

Impact of regional haze pollution and local meteorological conditions on urban residential areas

Chao Kang¹ and Yu Chen^{2,*}

¹ School of Economics and Management, Neijiang Normal University, Neijiang, Sichuan 641112, PR China

² School of Humanities and Social Sciences, Guangxi Medical University, Nanning, Guangxi 530021, PR China

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Abstract. With the accelerated process of economic construction and urbanization, motor vehicles and pollutants emitted from winter heating are constantly increasing, and regional haze pollution caused by these factors has affected people's living environment. This article took Nanning City, Guangxi Province, as the research area and analyzed the relationship between regional haze pollution and local meteorology by using the Pearson correlation coefficient. Then, cluster analysis was carried out to find out the main impacts of these two factors on urban residential areas. The results showed that among the local meteorological factors, average precipitation was strongly correlated with the occurrence of haze pollution, while other meteorological factors showed a very strong correlation. According to the results of cluster analysis, the impact of regional haze pollution and local meteorology on urban residential areas was mainly divided into three categories: reduced visibility, reduced human health, and reduced living comfort. The largest impact was on reduced visibility, and 79.11% of the total population felt that the visibility was affected.

Keywords: Regional haze pollution / local meteorology / urban residential area / Pearson correlation / cluster analysis

1 Introduction

As people's living standards have gradually improved, their housing needs have also increased. It is no longer limited to simple shelter from the wind and rain, but also includes higher requirements for the living environment. People have turned their attention to pollution in the living environment. Many places in the world still have high levels of air pollution [1], especially haze pollution, still persist. Although many studies have been carried out on the causes of haze pollution, there have been relatively fewer studies on its effects. For example, Wu et al. [2] used a time-series analysis to describe the differences in PM_{2.5} concentration across seasons, time periods, and areas, and examined the factors affecting air quality with a generalized additive model. The results showed that the interaction between air pollutants and meteorological elements was the most prominent, and wind speed played a crucial role throughout the diffusion process. Zhou [3] analyzed the spatial variation of PM_{2.5} concentration by constructing a wind direction weight matrix. The experimental results indicated that the growth of GDP per capita promoted the

reduction of PM_{2.5} pollution, while the increase of other socio-economic factors aggravated the haze pollution. Li et al. [4] identified the interactive patterns of environmental regulation with a dynamic fixed-effect Durbin model and studied its impact on the environment. The empirical results showed that there were regional differences in environmental regulation and haze pollution, and high-high and low-low clusters dominated the spatial pattern. Feng et al. [5] used a CMB model to simulate the sources and trends of PM_{2.5} pollution during the study period, and analyzed the reasons for the different pollution processes. The results showed that all three pollution processes occurred under unfavorable meteorological conditions, with relative humidity and temperature continuously increasing and wind speed and boundary layer height continuously decreasing. Zhou et al. [6] used spatial autoregressive and spatial Durbin models to measure the spatial effects of the electricity and thermal power industries on haze pollution. The final results showed that the electricity and thermal power industries were significant haze pollution producers and exhibited significant spatial spillover effects. Different researchers in the aforementioned studies have conducted relevant research on haze pollution and analyzed its influencing factors. This article employed Pearson's method to analyze the

* e-mail: chenpaju66828@163.com

Table 1. The regional meteorological data of Nanning City from 2015 to 2022.

	Average maximum temperature	Average minimum temperature	Relative humidity	Average precipitation	Average air pressure
2015	32.87	14.61	83.17%	101.86 mm	998.27 hPa
2016	33.31	13.43	79.96%	128.88 mm	997.94 hPa
2017	32.29	15.21	79.74%	129.12 mm	995.17 hPa
2018	31.68	13.87	79.31%	108.44 mm	994.38 hPa
2019	32.23	14.50	79.76%	101.88 mm	994.39 hPa
2020	31.81	13.30	72.06%	90.72 mm	995.71 hPa
2021	32.39	14.89	76.09%	84.23 mm	994.68 hPa
2022	31.36	14.18	76.28%	92.21 mm	994.62 hPa

correlation between haze pollution and local meteorological factors, as well as investigated the impact of haze pollution on urban residents' lives through questionnaire surveys and cluster analysis. This article took Nanning City, Guangxi Province, as the research object and analyzes the correlation between local meteorological elements and regional haze pollution using Pearson correlation coefficient. Finally, cluster analysis algorithm is used to cluster regional haze pollution and the impact of local meteorology on urban residential areas in Nanning City to find the main cause of the impact. It is hoped that appropriate solutions can be proposed for the impacts on urban residential areas identified in the study, thus providing a theoretical basis for reducing the impacts of regional haze pollution in the future. The novelty of this article lies in the use of Pearson's method and cluster analysis to analyze haze pollution, confirming the correlation between precipitation and other meteorological factors with haze pollution, and the analysis of the main impacts of haze pollution on local residents. The main contribution of this article is using Pearson's method and cluster analysis to analyze regional haze pollution and its impact on local weather, providing effective references for preventing adverse effects on local residents. The limitation of this article is that the correlation between haze pollution and local meteorological factors only considered a limited number of meteorological factors. Therefore, future research should aim to expand the scope of relevant factors that may affect the degree of haze pollution.

2 Concepts related to haze pollution

Haze is a weather phenomenon caused by the presence of large numbers of tiny aerosol particles in the air that cloud the air and reduce horizontal visibility to less than 10 kilometers. Haze has serious effects on human health and urban air quality [7]. The formation of haze pollution is mainly due to two reasons. First, population growth, industrial development, and an increase in the number of motor vehicles all lead to a significant increase in the emission of pollutants and suspended particles, which cause haze pollution. Second, unfavorable pollution diffusion conditions [8], such as tall buildings standing in

residential areas of the city, weaken the wind passing through the area due to blockage and friction. However, as the stagnant wind increases, it is not conducive to the diffusion of suspended particles [9], resulting in the accumulation of particulate matter in the city. The formation of haze leads to reduced visibility. Since city residents rely on vehicles for transportation, they have to drive slowly, and traffic accidents are more likely to occur, eventually leading to traffic congestion and discouraging people from going out. At the same time, because some particles in the haze are very fine, even invisible to the naked eye, these particles can easily enter the human respiratory system, causing various respiratory and cardiovascular diseases [10]. The densely populated urban residential areas lead to an increase in the number of people suffering from diseases. In addition, some toxic and harmful substances, when inhaled by the human body over a long period of time, can cause human lung cancer or even death. There is also a certain relationship between the occurrence of regional haze pollution and local meteorological conditions. "Local" in local meteorology in weather forecasting is not a specific location, but to some extent, expresses the uncertainty and extreme conditions of the forecast. Typical local meteorological elements include average temperature, wind speed, relative humidity, air pressure, visibility, and other meteorological factors [11].

3 Research data and methods

3.1 Data sources

The main topic of this article is regional haze pollution and local meteorology, so it is necessary to first determine the study area. The study area in this article was ultimately determined to be Nanning City, Guangxi Province. The relevant meteorological data were mainly collected from official websites such as the National Meteorological Science Data Center and the Guangxi Statistical Yearbook. During the data collection process, due to the age of some of the data, there were extremely rare cases where monthly data were missing, making it impossible to calculate annual averages. Therefore, in this article, the missing data were filled by averaging the data in the same period. The specific local meteorological data obtained in the end can be seen in Table 1.

Table 2. Correlation coefficients between haze pollution and local meteorology in Nanning City, Guangxi Province from 2015 to 2022.

Average maximum temperature	Average minimum temperature	Relative humidity	Average precipitation	Average air pressure
−0.921	−0.927	0.876	−0.763	0.853

objects, x_j and x_{ij} represent the j th attribute value of x and x_i , respectively.

- Based on the calculated distance, the object is assigned to cluster center c_i with the shortest distance.
- Steps (2) and (3) are repeated until the calculated value does not change significantly; otherwise, the clustering is repeated.

4 Case study

4.1 Analysis of the correlation between local meteorology and regional haze pollution

Firstly, the study used the Pearson correlation coefficient to explore the relationship between local meteorology and haze pollution in Nanning City, Guangxi Province. The results obtained are presented in Table 2.

Table 2 shows the Pearson correlation coefficients between the number of haze pollution days and meteorological elements in Nanning, Guangxi Province from 2015 to 2022. From the data in Table 2, it was seen that the average maximum temperature, minimum temperature, and precipitation in the local meteorological elements were negatively correlated with the occurrence of haze pollution. As the temperature decreased, the vertical flow in the lower atmosphere decreased, making it difficult for pollutants to disperse. At the same time, as the precipitation decreased, the humidity in the air decreased, causing particulate matter to remain suspended and eventually form haze pollution. In addition, according to the data in Table 2, relative humidity and average air pressure were positively correlated with the occurrence of haze pollution. Based on the classification criteria of Pearson correlation coefficients, where absolute values between 0.8 and 1 were considered as extremely strong correlation, and those between 0.6 and 0.8 were considered as strong correlation. It was seen that the average precipitation in local meteorological elements had a strong correlation with the occurrence of haze pollution, while the other meteorological elements all had an extremely strong correlation. Therefore, it is concluded that in areas where regional haze pollution increases, the average maximum temperature, minimum temperature, and precipitation in that region will tend to decrease, while relative humidity and average air pressure will tend to increase.

4.2 Cluster analysis

After understanding the relationship between local weather and regional haze pollution, in order to further

investigate the effects of regional haze pollution and local weather on people's lives in urban residential areas, the obtained questionnaire data were analyzed by cluster analysis using SPSS software, and the results are presented in Table 3.

According to the clustering results in Table 3, the impact of regional haze pollution and local weather on urban residential areas in Nanning was mainly divided into three categories. Cluster 1 involved keywords such as visibility, vague, traffic congestion, traffic jam, and accidents; cluster 2 involved keywords such as illness, bronchitis, and physical discomfort; and cluster 3 involved keywords such as inconvenient, masks, low precipitation, and dusty. Therefore, they were specifically classified as reduced visibility, reduced human health, and reduced living comfort. As shown in Table 3, more than half of the respondents indicated that regional haze pollution and local weather had affected daily visibility and living comfort. Moreover, 44.15% of the respondents believed that regional haze pollution and local weather had some impact on physical health. However, among the three clustering results, the most significant impact on urban residential areas was reduced visibility, which was the most frequently mentioned keyword in this cluster by people (534 people, accounting for 79.11%).

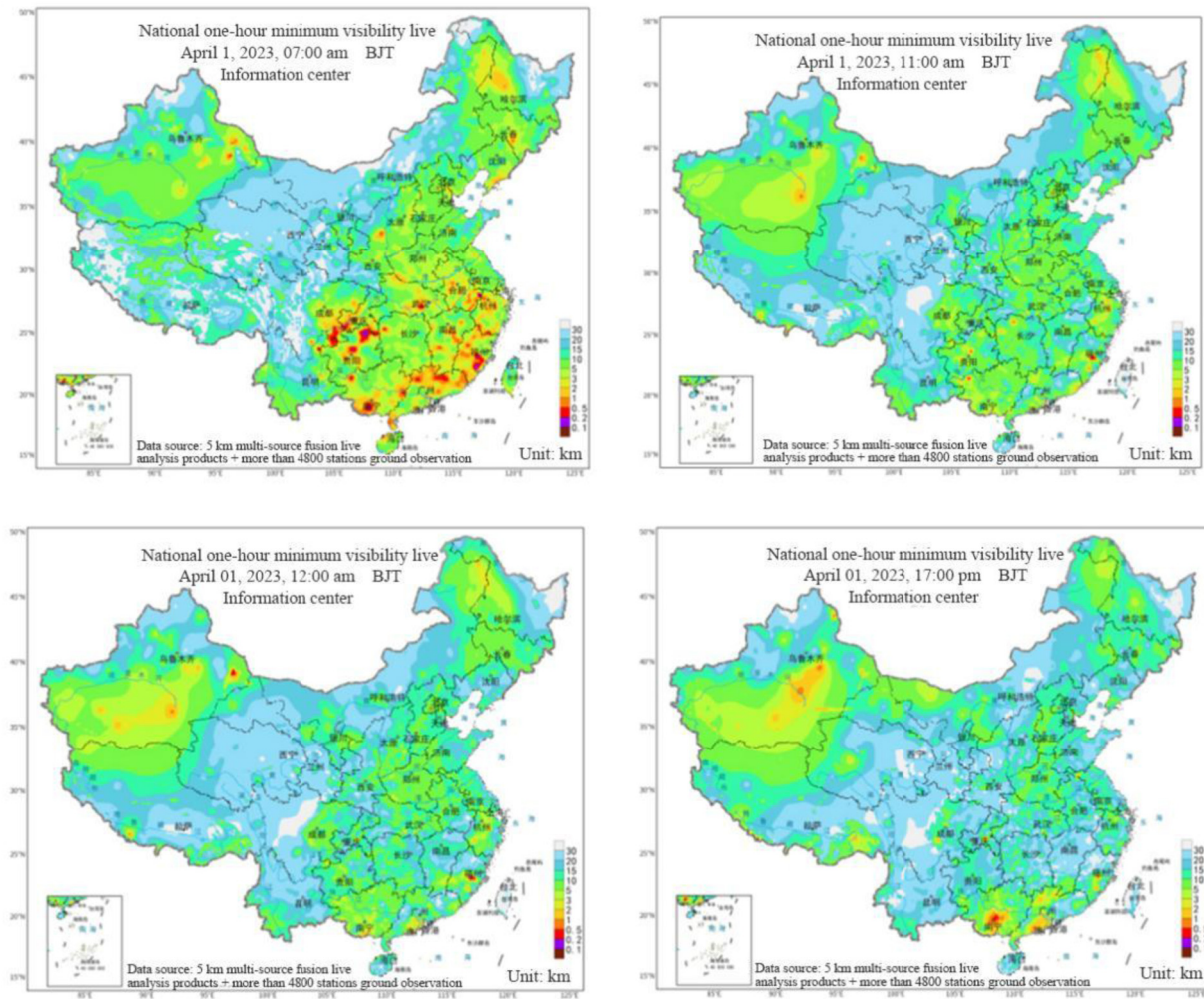
4.3 Visibility analysis

According to the data information from the above clustering results, it was found that most people considered that the haze pollution caused reduced visibility in urban residential areas. Therefore, the following analysis will mainly focus on the visibility in Nanning City.

During the data collection process, it was found through consulting the public data of the National Meteorological Science Data Center that on April 1, 2023, the time with the lowest visibility in Nanning City was at 4:00 a.m. In order to analyze the data more intuitively, this article selected the hourly minimum visibility actual observation chart for Nanning City, Guangxi Province on April 1, 2023, which is shown in Figure 2. It was seen that the minimum visibility of Nanning City at 7:00 a.m. and 5:00 p.m. on April 1, 2023 was 0.5 km, which was extremely poor weather conditions. This indicated that the material concentration in the atmosphere was very high. The minimum visibility at 11:00 a.m. and 12:00 p.m. was 10 km, indicating that the material concentration in the atmosphere was relatively low during that time period. At 7:00 a.m. and 5:00 p.m., the sun was just rising or about to set, the relative humidity of the air was high, and the

Table 3. Cluster analysis results on the effects of regional haze pollution and local meteorology on urban residential areas in Nanning City.

Serial number	Cluster name	Number of people mentioning it	Percentage
1	Reduced visibility	534	79.11%
2	Reduced human health	298	44.15%
3	Reduced living comfort	427	63.26%

**Fig. 2.** Minimum visibility during certain times in Nanning, Guangxi Province on April 1, 2023.

temperature was low, which was consistent with the correlation between regional haze pollution and local meteorology. Furthermore, this is also the time with the highest number of people travelling in urban residential areas, involving commuting, daily grocery shopping, and other activities. If the visibility is low at this time, it will bring great inconvenience to people's lives.

Next, the decrease in visibility was analyzed from aspects of the content of $PM_{2.5}$ and amount of precipitation to find out the reason for the low visibility of Nanning in some time periods on April 1, 2023.

It was seen from the data in Table 4 that seen that on April 1, 2023, the air quality index in Nanning was 36, which belongs to the first-level excellent grade, i.e., the air quality was good and there was almost no air pollution, indicating that there was no regional haze pollution in Nanning on that day. Furthermore, based on the classification of $PM_{2.5}$ levels, it was found that the $PM_{2.5}$ content in Nanning on that day was 23 micrograms per cubic meter, belonging to the excellent level and did not reach the level of causing air pollution. Although haze pollution can greatly reduce visibility, according to the air

Table 4. Air quality index data for Nanning on April 1, 2023 (unit: $\mu\text{g}/\text{m}^3$; unit of CO: mg/m^3).

Date	Air quality index	PM _{2.5}	PM ₁₀	SO ₂	NO ₂	CO	O ₃
2023-04-01	36	23	34	5	27	1.09	9

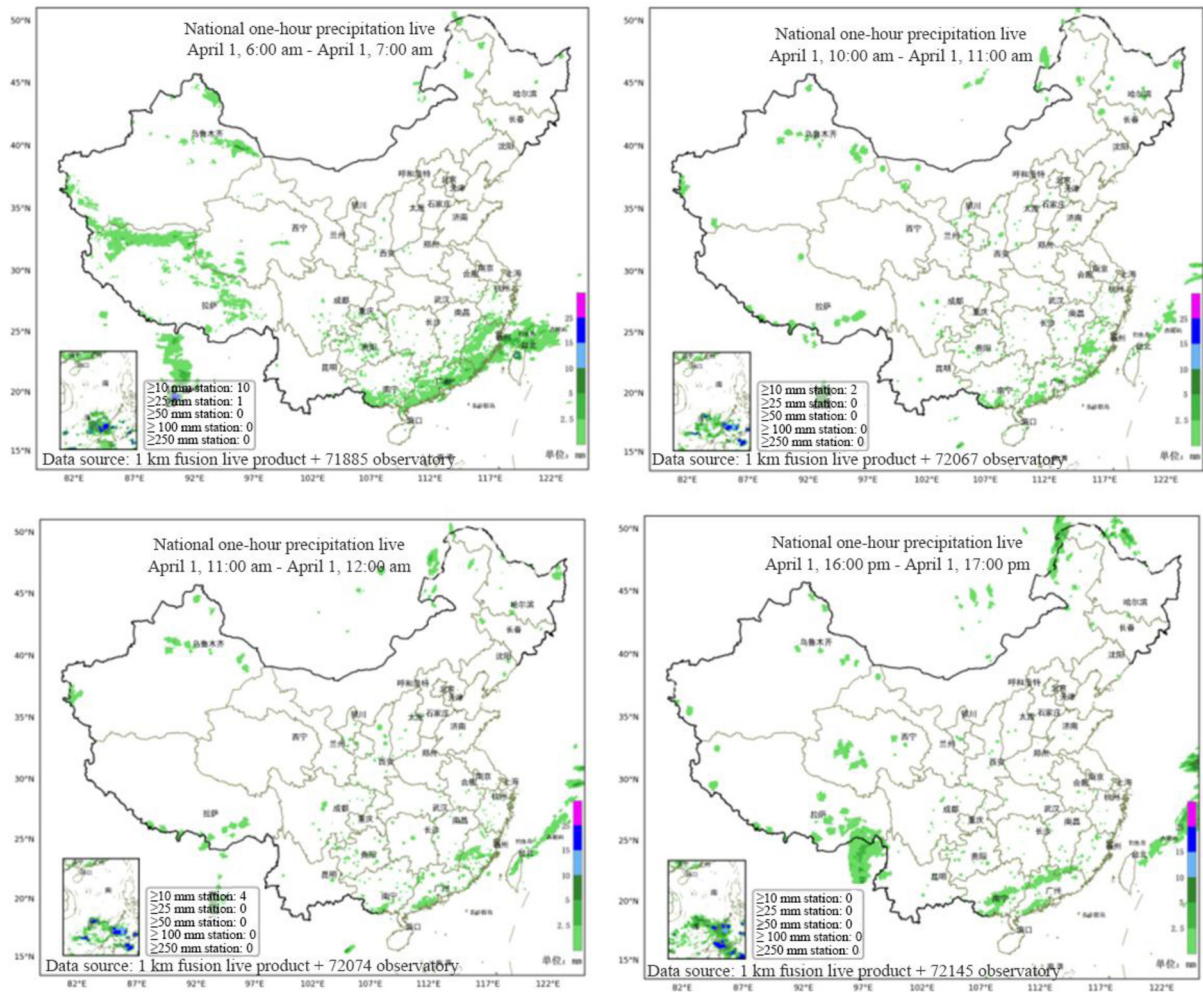


Fig. 3. Precipitation amounts during selected time periods in Nanning City, Guangxi Province, on April 1, 2023.

quality index of the day, it was found that there was no significant correlation between the visibility reduction of some periods in Nanning shown in Figure 2 and the PM_{2.5} content of that day.

It was seen from the data in Figure 3 that the precipitation amount in Nanning at 7:00 a.m. and 5:00 p.m. was around 5 mm, i.e., the relative humidity in the air was relatively high, and the presence of rain scattered light, reducing the visibility for pedestrians. However, at 11:00 a.m. and 12:00 p.m., there was almost no precipitation, so there was enough light to increase visibility. Combined with the analysis of PM_{2.5} content and precipitation amounts, it was concluded that the main cause of the

visibility reduction in the urban residential areas of Nanning on April 1, 2023 was the local meteorological precipitation.

5 Discussion

Haze pollution is an issue that cannot be ignored in the process of building sustainable cities [17], which will cause serious damage to human health and ecosystems [18]. This article took Nanning City, Guangxi Province, as the research area. The Pearson correlation coefficient was used to analyze the relationship between regional PM_{2.5} pollution and local meteorology, and cluster analysis was

used to identify the main effects of these two factors on urban residential areas. The results showed that, according to the cluster analysis, the effects of regional PM_{2.5} pollution and local meteorology on urban residential areas were mainly divided into three categories: reduced visibility, reduced human health, and reduced living comfort. Among them, reduced visibility was the most significant, mentioned by 534 respondents, accounting for 79.11% of the total number. Although the conclusion is that local meteorology is the cause of reduced visibility in Nanning on April 1, 2023, it cannot be assumed that all reduced visibility is due to local meteorology. The scattering of light caused by haze cannot be ignored. Therefore, the following recommendations are proposed to reduce regional PM_{2.5} pollution.

- Nanning should optimize the industrial structure, vigorously develop the energy-saving and environmental protection industries, actively develop and utilize clean energy, and accelerate the development and utilization of clean energy and new energy [19], especially the full utilization of hydropower and nuclear energy resources.
- The government should encourage the public to travel in an environmentally friendly way and reduce automobile exhaust emissions [20]. Due to haze pollution, visibility is reduced, leading to traffic accidents that cause traffic jams or slow-moving traffic. At this time, vehicles will be in a state of frequent starting and will consume more fuel and produce more exhaust emissions compared to when traffic is flowing smoothly, thus exacerbating haze pollution and forming a closed cycle. Therefore, it is necessary to encourage the public to use public transportation facilities such as subways and buses or ride bicycles to reduce car exhaust emissions.

6 Conclusion

The main purpose of this article is to briefly describe the regional haze pollution, local meteorology, and their effects on urban residential areas. The study took Nanning, Guangxi Province as the research area, and analyzed the relationship between regional haze pollution and local meteorology using Pearson correlation coefficient. Then, through clustering analysis, it identified the main effects of these two factors on urban residential areas. The following results were obtained. (1) According to the calculation of Pearson correlation coefficient, the average maximum temperature, minimum temperature, and precipitation in local meteorology were negatively correlated with the frequency of haze pollution, while relative humidity and average air pressure were positively correlated with it. (2) According to the clustering analysis, the effects of regional haze pollution and local meteorology on urban residential areas were categorized into three types: reduced visibility, reduced physical health, and reduced living comfort. (3) Among the three types of clustering effects,

reduced visibility was the most common, with 534 respondents mentioning it, accounting for 79.11% of the total number of respondents.

Conflicts of interest

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Data availability

Data associated with this article cannot be disclosed due to legal/ethical/other reason.

Author contributions

Conceptualization, C. Kang and Y. Chen; Methodology, C. Kang; Software, C. Kang; Validation, C. Kang, and Y. Chen; Formal Analysis, C. Kang; Investigation, Y. Chen; Resources, Y. Chen; Data Curation, Y. Chen; Writing – Original Draft Preparation, C. Kang; Writing – Review & Editing, Y. Chen; Visualization, Y. Chen; Supervision, Y. Chen; Project Administration, Y. Chen.

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