Using Numerical Simulation Technology to Assess the Contribution of Key Polluters to Air Pollution in the Huancui District, Weihai, China

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Abstract—We used observational data and numerical simulation technology for evaluating the rate at which that key polluters contribute to air pollutants in the Huancui district of the city of Weihai, China. We evaluated air quality monitoring data, meteorological data, high-altitude sounding data and the emissions intensity of key polluters as provided by the Shandong Provincial Department of Environmental Protection. We adopted the Aermod System, an atmospheric environmental impact assessment system, to simulate pollutant concentrations released from key polluters at each monitoring point in Weihai. Then, we compared the results with values from each monitoring point established by the Department of Environmental Protection of Shandong Province. The results showed the rates that key polluters contribute to air pollutants in the city of Weihai. The analysis concluded that contribution rates of sulphur dioxide and nitrogen oxides from key polluters in the Huancui district of Weihai were higher in the Huaxia Technical School zone at 32.72% and 81.39%, respectively, while they were lower for the remaining five monitoring sites. This study provides data support for the relevant government departments alongside a simple and convinient method to use for related research by using existing official monitoring statistics.

Index Terms—Contribution rate, nitrogen oxides, sulphur dioxide, numerical simulation.

I. INTRODUCTION

Most of the world's cities suffer severe air quality problems, which have received increasing attention. According to the World Health Organization, worldwide urban air pollution causes 800,000 deaths and years of life lost of approximately 4.6 million each year [1]. In China, with the sustained and rapid growth of economy, the expansion of urban population and the development of industry, China's cities are experiencing serious air pollution

in recent years [2]. Environmental pollution in China has become a problem that cannot be ignored [3]. To resolve the problem, understanding the rate that all kinds of pollution sources contribute to air pollutant concentrations is necessary [4]. This understanding is the basis for developing air pollution reduction programs.

The AMS/EPA Regulatory Model Improvement Committee (AERMIC) developed an atmospheric environmental impact assessment system, named AERMOD. The system is based on the statistical theory of diffusion, assuming that the distribution of pollutant concentrations, to a certain extent, follows Gaussian distribution theory. The system allows for a mode system that can be used for various emission sources (including point source, line source, non-point source and body source) [5]. It can also be used to simulate and predict the emission and diffusion situation anywhere in a rural or urban environment, flat or complex terrain, ground or elevated source [5]. It can be used to calculate dry and wet deposition and other scavenging processes [6]. Inputting values for parameters with the AERMOD model system is easy and clear. In accordance with the needs of users, outputting files having multiple formats and requirements at the same time is possible. Not only can it sort the pollutant concentrations, but it can make three types of contour maps, including the annual average, the daily average and the hourly value, using the predicted results. Langner and Klemm's experiments have shown that the predictions of the model are closer to field observations [7]. In cases with complex and urban terrain, AERMOD is the stronger model compared with AUSTAL2000. However, AERMOD does not take into account chemical reactions [8]. So, when used in model domains within 50 km $\times$ 50 km (e.g., small and medium sized cities), the predicted results with the model can have a high precision and accuracy [8].

We used Weihai, a city in the Shandong Province, as an example. We chose the levels of sulphur dioxide (SO_2) and nitrogen oxides (NO_X), two important air quality indexes, as research objects using the Aermod System, with AERMOD as the core model, as the atmospheric environmental impact assessment system. Combining the data regarding the emission of pollutants of key polluters and ambient air quality, which is published on the website of the Shandong Provincial Department of Environmental Protection, we researched the contribution rates of SO_2 and NO_X discharged from key polluters in Weihai and compared them to corresponding pollutant concentrations in discrete points. From this study, it can be roughly understood the extent that key polluters in Huancui district of Weihai influence air quality and can provide a basis for the government to plan air

pollution reduction programs and to develop other relevant policies.

II. METHODS

A. AERMET Meteorology Pre-treatment

For this experiment, the ground meteorological data was forecasted by inputting two months (March and April 2014) of meteorological material provided by the weather station of Weihai, including wind speed, wind direction, total cloud cover, low cloud cover and dry bulb temperature. High-altitude sounding data was downloaded online by the software.

Near-ground parameters (surface albedo at noon, daytime Bowen ratio and ground roughness length), used in the AERMOD system, according to the differences among the four seasons of the year, could be selected by referring to the user manual. The roughness data came from relevant experimental observation data. The corresponding parameters are shown in Table I.

TABLE I: AERMOD NEAR-GROUND PARAMETERS

	Albedo	Bowen ratio	Roughness length
Winter	0.35	1.5	0.38
Spring	0.14	1.0	0.38
Summer	0.16	2.0	0.38
Fall	0.18	2.0	0.38

B. AERMAP Terrain Pre-treatment

We imported the Google map of the Huancui district of the city of Weihai. We outputted the geographic elevation files and read a total of 577 grid points at the interval of 1500 m × 1500 m. The terrain data was imported automatically. We set the latitude and longitude coordinates (122°7′7.57″E, 37°25′12.98″N) as the coordinate of the reference grid point (0, 0). After implementing the AERMAP process, we obtained the actual geographical elevation, the effective height of each point on the grid and each of the discrete points (interest points and monitoring points) and the actual elevation data of various pollution sources.

TABLE II: COORDINATES OF DISCRETE MONITORING POINTS (M)

No.	monitoring points	Coordinates (x,y,z)
1	Lantian Hotel	(2118.87, 10826.89, 20)
2	Huxia Technical School	(1426.86, 712.73, 15)
3	City Environmental Monitoring	(−4951.73, 9793.43, 60)
4	Zhang Village Government	(−6951.63, 8452.10, 28)
5	Woodworking Factory	(−180.05, −12225.83,
6	Gao District Bank	(−5971.20, 11706.29, 6)

There are six air quality monitoring sites in Weihai: the Lantian Hotel, the Huaxia Technical School, the City Environmental Monitoring Station, the Zhang village government building, a woodworking factory and the Gao District Bank. The coordinates and location map of the six discrete points are shown in Table II and Fig. 1.

C. AERMOD Inputting Pollution Sources

For the values of the parameters for pollutant sources, we used the emissions intensity of enterprises, which we

obtained from the website of the Shandong Provincial Department of Environmental Protection. Emission rates of pollutants were calculated by using the average concentration values of SO_2 and NO_X released from each business during March and April 2014. The basic situation for each source of pollution is shown in Table III.

Fig. 1. location map of discrete points.

D. Checking and Analyzing Results

The Aermod System inputs the predicted concentrations of SO_2 and NO_X at the six discrete points affected by the key polluters, including a 1h average concentration and a 24h average concentration. Using the real-time monitoring data of SO_2 and NO_X at the six discrete points, obtained from Shandong Provincial Department of Environmental Protection, the rate of the contribution to SO_2 pollution of key polluters in Weihai and the concentration of NOx at discrete points were calculated from two aspects of the 1h average concentration and the 24h average concentration. Then, we determined which enterprises contributed to air pollution at the highest rate.

III. RESULTS AND DISCUSSION

A. Analysis of the Rates of Contribution to SO_2 of Key Polluters

The city's SO_2 pollution is part of the overall regional environmental problem. It is mainly caused by the residents' lifestyle, heating and industrial production processes [9], [10]. SO_2 is a pollution mainly resulting from burning coal [11], having harmful effects on the human body. The toxicity of SO_2 in the air mainly is manifested as acute and chronic poisoning caused by contact [12]. When concentrations of SO_2 and soot in the atmosphere are larger, the incidence of respiratory diseases can increase, and the condition of patients with chronic diseases can worsen [13]. After the SO_2 in atmosphere is oxidized to sulphuric acid mist, it can enter directly into the alveoli with the fly ash [14]. Additionally, the SO_2 emitted into the atmosphere will eventually be oxidized to form acid rain. The leading position of coal in China's energy production and consumption structure will not change for a long time [15], so SO_2 will be an important index indicating the long-term effects on China's air quality.

TABLE III: EMISSION SITUATION OF MAJOR INDUSTRIAL POLLUTION SOURCES IN HUANCUI DISTRICT OF WEIHAI CITY

| No.	Names	Coordinates of the basement of the exhaust pipes			Emission rates (g/s)	
		Xs[m]	Ys[m]	Zs[m]	SO_2	NO_X
1	Xinli Thermal Power Plant	2306.17	2834.24	16.99	1.26921056	7.78226472
2	Botong Thermal Power Plant	3687.66	−2744.94	19.71	6.877255	22.2692067
3	Xijiao Thermal Power Plant	−5036.42	9505.76	14.74	1.90187611	2.27297389
4	Weihai Thermal Power Plant	1112.33	7944.77	5.29	8.85354806	39.7489086
5	Blue Star Glass	53.33	−11283.18	68.81	2.51821139	20.4020783
6	Huaneng Weihai Power Plant	7625.57	2009.74	29.82	64.247035	239.065896

TABLE IV: 1 H AND 24 H AVERAGE CONCENTRATION OF SO_2 IN EACH DISCRETE POINT

No.	Discrete points	Average time (1 h)			Average time (24 h)		
		Predicted values [mg/m³]	Standard values [mg/m³]	The ratio of the predicted concentration to standard concentration [%]	Predicted values [mg/m3]	Standard values [mg/m3]	The ratio of the predicted concentration to standard concentration [%]
1	Lantian Hotel	0.00096	0.5	0.19168	0.00005	0.15	0.03549
2	Huaxia Technical School	0.00427	0.5	0.85342	0.00024	0.15	0.15804
3	City Environmental Monitoring Station	0.00069	0.5	0.13866	0.00004	0.15	0.02568
4	Zhang Village Government	0.00046	0.5	0.09167	0.00003	0.15	0.01698
5	Woodworking Factory	0.00089	0.5	0.17749	0.00005	0.15	0.03287
6	Gao District Bank	0.00074	0.5	0.14759	0.00004	0.15	0.02733

TABLE V: THE CONTRIBUTION RATE OF KEY POLLUTERS IN WEIHAI TO THE CONCENTRATIONS OF SO_2 IN EACH DISCRETE POINT (1H AND 24H AVERAGE CONCENTRATION)

No.	Discrete points	Average time (1 h)			Average time (24 h)		
		Predicted values [mg/m³]	Monitoring values [mg/m³]	Contribution rate (%)	Predicted values [mg/m³]	Monitoring values [mg/m³]	Contribution rate (%)
1	Lantian Hotel	0.00096	0.01655	5.80	0.00005	0.0165	0.30
2	Huaxia Technical School	0.00427	0.01305	32.72	0.00024	0.01395	1.72
3	City Environmental Monitoring Station	0.00069	0.01645	4.19	0.00004	0.015	0.27
4	Zhang Village Government	0.00046	0.01155	3.98	0.00003	0.0125	0.24
5	Woodworking Factory	0.00089	0.02635	3.38	0.00005	0.0282	0.18
6	Gao District Bank	0.00074	0.01945	3.80	0.00004	0.019	0.21

Fig. 2 shows the Aermod System's predictions of the SO_2 pollution levels of the Huancui district of the city of Weihai caused by key polluters. The predicted concentrations of SO_2 at six discrete points are shown in Table IV. It can be seen that the concentrations of SO_2 caused by the key polluters were far below the standard values.
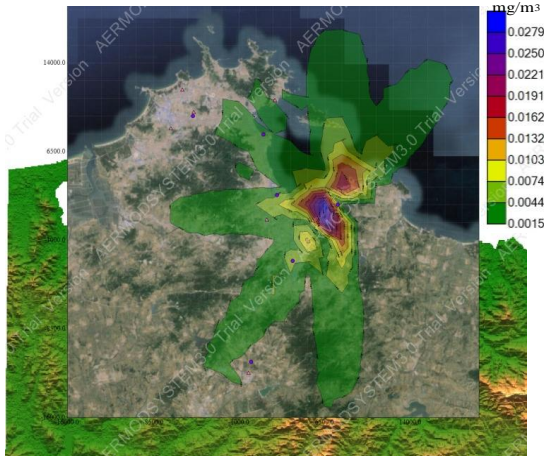
Fig. 2. The effect of SO_2 emitted from key polluters in Weihai.

The real-time monitoring data of SO_2 at the six discrete points was obtained from the Shandong Provincial Department of Environmental Protection. We evaluated the rate that key polluters in Weihai contributed to the concentrations of SO_2 at the six discrete points from two aspects: a 1h average concentration and a 24h average concentration. Table V shows the results.

As seen in Table V, when the 1-h average concentration of SO_2 is the largest, the contribution rates of key polluters in Weihai, ordered from highest to lowest, is as follows: 32.72% at the Huaxia Technical School, 5.80% at the Lantian Hotel, 4.19% at the City Environmental Monitoring Station, 3.98% at the Zhang village government building, 3.80% at the Gao District Bank and 3.38% at the woodworking factory. The rate at which the key polluters contributed to SO_2 concentration at the Huaxia Technical School was higher, while the rates at the remaining five monitoring points were lower. The reason might be that the key enterprise, Huaneng Weihai, has a large amount and a high concentration of emissions; also, the Huaxia Technical School is the nearest of all the discrete point to Huaneng Weihai.

When referring to 24h average concentrations, as shown in

Table V, the rates that key polluters contribute to the pollution at the Lantian Hotel, the Huaxia Technical School, the City Environmental Monitoring Station, the Zhang village government building, the woodworking factory and the Gao District Bank were respectively 0.30%, 1.72%, 0.27%, 0.24%, 0.18% and 0.21%. The rate that the key polluters in Weihai contribute to the SO_2 concentration of the Huaxia technical school zone is still higher than the contribution rates at the other five monitoring points.

B. Analysis of the Rates of Contribution to NO_X of Key Polluters

NO_X comprises NO, NO_2, N_2O_5, N_2O_3, NO_3, N_2O_4 and similar compounds. The atmospheric pollutants are mainly NO and NO_2 [16]. The percentage of NO_X from fuel combustion is the largest, accounting for more than 30%, 70% of which comes from the direct combustion of coal. Stationary sources are the main source of NO_X emissions, and the rest is mainly from motor vehicles [17]. The affinity of NO to haemoglobin is very strong. Inhalation of high concentration of NO_2 could lead to acute bronchospasm, late-onset pulmonary edema and late bronchiolitis obliterans [18]. Besides, NO_X can result in the formation of photochemical smog. High temperature combustion-generated NO can form acid rain. N_2O can be converted to NO, destroying the ozone layer [19]. NO_X is an important root of a series of atmospheric environmental issues in China [20]. The percentage of NO_x in the air is an important indicator when monitoring ambient air quality [21].

Fig. 3 shows the Aermod System's predicted result of NO_X pollution of the Huancui district of Weihai caused by key polluters. The predicted concentrations of NO_X at six discrete points are shown in Table VI. The concentrations of NO_X caused by the key polluters were far below the standard values (Table VI).
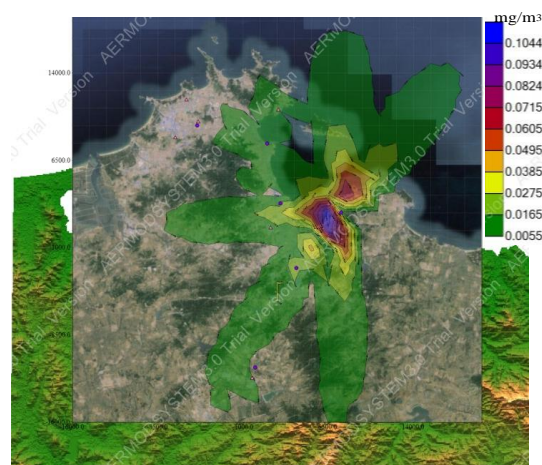

Fig. 3. The effect of NO_X emitted from key polluters in Weihai.

The real-time monitoring data of NO_X at the six discrete points were obtained from the Shandong Provincial Department of Environmental Protection. We evaluated the contribution rate of key polluters in Weihai to the concentrations of NO_X at the six discrete points from two aspects: a 1h average concentration and a 24h average concentration. Table VII shows the results.

TABLE VI: 1-H AND 24-H AVERAGE CONCENTRATION OF NO_X IN EACH DISCRETE POINT

No.	Discrete points	Average time (1 h)			Average time (24 h)		
		Predicted values [mg/m³]	Standard values [mg/m³]	The ratio of the predicted concentration to standard concentration [%]	Predicted values [mg/m³]	Standard values [mg/m³]	The ratio of the predicted concentration to standard concentration [%]
1	Lantian Hotel	0.00451	0.25	1.80237	0.00025	0.1	0.25033
2	Huaxia Technical School	0.0164	0.25	6.56087	0.00091	0.1	0.91123
3	City Environmental Monitoring Station	0.00282	0.25	1.12668	0.00016	0.1	0.15648
4	Zhang Village Government	0.00204	0.25	0.81729	0.00011	0.1	0.11351
5	Woodworking Factory	0.00694	0.25	2.77745	0.00039	0.1	0.38576
6	Gao District Bank	0.00306	0.25	1.22216	0.00017	0.1	0.16975

TABLE VII: THE CONTRIBUTION RATE OF KEY POLLUTERS IN WEIHAI TO THE CONCENTRATIONS OF NO_X IN EACH DISCRETE POINT (1H AND 24H AVERAGE CONCENTRATION)

No.	Discrete points	Average time (1 h)			Average time (24 h)		
		Predicted values [mg/m³]	Monitoring values [mg/m³]	Contribution rate (%)	Predicted values [mg/m³]	Monitoring values [mg/m³]	Contribution rate (%)
1	Lantian Hotel	0.00451	0.0282	15.99	0.00025	0.02275	1.10
2	Huaxia Technical School	0.0164	0.02015	81.39	0.00091	0.0137	6.64
3	City Environmental Monitoring Station	0.00282	0.04045	6.97	0.00016	0.02615	0.61
4	Zhang Village Government	0.00204	0.018	11.33	0.00011	0.0165	0.67
5	Woodworking Factory	0.00694	0.01955	35.50	0.00039	0.0191	2.04
6	Gao District Bank	0.00306	0.01545	19.81	0.00017	0.01535	0.11

As shown in Table VII, when the 1-h average concentration of NO_X is the largest, the contribution rates of key polluters in Weihai, ordered from the highest to lowest, is as follows: 81.39% at the Huaxia Technical School, 35.50% at the woodworking factory, 19.81% at the Gao District Bank, 15.99% at the Lantian Hotel, 11.33% at the Zhang village government building and 6.97% at the City Environmental Monitoring Station. The rate at which the key polluters in Weihai contributed to the NO_X concentration at Huaxia Technical School zone was higher, while the rates at the remaining five monitoring points were lower. The reason might be that the key enterprise, Huaneng Weihai, has a large amount and a high concentration of emissions; also, the Huaxia Technical School is the nearest of all the discrete points to Huaneng Weihai.

When referring to 24h average concentrations, as shown in Table VII, the rates that key polluters contribute to the pollution at the Lantian Hotel, the Huaxia Technical school, the City Environmental Monitoring Station, the Zhang village government building, the woodworking factory and the Gao District Bank were respectively 1.10%, 6.64%, 0.61%, 0.67%, 2.04% and 0.11%. The rate that key polluters in Weihai contribute to NO_X concentration at the Huaxia technical school zone is still higher than the contribution rates at the other five monitoring points.

In terms of the contribution rate of key polluters in Weihai to pollutants concentrations at each monitoring point, NO_X is significantly higher than SO_2. This might be because the proportion of nitrogen oxide emissions in total emissions of the key polluters in Weihai city is much higher than their emissions of sulphur dioxide. In addition, we find that, when comparing the one-hour average concentrations with the conditions during the 24-hour average concentrations, the contribution rate is more stable and reliable.

IV. CONCLUSION

In this research, by using the atmospheric environmental impact assessment system Aermod System, with air-quality monitoring data, meteorological data, high-altitude sounding data and the emissions intensity of key polluters, we investigated on the contribution rates of key polluters to air pollution in the city of Weihai, China. The results show that the rates that key polluters in Weihai contribute to SO_2 and NO_X concentrations at the Huaxia Technical School zone are higher, respectively, 32.72% and 81.39%, than the rates found at other monitoring sites. The rate of contribution was as follows: Contributions to SO_2 levels were 5.80% at the Lantian Hotel, 4.19% at the City Environmental Monitoring Station, 3.98% at the Zhang village government building, 3.80% at the Gao District Bank and 3.38% at the woodworking factory. Contributions to NO_X were 35.50% at the woodworking factory, 19.81% at the Gao District Bank, 15.99 % at the Lantian Hotel, 11.33% at the Zhang village government building and 6.97% at the Environmental Monitoring Station of the City.

This study provides reference and support to the relevant government departments when planning air pollution reduction programs and developing other environmental protection policies. The simulation method used in this study could also provide helpful ideas for determining contribution rates of pollutants in other regions by using existing official monitoring statistics.

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