Design and implementation of air pollution management system and an application case in Beijing

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Abstract. In recent years, the air pollution in China is becoming more and more serious, especially in Beijing. In this paper, an air pollution information management system was established by using ComGIS component of ArcEngine and Visual C# .NET platform and SQL Server technology. The system consists of three modules, including basic function, spatial analysis and early warning. It can monitor air pollution from different angles. In order to realize the simulation of pollution diffuse and the visual management of air pollution, we developed this system to monitor and analyse the air pollution situation in Beijing in quasi real time. Air pollution concentration data recorded by the monitoring station in Beijing on May 23, 2015 was obtained. The results showed that the severe atmospheric pollution in Beijing was mainly distributed in Chaoyang, Xicheng, Dongcheng and Fengtai districts. The area with severe PM2.5 exceeding the standard was located near the Monitoring station of Yizhuang Development. However, it indicated that the severely polluted areas extended from Daxing and Tongzhou districts to Xicheng, Dongcheng and Chaoyang districts when simulating the diffusion of PM2.5 pollutants by adding wind power and wind direction data on the same day.

1. Introduction

With the rapid development of China's industrial zones and the expansion of traffic scale, the emission of pollutants is increasing, which leads to the deterioration of environmental pollution and gradually threatens the quality of people’s life [1-2].

Gu et al and Wendt C H et al conducted theoretical research on urban air pollution control countermeasures [3-4]. Ren et al and Ganore Nikita Sanjay et al developed the environmental pollution monitoring system and began to realize the management of pollution sources [5-6]. Then Wu et al, Ma et al and Shaban K B et al studied various air pollution diffusion models and integrated them into the air pollution management system [7-9]. However, there are few complete monitoring, simulation and early warning systems for air pollution.

The system which can monitor air pollution from different angles was built by using ComGIS component of ArcEngine, Visual C# .NET platform and SQL Server technology. It included three modules, basic function, spatial analysis and early warning. It can monitor air pollution more comprehensively and accurately compared with other systems.
2. System design and methods

2.1. System design

Air pollution management system (Figure 1) is a relatively complete system from input, processing to output of environmental pollutant information, which can provide powerful tools for the treatment and management of environmental pollution.

Most of the application systems based on GIS transmit data in two forms: CS and BS, which are also called client server mode and browser server mode. Both have their own advantages and disadvantages. The amount of data involved in the study of atmospheric environmental pollution is often very large, and the system often involves editing, analysis and updating of data. As a result, the C/S model is more in line with the design requirements of the system (Figure 2) than B/S mode.

Figure 1. Overall framework.

Figure 2. System architecture.

2.2. Methods

The modules and methods of the system will be explained separately

2.2.1. Vectorization. The system is required to convert the document data obtained from the monitoring station into vector data, so as to facilitate data storage and management.

2.2.2. Attribute query and warning of excessive concentration. It can query the concentration of air pollutants and quickly locate the position where the concentration exceeds the standard, so as to realize the warning of excessive concentration.

2.2.3. Interpolation analysis. The monitoring site data were interpolated to obtain the pollutant concentration of the whole research area.

If two points \((x_0, y_0) (x_1, y_1)\) are known, interpolation \(P_{01}(x)\) is:

\[
P_{01}(x) = \frac{x-x_0}{x_1-x_0} y_0 + \frac{x-x_1}{x_1-x_0} y_1
\]

When there are three points \((x_0, y_0) (x_1, y_1) (x_2, y_2)\), interpolate between two points and then with the third value:

\[
P_{12}(x) = \frac{x-x_1}{x_2-x_1} y_1 + \frac{x-x_2}{x_2-x_1} y_2
\]
The interpolation formula is combined and simplified:

\[
P_{(0,1,2)} = \frac{x-x_2}{x_0-x_2} P_{0,0,2} + \frac{x-x_0}{x_0-x_2} P_{1,0,2}
\]

\[
P_{(0,2,1)} = \frac{x-x_2}{x_0-x_2} P_{0,0,2} + \frac{x-x_0}{x_0-x_2} P_{0,1,2} + \frac{x-x_0}{x_0-x_2} P_{1,1,2}
\]

There is recursion in the formula. So, the monitoring station data can be interpolated by this way. Assuming there are n points:

\[
P_{(0,1,...,n)} = \frac{x-x_n}{x_0-x_n} P_{0,0,2} + \frac{x-x_0}{x_0-x_n} P_{0,1,2} + \frac{x-x_0}{x_0-x_n} P_{0,2,1} + \ldots + \frac{x-x_n}{x_0-x_n} P_{0,n,2} + \frac{x-x_n}{x_0-x_n} P_{1,0,2} + \frac{x-x_0}{x_0-x_n} P_{0,n,1} + \frac{x-x_0}{x_0-x_n} P_{1,0,1} + \ldots + \frac{x-x_n}{x_0-x_n} P_{1,n,0}
\]

\[
(3)
\]

2.2.4. Diffusion analysis. Considering wind power and wind direction factors, the influence range of air pollution is determined according to the diffusion model;

1. Strong wind (U≥1.5 m/s) path:

The height of the monitoring station is set as h, with the average wind direction at the station as X axis, Q as the concentration of air pollutants monitored by the monitoring station, mg / s ; H is the relative height of atmospheric monitoring station, m ; t is the prediction time, s ; t is the pollutant diffusion duration considering the influence of wind factors, s ; u is the average wind speed, m / s; \( \sigma_x, \sigma_y, \sigma_z \) is the atmospheric diffusion coefficient along the x, y, z axes [10], m ; \( C_i(x, y, 0) \) is the predicted concentration of ground point \((x, y)\) at time \( t \), mg/m3. Then the concentration of \((x, y)\) at any point is [11-12]:

\[
C_i(x, y, 0) = \frac{Q}{\pi \mu \sigma_x \sigma_y \sigma_z} \exp \left[ \frac{y^2}{2 \sigma_y^2} - \frac{H^2}{2 \sigma_z^2} \right] G_i
\]

\[
(5)
\]

\[G_i = \begin{cases} 
\Phi(ut - x, \sigma_x) + \Phi(x, \sigma_x)^{-1} & t \leq T \\
\Phi(ut - x, \sigma_x) - \Phi(ut - uT - x, \sigma_x) & t > T 
\end{cases}
\]

\[
(6)
\]

\[
\Phi(s) = \frac{1}{\sqrt{2\pi}} \int e^{-\frac{t^2}{2}} dt
\]

\[
(7)
\]

2. Light wind (0.5m / s ≤ U < 1.5m/s) or calm wind (U < 0.5m / s) path:

At time \( t \), the concentration of \( a \) at any point \((x, y)\) on the ground is:

\[
C_i(x, y, 0) = \frac{Q}{\pi \mu \sigma_x \sigma_y \sigma_z} \exp \left[ \frac{x^2+y^2}{2 \sigma_x^2} - \frac{H^2}{2 \sigma_z^2} \right] G_i
\]

\[
(8)
\]

2.2.5. Distance analysis. After the analysis of air pollution, the system can provide appropriate paths for relevant departments, so that people can take actions more quickly to control air pollutants;

The cost is calculated in three different cases to obtain the appropriate path:

1. Cost of adjacent node

\[a_i = (\cos t_1 + \cos t_2)/2\]

\[\cos t_1, \cos t_2\] are the cost of pixels respectively and \( a_i \) is the total cost of connecting pixels.

2. Cumulative vertical cost

\[\text{ accum } \_\text{cost} = a_i + (\cos t_2 + \cos t_3)/2\]

\(\cos t_3\) is the cost of pixels and \(\text{ accum } \_\text{cost}\) is the total cost of connecting pixels.

3. Diagonal node cost

\[\text{ accum } \_\text{cost} = a_i + 1.414214(\cos t_2 + \cos t_3)/2\]

\[\text{ accum } \_\text{cost}\]

2.2.6. Thematic mapping. The output of result in the form of visualization is conducive to the relevant departments to better understand the situation of air pollution in this region.
3. Study area and dataset

3.1. Study area
Beijing is located in the north of China and the North China Plain. Its center latitude and longitude is 39° 56′N and 116° 20′E. Southeast wind prevails in summer and northwest wind in winter (Figure 3).

Figure 3. Study area.

3.2. Dataset
1. Beijing administrative division map (vector data) was downloaded from the Geospatial Data Cloud platform;
2. The distribution data of factories in Beijing was obtained from Amap POI;
3. The statistical data of pollutants in Beijing monitoring stations were obtained from Beijing Environmental Protection Bureau. The wind direction and wind speed data were from the weather report website. The air pollution data on May 23, 2015 was taken as the system test data. The wind power level of that day was level 3-4, direction is south and the speed was 4.5m/s;
4. Beijing satellite remote sensing image data (raster data) was downloaded from Geospatial Data Cloud platform.

4. System implementation and results

4.1. Basic function
1. Transforming into spatial elements
When we get the real-time data from the monitoring station, we can quickly convert and analyze to extract the areas with serious pollution (Figure 4). The site data is converted from excel table data to spatial point data, which paves the way for subsequent statistics and spatial analysis.
2. Spatial element queries
According to China’s national standards: when the concentration of NO2 > 40 μg / m3 or SO2 > 60 μg / m3 or PM2.5 > 35 μg /m3, the pollutants exceed the standard. Concentration of NO2 and SO2 in Beijing have basically reached the national standard, but PM2.5 is still the main pollutant in Beijing. The system realizes two query modes: attribute query and spatial query. By inquiring the NO2 concentration at a certain time of the monitoring station to determine the areas where pollution exceeds the standard (Figure 5).
4.2. Spatial analysis function

1. Spatial interpolation analysis

It is not enough to judge the air pollution status of Beijing as a whole through the pollution points obtained by monitoring stations. The pollution situation in Beijing can be predicted by interpolating the measured data of each monitoring station (Figure 6).

2. Pollutant Diffusion Analysis

The influence of wind factor was added into the analysis of air pollutant diffusion. According to different wind grades, the corresponding diffusion model is adopted to judge the diffusion range. The wind direction was south and speed of the experimental data was 4.5m/s. Areas with excessive pollution level was located in Yizhuang Development Zone of Daxing districts (Figure 7). Through diffusion analysis, it was found that the seriously polluted area extended to Dongcheng, Xicheng and Chaoyang districts (Figure 8).
3. Euclidean Distance Analysis
When obtained the location of excessive concentration and air pollution control department, the system can choose a more appropriate path for the relevant staff. So that people can take prompt measures against the pollutants (Figure 9) and then investigate the factories within the pollution range to realize the control of air pollution.

![Figure 9. Optimal cost path.](image1)

![Figure 10. Thematic mapping.](image2)

4.3. Early warning function
The representative situation of air pollution can be mapped and submitted to the relevant air pollution control departments, so as to achieve the purpose of air pollution warning (Figure 10).

5. Conclusions
The stability and accuracy of the system were tested with the concentration of pollutants in a certain day in Beijing. According to the test results, we reached the following conclusions:

1. The air pollution information management system can obtain the air pollution situation and output the thematic map.

2. Judging from the experimental data, the areas with serious air pollution on this day were mainly distributed in the middle and southeast, especially in Chaoyang, Xicheng, Dongcheng and Fengtai districts. When we get the data from the monitoring station, we can know the situation of air pollution in any area through this system.

3. The simulation result of the diffusion of PM2.5 pollutants showed that the heavily polluted areas were expanded from Daxing, Tongzhou districts to Xicheng, Dongcheng and Chaoyang districts. The system can monitor the diffusion of air pollution so as to take accurate measures to control it.

4. Climate factors should be considered to be more comprehensive (such as humidity, temperature, pressure and other natural climate conditions) in future researches, so as to more accurately define the areas with severe air pollution.

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