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RESEARCH ARTICLE

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A Study on the Temporal and Spatial Changes of Nitrogen Oxides in the Southwest Corner of Jingzhou City Wall

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Abstract: With the growth of people's consumption capacity, the production and consumption of energy are rapidly increasing every year, and the emissions of nitrogen oxides are also increasing. Nitrogen oxides include many types of compounds, such as nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), etc. Except for nitrogen dioxide, the properties of other nitrogen oxides are extremely unstable. Therefore, in the actual atmosphere, nitric oxide (NO) and nitrogen dioxide (NO_2) are usually collectively referred to as nitrogen oxides (NO_x). This article measured and compared the nitrogen oxide concentration and other meteorological indicators in the public, commercial, and civilian areas at the southwest corner of the city wall in Jingzhou City in March and April 2022. The following conclusions were drawn: the mass concentration of nitrogen oxide pollutants was highest around noon and evening, and the concentration was relatively small before and after sunrise and afternoon, with a "double peak and double valley" distribution. The nitrogen oxide concentration began to decrease at night and reached the first valley in the early morning, then it gradually rises, reaching its peak around 8:00 and then showing a downward trend. A second trough will appear around 13:00, followed by a continuous increase in concentration, and finally a small peak will appear at 18:00.

Keywords: NO_x; nitrogen oxides; meteorological factors

1. Research Methods

1.1. Overview of the research area

Jingzhou (111°15′~114°05′ E, 29°26′~31°37′ N) is an important prefecture level city in central China, located in the central and southern parts of Hubei, the middle reaches of the Yangtze River, and the hinterland of the Jianghan Plain. The area belongs to the humid climate zone of the northern subtropical monsoon, with distinct four seasons, suitable lighting, abundant heat, abundant rainfall, rainy and hot seasons, and long none frost period. The total annual radiation is 4366.8-4576.2MJ/m^2, with an annual sunshine of 1823-1978H and a sunshine rate of 41%~44%. The average temperature for six years is 16.2 ℃~16.6 ℃, with a frost free period of 250-267D and an annual precipitation of about 1100-1300mm. The overall atmospheric pollution meets the national second level standard (Wang, 1995; Liu et al., 2003; Guo et al., 2002).

Figure 1

The horizontal sampling strategy is used for sample collection, as shown in **Figure 1**. The observation points are concentrated at the southwest corner of the ancient city wall in Jingzhou City, including the Fourth Petroleum Machinery Factory (referred to as the Fourth Machinery Factory) and its affiliated residential areas. There are a total of 5 specific observation points. Point 1 is the new south gate of the ancient City wall, and the sampling point is located on the west side outside the exit of the city wall, near the main road. Point 2 is located at the

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wetland park in the southwest corner of the ancient city wall. The sampling point is located at the southwest corner of the city wall, close to the water body and surrounded by abundant green plants. Point 3 is located in the Lanzhou Garden community of the Fourth Machinery Factory, surrounded by many residential buildings. The sampling point is located in Zone B of the community, far from the west factory area of the Fourth Machinery Factory. Point 4 is located in the northern periphery of the Fourth Machinery Factory, on the main road inside the factory area. The surrounding public, commercial, and civilian areas are mixed. Point 5 is the Jianghanyuan residential area in the east of Jianghan Construction Machinery Company. The sampling point is located in Building 11 inside the residential area, close to the West Factory Area of Fourth Machinery Factory. The air pollution at these 5 points mainly comes from industrial and transportation pollution, followed by pollution from the surrounding catering industry and residential life (Yan et al., 2007).

1.2. Sampling method

Sampling will be conducted in March 2022 and April 2022. Short term sampling will be conducted in the sampling area on clear, windless or slightly windy weather, and pollutant observations will be conducted continuously for 11 hours. The observation period will start from 8:00 am to 8:00 pm on the same day, and a total of 6 atmospheric pollutant observations will be conducted. The specific time periods are (8:00-9:00, 10:00-11:00, 12:00-14:00, 15:00-16:00, 17:00-18:00, 19:00-20:00). Each observation can obtain 30 sets of data.

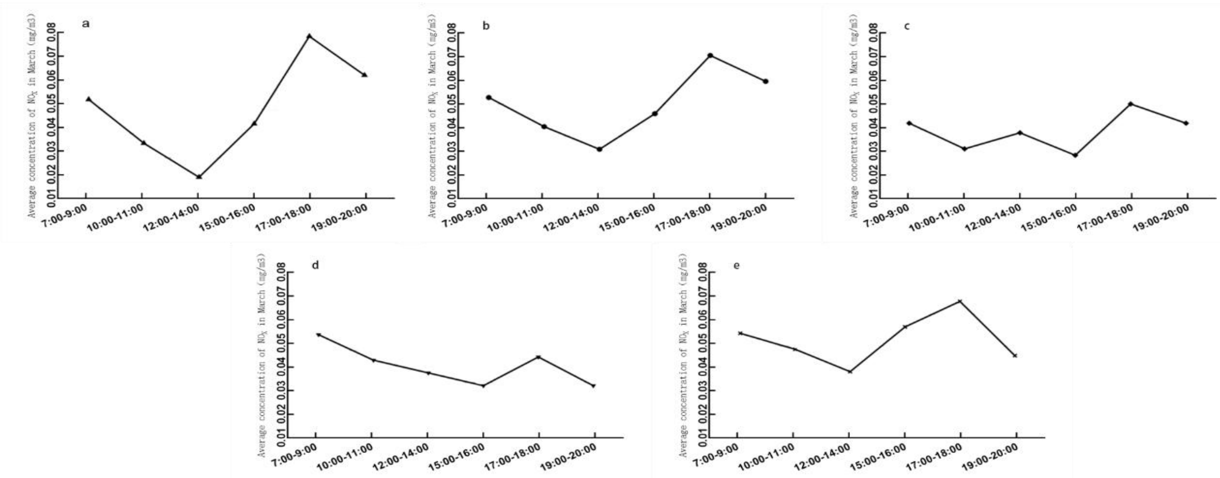
1.3. Data sources

The data on wind level and direction are obtained from the National Meteorological Information Center（https://data.cma.cn/）Hourly ground data is used as data.

2. Observation Results

2.1. Changes in nitrogen oxide concentration in the southwest corner of the city wall in March

Figure 2



The observation results of the diurnal concentration changes of nitrogen oxides at various sampling points in the southwest corner of Jingzhou City Wall in March are shown in **Figure 2**.

According to the variation of nitrogen oxide concentration in Figure 2a, the daytime variation of nitrogen oxide concentration at point 1 is divided into three stages, namely between 8:00-12:00, 13:00-17:00, and 18:00-20:00. The first stage of nitrogen oxide concentration variation range is 0.067~0.042 mg/m^3, with an average concentration of 0.054 mg/m^3, which is the lowest concentration. The second stage of nitrogen oxide concentration variation range is 0.038~0.076 mg/m^3, with an average concentration of 0.057 mg/m^3, which is the lowest concentration. The third stage of nitrogen oxide concentration variation range is 0.076~0.079 mg/m^3, with an average concentration of 0.077 mg/m^3, which is the highest concentration.

According to the variation of nitrogen oxide concentration in Figure 2b, the daytime variation of nitrogen oxide concentration at point 2 is divided into three stages, namely between 8:00-12:00, 13:00-17:00, and 18:00-20:00. The first stage of nitrogen oxide concentration variation range is 0.052~0.039 mg/m^3, with an average concentration of 0.045 mg/m^3, which is the lowest concentration. The second stage of nitrogen oxide concentration variation range is 0.036~0.065 mg/m^3, with an average concentration of 0.050 mg/m^3, which is the lowest concentration. The third stage of nitrogen oxide concentration variation range is 0.063~0.055 mg/m^3, with an average concentration of 0.059 mg/m^3, which is the highest concentration.

According to the variation of nitrogen oxide concentration in Figure 2c, the day time variation of nitrogen oxide concentration at point 3 is divided into three stages, namely between 8:00-12:00, 13:00-17:00, and 18:00-20:00. The first stage of nitrogen oxide concentration variation range is 0.042~0.034 mg/m^3, with an average concentration of 0.038 mg/m^3, which is the lowest concentration. The second stage of nitrogen oxide concentration variation range is 0.039~0.049 mg/m^3, with an average concentration of 0.044 mg/m^3, which is relatively high. The third stage of nitrogen oxide concentration variation range is 0.049~0.043 mg/m^3, with an average concentration of 0.046 mg/m^3, which is the highest concentration.

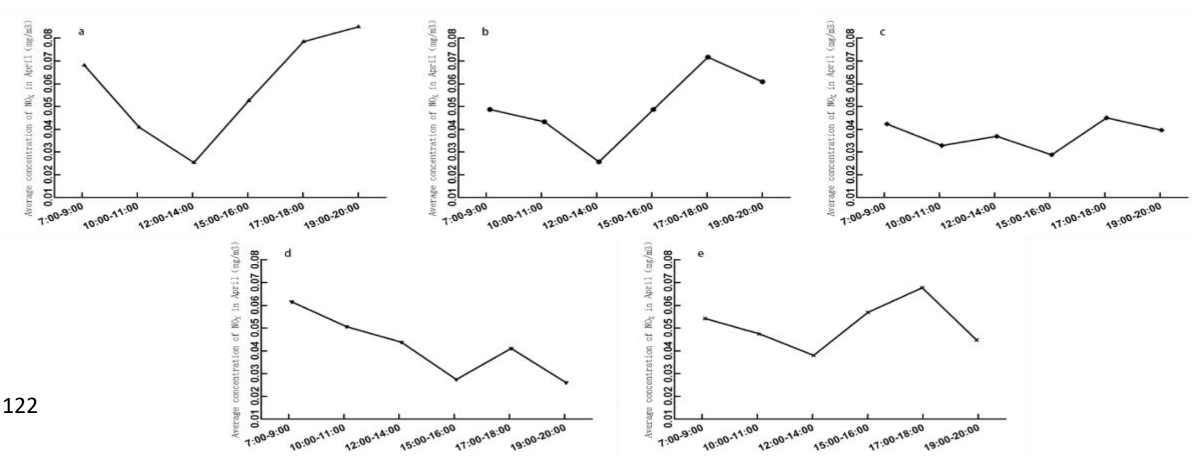
According to the variation of nitrogen oxide concentration in Figure 2d, the daytime variation of nitrogen oxide concentration at point 4 is divided into three stages, namely between 8:00-12:00, 13:00-17:00, and 18:00-20:00. The first stage of nitrogen oxide concentration variation range is 0.055~0.045 mg/m^3, with an average concentration of 0.050 mg/m^3, which is the highest concentration. The second stage of nitrogen oxide concentration variation range is 0.043~0.048 mg/m^3, with an average concentration of 0.046 mg/m^3, which is the highest concentration. The third stage of nitrogen oxide concentration variation range is 0.046~0.037 mg/m^3, with an average concentration of 0.041 mg/m^3, which is the lowest concentration.

According to the variation of nitrogen oxide concentration in Figure 2e, the daytime variation of nitrogen oxide concentration at point 5 is divided into three stages, namely between 8:00-12:00, 13:00-17:00, and 18:00-20:00. the first stage of nitrogen oxide concentration variation range is 0.054~0.045 mg/m^3, with an average concentration of 0.045 mg/m^3, which is the lowest concentration. The second stage of nitrogen oxide concentration variation range is 0.042~0.064 mg/m^3, with an average concentration of 0.053 mg/m^3, which is relatively high. The third stage of nitrogen oxide concentration variation range is 0.065~0.045 mg/m^3, with an average concentration of 0.055 mg/m^3, which is the highest concentration.

In summary, the changes in nitrogen oxides in Figures a and b in Figure 2 are relatively consistent, while the changes in nitrogen oxides in Figures c and e are relatively consistent. The changes in Figure d are unique. Considering the surrounding environment of the observation site, A and B are located in the same area as the ancient city wall walkway, with abundant green plants and close proximity. C and E are located in the same residential area, and the surrounding buildings to some extent affect the deposition of nitrogen oxides, so they have similar patterns of change, D is located in an open area, which is conducive to the diffusion of nitrogen oxides, so the pattern of change is unique. Moreover, other daytime observations in March have repeatedly shown this pattern (National Environmental Protection Administration, 2021), so this observation can represent the general pattern of nitrogen oxide concentration changes in the southwest corner of Jingzhou Ancient City in March.

2.2. Changes in nitrogen oxide concentration in the southwest corner of the city wall in April

Figure 3



The observation results of the diurnal concentration changes of nitrogen oxides at various sampling points in the southwest corner of Jingzhou City Wall in April are shown in **Figure 3**.

According to the variation of nitrogen oxide concentration in Figure 3a, the daytime variation of nitrogen oxide concentration at point 1 can be divided into three stages, namely between 8:00-12:00, 13:00-17:00, and 18:00-20:00. The first stage of nitrogen oxide concentration variation range is 0.069~0.046 mg/m^3, with an average concentration of 0.056 mg/m^3, which is the lowest concentration. The second stage of nitrogen oxide concentration variation range is 0.036~0.077 mg/m^3, with an average concentration of 0.057 mg/m^3, which is the lowest concentration. The third stage of nitrogen oxide concentration variation range is 0.077~0.082 mg/m^3, with an average concentration of 0.079 mg/ m^3, which is the highest concentration.

According to the variation of nitrogen oxide concentration in Figure 3b, the daytime variation of nitrogen oxide concentration at point 2 can be divided into three stages, namely between 8:00-12:00, 13:00-17:00, and 18:00-20:00. The first stage of nitrogen oxide concentration variation range is 0.049~0.044 mg/m^3, with an average concentration of 0.046 mg/ m^3, which is the lowest concentration. The second stage of nitrogen oxide concentration variation range is 0.032~0.065 mg/m^3, with an average concentration of 0.048 mg/m^3, which is the lowest concentration. The third stage of nitrogen oxide concentration variation range is 0.065~0.058 mg/m^3, with an average concentration of 0.059 mg/m^3, which is the highest concentration.

According to the variation of nitrogen oxide concentration in Figure 3c, the daytime variation of nitrogen oxide concentration at point 3 can be divided into three stages, namely between 8:00-12:00, 13:00-17:00, and 18:00-20:00. The first stage of nitrogen oxide concentration variation range is 0.043~0.036 mg/m^3, with an average concentration of 0.039 mg/m^3, which is the lowest concentration. The second stage of nitrogen oxide concentration variation range is 0.039~0.045 mg/m^3, with an average concentration of 0.042 mg/m^3, which is relatively high. The third stage of nitrogen oxide concentration variation range is 0.045~0.041mg/m^3, with an average concentration of 0.043 mg/m^3, which is the highest concentration.

According to the variation of nitrogen oxide concentration in Figure 3d, the daytime variation of nitrogen oxide concentration at point 4 can be divided into three stages, namely between 8:00-12:00, 13:00-17:00, and 18:00-20:00. The concentration range of nitrogen oxides in the first stage is 0.062~0.054mg/ m^3, with an average concentration of 0.058 mg/m^3, which is the highest concentration. In the second stage, the concentration range of nitrogen oxides is 0.049~0.047mg/m^3, with an average concentration of 0.048 mg/m^3, which is relatively high. In the third stage, the concentration range of nitrogen oxides is 0.047~0.036mg/m^3, with an average concentration of 0.041mg/m^3, which is the lowest concentration.

According to the variation of nitrogen oxide concentration in Figure 3e, the daytime variation of nitrogen oxide concentration at point 5 is divided into three stages, namely between 8:00-12:00, 13:00-17:00, and 18:00-20:00. The first stage of nitrogen oxide concentration variation range is 0.056~0.048 mg/m^3, with an average concentration of 0.052 mg/m^3, indicating a high concentration. The second stage of nitrogen oxide concentration variation range is 0.037~0.061 mg/m^3, with an average concentration of 0.049 mg/m^3, indicating the lowest concentration. The third stage of nitrogen oxide concentration variation range is 0.062~0.046 mg/m^3, with an average concentration of 0.054 mg/m^3, indicating the highest concentration.

In summary, the changes in nitrogen oxide concentrations in the five graphs a, b, c, d, and in **Figure 3** are consistent with those in March. Moreover, other daytime observations in April have repeatedly shown this pattern, indicating that this observation can represent the general pattern of nitrogen oxide concentration changes in the southwest corner of Jingzhou Ancient City in April.

2.3. Comparison of daily changes in nitrogen oxide concentration in the southwest corner of the city wall in March and April

Figure 4

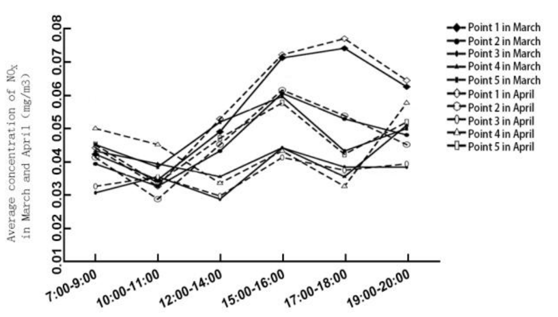


Figure 4 shows the variation of concentration at 5 locations in March and mid of April. It can be seen from the graph that the variation characteristics of nitrogen oxide concentration in the atmosphere at points 1 and 2 are the highest, lower, and lowest stages. The variation characteristics of nitrogen oxide concentration in the atmosphere at points 3 and 5 are the lowest, higher, and highest, while the variation characteristics of nitrogen oxide concentration in the atmosphere at point 4 are the lowest, higher, and highest. The trend of changes in the first and second stages of April 4th is not consistent with the overall trend. However, considering the high humidity in Jingzhou in April, it will to some extent affect the comparison with the data in March. Moreover, the average concentrations in the first and second stages of April are 0.049 mg/m^3 and 0.054 mg/m^3, and the difference between the two is not significant. Therefore, it is determined that the trend of changes is generally consistent. The overall level of nitrogen oxides in March was lower than that in April, but the change in March was greater.

3. Conclusion

According to various literature sources, the mass concentration of nitrogen oxide pollutants is highest around noon and evening, with lower concentrations before and after sunrise and afternoon, exhibiting a "double peak and double valley" distribution. The concentration of nitrogen oxides starts to decrease at night, reaches the first trough in the early morning, and then gradually increases (An et al., 2003; An et al., 2008). It reaches its peak around 8:00 and then shows a downward trend. A second trough appears around 13:00, and the concentration continues to rise. Finally, a small peak appears at 18:00. According to **Figures 2** and **3** and the previous analysis, it can be seen that the concentration of nitrogen oxides in most regions shows a distribution pattern of highest from 8:00 to 12:00, lowest from 13:00 to 17:00, and higher from 18:00 to 20:00. The reason for the highest concentration of nitrogen oxides in the first stage (8:00-12:00) is that around 8:00 in the morning is the peak traffic period, and the emission of vehicle exhaust leads to a rapid increase in nitrogen oxide concentration. In addition, the atmospheric diffusion conditions at this stage have not yet fully developed, and the accumulation of nitrogen oxide concentration is exacerbated by environmental factors such as the destruction of the early morning inversion layer (Li et al., 2004). The first peak concentration is reached around 8:00, which is the highest stage of concentration throughout the day.

The reason for the lowest concentration of nitrogen oxides in the second stage (13:00-17:00) is that with the end of the morning rush hour, the emission sources of nitrogen oxides are relatively reduced, and solar radiation begins to strengthen. Nitrogen oxides begin to undergo photo degradation, and O_3 is generated in the lower atmosphere. Nitrogen oxides, as an important precursor, are gradually consumed (An et al., 2003; Li et al., 2004), and the concentration begins to significantly decrease. Thus, a clear low value period was formed from 13:00 to 17:00. And due to the highest temperature around 12:00-16:00 every day, the strongest solar radiation, and the strongest convection, it is very conducive to the dilution and transfer of nitrogen oxides. Therefore, the daily variation curve of nitrogen oxide concentration reaches its lowest value around 14:00.

The reason for the high concentration of nitrogen oxides in the third stage (18:00-20:00) is that as the sun sets, radiation decreases, and the closure of nocturnal photochemical reactions reduces the consumption of nitrogen oxides as precursors of O_3. Air convection is significantly weakened, and the atmosphere gradually stabilizes, which is not conducive to the diffusion of pollutants. And at this time, it is the peak time for residents to go home and cook, as well as the peak time for the urban catering industry. There are a large number of vehicles driving on the road, resulting in high exhaust emissions and a slow increase in nitrogen oxide concentration (An et al., 2003; An et al., 2008). Therefore, between 18:00 and 20:00, nitrogen oxides form a small peak.

In summary, there search results are similar to the diurnal variation of nitrogen oxide concentration in previous literature, but the arrival time points of peak and valley values are different, which may be related to the weather conditions during the observation period. During the observation period, there were cloudy weather and frequent rainfall in Jingzhou City, which were unfavorable for the diffusion of pollutants. Due to the high emissions of motor vehicles, although weaker photochemical reactions in the morning consumed some nitrogen oxides, nitrogen oxides continued to accumulate during the day. In addition, the concentration of nitrogen oxides in the vertical upward transport, which was more active during the day, exceeded the consumption of nitrogen oxides by photochemical reactions, leading to a gradual increase in nitrogen oxide concentration, and nitrogen oxides near the ground reached their peak again at 18:00 (Lin et al., 2007; Wang et al., 2010).

4. Shortcomings

This study needs to be optimized in terms of observation data recording and observation locations, especially in the lack of comparability in location selection. Therefore, it was not possible to analyze the changes of nitrogen oxides in different environments and climates at a deeper level, and there is also a lack of data support for early morning observations in terms of time. Although many research results have shown that nitrogen oxide emission concentrations will gradually decrease at night due to reduced human activity, reaching a valley in the early morning. For example, on sunny days, the concentration of nitrogen oxides changes less with time before sunrise, reaching its lowest value around 6:00 and gradually increasing thereafter. These issues will be optimized in future experiments, and we look forward to more relevant discoveries in the future.

Conflict of Interest

The authors declare that they have no conflicts of interest to this work.

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