Meteorological Causes of a Severe Pollution Weather Process in Shaoyang Area

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Abstract Based on the monitoring data of air quality and conventional meteorological data in Shaoyang City, a severe pollution weather process in Shaoyang from December 25, 2023 to January 1, 2024 was analyzed from the aspects of changes in pollutant concentration, circulation background, and changes in various meteorological elements. The results show that this severe pollution weather process was a compound pollution process caused by accumulation of local pollutants and transportation of external pollutants, during which the primary pollutant was $PM_{2.5}$. During the accumulation stage, the ground was controlled by a uniform pressure field, and the conditions of atmospheric diffusion were poor. During the outbreak stage, the wind on the ground was from the northeast, which was conducive to the input of upstream pollution clusters into the city. Pollutant concentration was inversely correlated with daily average sea-level pressure, and positively correlated with daily average temperature. Wind speed and direction were closely related to $PM_{2.5}$ concentration. During the accumulation stage, the ground was mainly dominated by weak winds, and the conditions of atmospheric diffusion were poor. During the outbreak stage, the continuous northeastward wind continuously transported upstream pollutants to Shaoyang area. Local pollutants accumulated in the previous stable weather process and the terrain led to the outbreak of local pollution.

Key words Heavy pollution process; Pollution characteristics; Causes; Meteorological elements

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In recent years, there have been numerous studies on the meteorological conditions of air pollution in central Chinese cities and urban agglomerations. It has been found that regional air pollution is closely related to topography, transport channels, and static and stable meteorological conditions[1-3]. The atmospheric environment has become an important factor affecting people's quality of life. Shaoyang City is located in the southwest of Hunan Province. It is surrounded by mountains in the southeast, southwest and northwest, and there is the Hengyang Basin and the Shaoyang Basin in the middle and east. It is in the shape of a sieve that opens towards the northeast. It is one of the main channels for the southward transmission of pollutants from the north. Especially during the special protection period (from November to next January), due to the accumulation of local pollution, unfavorable meteorological conditions and the transmission of pollutants from the north and other factors, the number of polluted days has increased significantly.

From December 25, 2023 to January 1, 2024, a severe pollution weather process occurred in Shaoyang and its surrounding areas. In this paper, this process was analyzed from aspects of changes in pollutant concentration, evolution of weather patterns, and regional pollution transmission, so as to provide a theoretical basis for better forecast and early warning services of severe pollution weather.

1 Materials and methods

The data of urban air quality used were derived from the public data of the China National Environmental Monitoring Centre. The meteorological data were the daily observation data of Shaoyang Meteorological Bureau and the reanalysis data from the National Centers for Environmental Prediction (NCEP) of the United States.

2 Analysis of pollution situation

From December 25, 2023 to January 1, 2024, a continuous pollution weather process occurred in the urban area of Shaoyang. During the stage of pollutant accumulation (from December 25 to 28, the same below), the primary pollutant was PM_{10}. During the stage of pollutant outbreak (from December 29 to December 31, the same below), the primary pollutant was $PM_{2.5}$.

Due to the influence of the stable atmospheric weather and emissions of local pollutants before the appearance of this severe pollution process, the pollution was slight on December 25. At this time, the air quality in upstream areas such as Loudi, Changde, and Xiangtan was good. Since December 28, pollutants were transmitted to the north of Hunan Province, and rapidly spread to most areas of Hunan. Affected by the input of upstream pollutants, the city was severely polluted for three consecutive days from December 29 to 31. During the stage of pollutant removal (from January 1 to 2, 2024, the same below), cold air moved southwards on January 1, the conditions of atmospheric diffusion were improved, and air pollution became slight. On January 2, because of the southward movement of the main body of cold air and the joint clearance of effective precipitation, the air quality in the city was good.

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3 Analysis of causes

3.1 Circulation backgrounds From the evolution of the circulation pattern, it is known that during the stage of pollutant accumulation, a short-wave trough passed over Shaoyang area from December 25 to 26, and the circulation was relatively flat from December 27 to 28 on the 500 hPa situation field. On the sea level pressure field, the urban area of Shaoyang was located in a wide equalizing field at the bottom of the surface high pressure from December 25 to 27. On December 28 before the low pressure, it was still under the control of the surface equalizing field, which was conducive to the accumulation of pollutants. During the stage of pollutant outbreak, on the 500 hPa situation field, an upper-level trough passed over Shaoyang area from December 29 to 31, and the ground remained in a state of uniform pressure, while the stable situation was maintained. There was a northeasterly wind on the ground. Pollution clusters from the upstream areas of Xiangtan and Loudi were input into the city. Affected by the previous accumulation and upstream input, the concentration of pollutants increased rapidly. During the stage of pollutant removal, on January 1, cold air moved southwards, and the northerly wind on the ground continued to intensify (above force 3). Meanwhile, the rainfall in the urban area was 6 mm. The atmospheric diffusion conditions and the wet deposition effect of the rainfall were conducive to the dilution and diffusion of pollutants in Shaoyang area. As a result, the severe pollution that had lasted for three days in Shaoyang area was gradually improved, and the pollution in the urban area became slight. On January 2, the main body of the cold air moved southwards, and there was a force 9 northerly wind on the ground. The conditions of atmospheric diffusion continued to improve. A rainfall occurred in the urban area, with the precipitation of 12.3 mm, which was conducive to the wet removal of pollutants. The air quality in the urban area changed from light pollution to a good state. From the above analysis, it can be seen that the prolonged stable weather and regional transmission of pollutants were important factors causing this pollution.

3.2 Relationship between changes in pollutant concentration and various meteorological elements The changes in the concentration of pollutants PM_{10} and $PM_{2.5}$ at Shaoyang station were basically synchronous. During the stage of pollutant accumulation, PM_{10} concentration was greater than $PM_{2.5}$ concentration. During the stage of pollutant outbreak, $PM_{2.5}$ concentration was the highest.

3.2.1 Air pressure. From the temporal changes of $PM_{2.5}$ and air pressure during the pollution period, it can be found that during the stages of pollutant accumulation and outbreak, the daily average sea-level pressure in the urban area of Shaoyang showed a gradually decreasing trend, and was inversely correlated with the daily increasing pollutant concentration. During the stage of pollutant removal, the daily average sea-level pressure showed a gradually rising trend, and was inversely correlated with the daily decreasing pollutant concentration. During the accumulation stage, there was an equalizing pressure field on the ground, and local pollutants started to accumulate. During the outbreak stage, low pressure developed on the ground, and the superimposed outbreak of local and transported pollutants occurs. During the clearance stage, as the cold high pressure moved southwards, the wind speed on the ground increased, and the pollutants diffused accordingly.

3.2.2 Temperature. The temporal changes of $PM_{2.5}$ and temperature during the pollution period were analyzed. It can be found that before December 30, there was no influence of cold air, and the daily average temperature in the urban area of Shaoyang showed an upward trend (the highest temperature occurred on December 30, reaching 21.1 ℃). It was positively correlated with the daily increasing pollutant concentration. As the cold air gradually moved southwards on December 31, the daily average temperature in the urban area showed a downward trend, and was positively correlated with the daily decreasing pollutant concentration.

3.2.3 Wind speed and direction. The terrain of Shaoyang is higher in the southwest and lower in the northeast, presenting an open sieve-shaped pattern towards the northeast. Therefore, wind speed and direction were closely related with $PM_{2.5}$ concentration. Overall, during the accumulation stage of pollutants, the ground was mainly dominated by weak winds, and wind was mainly northerly and northeasterly. The conditions of atmospheric diffusion were poor, which was conducive to the local accumulation of pollutants, and $PM_{2.5}$ concentration gradually increased. During the stage of pollutant outbreak, the wind speed on the ground slightly increased, and wind was mainly northeasterly. The continuous northeasterly wind continuously transported upstream pollutants to Shaoyang area. Combined with the local pollutant accumulated during the previous stable stage, the pollutant concentration reached its peak on December 30. To sum up, apart from the influence of terrain, the transportation of pollutants brought by the continuous northeasterly wind since December 28 was the main cause of this pollution outbreak. During the clearance stage, wind speed continued to increase, and the conditions of atmospheric diffusion were improved. $PM_{2.5}$ concentration in the urban area of Shaoyang began to decline, and air quality became good on January 2.

4 Conclusions

Compared with the pollution caused by single external transportation or local pollutants, this pollution process was complex and special. Through in-depth analysis of this process, the following conclusions are drawn.

(1) The primary pollutant in this process was $PM_{2.5}$. In the early stage, due to the influence of stable atmospheric weather and emissions of local pollutants, slight pollution occurred. In the later stage, owing to the input of upstream pollutants and the accumulation of local pollutants in the early stage, severe pollution weather lasted for three consecutive days.

(To page 15)

collaborative education achievements into performance evaluations, and establishes long-term cooperation mechanisms.

In summary, the "five-bit synergy" forms an organic system. The goal of "localization" indicates the direction, the content of "integration" provides the carrier, the method of "contextualization" achieves transformation, the evaluation of "value-added" ensures quality, and the resources of "synergy" provide support. Local universities should make dynamic adjustments based on their own actual situation when applying this model, in order to embark on a distinctive path of first-class curriculum construction.

4 Conclusion and prospect

The three-dimensional integrated framework of "value – ability – knowledge" constructed in this paper provides theoretical support for the construction of new liberal arts courses. Practice has shown that through systematic curriculum reform, local universities can build first-class courses with height, depth, and warmth under resource constraints. The key is to transform the new liberal arts concept into concrete teaching actions[3].

In the future, challenges such as improving teachers' interdisciplinary abilities, building case libraries, and achieving long-term collaboration between schools and enterprises need to be addressed. In the future, artificial intelligence can be explored to empower teaching and evaluation, and long-term tracking of educational effects can be carried out.

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(2) From the analysis of the circulation background, it can be seen that this process was a compound pollution process caused by accumulation of local pollutants and transportation of external pollutants. During the accumulation stage, the ground was controlled by a uniform pressure field, and the upper-level circulation was relatively flat, while the conditions of atmospheric diffusion were poor. During the outbreak stage, the ground remained in a state of equalized pressure. An upper-level trough passed through the area, and the wind on the ground was from the northeast. Pollution clusters from the upstream areas of Xiangtan and Loudi were input into the city, so that the concentration of pollutants increased rapidly. Subsequently, with the southward movement of the main body of cold high pressure and the precipitation process, the local pollution entered the clearance stage.

(3) From the analysis of changes in $PM_{2.5}$ concentration and meteorological elements, it can be known that pollutant concentration was inversely correlated with daily average sea-level pressure, and positively correlated with daily average temperature. Wind speed and direction were closely related to $PM_{2.5}$ concentration. During the accumulation stage, the ground was mainly dominated by weak winds, and the conditions of atmospheric diffusion were poor, which was conducive to the local accumulation of pollutants. During the outbreak stage, the continuous northeastward wind continuously transported upstream pollutants to Shaoyang area. Local pollutants accumulated in the previous stable weather process and the terrain led to the outbreak of local pollution.

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