Postprint: Air Pollution and Characteristics of Pollution Weather Types in the Urban Agglomeration on the Northern Slope of Central Tianshan, 2017-2019

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Abstract

Using hourly atmospheric pollutant monitoring data and meteorological data from 2017 to 2019 for the urban agglomeration on the northern slope of the Central Tianshan Mountains (Urumqi City, Changji City, Shihezi City, and Wujiaqu City), we analyzed the intra-annual variation characteristics of atmospheric pollutants and the features of polluted weather types. The results show that: (1) Among the six categories of atmospheric pollutants in the four cities on the northern slope of the Central Tianshan Mountains, PM2.5 had the highest number of exceedance days (94–104 days annually), with annual average concentrations ranging from 64–73 g · m^{-3}, and the ranking was Wujiaqu City > Urumqi City > Shihezi City > Changji City. During the heating season, PM2.5 concentrations ranged from 100–118 g · m^{-3}, which was 4.00–5.00 times higher than during the non-heating season. The diurnal variation of PM2.5 concentrations in cities near the piedmont zone generally exhibited a "double-peak double-valley" pattern. (2) The polluted weather types in the four cities were mainly classified as static-stable type, dust type, and special type, with the static-stable type accounting for 86.2%–93.6% and the dust type accounting for 5.8%–13.2%. Static-stable polluted weather occurred mostly in winter, while dust-type polluted weather mainly occurred in spring and autumn. In static-stable polluted weather, pollution levels V–VI accounted for 45.8%–56.6%, while in dust-type polluted weather, pollution levels V–VI accounted for 14.9%–29.4%. (3) Under both static-stable and dust-type polluted weather conditions, significant linear correlations existed between PM2.5 and PM10 concentrations. In the former, PM10 concentration was 1.26 times that of PM2.5, while in the latter it reached 3.16 times. This ratio can serve as a criterion for distinguishing between static-stable and dust-type polluted weather.

Full Text

Characteristics of Air Pollution and Polluted Weather Types in the Urban Agglomeration on the North Slope of the Middle Tianshan Mountains from 2017 to 2019

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Abstract: The air pollution in the urban agglomeration (Urumqi City, Changji City, Shihezi City, Wujiaqu City) on the north slope of the middle Tianshan Mountains, Xinjiang, China is more serious than that in several eastern urban agglomerations. However, the characteristics of air pollution and corresponding polluted synoptic weathers on the north slope of the middle Tianshan Mountains are poorly understood. Herein, the variation characteristics of air pollutants and polluted synoptic types were analyzed using the hourly air pollutant data and meteorological data of four cities on the north slope of the middle Tianshan Mountains collected from 2017 to 2019. Results showed that: (1) Among the six pollutants, $PM_{2\cdot5}$ had the most exceedance days, accounting for nearly one-third of the year (94~104 days), making it the primary pollutant. The annual average $PM_{2\cdot5}$ concentrations in the four cities were: Wujiaqu City (73 $g\cdot m^{-3}$), Urumqi City (71 $g\cdot m^{-3}$), Shihezi City (65 $g\cdot m^{-3}$), and Changji City (64 $g\cdot m^{-3}$). The average $PM_{2\cdot5}$ concentration during the heating period ranged between 100~118 $g\cdot m^{-3}$, which was 4.00~5.00 times higher than during the non-heating period. The diurnal variation of $PM_{2\cdot5}$ concentration showed a "bimodal pattern" in the three cities near the mountains, while Wujiaqu City exhibited a "unimodal pattern." (2) 86.2%~93.6% of the polluted days in the study area belonged to stagnant pollution, while 5.8%~13.2% belonged to dust pollution. Stagnant pollution mostly occurred in winter, whereas dust pollution primarily occurred in spring and autumn. Level V pollution accounted for 45.8%~56.6% of stagnant pollution days and 14.9%~29.4% of dust pollution days. (3) The correlation between PM_{10} and $PM_{2\cdot5}$ was extremely high for both pollution types. The $PM_{10}/PM_{2\cdot5}$ ratios were 1.26 for stagnant pollution and 3.16 for dust pollution, which can serve as an effective criterion for distinguishing between the two pollution weather types.

Keywords: exceedance day; pollutant concentration; polluted weather types; stagnant weather; dusty weather

In 2013, China promulgated the *Action Plan for Air Pollution Prevention and Control*, which identified the Beijing-Tianjin-Hebei region as a key area for air pollution control. Since then, significant progress has been made in air pollution prevention and control across China, with primary pollutant concentrations declining in major economic regions such as the Yangtze River Delta. Emissions of pollutants including sulfur dioxide and nitrogen oxides have decreased substantially. However, China still faces severe challenges from complex air pollution, with widespread $PM_{2\cdot5}$ pollution affecting numerous regions and making further improvements increasingly difficult. Many scholars have investigated the spatiotemporal variation characteristics of air pollutants in key regions such as Beijing-Tianjin-Hebei, the Yangtze River Delta, the Pearl River Delta, and the Sichuan Basin, revealing distinct pollution characteristics across different regions. In the Beijing-Tianjin-Hebei region, $PM_{2\cdot5}$ pollution exhibits higher levels in the south and lower levels in the north, with heavy pollution days concentrated in winter and fine particulate matter as the primary pollutant. In the Yangtze River Delta, Jiangsu Province generally shows higher $PM_{2\cdot5}$ concentrations than Zhejiang Province, with heavy pollution occurring mainly in autumn and winter in inland cities. The Sichuan Basin experiences severe secondary pollution, particularly with $PM_{2\cdot5}$, and Chengdu recorded 150 days of heavy pollution in a single year. In Beijing, persistent heavy pollution events frequently occur during winter due to near-surface temperature inversions and atmospheric stagnation that hinder pollutant dispersion. These examples demonstrate that major heavily polluted urban agglomerations in China exhibit unique characteristics due to their wide geographical distribution and significant differences in weather and climate conditions.

In recent years, the Urumqi-Changji-Shihezi area on the northern foothills of the middle Tianshan Mountains has experienced frequent heavy pollution events, with regional air pollution problems becoming increasingly prominent. This region has emerged as a new high-incidence area for air pollution in China. The urban agglomeration on the north slope of the middle Tianshan Mountains includes Urumqi City, Shihezi City, Changji City, Fukang City, Wujiaqu City, and the counties of Hutubi, Manas, and Shawan. This region boasts superior geographical location, dense population, and rapid industrial development, serving as the core area of Xinjiang' s "Silk Road Economic Belt." Complex weather patterns and boundary layer structures, combined with winter temperature inversions, light winds, and strong easterly winds in the middle and lower troposphere, frequently trigger heavy pollution events in Urumqi and surrounding areas. In January 2019 alone, the Xinjiang Heavy Pollution Weather Emergency Command Office issued yellow alerts for heavy pollution weather in the Urumqi-Changji-Shihezi area on four occasions, drawing widespread attention. This study focuses on Urumqi City, Changji City, Shihezi City, and Wujiaqu City in the urban agglomeration on the north slope of the middle Tianshan Mountains. Based on hourly pollutant concentration data from 2017 to 2019, we analyzed regional variations in air pollutants and characteristics of polluted weather types to provide scientific support for future air quality forecasting, regional joint prevention and control of air pollution, and decision-making analysis.

1. Study Area Overview

The urban agglomeration on the north slope of the middle Tianshan Mountains is located on the southern edge of the Junggar Basin, extending approximately 445 km from north to south and 200 km from east to west, with geographical coordinates of 42°52 ~45°28 N, 88°40 ~91°33 E. The region is backed by the Tianshan Mountains to the south and bordered by the Gurbantünggüt Desert to the north [Figure 1: see original paper]. This area constitutes an important component of the Tianshan North Slope Economic Belt and represents the most developed core region in Xinjiang in terms of modern industry, agriculture, transportation, information, education, and technology. The region concentrates 83% of the province' s heavy industry and 62% of its urban population, generating 69% of Xinjiang's GDP on just 40.0% of its land area. Well-developed urban infrastructure, transportation networks, and energy systems enable this region to play a crucial role in driving, radiating, and demonstrating economic development across Xinjiang.

2.1. Data Sources

The study period spanned from 2017 to 2019. Hourly monitoring data for six major air pollutants ($PM_{2\cdot5}$, PM_{10}, SO_2, NO_2, CO, and O_3) were obtained from the official website of China' s Ministry of Ecology and Environment (https://www.mee.gov.cn). Within the study area, Urumqi City included seven environmental monitoring stations (Thirty-First Middle School, Railway Bureau, Monitoring Station, Seventy-Fourth Middle School, Midong District Environmental Protection Bureau, Toll Station, and Academy of Agricultural Sciences), Changji City included two stations (New District Government Center and Prefecture Monitoring Station), Shihezi City included two stations (Ai Qing Poetry Museum and Sunshine School), and Wujiaqu City included one environmental monitoring station, totaling 12 stations. All monitoring equipment, data collection, and quality control procedures strictly followed the national industry standard "HJ/T 193-2005 Technical Specifications for Automatic Air Quality Monitoring." Seasonal divisions were as follows: March-May as spring, June-August as summer, September-November as autumn, and December-February as winter.

2.2. Statistical Methods

According to the Ministry of Ecology and Environment' s "Technical Regulations for Ambient Air Quality Index (AQI) (Trial)" (HJ 633-2012), daily average concentrations of the six air pollutants were classified into six levels . Daily pollutant concentrations exceeding the Grade II standard of GB 3095-2012 were classified as exceedance days. Additionally, based on the classification methods for heavy pollution weather in Beijing, polluted weather in the urban agglomeration on the north slope of the middle Tianshan Mountains was divided into three types: stagnant pollution weather, dust pollution weather, and special pollution weather. Stagnant pollution weather refers to pollution events caused by the gradual accumulation of atmospheric pollutants under unfavorable atmospheric diffusion conditions. Dust pollution weather results from dust transport, while special pollution weather refers to short-term pollution caused by special factors such as firecracker burning during the Spring Festival. Classification was primarily based on weather phenomenon records during and around polluted days.

3.1. Overall Air Pollution Status in the Urban Agglomeration on the North Slope of the Middle Tianshan Mountains

From 2017 to 2019, the atmospheric pollutants exceeding standards in the urban agglomeration on the north slope of the middle Tianshan Mountains included $PM_{2\cdot5}$ and PM_{10}, with annual average exceedance days ranging from 94~104 days for $PM_{2\cdot5}$ and 56~92 days for PM_{10}, accounting for nearly one-third of the year. Among the four cities, Urumqi and Wujiaqu experienced more frequent exceedances than Changji and Shihezi. $PM_{2\cdot5}$ was the primary pollutant, with the number of days where $PM_{2\cdot5}$ served as the primary pollutant averaging 103 days in Urumqi, 321 days in Changji, 295 days in Shihezi, and 306 days in Wujiaqu. These values represented 86.2%, 92.3%, 90.2%, and 89.7% of the total polluted days, respectively. The annual average $PM_{2\cdot5}$ concentrations were 71 $\mathrm{g \cdot m^{-3}}$ in Urumqi, 64 $\mathrm{g \cdot m^{-3}}$ in Changji, 65 $\mathrm{g \cdot m^{-3}}$ in Shihezi, and 73 $\mathrm{g \cdot m^{-3}}$ in Wujiaqu, all exceeding the national Grade II annual average standard of 35 $\mathrm{g \cdot m^{-3}}$. Gas pollutants did not exceed annual average concentration standards.

3.2.1. Pollutant Concentrations at Different Stages

The monthly average exceedance days and concentration level distributions for all six pollutants showed distinct seasonal characteristics [Figure 2: see original paper]. The study area experienced more good air quality days and fewer exceedance days during the summer half-year, while the winter half-year featured frequent exceedance days and higher pollutant concentration levels, consistent with patterns observed in other Chinese cities. Exceedance days were most numerous in January, followed by December and February, which is associated with increased emissions from fossil fuel combustion for heating and motor vehicle exhaust during the heating season. Unlike $PM_{2\cdot5}$, PM_{10} showed exceedance days not only in the winter half-year but also in the summer half-year, related to cold air activities that entrain soil and dust particles into the urban atmosphere. Except for Wujiaqu, SO_2 exceedance days mainly occurred during the winter heating period.

From 2017 to 2019, the annual average concentrations of major pollutants in the urban agglomeration on the north slope of the middle Tianshan Mountains are shown in . The annual average $PM_{2\cdot5}$ concentrations were 71 $g \cdot m^{-3}$ in Urumqi, 64 $g \cdot m^{-3}$ in Changji, 65 $g \cdot m^{-3}$ in Shihezi, and 73 $g \cdot m^{-3}$ in Wujiaqu, representing 2.03, 1.83, 1.86, and 2.09 times the national Grade II standard, respectively. The annual average PM_{10} concentrations were 107 $g \cdot m^{-3}$, 106 $g \cdot m^{-3}$, 134 $g \cdot m^{-3}$, and 116 $g \cdot m^{-3}$, respectively. Compared with 2015 pollutant concentrations, $PM_{2\cdot5}$ in the four cities decreased by 8 $g \cdot m^{-3}$, 13 $g \cdot m^{-3}$, 22 $g \cdot m^{-3}$, and 0.37 $mg \cdot m^{-3}$, representing reductions of 10.1%, 16.9%, 25.3%, and 21.3%, respectively. The annual average ratio of fine to coarse particulate matter ranged from 0.54~0.61, indicating severe fine particle pollution. Based on $PM_{2\cdot5}$ concentration levels, the pollution severity ranking was: Wujiaqu > Urumqi > Changji > Shihezi.

During winter, the urban agglomeration on the north slope of the middle Tianshan Mountains is affected by coal heating, increased atmospheric stability, and frequent temperature inversions, which facilitate the accumulation of $PM_{2\cdot5}$. The average $PM_{2\cdot5}$ concentration during the heating period (November-March) ranged from 100~118 $g \cdot m^{-3}$, 4.00~5.00 times higher than during the non-heating period. After extensive pollution control efforts, the Beijing-Tianjin-Hebei region' s average $PM_{2\cdot5}$ concentration during the 2017-2018 heating period was 85 $g \cdot m^{-3}$. In contrast, the average concentration in the urban agglomeration on the north slope of the middle Tianshan Mountains during the same period was 123 $g \cdot m^{-3}$, 1.4 times higher, highlighting the severity of air pollution in this region.

3.2.2. Seasonal Diurnal Variation Characteristics of Fine Particulate Matter Concentrations

[Figure 3: see original paper] illustrates the diurnal variation characteristics of air pollutants across the four seasons in the urban agglomeration on the north slope of the middle Tianshan Mountains. Although the four cities share the same climatic zone along the northern Tianshan slopes, each city' s diurnal pollutant variation shows subtle differences. In spring, Urumqi, Changji, and Shihezi near the mountain front generally exhibited a "bimodal-bimodal" pattern, with daily maximum values appearing at 01:00 and 10:00, reaching 45 $g \cdot m^{-3}$ and 50 $g \cdot m^{-3}$, respectively. Concentrations gradually decreased to a morning valley at 08:00-11:00. A secondary peak occurred at 13:00-15:00, followed by a gradual decline to the daily minimum at 18:00-20:00, with values of 39 $g \cdot m^{-3}$ and 33 $g \cdot m^{-3}$, respectively. Wujiaqu showed a "unimodal-unimodal" pattern, with the highest value occurring at 10:00 (54 $g \cdot m^{-3}$) and the lowest at 15:00. This pattern resembles the diurnal variation of particulate matter in Lanzhou, where the first peak appears in the early afternoon (13:00-14:00), related to daytime valley winds and the geographical distribution of pollution sources.

In summer, the diurnal variation curves for Urumqi, Changji, and Shihezi remained similar to spring, showing a "bimodal-bimodal" pattern. However, longer daylight hours and more favorable atmospheric diffusion conditions caused the two peaks to occur closer together, with the maximum peak appearing later

(00:00-03:00) and the secondary peak earlier (09:00-11:00). Wujiaqu's "unimodal-unimodal" pattern became more pronounced, with the highest value at 03:00 and the lowest at 15:00. In autumn, all four cities showed a "bimodal-bimodal" pattern, with peak and valley times similar to spring. In winter, Changji and Shihezi maintained a "bimodal-bimodal" pattern, while Urumqi and Wujiaqu showed a "unimodal-unimodal" pattern. Due to the significant influence of mountain-valley winds on cities near the mountain front, Wujiaqu' s diurnal particulate concentration patterns differed markedly from the other three cities in most seasons.

3.3. Characteristics of Polluted Weather Types in the Urban Agglomeration on the North Slope of the Middle Tianshan Mountains

Previous studies have shown that air pollution in the urban agglomeration on the north slope of the middle Tianshan Mountains is primarily influenced by stable temperature stratification in winter, dust transport in spring and autumn, and special factors such as firecracker burning during the Spring Festival. These characteristics are similar to heavy pollution patterns in Beijing and Lanzhou. Therefore, this study classifies polluted weather into three types: stagnant pollution, dust pollution, and special pollution.

3.3.1. Annual Variation Characteristics of Different Polluted Weather Types

From 2017 to 2019, the four cities experienced 355, 321, 298, and 306 days of level III and above polluted weather, respectively. Stagnant pollution days numbered 276, 295, 275, and 286, accounting for 86.2%, 92.3%, 90.2%, and 89.7% of total polluted days. Dust pollution days numbered 46, 26, 23, and 20, representing 13.2%, 8.1%, 7.7%, and 6.5% of total polluted days. Special pollution days were minimal, with only 1-7 days annually .

Stagnant pollution occurred most frequently in winter, especially in January, while dust pollution mainly appeared in spring and autumn, predominantly at level III. Level V stagnant pollution accounted for 45.8%-56.6% of stagnant pollution days, whereas level V dust pollution accounted for 14.9%-29.4%. All special pollution events were level III. The monthly distribution shows that stagnant pollution peaked in January, while dust pollution peaked in March-April and October-November [Figure 4: see original paper].

3.3.2. Correlation Characteristics Between Coarse and Fine Particulate Matter Under Different Polluted Weather Types

The urban agglomeration' s polluted weather is dominated by stagnant and dust types, with varying $PM_{10}/PM_{2\cdot5}$ ratios. [Figure 5: see original paper] shows the correlation between coarse and fine particulate matter under stagnant and dust pollution conditions. Under stagnant pollution, PM_{10} and $PM_{2\cdot5}$ showed very significant linear correlations, with correlation coefficients of 0.90, 0.85, 0.88, and 0.66 for Urumqi, Changji, Shihezi, and Wujiaqu, respectively (average $r = 0.82$), all passing significance tests at the 0.01 level. Under dust pollution, the correlation was slightly weaker, with an average correlation coefficient of 0.58, but still significant.

The average $PM_{10}/PM_{2 \cdot 5}$ ratios under stagnant pollution were 1.26, 1.23, 1.28, and 1.28 for the four cities (average = 1.26), indicating severe fine particle pollution. Under dust pollution, the ratios were 3.16, 3.15, 3.18, and 3.14 (average = 3.16), showing coarse particulate matter concentrations far exceeding fine particulate matter. These distinct ratios provide an effective criterion for distinguishing between stagnant and dust pollution weather types.

3.3.3. Meteorological Characteristics of Different Polluted Weather Types

Wind significantly influences atmospheric pollutant concentrations, with wind speed determining the transport capacity. Higher wind speeds enhance dilution, diffusion, and transport of pollutants, while lower speeds facilitate accumulation. The urban agglomeration's annual average wind speed was 1.61 $m \cdot s^{-1}$, relatively low, particularly in Shihezi (1.22 $m \cdot s^{-1}$) and Wujiaqu (1.47 $m \cdot s^{-1}$). During polluted weather, wind speeds were even lower. For level III pollution, the average wind speed was 1.33 $m \cdot s^{-1}$, while for level V pollution it was 1.09 $m \cdot s^{-1}$. Under stagnant pollution, the average wind speed was 1.09 $m \cdot s^{-1}$ (minimum in Shihezi at 0.85 $m \cdot s^{-1}$), whereas under dust pollution, the average was 1.86 $m \cdot s^{-1}$ (maximum in Urumqi at 2.80 $m \cdot s^{-1}$). Notably, for dust pollution, Urumqi and Changji showed lower wind speeds during level V pollution than level III, suggesting greater contributions from long-distance dust transport, while Shihezi and Wujiaqu showed the opposite pattern, indicating larger local source contributions.

Humidity also significantly affects pollutants by promoting hygroscopic growth and gas-to-particle conversion, leading to sharp concentration increases. Relative humidity shows the highest correlation with $PM_{2 \cdot 5}$ among meteorological factors. The urban agglomeration's annual average relative humidity was 57.5%. During level III and V pollution days, relative humidity was 60.0% and 75.0%, respectively. Stagnant pollution averaged 75.0% humidity, while dust pollution averaged 30.4%. Higher pollution levels and more stable weather conditions corresponded to higher relative humidity.

Visibility also differed between pollution types, with annual average visibility of 17 km. During level III and V pollution, visibility was 15 km and 14 km, respectively. Stagnant and dust pollution showed visibilities of 14 km and 15 km, respectively. The combination of increased pollutant concentrations and high humidity reduced atmospheric visibility. Overall, air pollution occurred predominantly under conditions of low wind speed and high relative humidity, with these conditions becoming more severe during heavy pollution events.

4. Conclusions

Based on hourly air pollutant concentration data from the Urumqi-Changji-Shihezi area from 2017 to 2019, this study analyzed regional variations in air pollutants and characteristics of polluted weather types, yielding the following conclusions:

1) Among the six pollutants, $PM_{2\cdot5}$ was the primary pollutant with the most exceedance days, ranging from 94~104 days annually (nearly one-third of the year). The annual average $PM_{2\cdot5}$ concentrations were 71 $g \cdot m^{-3}$ in Urumqi, 64 $g \cdot m^{-3}$ in Changji, 65 $g \cdot m^{-3}$ in Shihezi, and 73 $g \cdot m^{-3}$ in Wujiaqu, representing 2.03, 1.83, 1.86, and 2.09 times the national Grade II standard, respectively. Exceedance days were concentrated in the winter half-year, particularly in January. The average $PM_{2\cdot5}$ concentration during the heating period (100~118 $g \cdot m^{-3}$) was 4.00~5.00 times higher than during the non-heating period. The diurnal variation of $PM_{2\cdot5}$ showed a "bimodal pattern" in three cities but a "unimodal pattern" in Wujiaqu.

2) Polluted weather was classified into three types: stagnant, dust, and special. Stagnant pollution occurred most frequently (average 286 days, accounting for 90.2% of polluted days), followed by dust pollution (average 29 days, 9.2%). Stagnant pollution predominated in winter, especially January, while dust pollution occurred mainly in spring and autumn, mostly at level III. Level V pollution accounted for 45.8%~56.6% of stagnant pollution and 14.9%~29.4% of dust pollution. The $PM_{10}/PM_{2\cdot5}$ ratios were 1.26 for stagnant pollution and 3.16 for dust pollution, providing an effective criterion for distinguishing between these weather types.

3) The urban agglomeration' s annual average wind speed, relative humidity, and visibility were 1.61 $m \cdot s^{-1}$, 57.5%, and 17 km, respectively. Stagnant pollution occurred under low wind speed (1.09 $m \cdot s^{-1}$) and high humidity (75.0%) conditions, while dust pollution was associated with higher wind speeds (1.86 $m \cdot s^{-1}$), lower humidity (30.4%), and relatively higher visibility. In dust pollution events, Urumqi and Changji showed lower wind speeds during level V pollution, indicating greater contributions from long-distance dust transport, while Shihezi and Wujiaqu showed higher wind speeds, suggesting larger local source contributions.

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