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Research Article

Trend of SO_2 Gas Dry Deposition in Vietnam

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Abstract

This research used the calculating method of dry deposition to estimate SO_2 dry deposition value and evaluate its trend in 5 recent years. The results indicate that SO_2 emission at Northern sites is more changing than Southern ones in months by affecting meteorology and weather. Summer and autumn seasons have SO_2 emitted concentrations higher than other seasons in 2019, 2020, and 2022 year at Yen Bai, Hoa Binh, and Ha Noi stations. The 2021 year has the highest SO_2 dry deposition and the 2019 year has the lowest SO_2 dry deposition in 5 recent years. The Hanoi site has the highest SO_2 dry deposition value from 2019 to 2022 year. Hoa Binh site has the highest SO_2 dry deposition at 2.45 kg/ha/year in 2023. High SO_2 dry deposition occurs normally in the summer and autumn (from April to August). Southern sites have lower SO_2 dry deposition amounts with not much change than the Northern sites of Vietnam. The increasing trend of SO_2 dry deposition happened from 1999 to 2023 year and it increases sharply from 1999 to 2021. Therefore, SO_2 dry deposition will have a light-increasing trend in the future.

Introduction

Acid deposition is one of the serious environmental pollution issues because it is formed in polluted atmospheric conditions due to excessive gas emissions from industrial waste sources. Acid deposition includes wet and dry deposition, in which wet deposition is collected through rainy water, and dry deposition is drawn from the air via monitoring stations. The dry deposition process controls the transfer of pollutants from the atmosphere to the surface [1]. In a dry deposition, acid substances exist under the gas form or dust particles and are emitted from natural sources such as volcanoes [2] and artificial sources including industry, energy, land-based transport, shipping, and biomass-burning [2-4]. They are blown by the wind, then fall down the ground, and trees and enter the river system. Sulfur dioxide is emitted from. Dry deposition depends so much on wind speed, temperature, humidity, solar radiation, precipitation amount, and cloud cover factors. Moreover, dry deposition normally is represented by strong acids, which can dissolve metal oxides and dust in the air and soil leading to reduce the pH of water when raining. This acid deposition causes crop damage and reduces productivity, threatening animal and plant living, and affecting human health.

Acid concentration monitoring in the air is one of the basic monitoring items in EANET [5]. EANET is an international organization of Acid Deposition Monitoring Network in East Asia with the cooperation of 13 countries with Vietnam as one of the participants and the acid deposition system has been operating for 25 years. Monitoring stations in Vietnam are covered from the North to South of Vietnam whereas dry deposition stations include 5 stations and are monitored frequently, weekly. Origin data is sent to EANET yearly to save and publish on the EANET website. However, publication data have only each year and it has not revealed the trend of acid deposition in many years. Furthermore, the estimation of dry deposition is calculated by multiplying measured concentrations and deposition velocities [6-8]. Therefore, this research estimates sulfur dioxide gas dry deposition in 5 recent years and displays the trend of sulfur dioxide gas from the 2019-2023 year to understand the changing of sulfur dioxide gas dry deposition in 5 years. This research helps planners to take out environmental policy and make plans to reduce gas emissions into the air.

Methodology

This study uses the inferential method to estimate sulfur dioxide gas dry deposition based on the equation [9,10] as follows:

$$F_i = V_d^i \times C_i$$

Whereas:

F_i is the dry deposition of SO_2 gas type

V_d is the deposition velocity of SO_2 gas type

C_i is the atmospheric concentration of SO_2 gas type.

Deposition velocity V_d is applied by the resistance model [8,11] and considering meteorological factors, deposition surface, and land use [10] to estimate deposition velocity. It is presented by the following equation:

$$V_d = \frac{1}{r_a + r_b + r_c}$$

Whereas:

V_d is the deposition velocity

R_a is the aerodynamic resistance

R_b is the quasi-laminar layer resistance

R_c is the surface resistance

The R_a and R_b parameters are calculated by the parameterizations of Erisman and Draaijers [12]. R_c is estimated by the equation of Wesely and Erisman [13] including stomal parameter, mesophyll, and surface resistance parameters. Data for wind speed, temperature, relative humidity, solar radiation, and precipitation are surveyed at the monitoring stations and used in calculating V_d.

Results and discussion

Total SO_2 concentration data are collected from monitoring stations and calculated SO_2 dry deposition for all of Vietnam. The trend of SO_2 dry deposition is presented in 5 years, from 2019 to 2023 years.

Concentration of SO_2 gas

From monitoring stations in Vietnam, data on SO_2 concentration is extracted and indicated that SO_2 emitted concentration is about 0.06 ppb to 0.75 ppb for all years. Vietnam's weather normally is separated into four seasons, including spring season, summer, autumn, and winter season. However, Southern Vietnam due to its geographic location is near the equator, so the temperature is higher, and sunny days are more than in Northern Vietnam, from that it forms 4 undistinctive seasons, which are the dry season and rainy season. Nevertheless, this research depends still on the 4 seasons of Northern to evaluate the emission of SO_2 gas and estimate its dry deposition.

Figure 1 and Table 1 show that SO_2 emission at Northern sites is more changing than at Southern ones in months by being affected by meteorology and weather. Moreover, the summer and autumn seasons have SO_2 emitted concentrations higher than other seasons in 2019, 2020, and 2022 year at Yen Bai, Hoa Binh, and Ha Noi stations, especially in June and August due to this time weather is normally hot and dry, leading to increase temperature, reduce humidity, diminishing SO_2 dry deposition by raining, from that causing SO_2 concentration is more spreading into the air. In contrast, the spring season has high humidity and lower temperature making the existence of SO_2 in the air shorter, therefore SO_2 concentration is lower than in other seasons. Furthermore, nowadays, winter time is not long and cold because of climate change and it also appears more rainy in the winter, especially in the Southern parts rain occurs with high intensity leading to lower SO_2 concentration in the air as well. In addition to climate change in recent times, SO_2 concentration has changed unordinary at the Hanoi site in the spring with high SO_2 concentration. Generally, SO_2 concentration at sites monthly has changed clearly, especially in 2019 and 2022 years.

Dry deposition of SO_2 gas

Based on calculating equations of dry deposition to estimate SO_2 dry deposition. High or low SO_2 dry deposition depends significantly on wind speed, temperature, humidity, solar radiation, precipitation amount, and cloud cover factors.

Table 2 indicates that total national SO_2 dry deposition in 5 years was 9.18 kg/ha/2019 year; 11.15 kg/ha/2020 year; 12.98 kg/ha/2021 year; 10.38 kg/ha/2022 year; and 11.06 kg/ha/2023 year. Thus, 2021 year has the highest SO_2 dry deposition and 2019 year has the lowest SO_2 dry deposition in 5 recent years. Furthermore, when considering SO_2 dry deposition in each year shows that the Hanoi site has the highest SO_2 dry deposition value from 2019 to the 2022 year as 2.22 kg/ha/year; 3.1 kg/ha/year; 4.04 kg/ha/year; and 2.66 kg/ha/year. However, in the 2023 year, Hanoi's SO_2 dry deposition is only 4th ranking while the Hoa Binh site has the highest SO_2 dry deposition at 2.45 kg/ha/year in 2023. Moreover, the Hoa Binh site has an SO_2 dry deposition value from 1.89 to 2.45 kg/ha/year in 5 years. Southern sites reveal a lower SO_2 dry deposition amount than Northern sites, including the Ho Chi Minh site from 1.6 to 1.89 kg/ha/year with the highest SO_2 dry deposition value in 2022. Can Tho site presented an SO_2 dry deposition value from 1.86 to 2.34 kg/ha/year with the highest SO_2 dry deposition amount in the 2023 year. Yen Bai site is a Northern area of Vietnam, which reveals SO_2 dry deposition value from 1.99-2.96 kg/ha/year with the best SO_2 dry deposition amount in the 2022 year. When considering medium SO_2 concentration in 5 years, 2021 year has a high SO_2 emitted concentration versus left years and the highest fluctuation amplitude in monthly.

When considering SO_2 dry deposition monthly, Figure 2 presents that the SO_2 dry deposition value is changed from 0-0.75kg/ha/month, in which the best SO_2 dry deposition value is in April at the Hanoi site. SO_2 dry deposition amount changes monthly and in season.

Figure 2 reveals high SO_2 dry deposition occurs normally in the summer and autumn (from April to August). Especially,

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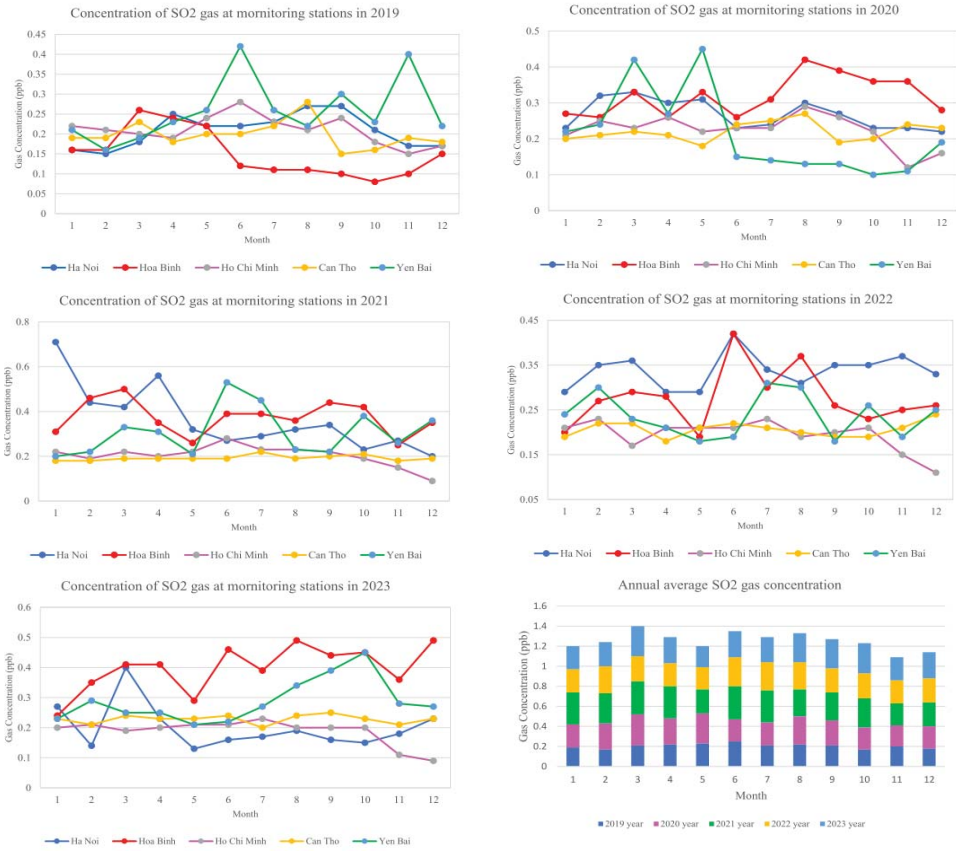

Figure 1: Changing of SO_2 concentration at stations in Vietnam.

Table 1: Concentration of SO_2 gas at stations in Vietnam (unit: ppb).

Station/month	1	2	3	4	5	6	7	8	9	10	11	12	Sum 2019
Ha Noi	0.16	0.15	0.18	0.25	0.22	0.22	0.23	0.27	0.27	0.21	0.17	0.17	2.5
Hoa Binh	0.16	0.16	0.26	0.24	0.22	0.12	0.11	0.11	0.1	0.08	0.1	0.15	1.81
Ho Chi Minh	0.22	0.21	0.2	0.19	0.24	0.28	0.23	0.21	0.24	0.18	0.15	0.17	2.52
Can Tho	0.19	0.19	0.23	0.18	0.2	0.2	0.22	0.28	0.15	0.16	0.19	0.18	2.37
Yen Bai	0.21	0.16	0.19	0.23	0.26	0.42	0.26	0.22	0.3	0.23	0.4	0.22	3.1
Station/month	1	2	3	4	5	6	7	8	9	10	11	12	Sum 2020
Ha Noi	0.23	0.32	0.33	0.3	0.31	0.23	0.24	0.3	0.27	0.23	0.23	0.22	3.21
Hoa Binh	0.27	0.26	0.33	0.26	0.33	0.26	0.31	0.42	0.39	0.36	0.36	0.28	3.83
Ho Chi Minh	0.21	0.25	0.23	0.26	0.22	0.23	0.23	0.29	0.26	0.22	0.12	0.16	2.68
Can Tho	0.2	0.21	0.22	0.21	0.18	0.24	0.25	0.27	0.19	0.2	0.24	0.23	2.64
Yen Bai	0.22	0.24	0.42	0.27	0.45	0.15	0.14	0.13	0.13	0.1	0.11	0.19	2.55
Station/month	1	2	3	4	5	6	7	8	9	10	11	12	Sum 2021
Ha Noi	0.71	0.44	0.42	0.56	0.32	0.27	0.29	0.32	0.34	0.23	0.27	0.2	4.37
Hoa Binh	0.31	0.46	0.5	0.35	0.26	0.39	0.39	0.36	0.44	0.42	0.25	0.35	4.48
Ho Chi Minh	0.22	0.19	0.22	0.2	0.22	0.28	0.23	0.23	0.22	0.19	0.15	0.09	2.44
Can Tho	0.18	0.18	0.19	0.19	0.19	0.19	0.22	0.19	0.2	0.21	0.18	0.19	2.31
Yen Bai	0.2	0.22	0.33	0.31	0.21	0.53	0.45	0.23	0.22	0.38	0.26	0.36	3.7
Station/month	1	2	3	4	5	6	7	8	9	10	11	12	Sum 2022
Ha Noi	0.29	0.35	0.36	0.29	0.29	0.42	0.34	0.31	0.35	0.35	0.37	0.33	4.05
Hoa Binh	0.2	0.27	0.29	0.28	0.19	0.42	0.3	0.37	0.26	0.23	0.25	0.26	3.32
Ho Chi Minh	0.21	0.23	0.17	0.21	0.21	0.21	0.23	0.19	0.2	0.21	0.15	0.11	2.33
Can Tho	0.19	0.22	0.22	0.18	0.21	0.22	0.21	0.2	0.19	0.19	0.21	0.24	2.48
Yen Bai	0.24	0.3	0.23	0.21	0.18	0.19	0.31	0.3	0.18	0.26	0.19	0.25	2.84
Station/month	1	2	3	4	5	6	7	8	9	10	11	12	Sum 2023
Ha Noi	0.27	0.14	0.4	0.23	0.13	0.16	0.17	0.19	0.16	0.15	0.18	0.23	2.41
Hoa Binh	0.24	0.35	0.41	0.41	0.29	0.46	0.39	0.49	0.44	0.45	0.36	0.49	4.78
Ho Chi Minh	0.2	0.21	0.19	0.2	0.21	0.21	0.23	0.2	0.2	0.2	0.11	0.09	2.25
Can Tho	0.23	0.21	0.24	0.23	0.23	0.24	0.2	0.24	0.25	0.23	0.21	0.23	2.74
Yen Bai	0.23	0.29	0.25	0.25	0.21	0.22	0.27	0.34	0.39	0.45	0.28	0.27	3.45

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Table 2: Dry deposition of SO_2 gas at stations in Vietnam.

Station/month	1	2	3	4	5	6	7	8	9	10	11	12	Sum 2019
Ha Noi	0.14	0.16	0.18	0.28	0.2	0.2	0.18	0.22	0.21	0.18	0.13	0.14	2.22
Hoa Binh	0.1	0.1	0.16	0.15	0.13	0.07	0.07	0.14	0.06	0.05	0.06	0.09	1.18
Ho Chi Minh	0.18	0.15	0.13	0.13	0.15	0.21	0.17	0.14	0.16	0.12	0.1	0.11	1.76
Can Tho	0.15	0.15	0.17	0.12	0.17	0.13	0.16	0.22	0.12	0.12	0.17	0.18	1.86
Yen Bai	0.08	0.07	0.09	0.14	0.18	0.33	0.22	0.19	0.22	0.17	0.3	0.16	2.16
Station/month	1	2	3	4	5	6	7	8	9	10	11	12	Sum 2020
Ha Noi	0.24	0.22	0.3	0.27	0.35	0.27	0.19	0.37	0.23	0.26	0.18	0.23	3.1
Hoa Binh	0.16	0.16	0.2	0.16	0.2	0.16	0.19	0.26	0.24	0.22	0.22	0.17	2.34
Ho Chi Minh	0.09	0.1	0.08	0.09	0.16	0.18	0.17	0.2	0.18	0.15	0.08	0.11	1.6
Can Tho	0.09	0.17	0.17	0.14	0.16	0.19	0.2	0.22	0.16	0.15	0.24	0.22	2.11
Yen Bai	0.13	0.15	0.26	0.25	0.41	0.13	0.08	0.08	0.12	0.09	0.07	0.23	2
Station/month	1	2	3	4	5	6	7	8	9	10	11	12	Sum 2021
Ha Noi	0.56	0.4	0.44	0.68	0.35	0.23	0.28	0.25	0.25	0.21	0.22	0.16	4.04
Hoa Binh	0.19	0.28	0	0.21	0.16	0.24	0.24	0.22	0.27	0.26	0.15	0	2.23
Ho Chi Minh	0.1	0.15	0.18	0.16	0.19	0.21	0.17	0.17	0.19	0.15	0.11	0.06	1.82
Can Tho	0.09	0.17	0.16	0.15	0.16	0.14	0.19	0.15	0.18	0.18	0.17	0.18	1.93
Yen Bai	0.13	0.16	0.2	0.28	0.2	0.45	0.36	0.2	0.15	0.35	0.18	0.31	2.96
Station/month	1	2	3	4	5	6	7	8	9	10	11	12	Sum 2022
Ha Noi	0.18	0.22	0.22	0.18	0.18	0.36	0.23	0.25	0.19	0.22	0.22	0.2	2.66
Hoa Binh	0.12	0.17	0.18	0.17	0.12	0.26	0.18	0.23	0.16	0.14	0.15	0	1.89
Ho Chi Minh	0.18	0.19	0.14	0.17	0.19	0.17	0.18	0.18	0.15	0.17	0.11	0.08	1.89
Can Tho	0.09	0.11	0.18	0.17	0.21	0.16	0.16	0.17	0.19	0.14	0.17	0.2	1.95
Yen Bai	0.15	0.24	0.13	0.16	0.11	0.13	0.23	0.22	0.11	0.2	0.13	0.18	1.99
Station/month	1	2	3	4	5	6	7	8	9	10	11	12	Sum 2023
Ha Noi	0.21	0.11	0.3	0.14	0.11	0.18	0.19	0.09	0.15	0.17	0.14	0.24	2.04
Hoa Binh	0.15	0	0.25	0.25	0.18	0.28	0.24	0.3	0.27	0	0.22	0.3	2.45
Ho Chi Minh	0.19	0.15	0.15	0.17	0.16	0.16	0.17	0.16	0.17	0.17	0.09	0.07	1.82
Can Tho	0.21	0.21	0.2	0.18	0.2	0.19	0.17	0.2	0.2	0.18	0.18	0.23	2.34
Yen Bai	0.1	0.21	0.19	0.19	0.14	0.18	0.25	0.25	0.27	0.3	0.19	0.15	2.41

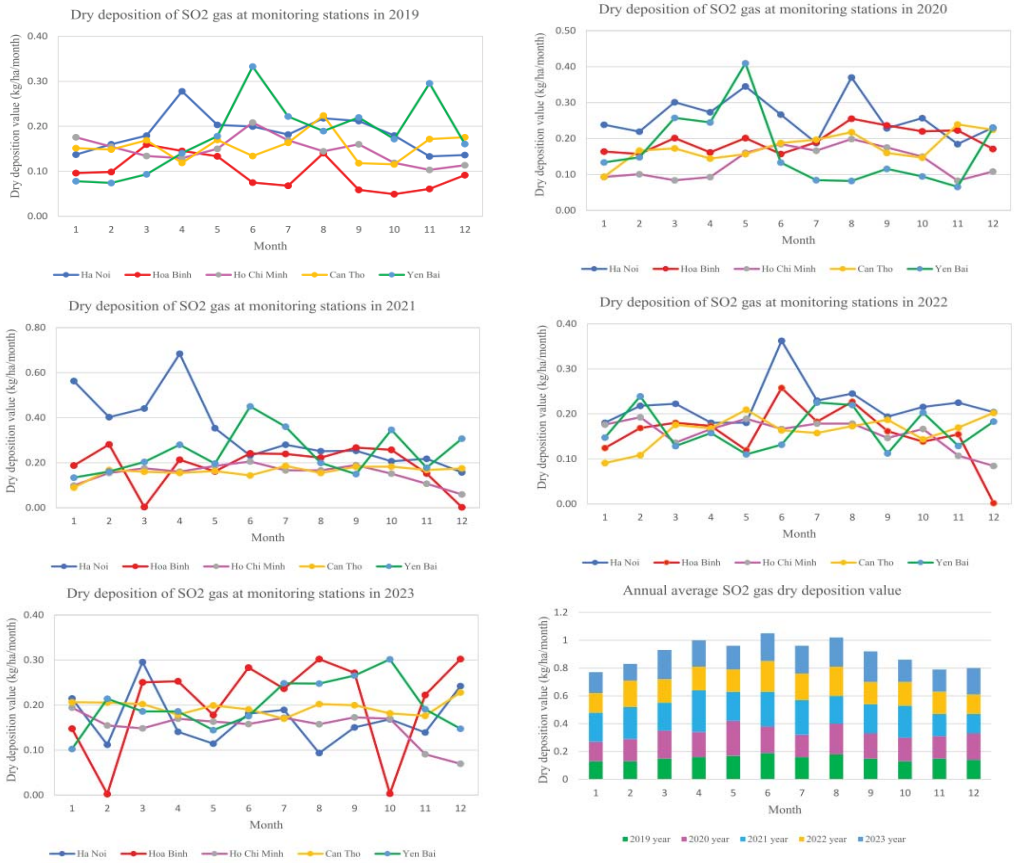

Figure 2: Changing of SO_2 gas dry deposition at stations in Vietnam.

April, May, and June have higher SO_2 dry deposition than other months from 1999 to 2023 year, and it happens at Northern stations of Vietnam as Hanoi and Yen Bai sites. In contrast, the Southern sites have lower SO_2 dry deposition amounts with not much change monthly as Can Tho and Ho Chi Minh sites. Besides, the Hoa Binh site indicates a big SO_2 dry deposition change in 12 months, particularly in the 2023 year with SO_2 dry deposition amount from 0-0.3 kg/ha/month, in which February and October have SO_2 dry deposition amount near zero while summer months exist still at high value versus other sites in the same year. Generally, the Northern site has a higher SO_2 dry deposition value than the left sites in 5 years. If considering medium SO_2 dry deposition value with yearly presents 2021 year has a higher SO_2 dry deposition amount than other years and the biggest fluctuation amplitude in 5 years.

The trend of SO_2 in 5 years

The figure below (Figure 3) shows the trend of SO_2 gas dry deposition in 5 years, it indicates the increasing trend of SO_2 dry deposition from 1999 to 2023 year. Especially, the sharp increase from 1999 to 2021, then its trend is lightly decreasing to the 2022 year and light growth to 2023 year. With increasing trend reveals that SO_2 dry deposition will be light growth in future years at sites in Vietnam.

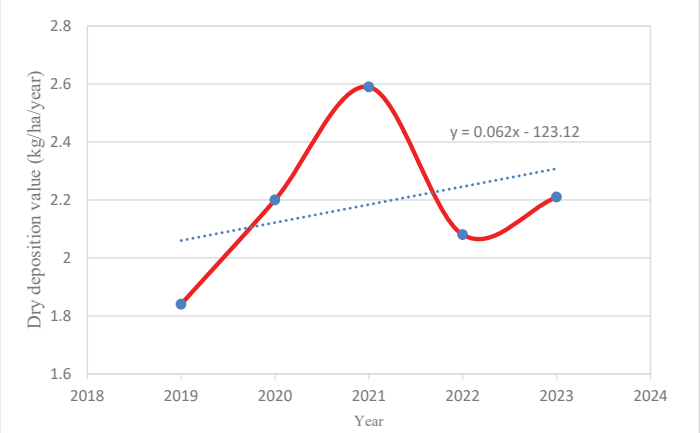

Figure 3: Trend of SO_2 gas dry deposition in 1999-2023 year.

Conclusion

From determining SO_2 emitted concentration via stations in Vietnam and estimating SO_2 dry deposition amount in sites, this research has drawn some significance as SO_2 emission at Northern sites is more changing than Southern ones in months being affected by meteorology and weather. Summer and autumn seasons have SO_2 emitted concentrations higher than other seasons in 2019, 2020, and 2022 year at Yen Bai, Hoa Binh, and Ha Noi stations. The 2021 year has the highest SO_2 dry deposition and the 2019 year has the lowest SO_2 dry deposition in 5 recent years. The Hanoi site has the highest SO_2 dry deposition value from 2019 to 2022 year. Hoa Binh site has the highest SO_2 dry deposition at 2.45 kg/ha/year in 2023. High SO_2 dry deposition occurs normally in the summer and autumn (from April to August). Southern sites have lower SO_2 dry deposition amounts with not much change than the Northern sites of Vietnam. The increasing trend of SO_2 dry deposition happened from 1999 to 2023 year and it increases sharply from 1999 to 2021. SO_2 dry deposition will have a light increasing trend in the future.

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