Table. S1 The numbers of $PM_{2.5}$, PM_{10} and O_3 pollution days in different seasons

	Winter	Spring	Summer	Autumn
$PM_{2.5}$($\mu g/m^3$)	67	17	2	10
PM_{10}($\mu g/m^3$)	44	7	0	9
O_3 ($\mu g/m^3$)	0	7	33	3

The daily averaged concentrations value exceeding national air quality standards of China

Table S2 Results of T-test and F-test

	T-test		**F-test**		**Model Summary**		
Winter Model	**Non-standardized coefficient**	**T**	**F**	**Sig.**	**R**	**R^2**	**Estimated standard error**
Constant	1.204	3.029	295.93	P < 0.01	0.88	0.77	0.082
SO_4^{2-}	-0.003	-5.531					
NO_3^-	0.006	15.476					
K^+	0.023	4.297					
Mg^{2+}	0.328	3.134					
Ca^{2+}	-0.017	-1.578					
T	-0.004	-2.581					
RH	0.001	0.060					
Spring Model	**T-test**		**F-test**		**Model Summary**		
Constant	0.533	2.835	219.02	P < 0.01	0.83	0.69	0.044
SO_4^{2-}	0.006	12.774					
NO_3^-	0.005	15.513					
K^+	-0.018	-2.745					
Mg^{2+}	-0.065	-0.898					
Ca^{2+}	-0.017	-3.375					
T	-0.001	-2.018					
RH	-0.009	-0.581					
Summer Model	**T-test**		**F-test**		**Model Summary**		
Constant	-1.389	-9.369	339.18	P < 0.01	0.82	0.67	0.045
SO_4^{2-}	0.007	18.481					
NO_3^-	0.006	14.972					
K^+	0.010	0.864					
Mg^{2+}	0.021	1.794					
Ca^{2+}	-0.003	-1.281					
T	0.005	9.903					
RH	0.066	5.279					
Autumn Model	**T-test**		**F-test**		**Model Summary**		
Constant	0.656	4.944	537.31	P < 0.01	0.86	0.74	0.057
SO_4^{2-}	0.006	16.318					
NO_3^-	0.003	15.854					
K^+	-0.003	-0.637					
Mg^{2+}	-0.064	-4.426					
Ca^{2+}	-0.040	-12.934					
T	-0.001	-3.197					
RH	0.012	1.435					

Table S3 Pearson correlation among factors in each season

Winter	**NHR**	**SO_4^{2-}**	**NO_3^-**	**K^+**	**Mg^{2+}**	**Ca^{2+}**	**T**	**RH**
NHR	1							
SO_4^{2-}	0.803**	1						
NO_3^-	0.862**	0.959**	1					
K^+	0.754**	0.849**	0.822**	1				
Mg^{2+}	0.412**	0.316**	0.361**	0.477**	1			
Ca^{2+}	0.229**	0.147**	0.189**	0.360**	0.689**	1		
T	-0.142**	-0.097*	-0.099*	-0.090*	-0.047	0.046	1	
RH	0.339**	0.390**	0.367**	0.479**	0.018	-0.024	-0.224**	1
Spring	**NHR**	**SO_4^{2-}**	**NO_3^-**	**K^+**	**Mg^{2+}**	**Ca^{2+}**	**T**	**RH**
NHR	1							
SO_4^{2-}	0.701**	1						
NO_3^-	0.743**	0.674**	1					
K^+	0.261**	0.397**	0.489**	1				
Mg^{2+}	-0.273**	-0.032	-0.072	0.376**	1			
Ca^{2+}	-0.327**	-0.104**	-0.116**	0.306**	0.898**	1		
T	-0.041	0.129**	-0.051	-0.149**	0.076*	0.051	1	
RH	0.151**	0.024	0.101**	0.117**	-0.248**	-0.242**	-0.845**	1
Summer	**NHR**	**SO_4^{2-}**	**NO_3^-**	**K^+**	**Mg^{2+}**	**Ca^{2+}**	**T**	**RH**
NHR	1							
SO_4^{2-}	0.751**	1						
NO_3^-	0.677**	0.664**	1					
K^+	0.385**	0.544**	0.383**	1				
Mg^{2+}	0.245**	0.125**	0.174**	-0.053	1			
Ca^{2+}	-0.016	0.013	-0.093**	0.473**	0.006	1		
T	0.072*	-0.037	-0.294**	-0.112**	0.215**	0.170**	1	
RH	0.057	0.064*	0.352**	0.05	0.044	-0.167**	-0.840**	1
Autumn	**NHR**	**SO_4^{2-}**	**NO_3^-**	**K^+**	**Mg^{2+}**	**Ca^{2+}**	**T**	**RH**
NHR	1							
SO_4^{2-}	0.786**	1						
NO_3^-	0.779**	0.801**	1					
K^+	0.274**	0.329**	0.501**	1				
Mg^{2+}	-0.067*	0.084**	-0.159**	-0.399**	1			
Ca^{2+}	-0.236**	-0.084**	0.043	0.556**	-0.236**	1		
T	0.135**	0.290**	0.071**	-0.485**	0.420**	-0.300**	1	
RH	0.229**	0.211**	0.130**	-0.129**	0.300**	-0.283**	-0.103**	1

**. At the 0.01 level (two-tailed), the correlation is significant

*. At the 0.05 level (two-tailed), the correlation is significant

Table S4 Aerosol acidity in various parts of China

Sampling Site	Year	Season	pH	Reference
Qinglin	2021 - 2022	Winter	4.6 ± 1.2	Liu et al. (2025)
Xi’an	2017	Winter	5.0 ± 0.6	Wu et al. (2018)
		Summer	4.1 ± 1.2	
Beijing	2016 - 2017	Winter	4.5 ± 0.7	Ding et al. (2019)
		Spring	4.4 ± 1.2	
		Summer	3.8 ± 1.2	
		Autumn	4.3 ± 0.8	
	2015 - 2016	Winter	4.3 ± 0.3	Liu et al. (2017)
	2014	Winter	4.1 ± 1.4	Tan et al. (2018)
		Spring	2.1 ± 0.7	
		Summer	1.8 ± 0.5	
		Autumn	3.1 ± 1.2	
Tianjin	2015	Winter	4.9 ± 0.8	Shi et al. (2019)
Xiamen	2018	Winter	3.5 ± 0.4	Xu et al. (2025)
		Spring	3.0 ± 0.5	
		Summer	2.7 ± 0.5	
		Autumn	2.5 ± 0.5	
Guangzhou	2012 - 2013	All	2.5 ± 0.7	Jia et al. (2020)
Shanghai	2019 - 2020	Winter	3.5 ± 0.4	Fu et al. (2022)
		Spring	3.1 ± 0.5	
		Summer	2.6 ± 0.5	
		Autumn	2.7 ± 0.6	
This Study	2022	Winter	4.9 ± 0.4	
		Spring	3.4 ± 0.7	
		Summer	2.8 ± 0.7	
		Autumn	3.2 ± 0.7	

Table S5 Average mass concentrations of NO_3, SO_4^{2-}, NH_4^+, $PM_{2.5}$, ALWC, H_{air}^+ and pH under clean and polluted conditions by season

Winter	**$PM_{2.5}$** (μg/m³)	**SO_4^{2-}** (μg/m³)	**NO_3^-** (μg/m³)	**NH_4^+** (μg/m³)	**RH** (%)	**T** (K)	**pH**	**ALWC** (μg/m³)	**H_{air}^+** (μg/m³)
Average	93.3 ± 40.2	7.3 ± 4.7	16.3 ± 11.9	7.3 ± 5.7	65 ± 21	278.2 ± 4.2	4.9 ± 0.4	80.4 ± 112.9	1.0E-06
Clean	56.4 ± 10.5	5.9 ± 2.8	11.7 ± 4.9	5.6 ± 2.4	75 ± 16	278.2 ± 3.8	4.8 ± 0.4	63.3 ± 78.1	5.2E-07
Polluted	114.9 ± 34.7	9.4 ± 5.4	23.8 ± 12.4	10.6 ± 6.1	71 ± 18	277.3 ± 4.1	5.0 ± 0.3	94.3 ± 130.6	1.0E-06
Spring	**$PM_{2.5}$**	**SO_4^{2-}**	**NO_3^-**	**NH_4^+**	**RH**	**T**	**pH**	**ALWC**	**H_{air}^+**
Average	62.7 ± 41.2	4.3 ± 1.7	6.4 ± 7.1	2.5 ± 2.6	62 ± 18	291.2 ± 5.8	3.4 ± 0.7	55.7 ± 132.2	6.4E-06
Clean	42.2 ± 14.0	4.4 ± 1.6	6.8 ± 7.4	3.0 ± 2.7	70 ± 18	291.0 ± 5.8	3.3 ± 0.7	58.9 ± 140.5	6.8E-06
Polluted	111.9 ± 35.1	7.0 ± 1.7	16.8 ± 8.1	6.0 ± 3.1	67 ± 21	288.1 ± 5.5	4.0 ± 0.3	32.5 ± 34.0	3.1E-06
Summer	**$PM_{2.5}$**	**SO_4^{2-}**	**NO_3^-**	**NH_4^+**	**RH**	**T**	**pH**	**ALWC**	**H_{air}^+**
Average	33.3 ± 13.7	3.5 ± 2.2	1.0 ± 1.2	1.1 ± 0.9	61 ± 16	302.0 ± 4.1	2.8 ± 0.7	10.0 ± 25.1	9.9E-06
Clean	30.7 ± 8.3	4.2 ± 2.2	1.2 ± 1.4	1.5 ± 0.9	66 ± 16	302.2 ± 4.1	2.8 ± 0.7	10.2 ± 25.4	1.0E-05
Polluted	82.8	7.0	2.0	2.0	48	307.3	3.0	1.1	9.7E-07
Autumn	**$PM_{2.5}$**	**SO_4^{2-}**	**NO_3^-**	**NH_4^+**	**RH**	**T**	**pH**	**ALWC**	**H_{air}^+**
Average	43.1 ± 25.1	4.4 ± 3.1	8.7 ± 10.8	3.8 ± 4.1	80 ± 13	290.3 ± 5.1	3.2 ± 0.7	76.2 ± 121.0	1.8E-05
Clean	36.8 ± 15.3	4.4 ± 2.9	6.1 ± 6.3	3.1 ± 2.5	82 ± 13	290.6 ± 5.2	3.1 ± 0.7	61.9 ± 111.5	1.8E-05
Polluted	90.9 ± 8.6	7.7 ± 1.0	29.7 ± 3.1	14 ± 1.3	86 ± 9	286.5 ± 1.3	3.9 ± 0.1	171.6 ± 149.5	1.7E-05

Table S6 Sensitivity of $PM_{2.5}$ pH to SO_4^{2-}, NH_x, NO_3^-, Cl^-, Ca^{2+}, RH and T. The greater the relative standard deviation (RSD), the greater the impact of the variable change.

Impact factor	SO_4^{2-}	NH_x	NO_3^-	Cl^-	RH	T	Ca^{2+}
Winter RSD（%）	5.83	4.66	0.85	0.96	4.48	4.38	3.25
Spring RSD（%）	5.58	28.34	4.11	0.23	10.85	9.22	8.75
Summer RSD（%）	21.79	9.06	1.76	0.06	12.11	7.13	6.16
Autumn RSD（%）	6.09	39.77	9.39	0.50	4.39	6.19	1.41

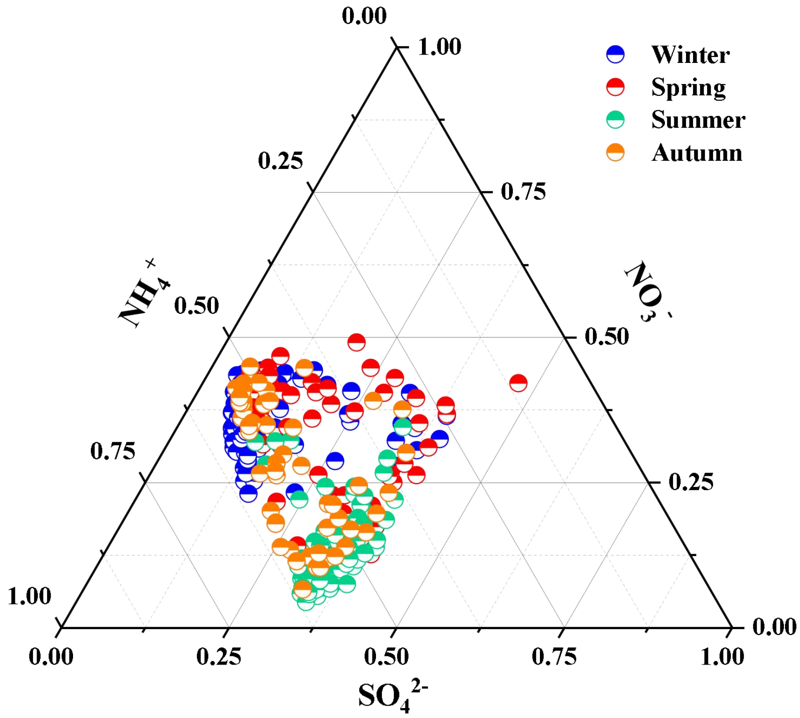

Fig. S1 Ternary diagram of molar concentration ratio of SO_4^{2-}、NO_3^- and NH_4^+ in each season

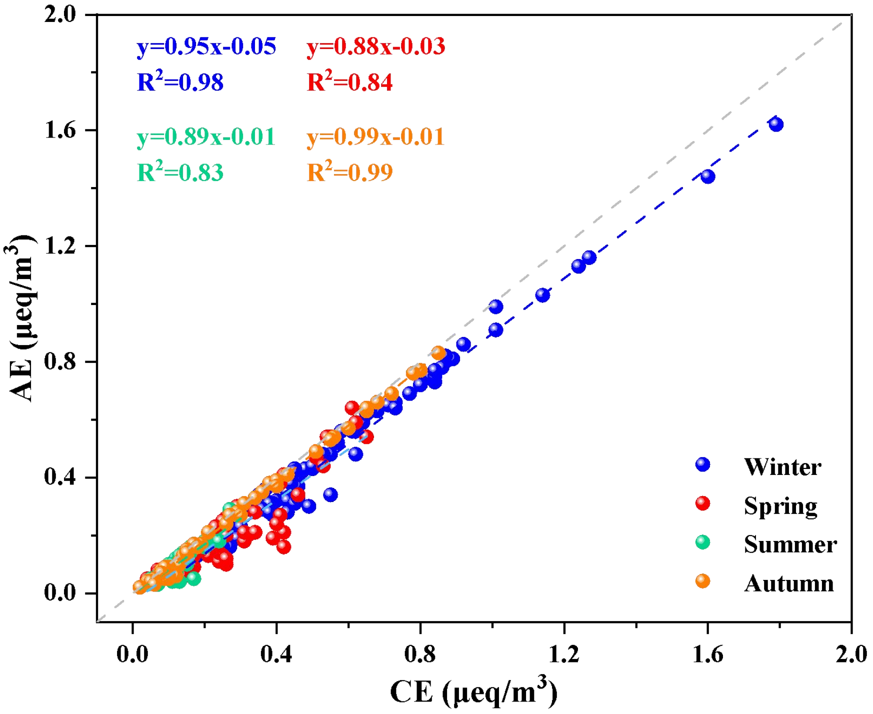

Fig. S2 Linear regression analysis of anion and cation equivalent concentration in each season

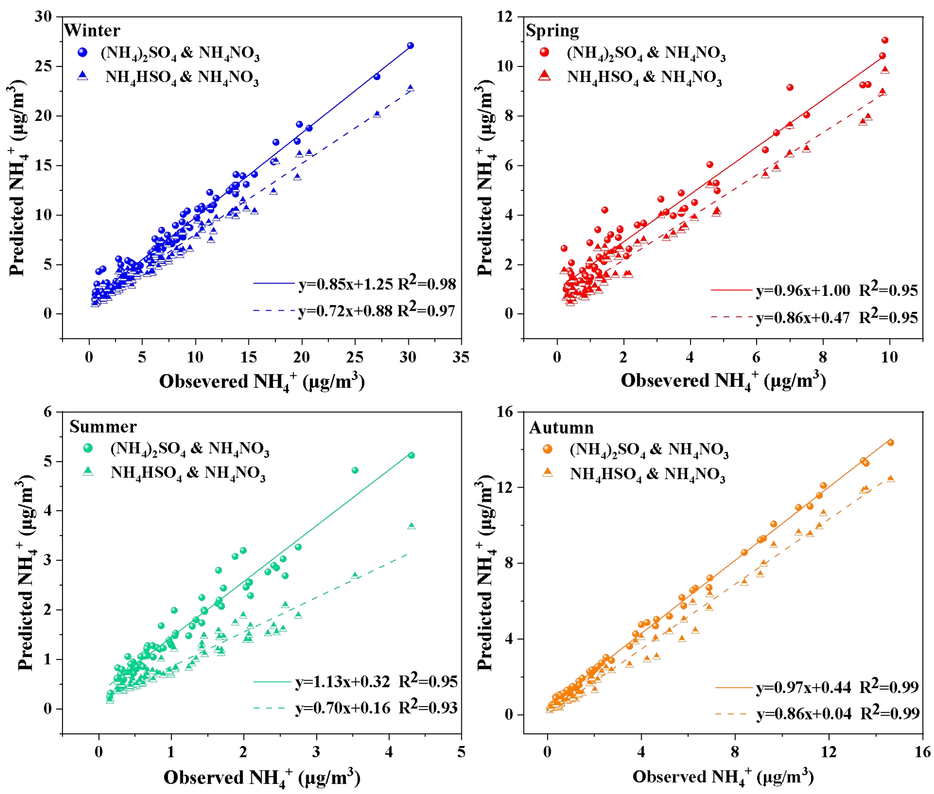

Fig. S3 Linear relationship between observed and predicted values of NH_4^+

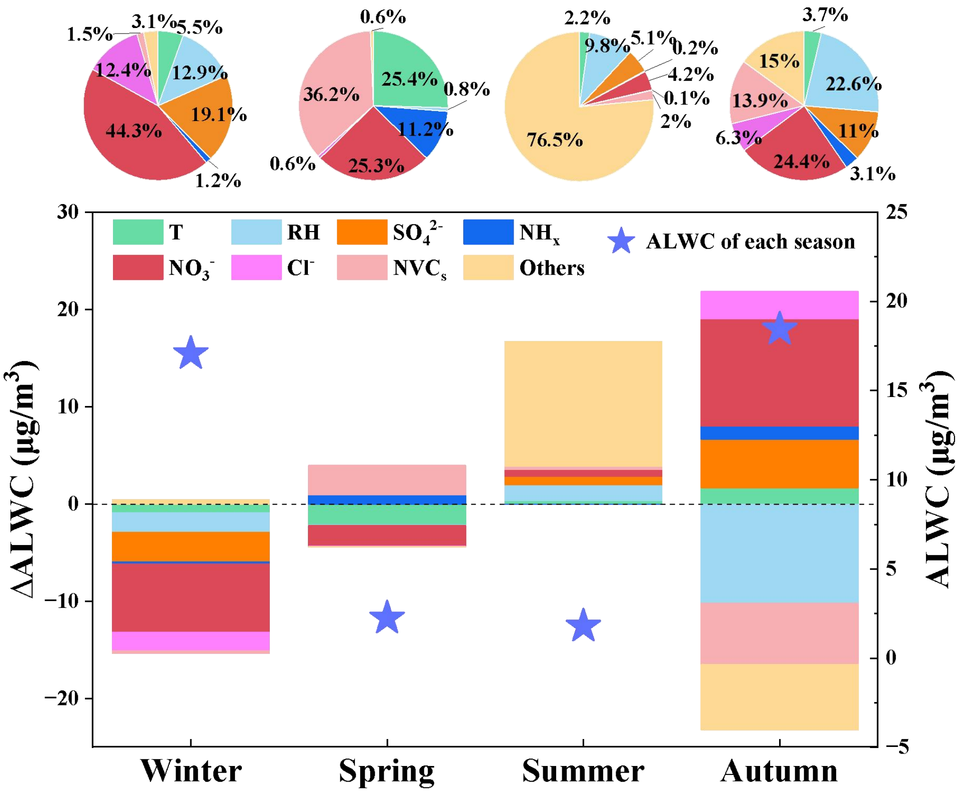

Fig. S4 The contribution of various influencing factors to the seasonal pH. The asterisk represents the pH of aerosols in each season. The pie chart shows the relative contributions of various influencing factors to the seasonal pH (absolute values of pH was taken for pie chart).