Analysis of Variation Characteristics and Influencing Factors of Negative Air Ion Concentration in Residential Areas of Xining City in Summer (Postprint)

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Abstract

Using air positive and negative ion concentration data observed in typical residential areas of Xining City, Qinghai Province from May to October 2022, this study analyzes the temporal distribution characteristics of air negative ion concentration, evaluates air freshness and cleanliness, and investigates their correlations with concurrent meteorological conditions and air pollutant concentrations. The results show that: (1) The air negative ion concentration in typical residential areas of Xining City is higher in the morning than in the afternoon and evening, and the concentration from August to October is higher than that from May to July. (2) The variation of air negative ion concentration in residential areas of Xining City is closely related to weather conditions during monitoring, following the pattern of "rainy day > cloudy day > partly cloudy day > sunny day". (3) High air negative ion concentration indicates fresh air but does not represent clean air; in plateau region cities, sunny days have relatively low air negative ion concentration with moderate air freshness but relatively high air cleanliness. (4) The main meteorological factors affecting the fluctuation of air negative ion concentration in residential areas of Xining City are relative humidity, sunshine duration, water vapor pressure, precipitation, and wind speed, while the primary air pollutants inhibiting the increase of air negative ion concentration are NO2, PM10, CO, and PM2.5. The research findings can provide scientific data support for living environment, tourism health management, and ecological environmental protection in plateau regions.

Full Text

Variation Characteristics and Influencing Factors of Air Negative Ion Concentration in Summer Residential Areas of Xining City

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Abstract

Positive and negative air ion concentrations were monitored in a typical residential area of Xining City, Qinghai Province, from May to October 2022. The temporal distribution characteristics of negative air ion concentration were analyzed, and air freshness and cleanliness were evaluated. The correlation between negative air ion concentration and concurrent meteorological conditions and air pollutant concentrations was investigated.

The results show that: (1) The negative air ion concentration in typical residential areas of Xining City is higher in the morning than in the afternoon and evening. The negative air ion concentrations from August to October are higher than those from May to July. (2) The variation in negative air ion concentrations in Xining residential areas is closely related to weather conditions during monitoring, following the pattern of "rainy > cloudy > sunny". (3) High concentrations of negative air ions indicate that air is fresh but do not necessarily mean that air is clean. On sunny days, the negative air ion concentration in plateau cities is not high and air freshness is moderate; however, air cleanliness is high. (4) Relative humidity, sunshine hours, water vapor pressure, precipitation, and wind speed are the main meteorological factors affecting the variation in negative air ion concentration. Concentrations of NO_2, PM_{10}, CO, and $PM_{2.5}$ inhibit the increase of negative air ion concentration. The results provide scientific data supporting living environment improvement, tourism health management, and ecological environmental protection in plateau areas.

Keywords: residential areas; negative air ions; meteorological elements; air quality; Qinghai-Tibet Plateau; Xining City

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1. Materials and Methods

1.1 Study Area Overview

Xining City, located in the northeastern part of the Qinghai-Tibet Plateau, has a continental plateau semi-arid climate with an average elevation of 2261 m. The city experiences an annual average temperature of 5.5°C, with summer temperatures averaging 17–19°C and extreme highs reaching 34.6°C. Winter temperatures can drop to -18.9°C. Annual precipitation is approximately 500 mm, while annual evaporation reaches 1363.6 mm. With 2510.1 hours of annual sunshine and a population of 2.47 million, Xining is known as "China's Summer Capital" and serves as a popular summer resort destination.

The air ion observation point in this study was established at the Xining Newspaper Office Residential Compound (36.6304°N, 101.7803°E, 2195.4 m). This compound is situated in the Chengzhong District of Xining, adjacent to the Nanchuan River to the west and the Huangshui River to the north. The southern area features the well-vegetated Triangle Garden and Central Square [Figure 1: see original paper], providing a favorable ecological environment.

1.2 Data Sources

Air positive and negative ion concentrations were measured using a COM-3200PRO air ion detector, which has an ion measurement range of 10–2,000,000 ions $\cdot$ cm^{-3} and ion resolution of 10 ions $\cdot$ cm^{-3}. The instrument measures temperature in the range of -20 to 60°C and relative humidity from 0% to 100%. Observations were conducted manually from 6:00 to 21:00 (Beijing Time) at irregular intervals each day during the period from May to October 2022. The sampling height was maintained at 1.5 m above ground level. At each measurement, instantaneous values were recorded from four directions (east, south, west, north) at the same location, with the average of these four values taken as the positive and negative ion concentration. Temperature and relative humidity were recorded simultaneously.

The instrument was calibrated to zero monthly to ensure that the positive and negative (oxygen) ion concentration readings were zero when the air inlet was sealed. The air inlet was cleaned weekly with anhydrous alcohol. A total of 117 sets of observation data were obtained. The average negative air ion concentration for different time periods was calculated as the sum of instantaneous concentrations within that period divided by the number of observations. Daily average concentration was derived from the sum of daily observations divided by the number of observations, and monthly average concentration was obtained from the sum of daily averages divided by the number of observation days in that month.

Concurrent meteorological data, including atmospheric pressure, water vapor pressure, wind speed, precipitation, and sunshine hours, were obtained from the Xinyoushan Meteorological Station in Xining (36.6667°N, 101.7333°E, 2334.2

m). Air pollutant concentrations ($PM_{2\cdot5}$, PM_{10}, SO_2, NO_2, O_3, CO) and Air Quality Index (AQI) data were sourced from the Xining Environmental Monitoring Station (36.6395°N, 101.7471°E, 2261.3 m).

1.3 Research Methods

This study adopted the Chinese meteorological industry standard QX/T380-2017 "Grade of Air Negative (Oxygen) Ion Concentration" for classifying negative air ion concentration levels and evaluating air freshness. The Ando air ion evaluation coefficient model (CI method) was used to assess air cleanliness. Weather conditions were classified based on the percentage of cloud cover: 0–10% as sunny, 10–30% as partly cloudy, 30–70% as cloudy, and >70% as overcast.

Statistical analysis was performed using SPSS software. Since the observation data did not follow a normal distribution and were not equally spaced, failing to meet the prerequisites for Pearson correlation analysis, Kendall correlation analysis was employed instead. Origin software was used for graphical representation.

According to QX/T380-2017 (Table 1), air with more than 1200 negative ions per cubic centimeter is considered fresh, 500–1200 ions$\cdot$cm^{-3} is relatively fresh, 100–500 ions$\cdot$cm^{-3} is moderate, and less than 100 ions$\cdot$cm^{-3} is not fresh enough.

Table 1 Grade of negative air ion concentration

Negative air ion concentration (N)	Grade
$ $1200	High concentration, fresh air
500–1200	Relatively high concentration, relatively fresh air
100–500	Moderate concentration, moderate air
<100	Low concentration, not fresh enough

The unipolar coefficient (q) refers to the ratio of positive ions to negative ions in the air:

$$q = \frac{n^+}{n^-}$$

where q is the unipolar coefficient, n^+ is the number of positive ions, and n^- is the number of negative ions in the air.

The Ando air ion evaluation coefficient (CI) indicates the degree to which air ionization levels approach natural conditions:

$$CI = \frac{n^-}{1000q}$$

A negative oxygen ion concentration of 1000 ions • cm^{-3} represents the basic standard for human health needs. Higher CI values indicate better air quality. The air cleanliness classification standard is shown in Table 2.

Table 2 Air cleanliness class standard

Cleanliness grade	Air cleanliness
A	$ $1.00
B	(1.00, 0.70]
C	(0.70, 0.50]
D	(0.50, 0.30]
E	<0.30

Note: CI is the Ando air ion evaluation coefficient. The same applies below.

2. Results and Analysis

2.1 Temporal Variation Characteristics of Negative Air Ion Concentration

The negative air ion concentration at the Xining Newspaper Office Residential Compound showed significant temporal variation from May to October 2022. Figure 2 illustrates the variation in negative air ion concentration across different time periods. Substantial differences were observed among various time slots, with the maximum concentration of 48150 ions • cm^{-3} occurring during 6:00–9:00 and the minimum of 25 ions • cm^{-3} during 10:00–13:00. The daily variation exhibited an inverted hook-shaped curve, with a peak in the morning (6:00–9:00) and a trough at 10:00–13:00. The concentration ranking by time period was: 6:00–9:00 > 10:00–13:00 > 14:00–17:00 > 18:00–21:00.

Figure 3 shows the daily average concentration variation, revealing seasonal differences in monthly negative air ion concentrations. The concentration ranking by month was: August > September > October > July > June > May. Overall, the morning negative air ion concentration at the residential compound was higher than that in the afternoon and evening.

Numerous factors influence negative air ion concentration variation. This study primarily investigated the sensitivity of concentration changes to meteorological conditions and air pollution levels.

2.2 Variation Characteristics Under Different Weather Conditions

Previous research has demonstrated that weather conditions significantly affect negative air ion concentrations. By comparing concentrations under different weather conditions at the Xining Newspaper Office Residential Compound, we found that the maximum concentration occurred on rainy days, while the minimum appeared on cloudy days. This suggests that the substantial variation in concentration across different time periods may be related to weather conditions during monitoring. Therefore, we further compared monthly negative air ion concentrations with corresponding weather conditions.

Table 3 presents the negative air ion concentrations under different weather conditions from May to October. The data show that the compound's negative air ion concentration was higher from August to October than from May to July. The monitoring periods with high negative ion concentrations were often rainy days, with the maximum concentration on rainy days reaching 48150 ions $\cdot$ cm^{-3}. In this study, the average negative air ion concentration on sunny days was greater than 500 ions $\cdot$ cm^{-3}, with a mean value of 742.8 ions $\cdot$ cm^{-3}—approximately 1.5 times higher than the results from Geng Shenglian et al., possibly due to the proximity of the observation point to water bodies.

Figure 4 shows the variation in negative air ion concentration across different time periods on sunny days. The difference in average concentration among different time slots on sunny days was not substantial, with the maximum concentration again appearing in the morning (6:00–9:00). During this period, the concentration ranged from 117.5 to 2170 ions $\cdot$ cm^{-3}, with an average of 1020 ions $\cdot$ cm^{-3}—about 1.4 times higher than other time periods. This further demonstrates that weather conditions significantly influence negative air ion concentration.

Geng Shenglian et al. observed negative air ion concentration variation at the Provincial Committee Residential Compound in Xining during sunny days in 2015, finding concentrations of 117.5–2656 ions $\cdot$ cm^{-3} on sunny days, 557.5–1740 ions $\cdot$ cm^{-3} on cloudy days, and 1020–1165 ions $\cdot$ cm^{-3} on rainy days, following the pattern of "rainy > cloudy > sunny." Raindrops generate Lenard effects through friction with air and collision with trees and buildings during their descent from the sky to the ground, accelerating the separation of positive and negative charges in the air and thereby increasing negative ion concentration.

In summary, weather conditions during monitoring periods significantly affect negative air ion concentration at the Xining Newspaper Office Residential Compound, with the highest concentrations on rainy days and the lowest on sunny days. The specific influencing factors can be further explored by examining the relationship between meteorological conditions and negative air ion concentration during monitoring periods.

2.3 Evaluation of Air Freshness and Cleanliness

The concentration of positive and negative ions in the air can reflect local air freshness and cleanliness. Using the positive and negative ion concentration data from the Xining Newspaper Office Residential Compound from May to October 2022, we conducted grade classification and freshness evaluation according to the standard, and assessed air cleanliness using the CI method.

Table 4 shows the negative air ion concentration grades, unipolar coefficients (q), and CI-based air cleanliness evaluation results for different time periods and weather conditions. The results indicate that the difference between positive and negative ion concentrations in rainy day air at the compound is substantial. From May to October, the air freshness at the compound was higher than "relatively fresh" during 6:00–21:00. The air freshness ranking by time period was: 6:00–9:00 > 10:00–13:00 > 14:00–17:00 > 18:00–21:00. The air was relatively fresh during 6:00–9:00, with freshness decreasing during 10:00–21:00.

The CI method for evaluating air cleanliness differs from the negative air ion concentration grade classification for air freshness. The air cleanliness at the compound showed seasonal variation across different months from May to October. Starting from August, the air cleanliness at the compound was significantly higher than in May, June, and July. Overall, the air cleanliness was higher from August to October than from May to July. From the perspective of weather conditions, the compound's air cleanliness from May to October consistently showed the pattern of "rainy > cloudy > sunny" [Figure 5: see original paper], which aligns with the variation pattern of negative air ion concentration under different weather conditions mentioned above.

In summary, the negative air ion concentration at the Xining Newspaper Office Residential Compound was higher from August to October than from May to July, while the variation in air freshness differed from this pattern. The air cleanliness was higher from August to October than from May to July. Among these months, May showed the greatest fluctuation in air freshness, ranging from "relatively fresh to not fresh enough." From the perspective of weather conditions, air freshness was moderate on sunny days in the compound from May to October, while it was higher on rainy days in August and September. The primary reason for the different evaluation results between air freshness and cleanliness is the concentration of positive ions in the air.

2.4 Relationship Between Negative Air Ion Concentration and Meteorological-Environmental Factors

The negative air ion concentration at the Xining Newspaper Office Residential Compound was higher on rainy and cloudy days than on sunny and partly cloudy days from May to October 2022. Different meteorological conditions may cause variations in negative air ion concentration. To further investigate the impact of meteorological factors on negative air ion concentration, Kendall correlation analysis was performed between daily average negative air ion concentration and concurrent temperature, atmospheric pressure, relative humidity, water vapor pressure, precipitation, wind speed, and sunshine hours.

Figure 5 presents the Kendall correlation coefficients between negative air ion concentration and meteorological/environmental factors. The results show that negative air ion concentration was significantly positively correlated with relative humidity (correlation coefficient = 0.441, $P < 0.001$), water vapor pressure (correlation coefficient = 0.517, $P < 0.001$), precipitation (correlation coefficient = 0.348, $P < 0.05$), and wind speed (correlation coefficient = 0.312, $P < 0.05$). Negative air ion concentration was significantly negatively correlated with sunshine hours (correlation coefficient = -0.288, $P < 0.05$), which is consistent with the phenomenon of higher negative air ion concentrations in the morning than in the afternoon mentioned earlier.

Some negative ions in the air originate from plant tip discharge and the photoelectric effect produced during photosynthesis. In summer afternoons, high temperatures and strong light cause plant leaf stomata to close, reducing photosynthesis intensity and consequently decreasing negative air ion concentration in the air, resulting in lower afternoon concentrations compared to morning levels. Precipitation was significantly positively correlated with relative humidity (correlation coefficient = 0.421, $P < 0.001$) and water vapor pressure (correlation coefficient = 0.373, $P < 0.001$), indicating that precipitation processes increase air humidity and water vapor pressure. Thus, compared to sunny days, rainy days have higher negative air ion concentrations, and higher air humidity, water vapor pressure, wind speed, and precipitation all contribute to higher negative air ion concentrations and fresher air.

In addition to meteorological conditions, environmental factors also influence negative air ion concentration to some extent. Air pollutants can adsorb negative air ions, and high pollutant concentrations can reduce negative air ion concentration. Kendall correlation analysis was conducted between daily average negative air ion concentration and concurrent AQI, $PM_{2\cdot5}$, PM_{10}, SO_2, NO_2, O_3, and CO concentrations.

As shown in Figure 5, negative air ion concentration at the compound was significantly negatively correlated with NO_2 (correlation coefficient = -0.347, $P < 0.05$), PM_{10} (correlation coefficient = -0.349, $P < 0.001$), CO (correlation coefficient = -0.265, $P < 0.05$), and $PM_{2\cdot5}$ (correlation coefficient = -0.271, $P < 0.05$). Negative correlations with AQI, SO_2, and O_3 were also observed but were not statistically significant. Precipitation was significantly negatively correlated with air pollutant concentrations, with correlation coefficients of -0.378 ($P < 0.001$) for $PM_{2\cdot5}$ and -0.304 ($P < 0.05$) for NO_2. These significant correlations indicate that high concentrations of air pollutants can inhibit the increase of negative air ion concentration, with $PM_{2\cdot5}$ having the greatest inhibitory effect on negative air ion concentration increase at the Xining Newspaper Office Residential Compound. Precipitation processes can reduce air pollutant concentrations, thereby increasing negative air ion concentration.

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3. Conclusions

Based on observations from May to October 2022 at the Xining Newspaper Office Residential Compound, the following conclusions were drawn:

1. Negative air ion concentration showed significant temporal variation, with higher concentrations in the morning than in the afternoon and evening. Monthly average negative air ion concentration exhibited seasonal variation, with higher concentrations from August to October than from May to July.
2. The variation in negative air ion concentration was closely related to weather conditions during observation, following the pattern of "rainy > cloudy > sunny." Negative air ion concentration varied little across different months on sunny days, but increased significantly on rainy and cloudy days.
3. The evaluation of air freshness and cleanliness using the CI method was consistent with the pattern of negative air ion concentration variation under different weather conditions, showing "rainy > cloudy > sunny" from May to October. High negative air ion concentration indicates fresh air but does not necessarily mean clean air. In plateau urban areas, sunny days have relatively low negative air ion concentration and moderate air freshness, but high air cleanliness.
4. The main meteorological factors affecting negative air ion concentration variation were relative humidity, sunshine hours, water vapor pressure, precipitation, and wind speed. Sunshine hours were significantly negatively correlated with negative air ion concentration, while relative humidity, water vapor pressure, wind speed, and precipitation were significantly positively correlated, with the positive correlation strength decreasing in that order. The primary air pollutants inhibiting negative air ion concentration increase were $PM_{2\cdot5}$, PM_{10}, NO_2, and CO.

These research results provide scientific data support for living environment assessment, tourism health management, and ecological environmental protection in plateau regions.

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Note: Figure translations are in progress. See original paper for figures.