Impact of Motor Vehicle Exhaust on the Air Quality of an Urban City

Baohua Wang\textsuperscript{1}, Bingquan Wang\textsuperscript{2}, Bo Lv\textsuperscript{1}, Rui Wang\textsuperscript{1,3*}

\textsuperscript{1} School of Environmental Science & Engineering, Shandong University, Jimo, Qingdao 266237, China
\textsuperscript{2} School of Chemistry and Molecular Engineering, Qingdao University of Science and Technology Qingdao 266042, China
\textsuperscript{3} Shenzhen Research Institute of Shandong University, Shenzhen 518057, China

ABSTRACT

The development of the economy and the prosperity of the industry have not only promoted the great progress of motor vehicle industry, but also made the number of motor vehicles in large and medium cities increase rapidly. In recent years, with the increasing number of urban motor vehicles, the environmental pollution caused by motor vehicle exhaust on both sides of the road has become increasingly serious. The high concentration of pollutants emitted by motor vehicles will seriously affect and threaten the health of pedestrians on both sides of the road and surrounding residents. In this work, the environmental monitoring data (NO\textsubscript{2}) from different areas of Jinan city over different time periods were summarized from 2001 to 2007. It was found that the NO\textsubscript{2} concentration in the ambient air of Jinan gradually decreased due to the treatment of motor vehicles taken in Jinan for the 29\textsuperscript{th} Olympic Games in 2005, the NO\textsubscript{2} concentration during the urban heating period fell by nearly 70%, and the air during the urban heating period was significantly higher than that in the non-heating period. In 2004, the concentration of NO\textsubscript{2} in the air during the urban heating period was nearly twice as high as during the non-heating period. Taking the city of Jinan, China in 2008 as an example, the contribution of motor vehicle emissions to the ambient air quality in Jinan, especially CO and NO\textsubscript{2}, was investigated through real-time monitoring of pollutants emitted by motor vehicles on several main roads in Jinan. The results showed that the pollutants emitted by motor vehicles in Jinan, especially CO and NO\textsubscript{2}, contribute greatly to the ambient air quality of Jinan. Among them, the highest average CO concentration was measured beside Jingqi Road, which was attributed to poor vehicle driving conditions and low speeds due to congestion on Jingqi Road. The necessary motor vehicle exhaust control measures were proposed.

Keywords: Motor vehicle exhaust, Ambient air quality, Control measures

1 INTRODUCTION

At present, there is no unified classification of motor vehicles in China. According to the total weight of vehicles, Chinese motor vehicles can be divided into four categories: light, medium, heavy and motorcycle. Motor vehicle exhaust contains more than 200 kinds of compounds (Zhu \textit{et al.}, 2008; Mohd Shafie and Mahmud, 2020; González \textit{et al.}, 2020), the main pollutants are CO, HC, NO\textsubscript{x} and lead compounds, sulfide, smoke, oil mist, etc. Among the pollutants of motor vehicle exhaust, CO makes the largest contribution to motor vehicle exhaust. NO\textsubscript{x} is the most toxic of the NO\textsubscript{x} and can form photochemical smog (Zamorategui-Molina \textit{et al.}, 2021; Biswas \textit{et al.}, 2021; Liu \textit{et al.}, 2022). These harmful gases diffuse into the air will cause air pollution and harm the human body. In 2016, on-road vehicles accounted for about 39% and 20% of total NO\textsubscript{2} and CO emissions in the European Union (EU), and it is found those passenger vehicles are the major cause of NO\textsubscript{2} and CO emissions from road transportation (Mohd Shafie and Mahmud, 2020; Iqbal \textit{et al.}, 2022).
The comprehensive ambient air pollution index was used to describe the comprehensive condition of urban ambient air quality. The comprehensive ambient air pollution indices were calculated as the quotients of the concentrations of several pollutants to the secondary values in the corresponding national ambient air quality standards (GB 3095-1996). It could be seen that since 2001, except for a slight increase in 2003, the overall trend of the comprehensive ambient air pollution index in Jinan has been decreased. The comprehensive ambient air pollution index has been decreased from 3.15 in 2003 to 2.55 in 2005. However, the inhalable particulate matter pollution in the urban area of Jinan should be taken seriously, and the pollution of fine particulate matter was more harmful to human health. This part of fine particulate matter has a great relationship with motor vehicle emissions. The particle size of particulate matter emitted by motor vehicles, mainly diesel vehicles, is often below 1 µm (Wen et al., 2009; Yang et al., 2022). When the motor vehicles drove on the road, the highest concentration of harmful substances emitted was about 1 m from the ground and was on the respiratory belt of pedestrians, which could reach the deepest part of the lungs and cause the greatest harm to human body. According to the source analysis results of ambient PM_{2.5} in Jinan (2008) (Gu et al., 2014; Yang et al., 2013), the primary pollution source of ambient PM_{2.5} in Jinan was motor vehicle exhaust dust, accounting for 27.1%, and the contribution rate of secondary particles transformed into NO_{2} and SO_{2} was 20.9%.

Breathing this polluted air for a long time has become an important pathogenic factor of cardiovascular diseases and cancer (Lin et al., 2020; Man and Li, 2021), such as pulmonary heart disease, coronary heart disease, arteriosclerosis, hypertension. Therefore, it is of positive significance to study the degree of influence of motor vehicle exhaust pollution on the ambient air quality of urban roads in Jinan and propose necessary motor vehicle exhaust control measures to protect people’s health.

In this paper, combined with the monitoring data of ambient air quality in Jinan, we conducted real-time monitoring the concentration of motor vehicle exhaust pollutants on both sides of several main roads in Jinan to analyze the degree of influence of motor vehicle exhaust on urban ambient air quality, and to propose feasible motor vehicle exhaust control strategies.
Table 2. The distribution of actual road monitoring points for motor vehicle emissions in Jinan.

| Road section | Road monitoring points | Ambient air automatic monitoring sub-stations | Monitoring time |
|--------------|------------------------|-----------------------------------------------|-----------------|
| Shanda Road  | Sidewalk at the gate of Jinan monitoring station | Sub-station of municipal monitoring station | September 25, 2008 7:00–19:00 |
| Weier Road   | East sidewalk at the intersection of Weier road and Jingqi Road | Sub-station of Chemical Plant | Monitoring frequency is 1 hour |
| Jingshi Road | Sidewalk of West Jingshi Road, Yanshan Overpass | Sub-station of Economics College |
| Jingqi Road  | Sidewalk of Jingqi Road near Quancheng Square | Sub-station of Quancheng Square |

2 METHODS

2.1 Layout Method of Road Monitoring Points

The road monitoring points were located on the sidewalk 3–5 m away from the road carriageway, about 1.5 m above the ground, and one monitoring point was set for each main traffic road. Infrared filtering method was used for CO and chemiluminescence method was used for NOx. Both NOx and CO were continuously monitored from 7:00 to 19:00 every day.

In this paper, the green represented that the pollutant concentration meets the Grade II for the Chinese National Ambient Air Quality Standard (GB 3095-1996), Same as the WHO Air Quality Guideline (AQG) in 2005 (WHO, 2006; Schwela and Haq, 2020). The yellow to represent that the pollutant concentration meets the Grade III for the Chinese National Ambient Air Quality Standard (GB 3095-1996). The red represented that the pollutant concentration exceeds the Grade III for the Chinese National Ambient Air Quality Standard (GB 3095-1996).

2.2. Distribution of Monitoring Points

In order to further understand the contribution of motor vehicle pollutant emissions to the ambient air quality in Jinan, actual road monitoring was conducted on four main traffic road (Shanda Road, Weier Road, Jingshi Road and Jingqi Road) in Jinan on September 25, 2008. The specific distribution of monitoring points is shown in Table 2, which also lists the automatic monitoring sub-stations corresponding to the road sections.

3 RESULTS AND DISCUSSION

3.1 The Influence of Motor Vehicles Exhaust on Ambient Air Quality in Jinan

The sub-station of Jinan Chemical Plant for automatic ambient air monitoring (near Jinan Long Distance Bus Station) was selected to represent the dense traffic area of Jinan. The sub-station of the Provincial Seed Warehouse for automatic ambient air monitoring (near Huangtai power plant) was selected to represent the industrial area of Jinan. November to March was selected to represent the heating period in Jinan, and April to October was selected to represent the non-heating period in Jinan.

The interannual variation of NO2 concentration in ambient air of Jinan from 2001 to 2007 are shown in Fig. 1. From 2001 to 2004, with the rapid growth of motor vehicle ownership, the NO2 concentration in the ambient air of Jinan increased significantly. After 2005, the NO2 concentration in the ambient air of Jinan gradually decreased. This was most pronounced in the air during the urban heating period, where the NO2 concentration fell by nearly 70%. This result is similar to the finding of previous study (Cheng et al., 2011), indicating that the greater impacts of the treatment of motor vehicles taken in Jinan after 2005 for the 29th Olympic Games in 2008 on the ambient air pollution. The concentration of NO2 in the ambient air of Jinan showed obvious seasonal variation and the air during the urban heating period was significantly higher than that in the non-heating period. In 2004, the concentration of NO2 in the air during the urban heating period was nearly twice as high as during the non-heating period. Song et al. (2021) investigated the
concentrations of four air pollutants including PM$_{2.5}$, SO$_2$, NO$_2$, and CO during the heating period in Northern China, the results showed that the air pollutants during the heating period were mostly derived from secondary inorganic source (26.5%), coal combustion (24.0%) and vehicle exhaust (21.4%). Gu et al. (2014) found that the weather of Jinan in winter was usually influenced by high pressure systems by the 1-year observation of PM$_{2.5}$ in Jinan, which caused formation of inversion layers that could inhibit pollutant dispersion. The NO$_2$ concentration in the ambient air of the dense traffic area was slightly higher than that in other areas of Jinan. It could be seen that the motor vehicle exhaust had an impact on ambient air quality in Jinan.

3.2 The Measured Results of CO and NO$_2$ Concentration Beside the Four Main Traffic Roads

Monitoring was carried out according to the distribution of monitoring points in Table 2, and the monitoring items were mainly NO$_2$ and CO. The measured results of CO concentration beside the four main traffic roads are shown in Fig. 2. It could be seen that the concentration of CO by the roadside in Jinan could meet the Grade II for the Chinese National Ambient Air Quality Standard. The CO concentration by the roadside of different main roads was different, and the highest average concentration of CO was measured beside Jingqi Road. It was probably due to Jingqi Road congestion resulting in poor vehicle driving conditions and lower speeds. In recent years, Jiang et al. (2017) found that when the vehicle is idling, decelerating and suddenly accelerating, the fuel will not be fully burned and the intensity of emission will increase significantly. The total amount of CO emission will be the least when the vehicle is driving at a medium speed and uniform speed. It could be seen that the congestion phenomenon of Jingqi Road caused the CO concentration of Jingqi Road to exceed the standard. Except 8:00–9:00 AM. in the morning, the measured average concentration of CO on Weier road was the lowest. The measured average concentration of CO by the road section was higher in the morning during working hours, and also higher at the end of working hours. It was coincided with the trend of increased traffic flow during the peak commuting hours.

The measured results of NO$_2$ concentration beside the four main traffic roads are shown in Fig. 3. The measured concentration of NO$_2$ beside Shanda Road was higher, followed by Jingshi Road, and the measured concentration of NO$_2$ beside Jingqi road was the lowest. Moreover, Shanda Road and Jingshi Road exceeded the standard for urban areas for some time. From the changing trend of the overall monitoring results, the high value of NO$_2$ appears at 14:00 noon and the afternoon after work peak. Overall, the daily average concentration of NO$_2$ meets the Grade II for the Chinese National Ambient Air Quality Standard. This trend was consistent with
previous research results (Zhu et al., 2008), the main reason for this situation was that Jinan has increased its efforts to prevent motor vehicle exhaust pollution in recent years. Eliminating a number of old diesel buses and banning a number of seriously polluting vehicles on the road.

### 3.3 Comparison between the Actual Monitoring Data of Shanda Road with the Ambient Air Data of the Sub-station of Jinan Monitoring Station

Comparison between the actual monitoring data of Shanda Road with the ambient air data of the sub-station of Jinan monitoring station are shown in Figs. 4(a) and 4(b). It could be seen that the pollutant data monitored by roadside was different from the data monitored by the Jinan automatic monitoring sub-station. The measured average concentrations of NO₂ and CO by the roadside of Shanda Road were higher than the ambient air, indicating that both NO₂ and CO emitted by motor vehicles of Shanda road had a great impact on the ambient air quality in Jinan. Li et al. (2020) found that the measured average concentration of VOCs by the roadside was
Fig. 4. Comparison between the actual monitoring data of Shanda Road with the ambient air data of the sub-station of Jinan monitoring station.

higher than the ambient air, the result was similar to the findings of this study. For CO, the measured data beside the roads was greater than the concentration of CO in the ambient air at all times except at 10:00 AM and 17:00 and 18:00 PM. This indicates that the concentration of CO emitted from vehicles on Shanda Road contributes more to the ambient air pollution in Jinan. For NO2, the measured data beside the roads was greater than the concentration of NO2 in the ambient air at all times except for the period 8:00—11:00 AM. Moreover, Shanda Road exceeded the standard for urban areas for some time. This indicates that the concentration of NO2 emitted from vehicles on Shanda Road contributes more to the ambient air pollution in Jinan. In conclusion, the concentration of CO and NO2 emitted by motor vehicles in this road section was high and concentrated near the ground, which is harmful to the human body.

3.4 Comparison between the Actual Monitoring Data of Weier Road with the Ambient Air Data of the Sub-station of Jinan Chemical Plant

Comparison between the actual monitoring data of Weier Road with the ambient air data of the sub-station of Jinan Chemical Plant are shown in Figs. 5(a) and 5(b). It could be seen that the measured average concentrations of NO2 and CO by the roadside of Weier Road were higher than the ambient air. It was similar to the result of Shanda Road. Especially the concentration of NO2 in Weier Road, the measured data beside the Weier Road was greater than the concentration of NO2 in the ambient air at all times. This indicates that the concentration of NO2 emitted from vehicles on Weier Road contributes more to the ambient air pollution in Jinan.

3.5 Comparison between the Actual Monitoring Data of Jingshi Road with the Ambient Air Data of the Sub-station of Jinan Economics College

Comparison between the actual monitoring data of Jingshi Road with the ambient air data of the sub-station of Jinan Economics College are shown in Figs. 6(a) and 6(b). It could be seen that the measured average concentrations of NO2 and CO by the roadside of Jingshi Road were higher than the ambient air, indicating that both NO2 and CO emitted by Jingshi road motor vehicles had a great impact on the ambient air quality in Jinan. It was similar to the result of Shanda Road and Weier Road.

3.6 Comparison between the Actual Monitoring Data of Jingqi Road with the Ambient Air Data of the Sub-station of Jinan Quancheng Square

Comparison between the actual monitoring data of Jingqi Road with the ambient air data of the sub-station of Jinan Quancheng Square are shown in Figs. 7(a) and 7(b). The NO2 concentration measured by the roadside was lower than the concentration of NO2 in the ambient air at other
times except for 14:00–15:00 P.M. For CO, the measured data beside the Jingqi Road was greater than the concentration of CO in the ambient air at all times. This indicates that CO emitted from motor vehicles on Jingqi Road contributes more to the ambient air pollution in Jinan, while NO\textsubscript{2} contributes less to the ambient air pollution in Jinan. This may be caused by the congestion of Jingqi Road leading to poor motor vehicle driving conditions and low motor vehicle speed.

According to the Jinan Municipal Government's Air Quality Status Report for April 2022, the current concentration of NO\textsubscript{2} near the sampling site was 0.034 mg m\textsuperscript{-3}, the current concentration of CO near the sampling site was 0.8 mg m\textsuperscript{-3}, all of which could meet the Grade II for the Chinese National Ambient Air Quality Standard (GB 3095-2012). Cheng et al. (2021) conducted a follow-up survey on the ambient air quality in Jinan. It was found that as Jinan improved the motor vehicle source control mechanism and standardized the motor vehicle exhaust inspection work, and carried out in-depth sampling and road inspection of motor vehicle parking places, the number of motor vehicles on Jinan’s roads was controlled (the number of vehicles on the road is stable) and the motor vehicle exhaust was relatively stable. This may be the reason why the concentrations of NO\textsubscript{2} and CO (2022) do not differ much from our observed data (2008). However, the current control measures in Jinan can only achieve a stable level of motor vehicle emissions.
Fig. 7. Comparison between the actual monitoring data of Jingqi Road with the ambient air data of the sub-station of Jinan Quancheng Square.

and do not lead to further reductions in pollutant emissions. The motor vehicle exhaust was still the main sources of air pollution in Jinan.

In conclusion, the pollutants emitted by motor vehicles in Jinan, especially NO₂ and CO, contribute more to the ambient air quality in Jinan, and the impact of pollutants emitted by motor vehicles on the environment on both sides of the road should be taken seriously. Therefore, reducing the emission of harmful substances from automobile exhaust is an important way to solve air pollution.

3.7 Control Strategies of Motor Vehicles Exhaust in Jinan

The emission control of motor vehicles exhaust in Jinan is a huge and complicated project. It is not only directly related to the use, maintenance and fuel quality of motor vehicles, but also closely related to urban traffic management, fiscal and tax policies, etc. At the same time, it also involves the vital interests of society, enterprises and motor vehicle owners. Therefore, every link affecting tailpipe emissions should be seized for control. According to the actual situation of motor vehicles in Jinan, the reduction of motor vehicle pollution should focus on the following measures:

1. Improve laws and regulations, strengthen supervision and management;
2. Promotion of new energy vehicles to a certain fraction and optimize the energy structure of motor vehicles to control pollution emissions;
3. Strengthen urban planning and speed up road construction;
4. Strengthen environmental protection publicity and enhance people's awareness of environmental protection;
5. Improve the traffic environment and enhance the environmental effect.

By taking the above control measures, the problem of automobile exhaust pollution in Jinan will be effectively controlled.

4 CONCLUSION

Through the monitoring of pollutants emitted by motor vehicles on both sides of several main roads in Jinan, the following conclusions were drawn:

1. The NO₂ concentration in the ambient air of Jinan gradually decreased due to the treatment of motor vehicles taken in Jinan for the 29th Olympic Games in 2008. Among them, the NO₂ concentration during the urban heating period fell by nearly 70%.
2. The concentration of NO₂ in the ambient air of Jinan showed obvious seasonal variation and the air during the urban heating period was significantly higher than that in the non-heating period.

Aerosol and Air Quality Research | https://aaqr.org 8 of 10 Volume 22 | Issue 8 | 220213
period. In 2004, the concentration of NO₂ in the air during the urban heating period was nearly twice as high as during the non-heating period.

(3) The CO concentration by the roadside of different main roads was different, and the highest average concentration of CO was measured beside Jingqi Road. It was probably due to Jingqi Road congestion resulting in poor vehicle driving conditions and lower speeds.

(4) The pollutants emitted by motor vehicles in Jinan, especially CO and NO₂, contribute greatly to the ambient air quality of Jinan. Therefore, reducing vehicle exhaust emissions in Jinan is of great significance to improve the ambient air quality in Jinan. Formulating strict local standards for motor vehicle emission in Jinan, establishing a motor vehicle emission charging system, strengthening urban planning, promoting new energy vehicles, enhancing environmental protection publicity and improving the traffic environment can all play a role in controlling motor vehicle emission pollution in Jinan to a certain extent.

ACKNOWLEDGEMENT

This work was supported by the Research and Development Program of Shandong Province, China [2006BS08020] and the Scientific Innovation Program of Shenzhen City, China, under basic research program (JCYJ20170818102915033).

REFERENCES

Biswas, M.S., Pandithurai, G., Aslam, M.Y., Patil, R.D., Anilkumar, V., Dudhambe, S.D., Mahajan, A.S. (2021). Effect of boundary layer evolution on nitrogen dioxide (NO₂) and formaldehyde (HCHO) concentrations at a high-altitude observatory in western India. Aerosol Air Qual. Res. 21, 200193. https://doi.org/10.4209/aaqr.2020.05.0193

Cheng, M., Tang, G., Lv, B., Li, X., Wu, X., Wang, Y., Wang, Y. (2021). Source apportionment of PM₂.₅ and visibility in Jinan, China. J. Environ. Sci. 102, 207–215. https://doi.org/10.1016/j.jes.2020.09.012

Cheng, S., Yang, L., Zhou, X., Wang, Z., Zhou, Y., Gao, X., Wang, W. (2011). Evaluating PM₂.₅ ionic components and source apportionment in Jinan, China from 2004 to 2008 using trajectory statistical methods. J. Environ. Monit. 13, 1662. https://doi.org/10.1039/c0em00756k

Deng, X. (2006). Economic costs of motor vehicle emissions in China: A case study. Transp. Res. Part D 11, 216–226. https://doi.org/10.1016/j.trd.2006.02.004

Feng, Y., Wu, J., Zhu, T., Bai, Z., Yan, H., Tan, X. (2004). Study on source appointment of TSP and PM₁₀ in air environment in Jinan. Environ. Sci. Res. 17, 1–5 https://doi.org/10.13198/j.res.2004.02.3.fengych.001 (in Chinese).

González, C.M., Gómez, C.D., Aristizábal, B.H. (2020). DROVE: An algorithm for spatial and temporal disaggregation of on-road vehicle emission inventories. Aerosol Air Qual. Res. 20, 2765–2779. https://doi.org/10.4209/aaqr.2020.04.0184

Gu, J., Du, S., Han, D., Hou, L., Yi, J., Xu, J., Bai, Z.P. (2014). Major chemical compositions, possible sources, and mass closure analysis of PM₂.₅ in Jinan, China. Air Qual. Atmos. Health 7, 251–262. https://doi.org/10.1007/s11869-013-0232-9

Iqbal, A., Ahmad, N., Mohy ud Din, H., Van Roozendael, M., Anjum, M.S., Zeeshan Ali Khan, M., Khokhar, M.F. (2022). Retrieval of NO₂ columns by exploiting MAX-DOAS observations and comparison with OMI and TROPOMI data during the time period of 2015–2019. Aerosol Air Qual. Res. 22, 210398. https://doi.org/10.4209/aaqr.210398

Jiang, Y., Gu, P., Chen, Y., He, D., Mao, Q. (2017). Influence of land use and street characteristics on car ownership and use: Evidence from Jinan, China. Transp. Res. Part D 52, 518–534. https://doi.org/10.1016/j.trd.2016.08.030

Li, J., Wang, X., Xue, L., Gao, X., Sun, L., Wang, W. (2019). Study on the characteristics and influencing factors of exhaust particulate matter pollution of typical motor vehicles in Jinan. J. Environ. Sci. 39, 35–43. https://doi.org/10.13671/j.hjkxxb.2018.0323 (in Chinese).

Li, M., Wu, L., Zhang, X., Wang, X., Bai, W., Ming, J., Yang, W. (2020). Comparison of PM₂.₅ chemical compositions during haze and non-haze days in a heavy industrial city in North China. Aerosol Air Qual. Res. 20, 1950–1960. https://doi.org/10.4209/aaqr.2019.11.0591
Li, T., Wang, W., Li, X. (2005). Analysis technology and application of air pollution impact of motor vehicles in urban traffic planning. Transp. Syst. Eng. Inf. 5, 90–96. https://doi.org/10.16097/j.cnki.1009-6744.2005.02.016 (in Chinese).

Lin, Y.C., Li, Y.C., Amesho, K.T.T., Chou, F.C., Cheng, P.C. (2020). Filterable PM$_{2.5}$, metallic elements, and organic carbon emissions from the exhausts of diesel vehicles. Aerosol Air Qual. Res. 20, 1319–1328. https://doi.org/10.4209/aaqr.2020.02.0081

Liu, X., Cui, K., Hsieh, Y.K., Wang, Y.F., Wang, R. (2022). Study on air quality index, atmospheric pollutants and dry deposition of PCDD/Fs in the ambient air near southwest China. Aerosol Air Qual. Res. 22, 220160. https://doi.org/10.4209/aaqr.220160

Man, Z., Li, Z. (2021). Motor vehicle exhaust detection technology and pollution prevention countermeasures. Internal Combust. Engine Parts 19, 184–185 https://doi.org/10.19475/j.cnki.issn1674-957x.2021.19.086 (in Chinese).

Mohd Shafie, S.H., Mahmud, M. (2020). Urban air pollutant from motor vehicle emissions in Kuala Lumpur, Malaysia. Aerosol Air Qual. Res. 20, 2793–2804. https://doi.org/10.4209/aaqr.2020.02.0074

Schwela, D.H., Haq, G. (2020). Strengths and weaknesses of the WHO urban air pollutant database. Aerosol Air Qual. Res. 20, 102–1037. https://doi.org/10.4209/aaqr.2019.11.0605

Song, A., Meng, J., Zhou, R., Li, Z., Li, Y., Chen, M., Hou, Z., Yan, L., Wang, Y. (2021). Characteristics and sources of single particles in the urban liaocheng of North China during the heating period. Aerosol Air Qual. Res. 21, 210144. https://doi.org/10.4209/aaqr.210144

Wang, F., Zheng, P., Dai, J., Wang, H., Wang, R. (2019). Fault tree analysis of the causes of urban smog events associated with vehicle exhaust emissions: A case study in Jinan, China. Sci. Total Environ. 668, 245–253. https://doi.org/10.1016/j.scitotenv.2019.02.348

Wen, X., Cui, Z., Zhang, G. (2009). Analysis of the source apportionment of PM$_{2.5}$ in Jinan. J. Univ. Jinan 23, 292–295 https://doi.org/10.13349/j.cnki.jdxbn.2009.03.009 (in Chinese).

Williams, M.L., Lott, M.C., Kitwiroon, N., Dajnak, D., Walton, H., Holland, M., Beevers, S.D. (2018). The Lancet Countdown on health benefits from the UK Climate Change Act: A modelling study for Great Britain. Lancet Planet. Heath 2, e202–e213. https://doi.org/10.1016/s2542-5196(18)30067-6

World Health Organization (WHO) (2006). Air quality guidelines: global update 2005: particulate matter, ozone, nitrogen dioxide and sulfur dioxide. World Health Organization. Regional Office for Europe. https://apps.who.int/iris/handle/10665/107823

Yang, L., Cheng, S., Wang, X., Nie, W., Xu, P., Gao, X., Wang, W. (2013). Source identification and health impact of PM$_{2.5}$ in a heavily polluted urban atmosphere in China. Atmos. Environ. 75, 265–269. https://doi.org/10.1016/j.atmosenv.2013.04.058

Yang, X., Zhong, Y., Li, G., Liao, Y., Cai, C., Chi, H. (2022). Distribution characteristics and source distribution of heavy metals in atmospheric dust in typical industrial cities -- A case study of Jinan City. Environ. Chem. 41, 94–103. https://doi.org/10.7524/j.issn.0254-6108.2020090803 (in Chinese).

Zamorategui-Molina, A., Gutiérrez-Ortega, N.L., Baltazar-Vera, J.C., Del Ángel-Soto, J., Tirado-Torres, D. (2021). Carbon monoxide and particulate matter concentrations inside the road tunnels of Guanajuato City, Mexico. Aerosol Air Qual. Res. 21, 210039. https://doi.org/10.4209/aaqr.210039

Zhao, N., Wang, G., Li, G., Lang, J. (2021). Trends in air pollutant concentrations and the impact of meteorology in Shandong province, coastal China, during 2013-2019. Aerosol Air Qual. Res. 21, 200545. https://doi.org/10.4209/aaqr.200545

Zhu, Z., Yang, X., Yang, C. (2008). The current situation and pollution control measures of motor vehicles in fleet Jinan. J. China Environ. Manage. Cadre College 18, 7–9. https://doi.org/10.13358/j.issn.1008-813x.2008.04.021 (in Chinese).