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Study on the Total Amount Control of Atmospheric Pollutant Based on GIS

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Objective To provide effective environmental management for total amount control of atmospheric pollutants. **Methods** An atmospheric diffusion model of sulfur dioxide on the surface of the earth was established and tested in Shantou of Guangdong Province on the basis of an overall assessment of regional natural environment, social economic state of development, pollution sources and atmospheric environmental quality. Compared with actual monitoring results in a studied region, simulation values fell within the range of two times of error and were evenly distributed in the two sides of the monitored values. Predicted with the largest emission model method, the largest emission of sulfur dioxide would be 54 279.792 tons per year in 2010. **Conclusion** The mathematical model established and revised on the basis of GIS is more rational and suitable for the regional characteristics of total amount control of air pollutants.

Key words: Total amount control of atmospheric pollutants; Atmospheric diffusion model; Pollution source; GIS

INTRODUCTION

Over many years, air pollution control methods used in many countries have constituted methodological systems of environmental management which mainly focus on concentration control[1]. However, concentration control fails to establish quantitative relation between the change of quantity of air pollutants and the goal of regional air quality, leading to a great disparity before the regional air quality is improved. Some large cities over the world have successively carried out researches on the total amount control of atmospheric pollutants and developed related pilot projects, and have accumulated extensive valuable experience. As a kind of new-type pollution control method, the total amount control of atmospheric pollutants is not mature in its theory or technology[2].

The total amount control of atmospheric pollutants is closely linked to the geographical factor. GIS is a computer-based system for inquiring, outputting, managing, analyzing, operating and expressing geographical messages. It can visualize and analyze the existing things and occurring incidents on the earth, integrating the map's unique vision effort and geographical analysis function with general database operation. Since most GIS softwares lack strong space analysis and simulation function, the total amount control of atmospheric pollutants is one of GIS's very important application directions. However, because the total amount control of atmospheric pollutants is usually studied independently of GIS, its scale is as complicated and huge as the latter. Though the importance of integration is well known[3-4], the combination of GIS with environmental protection field is still not enough. In many cases, GIS is only used as a data entry and result output tool, and its combination with the total amount control of atmospheric pollutants is rare[5].

Based on GIS and regional reality, the echoing relation between urban atmosphere pollution sources and environmental quality, foundation of air pollutant diffusion models, methods of total amount control and optimized assignment was studied in order to get a better understanding.

MATERIAL AND METHODS

To carry out the total amount control of atmospheric pollutants in a certain region, the method of systematic engineering is mainly applied to synthesize and analyze the regional social economy development, physical geography, pollution sources and environmental concentration distributing characteristic, *etc.*; meanwhile the dynamic echoing relationship between pollution sources was established in accordance with the regional characteristic and the atmospheric environmental quality

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concentration; discharge quota of each pollution source was determined by utilizing atmospheric resource and optimizing technological design to the maximum extent, thus making the total amount control of atmospheric pollutants possible and implementing the plan according to the regional economic development and environment loading capacity.

To realize the integration of GIS and total amount control of atmospheric pollutant analysis model, the pass-way problem of data interchange between them should be solved at first. GIS software is a space data model and uses vector and bar data models to express the geographical entity and phenomenon and their mutual relation in the real world. It is quite different from the special demand of dispersing continuous space and time while solving the total amount control of atmospheric pollutant analysis model, which brings difficulties in integrating the total amount control model with GIS on the level of data. It is necessary to establish a common space data model for GIS and the total amount control of atmospheric pollutants forming the bridge of data transmission between them.

The total amount control of atmospheric pollutant analysis model has the ability to solve specific problems of its domain, while GIS is needed to transfer the data for the model and to express the calculated result. The integration of GIS and total amount control model is actually a system development course that takes the data as a channel and GIS as the core. The total amount control of atmospheric pollutant model is linked to GIS through data interchange based on the connection in the space. The realization of GIS function and value solution of the model are both involved in dispersing the geographical space. Supported by GIS technology, according to the model's demand for dispersing space, the geographical space (studied region) is divided by net, and data of central point are obtained automatically, showing the space distribution of different parameters of the model and forming the necessary data (file) for the analysis model directly. After being put in a space geographical coordinate, the net data from dispersing space of the model form the space data file for GIS can be directly and visually expressed by utilizing GIS's analysis function.

RESULTS

Overview of Studied Region

The geographical coordinate of Shantou 116°34' 12" E to 116°58'54" E and 23°13' N to 23°28' N, located in the south of Hanjiang River delta by the South China Sea. Situated on the Chaoshan Plain and with its terrain downward a little from northwest to southeast, Shantou is the outlet of Hanjiang River, the second longest river in Guangdong Province. It has a subtropical maritime monsoon climate with an annual average temperature of 21.3℃ and an annual average precipitation of 1544 mm for many years, a relative humidity of 82%, and a long-term average wind speed of 2.7 m/s. The annual prevailing wind direction is ENE, with N to NNE in winter and SWS to SES in summer. The typhoon seasons fall in summer and autumn. The urban area of Shantou is 301.2 km^2 with constructed area of 96.7 km^2. The monitoring results from 1996 to 2003 indicate that the urban environmental quality in the studied region is good. The annual and daily mean values of pollution index accord with the second standard of the National Quality Specification of Surrounding Air (GB 3095-1996) on sulfur dioxide, nitrogen dioxide, inhalable particles and total suspended particulates. In 2000, the discharged waste-gas amounted to 19 277 million cubic meters, sulfur dioxide to 18 000 tons, fume to 2363 tons, and industrial dust to 18 tons. The sulfur dioxide is the main pollutant discharged in the studied region followed fume and industrial dust. According to the situation of pollutant discharge in the studied region, sulfur dioxide was chosen as the index of total amount control of atmospheric pollutants.

Establishment of Database

Large amount of data information is needed to carry out the total amount control of atmospheric pollutants in a certain area, and the source is quite complicated. In order to analyze the historical materials and their dynamic changes in unison, it is necessary to process and screen all materials, then to establish the database for the total amount control of atmospheric pollutants. The data information of the total amount control of atmospheric pollutants is divided into two kinds, one is the space data, including topography, surface features, population distribution, atmospheric zoning, pollution source distribution, monitor position, atmospheric environment objective, atmospheric control point and space distribution of pollutant concentrations. This kind of materials reflects the basic data of the studied region. The other kind is attributive data, including social and economic situation, monitor record of the pollution sources, routine monitor materials, meteorological materials of pollution, pollution control scheme and relevant technical parameters of calculation model, etc. This kind of materials reflects the level of pollution and pollution control state of the studied region.

The space data are directly input through GIS digitized system, edited and processed by GIS's subsystem. As to the attributive data, unified outside database was established and dynamically chained to the GIS system, then unified resource environmental information database system was established to inquire, search and analyze simulation at any time. Space and attributive databases was joined together through geographical code designed in unison.

Total Amount Control of Atmospheric Pollutant Model

Diffusion model of point source Pollutant concentration at any downward wind point source is provided by the following formula:

$$C(x,y,z)=\frac{Q}{2\pi u\sigma_y\sigma_z}\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left\{\exp\left[-\frac{(z-H_e)^2}{2\sigma_z^2}\right]+\exp\left[-\frac{(z+H_e)^2}{2\sigma_z^2}\right]\right\}$$

where: u is the average wind speed (m/s), He is the effective height of the chimney (m).

Diffusion model of area source The urban air pollution has a close relation with the area sources in the whole city. If the pollution of area sources is not estimated appropriately, it could directly influence the correct appraisal of the urban air pollution and plan-making. The method of virtual point sources is commonly applied to area sources. Every area source unit is simplified to one "equivalent point source" and moved to a certain windward position, the area source of that unit equivalent to the windward virtual point source is made and the following method is used to confirm the position to which the central point of area source moves.

$$X_{y0}=\left(\frac{\sigma_{y0}}{\gamma_1}\right)^{1/a_1}\qquad X_{z0}=\left(\frac{\sigma_{z0}}{\gamma_2}\right)^{1/a_2}$$

where: X_{Y0}: Rear mounted distance while calculating $б_Y$,

X_{Z0}: Rear mounted distance while calculating $б_Z$

Namely the calculating point distance is confirmed by X_{Y0} and X_{Z0}.

$$\sigma_y=\sigma_y\left(X+X_{Y0}\right)\qquad \sigma_Z=\sigma_Z\left(X+X_{Z0}\right)$$

where: X: The distance from the control area source to the calculating point

Multiple sources Gaussian diffusion model To calculate the concentration of evaluated spots with Gaussian diffusion model of multiple sources, concentration contributions are added to the spots from all point and area sources. The diffusion formula of various kinds of pollution sources in multiple source diffusion models is the same as in Gaussian model, while we should notice the coordinate changing and decaying of the pollutant.

Generally, the regular system of coordinates is chosen as EON to make E axle point to the due east and N axle point to the due north. The left below of the whole appraisal area is selected as the coordinate origin, the coordinates of pollution source P are EP and NP, and those of calculating point are Er and Nr. The XOY system of coordinates in Gaussian diffusion model still changes with wind direction and makes X axle keep the same direction with wind. If the angle of the wind direction is θ, the position of calculating spot in XOY system of coordinates should be:

$$\left\{\begin{array}{l} x=(N_p-N_r)\cos\theta+(E_p-E_r)\sin\theta \\ \\ y=(N_P-N_r)\sin\theta-(E_p-E_r)\cos\theta \end{array}\right\}$$

When X and Y values of above formula are put in Gaussian model, we can calculate the concentration of pollution source spot P at r, and while the densities of all pollution sources are added to at r, we can get the total concentration at r, namely $C_r=\sum C_{ir}$.

Long-term average concentration model In order to prevent the fluctuation and weak representative of short-term concentration, long-term average concentration control of the pollutants is usually adopted. The long term influence on the concentration from different wind directions, wind speed and stability are quite different. The annual and daily concentrations should be recorded according to each wind direction, speed and stability frequency proportionally weighted in average.

The concentration formula at this moment is[6]

$$C(x,y,z)=\sum_i\sum_j\sum_k C(D_i,D_j,W_k)\cdot f(D_i,D_j,W_k)$$

where: C (D_i, D_j, W_k): Density under wind direction D_i , wind speed D_j , stability W_k

f (D_i, D_j, W_k): Frequency under wind direction D_i , wind speed D_j , stability W_k

Total amount control of atmospheric pollutant model Air pollution condition of the studied region and its social economic development in future should be considered comprehensively in choosing the models[7-9], and the biggest discharge model is the first choice. The meaning of this model lies not only in guaranteeing the discharging concentration of pollution sources within the environmental goal, but also in fully utilizing the diffusion and dilution function of atmosphere, thus allowing the emission as much as possible, and extending the space at most for regional development. On the other hand, concentration of the controlled point is the superposed result from the concentration of many point and area sources. The largest emission comes from the point source but not area source, and area sources are not required to be the biggest discharge in principle. In the biggest discharge model, pollution sources are area sources, and the environmental goal value of the function district where pollution sources are located is one of point sources in nature. If the area source's sharing rate r_i is calculated by multiple sources model, the sharing rate of spot source is 1- r_i, and then the environmental goal value of point source is C (1 - r_i).

As for A_{ij}, the simulation of long-term average concentration is more effectual than the estimation of short-term concentration, due to the air quality mode input parameters and obtained data. Thus, A_{ij} stands for the annual daily average density contribution index, which can be confirmed by the calculation formula of the long-term average concentration.

Appraisal period is selected, Q_j from the addition formula is proposed, and the above formula could be written as:

$$\overline{C} = Q_j A_{ij} \qquad A_{ij} = \frac{\overline{C}_{ij}}{Q_j}$$

In fact the above-mentioned model is a linear programming model, which can be solved with several kinds of methods, and the commonly used one is the simple method solving with computer.

It solves as follows:

If $D_i=C_i(1\text{-}ri)$, above-mentioned linear planning problem turns to the following form :

Goal function: $\max F(Q) = \sum_{j=1}^{n} Q_j$

Restraining condition:

$$\sum_{j=1}^{n} A_{ij} Q_j \leqslant D_i \qquad Q_j \geqslant 0$$

Simulation of Total Amount Control of Atmospheric Pollutants

The meteorological condition of regional pollution, pollution sources and diffusion models is organically integrated with GIS system by changing its simulation result into the systematic picture layer, in order to be synthesized and analyzed with other information and to realize the cartoon simulation of the motive force course as well.

Simulation of density of atmospheric pollutants Calculated by simulation, the sulfur dioxide polluted concentration fields of the studied region are shown in Fig. 1. Simulated annual and daily sulfur dioxide

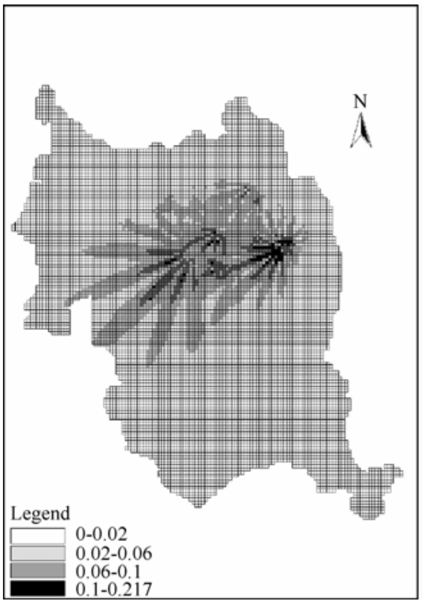

FIG. 1. The sulfur dioxide pollute contration fields of studied region of simulation (mg/m^3).

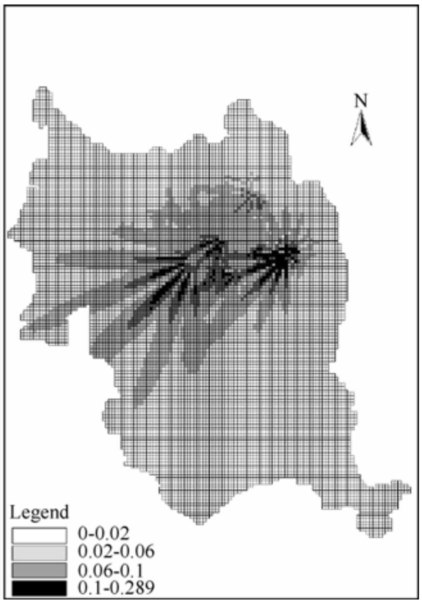

FIG. 2. The sulfur dioxide pollute concentration fields of studied region of simulation in 2010 (mg/ m^3).

floor concentrations of the studied region reached 0.2073 mg/m^3, and simulated annual average value was 0.0139 mg/m^3, exceeding standard rate was 3.56%. In contrast to the actual monitoring result, the absolute error of simulation value and monitoring value fell in -0.004-0.006, with a relative error of -28.57-33.33%. Simulation value fell within the range of two times of error and was evenly distributed on the two sides of monitoring value, and so the model can be used for predicting the overall air pollutant control of the studied region. According to the social economic development in the studied region[10], the largest floor concentration of sulfur dioxide in the studied region would become 0.2754 mg/m^3 in 2010, and the annual daily average value would be 0.0184 mg/m^3. It may exceed the standard to a certain degree, the exceeding standard rate was up to 6.05%. The sulfur dioxide polluted concentration field is shown in Fig. 2.

Simulation of total amount control of atmoseric pollutants In the maximum emission model, A_{ij} is taken as the annual daily concentration contribution index. Eleven control points were selected according to the actual conditions, 32 point sources were chosen. The annual sulfur dioxide discharge in 2000 was greater than 10 tons, and the pollutant discharged in the 32 point sources accounted for 85% of the total emission in the studied region. According to the simulating result, when the regional average deletion rate of sulfur dioxide was 45% in 2010, the best emission will be 54 279.792 tons per year, and 4657 tons of sulfur dioxide need to be subdued. When the regional average deletion rate of sulfur dioxide is 60%, the best emission will be 57 313.557 tons per year, and there is no need to subdue the emission of pollution sources of the studied region.

CONCLUSION

1. The model developed on the basis of GIS can simulate the current situation of sulfur dioxide concentration on the surface of the earth. In contrast to actual monitoring result of the studied region, simulation value falls within the range of two times of error and is almost evenly distributed on the two sides of monitor value, and therefore the model can be used for predicting the total amount control of atmospheric pollutants of studied region. As predicted, the largest floor concentration of sulfur dioxide in the studied region will be 0.2754 mg/m^3 in 2010, the annual daily average value will be 0.0184 mg/m^3, which may exceed the standard with a rate of 6.05%.

2. As predicted with the largest emission model method, the largest emission of sulfur dioxide will be 54 279.792 tons in 2010. When the purification rate is 45%, 4657 tons of sulfur dioxide need to be subdued. Most pollution sources can increase or maintain the present discharge level of sulfur dioxide, 4657 tons need to be subdued. The largest emission of sulfur dioxide will be 57 313.557 tons per year, with the purification rate of 60% in 2010, all pollution sources can increase or maintain the present discharge level.

3. GIS space analysis in combination with the total amount control of atmospheric pollutant model can realize dynamic analysis and visual simulation, dynamic establishment of the database and air pollutant total mount control simulation, data store, output or graphical simulation result. The mathematics model established and revised on the basis of GIS is more rational and suitable for the regional characteristics of total amount control of air pollutants.

REFERENCES

1. Liu, S. S. and Lin, L. H. (1995). Foreign policy of blow down trade under the total amount control of pollutants. *Scientific Research* **8** (2), 56-59.
2. Wan, Q. G. and Li, Z. K. (1995). Study on the total amount control of atmospheric pollutants of small and medium-sized cities of our country. *Environmental Science Progress* **3**(6), 9-16.
3. Wu, X. C. (1998). Basic technology and developing trends of GIS. *Geoscience* **23** (4), 20-23.
4. Duan,K., Yuan, G. L., He. B., and Chao, B.Y. (1999). Study on spatial information system of air pollutant dispersion. *Environmental Scientific Research* **12** (6), 10-13.
5. Liu, Y. (1997). GIS and its application in environmental science. *Environmental Science* **18** (2), 34-35.
6. Xia, Q., Han, Y. H., and Ge, D. L. (1990). Integrated control of atmospheric scheme. Beijing, China: Environmental Science Press.
7. Hu, B. Q. (1999). The disperse scheme model of implementing optimization in regional the total amount control of pollutants. *Environmental Protection* **12**, 13-15.
8. Li , Y. J., Yuan, J. Y., and Wang, Y. (2001). Comparison and Analysis of Two Optimal Methods of Intensity of Pollution Sources in Total Amount Control. *Environmental Scientific Research* **14** (3), 52-55.
9. The Municipal Government of Shantou. (1999). Social Economic Ninth Five-Year Plan of Shantou and 2010 Development Scheme, Shantou, China.
10. The Municipal Government of Shantou (1998). The Environntal Protection's Ninth Five-Year Plan of Shantou and 2010 Development Scheme, Shantou, China.

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