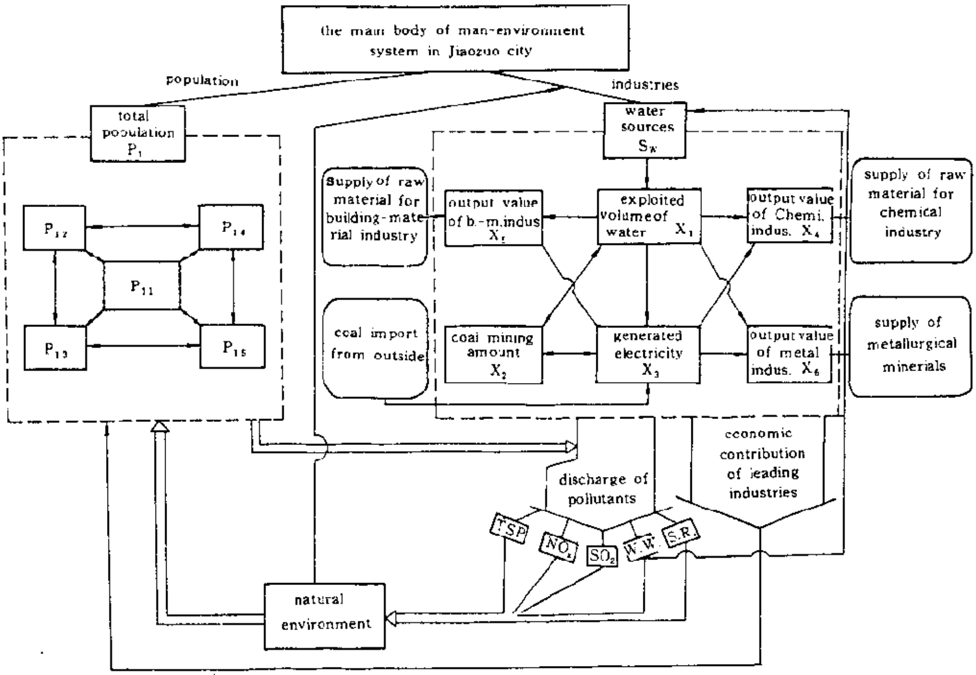

Fig. 1 The structure of man-environment system in Jiaozuo City

(2) model of population distribution in sub-regions

$$\frac{dP_{1i}}{dt} = \varepsilon_i(\lambda_i P_{1i} + M_i^{in} - M_i^{out}) \tag{4}$$

$$M_i^{in} = \alpha_i \sum_{j\neq 1} n_j \frac{A_{ij}}{\sum_k A_{kj} + \sum_l A_{lj}} \alpha_i' \sum_{m\neq 1} N_m \frac{A_{im}}{\sum_l A_{lm} + \sum_k A_{km}} \tag{5}$$

$$M_i^{out} = \beta_i \sum_{j\neq 1} n_i \frac{A_{ji}}{\sum_k A_{ki} + \sum_l A_{li}} \beta_i' \sum_{i\neq m} n_i \frac{A_{mi}}{\sum_l A_{li} + \sum_k A_{ki}} \tag{6}$$

$$A_{ij} = \psi_1 \frac{Z_i}{Z_j} + \psi_2 \frac{F_i}{F_j} + \psi_3 \frac{W_i}{W_j} + \psi_4 \frac{H_i}{H_j} + \psi_5 \frac{J_i}{J_j} \tag{7}$$

$$A_{im} = \left(\psi_1 \frac{Z_i}{Z_m} + \psi_2 \frac{F_i}{F_m} + \psi_3 \frac{W_i}{W_m} + \psi_4 \frac{H_i}{H_m} + \psi_5 \frac{J_i}{J_m}\right) e^{-dim} \tag{8}$$

$$A_{lm} = \left(\psi_1 \frac{Z_l}{Z_m} + \psi_2 \frac{F_l}{F_m} + \psi_3 \frac{W_l}{W_m} + \psi_4 \frac{H_l}{H_m} + \psi_5 \frac{J_l}{J_m}\right) e^{-dlm} \tag{9}$$

where

P_{1i}—the amount of people living in different sub-region;
M_i^{in}, M_i^{out}—the amount of people who move in or out from different sub-region;
$\varepsilon_i, \alpha_i, \beta_i, \alpha_i', \beta_i'$—the parameters to be defined;
n_i, n_j, N_m—the amount of people who may move freely in i, j sub-regions and city m;
A_{ij}, A_{im}—attraction potentials from i to j sub-region and city m;
A_{1m}—attraction potentials from city 1 to m;
D_{im}, D_{1m}—the distances between sub-region i and city m, city 1 and city m;
ψ_i—the statistical weights to be defined;
Z_i, Z_j—housing conditions in i, j sub regions;
F_i, F_j—welfare conditions in i, j sub regions;
W_i, W_j—environmental conditions in i, j sub regions;
J_i, J_j—traffic conditions in i, j sub regions.

2. Models of industrial structure and development

(1) water sources exploitation

$$\frac{dx_1}{dt} = r_1 x_1 (1 - \frac{x_1}{N_1}) \eta_1 (x_2 - x_{20}) + \delta_1 \tag{10}$$

$$\frac{1}{N_1} = \left(\frac{1}{S_\omega - \xi_\omega P_{ww}} + \frac{\xi_1^2}{\xi(t) C_o / W_1} \right) \tag{10}$$

(2) coal mining

$$\frac{dx_2}{dt} = r_2 x_2 (1 - \frac{x_2}{N_2}) + \delta_2 \tag{12}$$

$$\frac{1}{N_2} = \left(\frac{1}{\eta_2 x_3 / W_2} + \frac{1}{(\theta_2 x_1 / W_2) \cdot b} \right) \cdot \varphi(C, B)$$

$$\varphi(C, B) = k e^{-\frac{(C-B)}{B+\Delta B}} \tag{13}$$

(3) Power industry

$$\frac{dx_3}{dt} = r_3 x_3 (1 - \frac{x_3}{N_3}) + \delta_3 \tag{14}$$

$$\frac{1}{N_3} = \left(\frac{1}{\theta_3 x_1 / W_2} + \frac{1}{(\eta_3 x_3 + \theta_c) / W_3} \right) \tag{15}$$

(4) chemical industry

$$\frac{dx_4}{dt} = r_4 x_4 (1 - \frac{x_4}{N_4}) + \delta_4 \tag{16}$$

$$\frac{1}{N_4} = \left(\frac{\xi_4^2}{\vartheta_s(t) / V_4} + \frac{1}{\theta_4 x_1 / W_4} + \frac{1}{\eta_4 x_3 / W} \right) \tag{17}$$

(5) building material industry

$$\frac{dx_5}{dt} = r_5 x_5 (1 - \frac{x_5}{N_5}) + \delta_5 \tag{18}$$

$$\frac{1}{N_5} = \left(\frac{1}{\theta_5 x_1 / W_5} + \frac{1}{\eta_5 x_3 / W_5} \right) \cdot \varphi(T) \tag{19}$$

(6) metallurgical industry

$$\frac{dx_6}{dt} = r_6 x_6 (1 - \frac{x_6}{N_6}) + \delta_6 \tag{20}$$

$$\frac{1}{N_6} = \left(\frac{\xi_6^2}{\vartheta_T / V_6} + \frac{1}{\theta_6 x_1 / W_6} + \frac{1}{\eta_6 x_3 / W_6} \right) \tag{21}$$

where

$x_1, x_2, x_3, x_4, x_5, x_6$—the annual expoited quantity of water, annual productivity of coal mining electrical power, annual output values of chemical industry, building material and metallurgy, respectively;

$r_1, r_2, r_3, r_4, r_5, r_6$—the parameters to be defined, with denote the different characteristics of the above-mentioned industrial sectors;

$\delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \delta_6$—fluctuation terms of the six sectors of industry;

η_1—water discharge coefficient, i.e., quantity of water discharged for unit coal output;

x_{20} —the coal output in previous year;

ξ_ω—the damage coefficient, i.e., quantity of waste water discharged into water sources;

ξ_1—the ratio of quantity tap water exploited to total quantity water exploited;

$\xi(t)$—investment coefficient function of equipment maintenance for tap water source;

c_o—investment of equipment maintenance for tap water sources in standard year;

ω_1—investment of equipment maintenance for unit tap water sources;

s_w—total amount of natural water sources in Jiaozuo area;

P_{ww}—discharge amount of waste water per year;

η_2—percentage of coal for electric utility;

ω_2—electric consumption coefficient in coal mining;

θ_2—the percentage of coal mining discharged water to total water exploitation;

w_2—water discharge coefficient in coal mining;

b—comprehensive benefit coefficient of water discharged in coal mining;

$\varphi(C, B)$—cost-benefit function of coal mining, where B is the unit price of coal; C is the unit cost of coal, and ΔB is the comprehensive benefit in coal mining;

θ_3—water utilization proportion for power industry;

w_3—water consumption coefficient in electricity generation;

η_3—coal utilization proportion of total coal mining quantity in Jiaozuo area for generation electricity;

θ_c—the quantity of coal imported from outside for generating electricity;

ω_3—coal consumption coefficient in generating electricity;

V_4—mineral consumption coefficient in basic chemical industry;

ξ_4—the output value proportion of basic chemical industry;

$Q_s(t)$—the quantity of mineral mining for basic chemical industry;

θ_4, η_4—the utilization proportion of water and electricity for chemical industry;

W_4, ω_4—consumption coefficients of water and electricity in chemical industry;

θ_5, η_5—the utilization proportions of water and elctricity for building-material industry;

W_5, ω_5—the consumption coefficients of water and electricity in building-material industry;

$\varphi(T)$—the limited factor of technique;

ξ_6—the output value proportion of that part of metallurgical industry which depend on imported minerals to the total values;

Q_T—imported quantity of minerals per year;

v_6—mineral consumption coefficient in metallurgical industry;

θ_6, η_6—the utilization proportion of water and electricity for metallurgical industry;

w_5, w_6—the consumption coefficient of water and electricity in metallurgical industry.

3. Models of pollutants distribution

(1) Models of discharge of industrial pollutants

$$P_{21} = \sum_{i=1}^{5} \varepsilon_{1i} x_i + \varepsilon_1 x_{0th} \tag{22}$$

$$P_{22} = \sum_{i=1}^{5} \varepsilon_{2i} x_i + \varepsilon_2 x_{0th} \tag{23}$$

$$P_{23} = \sum_{i=1}^{5} \varepsilon_{3i} x_i + \varepsilon_3 x_{0th} \tag{24}$$

$$P_{24} = \sum_{i=1}^{5} \varepsilon_{4i} x_i + \varepsilon_4 x_{0th} \tag{25}$$

where

$P_{21}, P_{22}, P_{23}, P_{24}$—the discharged quantity of SO_2, NOx, TSP and waste water per year respectively;

$x(i = 1, \cdots, 5)$—the output quantity (or value) of coal mining industry, power industry, chemical industry, building material industry and metallurgical industry respectively;

$\varepsilon_{1i}, \varepsilon_{2i}, \varepsilon_{3i}, \varepsilon_{4i}$—the discharge coefficient of SO_2, NOx, TSP ans waste water discharged by every leading industry;

$\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4$—the average discharge coefficients of the other industries;

x_{0th}—the output value of the other industries.

(2) model of air pollutant

$$\frac{dP'_{21}}{dt} = \rho_1 P'_{21} + \sum_i \varepsilon_{1i} x_i + \varepsilon_1 x_{0th} + \sigma_1 \tag{26}$$

$$\frac{dP'_{22}}{dt} = \rho_2 P'_{22} + \sum_i \varepsilon_{2i} x_i + \varepsilon_2 x_{0th} + \sigma_2 \tag{27}$$

$$\frac{dP'_{23}}{dt} = \rho_3 P'_{23} + \sum_i \varepsilon_{3i} x_i + \varepsilon_3 x_{0th} + \sigma_3 \tag{28}$$

$$(i = 1, 2, 3, 4, 5)$$

where

$P'_{21}, P'_{22}, P'_{23}$— the quantity of SO_2, NOx and TSP existing in air per year respectively;

ρ_1, ρ_2, ρ_3—the purification coefficients of SO_2, NOx and TSP (including natural and artificial purification processes);

$\sigma_1, \sigma_2, \sigma_3$—fluctuation terms, which denote the influences of stochastic factors to the pollutant quantity existing in air.

(3) model of pollutants distribution

$$\bar{C}_1 = P'_{21}/(365 \cdot V_1) \tag{29}$$
$$\bar{C}_2 = P'_{22}/(365 \cdot V_1) \tag{30}$$
$$\bar{C}_3 = P'_{23}/(365 \cdot V_1) \tag{31}$$
$$\bar{C}_{1j} = k_{1j}\bar{C}_1 \tag{32}$$
$$\bar{C}_{2j} = k_{2j}\bar{C}_2 \tag{33}$$
$$\bar{C}_{3j} = k_{3j}\bar{C}_3 \tag{34}$$
$$(j = 1, 2, 3, 4, 5)$$

where

$\bar{C}_1, \bar{C}_2, \bar{C}_3$—the daily average concentration of SO_2, NOx and TSP, respectively;

V_1, V_2—the volume of distribution space for pollutants;

$C_{1j}, \bar{C}_{2j}, \bar{C}_{3j}$—the daily average concentration of pollutants (SO_2, NOx and TSP) in sections with different function (industrial quarter, living quarter, cultural quarter, dense traffic areas and control quarter);

k_{1j}, k_{2j}, k_{3j}—the distribution weights of pollutants (SO_2, NOx and TSP) in different function sections.

Method

The advandage of our model is: the dynamic binding term (1 / AY) + (1 / BZ) + $\cdots$ expresses the dependence and conditioning relationships among the sectors of industries. This binding term defines the complete coupling within the sub–systems of leading industries. The results reveal deeply the characteristics of industrial development in Jiaozuo City and the intense dependence upon energy and natural resources. Meanwhile, this method satisfies the general constrains of the equations of self–organization theory (Haken, 1984).

Due to the species dynamic coupling characters of models, the traditional methods for parameter tuning can not be applied in these models. In this paper, the authors have found a new method for parameter tuning. The framework is as follows (Figure 2). Because of the intense coupling characteristic among models, parameter tuning can not be done for a single equation, it must be carried out for all equations at the same time.

Based on statistical data and information relevant to Jiaozuo City, we obtained the following parametric values:

In the models of population,

$$\varepsilon = 1.2, \quad \varepsilon_1 = 1.1, \quad \varepsilon_2 = 0.9, \quad \varepsilon_3 = 0.95.$$

In the structural and development models of leading industries,

$$r_1 = 0.11, \quad r_2 = 0.24, \quad r_3 = 0.34,$$
$$r_4 = 1.15, \quad r_5 = 1.05, \quad r_6 = 0.60$$

In the models of pollution,

$$\rho_1 = -10.5, \quad \rho_2 = -27.5, \quad \rho_3 = -3.5$$

Using the model equations in which parameters have been defined to simulate the system, results were obtained and compared with historical data for the 1975–1984 period (refer to Figure 3).

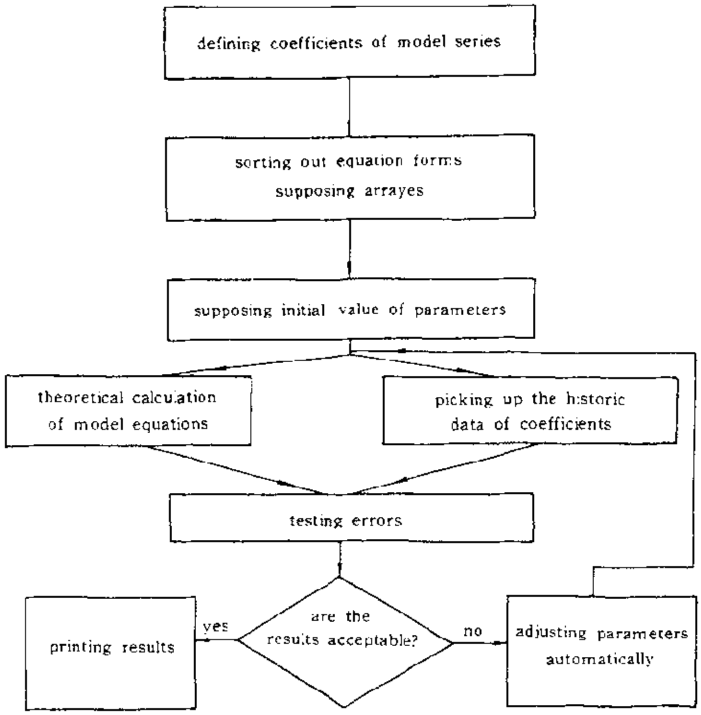

Fig. 2 The framework for adjusting parameters

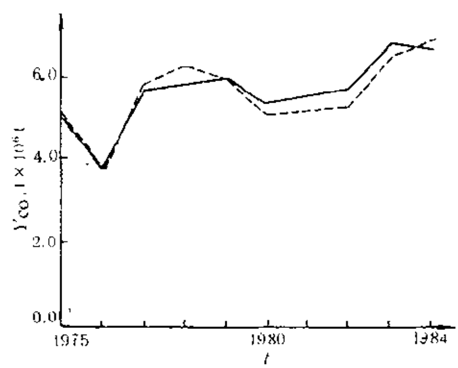

Fig. 3 The simulation curve of coal mining

The model equations were applied to predict the development prospect of the man–environment system in Jiaozuo City. The predicted period is 1985–2010. The initial values in the equations are the corresponding statistical data in 1984.

Examples of model predictions are:

(1) Prediction of the population development.

The results of prediction for 2 different conditions can be referred in Figure 4.

Note that the curves of 1,2,3,4 in Figure 4 represent the amount of people living in 4 different sub–regions.

(2) Prediction of development prospects for leading industries.

The results of prediction for 7 different conditions can be referred in Figure 5.
(3) Prediction of the discharge, existing quantities and distribution of pollutants.
The results can be referred in Figure 6 based on 6 kinds of conditions.

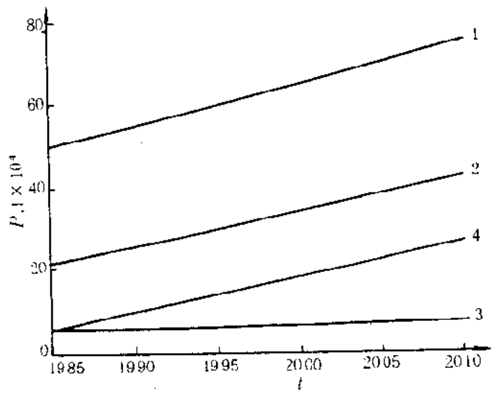

Fig. 4 The predictive curves of population

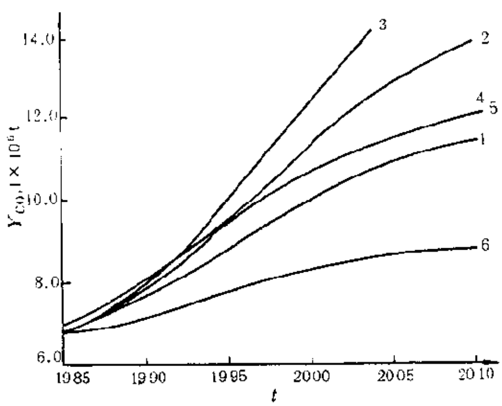

Fig. 5 The predictive curves of coal mining

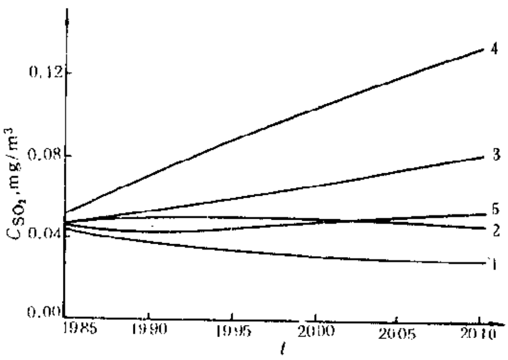

Fig. 6 The predictive curves of SO_2 concentration in industrial quarter (daily average)

DISCUSSIONS

The population in the Jiaozuo City proper and its downtown, as predicted, will expand quickly. At the same time, the population in satellite towns will decline. This tendency will intensify the environment problems in the center of Jiaozuo City and its downtown.

The devèlopment of industries which consume large amount of energy and resources bring serious pollution to Jiaozuo City. Although pollution abatement measures have been taken, environmental quality of Jiaozuo City will be getting worse at the end of this century or at the beginning of the next century.

More attention should be paid to the utilization of energy and natural resources, especially water resources. At the end of this century or in the first decade of the next century, the structure of the man–environment system in Jiaozuo City will experience great changes because of the deficiency of water resources.

CONCLUSION

The problems of population growth and distribution, industrial development, the utilization of energy and natural resources and environmental pollution in Jiaozuo City have been studied. The self–organization theory synergetics have been applied.

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