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THE INFLUENCES OF SOURCE INTENSITY AND METEOROLOGICAL FACTORS ON SULFUR DIOXIDE AND NITROGEN OXIDES BASED ON THE PATH ANALYSIS MODEL

With rapid economic development and industrialization, air pollution is becoming a critical global issue affecting health. Sulfur dioxide and nitrogen oxides are the major contributors to acid rain and the key indicators for evaluating atmospheric pollution. And source intensity and meteorological factors are the main ways to influence the concentrations of sulfur dioxide and nitrogen oxides. Thus, to investigate the specific effects of source intensity, temperature, humidity, wind speed and atmospheric pressure on SO_2 and NO_x, the path analysis method was used for the model. The results showed that Source intensity significantly affects the concentrations of SO_2 and NO_2. For both NO_2 and SO_2, the source intensity accounted for around 40%. Meteorological factors have very limited effects on the concentrations of SO_2 and NO_2. The effects of the meteorological factors on air pollutants are specific as differences in material properties. Humidity significantly affects the concentration of SO_2 while temperature, humidity and wind speed have significantly affected the concentration of NO_2.

1. INTRODUCTION

Following the development of the economy and technology, air pollution is becoming a critical issue, especially in developing countries [1–3]. Air quality is relevant to everyone's life [1] and air pollution adversely affects health significantly [2]. The World Health Organization showed that millions of deaths were attributable to air pollution, globally [3, 4]. In China, air pollution caused between 35 000 and 500 000 people to die prematurely [3, 5] and it became the fourth threat to people's health in China [6]. Unprecedented industrialization, motorization, and economic activity not only deteriorate

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the air quality, but also makes air pollution complicated, consisting of particulate matter, ozone (O_3), sulfur dioxide (SO_2), and nitrogen oxides (NO_x) [7, 8].

Currently, the contribution of NO_x and SO_2 to air pollution is nonnegligible. SO_2 is usually released by volcanic eruptions or fossil fuels with sulfur combustion; it is often used as an indicator to measure atmospheric pollution [9]. Due to photochemical and catalytic reactions in the atmosphere, SO_2 often converts to SO_3 or sulfuric acid (H_2SO_4) aerosols, and its salt particles [10], which would cause haze events and harm public health. While nitrogen oxides in air pollution mainly include nitric oxide (NO) and nitrogen dioxide (NO_2), which derive from fossil fuel combustion such as car driving and kiln firing [11]. Under light conditions, the photochemical reaction between NO_2 and volatile organic compounds (VOCs) produces O_3, thus, NO_2 has a very short life in the atmosphere [11, 12]. The generated O_3 and NO_x with strong oxidizing could have a serious impact on public health.

High emission intensity, unfavorable meteorological conditions, special terrain, and chemical conversion would result in air pollution [13]. Emission intensity determines the released concentration of pollutants, while meteorological conditions have limited influence [14]. Of all meteorological factors, wind direction and wind speed are the key factors to influence all pollutants by atmosphere turbulence [15]. The effects of other meteorological factors on pollutants would be specific and seasonal [16]. The research [9] showed that high SO_2 days are associated with stagnant warmed moist air masses. For SO_2, Xue's study [10] found that SO_2 were negatively correlated with temperature, humidity, and wind speed and positively correlated with air pressure. Moreover, humidity has the dominant effect on the concentration of SO_2 in meteorological factors [17]. While several meteorological factors have significant effects on the concentration of NO_2 [11].

Polluted weather could occur for many factors. Moreover, different types of air pollution vary from place to place, with human pollutant emissions and the meteorological factor being the main factors [18]. The path analysis model is used to investigate the effects of source intensity and meteorological conditions on SO_2 and NO_2 concentrations. The rest of the article is organized as follows. Section 2 introduces the path analysis model and the data. Section 3 shows the results of the path analysis model, which finds the effects of source intensity and meteorological conditions on SO_2 and NO_2 concentrations. In Section 4, we discuss the results of the path analysis model combined with other studies. Section 5 drew conclusions.

2. DATA AND METHODS

Data overview. All the data were collected from national atmospheric monitoring stations. Pollutants included SO_2 and NO_2 as dependent variables. The concentration of SO_2 varied from 0 to 47 $\mu g/m^3$. The maximum value was measured at 11:00 on 14 April

2020. The concentration of NO_2 varied from 2 to 211 μg/m^3. The maximum value was measured at 10:00 on 16 January 2021. The total number of samples was 19 342.

The hourly meteorological data from 1:00 on 16 April 2019 to 23:00 on 30 June 2021 includes temperature (*T*), humidity (*H*), wind speed (*WS*) and atmospheric pressure (*AP*). According to the literature [17, 19, 20], these four meteorological indicators are representative. The study site has a mild climate with temperatures varying from 5 to 38 °C, humidity from 14 to 99% *RH*, atmospheric pressure from 993.5 to 1029.2 hPa and wind speed from 0.1 to 5.8 m/s.

To investigate the effects of source intensity (*S*) on pollutant concentrations, each source intensity data was approximated by the pollutant concentrations from 24 hours ago. This is due to the continuous and periodic nature of pollutant emissions [21].

Path analysis. The path analysis model is a multivariate statistical analysis method, usually employed to describe linear relationships between multiple independent variables and dependent variables. The path analysis model only has observable variables and residual variables, which is a special form of the structural equation model [22]. In the path analysis method, the influence of the independent variable on the dependent variable was decomposed into direct and indirect parts [23]. Moreover, the relative importance of independent variables could be found. In the present study, the path analysis model was applied to calculate the direct and indirect effects of meteorological factors and source intensity on air pollutants. The path analysis model is shown in Fig. 1.

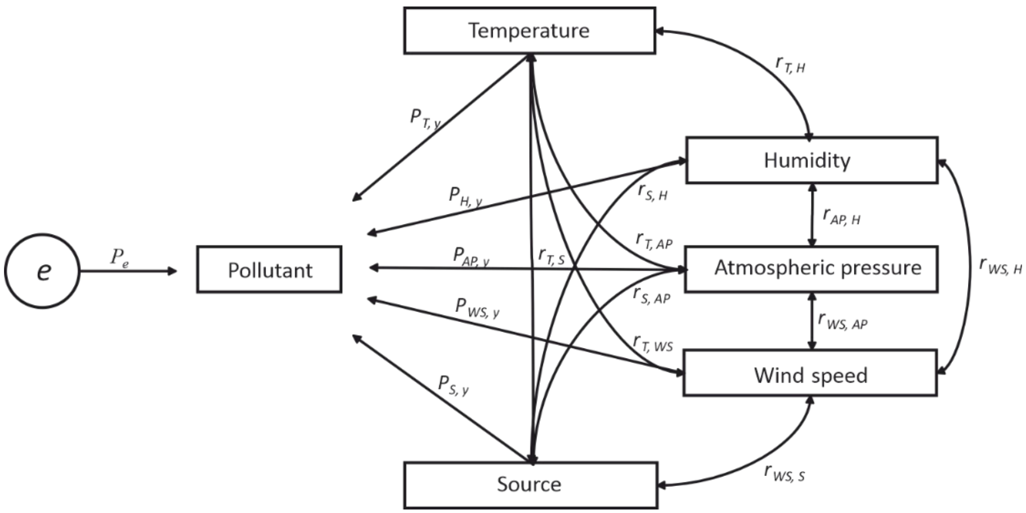

Fig. 1. Schematic representation of path diagram

In Figure 1, pollutant (*y*) is the dependent variable including the concentration of pollution, while *T*, *H*, *AP*, *WS*, and *S* are independent variables (*x*). *e* is the residual variable. $P_{x,y}$ indicates the direct path coefficient between the ith independent variable and dependent variable. $r_{xi,xk}$ indicates correlation coefficients between independent variables. x_i and x_k include independent variables. One-way arrow (→) shows a causal relationship between pollutant and independent variables and errors. For example, T→ pollutant shows the direct effect from T to pollution. The two-way arrow shows the correlations between the independent variables. For instance, T←→H shows the correlation between T and H denoted by $r_{T,H}$.

According to the theory of path analysis model [23–26], the influence of independent variable on the dependent variable included direct part and indirect part. $P_{x,y}$ was direct part and $\sum_{i \neq j} r_{i,j} P_{j,y}$ was the indirect part. The path coefficients were calculated by:

$$\begin{bmatrix} 1 & r_{T,H} & r_{T,AP} & r_{T,WS} & r_{T,S} \\ r_{T,H} & 1 & r_{H,AP} & r_{H,WS} & r_{H,S} \\ r_{T,AP} & r_{H,AP} & 1 & r_{WS,AP} & r_{AP,S} \\ r_{T,WS} & r_{H,WS} & r_{WS,AP} & 1 & r_{WS,S} \\ r_{T,S} & r_{H,S} & r_{AP,S} & r_{WS,S} & 1 \end{bmatrix} \begin{bmatrix} P_{T,y} \\ P_{H,y} \\ P_{AP,y} \\ P_{WS,y} \\ P_{S,y} \end{bmatrix} = \begin{bmatrix} r_{T,y} \\ r_{H,y} \\ r_{AP,y} \\ r_{WS,y} \\ r_{S,y} \end{bmatrix} \tag{1}$$

The path coefficient of the error term could be obtained from [25]:

$$P_e = \sqrt{1 - \sum_{j=1}^{5} r_{j,y} P_{j,y}} \tag{2}$$

where P_e shows a causal relationship between pollutant and errors.

Coefficient of determination. The coefficient of determination D_i from ith independent variable to the dependent variable reflects the importance of the independent variable in determining the dependent variable:

$$D_i = P_{i,y}^2 + 2\sum_{i \neq j} P_{i,y} r_{i,j} P_{j,y} \tag{3}$$

It contains the direct $P_{i,y}^2$ and indirect $2\sum_{i \neq j} P_{i,y} r_{i,j} P_{j,y}$ parts. As the determined coefficient of the indirect path is uncertain, D_i would be negative. When D_i is greater than zero, it means that x_i has a facilitating effect on y. When D_i is lower than zero, it means that x_i has a limiting effect on y.

Test of the path coefficient. For testing the significance of the path coefficients, an F-test was applied

$$F = \frac{\dfrac{P_i^2}{C'_{ii}}}{\dfrac{SSE}{n-m-1}} \sim F(n-m-1) \tag{4}$$

$$SSR = \sum_{i=1}^{5} P_{i,y} r_i \tag{5}$$

where C'_{ii} is the diagonal element of the inverted matrix of the correlation coefficients among independent variables. *SSE* and *SSR* are the sums of residual squares and the sum of regression squares, n is the number of samples equal to 19 342, and m is the number of independent variables equal to 5.

3. RESULTS

3.1. CORRELATION BETWEEN VARIABLES

The correlation coefficients among variables are shown in Table 1. The correlations between *WS* and *AP*, *S* were not significant. That between NO_2 and *H* was significant at the level of 80%. Most of the correlation coefficients among variables were significant at the confidence level of 99%. The absolute value of the correlation coefficients among independent variables ranged from 0.031 to 0.823. The correlation coefficients between SO_2 concentration and *T*, *H*, *AP*, *WS*, and *S* were –0.141, –0.450, 0.296, –0.0987, and 0.632, respectively. Those between NO_2 concentration and *T*, *H*, *AP*, *WS*, and S were –0.353, –0.046, 0.306, –0.466, and 0.588, respectively.

Table 1

Pearson correlation coefficients (r) among variables

Variable	*T*	*H*	*AP*	*WS*	*S*(SO_2)	*S*(NO_2)	SO_2	NO_2
T	1.000	0.122*	–0.823*	0.084*	–0.151*	–0.318*	–0.141*	–0.353*
H		1.000	–0.399*	–0.266*	–0.355*	–0.032	–0.450*	–0.046
AP			1.000	–0.031	0.277*	0.295*	0.296*	0.306*
WS				1.000	–0.040	–0.257*	–0.097*	–0.466*
S(SO_2)					1.000	-	0.632*	–
S(NO_2)						1.000	–	0.588*
SO_2							1.000	–
NO_2								1.000

Asterisks (*) indicate statistical significance at 0.01 level. The number of samples is 19 342.

3.2. PATH MODEL: SO_2 CONCENTRATION AS A DEPENDENT VARIABLE

Figure 2 shows the results of the path analysis between SO_2 concentration and five independent variables. The total path coefficients of *T*, *H*, *AP*, *WS* and *S* for SO_2 were –0.1406, –0.4495, 0.2963, –0.0968 and –0.6324, respectively. All the direct effects coefficients are significant at a confidence level of 99%. The direct effect coefficients of *T*, *H*, *AP*, *WS*, and *S* were 0.0423, –0.2860, 0.0704, –0.1536, and 0.5117, respectively. The total indirect effect coefficients of *T*, *H*, *AP*, *WS*, and *S* were –0.1829, –0.1635, 0.2258, 0.0569, and 0.1208, respectively.

For independent variable *T*, the indirect path coefficients of $T \to H \to SO_2$, $T \to AP \to SO_2$, $T \to WS \to SO_2$ and $T \to S \to SO_2$ were –0.0349, –0.0579, –0.0130, –0.0771, respectively. *T* makes a negative contribution to SO_2 through the indirect path.

For independent variables *H*, the effects of path $H \to T \to SO_2$ and $H \to WS \to SO_2$ were positive, with path coefficients 0.0052 and 0.0409, respectively. While the effects of paths $H \to AP \to SO_2$ and $H \to S \to SO_2$ were negative, with path coefficients –0.0281 and –0.1814, respectively.

The independent variables *AP* and *S* had similar trends. For example, the effects of paths *AP* or $S \to T \to SO_2$ were negative, with path coefficients –0.0349 and –0.0063, respectively. While the effects of the other paths were positive. The indirect path coefficients of path $AP \to H \to SO_2$, $AP \to WS \to SO_2$ and $AP \to S \to SO_2$ were 0.1142, 0.0048, and 0.1417, respectively. The indirect path coefficients of path $S \to T \to SO_2$, $S \to H \to SO_2$ and $S \to AP \to SO_2$ were 0.1014, 0.0195, and 0.0062, respectively.

For the independent variable *WS*, the effects of path $WS \to T \to SO_2$ and $H \to WS \to SO_2$ were positive, with path coefficients 0.0035 and 0.0761, respectively. While the effects of path $WS \to AP \to SO_2$ and $WS \to S \to SO_2$ were negative, with path coefficients –0.0022 and –0.0206, respectively.

3.3. PATH MODEL: NO_2 CONCENTRATION AS A DEPENDENT VARIABLE

The results of the path analysis between NO_2 concentration and five independent variables was shown in Fig. 3. The total path coefficients of *T*, *H*, *AP*, *WS* and *S* for NO_2 were –0.3534, –0.0456, 0.3062, –0.4660 and 0.5880, respectively. At the confidence level of 99%, all the direct effects coefficients were significant. The direct path coefficients of *T, H, AP, WS* and *S* for NO_2 were –0.2305, –0.1332, –0.0774, –0.3722 and 0.4378, respectively. The indirect path coefficients of *T*, *H*, *AP, WS* and S for NO_2 were –0.1229, –0.0876, 0.3836, –0.0939 and 0.1502, respectively.

For the independent variable *T*, the indirect path coefficients of $T \to H \to NO_2$, $T \to AP \to NO_2$, $T \to WS \to NO_2$ and $T \to S \to NO_2$ were –0.0163, 0.0637, –0.0313, –0.1391, respectively. *T* made a negative contribution to NO_2 through the indirect path.

The independent variables *H* and *WS* had similar trends. E.g., the effects of paths *H or* $WS \to T \to NO_2$ were negative, with path coefficients –0.0282 and –0.0194, respect-

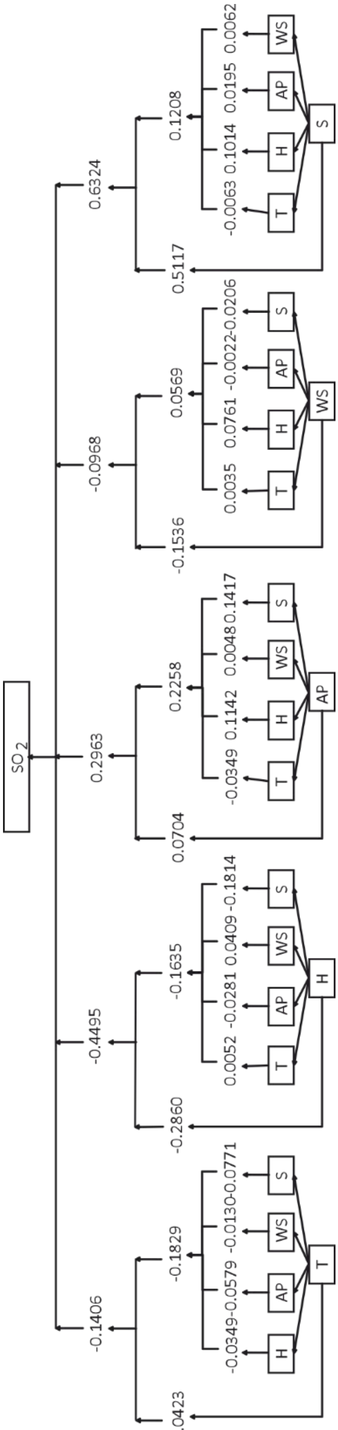

Fig. 2. The results of path analysis between SO_2 concentration, *T*, *H*, *AP*, *WS* and *S*

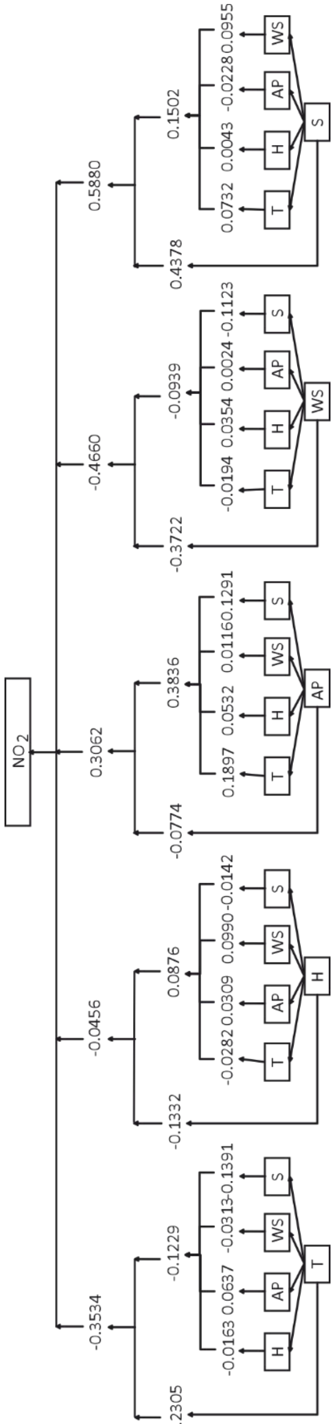

Fig. 3. The results of path analysis between NO_2 concentration, *T*, *H*, *AP*, *WS* and *S*

tively. And the effects of paths *H* or *WS*→*S*→NO_2 were negative, with path coefficients –0.0142 and –0.1123, respectively. While the effects of the other paths were positive. The indirect path coefficients of path *H*→*AP*→NO_2 and *H*→*WS*→NO_2 were 0.0309 and 0.0024, respectively. The indirect path coefficients of path *WS*→*H*→NO_2 and *WS*→*AP*→NO_2 were 0.0354 and 0.0024, respectively.

By contrast, the independent variable *AP* had positive effects on NO_2 through an indirect path. Especially all the indirect path coefficients were positive. The effect of path coefficients of *AP*→*T*→NO_2, *AP*→*H*→NO_2, *AP*→*WS*→NO_2 and *AP*→*S*→NO_2 were 0.1897, 0.0532, 0.0116 and 0.1291, respectively. Similarly, *S* made a positive contribution to NO_2 through an indirect path. The effect of path coefficients of *S*→*T*→NO_2, *S*→*H*→NO_2, *S*→*AP*→NO_2 and *S*→*WS*→NO_2 were 0.0732, 0.0043, –0.0228 and 0.0955, respectively.

3.4. COEFFICIENT OF DETERMINATION

3.4.1. COEFFICIENT OF DETERMINATION FOR SO_2

Five independent factors could explain about 58.99% variance of SO_2 concentration. The total determination coefficients [27] of *T, H*, *AP*, *WS*, *S* and error term were –1.37, 17.53, 3.68, 0.61, 38.54 and 41.01%, respectively [26]. The source intensity could explain about 38.54% variance of SO_2 concentration. All meteorological factors (*T*, *H*, *AP* and *WS*) could explain about 20.45% variance of SO_2 concentration. Thus, except for other unknown factors, the source intensity was the most dominant factor in SO_2.

Table 2

Direct, indirect and total coefficients of determination for SO_2 [%]

Variable	→*y*	→*T*	→*H*	→*AP*	→*WS*	→*S*	Indirect	Total	*e*
T	0.18	–	–0.30	–0.49	–0.11	–0.65	–1.55	–1.37	
H	8.18	–0.3	–	1.61	–2.34	10.38	9.35	17.53	
AP	0.50	–0.49	1.61	–	0.07	2.00	3.18	3.68	
WS	2.36	–0.11	–2.34	0.07	–	0.63	–1.75	0.61	
S	26.18	–0.65	10.38	2	0.63	–	12.36	38.54	
e									41.01

The determination coefficients of the direct effect of *T*, *H*, *AP*, *WS*, and *S* were 0.18, 8.18, 0.50, 2.36, and 26.18%, respectively. The determination coefficients of the indirect effect of *T* and *WS* were negative, with corresponding determination coefficients –1.55 and –1.75%. While those of *H*, *AP*, and *S* were positive, with corresponding determination coefficients of 9.35, 3.17, and 12.36%, respectively.

Based on the path analysis model, the pollutant source which could explain the 38.54% variance of SO_2 was the determining factor. The meteorological factors which could explain about 20% variance of SO_2 concentration, played an important role in the concentration of SO_2. The error term would explain about 40% variance of SO_2, which indicated that there are some indispensable factors to influence the concentration of SO_2.

3.4.2. COEFFICIENT OF DETERMINATION FOR NO_2 CONCENTRATION

The coefficients of determination for NO_2 concentration were shown in Table 3. The total coefficients of determination of *T*, *H*, *AP*, *WS*, *S* and error term were 10.98, –0.56, –5.34, 20.84, 32.32 and 41.76%, respectively [26]. The source intensity could explain about 32.32% variance of NO_2 concentration. All meteorological factors (*T*, *H*, *AP* and *WS*) could explain about 25.92% variance of NO_2 concentration. Similarly, the source intensity was the most dominant factor in NO_2.

Table 3

Direct, indirect and total coefficients of determination for NO_2 [%]

Variables	→*y*	→*T*	→*H*	→*AP*	→*WS*	→*S*	Indirect	Total	*e*
T	5.31		0.75	–2.94	1.44	6.41	5.66	10.98	
H	1.77	0.75		–0.82	–2.64	0.38	–2.33	–0.56	
AP	0.60	–2.94	–0.82		–0.18	–2.00	–5.94	–5.34	
WS	13.85	1.44	–2.64	–0.18		8.36	6.98	20.84	
S	19.17	6.41	0.38	–2.00	8.36		13.15	32.32	
e									41.76

The determination coefficients of the direct effect of *T*, *H*, *AP*, *WS*, and *S* were 5.31, 1.77, 0.60, 13.85, and 19.17%, respectively. The determination coefficients of the indirect effect of *H* and *AP* were negative, with corresponding determination coefficients of –2.33 and –5.94%. While those of *T*, *WS* and *S* were positive, with corresponding determination coefficients of 5.31, 13.85 and 19.17%.

Similarly, the pollutant sources which could explain the 32.32% variance of NO_2, were the determinate factor. The meteorological factors which could explain about 25% variance of NO_2, significantly affected the concentration of NO_2. The error term would explain about 40% variance of NO_2, which showed that there are some indispensable factors to influence the concentration of NO_2.

4. DISCUSSION

4.1. INFLUENTIAL FACTORS OF THE CONCENTRATION OF SO_2

Four meteorological factors and source intensity were considered independent variables in path analysis models. The total path coefficients of the five independent factors for SO_2 were –0.1406, –0.4495, 0.2963, –0.0968, and 0.6324, respectively. This means that the effects of *T*, *H* and *WS* on the concentration of SO_2 were negative, while those of *AP* and *S* were positive. Further, the direct effect coefficients of *T*, *H*, *AP*, *WS*, and *S* were 0.0423, –0.2860, 0.0704, –0.1536, and 0.5117, respectively. Ranking of the direct effect coefficients was $P_{S,y} > P_{AP,y} > P_{T,y} > 0 > P_{WS,y} > P_{H,y}$. The determination coefficient of *T*, *H*, *AP*, *WS*, and *S* for SO_2 were –1.37, 17.53, 3.68, 0.61 and 38.54%, respectively, and ranking the absolute determination coefficients was $D_{S,y} > D_{H,y} > D_{AP,y} > D_{T,y} > D_{WS,y}$.

This means that *S* and *H* play the most important roles to affect the concentration of SO_2. The effect of source intensity is positive and increase of the source intensity by one unit would lead to increasing concentration of SO_2 by 0.6324 units. Wang et al. [28] proved that the chemical industry and thermal power plants are the main contributor to SO_2 in atmosphere, and the most important means of reducing the occurrence of SO_2 pollution is to limit SO_2 emissions.

By contrast, the effect of *H* is negative, the concentration of SO_2 would decrease by 0.4495 units if *H* increases by one unit. For all the meteorological factors, humidity makes the greatest negative contribution to the concentration of SO_2. Some authors could explain these results, e.g., the aerosol water in high humidity conditions serves as a reactor [17]. Under good lighting conditions, photochemical reactions produce H_2O_2 and O_3 [29], which would react with SO_2 to form sulfate as follows:

$$\mathrm{HSO_3^- + H_2O_2 \rightarrow SO_4^{2-} + H^+ + H_2O}$$

$$\mathrm{SO_2 + O_3 + H_2O \rightarrow SO_4^{2-} + 2H^+ + H_2O}$$

Under low light conditions, gas-phase NO_2 could react with SO_2 dissolved directly in the aqueous phase and produce nitrite and sulfate in the presence of aerosol water [29]. The reaction equation is as follows:

$$\mathrm{SO_2(g) + 2NO_2(g) + 2H_2O(aq) \rightarrow 2H^+(aq) + SO_4^{2-}(aq) + 2HONO(g)}$$

Moreover, the mechanism of the reaction is self-amplifying. The reaction of NO_x and SO_2 would produce sulfate and nitrate, which could make particulate pollution worse and lower light levels. Thus, photochemical reaction is weakened, and more nitrogen oxides react with SO_2 [17, 29]. In high humidity atmosphere, SO_2 and nitrogen oxides convert from gas phase to particle phase, which would cause haze events [30].

For all independent variables, the effect of *WS* is least. Increase of *WS* by one unit would lead to a decrease of the concentration of SO_2 only by 9.68%. Further, the direct path coefficient of *WS* is negative while the indirect path coefficient of *WS* is positive. The higher *WS* would cause less stable atmosphere, and more pollutants are diffused by wind. Li et al. [31] found that the correlation between SO_2 concentration and *WS* is negative. While the concentration of SO_2 and humidity would be directly influenced by *WS*. Decrease in humidity would weaken the atmospheric sulfur chemistry.

Similarly, the direct and indirect effects of temperature on SO_2 concentration are opposite. The direct effect of temperature is positive and negligible, while the indirect effect is negative and dominant. The absolute determination coefficient of *T* for SO_2 was only 1.37%, which means that the effect would be negligible. According to the literature [17], an increase in *T* would strengthen atmospheric turbulence and convection. Especially, the concentration of SO_2 would significantly decrease when *T* is higher than 25 °C [31]. Summarily, on a sunny day, great temperature differences and strong vertical air convection could make the inversion layer disappear quickly, that would accelerate pollutants diffusing [18].

AP is the only meteorological factor that has a positive effect on SO_2 concentration The direct and indirect effects are all positive and the indirect path is the main pathway. The high *AP* take sunny and stables atmosphere conditions, without precipitation [10].

4.2. INFLUENTIAL FACTORS OF THE CONCENTRATION OF NO_2

NO_2 is an important substance in photochemical reactions. To investigate the main influencing factors and degree of influence of atmospheric NO_2, four meteorological factors, and source intensity were considered independent variables in path analysis models. The total path coefficients of the five independent factors for NO_2 were –3534, –0.0456, 0.3062, –0.4660 and 0.5880, respectively. It showed that the effects of *T*, *H* and *WS* on the concentration of NO_2 are negative, while that of *AP* and *S* is positive. Moreover, the direct effect coefficients of *T*, *H*, *AP*, *WS*, and *S* were –0.2305, –0.1332, –0.0774, –0.3722 and 0.4378, respectively. Ranking of the direct effect coefficients was $P_{S,y} > P_{AP,y} > 0 > P_{H,y} > P_{T,y} > P_{WS,y}$. The determination coefficient of *T*, *H*, *AP*, *WS*, and *S* for NO_2 were 10.98, –0.56, –5.34, 20.84 and 32.32%, respectively, and ranking the absolute determination coefficients was $D_{S,y} > D_{WS,y} > D_{T,y} > D_{AP,y} > D_{H,y}$.

Thus, the source intensity makes a great contribution to the concentration of NO_2. The determination coefficient of *S* is the largest among the five independent variables. Large amounts of NO_2 mainly come from the direct emission of NO_x and photochemical reactions [29], where the main source of NO_2 is the oxidation of NO.

$$NO + O_3 \rightarrow NO_2 + O_2$$

and NO reacts with oxidizing agents such as O_3 and oxidative free radicals to form NO_2

$$RH + HO^{\bullet} + O_2 + NO \rightarrow RO^{\bullet} + H_2O + NO_2$$

The $RO^{\bullet}$ radicals further react with oxygen

$$RO^{\bullet} + O_2 + NO \rightarrow R'CHO + HO_2^{\bullet} + NO_2$$

In photochemical reactions, NO_2 decomposes in two main pathways. On the one hand, NO_2 reacts with free radicals to form nitrate particles

$$NO_2 + HO^{\bullet} \rightarrow HNO_3$$

On the other hand, photolysis of NO_2 proceeds by absorption of light at wavelengths lower than 420 nm. The oxygen radicals generated react with oxygen to produce ozone. It seems to be the only known source of anthropogenic ozone in the atmosphere

$$NO_2 + h\nu \rightarrow NO + O^{\bullet}$$

$$O^{\bullet} + O_2 + M \rightarrow O_3 + M$$

During haze days, photochemical reactions would weaken while the stagnant weather would trap more NO_2 in the lower atmosphere causing NO_2 concentration to increase. On a sunny day, photochemical reactions would strengthen. However, NO_2 is an intermediate product of photochemical reactions, and when light is strong, large amounts of NO_2 are produced and consumed at the same time [17]. Overall, NO_2 is present in the air for a short time as an intermediate product in a series of reactions. Its concentration in air is still largely dependent on the source intensity.

Similarly, the total path coefficient is positive. However, the direct path coefficient is negative and negligible. *AP* mainly affects NO_2 concentrations by influencing other meteorological factors.

Results show that *WS* is negatively related to NO_2 concentration; moreover, *WS* has the most negative effects. The increase in wind speed can directly lead to a change in atmospheric stability and acceleration of inter-air movement resulting decrease of NO_2. Similarly, *T* is negatively related to NO_2 concentration, further, its impact is second only to that of *WS*. *T* affects pollutant concentrations mainly by influencing atmospheric turbulence and chemical reactions [13]. On the one hand, unstable atmospheric turbulence accelerates the dispersion of pollutants resulting in lower pollutant concentrations. High temperatures can supply energy for chemical reactions to some extent, but for NO_2 this effect is rather limited. This is because NO_2 undergoes a photochemical reaction, which occurs when irradiated by light in a specific wavelength band. This is also the reason why photochemical pollution is little affected by seasonal changes.

In contrast to SO_2, the effect of humidity on NO_2 concentration is negligible. NO_2 is mainly a photochemical reaction and does not require an aerosol water container, so it is not sensitive to changes in humidity.

4.3. THE INFLUENCE OF OTHER FACTORS ON POLLUTANTS

From the coefficient of determination results, five independent variables could explain about 60% variance of SO_2 and NO_2 concentrations. There should be more factors that were not considered such as topography [32], chemical reactions between atmospheric pollutants [33] and seasonal factors [34, 35].

According to the study [30], the spatial and temporal distribution and variation characteristics of major air pollutants in 336 prefecture-level cities across China from 2015 to 2016 were studied, and SO_2 and NO_2 concentrations were significantly correlated with regional rainfall and daytime temperature variations, in addition to the five factors studied in present study. Wu et al. [36] used meteorological factors regression and back propagation neural network modeling techniques to investigate the effect of meteorological factors on NO_2 and they found that cloudiness and light have a significant effect on NO_2 concentrations and there is a non-linear relationship between meteorological factors and NO_2 concentrations.

5. CONCLUSION

A path analysis model was applied to investigate the influence of the source intensity and meteorological factors on SO_2 and NO_2 concentrations. Conclusions could be summarized as follow:

- Source intensity plays a significant part in the effect of the concentrations of SO_2 and NO_2 in the atmosphere. For both variances of NO_2 and SO_2, the source intensity is explained by around 40%.
- Meteorological factors could have an impact on pollutant concentrations. However, the impact of the four meteorological factors is very limited.
- Because of the different migration and transformation pathways of pollutants in the atmosphere, the effects of the meteorological factors on air pollutants are specific. Humidity has the most significant effect on the concentration of SO_2 while temperature, humidity and wind speed significantly impact the concentration of NO_2.

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