A study of $PM_{2.5}$ and PM_{10} concentrations in the atmosphere of large cities in Gansu Province, China, in summer period

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Due to rapid economic growth of the country in the last 25 years, particulate matter (PM) has become a topic of great interest in China. The rapid development of industry has led to an increase in the haze created by pollution, as well as by high levels of urbanization. In 2012, the Chinese National Ambient Air Quality Standard (NAAQS) imposed 'more strict' regulation on the PM concentrations, i.e., 35 and 70 μg/m^3 for annual $PM_{2.5}$ and PM_{10} in average, respectively (Grade-II, GB3095-2012). The Pearson's correlation coefficient was used to determine the linear relationship of pollution between pollution levels and weather conditions as well as the temporal and spatial variability among neighbouring cities. The goal of this paper was to investigate hourly mass concentration of $PM_{2.5}$ and PM_{10} from June 1 to August 31, 2015 collected in the 11 largest cities of Gansu Province. This study has shown that the overall average concentrations of $PM_{2.5}$ and PM_{10} in the study area were 26 and 66 μg/m^3. In $PM_{2.5}$ episode days (when concentration was more than 75 μg/m^3 for 24 hrs), the average concentrations of $PM_{2.5}$ was 2–3 times higher as compared to non-episode days. There were no observed clear differences during the weekday/weekend PM and other air pollutants (SO_2, NO_2, CO and O_3) in all the investigated cities.

1. Introduction

In recent decades, rapidly expanding economic development has resulted in tremendous increase in energy consumption, air pollutant emission, and air pollution in China. This deterioration of air quality has been one of the main environmental problems for the country. Past studies of $PM_{2.5}$ (particle's aerodynamic diameter less than 2.5 μm) showed that annual average concentrations had exceeded 90 μg/m^3 in Guangzhou (Hagler *et al.* 2006), over 120 μg/m^3 in Beijing (Yao *et al.* 2002; Guinot *et al.* 2007) and 95 μg/m^3 in Shanghai (Feng *et al.* 2009). A study of air pollution in Lanzhou showed that the average concentration of $PM_{2.5}$ in 2007–2009 was 90 μg/m^3 (Fang *et al.* 2014), and that of PM_{10} in the same period exceeded 129, 132 and 150 μg/m^3, respectively (Hou *et al.* 2011) and made 150 μg/m^3 (Tao *et al.* 2014). Recent studies of Zhai *et al.* (2015) showed that the average monthly concentration of $PM_{2.5}$ and PM_{10} in winter months of 2013 had exceeded 95 and 290 μg/m^3, and in summer months, 48 and 110 μg/m^3, respectively, which greatly exceeded the World Health Organization (WHO) annual average guideline value of 10 μg/m^3 (WHO 2005).

Atmospheric particulate matters (PM), i.e., PM_{10} and $PM_{2.5}$ (particles of aerodynamic diameter $\leq$2.5 μm), attracted more and more attention in recent years due to its important roles in atmospheric

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processes, adverse effects on health, and global climate. Ambient air quality is primarily affected by particulate matter (PM), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3) concentrations in the atmosphere.

Impact of air pollution is particularly important in many developing countries where the problem of air pollution is becoming increasingly serious (Gupta *et al.* 2003). In China, a considerable number of studies have been dedicated to investigate the variations of concentrations of PM and gaseous pollutants during meteorological phenomena, e.g., dust storms and haze episodes (Xie *et al.* 2005; Choi *et al.* 2008; Chu *et al.* 2008a, b; Yang *et al.* 2011; Fan *et al.* 2013). Other studies have considered pollutant conditions in one large city, several cities, or a region (An *et al.* 2007; Chu *et al.* 2008a; Quan *et al.* 2008; Wang *et al.* 2009; Li *et al.* 2010; Fan *et al.* 2014). Other investigators focused on the chemical components of $PM_{2.5}$ in several large cities (Yu and Yu 2012; Zhang *et al.* 2012).

This paper presents the results of a detailed hourly, daily and seasonal study of the composition, concentration, and sources of air pollution measured in 11 cities of Gansu Province during the summer period of 2015. The spatial and temporal variations of these pollutants were compared. There are several reasons that pushed us to perform this study. First: high concentration of PM pollution has been reported in summer period in this region. Second: the problem of air pollution has caused considerable public awareness in China. Therefore, investigations into the spatio-temporal variation of concentrations of PM and gaseous pollutants across China are necessary and important. Third: previous studies in the region mainly covered small territory (e.g., Ta *et al.* 2004). The main objective of this work is to present updated information about the size and characteristics of the summer $PM_{2.5}$ and PM_{10}, as well as main gas pollutants of ground measurement data in 11 cities of Gansu Province. This knowledge can further be used to investigate the sources and PM management strategies.

2. Methods

2.1 *Investigated area*

Gansu Province has a population of 25.8 million (as of 2010) and covers an area of 454,000 km^2; the average altitude is 1000–3000 m above sea level. The province is located in the northwest of China, between the Tibetan highland and the Mongolian Plateau; it borders the Inner Mongolia Autonomous Region and Ningxia Hui in the northeast, Shaanxi in the east, Sichuan in the south, Qinghai in the southwest, Xinjiang in the west, and a small section of the Mongolian border in the north (Govi–Altai Province). The center of province and the largest city is Lanzhou.

The province contains highly developed oil production and refining, extraction of coal, copper, and iron ore as well as non-ferrous metallurgy, machine-building, chemical, petrochemical, metal processing, textile industry, the production of fissile materials, building materials, and electronics. The area suffers from dust storms from the Gobi desert, especially in winter. The main source of air pollution includes industrial emissions, as well as coal-fired power stations (Wang *et al.* 2008).

Eleven cities in the Gansu Province, i.e., Lanzhou, Jiayuguan, Zhangye, Wuwei, Baiyin, Dinxi, Tianshui, Qingyang, Pingliang, Jinchang, Longnan, are covered on this study (figure 1).

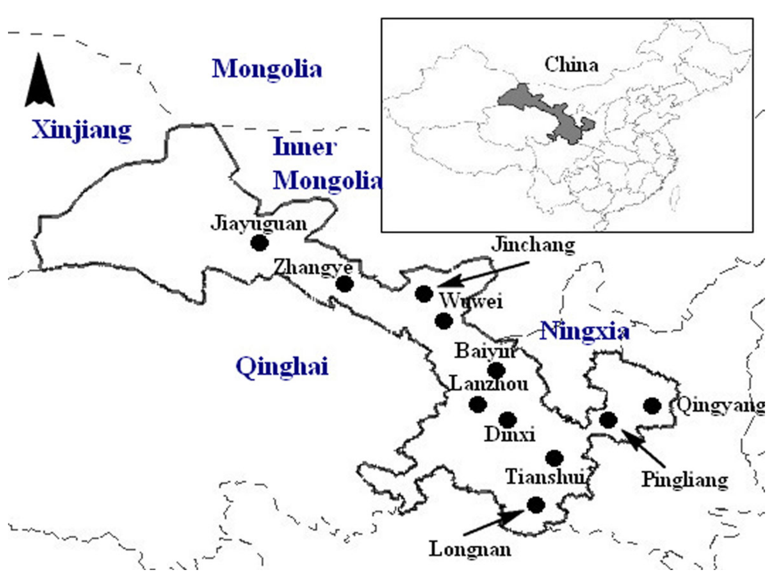

Figure 1. Geolocation of the study area in Gansu Province, northwestern China.

2.2 *Data source*

The mass concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO and O_3 were recorded by the Data Centre, the Ministry of Environmental Protection of the People's Republic of China (http://datacenter.mep.gov.cn/ and 113.108.142.147:20035/emcpublish/). Data presented in this study were obtained from the national air quality monitoring stations located in each city studied in the period from June 1, 2015 to August 31, 2015. Automated monitoring systems have been constructed for measuring the ambient concentration of SO_2, NO_2, O_3 and CO in accordance with the norm from the China Environmental Protection Standards HJ193-2013 (MEP 2013a), as well as $PM_{2.5}$ and PM_{10} according to the China Environmental Protection Standards HJ655-2013 (MEP 2013b). Ground-based meteorological parameters, surface wind speed (WS), temperature (T), and relative humidity (RH) at the surface of the ground, and the meteorological observations were received from the National Meteorological Center of CMA (http:/nmc.cn/).

2.3 *$PM_{2.5/10}$ concentration data and statistical analysis*

In order to protect air quality as well as monitoring air quality standards, the Ministry of Environmental Protection of the People's Republic of China (MEP) and Gansu Provincial Department of Environmental Protection, constructed more than 28 air quality monitoring stations in the cities of Gansu. These ground-based monitoring stations measure the concentration of weighted particles in the air, show hourly and daily average concentrations. In this work we used a daily average $PM_{2.5}$ mass concentration (in μg/m^3). The $PM_{2.5/10}$ mass concentrations from these stations were measured using a Tapered Element Oscillating Microbalance (TEOM 1400a) with a precision of ±1.5 μg/m^3 for the hourly mean value, and of ±0.5 μg/m^3 for the daily 24-hour average value, and calculates real-time PM mass concentrations. With TEOM 1400a, sampling and determining the mass of the particles is performed at specific time intervals, with following weighting and measurement of their deposition on the filter. The filter is attached to the vibrating hollow conical glass tube whose frequency is influenced by the load of the filter. TEOM's opening is heated to 50°C in order to eliminate the effect of the condensation and evaporation of water particles in the filter. This heating aerosol flow is caused by the loss of semi-volatile species (Charron *et al.* 2004; Charron and Harrison 2005). The data from all stations were utilized in this research. Detailed information on the monitoring sites is given in table 1.

Average hourly and per diem concentrations of pollutants for each of the cities, as well as data were obtained by averaging the hourly data from all air quality monitoring station. Daily average concentrations of all pollutants were computed after 16 hours of data receiving.

The days when the daily mean concentrations were higher than the Grade II standard ($PM_{2.5} \geq 75$ μg/m^3 and $PM_{10} \geq 150$ μg/m^3) are defined as PM episode days and days with average concentration of less than quality I standard ($PM_{2.5} \leq 35$ μg/m^3 and $PM_{10} \leq 50$ μg/m^3) are determined as non-episode days. Pearson's correlation coefficient was utilized to define the linear relationship between the factors affecting the level of pollution and contamination. Multivariate analysis was conducted to assess the main factors related to $PM_{2.5/10}$ levels under background conditions and potentially unfavourable factors (Hatch *et al.* 1982; Breiman and Friedman 1985).

Table 1. *Basic Information of the 11 studied cities.*

City	Number of monitoring sites	Population (as of 2010)*	Area of the city (km^2)	Latitude and longitude
Jiayuguan	2	231,853	2935	N39°49′ E98°18′
Zhangye	2	1,199,515	40,874	N38°36′ E100°27′
Jinchang	3	464,050	8896	N38°29′ E102°10′
Wuwei	2	1,815,059	33,249	N37°55′ E102°38′
Baiyin	2	1,708,752	21,209	N36°33′ E104°12′
Lanzhou	5	3,616,163	13,271	N36°02′ E103°48′
Dinxi	2	2,698,624	19,609	N35°34′ E104°37′
Pingliang	2	2,068,033	11,325	N35°32′ E106°41′
Qingyang	3	2,211,191	27,119	N35°44′ E107°37′
Tianshui	3	3,262,549	14,392	N34°35′ E105°44′
Longnan	2	2,567,718	27,923	N33°24′ E104°55′

Note. ∗: Total population of the administrative region.

3. Results

3.1 *Summer-time air quality overview*

Figures 2 and 3 show the mass concentration indicators $PM_{2.5}$ and PM_{10}, CO, NO_2, SO_2 and 8-hr peak O_3 values for the entire study period (1 June–31 August 2015) in the study area. Average $PM_{2.5}$ concentrations in the province were not high with an average concentration of 25–28 μg/m^3 in all cities except for Lanzhou and Pingliang, where the average concentrations of $PM_{2.5}$ exceeded 35 μg/m^3. Minimum concentrations were observed in the southern part of the province where the concentration was 16 μg/m^3 (Tianshui). PM_{10} displayed analogous spatial pattern. PM_{10} concentrations varied from 50 to 70 μg/m^3 in most cities, and was 100 μg/m^3 in Lanzhou city. The gaseous pollutants (CO, SO_2, NO_2, O_3) demonstrated varied spatial allocation. Exceeded levels of NO_2 were observed in Lanzhou and Pingliang with 42.59 and 40.8 μg/m^3, respectively; the high concentration of NO_2 is associated with a well-developed coal industry in Pingliang, and chemical and petrochemical industry in Lanzhou. Increased concentrations of NO_2 in Lanzhou is associated with a large number of exhaust emissions from cars and rail transport, as the city is a major transportation center in the northwest of China. The levels of SO_2 in the summer months were not high, with an average of 12 μg/m^3, except for Baiyin and Jinchang cities with the highest SO_2 that exceeded the NAAQS standards Grade 1 (35.06 and 26.34 μg/m^3, respectively). Concentration levels of O_3 did not exceed specified levels of pollution with an average of 58±15 μg/m^3 for the province. In general, gaseous pollutants showed no high effect in almost all cities of Gansu Province. The concentrations of pollutants in all towns of studied area in summer are shown in table 2.

3.2 *Spatial variability*

Spatial variability was measured using Pearson's linear correlation analysis between the cities of the region in order to study the regional correlations of PM pollution indicators. The correlation coefficient (r) of daily average PM_{10} and $PM_{2.5}$ between all the studied cities in the province are shown in table 2. The correlation coefficient 0.000–0.299 was accepted as a weak correlation, 0.300–0.499 as a moderate correlation, and 0.500–1.000 as a strong

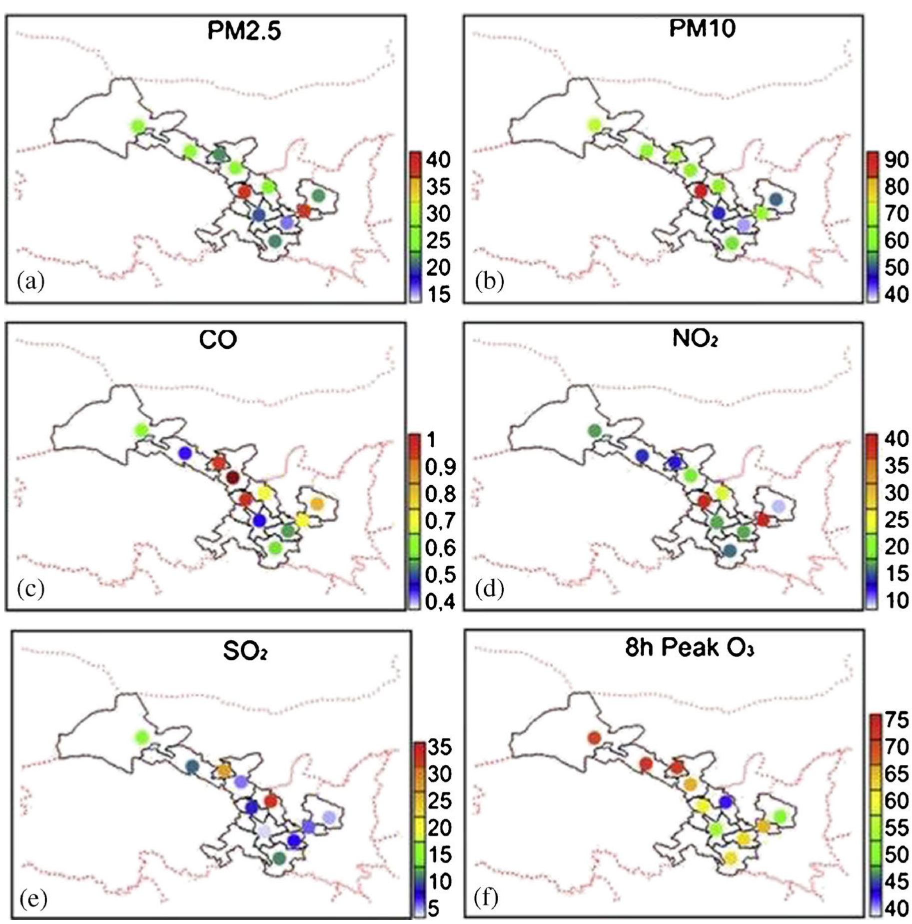

Figure 2. Summer-time concentrations of (**a**) $PM_{2.5}$, (**b**) PM_{10}, (**c**) CO, (**d**) NO_2, (**e**) SO_2, and (**f**) 8-hr peak O_3.

correlation, −0.001 to −0.300 as a weak negative correlation. Table 3 shows that most of the pairs of cities presented moderate and strong correlation. The correlation between Lanzhou and Baiying and Dingxi ($r = 0.479$ for $PM_{2.5}$, $r = 0.831$ for PM_{10} between Lanzhou and Baiying; $r = 0.475$ for $PM_{2.5}$ and $r = 0.708$ for PM_{10} between Lanzhou and Dingxi; $r = 0.653$ for $PM_{2.5}$ and $r = 0.743$ for PM_{10} between Baiying with Dingxi), and between Jiayuguan and Zhangye and Wuwei ($r = 0.535$ for $PM_{2.5}$, $r = 0.667$ for PM_{10} between Jiayuguan and Zhangye; $r = 0.743$ for $PM_{2.5}$, $r = 0.772$ for PM_{10} between Jiayuguan and Wuwei; $r = 0.729$ for $PM_{2.5}$, $r = 0.817$ for PM_{10} between Zhangye with Wuwei). This indicates that a significant proportion of $PM_{2.5}$ in urban areas was presented as secondary organic aerosol, such as ammonium sulfate ($(NH_4)_2SO_4$), or fugitive dust, which has a broader distribution among the region than just the primary anthropogenic pollutant. Weak negative correlation was observed between pairs of cities Longnan and Jinchang ($r = -0.1$ for $PM_{2.5}$, $r = -0.036$ for PM_{10}), located 620 km from each other. The correlation coefficient for PM_{10}, as a rule, was higher as compared to $PM_{2.5}$. However, there are some factors that may influence concentration of $PM_{2.5}$ in urban areas, including: (1) local sources of primary PM; (2) topographical barriers between cities; (3) indicators processing period; (4) meteorological phenomena; and (5) differences in the behaviour of semi-volatile components (Sheppard *et al.* 2001). Cities located closer to each presented with higher correlations.

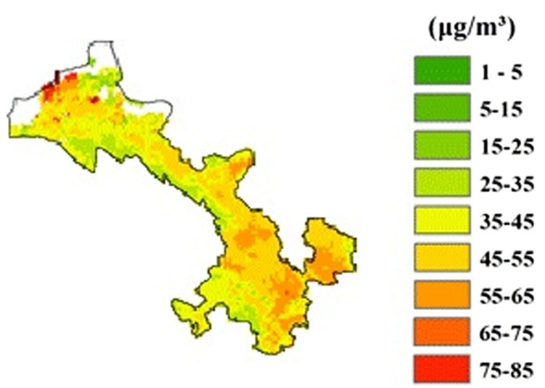

Figure 3. The concentration of $PM_{2.5}$ in Gansu Province.

Table 2. *Summer average concentrations in studied cities.*

City	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	CO (mg/m^3)	NO_2 (µg/m^3)	SO_2 (µg/m^3)	8-hr peak O_3
Jiayuguan	26.53	78.26	0.68	20.61	18.25	70
Zhangye	26.51	59.48	0.47	15.11	13.01	73
Jinchang	21.4	72.5	0.93	15.14	26.34	73
Wuwei	27.3	71.5	1.76	23.22	7.07	65
Baiyin	25.32	70.76	0.74	25.73	35.06	44
Lanzhou	38.8	98.8	0.94	42.59	11.34	58
Dinxi	22.41	49.42	0.47	17.94	6.3	55
Pingliang	36	71.42	0.74	40.8	8.6	65
Qingyang	23.78	54.81	0.81	11.54	5.39	53
Tianshui	16.41	40.37	0.57	18.15	9.4	63
Longnan	24.9	61.13	0.60	18.42	13.06	65

Table 3. *Correlation coefficients for $PM_{2.5}$ and PM_{10} between studied cities.**

	Jiayuguan	Zhangye	Jinchang	Wuwei	Baiyin	Lanzhou	Dinxi	Pingliang	Qingyang	Tianshui	Longnan
Jiayuguan		0.103	0.1928	0.1228	0.0491	0.0862	−0.017	0.0565	−0.0193	−0.054	−0.1001
Zhangye	0.538		0.5354	0.7433	0.3882	0.3743	0.2376	0.242	−0.0181	0.068	0.0555
Jinchang	0.6392	0.6677		0.7294	0.4138	0.1818	0.1654	0.096	−0.0121	0.1235	0.0865
Wuwei	0.6282	0.7724	0.8174		0.6629	0.3687	0.4495	0.0017	−0.1071	0.096	0.2256
Baiyin	0.4397	0.6016	0.4855	0.669		0.4798	0.6531	−0.0932	−0.0107	0.2434	0.159
Lanzhou	0.3312	0.5793	0.4148	0.5178	0.8311		0.4755	0.17	0.225	0.2371	0.317
Dinxi	0.258	0.4908	0.3241	0.5251	0.7437	0.708		−0.1881	−0.0281	0.2654	0.4014
Pingliang	0.0995	0.1866	0.1575	0.066	0.3023	0.4123	0.2353		0.6041	0.3836	0.1239
Qingyang	0.0259	0.0285	0.1167	0.0595	0.2477	0.3398	0.2341	0.4454		0.5524	0.2895
Tianshui	0.0505	0.0604	0.1591	0.1109	0.3279	0.4116	0.353	0.3646	0.7543		0.6394
Longnan	0.0364	0.1007	0.0685	0.1001	0.2436	0.3028	0.2724	0.3249	0.4825	0.715	

Note. ∗: $PM_{2.5}$ values are shown above diagonal; that of PM_{10} below diagonal.

The correlation coefficients were compared taking into account the distance between cities. Strong and similar relation was detected among the r values and the distance between the cities in the region. The results are shown in figure 4. The correlation coefficient between the cities with distance of 250 km is 0.6 for $PM_{2.5}$ and less than 0.7 for PM_{10} when the distance between the cities is more than 180 km. The $PM_{2.5}/PM_{10}$ ratio in summer $R^2 = 0.54$, $p < 0.01$. This result of the relationship can be associated with climatic, geographic and geological conditions of the study area. The province has deserts in the north, a mountainous part in the center and plains in the south. All these affect the speed of particles movement in the atmosphere, especially dry air of the central and northern parts.

3.3 *Temporal variability*

3.3.1 *$PM_{2.5}/PM_{10}$ and meteorology variation*

Figure 5 illustrates the temporal variation of daily average $PM_{2.5}$ and PM_{10} concentrations, wind speed, and temperature parameters in Lanzhou and Tianshui, the largest city in the province. A negative correlation was observed between the indicators of $PM_{2.5}$ and the wind speed: usually high concentrations of $PM_{2.5}$ were present during weaker winds, and lower concentrations of $PM_{2.5}$ occurred with stronger winds. In general, there was no obvious relationship between detected $PM_{2.5}/PM_{10}$ and the air temperature. This relationship between $PM_{2.5}$ concentrations and WS, RH and T, will be demonstrated in further studies

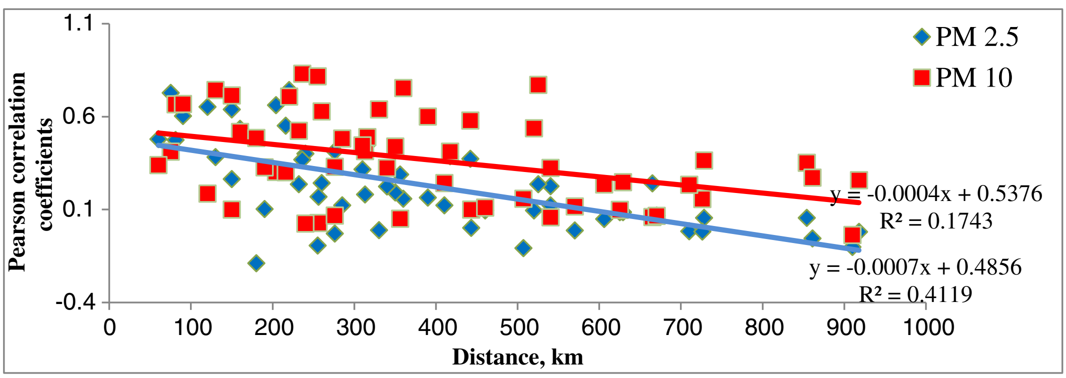

Figure 4. Pearson correlation coefficients for $PM_{2.5}$ and PM_{10} between cities in the region.

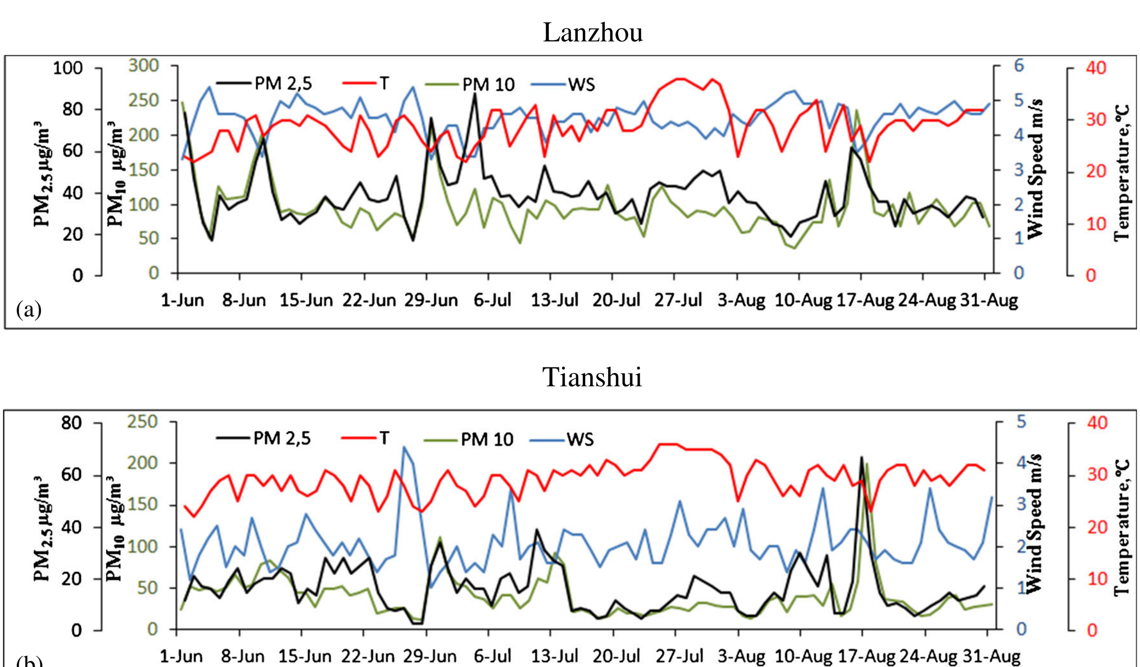

Figure 5. Daily $PM_{2.5/10}$ concentrations, wind speed and temperature in summer 2015 in Lanzhou and Tianshui.

using linear regression analysis for all the days in the summer period. In Lanzhou, some regression coefficients for $PM_{2.5}$ is negative associated with wind speeds by a factor of −0.94 and −0.71 for PM_{10}; also, the relationship between $PM_{2.5}$, PM_{10} and air temperature showed weak negative correlation of −0.13 and −0.19, but positively associated to relative humidity with a coefficient of 0.19 and 0.21, respectively (table 4b). In Tianshui, the association between $PM_{2.5}$ and three meteorological parameters was minimal, with the regression coefficient −0.007 that characterizes the small effect of temperature, wind speed and air humidity on the level of polluting particles in the atmosphere. Therefore, since Gansu Province has a transitional, from semi-dry to dry continental climate with warm and hot summer resulting in low wind speed, it is not the main factor for the dispersion of pollutants. Typically, stagnant conditions with wind speed less of 3 m/s, which lead to absorption of PM and other gaseous pollutants, are often observed in Lanzhou and have increased indicators of PM contamination.

Table 4. *(a) $PM_{2.5}/PM_{10}$ ratio; (b) correlation coefficients between mass concentrations of $PM_{2.5}$ and PM_{10} and average meteorological factors: air temperature (T), wind speed (WS) and relative humidity (RH).*

(a)						(b) $PM_{2.5}$			PM_{10}		
	June	July	August	Episode	Non-episode	T	WS	RH	T	WS	RH
Jiayuguan	0.312	0.442	0.305	0.283	0.29	−0.01	0.07	−0.09	0.02	0.12	−0.12
Zhangye	0.439	0.45	0.441	0.39	0.624	−0.35	−0.22	0.09	−0.34	−0.19	−0.39
Jinchang	0.32	0.294	0.271	0.262	0.359	0.22	0.17	0.26	0.12	0.31	0.11
Wuwei	0.442	0.381	0.343	0.404	0.41	−0.12	−0.26	−0.16	−0.10	−0.26	0.09
Baiyin	0.348	0.369	0.362	0.325	0.408	−0.14	−0.43	−0.11	−0.18	−0.44	−0.27
Lanzhou	0.352	0.475	0.386	0.319	0.469	−0.13	−0.94	0.19	−0.12	−0.71	−0.21
Dinxi	0.419	0.474	0.472	0.384	0.448	−0.12	−0.36	0.05	−0.23	−0.15	0.29
Pingliang	0.434	0.6	0.487	0.382	0.613	−0.21	−0.04	0.35	−0.27	−0.20	0.22
Qingyang	0.393	0.485	0.424	0.376	0.508	−0.03	−0.01	0.15	0.00	0.12	−0.05
Tianshui	0.375	0.435	0.423	0.344	0.435	−0.15	−0.16	0.13	−0.17	−0.21	0.04
Longnan	0.305	0.448	0.476	0.38	0.434	−0.2	0.12	0.08	−0.11	0.16	−0.12

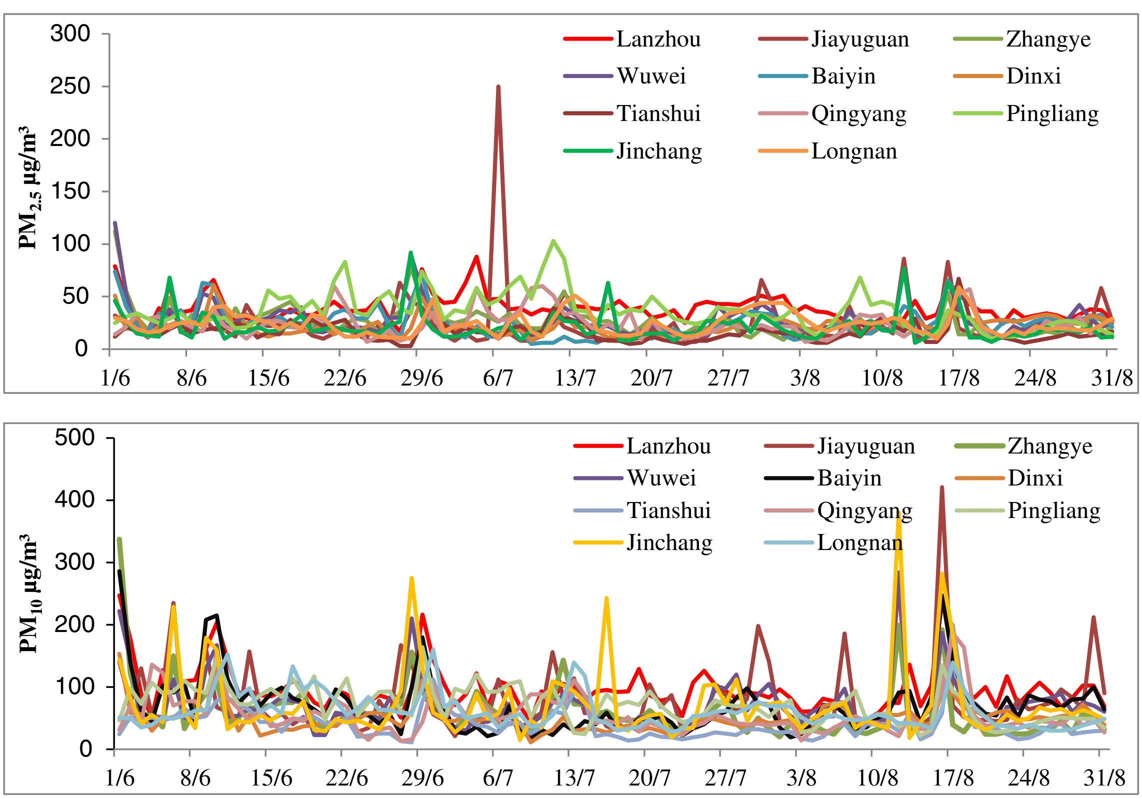

Figure 6. Concentration of $PM_{2.5}$ and PM_{10} in the cities of Gansu Province (summer 2015).

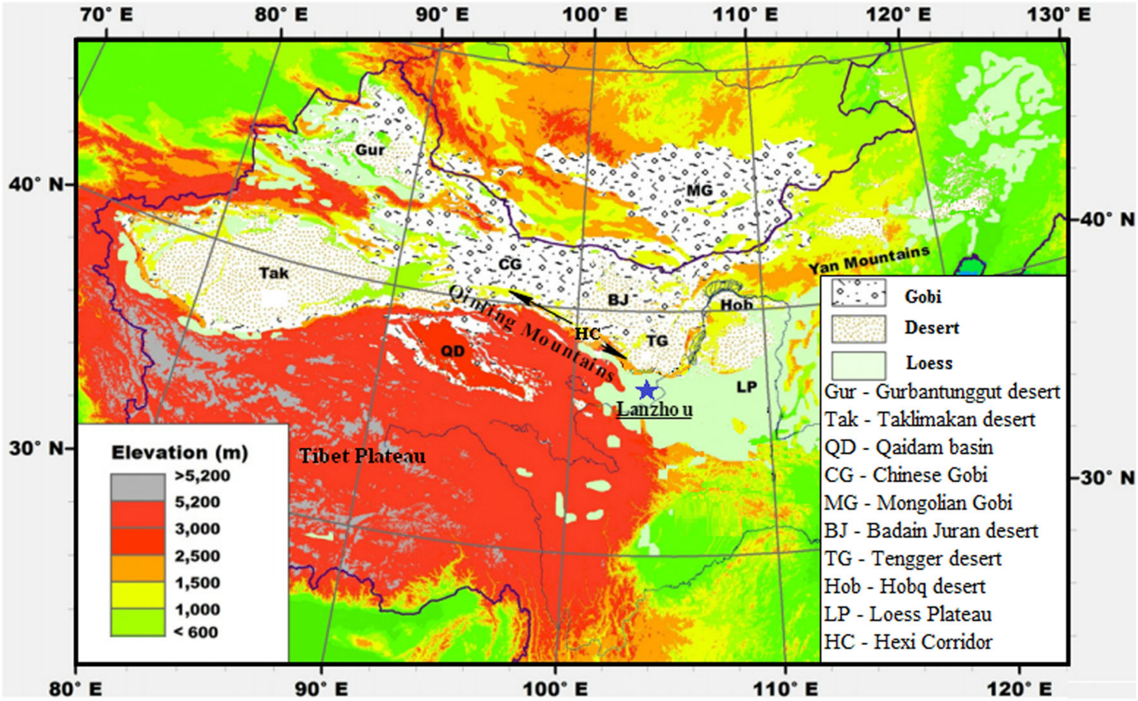

Figure 7. Distributions of nine major deserts and elevation distribution in northern and northwestern China.

3.3.2 *Concentration $PM_{2.5}$ and PM_{10} on episode and non-episode days*

Figure 6 shows the concentration of $PM_{2.5}$ and PM_{10} particles in all cities of the study area. Episode days and non-episodes days were of irregular occurrence in the cities of the province, therefore, maximum peaks were observed in cities with well-developed non-ferrous metallurgy – Lanzhou, Wuwei, (88 and 120 $\mu g/m^3$ for $PM_{2.5}$, respectively). In one day in Jiayuguan, there was an unusual index growth of $PM_{2.5}$ up to 250 $\mu g/m^3$ for this region. The average concentration of $PM_{2.5}$ in all episode days was between 80 and 100 $\mu g/m^3$, which is much higher than the concentrations of $PM_{2.5}$ in non-episode days (15–20 $\mu g/m^3$).

PM_{10} indicator for episode days took place almost simultaneously in all the cities of Gansu Province. Figure 6 shows that PM_{10} is clearly expressed for eight episode days: June 1–2, June 9–10, June 28–29, and August 16–17. The average concentration of PM_{10} in episode days was 200 and 30–40 $\mu g/m^3$ in the non-episode day. Non-episode days were also evenly distributed throughout the study.

According to previous studies, one of the main sources of air pollution with PM indicators are dust storms characterized by high PM_{10} concentrations and relatively low concentrations of $PM_{2.5}$ due to the invasion of large particles; the $PM_{2.5}/PM_{10}$ ratio has decreased on the whole. Thus, the $PM_{2.5}/PM_{10}$ ratio may be used as a key measurement to determine the sources of dust (Zhang *et al.* 1998).

The monthly average $PM_{2.5}/PM_{10}$ ratio in the cities of the province was 0.405 (0.271–0.487), low coefficients of $PM_{2.5}/PM_{10}$ indicate the increase in dust and aerosols (table 4a).

The $PM_{2.5}/PM_{10}$ ratio for cities in the episode day varies from 0.262 in the city of Jinchang to 0.404 in Wuwei, which indicated the predominance of primary sources of PM pollution. For non-episode days, the $PM_{2.5}/PM_{10}$ ratio showed low change towards indices in Pingliang 0.613 and 0.382 in non-episode days, Zhangye 0.624 and 0.39, respectively, which included both primary and secondary pollution sources.

3.3.3 *Long-range transport of dust in Gansu*

Tracking sources and contaminant pathways in the Gansu Province trajectories were calculated using the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) developed by Air Resources Laboratory (ARL) in the National Oceanic and Atmospheric Administration (NOAA). 72-hr backward trajectories were utilized, starting at 100, 500, and 1000 m. Zhang *et al.* (1998) found that Asian particles had originated from two regions in China: deserts in northern and northwestern China (Taklimakan Desert and Badain Juran Desert (figure 7)). In general, we can distinguish between three trajectories that were selected above cities of Gansu Province. (1) 'North', which is associated with air masses passing through the Gobi Desert, Republic of Mongolia, and Inner Mongolia (figure 8b, d, e, f). (2) 'North-West',

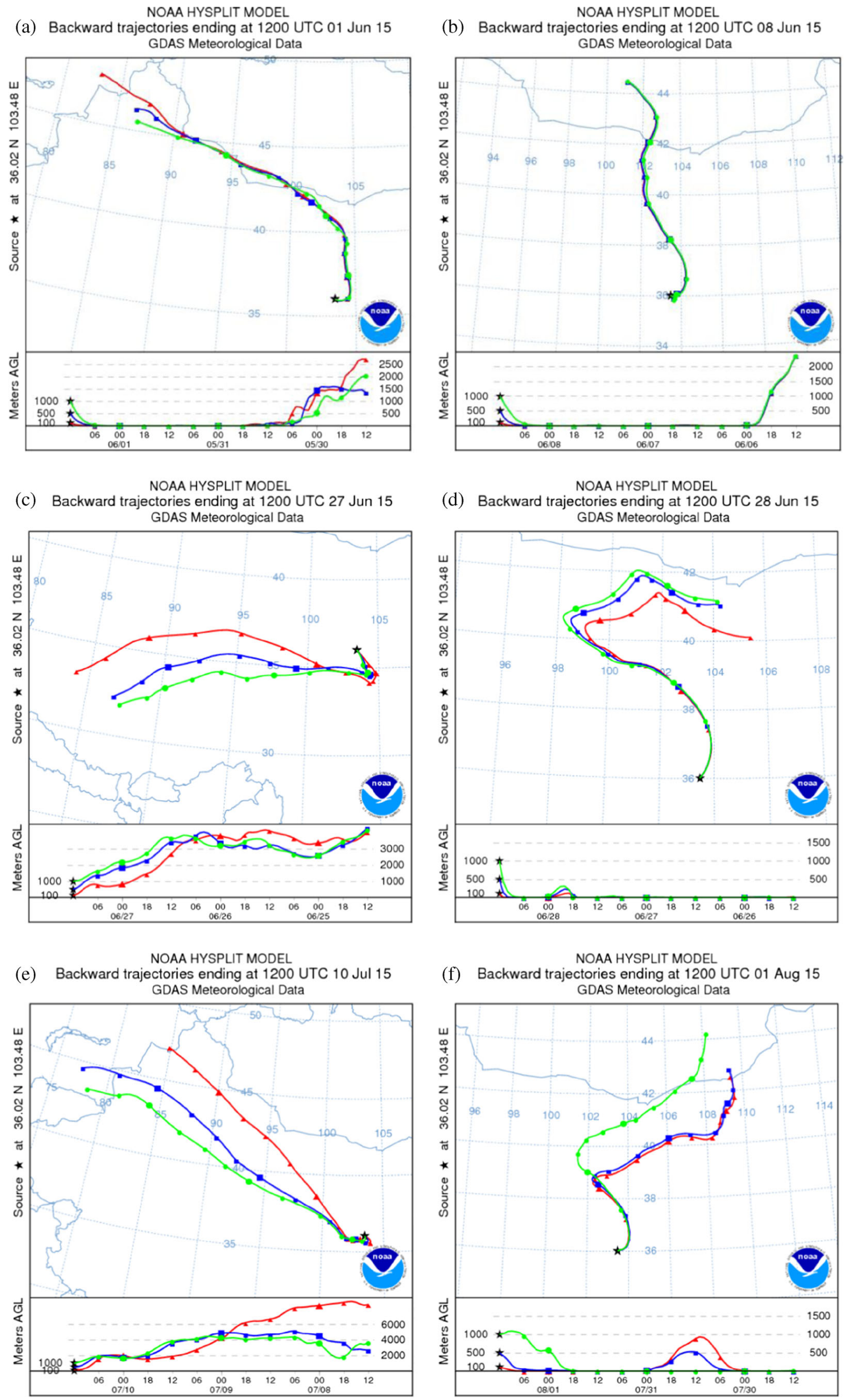

Figure 8. 72-hr backward trajectories starting at three altitudes of 100, 500 and 1000 m in Lanzhou. (**a**) 12:00 am June 1*, (**b**) 12:00 am June 8**, (**c**) 12:00 am June 27**, (**d**) 12:00 am June 28*, (**e**) 12:00 am July 10**, (**f**) 12:00 am August 1**. Note. ∗: Episode day; **: Non-episode day.

appearing mainly in the northwestern part of Xinjiang (Gurbantunggut Desert), where air mass go through Inner Mongolia and Ningxia to Lanzhou city (figure 8a, b). (3) 'Western', which originated in the western deserts (Taklimakan desert in Xinjiang) and in the desert of Qaidam basin, where air masses pass through the Tibetan Plateau and Qinghai (figure 8c).

Despite the different ways of dust passage in the Gansu Province, they showed similar features. Large part of air masses penetrated into the province mainly from the north direction, except for air

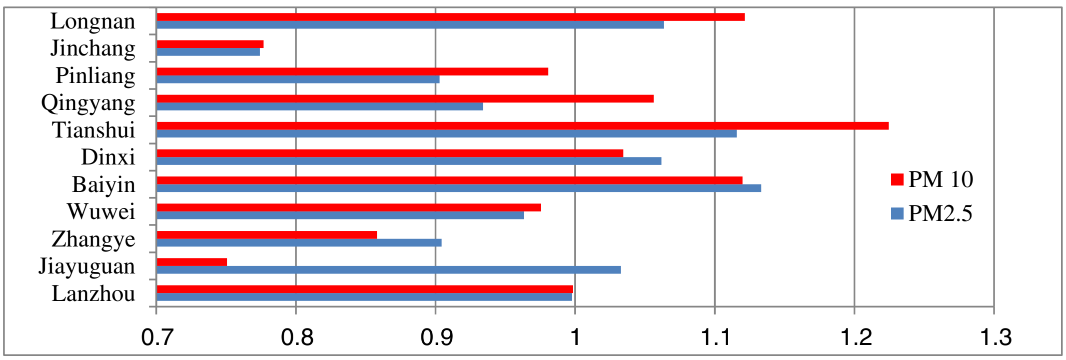

Figure 9. Weekday/weekend $PM_{2.5}$ and PM_{10} ratios in every city of the region.

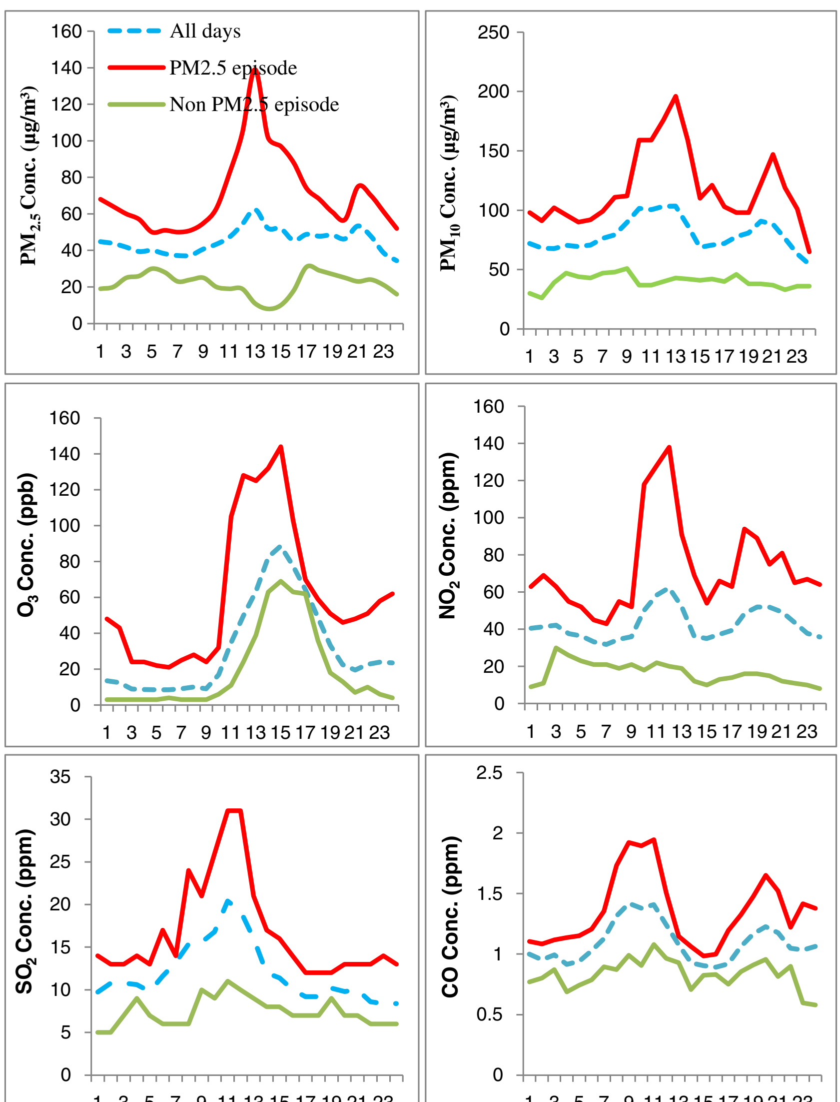

Figure 10. Diurnal changes of $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2 and CO in the episode and non-episode days in Lanzhou.

masses from the Tibetan plateau, although the air passage was mainly from the north-west and north-east directions. Figure 7 displays Hexi Corridor (Gansu Corridor), which stretches within 1000 km from the north-west (from the central part of Gansu, to Jiayuguan and Dunhuang), stretches along the northeastern foothills of the Qinling mountains with an altitude of over 3000 m. The width of the corridor is from 20 to 100 km, the altitude from 800 m in the west to 1500 m in the east. Air masses moving from the Gobi Desert and deserts of provinces, bump into high Qinling mountains and change their direction to Hexi Corridor, grabbing dusty desert air, which is characterized by presence of ground-level air masses (figure 8a, b, e, f). Another feature was the elevation of air masses during its transport. Figure 8(c and d) shows that air masses were more than 3000 m above ground and were carried to the upper atmosphere for long distances before reaching Lanzhou, with gradual lowering. The height level was mainly associated with a unique landscape of Taklimakan Desert and hilly Tibet Plateau, which gradually declined from over 4000 to 1800 m as it enters the city of Lanzhou.

3.3.4 *Weekday and weekend difference, diurnal changes*

Differences in concentration of pollutants in the atmosphere in the weekdays/weekends relationships have been investigated in many places for many years (Graedel *et al.* 1977; Marr and Harley 2002; Qin *et al.* 2004; Jones *et al.* 2008). Figure 9 shows the weekday/weekend $PM_{2.5}$ and PM_{10} ratios in all cities in this study. The concentrations of $PM_{2.5}$ and PM_{10} in studied cities showed minor differences between weekdays and weekends, at a ratio of the week/weekend with a difference of ±0.1 with a coefficient of 1. Small changes of $0.9-1.1$ were found for the gaseous pollutants and in rare cases exceeded 1.2.

Diurnal changes of $PM_{2.5/10}$, O_3, SO_2, NO_2, and CO in the periods of episode and non-episode days were studied in Lanzhou and are shown in figure 10. In Lanzhou, $PM_{2.5}$ and PM_{10} showed high concentrations and stronger diurnal changes during episode days. On episode days, both $PM_{2.5}$ and PM_{10} started to increase rapidly at 7–8 am local time with an hourly rate of 15 $\mu g/m^3$ for 5–6 hrs and reached peak concentration of $\sim$140 $\mu g/m^3$ at mid-day. The concentration of both indicators in the afternoon began to deccrease slowly and at 8 pm, there was a sharp increase of concentrations: $PM_{2.5}$ from 55 to 75 $\mu g/m^3$ and PM_{10} from 100 to 125 $\mu g/m^3$, following with concentration decline until midnight. This indicates that the emergence of carbon particles in Lanzhou is derived from common sources of emissions, such as automobile exhaust and industrial emissions, which are characterized by elevated concentrations of PM_{10} indicators. O_3 is present in a high level of concentration and diurnal variation in the episode and non-episode days, with a maximum concentration of 144 $\mu g/m^3$. Also, significant differences were found in the concentrations of daily changes in the episode and the non-episode days. A large distinction in the diurnal variation was observed in concentration of NO_2, SO_2, and CO, performance variations in the daily course of the day showed high concentration in episode days. Increase in concentration of all the indicators occured relatively in parallel: from 7–8 am to peak concentration at 1 pm. The above analysis makes it clear that Lanzhou experiences high levels of $PM_{2.5}$, PM_{10} and diurnal variations, therefore, the difference of O_3, NO_2 and additional particles must be further explored.

4. Conclusion

The concentration of pollutants in Gansu Province between June 1 and August 31 in 2015 was received based on monitoring of air quality from Ministry of Environmental Protection of the People's Republic of China. The results showed that:

1. Average PM concentrations in region exceeded the World Health Organization guideline values, which indicated serious impact on humans and the environment in Gansu Province.
2. The PM pollution is much more severe in China than those in USA and Europe.
3. Studies have shown that 20% of all summer days had higher concentration of $PM_{2.5}$, exceeding NAAQS Grade I and II standards, and 33% of days were for PM_{10}. PM_{10} concentrations were practically similar for all studied cities and varied in the range of 60–70 $\mu g/m^3$; it was indicated that PM pollution was a regional problem.
4. Apart from local pollution sources, there are external sources of pollution located outside the study area associated with passage of contaminants from elevated and desert regions of western and northern China.
5. The previous studies being compared, it can be assumed that atmospheric concentrations of pollutants gradually decreased, but are still at a high level.
6. There is no clear distinction between working days and holidays in the concentrations of seven pollutants that indicate a weak influence of weekly human activities.

To get more detailed and accurate information, as well as to identify patterns of distribution of substance concentration in the atmosphere of cities in Gansu Province, a more detailed investigation of the area for a long period (all seasons) is needed.

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