Aerosol and Air Quality Research, 19: 282–306, 2019

ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2018.11.0410

Characterization of the Air Quality Index for Urumqi and Turfan Cities, China

Zhiming Yin[1], Kangping Cui[1*], Shida Chen[1], Yixiu Zhao[1], How-Ran Chao[2*], Guo-Ping Chang-Chien[3,4*]

[1] *School of Resources and Environmental Engineering, Hefei University of Technology, Hefei 246011, China*
[2] *Emerging Compounds Research Center, Environmental Science and Engineering, National Pingtung University of Science and Technology, Neipu, Pintung 91201, Taiwan*
[3] *Center for Environmental Toxin and Emerging-Contaminant Research, Cheng Shiu University, Kaohsiung 83347, Taiwan*
[4] *Super Micro Mass Research and Technology Center, Cheng Shiu University, Kaohsiung 83347, Taiwan*

ABSTRACT

This study investigated the atmospheric $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3 in Urumqi and Turfan cities from 2015 to 2017. In addition, six AQI categories and AQI values and seasonal changes in the major pollutants in Urumqi and Turpan were studied. In the three-year (2015–2017) study, in Urumqi, the average proportion of grades I, II, III, IV, V, and VI in spring were 16.3%, 59.7%, 16.0%, 5.33%, 2.67%, and 0%, respectively, were 12.0%, 82.7%, 5.33%, 0%, 0%, and 0% in summer; were 13.3%, 65.7%, 16.3%, 3.33%, 1.33%, and 0% in fall, and were 0.667%, 14.3%, 22.3%, 15.3%, 33.7%, and 13.7% in winter. In the Turpan region, the mean proportion of Grade I, II, III, IV, V, and VI pollutants were 0%, 61%, 21.3%, 8.00%, 2.33%, and 7.33% in spring, respectively; were 0.67%, 74.7%, 20.0%, 2.00%, 0.67%, and 2.00% in summer, were 1.33%, 59.7%, 42.3%, 7.67%, 0.33%, and 2.00% in fall, and were 0%, 11.0%, 35.3%, 29.3%, 20.3%, and 4.00% in winter. In the three-year (2015–2017) study, based on the results of the survey, it was determined that two cities have the best air quality in summer and the worst air quality in winter. In Urumqi, when the AQI was between 101–150, the main air pollutants in 2015 were $PM_{2.5}$ and PM_{10}. In 2016, the main air pollutant was $PM_{2.5}$, and in 2017, the main air pollutants were $PM_{2.5}$ and PM_{10}. In Turpan, the main air pollutants in 2015 were $PM_{2.5}$ and PM_{10}, were $PM_{2.5}$, PM_{10}, and O_3 in 2016, and was PM_{10} in 2017. When the AQI was between 151 and 200, in Urumqi, the main atmospheric pollutant in the three-year period was $PM_{2.5.}$ In Turpan, the main atmospheric pollutants in the three-year period were $PM_{2.5}$ and PM_{10}. When the AQI was between 201 and 300 in Urumqi, $PM_{2.5}$ was the main atmospheric pollutant from 2015–2017. In Turpan, the main atmospheric pollutants in the three-year period were $PM_{2.5}$ and PM_{10}. To summarize, in both Urumqi and Turpan, $PM_{2.5}$ and PM_{10} were the most predominant air pollutants causing high AQI values. More attention should thus be paid to the sources and reduction of these pollutants.

Keywords: AQI; PM_{10}; $PM_{2.5}$; SO_2; NO_x; CO; O_3.

INTRODUCTION

With economic growth and urban construction, and with industrialization, urbanization is further expanded, so environmental pollution has become more and more serious (Heal *et al.*, 2012; Chen *et al.*, 2013). Industrial activities, the burning of chemical fuels, the emission of smoke from domestic stoves, and the emission of automobile exhaust caused by an increase in the number of automobiles have caused serious air pollution. At present, air pollution is a major risk affecting human health.

The harmful effects of atmospheric pollutants on the human body vary. $PM_{2.5}$ causes cardiovascular disease and lung cancer. $PM_{2.5}$ also affects air visibility and contributes to global climate change (Matawle *et al.*, 2015; Liang *et al.*, 2016; Du *et al.*, 2018). The harm of PM_{10} cannot be ignored. It can affect visibility and temperature. Nitrogen dioxide in the atmosphere has a variety of toxicities and damages the bronchus and lungs after entering the human body, which can induce various types of respiratory inflammation (Ezzati and Kammen, 2002; Tong *et al.*, 2018). SO_2 and NO_x released from the combustion of fossil fuels or some types of industrial production are discharged into the atmosphere and undergo a chemical reaction to form sulfuric acid or nitric acid. After rainwater falls onto the ground, they

* Corresponding author.
E-mail address: cuikangping@163.com (K. Cui);
hrchao@mail.npust.edu.tw (H.R. Chao);
guoping@gcloud.csu.edu.tw (G.P. Chang-Chien)

cause acidification of groundwater and surface water, contaminate the soil, and affect crop yields (Crutzen, 1979; Garg *et al*., 2001). Carbon monoxide (CO) is a very toxic pollutant. Carbon monoxide (CO) in the air passes through the respiratory system and enters the body's bloodstream (Peng *et al*., 2005; Brauer *et al*., 2016), resulting in oxygen deprivation of the body tissues, with the most significant effects on the heart and brain (Amato *et al*., 2011; Wei *et al*., 2012). After entering the human body, ozone stimulates the respiratory tract, triggers bronchitis and emphysema, and affects the nervous system of humans. The Air Quality Index (AQI) is a conceptual value that evaluates air quality, representing the air quality status and trends in a given area. It includes a measurement of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), fine particulate matter ($PM_{2.5}$), and coarse particulate matter (PM_{10}), which determine the air quality index on a given day. At present, the number of deaths caused by air pollution continues to increase. The harm caused by air pollution seriously affects sustainable development. Therefore, air pollution deserves serious attention.

As air pollution becomes more serious, China has begun to implement corresponding measures to gradually improve air quality. For example, in 2013, China began to implement the "Air Pollution Prevention Action Plan," which also improved its air quality. Based on this, the current study focused on the air pollution characteristics of Urumqi and Turpan through the use of AQI values. Both Urumqi and Turpan are located in the northwest part of China. Urumqi is one of the last ten cities in China with poor air quality, which is of great importance for the study of air quality in northwestern China (Pope and Dockery, 2013). The local government provided an important basis for the implementation of an air pollution control strategy.

This study discussed the content of six standard pollutants $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3 in air over a three-year period in Urumqi and Turpan. In addition, the study provides an Air Quality Index (AQI) analysis section illustrating changes in air quality over the study period.

METHODS

Urumqi (43°45′N, 87°36′E) is located in the middle of Xinjiang, bordering the city of Turpan. Turpan (42°25'N, 89°36'E) is located in the central part of the Xinjiang Uygur Autonomous Region and is located in the Tianshan mountain basin. Xinjiang is located in the northwestern part of China. It is far from the sea, surrounded by high mountains that block the flow of the oceans, and is difficult to reach, thus forming a clear temperate continental climate (Jin *et al*, 2017; Wu *et al*., 2017). There is a large temperature difference depending on hours of sunshine, with annual hours of sunshine ranging from 2500–3500. There is little rainfall, so the climate is dry. The two cities have been developing rapidly in recent years. According to past surveys, the industrialization and urbanization of a city are directly proportional to environmental pollution (Che *et al*., 2009). This study is of great significance to the environmental protection and human health of these two cities in the Xinjiang region.

Data were obtained for three years from January 2015 to December 2017 in both Urumqi and Turpan cities. The PM mass concentration (including daily $PM_{2.5}$ and PM_{10}) and gaseous pollutants (including daily SO_2, NO_2, CO, and 8 hr-averaged O_3) were obtained from the China air quality online monitoring and analysis platform (http://www.aqistudy.cn/).

Air Quality Index (AQI)

The sub-AQIs for the six standard contaminants were calculated by observing the concentrations, as shown in Eq. (1) (She *et al*., 2017; Shen *et al*., 2017). The overall AQI represents the maximum of the sub-AQI of all pollutants, where when the AQI is higher than 50, the highest sub-AQI contributor is defined as the primary pollutant on that day, as shown in Eq. (2) (She *et al*., 2017; Shen *et al*., 2017)

$$IAQI_P = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C_P - C_{low}) + I_{low} \tag{1}$$

$$AQI = \max\left(I_1, I_2, \ldots, I_n\right), \tag{2}$$

where
$IAQI_P$: the air quality sub index for air pollutant P;
C_P: the concentration of pollutant P;
C_{low}: the concentration breakpoint that is $\leq C_P$;
C_{high}: the concentration breakpoint that is $\geq C_P$;
I_{low}: the index breakpoint corresponding to C_{low};
I_{high}: the index breakpoint corresponding to C_{high}.

AQI refers to the air pollution index. According to the ambient air quality standards and the impact on the human social environment, the AQI simplifies the concentration of pollutants into a single numerical value to reflect the current air quality status. Six standard air pollutants have a dramatic impact on health. The daily AQI value is calculated from the 24-hour average concentrations of SO_2, NO_2, $PM_{2.5}$, PM_{10}, CO, and the daily maximum 8-hour concentration of O_3. According to some studies, AQI in the air is generally divided into six categories: Level I: 0–50 (good, green); Level II: 51–100 (medium, yellow); Level III: 101–150 (the sensitive group is not healthy; Orange); IV: 151–200 (unhealthy; red); V: 201–300 (very unhealthy; purple), VI: 300–500 (dangerous; brown) (Hu *et al*., 2015; She *et al*., 2017; Zhao *et al*., 2018).

RESULTS AND DISCUSSION

$PM_{2.5}$ Concentration

$PM_{2.5}$ refers to particulate matter less than 2.5 microns in diameter. It is suspended in the air for a long time and has a significant impact on the human body. PM tends to accumulate in human respiratory tract and thus is classified as a severe health hazard (Tao *et al*., 2009; Bilal *et al*., 2017; Xu *et al*., 2017). $PM_{2.5}$ enters the body's respiratory tract and cardiovascular system, leading to respiratory diseases. The monthly average $PM_{2.5}$ concentration in the ambient air of Urumqi and Turfan for the period 2015–2017 are shown in Tables 1(a), 1(b) and 1(c), respectively.

In Urumqi, the average monthly $PM_{2.5}$ concentration ranged from 24–147 µg m^{-3} in 2015, with an average of 65 µg m^{-3}; in 2016, it was 24–201 µg m^{-3}, with an average of 73 µg m^{-3}; in 2017, it was 19–228 µg m^{-3}, with an average of 71 µg m^{-3}. According to the average, the $PM_{2.5}$ concentration was the lowest in 2015. From 2015 to 2016, the $PM_{2.5}$ concentration increased by about 10.6%. From 2016 to 2017, it decreased by about 2.70%. In the three

Table 1(a). Monthly average atmospheric $PM_{2.5}$ concentrations in Urumchi and Turpan in 2015.

Month	Urumchi			Turpan		
	Range (µg m^{-3})	Mean (µg m^{-3})	RSD (%)	Range (µg m^{-3})	Mean (µg m^{-3})	RSD (%)
Jan.	43.0–252	119	42.6	50.0–208	144	30.4
Feb.	28.0–273	126	61.8	28.0–197	99.4	50.8
Mar.	22.0–186	65	54.0	33.0–74.0	54.2	21.9
Apr.	14.0–186	47	62.4	28.0–216	60.8	71.3
May	14.0–113	41	45.8	23.0–162	52.0	57.8
June	16.0–59	29.6	35.1	9.00–41.0	23.2	33.2
July	14.0–78.0	33.1	42.2	8.00–96.0	27.9	61.4
Aug.	9.00–48.0	28.9	35.5	20.0–128	39.5	57.7
Sep.	11.0–50.0	24.0	38.1	14.0–160	29.8	86.7
Oct.	12.0–101	44.8	52.8	22.0–100	48.4	32.3
Nov.	24.0–154	68.9	47.5	39.0–136	85.6	30.2
Dec.	20.0–327	147	52.7	56.0–219	115	38.7
Annual	9.00–327	64.5	47.5	8.00–219	65.0	47.7

Table 1(b). Monthly average atmospheric $PM_{2.5}$ concentrations in Urumchi and Turpan in 2016.

Month	Urumchi			Turpan		
	Range (µg m^{-3})	Mean (µg m^{-3})	RSD (%)	Range (µg m^{-3})	Mean (µg m^{-3})	RSD (%)
Jan.	93.0–397	185	34.9	55.0–265	133	43.1
Feb.	27.0–348	201	45.5	57.0–150	84.0	22.6
Mar.	23.0–159	78.8	53.0	36.0–244	85.1	59.4
Apr.	14.0–34.0	24.5	25.2	25.0–142	51.5	54.6
May	14.0–50.0	25.1	31.8	26.0–359	65.9	99.1
June	10.0–48.0	25.0	35.0	14.0–150	42.8	80.5
July	10.0–36.0	23.8	26.6	16.0–174	38.3	73.0
Aug.	16.0–48.0	26.2	27.8	18.0–158	36.5	74.1
Sep.	14.0–40.0	28.4	20.7	21.0–47.0	32.2	22.3
Oct.	9.00–90.0	42.5	45.0	23.0–230	68.5	73.3
Nov.	14.0–203	74.9	68.2	30.0–108	75.4	26.1
Dec.	46.0–297	142	46.3	46.0–188	132	26.3
Annual	9.00–397	73.1	38.3	14.0–359	70.4	54.5

Table 1(c). Monthly average atmospheric $PM_{2.5}$ concentrations in Urumchi and Turpan in 2017.

Month	Urumchi			Turpan		
	Range (µg m^{-3})	Mean (µg m^{-3})	RSD (%)	Range (µg m^{-3})	Mean (µg m^{-3})	RSD (%)
Jan.	128–353	228	25.9	62.0–161	118	19.6
Feb.	28.0–350	176	45.3	56.0–137	91.3	27.1
Mar.	46.0–197	101	41.6	32.0–118	57.7	33.4
Apr.	13.0–59.0	27.3	43.0	18.0–222	55.6	73.4
May	13.0–38.0	23.4	27.0	23.0–222	60.5	66.4
June	10.0–44.0	22.6	35.0	17.0–145	44.4	69.4
July	11.0–38.0	21.7	32.4	17.0–70.0	34.8	32.7
Aug.	11.0–41.0	18.8	28.9	19.0–216	36.0	95.5
Sep.	13.0–36.0	22.8	27.1	21.0–162	43.5	59.3
Oct.	13.0–91.0	45.6	44.8	28.0–118	56.0	34.1
Nov.	13.0–130	69.8	49.6	38.0–137	82.0	35.5
Dec.	22.0–224	93.4	45.2	60.0–168	136	20.8
Annual	10.0–353	70.8	37.2	17.0–222	68.0	47.3

years under investigation, the average concentration of $PM_{2.5}$ was 70 µg m^{-3}, which was 7 times higher than the WHO air quality regulatory standard (10 µg m^{-3}). Therefore, it is important to decrease the levels of $PM_{2.5}$ in the ambient air. During the three years examined, the maximum daily average concentration occurred in January 2016 (397.0 µg m^{-3}), and the minimum occurred in August 2015 (9.20 µg m^{-3}). This is because the burning of coal during the heating period in winter causes an increase in the amount of pollutants in the air.

In the case of Turpan, the average concentration of $PM_{2.5}$ in 2015 ranged from 23–115 µg m^{-3}, with an average of 65 µg m^{-3}; in 2016, it was 32–133 µg m^{-3}, with an average of 70 µg m^{-3}; in 2017, it was 35–136 µg m^{-3}, with an average of 68 µg m^{-3}. From 2015 to 2017, the $PM_{2.5}$ content in the air increased slightly, an increase of about 4.60%. The average daily maximum occurred in May 2016 (359 µg m^{-3}), and the minimum occurred in July 2015 (8.0 µg m^{-3}). The Turpan region is located in the northwestern part of China, where sandstorms often occur, so in May 15, 2016, the content of $PM_{2.5}$ and PM_{10} in the air increased abnormally. Overall, the average annual values for these three years were 65 µg m^{-3}, 70 µg m^{-3} and 68 µg m^{-3}, respectively, with a three-year average of 68 µg m^{-3}, which is 6.8 times higher (10 µg m^{-3}) than the WHO air quality regulatory standard.

Regarding seasonal changes, the average concentrations of $PM_{2.5}$ in spring, summer, autumn, and winter in Urumqi in 2015 were 80, 34, 33 and 111 µg m^{-3}, respectively; and in 2016, they were 101, 25, 32 and 134 µg m^{-3}, respectively. In 2017, the numbers were 101, 23, 29 and 130 µg m^{-3}, respectively. On the basis of the three years, it can be seen that the $PM_{2.5}$ content in the air changes due to seasonal changes. Generally, the $PM_{2.5}$ content in the winter air is greater than the $PM_{2.5}$ content in the spring air when the content of $PM_{2.5}$ in the air is greater than the $PM_{2.5}$ content in summer and autumn. Among the seasons, the $PM_{2.5}$ content in the air in winter was the highest in 2016, and the $PM_{2.5}$ content in the air in the summer of 2017 was the lowest. The highest value was in the winter of 2016 (134 µg m^{-3}), which was 5.8 times the lowest value in the summer of 2017 (23 µg m^{-3}).

In the case of Turpan, in 2015, the average $PM_{2.5}$ concentrations in spring, summer, fall, and winter were 71, 34, 39, and 115 µg m^{-3}, respectively, and those in 2016 were 74, 49, 46, and 113 µg m^{-3}, respectively. Those in 2017 were 68, 47, 45, and 112 µg m^{-3}, respectively. The $PM_{2.5}$ concentration in the winter air was higher than the $PM_{2.5}$ concentration in the spring air, and $PM_{2.5}$ concentration was the lowest in the summer and autumn air. Among the seasons, the $PM_{2.5}$ content in the air in the winter was the highest in 2015, and the $PM_{2.5}$ content in the air in the summer was the lowest in the summer of 2015. The highest value was in the winter of 2015 (115 µg m^{-3}), which was about 5.8 times the lowest value in the summer of 2015 (34 µg m^{-3}).

Previous studies have reported that urban transport has become a major source of atmospheric particulates in China's megacities due to rapid urbanization and industrialization (Song *et al.*, 2012; Zhao *et al.*, 2013; Lanzafame *et al.*, 2015; Xie *et al.*, 2016; Tao *et al.*, 2017). In addition to transportation, fuel combustion and industrial production are also important sources of $PM_{2.5}$. $PM_{2.5}$ has a small particle size and a long residence time in air and therefore has a great impact on air quality and human health.

PM_{10} Concentration

PM_{10} is a particulate with a particle size of less than 10 microns. Increases in PM_{10} pollution has important effects on air quality and human health. The sources of PM_{10} can be divided into natural factors and human factors. Natural factors include sandstorms and resuspension of local soils. The human factors generally include coal combustion (Evagelopoulos *et al.*, 2006; Matawle *et al.*, 2015), various industrial activities, and the cement ground car grinding process (Kong *et al*, 2011; Yang *et al.*, 2016). The content of PM_{10} pollution plays a crucial role in the study of air quality. The monthly mean PM_{10} concentrations in the ambient air of Turpan and Urumqi are listed in Tables 2(a), 2(b) and 2(c), respectively, for the period from 2015 to 2017.

In the case of Urumqi, the average PM_{10} concentration in 2015 was between 77 and 220 µg m^{-3}, with an average of 131 µg m^{-3}, and in 2016, it was 65 to 287 µg m^{-3}, with an average of 123 µg m^{-3}. In 2017, it was 61 to 271 µg m^{-3}, with an average of 115 µg m^{-3}. For three years, the concentration of PM_{10} in the area gradually decreased. From 2015 to 2016, it decreased by about 6.11%, and from 2016 to 2017, it decreased by about 6.50%.

In the case of Turfan, the average concentration of PM_{10} in 2015 was ranged from 61–282 µg m^{-3}, with an average of 140 µg m^{-3}, and in 2016, it was 105–277 µg m^{-3}, with an average of 171 µg m^{-3}. In 2017, the concentration ranged from 95–219 µg m^{-3}, and the average value was 160 µg m^{-3}. According to the average annual PM_{10} concentration, the annual average value of PM_{10} in the three years from 2015 to 2017 gradually increased. The PM_{10} concentration was the highest in 2016 and increased by approximately 22.1% from 2015 to 2016. From 2016 to 2017, the PM_{10} decreased by approximately 6.43%. The above results also show that the concentration of PM_{10} in Turpan was about eight times higher than the World Health Organization's air quality supervision standard (20 µg m^{-3}) during the study period. Therefore, efforts to implement more effective strategies to improve air quality in this region must be increased.

The three-year PM_{10} concentration in Urumqi for the three years under investigation ranged from 61 to 287 µg m^{-3} with an average of 123 µg m^{-3}, and the PM_{10} concentration in Turpan was between 61 and 282 µg m^{-3}, with an average of 157 µg m^{-3}. Therefore, the PM_{10} concentration in Turpan was higher than that in the Urumqi during the three years under study. It is possible that urbanization and industrialization in Turpan had already preceded that occurring in Urumqi. With economic development, it is also necessary to strengthen the protection of the environment.

Regarding the seasonal changes in the Urumqi region, the average PM_{10} concentrations in spring 2015, summer, autumn, and winter were 123, 102, 100, and 199 µg m^{-3},

Table 2(a). Monthly average atmospheric PM_{10} concentrations in Urumchi and Turpan in 2015.

Month	Urumchi			Turpan		
	Range (μg m^{-3})	Mean (μg m^{-3})	RSD (%)	Range (μg m^{-3})	Mean (μg m^{-3})	RSD (%)
Jan.	53.0–352	169	42.8	70.0–369	201	39.0
Feb.	45.0–466	207	64.8	65.0–768	282	71.5
Mar.	33.0–251	116	48.3	81.0–279	142	35.0
Apr.	35.0–387	127	54.5	56.0–722	175	89.2
May	27.0–268	126	46.6	44.0–387	121	67.3
June	37.0–169	93.3	36.4	27.0–120	61.3	37.9
July	50.0–188	118	30.9	25.0–266	88.2	62.9
Aug.	29.0–210	95.8	50.2	54.0–405	112	62.9
Sep.	20.0–145	77.0	41.6	32.0–558	86.5	108
Oct.	28.0–237	111	54.3	56.0–238	120	37.3
Nov.	40.0–221	112	43.9	62.0–347	140	35.9
Dec.	39.0–434	220	49.8	78.0–298	145	32.1
Annua	20.0–466	131	47.0	25.0–768	140	56.6

Table 2(b). Monthly average atmospheric PM_{10} concentrations in Urumchi and Turpan in 2016.

Month	Urumchi			Turpan		
	Range (μg m^{-3})	Mean (μg m^{-3})	RSD (%)	Range (μg m^{-3})	Mean (μg m^{-3})	RSD (%)
Jan.	128–523	257	34.1	75.0–368	199	39.1
Feb.	60.0–460	287	39.0	106–805	234	62.3
Mar.	46.0–262	130	43.9	84.0–1108	277	91.7
Apr.	31.0–252	81.1	51.7	52.0–469	135	73.2
May	29.0–132	67.5	40.6	64.0–1196	174	123
June	28.0–119	67.3	36.3	48.0–529	118	83.3
July	24.0–109	64.7	34.7	44.0–490	106	76.7
Aug.	36.0–133	77.7	31.2	55.0–548	109	85.0
Sep.	41.0–106	75.7	17.5	72.0–164	105	22.0
Oct.	20.0–143	67.6	43.6	79.0–861	215	89.3
Nov.	25.0–249	109	59.3	87.0–242	172	23.5
Dec.	64.0–406	193	44.2	103–292	202	22.8
Annual	20.0–523	123	39.7	44.0–1196	171	66.0

Table 2(c). Monthly average atmospheric PM_{10} concentrations in Urumchi and Turpan in 2017.

Month	Urumchi			Turpan		
	Range (μg m^{-3})	Mean (μg m^{-3})	RSD (%)	Range (μg m^{-3})	Mean (μg m^{-3})	RSD (%)
Jan.	106–472	271	33.0	116–222	168	13.8
Feb.	36.0–355	206	44.1	105–582	219	39.9
Mar.	59.0–262	128	40.2	102–602	177	52.0
Apr.	25.0–124	63.2	40.3	44.0–970	162	102
May	25.0–153	80.9	44.2	72.0–662	172	75.7
June	27.0–168	68.1	40.6	48.0–424	127	76.6
July	44.0–123	73.3	26.5	52.0–220	95	39.1
Aug.	25.0–206	60.5	52.7	60.0–784	120	105
Sep.	33.0–154	81.7	32.7	56.0–688	160	74.2
Oct.	18.0–199	105	47.2	91.0–492	157	49.6
Nov.	26.0–238	115	48.7	80.0–274	161	30.0
Dec.	52.0–324	131	45.0	96.0–238	201	16.9
Annual	18.0–472	115	41.3	44.0–970	160	56.2

respectively. The average values in 2016 were 93, 70, 84, and 246 μg m^{-3}, respectively, and the mean values in 2017 were 91, 67, 101, and 203 μg m^{-3}. The PM_{10} concentration in the winter was higher than that in the spring in the three year study period, which is far greater than the concentration of PM_{10} in the summer. For Turpan, in the spring of 2015, the average concentrations of PM_{10} in the summer, autumn, and winter were 126, 81, 95, and 136 μg m^{-3}, respectively. In the spring of 2016, the average concentrations of PM_{10} in the summer, autumn, and winter were 117, 78, 90, and

112 μg m^{-3}, respectively. In the spring of 2017, the average concentrations of PM_{10} in the summer, autumn, and winter were 93, 67, 90, and 90 μg m^{-3}, respectively. In the three year period under observation, the average concentration of PM_{10} in the spring and winter was higher than that in the summer and autumn, and the PM_{10} concentration was the lowest in summer. Generally speaking, the air quality in winter is poor. This is because the winter temperature is low, and a lot of coal is used for heating in the winter and spring (Shang *et al.*, 2015). Exhaust gas from fuel combustion contributes greatly to the accumulation of elements such as V, Cr, Cu, and Fe (Lelieveld *et al.*, 2015; Matawle *et al.*, 2015), and low-temperature air may hinder the diffusion of pollutants (Tang *et al.*, 2017; Xing *et al.*, 2017; Wang *et al.*, 2018). In the summer, air circulation is smooth and conducive to pollution, so the PM_{10} concentration in the summer is lower than the PM_{10} concentration in the winter.

Within the three year study period, the concentration of PM_{10} in Turpan was very high and fluctuated greatly with the change of seasons, mainly because sandstorms occur frequently in the area, and the area is surrounded by mountains, which is not conducive to air circulation. Coal combustion and power plant production are also sources of $PM_{2.5}$ and PM_{10} pollution. A recent report showed that cars also exacerbate air pollution. PM does great harm to the human body, affecting the human respiratory and nervous systems (Lee *et al.*, 2008; Wu *et al.*, 2013; Wang *et al.*, 2016). Previous studies have shown that air quality can be assessed by the ratio of $PM_{2.5}$ to PM_{10} (Zaveri *et al.*, 2008). Fossil fuel combustion, industrial activities, and vehicle exhaust emissions are important sources of PM_{10} (Kong *et al.*, 2011). Therefore, the concentration of PM_{10} must be appropriately lowered to improve the air quality.

$PM_{2.5}/PM_{10}$ Ratio

$PM_{2.5}$ and PM_{10} are particulates in the air. We often use $PM_{2.5}/PM_{10}$ to reflect air pollution. The monthly averages of the $PM_{2.5}/PM_{10}$ ratios in the ambient air of Urumqi and Turpan are shown in Tables 3(a), 3(b), and 3(c).

In Urumqi, the monthly $PM_{2.5}/PM_{10}$ ratio ranged from 0.28 to 0.71 in 2015, with an average of 0.47. The monthly $PM_{2.5}/PM_{10}$ ratio for 2016 ranged from 0.33 to 0.78, with an average of 0.52. The monthly $PM_{2.5}/PM_{10}$ ratio for 2017 ranged from 0.29 to 0.88, with an average of 0.53. In Turpan, the monthly $PM_{2.5}/PM_{10}$ ratio for 2015 was 0.32 to 0.78, with an average of 0.47. In 2016, the monthly $PM_{2.5}/PM_{10}$ ratio was 0.31 to 0.67, with an average of 0.43. In 2017, the monthly $PM_{2.5}/PM_{10}$ ratio was 0.30 to 0.71, with an average of 0.43. These results show that the annual average $PM_{2.5}/PM_{10}$ ratios in both Urumqi and Turpan were all lower than those reported in the Beijing-Tianjin-Hebei region (0.83), the Yangtze River Delta region (0.76), and the Pearl River Delta region (0.74) (Alghamdi *et al.*, 2015). The $PM_{2.5}/PM_{10}$ ratio refers to the ratio of $PM_{2.5}$ to PM_{10} and reflects the $PM_{2.5}$ and PM_{10} pollution proportion of PM pollution in the air. It has a certain guiding significance for PM pollution control.

In the case of Urumqi, in 2015, the three highest monthly averages for the $PM_{2.5}/PM_{10}$ ratio were 0.71 in January, 0.62 in February, and 0.66 in December. The three lowest

Table 3(a). Monthly average $PM_{2.5}/PM_{10}$ ratio in Urumchi and Turpan in 2015.

Month	Urumchi		Turpan	
	Range	Mean	Range	Mean
Jan.	0.62–0.82	0.71	0.48–1.56	0.75
Feb.	0.39–0.72	0.62	0.25–0.74	0.41
Mar.	0.19–0.80	0.58	0.26–0.53	0.40
Apr.	0.22–0.89	0.41	0.21–0.61	0.39
May	0.23–0.55	0.34	0.29–1.05	0.46
June	0.20–0.50	0.33	0.23–0.78	0.40
July	0.17–0.46	0.28	0.22–0.45	0.32
Aug.	0.20–0.56	0.33	0.22–0.52	0.36
Sep.	0.17–0.55	0.33	0.27–0.65	0.37
Oct.	0.23–0.63	0.42	0.33–0.56	0.41
Nov.	0.49–0.74	0.61	0.30–0.81	0.63
Dec.	0.51–0.75	0.66	0.51–1.06	0.78
Annual	0.17–0.89	0.47	0.21–1.56	0.47

Table 3(b). Monthly average $PM_{2.5}/PM_{10}$ ratio in Urumchi and Turpan in 2016.

Month	Urumchi		Turpan	
	Range	Mean	Range	Mean
Jan.	0.60–0.81	0.72	0.52–0.86	0.67
Feb.	0.45–0.85	0.68	0.19–0.62	0.42
Mar.	0.34–0.76	0.59	0.17–0.50	0.36
Apr.	0.13–0.58	0.33	0.20–0.78	0.43
May	0.28–0.56	0.39	0.30–0.57	0.41
June	0.24–0.51	0.38	0.23–0.81	0.37
July	0.27–0.54	0.38	0.25–0.56	0.37
Aug.	0.26–0.51	0.35	0.24–0.56	0.35
Sep.	0.25–0.51	0.38	0.23–0.42	0.31
Oct.	0.43–0.88	0.63	0.20–0.51	0.35
Nov.	0.31–0.88	0.67	0.32–0.59	0.44
Dec.	0.66–0.91	0.78	0.43–0.74	0.65
Annual	0.13–0.91	0.52	0.17–0.86	0.43

Table 3(c). Monthly average $PM_{2.5}/PM_{10}$ ratio in Urumchi and Turpan in 2017.

Month	Urumchi		Turpan	
	Range	Mean	Range	Mean
Jan.	0.65–1.40	0.88	0.39–0.88	0.71
Feb.	0.58–1.37	0.87	0.24–0.58	0.43
Mar.	0.26–1.00	0.79	0.20–0.64	0.34
Apr.	0.22–0.70	0.45	0.16–0.85	0.38
May	0.19–0.58	0.32	0.24–0.61	0.37
June	0.21–0.44	0.34	0.22–0.60	0.37
July	0.21–0.37	0.29	0.20–0.62	0.38
Aug.	0.20–0.69	0.34	0.22–0.44	0.31
Sep.	0.19–0.55	0.29	0.14–0.50	0.30
Oct.	0.25–0.72	0.46	0.23–0.58	0.38
Nov.	0.34–0.84	0.61	0.35–0.63	0.51
Dec.	0.37–0.91	0.71	0.53–0.76	0.67
Annual	0.19–1.40	0.53	0.14–0.88	0.43

monthly averages for the $PM_{2.5}/PM_{10}$ ratio were 0.33 in June, 0.28 in July, and 0.33 in August. In 2016, the three highest monthly averages of the $PM_{2.5}/PM_{10}$ ratio were 0.72 in January, 0.68 in February, and 0.78 in December. The three lowest monthly averages were 0.33 in April, 0.38 in July, and 0.35 in August. In 2017, the three highest monthly averages of $PM_{2.5}/PM_{10}$ ratio were 0.88 in January, 0.87 in February, and 0.71 in December. The three lowest monthly averages were 0.32 in May, 0.29 in July, and 0.29 in September.

In the case of Turpan, in 2015, the three highest monthly averages for the $PM_{2.5}/PM_{10}$ ratio were 0.75 in January, 0.63 in November, and 0.78 in December. The three lowest monthly averages for the $PM_{2.5}/PM_{10}$ ratio were 0.32 in July, 0.36 in August, and 0.37 in September. In 2016, the three highest monthly averages of the $PM_{2.5}/PM_{10}$ ratio were 0.67 in January, 0.44 in November, and 0.65 in December. The three lowest monthly averages were 0.35 in August, 0.31 in September, and 0.35 in October. In 2017, the three highest monthly averages of the $PM_{2.5}/PM_{10}$ ratio were 0.71 in January, 0.51 in November, and 0.67 in December. The three lowest monthly averages were 0.34 in March, 0.31 in August, and 0.30 in September.

In general, the $PM_{2.5}/PM_{10}$ value is higher when the winter temperature is low. When the summer temperature is high, the $PM_{2.5}/PM_{10}$ value is smaller. PM_{10} contains $PM_{2.5}$ based on the particle size. Compared with PM_{10}, $PM_{2.5}$ is a comprehensive pollutant; its range is relatively wide, and considerable parts of $PM_{2.5}$ are nitrogen oxides, sulfur dioxide and VOC derivative compounds that are produced by chemical conversion in the air. Therefore, to control $PM_{2.5}$, it is necessary not only to control particulate matter, but also to control sulfur dioxide, nitrogen oxides, volatile organic compounds, and so on. Because $PM_{2.5}$ has a small particle size, long residence time in the atmosphere, long transport distance, easy inhalation into the lungs, and a significant influence on human health and air quality, it should be of great concern.

SO_2 Concentration

SO_2 is a simple sulfur oxide, which is mainly derived from volcanic eruptions, coal combustion, and the combustion of petroleum and chemical fuels (Kato *et al.*, 2016). SO_2 can also undergo a series of reactions to form acid rain, which has negative effects on the ecosystem and the social environment. According to a US Environmental Protection Agency report, SO_3 and H_2SO_4 aerosols can have a range of adverse effects on the human body, including respiratory irritation and dyspnea (Li *et al.*, 2017a). Therefore, SO_2 pollution deserves scientific study. Figs. 1(a), 1(b), and 1(c) provide the average concentrations of SO_2 in Urumqi and Turpan, respectively, from 2015 to 2017.

In Urumqi, the monthly average concentration of SO_2 in 2015 was ranged from 0.700–27.7 ppb, with an average of 5.53 ppb. The average concentration in 2016 ranged from 1.10–20.3 ppb, with an average of 5.06 ppb. The average concentration in 2017 ranged from 2.10–16.5 ppb, with an average of 4.74 ppb. It was observed that the SO_2 concentration gradually decreased by approximately 8.50% from 2015 to 2016 and decreased by 11.7% from 2016 to 2017.

In Turpan, the average concentration of SO_2 in 2015 ranged from 0.700 to 47.6 ppb, with an average of 7.00 ppb; the average SO_2 concentration in 2016 ranged from 0.700 to 26.6 ppb, with an average of 5.13 ppb; the average concentration of SO_2 in 2017 ranged from 0.700 to 174 ppb, with an average is 4.93 ppb. The annual average concentration of SO_2 decreased by approximately 26.7% from 2015 to 2016 and decreased by approximately 3.90% from 2016 to 2017.

In the three year study period, the SO_2 concentration averaged 5.11 ppb in Urumqi and 5.69 ppb in Turpan, and the results showed that the concentrations of SO_2 in Urumqi and Turpan were lower than the World Health Organization air quality standard of 7.00 ppb, and that of Turpan was slightly higher than the concentration of SO_2 in Urumqi. The combustion of coal produces SO_2, which is easily oxidized into SO_3 in the air and has a significant impact on the environment (Kato *et al.*, 2016). Most of the SO_3 entering the air will form sulfuric acid vapor, which corrodes buildings. SO_2 has also attracted widespread attention, and China has also carried out corresponding control measures, such as gas desulfurization and modification of electrostatic precipitation and wet electrostatic precipitation (Schecter *et al.*, 2006). These measures have played a certain role in the control of SO_2. Urumqi adopted desulfurization construction of coal-fired plants as well as measures such as coal-fired heating control during the warm season. Accordingly, seasonal changes are further discussed.

In Urumqi, the average concentrations of sulfur dioxide in the spring, summer, autumn, and winter in 2015 were 4.83, 3.10, 3.87, and 10.33 ppb, respectively. In 2016, they were 4.07, 2.77, 4.60, and 8.80 ppb, respectively. In 2017, they were 3.67, 2.97, 4.43, and 7.90 ppb, respectively. In Turpan, the average SO_2 concentrations in the spring, summer, autumn, and winter of 2015 were 4.43, 2.80, 4.55, and 16.7 ppb, respectively. In 2016, they were 2.80, 2.57, 4.43, and 10.7 ppb, respectively. In 2017, they were 4.20, 2.33, 3.50, and 9.68 ppb, respectively. In the spring, summer, autumn and winter in Turpan, the average SO_2 concentrations were 3.81, 2.57, 4.16, and 12.4 ppb, and in the spring, summer, autumn and winter of Urumqi, the average SO_2 concentrations were 4.19, 2.95, 4.30, and 9.01 ppb. It is clear that the concentration of SO_2 in winter in these two regions is significantly higher than in other seasons. In general, the lowest SO_2 content in the air occurs in the summer because the burning of coal in the area in the winter is higher than in the other three seasons. The area around Turpan is surrounded by mountains, which lowers air circulation. Therefore, the SO_2 concentration changes with the season. Both cities are located in the northwestern part of China. They are cold in the winter and hot in the summer, especially in the case of Turpan. Extreme temperatures and low rainfall also cause differences in the levels of air pollutants in the winter and summer.

NO_2 Concentration

NO_2 is a toxic gas that can undergo a series of complex

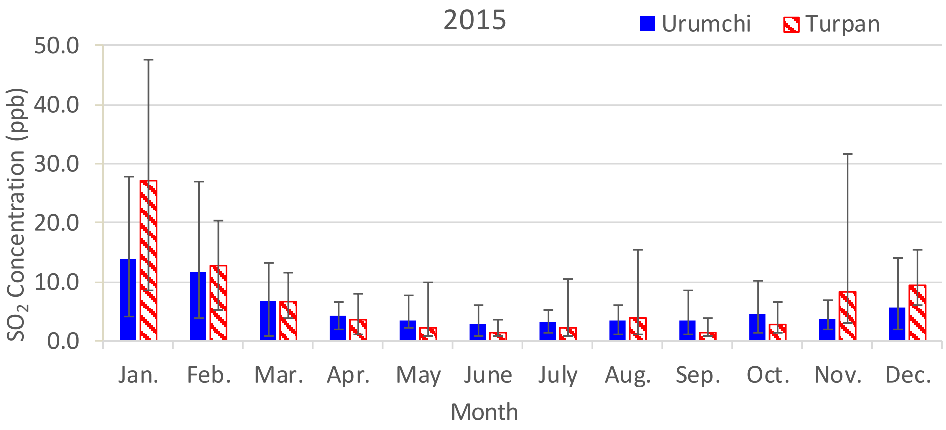

Fig. 1(a). Monthly average atmospheric SO_2 concentrations in Urumchi and Turpan in 2015.

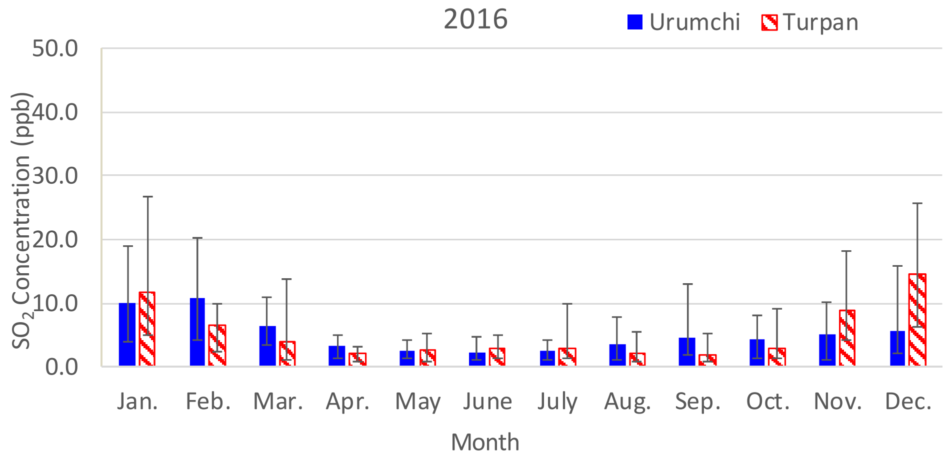

Fig. 1(b). Monthly average atmospheric SO_2 concentrations in Urumchi and Turpan in 2016.

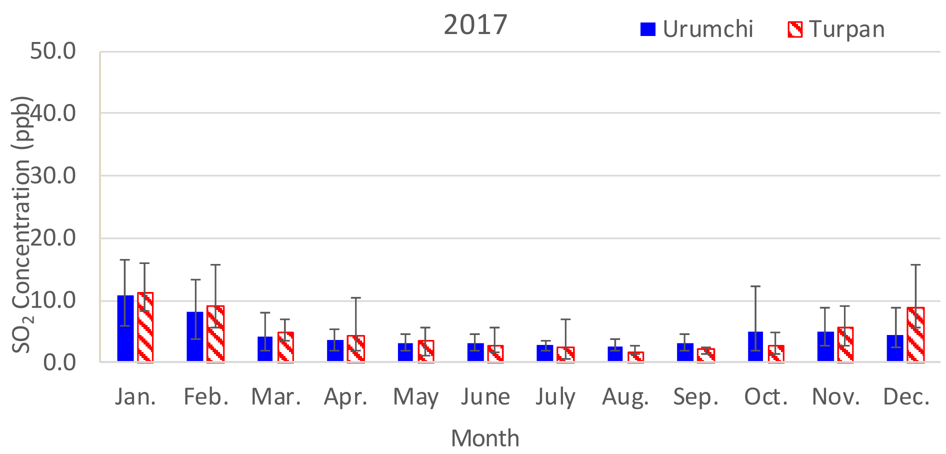

Fig. 1(c). Monthly average atmospheric SO_2 concentrations in Urumchi and Turpan in 2017.

reactions in the air (Thompson, 1992; Olivier *et al.*, 1998; Khokhar *et al*, 2016). Nitrogen dioxide is also one of the causes of acid rain and poses a significant environmental hazard. Generally speaking, NO_2 is mainly derived from human activities, including industrial NO_2 emissions, vehicle exhaust emissions, and fuel combustion (Cheng *et al.*, 2018). Figs. 2(a), 2(b), and 2(c) show the average concentrations of nitrogen dioxide in Urumqi and Turpan from 2015 to 2017, respectively.

In the case of Urumqi, the monthly NO_2 concentration was between 8.80 and 61.4 ppb, with an average of 24.8 ppb in 2015. In 2016, these values ranged from 10.2 to 68.7 ppb, with an average of 18.5 ppb, and from 8.80 to 66.2 ppb in 2017, with an average of 24.3 ppb. The average NO_2

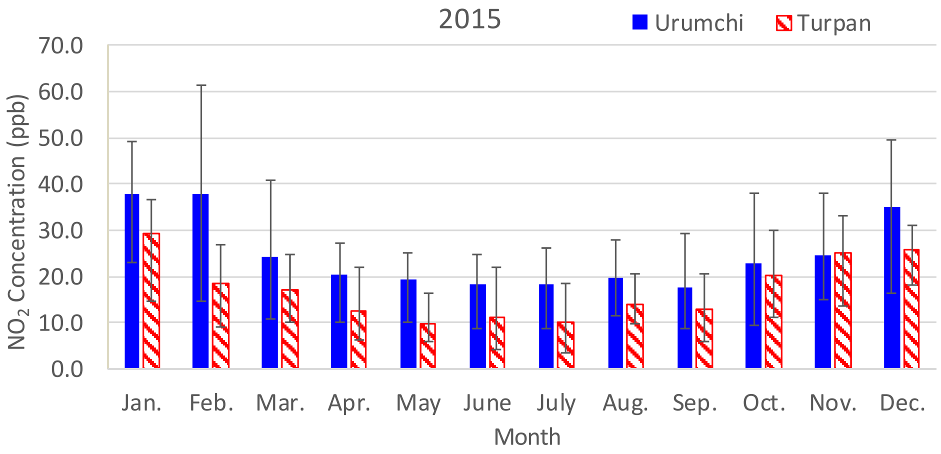

Fig. 2(a). Monthly average atmospheric NO_2 concentrations in Urumchi and Turpan in 2015.

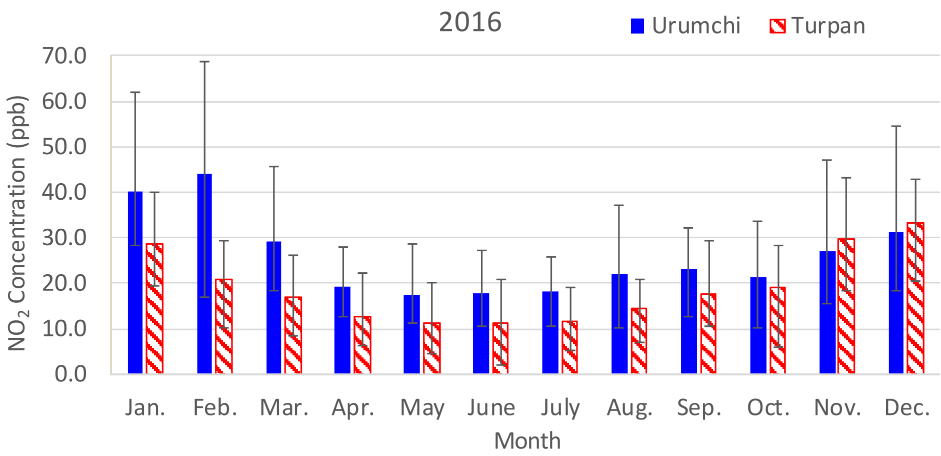

Fig. 2(b). Monthly average atmospheric NO_2 concentrations in Urumchi and Turpan in 2016.

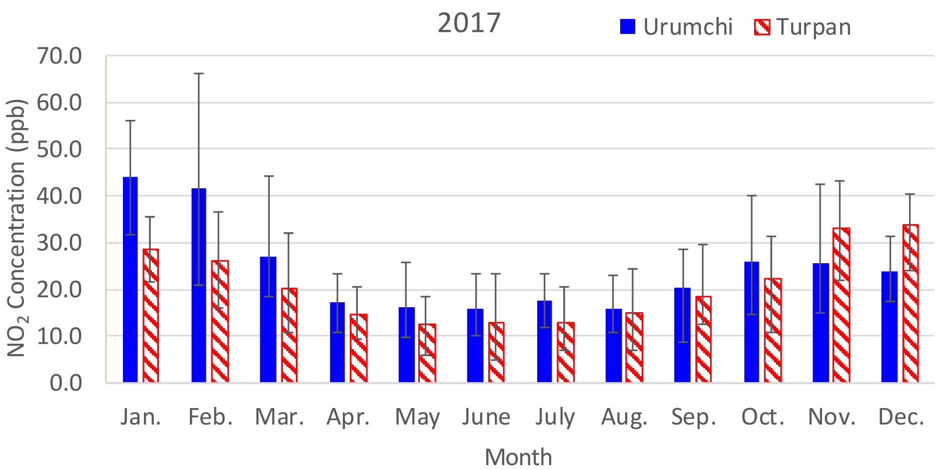

Fig. 2(c). Monthly average atmospheric NO_2 concentrations in Urumchi and Turpan in 2017.

concentration decreased by approximately 25.4% from 2015 to 2016 and increased by 31.4% from 2016 to 2017.

In Turpan, the monthly average NO_2 concentration in 2015 ranged between 3.41 and 36.5 ppb, with an annual average of 17.3 ppb. The monthly average NO_2 concentration in 2016 ranged between 1.90 and 43.3 ppb, with an annual average of 19.0 ppb. In 2017, these values ranged from 4.87 to 43.3 ppb, with an annual average of 21.0 ppb. The average NO_2 concentration increased slowly during the three-year period, rising by approximately 9.83% from 2015 to 2016 and increasing by 19.5% from 2016 to 2017.

Overall, the average NO_2 concentration range for

Urumqi and Turpan during the three-year period was 8.80–68.7 ppb and 1.90–43.3 ppb, respectively. The corresponding average concentrations are 22.5 and 19.1 ppb, respectively. The annual average NO_2 level in Urumqi (22.5 ppb) was slightly higher than WHO's air quality supervision standard (19.5 ppb). The average annual NO_2 level in Turpan (19.1 ppb) was close to the World Health Organization's air quality supervision standard (19.5 ppb).

Urumqi is the capital of Xinjiang and, according to official statistics, the population of Urumqi (2.67 million) is more than that of Turpan (650,000) (http://www.xjtj.gov.cn/). In recent years, along with economic development, urbanization and industrialization has accelerated. There are more vehicles and factories in Urumqi than in Turpan. Studies have shown that motor vehicles are the main source of nitrogen dioxide emissions (Sillman, 1999; Pudasainee *et al*., 2006). In 2015, the number of motor vehicles in Urumqi was 800,000. As of the end of 2016, the number of motor vehicles in Urumqi was 943,100, an increase of 14.2% over the previous year. By 2017, the number of motor vehicles reached 1.09 million. In Turpan, in 2015, the number of motor vehicles was 145,000. As of the end of 2016, the number of motor vehicles was 111,000, a decrease of 23.3% from the previous year. In 2017, the number of motor vehicles was 126,800 (http://www.tjcn.org/). As a result, The number of cars in Urumqi is higher than that in Turpan, the amount of nitrogen oxides (NO_x) emitted by automobile exhaust gases in Urumqi is greater, resulting in higher concentrations of NO_2 in the atmosphere.

In terms of seasonal variations, in Urumqi, the NO_2 concentrations in the spring, summer, autumn, and winter in 2015 were 21.5, 18.9, 21.8, and 37.0 ppb, respectively, and the NO_2 concentrations in 2016 were 22.0, 19.4, 23.9, and 38.4 ppb respectively; the NO_2 concentrations in 2017 were 20.2, 16.5, 24.0, and 36.4 ppb. In the Turpan region, the NO_2 concentrations in the spring, summer, autumn and winter in 2015 were 13.1, 11.9, 19.6, and 24.5 ppb respectively, and the NO_2 concentrations in 2016 were 13.6, 12.5, 22.1, and 27.6 ppb respectively; the NO_2 concentrations in 2017 were 15.9, 13.8, 24.7, and 29.7 ppb. In Urumqi, the maximum value of NO_2 occurred in the winter of 2016 (38.4 ppb), and the minimum occurred in the summer of 2017 (16.5 ppb). In Turpan, the maximum value of NO_2 occurred in the winter of 2017 (29.7 ppb), and the minimum occurred in the summer of 2015 (11.9 ppb). It can be seen from the data that in Urumqi, the concentration of NO_2 in the autumn and winter was higher than that in the spring and summer. In Turpan, the concentration of NO_2 was the highest in the winter and the lowest in NO_2 in the summer. This phenomenon may be related to different meteorological conditions in different seasons. Both cities are located in northwestern China, with a dry climate and large temperature differences. The increase in the use of coal and vehicles during winter results in an increase in NO_2 concentration; therefore, corresponding measures should be taken to reduce NO_2 emissions.

CO Concentration

Carbon monoxide (CO) is a common air pollutant that poses a significant threat to human health. Carbon monoxide (CO) is mainly derived from the combustion of fossil fuels and the presence of CO in domestic gas or coal stoves and automobile exhaust. Once CO enters the body, it immediately binds to hemoglobin, which forms carboxyhemoglobin (COHb), which causes tissue hypoxia (Dary *et al*., 1981; Li *et al*., 2017b), causing symptoms such as vomiting, dizziness, and even death (Jarvis *et al*, 1986; Scharte *et al*, 2000). Carbon monoxide (CO) is an important indicator of air pollutants, and thus, research on carbon monoxide has important implications. The monthly mean concentrations of CO in Urumqi and Turpan from 2015 to 2017 are shown in Tables 4(a), 4(b), and 4(c), respectively.

In Urumqi, the monthly average CO concentration ranged from 0.516 to 2.28 ppm in 2015, from 0.421 to 2.76 ppm in 2016, and from 0.605 to 2.60 ppm in 2017, corresponding to an annual average of 1.13, 1.17, and 1.13 ppm, respectively. The carbon monoxide concentration did not fluctuate in the three year period. The annual average concentration of carbon dioxide in 2016 increased by approximately 3.54% from 2015 and decreased by approximately 3.42% from 2016 to 2017.

Table 4(a). Monthly average atmospheric CO concentrations in Urumchi and Turpan in 2015.

Month	Urumchi			Turpan		
	Range (ppm)	Mean (ppm)	RSD (%)	Range (ppm)	Mean (ppm)	RSD (%)
Jan.	0.880–3.52	2.21	29.7	1.52–3.92	2.92	20.6
Feb.	0.880–3.52	2.15	39.0	1.52–3.36	2.20	28.0
Mar.	0.560–2.48	1.21	37.8	0.480–2.08	0.870	48.4
Apr.	0.480–1.12	0.749	24.7	0.320–1.04	0.706	30.0
May	0.480–0.800	0.625	14.6	0.400–0.720	0.539	17.1
June	0.320–0.800	0.565	20.3	0.400–1.36	0.986	29.6
July	0.320–0.800	0.594	18.3	0.320–1.36	0.672	33.2
Aug.	0.400–0.720	0.516	19.1	0.480–0.880	0.642	19.2
Sep.	0.320–0.880	0.520	26.1	0.320–0.640	0.480	15.2
Oct.	0.320–1.76	0.805	42.8	0.560–1.76	0.991	27.4
Nov.	0.800–2.40	1.37	35.4	0.880–3.12	1.87	30.3
Dec.	0.880–3.76	2.28	31.7	2.16–5.12	3.07	22.3
Annual	0.320–3.76	1.13	28.3	0.320–5.12	1.33	26.8

Table 4(b). Monthly average atmospheric CO concentrations in Urumchi and Turpan in 2016.

Month	Urumchi			Turpan		
	Range (ppm)	Mean (ppm)	RSD (%)	Range (ppm)	Mean (ppm)	RSD (%)
Jan.	1.52–4.32	2.53	24.6	2.80–6.16	4.06	19.3
Feb.	1.12–4.32	2.76	27.5	0.480–3.12	1.11	44.0
Mar.	0.720–3.36	1.43	44.7	0.560–1.28	0.895	21.3
Apr.	0.400–0.80	0.549	19.0	0.320–0.960	0.642	30.6
May	0.320–0.800	0.488	20.0	0.400–0.880	0.598	22.6
June	0.320–0.560	0.421	15.7	0.640–1.12	0.890	11.0
July	0.320–0.560	0.472	12.6	0.400–1.12	0.705	31.2
Aug.	0.320–0.960	0.542	25.5	0.560–1.12	0.834	13.7
Sep.	0.480–0.880	0.643	18.6	0.480–0.800	0.606	13.7
Oct.	0.560–1.44	0.844	26.8	0.320–1.36	0.849	27.4
Nov.	0.640–2.88	1.43	45.7	1.12–2.88	1.96	24.7
Dec.	1.12–3.84	1.99	34.7	1.44–3.92	2.74	19.5
Annual	0.320–4.32	1.17	26.3	0.320–6.16	1.32	23.2

Table 4(c). Monthly average atmospheric CO concentrations in Urumchi and Turpan in 2017.

Month	Urumchi			Turpan		
	Range (ppm)	Mean (ppm)	RSD (%)	Range (ppm)	Mean (ppm)	RSD (%)
Jan.	1.52–3.84	2.60	23.1	1.76–3.12	2.52	15.2
Feb.	0.960–3.20	2.12	28.6	0.960–2.40	1.70	28.1
Mar.	0.800–2.24	1.27	30.6	0.640–1.20	0.875	15.5
Apr.	0.480–0.880	0.659	16.5	0.320–0.880	0.630	22.1
May	0.480–0.800	0.617	12.2	0.320–0.720	0.555	19.0
June	0.480–0.800	0.605	13.3	0.320–1.12	0.582	36.4
July	0.560–0.720	0.640	9.1	0.320–0.720	0.573	19.8
Aug.	0.560–0.720	0.643	7.5	0.480–0.880	0.702	13.1
Sep.	0.480–0.800	0.664	13.1	0.480–0.880	0.710	13.8
Oct.	0.560–1.68	0.973	29.3	0.640–1.60	0.958	20.6
Nov.	0.640–1.92	1.24	30.1	0.960–2.72	1.67	31.4
Dec.	0.960–2.80	1.50	32.5	1.76–3.36	2.72	14.4
Annual	0.480–3.84	1.13	20.5	0.320–3.36	1.18	20.8

In Turpan, the monthly average CO concentrations ranged from 0.480 to 3.07 ppm in 2015, 0.598 to 4.06 ppm in 2016, and 0.555 to 2.27 ppm in 2017, for which the corresponding annual averages were 1.33, 1.32, and 1.18 ppm, respectively. The average CO concentration in 2015 and 2016 did not change much, and it decreased by 0.75% from 2015 to 2016. From 2016 to 2017, the average CO concentration decreased by 10.6%, so carbon monoxide in the air has decreased annually.

The annual average CO concentrations in Urumqi and Turpan were 1.14 and 1.28 ppm, respectively. The concentrations of carbon monoxide in Urumqi and Turpan were both lower than the 8-hour average of the WHO Air Quality Standard (8.00 ppm), indicating that carbon monoxide has no serious impact on the air quality of the two cities.

As for seasonal changes in CO concentration, in Urumqi, the CO concentrations in the spring, summer, autumn, and winter of 2015 were 0.861, 0.558, 0.897, and 2.21 ppm, respectively; in 2016, they were 0.821, 0.479, 0.972, and 2.43 ppm, respectively. In 2017, they were 0.849, 0.629, 0.958, and 2.08 ppm, respectively. As for Turpan, in 2015, the concentrations of CO in spring, summer, autumn, and winter were 0.512, 0.578, 0.875, and 1.144 ppm, respectively, and in 2016, they were 0.666, 0.758, 1.17, and 1.26 ppm, respectively. In 2017, they were 0.933, 0.696, 1.17, and 1.54 ppm, respectively. In Urumqi, the CO concentration was the highest (2.43 ppm) in the winter of 2016, and the CO concentration was the lowest (0.479 ppm) in the summer of 2016. The highest value was five times higher than the lowest value. In Turpan, the CO concentration was the highest (1.54 ppm) in the winter of 2017, and the CO concentration was the lowest (0.512 ppm) in the spring of 2015. The highest value was three times higher than the lowest value. From the data, it can be seen that the CO concentration in the two cities varies greatly between the seasons, and in the winter, the concentration of CO was the highest in Urumqi, whereas it was at its lowest level in summer. In the spring and summer, both values were at the middle level. Turpan, however, had the lowest CO concentration in the spring and summer of 2015 and 2016, with the CO concentration in autumn at a moderate level and the highest concentration in winter. Seasonal variations in CO concentrations are related to temperature and are also related to the increase in CO concentration caused by coal combustion in winter.

O_3 Concentration

O_3 is an oxygen allotrope with poor stability and is a source of greenhouse gases. High levels of O_3 have strong oxidative properties that adversely affect human health and vegetation (Monks *et al*., 2015). O_3 is a greenhouse gas that plays an important role in global warming (Stocker *et al*., 2013). Ozone concentrations have been rising over the past decade (Akimoto, 2003; Vingarzan, 2004; Xu *et al*., 2011; Feng *et al*., 2015). With the development of urbanization and industrialization in China, O_3 has become a growing public concern (Ou *et al*., 2016; Gong *et al*., 2018). In contaminated air, the largest contributors to O_3 forming precursors are NO_x and VOCs, especially unsaturated VOCs. The simplified general equation for the regulation of atmospheric photochemistry is summarized in Wang *et al*. (2018).

Figs. 3(a), 3(b), and 3(c) show the changes in monthly average O_3 concentrations in Urumqi and Turpan in 2015, 2016, and 2017, respectively.

In Urumqi, the monthly average concentration of O_3 in 2015 was between 2.30 and 77.4 ppb, and the average in 2015 was 28.2 ppb. The monthly average concentration of O_3 in 2016 was between 4.20 and 75.5 ppb, and the average in 2016 was 27.7 ppb. In 2017, the monthly average concentration was between 6.10 and 72.2 ppb, with an average of 34.0 ppb. We can see that the O_3 level in Urumqi dropped by about 1.77% from 2015 to 2016, and the O_3 level increased by about 22.7% from 2016 to 2017.

In the Turpan region, the monthly average concentration of O_3 in 2015 was between 4.70 and 67.6 ppb; the average concentration of O_3 in 2015 was 37.5 ppb; the monthly average concentration of O_3 in 2016 was between 6.99 and 95.1 ppb, and the average concentration of O_3 in 2016 was 45.9 ppb. The monthly average concentration of O_3 in 2017 was between 8.39 and 91.3 ppb, and the average concentration of O_3 in 2017 was 41.0 ppb. It increased by approximately 22.4% from 2015 to 2016 and decreased by approximately 10.7% from 2016 to 2017. The results show that the Turpan O_3 concentration is lower than the WHO air quality supervision standard, but we still need to implement appropriate control measures to reduce the O_3 concentration.

In Urumqi, seasonal average O_3 concentrations in the spring, summer, autumn, and winter of 2015 were 29.3, 51.5, 21.4, and 10.7 ppb, respectively. In the spring, summer, autumn and winter of 2016, they were 28.3, 47.5, 24.4, and 10.5 ppb, respectively, and in 2017, they were 35.6, 52.2, 30.8, and 17.5 ppb for spring, summer, autumn, and winter, respectively. In Turpan, the seasonal concentrations of ozone in the spring, summer, autumn, and winter of 2015 were 46.4, 51.3, 31.1, and 21.1 ppb, respectively, while those in 2016 were 61.7, 61.2, 37.9, and 23.0 ppb, respectively. In 2017, these values were 44.4, 62.4, 35.6, and 21.4 ppb, respectively. According to the data, in Urumqi, in the summer of 2015, 2016, and 2017, the ozone concentrations were 51.5, 47.5, 61.2, and 52.2 ppb, respectively, which exceeded the WHO's air quality supervision standard of 46.6 ppb. In Turpan, for the summer of 2015, the spring of 2016, and the summer of 2017, the ozone concentrations were 55.3, 61.7, 61.2, and 62.4 ppb, respectively, which exceeded the WHO's air quality regulated standard of 46.6 ppb.

Although the average O_3 concentration in both cities was below the World Health Organization's 46.6 ppb air quality regulated standards, in some seasons, the air O_3 concentration was higher than the air quality monitoring standard. According to the data, in Urumqi and Turpan, O_3 concentration in the air was in the following order: summer > spring > autumn > winter. This shows that summer is the season with the highest O_3 pollution. Previous studies have shown that in humid environments, the presence of water vapor facilitates the removal of O_3 (Fiore *et al.*, 2002), and the movement of the gas stream also has an effect on the concentration of O_3. Urumqi has a large temperature difference between day and night, with severe changes in temperature and heat and less precipitation. Turpan has typical drought and desert characteristics, where the annual amount of radiation is large, especially in spring and summer. This leads to high temperatures in the summer and strong radiation in these two cities, causing NO_x to form O_3 under ultraviolet light. The higher the temperature is, the longer the illumination time is, and the easier it is for ozone to exceed the standard. The summer is a season with severe ozone pollution. After entering autumn, the ozone concentration gradually decreases. According to a survey conducted by the Environmental Monitoring Station in Urumqi, ozone in the air is not emitted directly, but is a secondary pollutant generated under the effect of sunlight. Motor vehicles are also one of the sources of O_3. Pollutants emitted by powerplants and the petrochemical industry are emitted under specific meteorological conditions. Therefore, it is necessary to control plant pollution emissions, reduce vehicle exhaust, improve gasoline quality, etc. to reduce the formation of O_3.

AQI Analysis

AQI is the ambient air quality index. It is a universal global air quality assessment system used to evaluate air quality and assess health risks. Pollutants monitored include sulfur dioxide, nitrogen dioxide, PM_{10}, $PM_{2.5}$, carbon monoxide, and ozone. The air quality index (AQI) range and corresponding air quality categories can be divided into six categories: excellent air quality, good air quality, mild pollution, moderate pollution, heavy pollution, and severe pollution. Based on the different air quality categories, appropriate air pollution measures are implemented. Figs. 4(a)–4(f) shows a small portion of the six AQI categories in different seasons in Urumqi and Turpan from 2015 to 2017, where the accumulated days with the major pollutants are shown in the table. Figs. 3(a)–3(b). In Urumqi, in 2015, the daily AQI range was 30–357, and the annual average was 105. In 2016, the daily AQI range was 27–432, and the annual average was 110. In 2017, the daily AQI range was 35–402. The annual average was 110. In Turpan, in 2015, the daily AQI range was 37–500, and the annual average was 110. In 2016, the daily AQI range was 53–500, and the annual average was 130. In 2017, the daily AQI range was 54–500. The annual average was 121. As can be seen from the data, the AQI remained basically

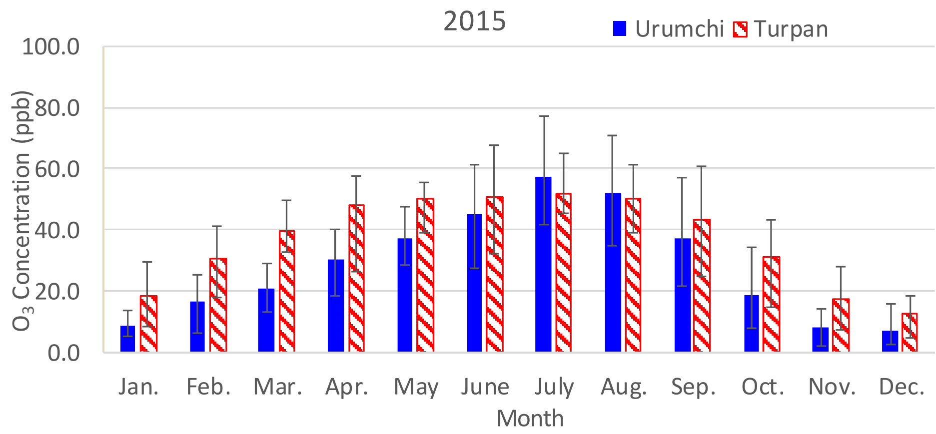

Fig. 3(a). Monthly average atmospheric O_3 concentrations in Urumchi and Turpan in 2015.

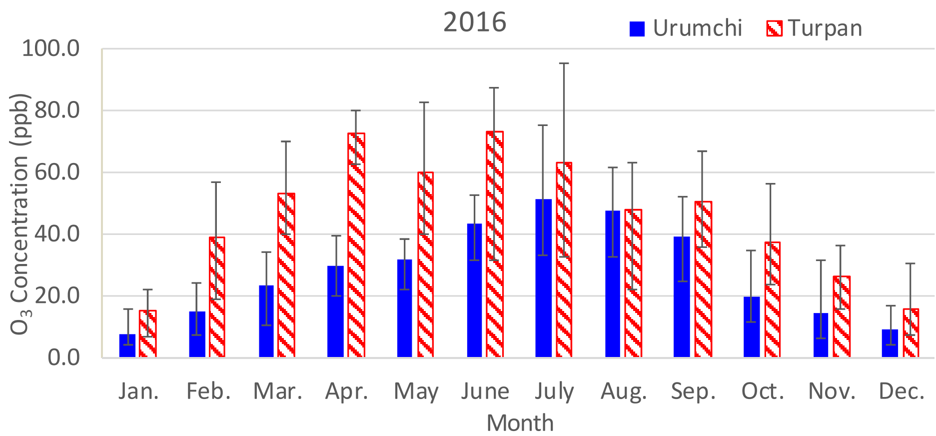

Fig. 3(b). Monthly average atmospheric O_3 concentrations in Urumchi and Turpan and in 2016.

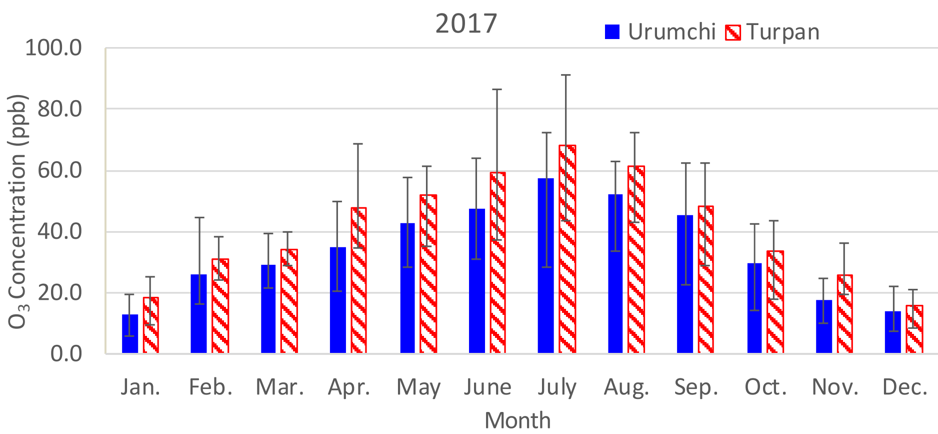

Fig. 3(c). Monthly average atmospheric O_3 concentrations in Urumchi and Turpan in 2017.

unchanged in Urumqi during the three years under investigation. There was no significant improvement in Turpan's AQI during this period, with the highest AQI value in 2016. Among them, the maximum AQI in Turpan reached 500, which indicates that there was severe pollution in Turpan.

In Urumqi, Figs. 4(b)-(A), 4(d)-(A), and 4(f)-(A) show that in the spring of 2015, the I, II, III, IV, V, and VI ratios were 9%, 63%, 22%, 4%, 2%, and 0%, respectively. In 2016, the ratios of I, II, III, IV, V, and VI were 21%, 62%, 9%, 5%, 3%, and 0%, respectively. In 2017, the ratios of I, II, III, IV, V, and VI were 19%, 54%, 17%, 7%, 3%, and 0%, respectively. The proportion of Class I increased, rising by 10% from 2015 to 2017, but there was no significant fluctuation in the proportion of the remaining categories. As can be seen from Table 5(a), PM_{10} was the

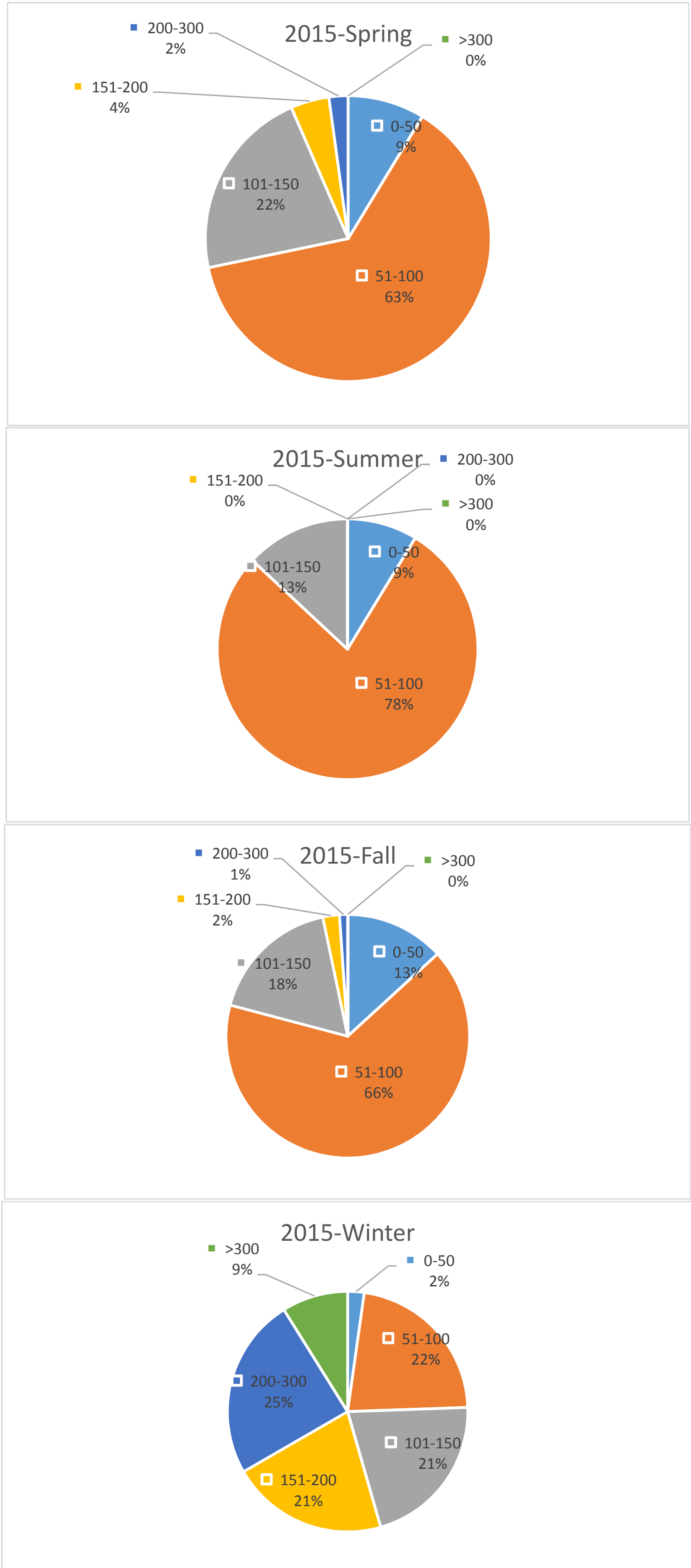

Fig. 4 (a). The fractions of the six AQI categories for Urumchi in (A) Spring, (B) Summer, (C) Fall, and (D) Winter in 2015.

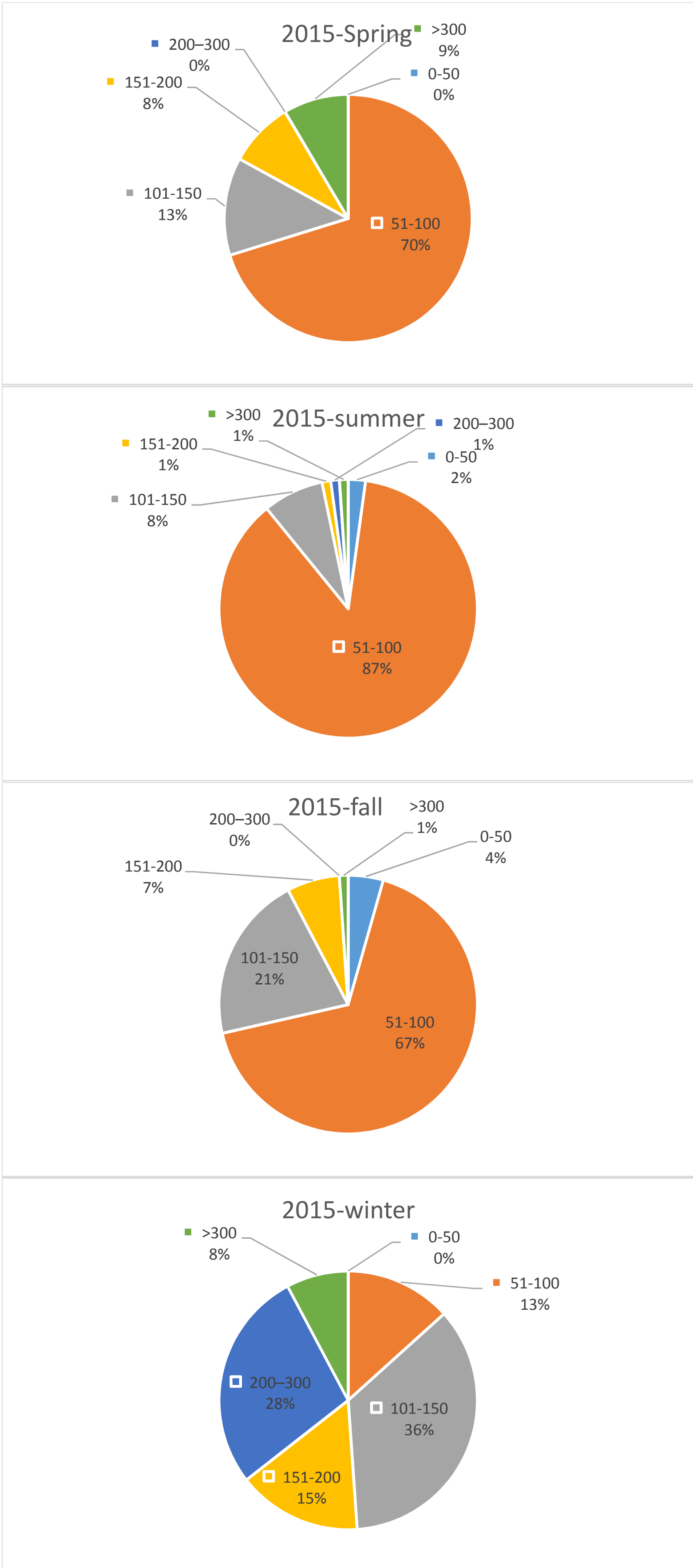

Fig. 4(b). The fractions of the six AQI categories for Turpan in (A) Spring, (B) Summer, (C) Fall, and (D) Winter in 2015.

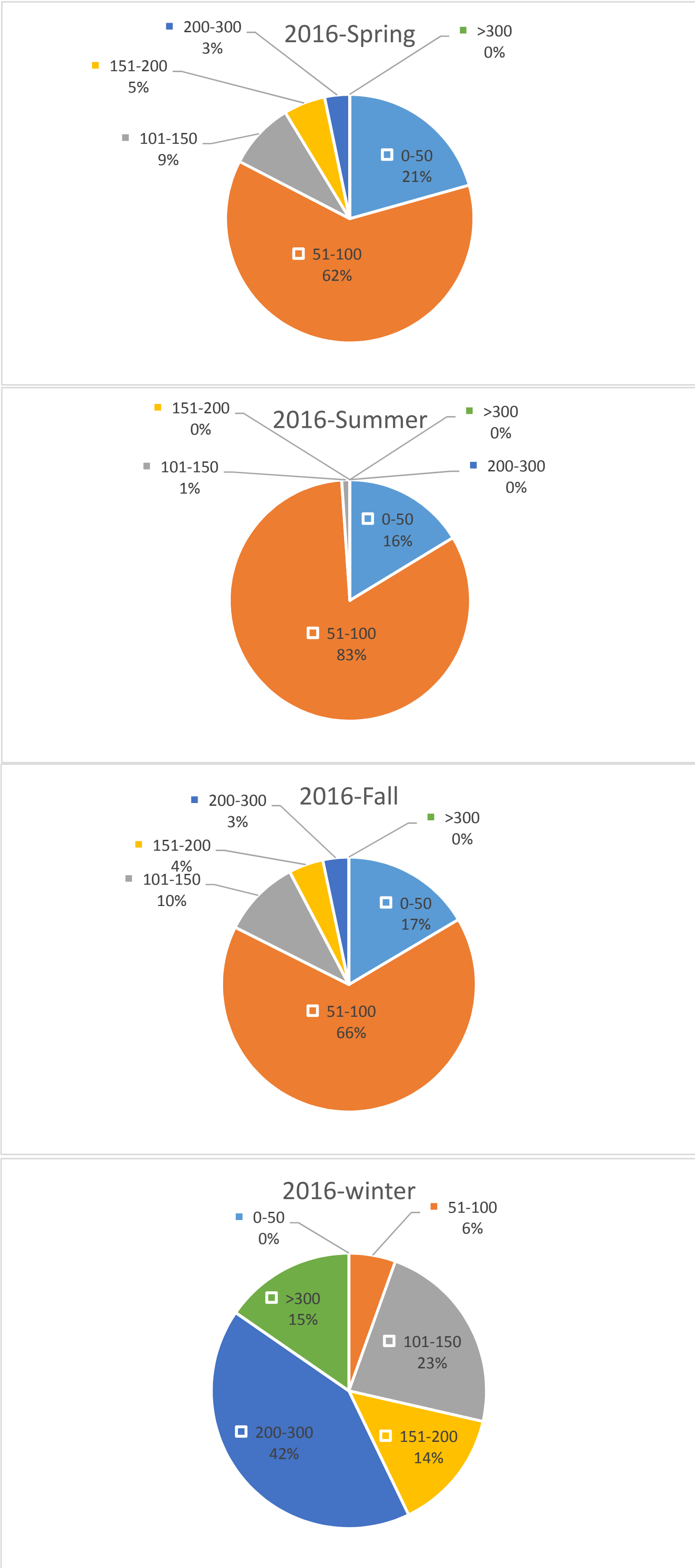

Fig. 4(c). The number fractions of the six AQI categories for Urumchi in (A) Spring, (B) Summer, (C) Fall, and (D) Winter in 2016.

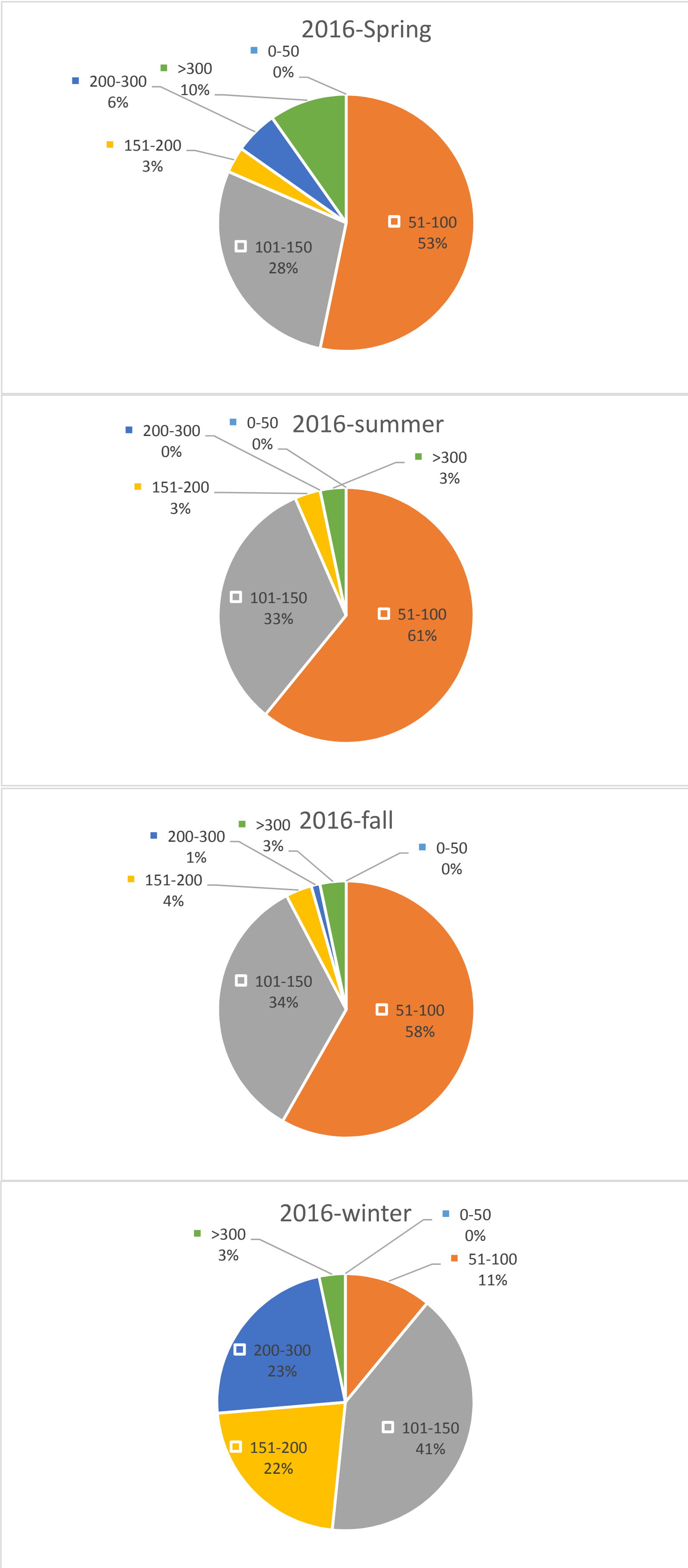

Fig. 4(d). The fractions of the six AQI categories for Turpan in (A) Spring, (B) Summer, (C) Fall, and (D) Winter in 2016.

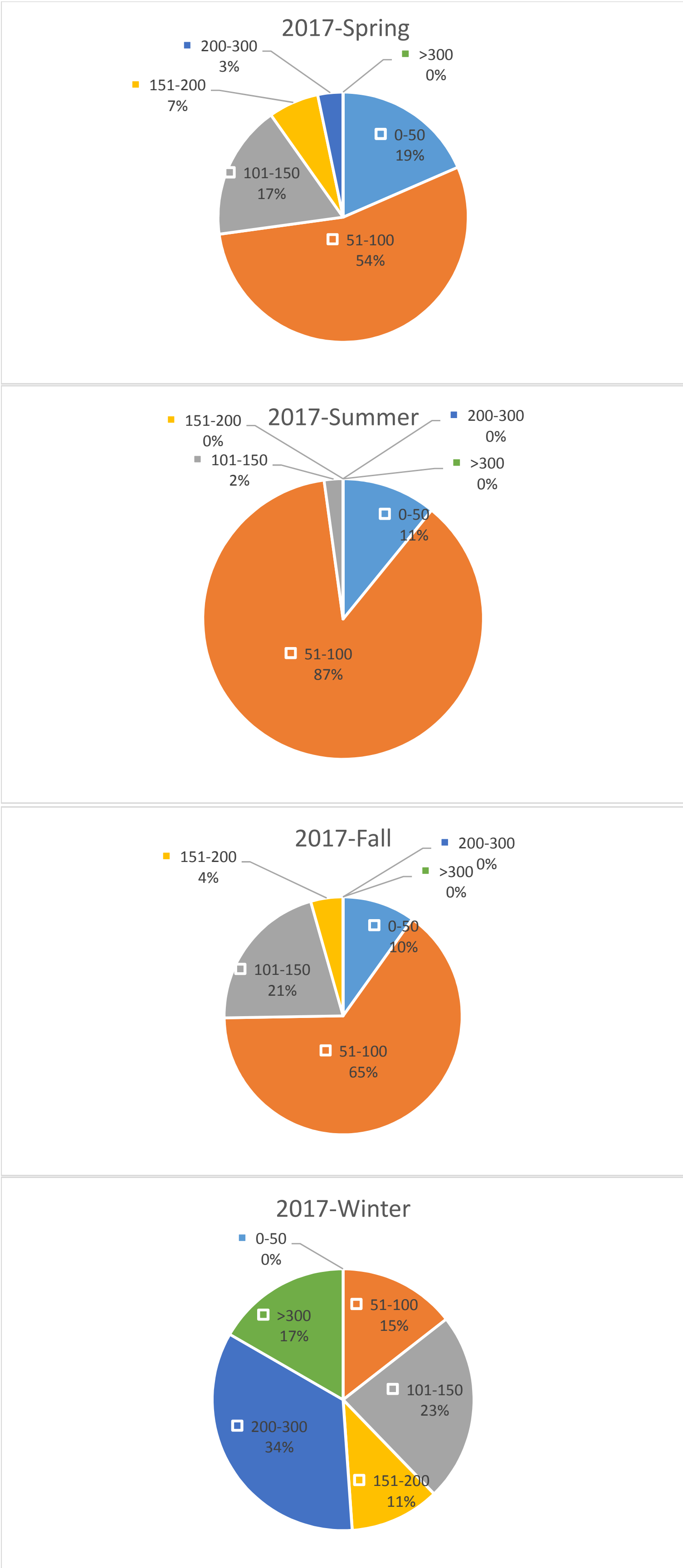

Fig. 4(e). The number fractions of the six AQI categories for Urumchi in (A) Spring, (B) Summer, (C) Fall, and (D) Winter in 2017.

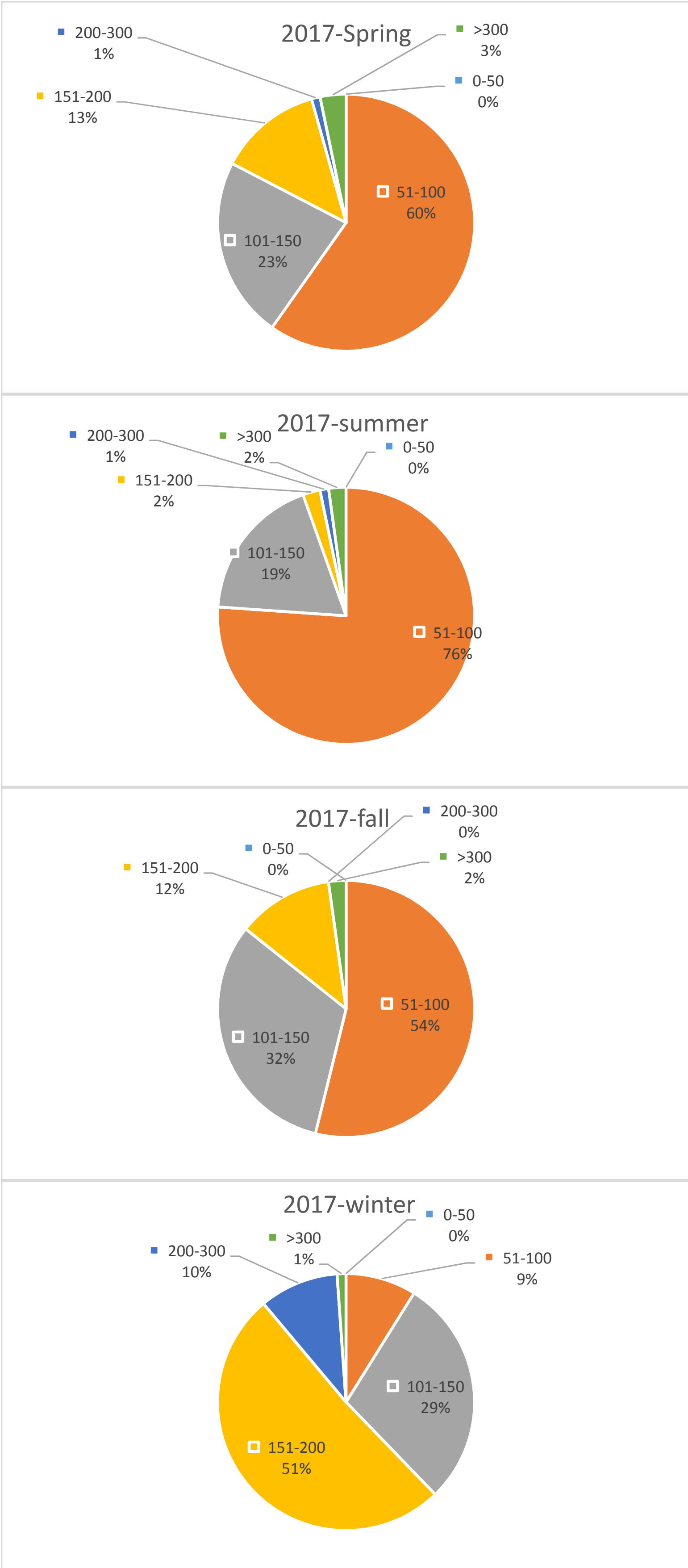

Fig. 4(f). The fractions of the six AQI categories for Turpan in (A) Spring, (B) Summer, (C) Fall, and (D) Winter in 2017.

most common major pollutant in the spring, followed by $PM_{2.5}$, and NO_x pollutants also were found. This shows that in addition to controlling PM pollution in Urumqi in the spring, controlling NO_x pollution is also critical.

Figs. 4(b)-(B), 4(d)-(B), and 4(f)-(B) show that in the summer of 2015, the ratios of I, II, III, IV, V, and VI were 9%, 78%, 13%, 0%, 0%, and 0%, respectively. In 2016, the ratios of I, II, III, IV, V, and VI were 16%, 83%, 1%, 0%, 0%, and 0%, respectively. In 2017, the ratios of I, II, III, IV, V, and VI were 11%, 87%, 2%, 0%, 0%, and 0%, respectively. From 2015 to 2017, Grades I and II increased by 2% and 8%, respectively, and Grade III decreased by 11%. This shows that Urumqi's summer air quality is gradually improving. As can be seen from Table 5(a), in the summer of Urumqi, PM_{10} was the primary air pollutant, followed by O_3. High temperatures in the summer and intense radiation accelerate the formation of O_3. From 2015 to 2017, the number of days with O_3 pollution in the air increased. Therefore, it is urgent to take effective measures to prevent this increase of O_3 in the summer.

Figs. 4(b)-(C), 4(d)-(C), and 4(f)-(C) show that in the fall of 2015, the I, II, III, IV, V and VI scales were 13%, 66%, 18%, 2%, 1%, and 0%, respectively. In 2016, the ratios of I, II, III, IV, V, and VI were 17%, 66%, 10%, 4%, 3%, and 0%, respectively. In 2017, the ratios of I, II, III, IV, V, and VI were 10%, 65%, 21%, 4%, 0%, and 0%, respectively. From 2015 to 2017, Grades I and II decreased by 3% and 1%, respectively, and Grades III and IV increased by 3% and 2%, respectively. In 2015 and 2016, the proportions of V grades were 1% and 3%, respectively. In 2017, the proportion of V grades was 0%. Table 5(a) shows that PM_{10} was the main air pollutant, followed by $PM_{2.5}$ and NO_x. NO_x has increased significantly relative to the other two seasons because of the burning of coal during the autumn heating period, which increases NO_x emissions.

Figs. 4(b)-(D), 4(d)-(D), and 4(f)-(D) show that in the winter of 2015, I, II, III, IV, V, and VI proportions were 2%, 22%, 21%, 21%, 25%, and 9%, respectively. In the winter of 2016, I, II, III, IV, V, and VI were 0%, 6%, 23%, 14%, 42%, and 15%, respectively. In the winter of 2017, I, II, III, IV, V and VI were 0%, 15%, 23%, 11%, 34%, and 17%, respectively. It can be seen that the winter air quality in Urumqi was relatively poor. Comparing the proportions of different AQI categories from 2015 to 2017, I, II, and IV fell by 2%, 7%, and 10%, respectively, while Grades V and VI increased by 9% and 8%, respectively. In the three years under investigation, the air quality in Urumqi deteriorated. Table 5(a) shows that $PM_{2.5}$ was the main air pollutant, followed by PM_{10} and NO_x. This was also because the combustion of coal in winter boilers leads to an increase in $PM_{2.5}$ emissions, so $PM_{2.5}$ should be controlled during the heating period.

Figs. 4(a)-(A), 4(c)-(A), and 4(e)-(A) show that in 2015, the proportions of I, II, III, IV, V and VI were 0%, 70%, 13%, 8%, 0%, and 9%, respectively. In 2016, these proportions were 0%, 53%, 28%, 3%, 6%, and 10%, respectively. In 2017, these proportions were 0%, 60%, 23%, 13%, 1%, and 3%, respectively. Comparing the proportion of different AQI categories from 2015 to 2016, the I level was 0%, while the II and IV levels were reduced by 24.3% and 62.5%, respectively. Level III rose from 13% to 28%. The V level also rose by 6%. The decrease in Grade II and the increase in Grade III and Grade V indicate that Turpan's air quality gradually deteriorated from 2015 to 2016. Grade VI occurred frequently in 2015 and 2016, at 6% in 2015 and 10% in 2016. This indicates that air pollution incidents frequently occurred in the spring of 2015 and 2016 in Turpan and that air pollution incidents from 2015 to 2016 increased. Grade II increased by 13.2% from 2016 to 2017, but the III, V and VI grades decreased. This may be due to changes in meteorological conditions and increased vegetation coverage, which is conducive to the dilution of pollutants. Table 5(b) shows that PM_{10} was the most common major atmospheric pollutant, followed by $PM_{2.5}$ and O_3. Especially in 2016, the frequency of O_3 as the main pollutant was significantly higher than other years. This was also due to the emission of NO_x and VOC, as well as the occurrence of high temperature solar radiation. This result shows that, in addition to reducing PM pollution in the spring, controlling ozone pollution is essential for improving air quality.

Figs. 4(a)-(B), 4(c)-(B), and 4(e)-(B) show the distribution of six AQI species in Turpan in summer. In 2015, the proportions of I, II, III, IV, V, and VI were 2%, 87%, 8%, 1%, 1%, and 1%, respectively; in 2016, they were 0%, 61%, 33%, 3%, 0%, and 3% respectively. In 2017, they were 0%, 76%, 19%, 2%, 1%, and 2%, respectively. During the three years, the number of days with Level II accounted for the majority, followed by Level III. There was a significant increase in Grade III weather from 2015 to 2016, from 8% to 33%. In 2017, Level III accounted for 19%. Compared with spring, the proportion of days of IV, V, and VI were relatively small, which indicates that the air in summer was relatively good. As can be seen from Table 5(b), in the three year period, PM_{10} and O_3 were the most common pollutants in Turpan in the summer. This was also due to the increase in O_3 concentration due to the increase in VOC emissions in recent years. High temperature weather and solar radiation can promote the formation of O_3. This result is consistent with previous research results (Atkinson and Arey, 2003; Zhang and Ying *et al.*, 2011; Li *et al.*, 2012; He *et al.*, 2017; Shen *et al.*, 2017).

Figs. 4(a)-(C), 4(c)-(C), and 4(e)-(C) show that in the fall of 2015, the proportions of I, II, III, IV, V, and VI were 9%, 81%, 10%, 0%, 0%, and 0%, respectively. In 2016, the I, II, III, IV, V and VI proportions were 8%, 87%, 5%, 0%, 0%, and 0%, respectively, and in 2017, they were 4%, 89%, 7%, 0%, 0%, and 0%, respectively. Grade II accounted for the majority. From 2015 to 2017, Grade II gradually increased from 81% to 89%, and the ratio of I and III decreased. At the same time, the ratios of IV, V, and VI were 0%. This shows that the air quality in Turpan was good in the autumn and that there were no serious pollution incidents. As can be seen from Table 5(b), PM_{10} was the main pollutant in the autumn in Turpan, followed by $PM_{2.5}$, and the concentration of O_3 was significantly reduced in autumn.

Table 5(a). Cumulative number of days of primary pollutants in Urumchi from 2015–2017.

Year	AQI	Spring				Summer				Fall				Winter			
	Class	$PM_{2.5}$	PM_{10}	NO_x	O_3	$PM_{2.5}$	PM_{10}	NO_x	O_3	$PM_{2.5}$	PM_{10}	NO_x	O_3	$PM_{2.5}$	PM_{10}	NO_x	O_3
2015	51–100	8	52	6	0	0	52	1	19	14	41	7	0	10	1	10	0
	101–150	5	12	0	0	0	10	0	2	9	7	0	0	23	1	0	0
	151–200	2	2	0	0	0	0	0	0	2	0	0	0	12	2	0	0
	201–300	2	0	0	0	0	0	0	0	1	0	0	0	26	0	0	0
	> 300	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0	0
2016	51–100	6	48	4	0	0	45	5	29	17	26	23	0	2	2	1	0
	101–150	8	0	0	0	0	0	0	1	7	2	0	0	20	1	0	0
	151–200	4	1	0	0	0	0	0	0	4	0	0	0	11	0	0	0
	201–300	3	0	0	0	0	0	0	0	3	0	0	0	38	0	0	0
	> 300	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0
2017	51–100	9	39	2	2	0	52	1	49	8	35	10	8	10	1	2	0
	101–150	13	3	0	0	0	2	0	0	8	10	1	0	20	0	1	0
	151–200	6	0	0	0	0	0	0	0	4	0	0	0	10	0	0	0
	201–300	3	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0
	> 300	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0

Table 5(b). Cumulative number of days of primary pollutants in Turpan from 2015–2017.

Year	AQI	Spring				Summer				Fall				Winter			
	Class	$PM_{2.5}$	PM_{10}	NO_x	O_3	PM_{25}	PM_{10}	NO_x	O_3	$PM_{2.5}$	PM_{10}	NO_x	O_3	$PM_{2.5}$	PM_{10}	NO_x	O_3
2015	51–100	3	57	0	16	0	38	0	40	6	48	1	6	5	2	0	0
	101–150	0	11	0	0	0	7	0	0	13	7	0	0	2	5	0	0
	151–200	1	7	0	0	0	1	0	0	5	1	0	0	12	2	0	0
	201–300	0	1	0	0	0	1	0	0	0	0	0	0	23	2	0	0
	> 300	0	5	0	0	0	1	0	0	0	1	0	0	0	7	0	0
2016	51–100	1	19	0	31	0	33	0	23	2	49	0	3	5	1	0	0
	101–150	1	16	0	9	1	7	0	23	6	25	0	0	22	13	0	0
	151–200	0	3	0	0	1	2	0	0	0	3	0	0	17	3	0	0
	201–300	0	5	0	0	0	0	0	0	0	1	0	0	19	2	0	0
	> 300	0	9	0	0	0	3	0	0	0	3	0	0	1	2	0	0
2017	51–100	2	45	0	8	1	24	0	47	5	41	0	3	3	5	0	0
	101–150	3	18	0	0	1	9	0	7	8	21	0	0	11	14	0	0
	151–200	1	11	0	0	0	2	0	0	6	5	0	0	42	4	0	0
	201–300	0	0	0	0	0	1	0	0	0	0	0	0	9	0	0	0
	> 300	0	4	0	0	0	2	0	0	0	2	0	0	0	1	0	0

Figs. 4(a)-(D), 4(c)-(D), and 4(e)-(D) show that in the winter of 2015, the proportions of I, II, III, IV, V, and VI were 8%, 58%, 27%, 4%, 3%, and 0%, respectively. In 2016, the ratios of I, II, III, IV, V, and VI were 2%, 84%, 8%, 4%, 2%, and 0%, respectively. In 2017, the ratios of I, II, III, IV, V, and VI were 4%, 88%, 8%, 0%, 0%, and 0%, respectively. Grade II was still the majority. From 2015 to 2017, the proportion gradually increased. From 2015 to 2016, it increased by 26%. From 2016 to 2017, it increased by 4%, while the proportion of Grade III decreased from 27% in 2015 to 8% in 2016. There were grades IV and V in 2015 and 2016, with 4% in 2015 and 2016, and 3% in 2015 and 2016. In 2017, the proportion of Grade IV and V was 0%. This shows that the air quality in Turpan gradually improved in the winter during the three year period. As can be seen from Table 5(b), $PM_{2.5}$ was the main pollutant in winter in Turpan, followed by PM_{10}. This is mainly related to large quantities of coal burning and adverse meteorological conditions in winter (Sun *et al.*, 2014; Zhou *et al.*, 2017). Compared with summer, due to the low temperatures in winter, the working temperature of car engines is not high, causing incomplete combustion that results in $PM_{2.5}$.

In general, the air quality in Turpan is better than that in Urumqi. Overall, during the three years of the study, in Urumqi, in spring, the average ratios of I, II, III, IV, V, and VI were 16.3%, 60.0%, 16.0%, 5.33%, 2.67%, and 0%, respectively; were12.0%, 82.7%, 5.33%, 0%, 0%, and 0% in summer, were 13.3%, 65.7%, 16.3%, 3.33%, 1.33%, and 0% in fall, respectively, and were 0.67%, 14.3%, 22.3%, 15.3%, 33.7%, and 13.7% in winter, respectively. The average ratios of I, II, III, IV, V, and VI in the spring of Turpan were 0%, 61.0%, 21.3%, 8.00%, 2.33%, and 7.33%, respectively. In the summer, they were 0.67%, 72.7%, 20.0%, 2.00%, 0.67%, and 2%, respectively, and were 7.00%, 85.7%, 7.33%, 0%, 0%, and 0%, respectively, in fall. In winter, they were 4.67%, 76.7%, 14.3%, 2.67%, 1.67%, and 0%, respectively. In general, the summer air quality was the best, and the spring and winter air quality were the worst. Due the seasonal changes, the main pollutants in the air also change accordingly. In Urumqi, in the spring, PM_{10} was the main air pollutant, followed by $PM_{2.5}$, and NO_x pollution also occurred. In summer, PM_{10} and O_3 were the main air pollutants. In the fall, PM_{10} was the main air pollutant, followed by $PM_{2.5}$ and NO_x. Especially in the autumn in Urumqi, the number of days of NO_x pollution was high. In the winter, $PM_{2.5}$ was the main air pollutant. In Turpan, in the spring and autumn, PM_{10} was the main air pollutant, where the majority of pollution were from PM_{10}. In the summer, in addition to PM_{10}, O_3 was also a main air pollutant. In the winter, $PM_{2.5}$ replaced PM_{10} as the primary pollutant. Therefore, as the seasons change, it is necessary to control $PM_{2.5}$, PM_{10}, and O_3. In Urumqi, in addition to controlling $PM_{2.5}$, PM_{10}, and O_3, it is also important to take appropriate measures to control NO_x.

CONCLUSION

The results of this study on atmospheric deposition in Urumqi and Turpan can be summarized as follows:

1. The average concentration of $PM_{2.5}$ in Urumqi for the 3 years under investigation was 19–228 µg m^{-3}; the annual average concentration was 69 µg m^{-3}; the average concentration of $PM_{2.5}$ in Turpan for the 3 years was 23–136 µg m^{-3}, and the average annual concentration was 69 µg m^{-3}. The average concentration of $PM_{2.5}$ in the two cities was very similar, and the concentration of $PM_{2.5}$ in the winter was higher than that in the summer.
2. The 3-year PM_{10} concentration in Urumqi ranged between 61 and 287 µg m^{-3}, with an average of 123 µg m^{-3}. The Turpan data ranged from 61 to 282 µg m^{-3}, with an average of 157 µg m^{-3}. The PM_{10} levels in Turpan were higher than those in Urumqi. In general, PM_{10} concentration in the summer was lower than that in the winter. The PM_{10} concentration in the summer in Urumqi (80.2 µg m^{-3}) was 63.0% lower than that in the winter (217 µg m^{-3}). In Turpan, the concentration in the summer (75.0 µg m^{-3}) was 34.2% lower than that in the winter (114 µg m^{-3}).
3. The three-year average SO_2 concentration fluctuated from 0.700 to 27.7 ppb in Urumqi and from 0.700 to 47.6 ppb in Turpan, with corresponding averages of 5.11 and 5.69 ppb, respectively. The results show that the SO_2 concentrations in the spring and winter of the two cities fluctuated significantly, but the SO_2 concentration had little impact on the air quality of the two cities.
4. During the three-year period, the average NO_2 concentration in Urumqi ranged from 15.9 to 43.9 ppb, with an average of 22.3 ppb. The average NO_2 concentration in Turpan ranged from 9.74 to 34.1 ppb, with an average of 19.1 ppb. In general, NO_2 concentrations in the autumn and winter were higher than those in the spring and summer. The concentration of NO_2 in Urumqi was higher than that in Turpan, and NO_2 was an important pollutant. Therefore, it is necessary to control the emission of NO_2 from automobile exhaust and winter boilers in order to meet the environmental protection requirements.
5. During the three-year period, the average CO in Urumqi ranged from 0.421 to 2.76 ppm, and the average value in Turpan ranged from 0.480 to 4.06 ppm, corresponding to an average of 1.14 and 1.28 ppm, respectively. The concentration of carbon monoxide in the two cities was lower than the 8:00 ppm required by the WHO's air quality supervision standard, which indicates that carbon monoxide has never had a serious impact on the air quality in the two cities. Under normal circumstances, the highest concentration of carbon monoxide was in the winter, and the lowest concentration of carbon monoxide occurred in the summer.
6. During the three-year period, the average O_3 concentration in Urumqi ranged from 7.20 to 57.4 ppb, and the average concentration of Urumqi was 30.0 ppb. The average O_3 concentration in Turpan ranged from 13.0 to 73.2 ppb, with an average concentration of 41.5 ppb. O_3 pollution generally occurred during the summer months. The highest concentration exceeded

the WHO Air Quality Regulation Standard (46.6 ppb). Ozone pollution has a significant impact on the environment, and controlling ozone pollution is a serious challenge.

7. The air quality of Urumqi and Turpan fluctuates seasonally. In the spring in Urumqi, air quality was mainly concentrated in Grade II and Grade III, with mildly polluted weather. $PM_{2.5}$ and PM_{10} were the main pollutants. In the spring in Turpan, unlike the spring in Urumqi, air quality was mainly concentrated in Class II, Class III, and Class IV, where PM_{10} and O_3 were the main pollutants.
8. In the summer in Urumqi, air quality was mainly concentrated in Class II, and PM_{10} and O_3 were the main pollutants. In the summer in Turpan, air quality was mainly concentrated in Class II and Class III, and PM_{10} and O_3 were the main pollutants.
9. In the autumn in Urumqi, air quality was mainly concentrated in Class II and Class III, and $PM_{2.5}$, PM_{10}, and NO_x were the main pollutants. In the fall in Turpan, air quality was mainly concentrated in grades II and III, and $PM_{2.5}$ and PM_{10} were the main pollutants.
10. In the winter in Urumqi, air pollution was serious; $PM_{2.5}$ was the main pollutant, and occasionally NO_x pollution occurred. In the winter in Turpan, air quality was mainly concentrated in Class III, Class IV, and Class V, and $PM_{2.5}$ and PM_{10} were the main pollutants. The winter air pollution levels of the two cities were much higher than in the other three seasons.
11. The results of this study provide useful information for the establishment of air pollution control strategies and for the future studies made by the scientific community on this issue.

REFERENCES

Akimoto, H. (2003). Global air quality and pollution. *Science* 302: 1716–1719.

Alghamdi, M.A., Almazroui, M., Shamy, M., Redal, M.A., Alkhalaf, A.K., Hussein, M.A. and Khoder, M.I. (2015). Characterization and elemental composition of atmospheric aerosol loads during springtime dust storm in Western Saudi Arabia. *Aerosol Air Qual. Res.* 15: 440–453.

Amato, F., Viana, M., Richard, A., Furger, M., Prévôt, A.S.H., Nava, S., Lucarelli, F., Bukowiecki, N., Alastuey, A., Reche, C., Moreno, T., Pandolfi, M., Pey, J. and Querol, X. (2011). Size and time-resolved roadside enrichment of atmospheric particulate pollutants. *Atmos. Chem. Phys.* 11: 2917–2931.

Atkinson, R. and Arey, J. (2003). Atmospheric degradation of volatile organic compounds. *Chem. Rev.* 103: 4605–4638.

Bilal, M., Nichol, J.E. and Spak, S.N. (2017). A new approach for estimation of fine particulate concentrations using satellite aerosol optical depth and binning of meteorological variables. *Aerosol Air Qual. Res.* 17: 356–367.

Brauer, M., Freedman, G., Frostad, J., Van Donkelaar, A., Martin, R.V., Dentener, F. and Balakrishnan, K. (2016). Ambient air pollution exposure estimation for the global burden of disease 2013. *Environ. Sci. Technol.* 50: 79–88.

Fiore, A.M., Jacob, D.J., Bey, I., Yantosca, R.M., Field, B.D., Fusco, A.C. and Wilkinson, J.G. (2002). Background ozone over the United States in summer: Origin, trend, and contribution to pollution episodes. *J. Geophys. Res.* 107: ACH 11-1–ACH 11-25.

Che, H., Zhang, X., Li, Y., Zhou, Z., Qu, J.J. and Hao, X. (2009). Haze trends over the capital cities of 31 provinces in China. *Theor. Appl. Climatol*. 97: 235–242.

Chen, Y.Y., Jin, G.Z., Kuamr, N. and Shi, G. (2013). The promise of Beijing: Evaluating the impact of the 2008 Olympic Games on air quality. *J. Environ. Econ. Manage.* 66: 424–443.

Cheng, N.L., Li, Y.T., Sun, F., Chen, C., Wang, B.Y., Li, Q., Wei, P. and Cheng, B.F. (2018). Ground-level NO_2 in urban Beijing: Trends, distribution, and effects of emission reduction measures. *Aerosol Air Qual. Res.* 18: 343–356.

Crutzen, P.J. (1979). The role of NO and NO_2 in the chemistry of the troposphere and stratosphere. *Annu. Rev. Earth Planet. Sci.* 7: 443–472.

Dary, O., Pineda O. and Belizan, J.M. (1981). Carbon monoxide contamination in dwellings in poor rural areas of Guatemala. *Bull. Environ. Contam. Toxicol.* 26: 24–30.

Du, P.R., Du, R., Lu, Z.D., Ren, W.S. and Fu, P.Q. (2018). Variation of bacterial and fungal community structures in $PM_{2.5}$ collected during the 2014 APEC summit periods. *Aerosol Air Qual. Res.* 18: 444–455.

Evagelopoulos, V., Zoras, S., Triantafyllou, A.G. and Albanis, T.A. (2006). PM_{10}-$PM_{2.5}$ time series and fractal analysis. *Global NEST. J.* 8: 234–240.

Ezzati, M. and Kammen, D. (2002). The health impacts of exposure to indoor air pollution from solid fuels in developing countries: Knowledge, gaps, and data needs. *Environ. Health Perspect.* 110: 1057–1068.

Feng, Z., Hu, E., Wang, X., Jiang, L. and Liu, X. (2015). Ground-level O_3 pollution and its impacts on food crops in China: A review. *Environ. Pollut.* 199: 42–48.

Garg, A., Shukla, P.R., Bhattacharya, S. and Dadhwal, V.K. (2001). Sub-region (district) and sector level SO_2 and NO_x emissions for India: Assessment of inventories and mitigation flexibility. *Atmos. Environ.* 35: 703–713.

Gong, X., Hong, S. and Jaffe, D.A. (2018). Ozone in China: Spatial distribution and leading meteorological factors controlling O_3 in 16 Chinese cities. *Aerosol Air Qual. Res.* 18: 2287–2300.

He, J.J., Gong, S.L., Yu, Y., Yu, L.J., Wu, L., Mao, H.J., Song, C.B., Zhao, S.P., Liu, H.L., Li, X.Y. and Li, R.P. (2017). Air pollution characteristics and their relation to meteorological conditions during 2014-2015 in primary Chinese cities. *Environ. Pollut.* 223: 484–496.

Heal, M.R., Kumar, P. and Harrison, R.M. (2012). Particles, air quality, policy and health. *Chem. Soc. Rev.* 41: 6606–6630.

Hu, J.L., Ying, Q., Wang, Y.G. and Zhang, H.L. (2015).

Characterizing multi-pollutant air pollution in China: Comparison of three air quality indices. *J. Environ. Int.* 15: 17–25.

Jarvis, M.J., Belcher, M., Vesey, C. and Hutchison, D.C. (1986). Low cost carbon monoxide monitors in smoking assessment. *Thorax* 41: 886–887.

Jin, L., Luo, X.S., Fu, P.Q. and Li, X.D. (2017). Airborne particulate matter pollution in urban China: A chemical mixture perspective from sources to impacts. *Nat. Sci. Rev.* 4: 593–610.

Kato, S., Shiobara, Y., Uchiyama, K., Miura, K., Okochi, H., Kobayashi, H. and Hatakeyama, S. (2016). Atmospheric CO, O_3, and SO_2 measurements at the summit of Mt. Fuji during the Summer of 2013. *Aerosol Air Qual. Res.* 16: 2368–2377.

Khokhar, M.F., Mehdi, H., Abbas, Z. and Javed, Z. (2016). Temporal assessment of NO_2 pollution levels in urban centers of Pakistan by employing ground-based and satellite observations. *Aerosol Air Qual. Res.* 16: 1854–1867.

Kong, S.F., Ji, Y.Q., Lu, B., Chen, L., Han, B., Li, Z.Y. and Bai, Z.P. (2011). Characterization of PM_{10} source profiles for fugitive dust in Fushun-A city famous for coal. *Atmos. Environ.* 45: 5351–5365.

Lanzafame, R., Monforte, P., Patane, G. and Strano, S. (2015). Trend analysis of Air Quality Index in Catania from 2010 to 2014. *Energy Procedia* 82: 708–715.

Lee, C., Richter, A., Weber, M. and Burrows, J.P. (2008). O_2 Retrieval from SCIAMACHY using the Weighting Function DOAS (WFDOAS) technique: Comparison with Standard DOAS retrieval. *Atmos. Chem. Phys.* 8: 6137–6145.

Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D. and Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature* 525: 367–371.

Li, J.Y., Zhang, H.L. and Ying, Q. (2012). Comparison of the SAPRC07 and SAPRC99 photochemical mechanisms during a high ozone episode in Texas: Differences in concentrations, OH budget and relative response factors. *Atmos. Environ.* 54: 25–35.

Li, K., Chen, L., Han, K., Lv, B., Bao, K., Wu, X., Guo, X. and Cen, K. (2017a). Smog chamber study on aging of combustion soot in isoprene/SO_2/NO_x system: Changes of mass, size, effective density, morphology and mixing state. *Atoms. Res.* 184: 139–148.

Li, X., Qiao, Y. and Shi, L. (2017b). The aggregate effect of air pollution regulation on CO_2 mitigation in China's manufacturing industry: An econometric analysis. *J. Clean. Prod.* 142: 976–984.

Liang, D., Wang, Y.Q., Ma, C. and Wang, Y.J. (2016). Variability in transport pathways and source areas of PM_{10} in Beijing during 2009–2012. *Aerosol Air Qual. Res.* 16: 3130–3141.

Matawle, J.L., Pervez, S., Dewangan, S., Shrivastava, A., Tiwari, S., Pant, P., Deb, M.K. and Pervez, Y. (2015). Characterization of $PM_{2.5}$ source profiles for traffic and dust sources in Raipur, India. *Aerosol Air Qual. Res.* 15: 2537–2548.

Monks, P.S., Archibald, A.T., Colette, A., Cooper, O., Coyle, M., Derwent, R., Fowler, D., Granier, C., Law, K.S., Mills, G.E., Stevenson, D.S., Tarasova, O., Thouret, V., von Schneidemesser, E., Sommariva, R., Wild, O. and Williams, M.L. (2015). Tropospheric ozone and its precursors from the urban to the global scale from air quality to short-lived climate forcer. *Atmos. Chem. Phys.* 15: 8889–8973.

Olivier, J.G.J., Bouwman, A.F., Van der Hoek, K.W. and Berdowski, J.J.M. (1998). Global air emission inventories for anthropogenic sources of NO_x, NH_3 and N_2O in 1990. *Environ. Pollut.* 102: 135–148.

Ou, J., Yuan, Z., Zheng, j., Huang, Z., Shao, M., Li, Z., Huang, X., Guo, H. and Louie, P.K.K. (2016). Ambient ozone control in a photo chemically active region: Short term despiking or long-term attainment? *Environ. Sci. Technol.* 50: 5720–5728.

Peng, C.Y., Lin, C.Y. and Jong, T.C. (2005). Emissions of Particulate and Gaseous Pollutants within the Keelung Harbor Region of Taiwan. *Environ. Monit. Assess.* 109: 37–56.

Pope, C.A. and Dockery, D.W. (2013). Air pollution and life expectancy in China and beyond. *Proc. Natl. Acad. Sci. U.S.A.* 110: 12861–12862.

Pudasainee, D., Sapkota, B., Shrestha, M. L., Kaga, A., Kondo, A. and Inoue, Y. (2006). Ground level ozone concentrations and its association with NO_x and meteorological parameters in Kathmandu valley, Nepal. *Atmos. Environ.* 40: 8081–8087.

Scharte, M., Bone, H.G. Van Aken, H. and Meyer, J. (2000). Increased carbon monoxide in exhaled air of critically ill patients. *Biochem. Biophys. Res. Commun.* 267: 423–426.

Schecter, A., Birnbaum, L., Ryan, J.J. and Constable, J.D. (2006). Dioxins: An overview. *Environ. Res.* 101: 419–428.

Shang, X.N., Lee, M., Han, J.Y., Kang, E., Kim, S.W., Gustafsson, O. and Chang, L. (2015). Distribution of ozone and related compounds in the marine boundary layer of the northern South China Sea in 2010. *Aerosol Air Qual. Res.* 15: 1990–2008.

She, Q.N., Peng, X., Xu, Q., Long, L.B., Wei, N. Liu, M. and Jia, W.X. (2017). Air quality and its response to satellite-derived urban form in the Yangtze River Delta, China. *Environ. Res. Sci.* 75: 297–306.

Shen, F.Z., Ge, X.L., Hu, J.L., Nie, D.Y., Tian, L. and Chen, M.D. (2017). Air pollution characteristics and health risks in Henan Province, China. *Environ. Res. Sci.* 156: 625–634.

Sillman, S. (1999). The relation between ozone, NO_x and hydrocarbons in urban and polluted 637 rural environments. *Atmos. Environ.* 33: 1821–1845.

Song, S.J., Wu, Y., Jiang, J.K., Yang, L., Cheng, Y. and Hao, J.M. (2012). Chemical characteristics of size-resolved $PM_{2.5}$ at a roadside environment in Beijing, China. *Environ. Pollut.* 161: 215–221.

Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M.M.B., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (2013). *IPCC: Climate change 2013:*

The assessment reports of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK, p. 1552.

Sun, Y., Jiang, Q., Wang, Z., Fu, P., Li, J., Yang, T. and Yin, Y. (2014) Investigation of the sources and evolution processes of severe haze pollution in Beijing in January 2013. *J. Geophys. Res.* 119: 4380–4398.

Tang, H.Y., Cui, K.P., Xing, J., Zhu, J.N., Lee, W.J., John, K.M. and Lee, Y.C. (2017). Part I: $PM_{2.5}$ and polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) in the ambient air of southern China. *Aerosol Air Qual. Res.* 17: 1550–1569.

Tao, J., Ho, K.F., Chen, L., Zhu, L., Han, J. and Xu, Z. (2009). Effect of chemical composition of $PM_{2.5}$ on visibility in Guangzhou, China, 2007 spring. *Particuology* 7: 68–75.

Tao, J., Zhang, L., Cao, J. and Zhang, R. (2017). A review of current knowledge concerning $PM_{2.5}$ chemical composition, aerosol optical properties and their relationships across China. *Atmos. Chem. Phys.* 17: 9485–9518.

Thompson, A.M. (1992). The oxidizing capacity of the earth's atmosphere: Probable past and future changes. *Science* 256: 1157–1165.

Tong, X., Wang, B., Dai, W.T., Cao, J.J., Ho, S.S.H., Kwok, T.C.Y., Lui, K.H., Lo, C.M. and Ho, K.F. (2018). Indoor air pollutant exposure and determinant factors controlling household air quality for elderly people in Hong Kong. *Air Qual. Atmos. Health* 11: 695–704.

Vingarzan, R. (2004). A review of surface ozone background levels and trends. *Atmos. Environ.* 38: 3431–3442.

Wang, H. and Chen, H. (2016). Understanding the recent trend of haze pollution in eastern China: Roles of climate change. *Atmos. Chem. Phys.* 16: 4205–4211.

Wang, W.W., Cui, K.P., Zhao, R., Zhu, J.N., Huang, Q.L. and Lee, W.J. (2018). Sensitivity analysis of $PM_{2.5}$-bound total PCDD/Fs-TEQ content: In the case of Wuhu city, China. *Aerosol Air Qual. Res.* 18: 407–420.

Wei, X., Liu, Q., Lam, K.S. and Wang, T. (2012). Impact of precursor levels and global warming on peak ozone concentration in the Pearl River Delta Region of China. *Adv. Atmos. Sci.* 29: 635–645.

Wu, B., Shen, X., Cao, X., Yao, Z. and Wu, Y. (2013). Chemical constituents of fine particulate air pollution and pulmonary function in healthy adults: The Healthy Volunteer Natural Relocation study. *J. Hazard. Mater.* 260: 183–191.

Wu, Y., Zhang, S., Hao, J., Liu, H., Wu, X., Hu, J., Walsh, M.P., Wallington, T.J., Zhang, K.M. and Stevanovic, S. (2017). On-road vehicle emissions and their control in China: A review and outlook. *Sci. Total Environ.* 574: 332–349.

Xie, H., Wang, L., Ling, X., Miao, Y., Shen, X., Wang, M. and Xin, Y. (2016). China air quality management assessment report (2016), http://en.cleanairchina.org/product/8348.html, Last Access: 1 April 2017.

Xing, J., Cui, K.P., Tang, H.Y., Lee, W.J., Wang, L.C., Zhu, J.N. and Huang, Q.L. (2017). Part II: $PM_{2.5}$ and polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) in the ambient air of northern China. *Aerosol Air Qual. Res.* 17: 2010–2016.

Xu, J., Ma, J.Z., Zhang, X.L., Xu, X.B., Xu, X.F., Lin, W.L., Wang, Y., Meng, W. and Ma, Z.Q. (2011). Measurements of ozone and its precursors in Beijing during summertime: Impact of urban plumes on ozone pollution in downwind rural areas. *Atmos. Chem. Phys.* 11: 12241–12252.

Xu, G., Jiao, L.M., Zhang, B.E., Zhao, S.L., Yuan, M., Gu, Y.Y., Liu, J.F. and Tang, X. (2017). Spatial and temporal variability of the $PM_{2.5}/PM_{10}$ ratio in Wuhan, central China. *Aerosol Air Qual. Res.* 17: 741–751.

Yang, Y.Q., Wang, J.Z., Gong, S.L., Zhang, X.Y., Wang, H., Wang, Y.Q., Wang, J., Li, D. and Guo, J.P. (2016) PLAM – A meteorological pollution index for air quality and its applications in fog-haze forecasts in North China. *Atmos. Chem. Phys.* 16: 1353–1364.

Zaveri, R.A., Easter, R.C., Fast, J.D. and Peters, L.K. (2008). Model for Simulating Aerosol Interactions and Chemistry (MOSAIC). *J. Geophys. Res.* 113: D13204.

Zhang, H.L. and Ying, Q. (2011). Contributions of local and regional sources of NO_x to ozone concentrations in Southeast Texas. *Atmos. Environ.* 45: 2877–2887.

Zhao, P.S., Dong, F., He, D., Zhao, X.J., Zhang, X.L., Zhang, W.Z., Yao, Q. and Liu, H.Y. (2013). Characteristics of concentrations and chemical compositions for $PM_{2.5}$ in the region of Beijing, Tianjin, and Hebei, China. *Atmos. Chem. Phys.* 13: 4631–4644.

Zhao, R., Cui, K.P., Wang, W.W., Wang, L.C. and Yan, P. (2018). Atmospheric $PM_{2.5}$ and total PCDD/Fs-WHO_{2005}-TEQ level: A case of Handan and Kaifeng cities, China. *Aerosol Air Qual. Res.* 18: 994–1007.

Zhou, S., Behrooz, L., Weitzman, M., Pan, G., Vilcassim, R., Mirowsky, J.E., Breysee, P., Rule, A. and Gordon, T. (2017). Secondhand hookah smoke: An occupational hazard for hookah bar employees. *Tobacco Control* 26: 40–45.

Received for review, November 13, 2018
Revised, January 3, 2019
Accepted, January 4, 2019