# Characterization of roadside air pollutants: An artery road of Lanzhou city in northwest China

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**Abstract.** Due to the lack of air and traffic monitoring data in China, this study employed a remote sensing (RS) system and air quality monitoring sensors to investigate the air pollutant concentrations, traffic profiles and meteorological data in order to characterize roadside pollutant concentrations and identify their influence factors for a major road in Lanzhou. The results suggested that the temporal variations of concentrations of $SO_2$, $NO_2$, $PM_{2.5}$, $PM_{10}$ and CO peaked at 5:00-7:00 while $O_3$ peaked at 17:00. The concentrations of roadside air pollutants were lower on weekdays than weekends except $O_3$. The concentrations of $PM_{2.5}$ and $PM_{10}$ declined with the height of the monitoring sites increased, peaking at 2-meter height whereas $SO_2$, $NO_2$, CO, and $O_3$ reached their highest concentrations at 4-meter height. The concentrations of roadside $NO_2$ and CO show positive correlations with the volume of heavy-duty trucks (HDTs) and light-duty passenger vehicles (LDPVs), respectively. This study provided scientific support to the establishment of roadside air quality monitoring systems and the assessment of the environmental and health impact from vehicle emissions.

## 1 Introduction

With the growing motor vehicle ownership in China, exhaust emissions have become increasingly prominent in urban and regional air pollution [1-4]. Statistics show that China registered 372 million motor vehicles and there were 15.93 million tons of emissions from four vehicle-based pollutants at the end of 2020, where mobile sources were the primary contributor to $PM_{2.5}$ in certain cities [5]. Several studies have shown that vehicular $NO_X$ is the culprit of high $NO_2$ concentrations in urban areas. In addition, VOCs and $NO_X$ emissions from vehicles are important precursors of $O_3$, contributing significantly to summertime $O_3$ pollution [6-8]. Meanwhile, such emissions, being near the earth's surface,

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have a particular impact on the health of populations subject to long-term exposure to traffic pollution or high traffic density [9-11].

There have been few studies on the characteristics of air pollution at the level of traffic monitoring sensors in China, and the existing ones mainly focus on large cities such as Beijing, Shanghai, Guangzhou, and Shenzhen [12-14]. The 14*th* Five-Year Plan for Ecological Environment Monitoring clearly states that roadside air quality sensors shall be built along major arterial roads in municipalities for the monitoring of $PM_{2.5}$, NMHC, $NO_X$ and traffic flow. Lanzhou, the capital of the Gansu province at the geometric center of China, is an important hub for transportation and a golden node of the Belt and Road Initiative. As the first victim of photochemical smog in China, Lanzhou has seen its vehicle ownership soaring from 89.9 in 2016 to 1.145 million in 2020, growing 6.25% per year, higher than the provincial average of 5.2%. Compounded by factors such as its industrial, geographical and climate features, Lanzhou paints a bleak picture of atmospheric pollution [15]. A wealth of studies has demonstrated that Lanzhou are on an upward trend in terms of $NO_2$ and $O_3$ concentrations [16-18].

This paper investigates the spatiotemporal variations in roadside air pollutant concentrations and analyzes their influencing factors with Lanzhou as the case study, where pollutant concentrations, meteorological data, and traffic flow were watched by the roadside monitoring sensors and vehicle exhaust RS (remote sensing), aiming to provide scientific evidence to support the design and deployment of traffic-based air quality monitoring system, environment impact assessment of vehicle emissions, and relevant research on public health.

## 2 Overview: roadside monitoring

### 2.1 Road selection

In 2016, to enhance the prevention and control of vehicle exhaust pollution, fleet screening for high emitters, and air quality in the city, Lanzhou's Bureau of Ecology and Environment selected six sites along the entrances and exits of urban areas and major transport linkages to install RS for the monitoring of vehicle emissions.

In consideration of traffic flow, site conditions and other factors, the study selected the Fuci Street in Chengguan District as the section during the monitoring period of July 1-30, 2021. Fuci Street, as the artery of National Highway G109, is a key passage linking north and south Lanzhou.

### 2.2 Monitoring sites

In accordance with the topographic and geomorphological features of the selected 1km-long road section, researchers used pole-mounted units and set up four air quality monitoring sites spaced 500 meters apart and distributed symmetrically on both sides of the road, with each monitoring site fitted with monitoring equipment at a height of 2m, 4m and 6m off the ground. See Table 1 for the longitude and latitude information of the four monitoring sites, and Figure 1 for the roadside monitoring system deployment. RS for vehicle exhaust monitoring is also available on the selected road.

### 2.3 Monitoring equipment

A total of 12 air quality monitoring sensors and 1 vehicle exhaust remote sensor were used in this study. The 12 devices are XHAQSN-812 Air Quality Sensor (Micro-station) from

Sailhero Environmental Protection, which monitor the six conventional air pollutants: $SO_2$, $NO_2$, $PM_{2.5}$, $PM_{10}$, CO, and $O_3$, as well as meteorological parameters including wind speed, wind direction, temperature, humidity, and atmospheric pressure. The exhaust sensor is a Hikvision iDS-TCV300 License Plate Recognition (LPR) unit by Sailhero's XHRCM2000 Continuous Particulate Monitor.

Consisting of high-precision electrochemical and optical sensors, the solar-powered air quality sensors, with low detection limits, reliable data, high time resolution, compact size among other merits, are suitable for grid and dense layout, which have numerous monitoring applications including air quality in cities and industrial parks, as well as vehicle exhausts in the roadside atmosphere. The equipment selection is mainly based on the Technical Specification for Installation and Acceptance and Operation of Grid-based Monitoring System for Air Pollution Prevention and Control (DB13/T2546-2017) and the Technical Specification for Automatic Ambient Air Quality Monitoring (HJ193-2005).

**Table 1.** Longitude and latitude information of the monitoring sites.

| Monitoring sites | Longitude(°) | Latitude(°) |
|---|---|---|
| V1 | 103.8368 | 36.0841 |
| V2 | 103.8368 | 36.0836 |
| V3 | 103.8382 | 36.0864 |
| V4 | 103.8378 | 36.0865 |

**Fig. 1.** Roadside monitoring system deployment.

## 3 Results and analysis

### 3.1 Characteristics: concentrations of roadside air pollutants

From the monitored data of atmospheric pollutants by hour from July 1st to 30th, this study conducts a statistical analysis on the variations by day, by weekday/weekend, and by height.

Figure 2 shows the daily variations of mass concentrations of the six air pollutants, which moved up, down and then up again for $SO_2$, $NO_2$, $PM_{2.5}$, $PM_{10}$ and CO while $O_3$ indicated an opposite trend. The peaks of the daily average concentrations of $SO_2$, $NO_2$, $PM_{2.5}$, $PM_{10}$ and CO were 81.1μg/m$^3$, 30.9μg/m$^3$, 90.6μg/m$^3$, 1.00mg/m$^3$ and the valleys 3.9μg/m$^3$, 22.7μg/m$^3$, 16.8μg/m$^3$, 40.2μg/m$^3$, 0.35mg/m$^3$, reached between 15:00 and 17:00, with the peak values being 2.9, 3.6, 1.8, 2.3, 2.9 and 3.1 times of valley values, respectively. Meanwhile, the crest and trough of $O_3$ were 157.2μg/m$^3$ at 15:00 and 51.0μg/m$^3$ at 7:00.

Figure 3 shows the weekday/weekend variations of mass concentrations of the six pollutants in roadside atmosphere, where less $SO_2$, $NO_2$, $PM_{2.5}$, $PM_{10}$, and CO whereas more $O_3$ pollution was observed on weekdays, with the average daily value of the former five being 5.8μg/m$^3$, 45.8μg/m$^3$, 22.8μg/m$^3$, 61.5μg/m$^3$, 0.50mg/m$^3$ and 99.3μg/m$^3$ from Monday to Friday while 6.1μg/m$^3$, 51.1μg/m$^3$, 23.1μg/m$^3$, 65.9μg/m$^3$, 0.55mg/m$^3$ and 96.0μg/m$^3$ on the weekend.

In general, $SO_2$, $NO_2$, $PM_{2.5}$, $PM_{10}$, and CO pollution levels were 5.2%, 10.3%, 1.5%, 6.7%, and 8.2% lower on weekdays than weekends, while the weekend $O_3$ pollution was 3.3% lower. Specifically, $SO_2$ and CO were higher on Tuesday and lower on Monday, $NO_2$ and $PM_{10}$ higher on Saturday and lower on Monday and Wednesday, respectively, $PM_{2.5}$ higher on Thursday and lower on Friday, while $O_3$ higher on Friday and lower on Sunday.

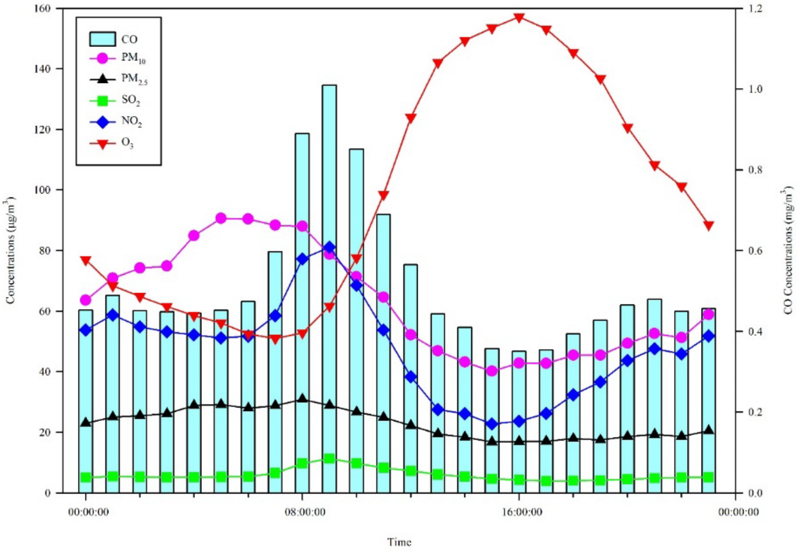


**Fig. 2.** $SO_2$, $NO_2$, $PM_{2.5}$, $PM_{10}$, CO, and $O_3$: daily variations of mass concentrations in roadside atmosphere.

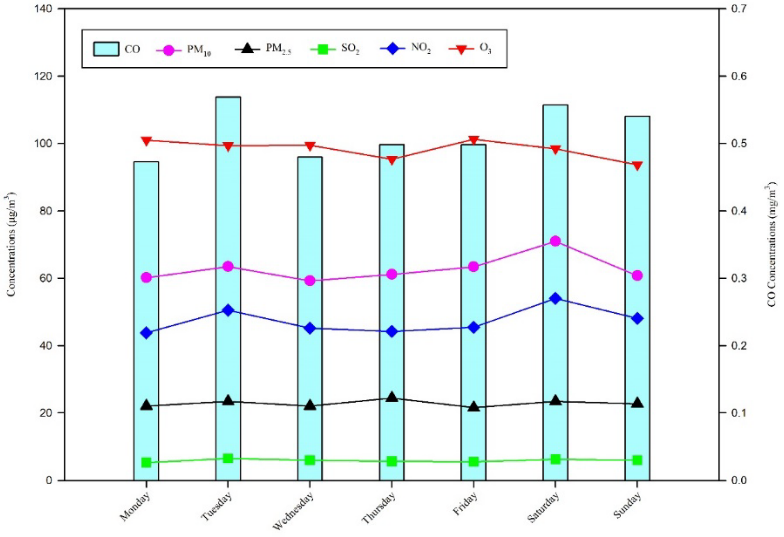


**Fig. 3.** $SO_2$, $NO_2$, $PM_{2.5}$, $PM_{10}$, CO, and $O_3$: weekday/weekend variations of mass concentrations in roadside atmosphere.

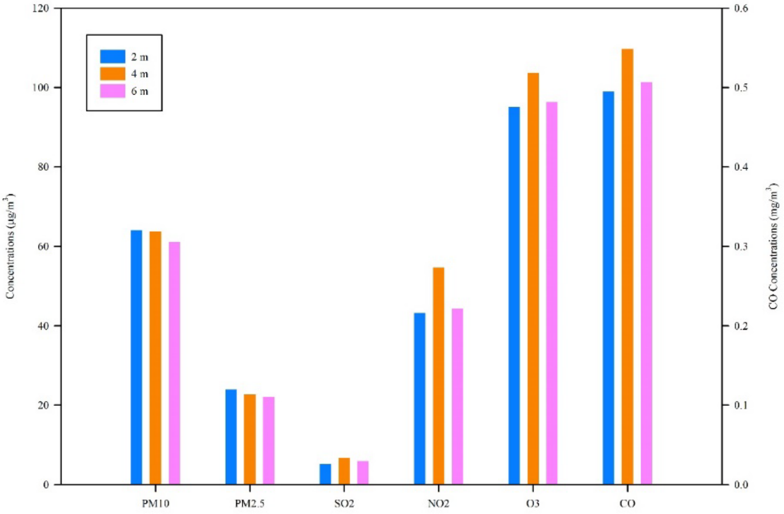


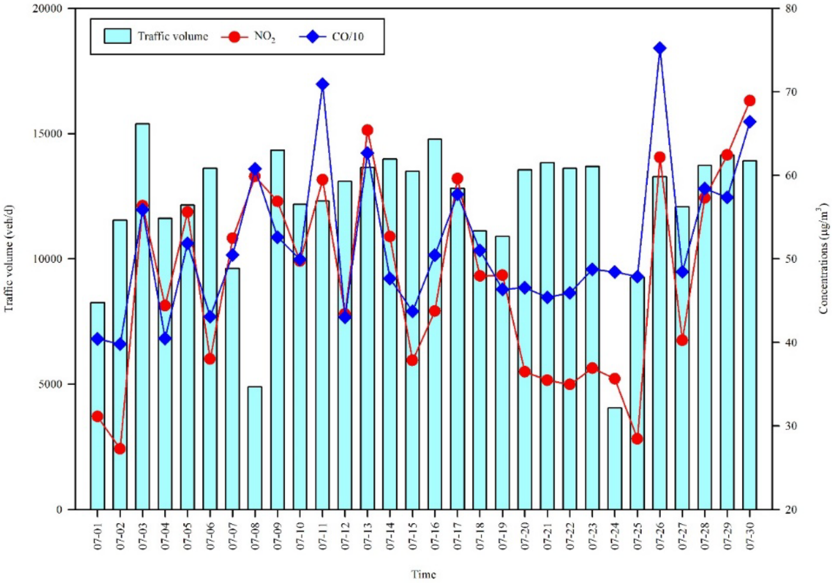
**Fig. 4.** $SO_2$, $NO_2$, $PM_{2.5}$, $PM_{10}$, CO, and $O_3$: vertical variation of mass concentrations in roadside atmosphere.

Figure 4 shows the mass concentrations variations of the six pollutants at different levels above ground. Both $PM_{2.5}$ and $PM_{10}$ gradually decline with height, with the average concentrations at 2-meter height being 23.9μg/m³ and 64.0μg/m³, and 6-meter height 22.1μg/m³ and 61.2μg/m³, which were 7.8% and 4.4% lower compared with 2m height. $SO_2$, $NO_2$, CO, and $O_3$ first increased before decreasing with the highest concentrations at 4-meter height and the lowest at 2-meter height. The average concentrations at 4-meter height were 6.7μg/m³, 54.6μg/m³, 0.55mg/m³ and 103.7μg/m³, and the 2-meter average 5.1μg/m³, 43.2μg/m³, 0.50mg/m³, and 95.0μg/m³. Compared with 4-meter level, the concentrations of $SO_2$, $NO_2$, CO and $O_3$ at 2-meter was lower by 23.1%, 20.9%, 9.7% and 8.4%, respectively. The vertical variations in pollutant concentrations may be related to the location of vehicle exhausts, physicochemical properties of pollution, as well as diffusion and dispersion processes.

## 3.2 Influencing factor analysis: concentrations of roadside atmospheric pollutants

Some studies [8,19] have found that $NO_X$ is mainly produced by vehicle exhausts and CO by coal combustion and vehicle exhausts. Figure 5 shows the correlation between $NO_2$ and CO mass concentrations and roadside traffic flow. $NO_2$ and CO concentrations were largely influenced by traffic flow, showing a positive correlation with the correlation coefficients of $NO_2$ being 0.72 and 0.94, while of CO being 0.78 and 0.62 for day 1-5 and day 25-30, respectively. In addition, $NO_2$ and CO exhibited similar trends in daily variations, where the correlation coefficient reached as high as 0.81.

Statistics [5] show that $NO_X$ emissions from diesel vehicles and CO from gasoline vehicles both exceed 80% of total vehicle emissions. The study selected the traffic volume of HDTs (heavy duty trucks) and LDPVs (light duty passenger vehicles) to analyze their correlation with $NO_2$ and CO. As shown in Figure 5, the concentrations of roadside $NO_2$ is mainly pegged to the volume of HDTs while CO to LDPVs. The correlation coefficients of roadside $NO_2$ concentrations and HDTs were 0.94 and 0.84, and CO to LDPVs 0.79 and 0.60 in the representative time periods of day 1-5 and day 25-30.



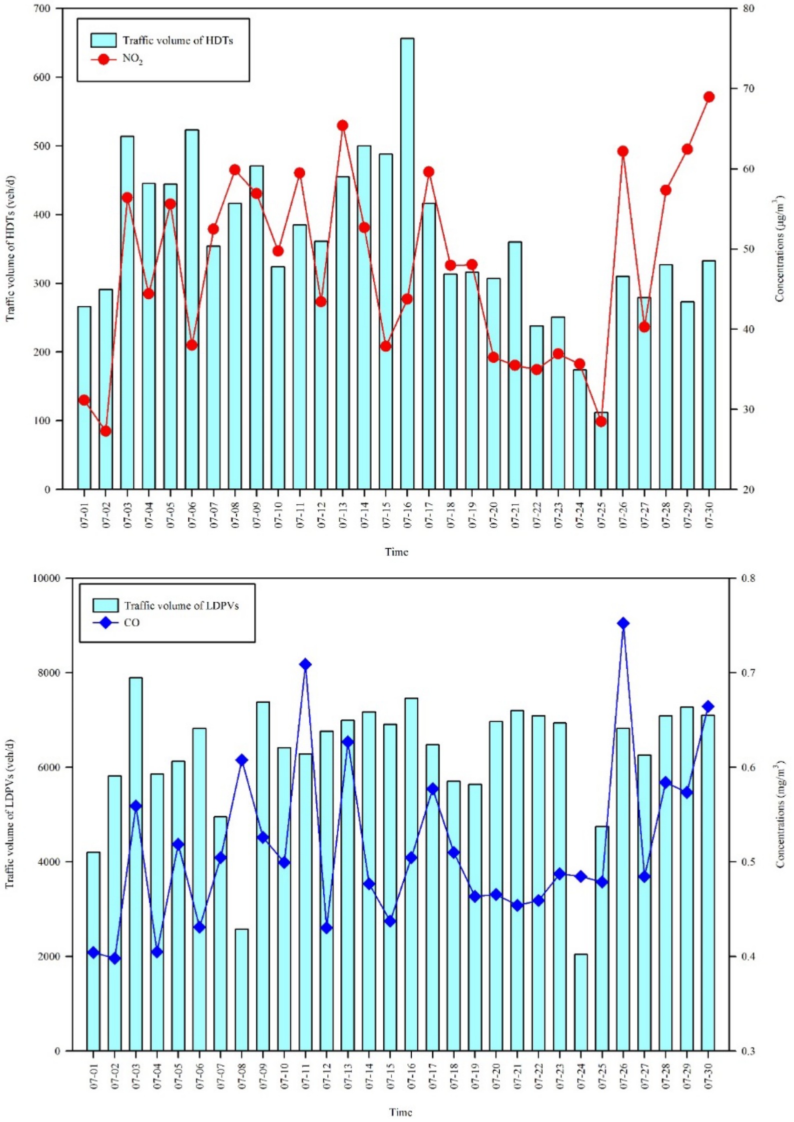
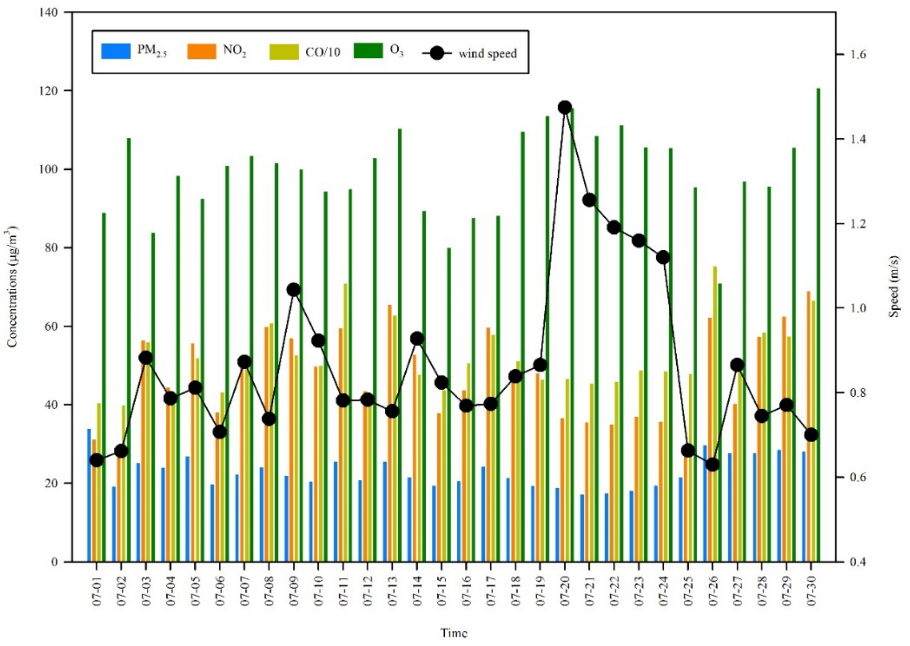


**Fig. 5**. $SO_2$, $NO_2$, $PM_{2.5}$, $PM_{10}$, CO, and $O_3$: correlation analysis of mass concentrations and traffic flow.

Meteorological conditions also play a key role in the concentrations of air pollutants on urban roads. The 30-day monitoring Fuci Street shows that the monthly average wind speed, relative humidity, and temperature were 0.87m/s, 36.5%, and 27.9°C, respectively. Figure 6 is the correlation between $NO_2$, $PM_{2.5}$, CO, $O_3$ concentrations and meteorological parameters in the roadside atmosphere. The concentrations of $NO_2$, $PM_{2.5}$, and CO was negatively correlated with wind speed, while the correlation coefficient between $PM_{2.5}$ and wind speed was -0.60. The greater the wind speed, the more dispersion, and the lower roadside concentrations of $NO_2$, $PM_{2.5}$, and CO. The higher the wind speed, the less dispersion, and the higher roadside concentrations of $NO_2$, $PM_{2.5}$, and CO. Roadside $O_3$ is mainly produced as a result of a complex set of photochemical reactions that involve precursors $NO_X$ and volatile organic compounds (VOCs). $NO_2$, as a precursor to ground-level $O_3$, is consumed when weather conditions are favorable for $O_3$ formation, hence $NO_X$ and $O_3$ display opposite trends.

In general, higher relative humidity leads to poorer dispersion, causing pollutants to concentrate in the roadside atmosphere. There is negative correlation between the concentrations of $NO_2$, $PM_{2.5}$, CO, $O_3$ and relative humidity with the correlation coefficient between $NO_2$ and relative humidity being -0.67, which may be related to the summer monitoring period when it's hotter and drier in Lanzhou with an average relative humidity of 18-56%. Roadside $O_3$ concentrations is closely linked to meteorological elements such as temperature, humidity, radiation, and boundary layer height. Heat, humidity, and light are conducive to $O_3$ pollution.

The average wind speed was only 0.87m/s during the monitoring period, determined mainly by the geographical location and climatic features of Lanzhou. Studies [20] show that the northeast trade winds are dominant in Lanzhou with the average wind speed being only 0.9m/s. Due to the meteorological conditions including weak winds, downward pollutant flow, strong atmospheric stability, unfavorable dispersion conditions, Lanzhou suffers from stagnant air, trapping and accumulating local pollution. Motor vehicles are a local source of air pollutants, therefore, reducing vehicle emissions can improve the air quality in Lanzhou.



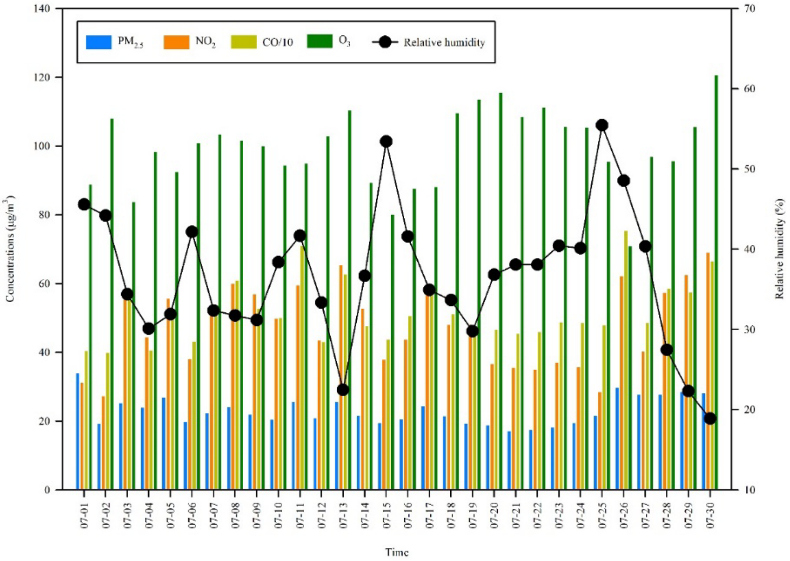


**Fig. 6.** NO$_2$, PM$_{2.5}$, PM$_{10}$, CO, and O$_3$: correlation analysis of mass concentrations and meteorological elements.

## 4 Conclusion

Based on the new policies on ecological monitoring in the 14*th* Five-Year Plan and a lack of air and traffic monitoring data, this study characterized roadside air pollutant concentrations and its influencing factors for a major road in Lanzhou, where a remote sensing (RS) system and air quality monitoring sensors were employed to investigate roadside air pollutant concentrations, traffic profiles, and meteorological data. The major findings can be summarized as follows:

(1) The temporal variations of concentrations of SO$_2$, NO$_2$, PM$_{2.5}$, PM$_{10}$ and CO peaked at 5:00-9:00 while O$_3$ peaked at 15:00. The concentrations of SO$_2$, NO$_2$, PM$_{2.5}$, PM$_{10}$ and CO during the peak periods were 2.9, 3.6, 1.8, 2.3, 2.9 and 3.1 times higher than those during the off-peak periods, respectively. In addition, SO$_2$, NO$_2$, PM$_{2.5}$, PM$_{10}$, and CO concentrations on weekdays were 5.2%, 10.3%, 1.5%, 6.7%, and 8.2% lower than weekends. The concentrations of PM$_{2.5}$ and PM$_{10}$ declined with the height of the monitoring sites increased, peaking at 2-meter height whereas SO$_2$, NO$_2$, CO, and O$_3$ first reached their highest concentrations at 4-meter height.

(2) Roadside NO$_2$ and CO concentrations showed positive correlations with the traffic volumes of HDTs and LDPVs, respectively. The concentrations of NO$_2$, PM$_{2.5}$, and CO are negatively correlated with wind speed, and there is negative correlation between the concentrations of NO$_2$, PM$_{2.5}$, CO, O$_3$ and relative humidity.

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