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Using grey model GM (1, N) to evaluate impact level of different factors in environmental impact assessment of sewer system

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Abstract: In this study, the impact levels in environmental impact assessment reports of 6 sewer systems were quantified and discussed. The relationship between the quantified impact levels and the system scale factors of Banghsin, Chungli, Taichung Harbor and Kaohsiung Fonshan regions were constructed and the impact levels of Hualien (HL) and Taichung City (TC) regions were predicted using grey model GM (1, N). Finally, the effects of system scale factors on impact levels were evaluated using grey model GM (1, N) too. According to the predicted results of GM (1, N), the relative errors of topography/geology/soil, hydrology/water quality, air quality, noise, solid waste, terrestrial fauna/flora, aquatic fauna/flora, landscape and traffic in HL region were 19 %, 56 %, 13 %, 29 %, 56 %, 19 %, 13%, 19 % and 16 %, respectively. The relative errors of those environmental items in TC region were 25 %, 33 %, 58 %, 136 %, 33 %, 50 %, 58 %, 50 % and 98 %, respectively. According GM (1, N), plant area (PA) and average flowrate (AF) were the system scale factors that affected the impact levels significantly. So PA and AF were the most significant system scale factors. GM (1, N) was applicable to predict the environmental impact and analyze the reasonableness of the impact. If there is a new sewer system EIA to be reviewed in the future, the official committee of EPA could review the reasonableness of impact levels in EIA reports quickly.

Keywords: Environmental impact assessment (EIA); sewer system; grey system theory; grey model.

Introduction

Collection and treatment of municipal wastewater become more important in Taiwan because the amount of wastewater generated from residential and business sectors is increasing year by year with the expansion of population. But it encounters a challenge because of the low coverage of sewer system in Taiwan, only 12 % by 2005. The Executive Yuan announced that the coverage will be promoted to 20% by 2008. Sewer system will

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result in environmental impact before and after construction. So the environmental impact assessment (EIA) of sewer system will become very important in the future. Theoretically, one should study the impact of all possible indices in each EIA. However, such process may not only be too complicated, but also costly and time-consuming. More important, such process may not be necessary because not all indices would have a detectable or significant impact.

In Taiwan, all EIA which were reviewed by the committee members of Environmental Protection Administration (EPA) were evaluated individually, their relations between cases were ignored. If the relations between system scales and environmental impacts could be sought, one could predict the impacts of new system easily. Although some soft computation algorithms, such as artificial neural network, could be applied on prediction successfully, they required a large quantity of data for computation. Due to the fact that only few sewer systems were constructed in Taiwan, to adopt an appropriate method to best present complete and informational data of sewer system EIA is suggested. In order to gain consistent results from the system data and predict the impacts, the grey system theory (GST) was an applicable method.

The GST proposed by Deng (1989) can resolve the problem of incomplete information and data and has gained many significant and effective results (Chang et al., 2007; Pai et al., 2007a; Pai et al., 2007b; 2007c). Overall speaking, system behavioral data often does not follow a particular pattern and it changes unpredictably according to its circumstances. For this kind of dispersed data, regression analysis or mathematical statistics are most commonly used to analyze them. The downside of this method is that it requires a very large sum of data. If there is not sufficient amount of data, functions will not be correctly calculated and this statistical summary will not lead to a good result. Contrarily, GST focuses on the relational analysis, model construction, and prediction of the indefinite and incomplete information. It requires only a small amount of data and the better prediction results can be obtained.

There are many analysis methods in GST including grey model (GM). In environmental management, there were many environmental indices and monitoring data. If the significant variation trend could be evaluated, a better control strategy could be sought. Chang et al. (2007) adopted GST to evaluate the air quality variation trend in Taiwan. Pai et al. (2007a) used grey system theory to evaluate transportation on air quality trends in Japan. Pai et al. (2007b) adopted GM to predict the effluent quality from a hospital wastewater treatment plant. However, few studies have been done on EIA using GM. In this study, we attempt to correlate the some cases to be a reference of future EIA cases. If the impact could be predicted, the official committee could evaluate the reasonableness of impact levels in the future EIA reports quickly.

So, the objectives of this study are listed as follows. (1) Construct the relationship between the impact levels and system scale factors using GM (1, N) model. (2) Use the GM (1, N) model to predict the impact levels of other sewer systems.

Materials and methods

Data collection

Temporarily, the cases in which the EIA must be implemented are only 6 sewer systems including Banghsin (BH), Chungli (CL), Taichung Harbor (TH), Kaohsiung Fonshan (KH), Hualien (HL) and Taichung City (TC) regions in Taiwan. Their system scale factors including servicing population (SP), servicing area (SA), average daily flowrate (AF) and plant area (PA) were shown in Table 1. These data were summarized according the EIA reports (Construction and Planning Agency of Ministry of Interior, 1995; 1997; 1998a, b, c; 1999).

Table 1. System scale factors of six regions

System scale factor	BH	CL	TH	KH	HL	TC
Average daily flowrate (AF) (CMD)	94970	331200	301500	185000	165000	557000
Plant area (PA) (ha)	8.37	25	22.08	10	13	29.2
Servicing population (SP)	243000	640000	716120	637000	261600	1436000
Servicing area (SA) (ha)	6700	11736	8568	3000	5500	12610

Article 6 and 11 in EIA Act of Taiwan prescribe that the draft environmental impact assessment report shall record the "summary chart of strategies for the prevention and mitigation of the adverse impact of the development activity on the environment" (herein referred to as the summary chart). In the summary chart, the denotation "O" represented that the development activity has no impact on environment. The denotations "+", "++", and "+++" represented that the development activity has a "slightly positive", "positive", and "significantly positive" impact on environment, respectively. The denotations "-", "--", and "---" represented that the development activity has a "slightly adverse", "adverse", and "significantly adverse" impact on environment. Then the impact levels in the summary charts of 6 sewer systems were transformed into numbers and quantified as shown in Table 2. The assessment items included topography/geology/soil, hydrology/water quality, air quality, noise, solid waste, terrestrial fauna/flora, aquatic fauna/flora, landscape and traffic. The relationship between the quantified impact levels and system scale factors of BH, CL, TH and KH regions were constructed and the impact levels of HL and TC regions were predicted using grey model GM (1, N).

Table 2. Impact levels of different environmental items of six regions

Assessment items	BH	CL	TH	KH	HL	TC
1. Topography/geology/soil	5	5	6	5	5	6
2. Hydrology/water quality	6	5	5	5	5	6
3. Air quality	6	6	6	6	6	6
4. Noise	5	6	6	7	6	5
5. Solid waste	6	5	5	5	5	6
6. Terrestrial fauna/flora	5	5	6	5	5	5
7. Aquatic fauna/flora	5	5	5	5	5	5
8. Landscape	5	5	6	5	5	5
9. Traffic	5	6	6	6	6	5

Grey modeling process

In a situation where information is lacking, using fewer (at least 4) systems' information, one can create a GM to describe the behavior of the few outputs. By means of accumulated generating operation (AGO), the disorderly and the unsystematic data may become exponentially behaved such that a first-order differential equation can be used to characterize the system behavior. Solving the differential equation will yield a time response solution for prediction. Through inverse accumulated generating operation (IAGO), the forecast can be transformed back to the sequence of original series. A grey modeling process is described as follows.

Assume that the original series of data with n samples is expressed as:

$X^{\{0\}} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)),$

where the superscription (0) of $X^{(0)}$ represents the original series. Let $X^{(1)}$ be the first-order AGO of $X^{(0)}$, whose elements are generated from $X^{(0)}$:

$X^{(1)} = (x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n)),$

where $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), \text{ for } k = 1,2,\cdots,n$. Further operation of AGO can be conducted to reach the rth-order AGO series, $X^{(r)}$:

$X^{\{r\}} = (x^{(r)}(1), x^{(r)}(2), \cdots, x^{(r)}(n)),$

where $x^{(r)}(k) = \sum_{i=1}^{k} x^{(r-1)}(i), \text{ for } k = 1,2,\cdots,n$. The IAGO is the inverse operation of AGO. It transforms the AGO-operational series back to the one with a lower order. The operation of IAGO for the first-order series is defined as follows: $x^{(0)}(1) = x^{(1)}(1)$ and

$x^{(0)}(k) = x^{(1)}(k) - x^{(1)}(k-1) \text{ for } k = 2,3,\cdots,n$.

After extending this representation to the IAGO of r-order series, we have $x^{(r-1)}(k) = x^{r}(k) - x^{r}(k-1) \text{ for } k = 2,3,\cdots,n$.

The tendency of AGO can be approximated by an exponential function. Its dynamic behavior is like a form of differential equation. The grey model GM (h, N) thus adopts an n-order differential equation to fit the AGO-operational series. The parameters h and N in GM (h, N) denotes the order and the number of variables concerned in the differential equation, respectively. The GM (h, N) can be generally expressed as

$$\sum_{i=0}^{h} a_i \frac{d^{(i)} x_1^{(1)}}{dt^{(i)}} = \sum_{j=2}^{N} b_j x_j^{(1)}(k) \qquad (1)$$

where the parameter a is the developing coefficient and b is the grey input.

According to the definition of GM (h, N), GM (1, N) is that the order in grey differential equation is equal to 1 and defined as follows:

$$\begin{aligned} & x_1^{(0)}(k) + a z_1^{(1)}(k) \\ & = \sum_{j=2}^{N} b_j x_j^{(1)}(k) \\ & = b_2 x_2^{(1)}(k) + b_3 x_3^{(1)}(k) + \cdots + b_N x_N^{(1)}(k) \end{aligned} \qquad (2)$$

where $z_1^{(1)}(k) = 0.5x_1^{(1)}(k-1) + 0.5x_1^{(1)}(k)$ k = 2, 3, 4, …, n. Expanding Equation (2), we have

$$\begin{aligned} & x_1^{(0)}(2) + a z_1^{(1)}(2) = \\ & b_2 x_2^{(1)}(2) + \ldots b_N x_N^{(1)}(2) \\ & x_1^{(0)}(3) + a z_1^{(1)}(3) = \\ & b_2 x_2^{(1)}(3) + \ldots b_N x_N^{(1)}(3) \\ & x_1^{(0)}(n) + a z_1^{(1)}(n) = \\ & b_2 x_2^{(1)}(n) + \ldots b_N x_N^{(1)}(n) \end{aligned} \qquad (3)$$

Transforming Equation (3) into matrix form, we have

$$\begin{bmatrix} x_1^{(0)}(2) \\ x_1^{(0)}(3) \\ \vdots \\ x_1^{(0)}(n) \end{bmatrix} = \begin{bmatrix} -z_1^{(1)}(2) & x_2^{(1)}(2) & \cdots & x_N^{(1)}(2) \\ -z_1^{(1)}(3) & x_2^{(1)}(3) & \cdots & x_N^{(1)}(3) \\ \vdots & & \vdots & \\ -z_1^{(1)}(n) & x_2^{(1)}(n) & \cdots & x_N^{(1)}(n) \end{bmatrix} \begin{bmatrix} a \\ b_2 \\ \vdots \\ b_N \end{bmatrix} \qquad (4)$$

Then the coefficients can be estimated by solving matrix, $\hat{\theta} = (B^T B)^{-1} B^T Y$,
where

$$\hat{\theta} = \begin{bmatrix} a \\ b_2 \\ \vdots \\ b_N \end{bmatrix} \quad Y = \begin{bmatrix} x_1^{(0)}(2) \\ x_1^{(0)}(3) \\ \vdots \\ x_1^{(0)}(n) \end{bmatrix} \quad B = \begin{bmatrix} -z_1^{(1)}(2) & x_2^{(1)}(2) & \cdots & x_N^{(1)}(2) \\ -z_1^{(1)}(3) & x_2^{(1)}(3) & \cdots & x_N^{(1)}(3) \\ \vdots & & \vdots & \\ -z_1^{(1)}(n) & x_2^{(1)}(n) & \cdots & x_N^{(1)}(n) \end{bmatrix}$$

The $\hat{\theta}$ values represent the weight of comparative series to the referential series. Additionally, the GM (1, N) model could be used for prediction and described as:

$$\hat{x}_1^{(0)}(k) = \sum_{i=2}^{N} \beta_i x_i^{(1)}(k) - \alpha x_1^{(1)}(k-1) \qquad (5)$$

where $\alpha = \dfrac{a}{1+0.5a}, \quad \beta_i = \dfrac{b_i}{1+0.5a}$.

The structure diagram of GM (1, N) is shown in Figure 1. It correlated the system scale factors and impact indices.

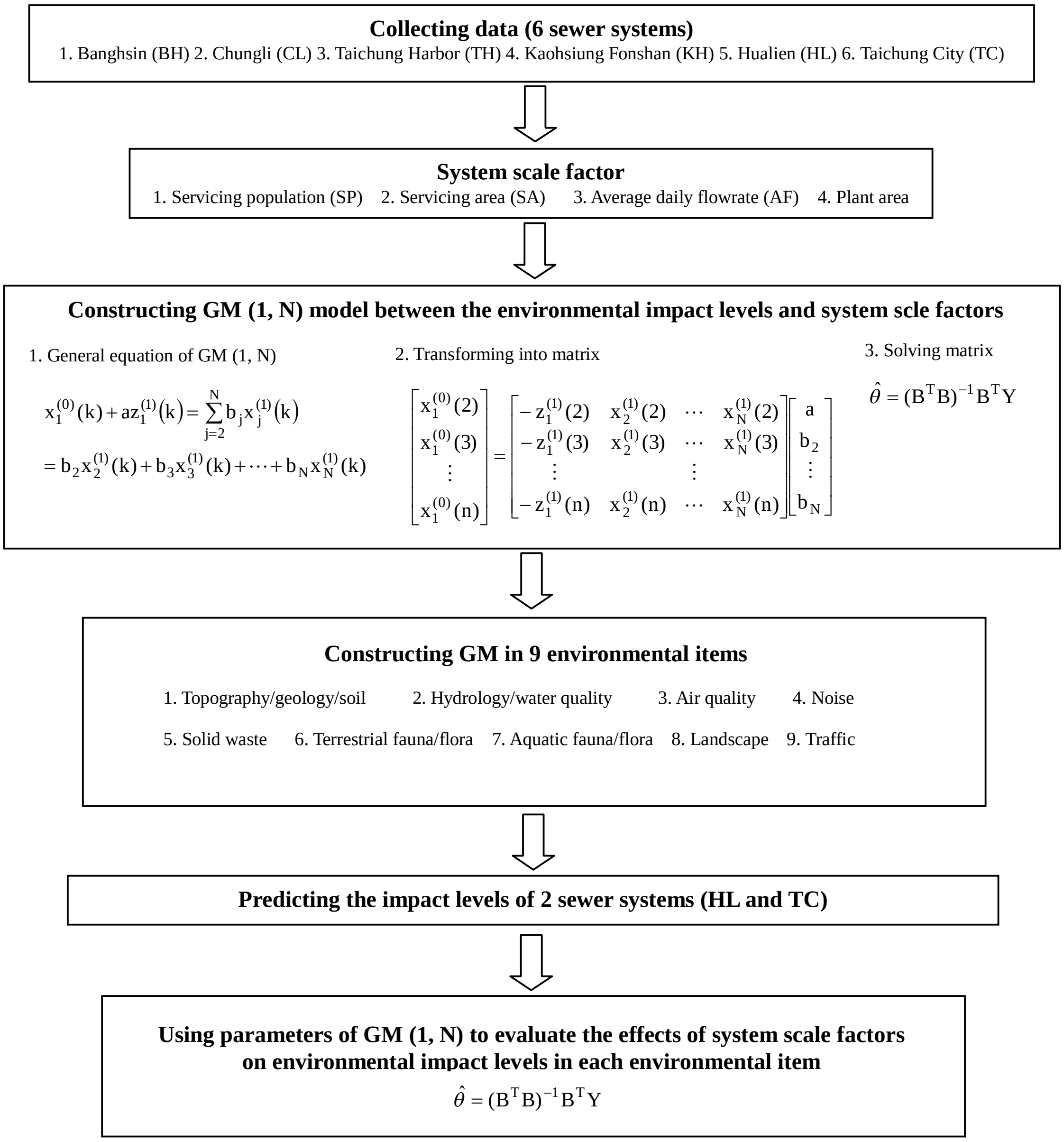

Figure 1. The structure diagram of GM (1, M)

Results and discussion

Using GM to predict impact levels

The impact levels of 4 sewer systems (BH, CL, TH and KH regions) were used to construct GM (1, N) model. After construction of GM (1, N), the impact levels of HL and TC regions were predicted using the constructed GM (1, N). The impact levels of quantified values and model values in different environmental items were shown in Figure 2.

In the item of topography/geology/soil as shown in Figure 2 (a), the average relative errors were 0 % when constructing GM, revealing a good consistency between actual impact values and predicted value. When predicting, the model values of HL and TC regions were 5.966 and 7.507, respectively. Their relative errors were 19 % and 25 %, respectively and average error was 22 %. The relative error of HL and TC regions were higher than that of model construction by 19 % and 25 %, respectively.

In the environmental item of hydrology/water quality (Figure 2 (b)), the average relative errors were 0 % as constructing GM, showing a good consistency between actual impact values and predicted value. The model values of HL and TC regions were 7.815 and 7.967, respectively as predicting. Their relative errors were 56 % and 33 %, respectively and average error was 45 %. The relative error of HL and TC regions were higher than that of model construction by 56 % and 33 %, respectively.

Figure 2 (c) shows the prediction for air quality item. When constructing GM, it reveals a good consistency between actual air quality impacts and predicted values because the average relative error was 0 %. When predicting, the model values of HL and TC regions for air quality item were 6.771 and 9.502, respectively. Their relative errors were 18 % and 58 %, respectively and average error was 36 %. The relative error of HL and TC regions were higher than that of model construction by 18 % and 58 %, respectively.

In the aspect of noise as shown in Figure 2 (d), the average relative errors were 0 % when constructing GM, revealing a good consistency between actual noise impact values and predicted value. When predicting, the model values of HL and TC regions were 4.280 and 11.823, respectively. Their relative errors were 29 % and 136 %, respectively and average error was 85 %. The relative error of HL and TC regions were higher than that of model construction by 29 % and 136 %, respectively.

Figure 2 (e) depicts the prediction of impact of solid waste. The average relative errors were 0 % when constructing GM. When predicting, the model values of HL and TC regions were 7.815 and 7.967, respectively. Their relative errors were 56 % and 33 %, respectively and average error was 45 %. The relative error of HL and TC regions were higher than that of model construction by 56 % and 33 %, respectively.

The prediction of terrestrial fauna/flora is shown in Figure 2 (f), the values between actual impact values and predicted value are consistent since the average relative errors were 0 % when constructing GM,. The model values of HL and TC regions were 5.966 and 7.507, respectively when predicting. Their relative errors were 19 % and 50 %, respectively and average error was 35 %. The relative error of HL and TC regions were higher than that of model construction by 19 % and 50 %, respectively.

In the aspect of aquatic fauna/flora as shown in Figure 2 (g), the average relative errors were 0 % for GM construction. It represented that the actual impact values and predicted value were consistent. When predicting, the model values of HL and TC regions were 5.645 and 7.917, respectively. Their relative errors were 13 % and 58 %, respectively and average error was 36 %. The relative error of HL and TC regions were higher than that of model construction by 13 % and 58 %, respectively.

Figure 2 (h) shows the prediction for landscape, the average relative errors were 0 % when constructing GM, revealing a good consistency between actual landscape impact values and predicted value. When predicting, the model values of HL and TC regions for landscape were 5.966 and 7.507, respectively. Their relative errors were 19 % and 50 %, respectively and average error was 35 %. The relative error of HL and TC regions were higher than that of model construction by 19 % and 50 %, respectively.

In the aspect of traffic as shown in Figure 2 (i), the average relative errors were 6 % when constructing GM, revealing a good consistency between actual impact values and predicted value. When predicting, the model values of HL and TC regions were 5.039 and 9.884, respectively. Their relative errors were 16 % and 98 %, respectively and average error was 57 %. The relative error of HL and TC regions were higher than that of model construction by 16 % and 98 %, respectively. The relative errors of HL region of different items lay between 13 % and 56 %. But all the relative errors of TC region were greater than 25 %. It could be explained by the following two reasons.

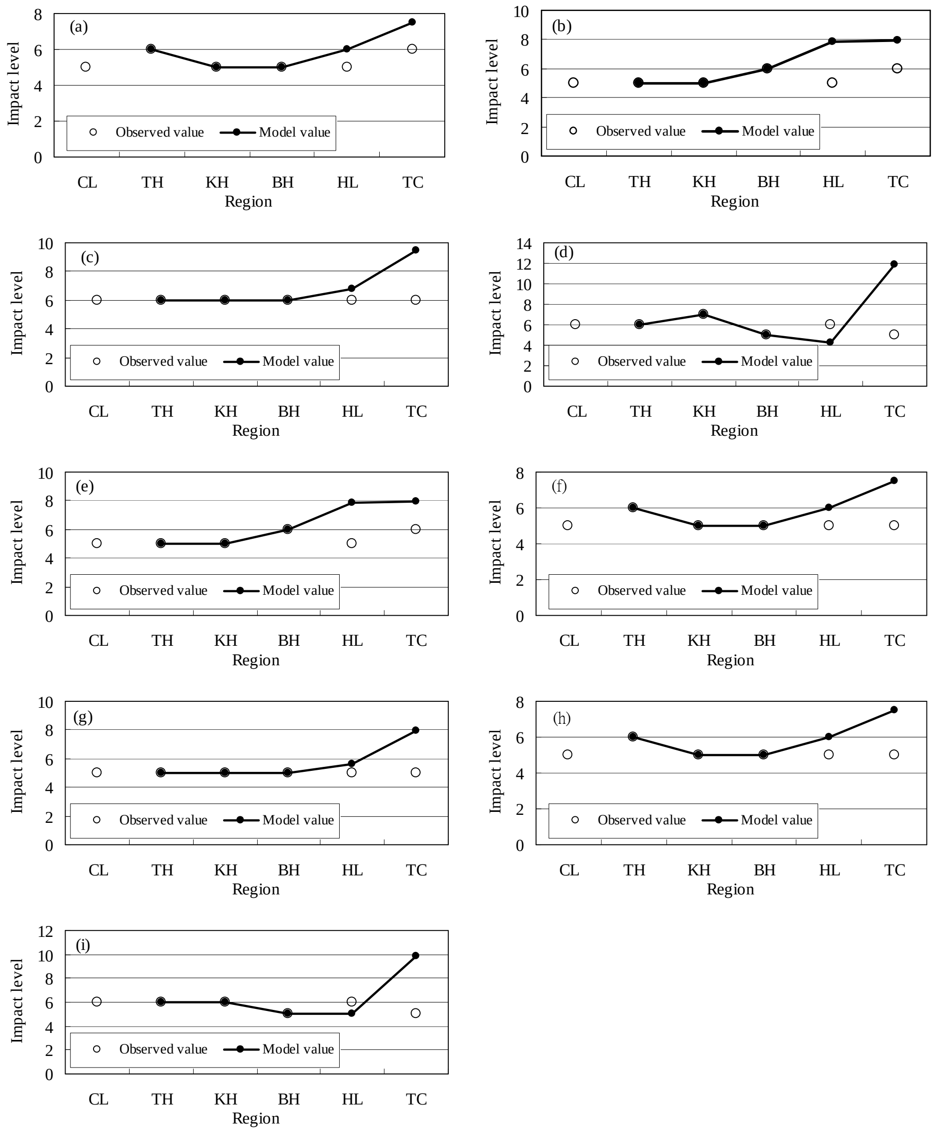

Figure 2. The impact levels of observed values and model values of different environmental items: (a) topography/geology/soil, (b) hydrology/water quality, (c) air quality, (d) noise, (e) solid waste, (f) terrestrial fauna/flora(g) aquatic fauna/flora, (h) landscape and (i) traffic. (In each figure, first 4 points were used to construct model, the last points were used for prediction.)

First, all BH, CL, TH and KH regions were smaller metropolitan regions and HL region was suburban region. Their background environmental impacts were lower too. While TC region was a large metropolitan region crowded with high density of population, burdened heavy traffic, business and industries. When GM was constructed, the SA of BH, CL, TH and KH regions were utilized, the system scale of HL region was analogous to those of the 4 regions. So the relative errors were small. The background of TC region was not analogous to those of the 4 regions, so it resulted in greater error.

Second, because the background environmental impacts of TC region were heavier, the environmental impacts when constructing the sewer system were underestimated relatively.

GM (1, N) was applicable to predict the environmental impact and analyze the reasonableness of the impact. If there is a new sewer system EIA to be reviewed in the future, the official committee of EPA could review the reasonableness of impact levels in EIA reports quickly.

Using GM (1, N) to evaluate the effect of scale factors on environmental impact

In GM (1, N), AF, PA, SP and SA were regarded as the input parameters to predict impact levels. The parameters $|b_2|$, $|b_3|$, $|b_4|$ and $|b_5|$ in matrix $\hat{\theta}$ represented the effects of AF, PA, SP and SA on impact levels, as shown in Table 3.

According to Table 3, in the environmental item of topography/geology/soil, the values of parameter b_2 to b_5 were 1.020, 1.273, 0.417 and 0.874, respectively. The effect of system scale was in the order: $|b_3| > |b_2| > |b_5| > |b_4|$. It indicated that PA and AF affected the impact level of topography/geology/soil significantly.

Table 3. The parameter values of system scale factors in each environmental item

Assessment items	Average daily flowrate (AF) b_2	Plant area (PA) b_3	Servicing population (SP) b_4	Servicing area (SA) b_5
1. Topography/geology/soil	1.020	1.273	0.417	0.874
2. Hydrology/water quality	0.738	0.930	0.400	0.632
3. Air quality	0.776	0.919	0.160	0.592
4. Noise	0.235	0.061	0.782	0.110
5. Solid waste	0.738	0.930	0.400	0.632
6. Terrestrial fauna/flora	1.020	1.273	0.417	0.874
7. Aquatic fauna/flora	0.650	0.766	0.135	0.488
8. Landscape	1.020	1.273	0.417	0.874
9. Traffic	0.670	0.711	0.177	0.401
Average values	0.763	0.904	0.367	0.608

In the environmental item of hydrology/water quality, the values of parameter b_2 to b_5 were 0.738, 0.930, 0.400 and 0.632, respectively. The effect of system scale was in the order: $|b_3| > |b_2| > |b_5| > |b_4|$. It indicated that PA and AF affected hydrology/water quality significantly.

In the air quality item, the values of parameter b_2 to b_5 were 0.776, 0.919, 0.160 and 0.592, respectively. The effect of system scale was in the order: $|b_3| > |b_2| > |b_5| > |b_4|$. It indicated that AF and PA affected air quality significantly.

In the aspect of noise the values of parameter b_2 to b_5 were 0.235, 0.061, 0.782 and 0.110, respectively. The effect of system scale was in the order: $|b_2| > |b_4| > |b_5| > |b_3|$. It indicated that AF and SP affected noise significantly.

In the aspect of solid waste, the values of parameter b_2 to b_5 were 0.738, 0.930, 0.400 and 0.632, respectively. The effect of system scale was in the order: $|b_3|$ > $|b_2|$ > $|b_5|$ > $|b_4|$. It indicated that PA and AF affected solid waste significantly.

In the aspect of terrestrial fauna/flora, the values of parameter b_2 to b_5 were 1.020, 1.273, 0.417 and 0.874, respectively. The effect of system scale was in the order: $|b_3|$ > $|b_2|$ > $|b_5|$ > $|b_4|$. It indicated that PA and AF affected terrestrial fauna/flora significantly.

In the aspect of aquatic fauna/flora, the values of parameter b_2 to b_5 were 0.650, 0.766, 0.135 and 0.488, respectively. The effect of system scale was in the order: $|b_3|$ > $|b_2|$ > $|b_5|$ > $|b_4|$. It indicated that PA and AF affected aquatic fauna/flora significantly.

In the aspect of landscape, the values of parameter b_2 to b_5 were 1.020, 1.273, 0.417 and 0.874, respectively. The effect of system scale was in the order: $|b_3|$ > $|b_2|$ > $|b_5|$ > $|b_4|$. It indicated that PA and AF affected landscape significantly.

In the aspect of traffic, the values of parameter b_2 to b_5 were 0.670. 0.711, 0.177 and 0.401, respectively. The effect of system scale was in the order: $|b_3|$ > $|b_2|$ > $|b_5|$ > $|b_4|$. It indicated that PA and AF affected traffic significantly.

In the environmental items of topography/geology/soil, hydrology/water quality, air quality, solid waste, terrestrial fauna/flora, aquatic fauna/flora, landscape and traffic, the effects of system scales were in the order: PA > AF > SA > SP. In the noise item, they were in the order: AF > SP > SA > PA. Their average values were in the order: PA (0.904) > AF (0.763) > SA (0.608)> SP (0.370), as shown in Table 3. The results revealed that PA and AF were the system scale factors that affected the impact levels significantly.

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