The Impact of Urbanization Development on the Meteorological and Environmental Elements in the Central Cities of Liaoning Province

Yangfeng Wang¹, Zhongyan Lu²*, Hujia Zhao¹, Yanjun Ma¹

¹ Institute of Shenyang Atmospheric Environment CMA, Shenyang, 110166, China
² Liaoning Province Meteorological Observatory, Shenyang, 110166, China

*Corresponding author’s e-mail: luzhongyan1025@163.com

Abstract. Based on the meteorological and environmental data on Shenyang, Anshan, Fushun and Benxi and the data on urbanization indexes in central cities of Liaoning from 1992 to 2012, this paper analyzes the law of annual changes of urbanization indexes and meteorological and environmental factors in central cities of Liaoning, and studies the influence of urbanization development factors on meteorological environment factors through correlation analysis, grey correlation analysis and the GM (1, n) model. Then the important influence factors are selected. The results show that the main urbanization factors affecting the wind speed, temperature, humidity and other meteorological factors in the central cities of Liaoning Province are the completed area of houses, population density, smoke and exhaust emissions, road length and so on. The urbanization factors that affect PM10, SO2, NO2 and other environmental factors mainly include the emission of smoke and gas, the total amount of water supply in the city, the completed area of houses and population density. The main influence factors of urbanization are different among central cities of Liaoning. The fitting results of the GM (1, n) model show that there has a close relationship between urban development factors and meteorological and environmental factors. In addition, the GM (1, n) model has a high precision, which also shows the superiority of the GM (1, n) model in the application of urban multi factor correlation system.

1. Introduction

The influence of the layout of urban buildings and the surrounding mountains, water bodies or other large terrain on the dynamic diffusion of atmospheric environment is an important background for the formation of some urban climate characteristics [1]. With the development of urbanization, dense buildings, block roads, viaducts and so on have replaced the natural surface and changed the surface conditions of these places, which will change the power and thermal structure of the local atmosphere and the specific diffusion conditions of pollution power.

So far, there are some studies on the local meteorological and environmental changes caused by the change of land-use types, and in-depth exploration has been carried out from different perspectives in China[2-9]. However, there are few researches on the meteorological environment in central cities of Liaoning. In this paper, the central urban agglomeration of Liaoning Province is taken as the experimental area, and the influence of urbanization development factors on meteorological environment factors is studied by using grey correlation analysis, and the important influence factors
of meteorological and environmental changes are screened out. Then we hope that it can provide decision-making reference for the planning and layout of urban agglomeration.

2. Data and method

2.1 The data on meteorological and environmental
The meteorological data comes from Meteorological Information Center in Liaoning, which includes the temperature, humidity, wind speed and precipitation of Shenyang, Anshan, Fushun and Benxi from 1992 to 2012. The environmental data comes from the Environmental Monitoring Center of Liaoning Province, which is the mass concentration of PM10, SO2 and NO2 in Shenyang, Anshan, Fushun and Benxi from 2002 to 2012.

2.2 The data on urban development
According to the scientific and systematic principles, the urbanization evaluation system as shown in Table 1 is constructed, which is divided into four categories: land use, human heat, emission sources and economic construction. There are 23 specific Urbanization Factors. The data comes from the Statistical Yearbooks of Shenyang, Anshan, Fushun and Benxi in Liaoning Province from 1992 to 2012.

| Table 1 Index system of urbanization. |
|---------------------------------------|
| Urbanization factors                  |
| Land and use                          |
| Urban area                            |
| The per capita green area             |
| Green area                            |
| Anthropogenic heat                    |
| The number of public vehicles every 10000 persons |
| Total annual water supply in urban area |
| Total LPG supply                      |
| Permanent population                  |
| Population density                    |
| Non-agricultural population           |
| Length of road                        |
| Electricity consumption in one year   |
| Emissions sources                     |
| Total energy consumption              |
| Industrial sulfur dioxide emissions   |
| Exhaust emissions                     |
| Industrial smoke and dust emission    |
| Economic construction                 |
| Total output value                    |
| Total agricultural output value       |
| Total industrial output value         |
| The tertiary industry value           |
| Finished output value of heavy industry |
| Per Capita GDP                        |
| The total fixed assets investment     |
| The area of completed buildings       |

2.3 Research methods
Through correlation analysis, grey correlation analysis and the GM (1, n) model, this paper studies the impact of urbanization development factors on meteorological and environmental factors, and the important factors that affect the change of meteorology and environment are selected. We aim to clarify the main relationship among the factors in the system by using the grey relation analysis and
find out the important factors. The measurement of the size of relevance is called the degree of relevance. The ranking of the degree of relevance can reflect the relative influence of various factors on the research object.

The GM (1, n) grey system is used to predict and model. For the original data with n series and M series length, the data matrix can be used to model through the process of series modeling, parameter estimation, prediction model and model test. Because the requirement of the GM (1, n) prediction data quantity is not too large, generally no more than 10 input factors, it is necessary to filter the input factors according to the results of grey system correlation analysis.

3. Results and discussion

3.1 The evolution of meteorological and environmental factors

Figure 1 shows the annual mean change of urban wind speed in central cities in Liaoning Province from 1983 to 2012. It can be seen that the annual average ground wind speed of the four cities shows an obvious decreasing trend as a whole, with a decreasing rate of 0.24 m·s\(^{-1}\) (10a\(^{-1}\)). The decline rate of each decade is -0.15 m·s\(^{-1}\) (10a\(^{-1}\)), -0.15 m·s\(^{-1}\) (10a\(^{-1}\)), -0.18 m·s\(^{-1}\) (10a\(^{-1}\)).

\[
y = -0.0248x + 52.027
\]

\[R^2 = 0.8827\]

Figure 1 Annual mean change of urban wind speed in central cities of Liaoning from 1983 to 2012

Figure 2 shows the change of SO\(_2\) annual average concentration value in central cities of Liaoning from 2001 to 2012. It can be seen that the SO\(_2\) concentration in the four cities generally shows a decreasing trend year by year from 2001 to 2012. Anshan declined obviously.

Figure 2 The change of SO\(_2\) annual average concentration in central cities of Liaoning from 2001 to 2012
3.2 The key urbanization factors
Table 2 shows the grey correlation between meteorological elements and urban development indicators in central cities of Liaoning. Table 3 shows the grey correlation between environmental elements and urban development indicators in central Liaoning. For example, the order of correlation degree between urban factors and wind speed is given. In turn, it includes industrial smoke and dust emissions, population density, annual water supply, housing completed area, non-agricultural population and annual electricity consumption. Finally, the important urbanization factors are screened out that include the completed area of houses, population density, smoke and gas emissions, road length, etc.

Table 2 The grey correlation between meteorological elements and urban development indicators in central cities of Liaoning.

| Index system of urbanization                  | Wind speed | Temperature | Humidity | Precipitation | Frequency |
|----------------------------------------------|------------|-------------|----------|---------------|-----------|
| Urban area                                   | 0.512      | 0.601       | 0.696    | 0.416         | 1         |
| Urban area                                   | 0.514      | 0.613       | 0.699    | 0.42           | 1         |
| The per capita green area                    | 0.512      | 0.592       | 0.704    | 0.414         | 1         |
| Green area                                   | 0.554      | 0.638       | 0.730    | 0.454         | 4         |
| The number of public vehicles every 10000 persons | 0.511    | 0.598       | 0.662    | 0.373         | 0         |
| Total annual water supply in urban area      | 0.639      | 0.736       | 0.544    | 0.357         | 2         |
| Total LPG supply                            | 0.542      | 0.603       | 0.704    | 0.502         | 2         |
| Permanent population                         | 0.501      | 0.615       | 0.714    | 0.395         | 2         |
| Population density                           | 0.74       | 0.753       | 0.563    | 0.335         | 2         |
| Non-agricultural population                 | 0.522      | 0.612       | 0.713    | 0.391         | 1         |
| Length of road                               | 0.519      | 0.59        | 0.721    | 0.458         | 2         |
| Electricity consumption in one year          | 0.511      | 0.605       | 0.71     | 0.408         | 1         |
| Total energy consumption                     | 0.505      | 0.599       | 0.702    | 0.414         | 0         |
| Industrial sulfur dioxide emissions          | 0.538      | 0.657       | 0.764    | 0.347         | 3         |
| Exhaust emissions                            | 0.569      | 0.634       | 0.752    | 0.424         | 3         |
| Industrial smoke and dust emission           | 0.815      | 0.790       | 0.568    | 0.393         | 2         |
| Total output value                           | 0.509      | 0.596       | 0.695    | 0.428         | 1         |
| Total agricultural output value              | 0.515      | 0.600       | 0.693    | 0.437         | 1         |
| Total industrial output value                | 0.506      | 0.597       | 0.691    | 0.424         | 0         |
| The tertiary industry value                  | 0.508      | 0.598       | 0.697    | 0.427         | 0         |
| Finished output value of heavy industry      | 0.507      | 0.601       | 0.696    | 0.420         | 0         |
| Per Capita GDP                               | 0.507      | 0.589       | 0.704    | 0.429         | 1         |
| The total fixed assets investment            | 0.505      | 0.596       | 0.687    | 0.432         | 1         |

Table 3 The grey correlation between meteorological elements and urban development indicators in central cities of Liaoning.

| Index system of urbanization                  | PM10       | SO2        | NO2       | Frequency |
|----------------------------------------------|------------|------------|-----------|-----------|
| Urban area                                   | 0.569      | 0.646      | 0.36      | 1         |
| The per capita green area                    | 0.573      | 0.655      | 0.341     | 1         |
| Green area                                   | 0.564      | 0.633      | 0.365     | 1         |
| The number of public vehicles every 10000 persons | 0.614   | 0.65       | 0.358     | 2         |
3.3 The verification of the GM (1, n) model
The influencing factors were screened, and the GM (1, n) model was established by using the factors with high correlation degree as the significant influencing factors \([11]\). According to the partial order of grey correlation degree, 7 factors are selected. The order is industrial smoke and dust emissions (a), population density (b), total water supply in urban area (c), industrial sulfur dioxide emissions (d), completed area of housing (E), industrial exhaust emissions (f), permanent population (g). The GM (1,7) prediction model is used to fit the temperature and PM10 by using the above seven factors.

The temperature of Shenyang from 1992 to 2012 are used to fit the urban development data. Through fitting calculation, the temperature GM (1, n) fitting model is as follows:

\[
y = 0.00402x_1 + 0.00744x_2 + 3.68 \times 10^{-5}x_3 + 4.52 \times 10^{-7}x_4 - 7.32 \times 10^{-6}x_5 - 7.32 \times 10^{-6}x_6 - 3.66x_7 - 0.54x_8 + 0.05 \exp(-0.954t)\]

\[
(0.00383x_1 + 0.0071x_2 + 3.51 \times 10^{-5}x_3 + 4.31 \times 10^{-7}x_4 - 6.98 \times 10^{-6}x_5 - 3.49x_6 - 0.515x_7 - 8.05)
\]

The PM10 GM (1, n) fitting model is as follows:

\[
y = 4.87e^{-7}x_1 + 7.96e-6x_2 - 2.04e-6x_3 + 1.87e-5x_4 - 1.54e-9x_5 + 0.00104x_6 - 0.0216x_7 - 0.453\exp(-2.21t) \times (1.08e-6x_1 + 1.76e-5x_2 - 4.5e-6x_3 + 4.31e-5x_4 - 3.41e-9x_5 + 0.00229x_6 - 0.0478x_7 - 0.361)
\]

The comparison between the fitting value and the measured value is shown in Fig. 3. It can be seen that the trend of the fitting result and the measured result is relatively close, and the mean value of the relative error of wind speed is 4.98\%, and the mean value of the relative error of temperature is 3.83\%, and the mean value of the relative error of PM10 is 5.54\%, and the mean value of the relative error of SO2 is 3.91\%. The fitting model not only comprehensively considers the influence of various urban factors, but also eliminates the relatively small factors through the correlation degree, so the fitting effect is good. It is feasible to use the grey system to analyze the relationship between urban meteorological environment factors and urban factors.
4. Conclusions and discussions.

(1) The urbanization factors that affect the wind speed, temperature, humidity and other meteorological factors in the central cities of Liaoning Province mainly include the completed area of houses, population density, smoke and exhaust emissions, road length and so on. The urbanization factors that affect PM$_{10}$, SO$_2$, NO$_2$ and other environmental factors mainly include the emission of smoke and gas, the total amount of water supply in the city, the completed area of houses and population density. The main influencing factors of urbanization are different among cities.

(2) The fitting results of the GM (1, n) model show that there is a close relationship between urban development factors and meteorological environment factors. In addition, the GM (1, n) model has a high precision, which also reflects the superiority of the GM (1, n) model in the application of urban multi factor correlation system.

(3) Through the grey correlation analysis method, we can only qualitatively explain the impact degree of Urbanization Factors on environmental factors. In the future, we need to use the numerical model to further analyze the quantitative impact of urbanization factors such as land use, pollution source emissions on meteorological environmental factors.

Acknowledgements

The project was financially supported by the National Natural Science Foundation of China(41730647), the National Key Project of MOST(2017YFC0212301), and the Key Technology Integration Project of China Meteorological Administration(CMAHX20160306). *Zhongyan Lu is the corresponding author(e-mail: luzhongyan1025@163.com)
References
[1] Xu.X.D, Tang.X, Xu.D.H et al. (2002) Introduction to environmental meteorology of urbanization. Beijing: China Meteorological Press: 2-3.
[2] Lutfi S.O, Wang.Y.Q, Wang.B. (2004) Impact of Indochina Deforestation on the East Asian Summer Monsoon. Journal of Climate, 17:1366-1380.
[3] Narisma G.T, Pitman.A.J. (2003) The Impact of 200 Years of Land Cover Change on the Australian Near-Surface Climate. Journal of Hydro meteorology, 4: 424-436.
[4] Zhang.J.Y, Dong.W.J, Ye.D.Z et al. (2003) New evidence for effects of land cover in China on summer climate. Chinese Science Bulletin, 48: 91-95.
[5] Cheng.S.L. (2005) Urbanization Effect on Air Temperature Change in Lanzhou City for Recent 60 Years. Meteorology, 31: 29-34.
[6] Chen.Y, Jiang.W.M, Guo.W.L et al. (2005) Study on the effect of the city group development in Pearl River Delta on local air pollutant dispersion by numerical modeling. Acta Scientiae Circumstantiae, 25: 700-710.
[7] Liu.N.W, Zhou.X.S. (2004) Numerical Experiment on Influence of Vegetation Change on Summer Climate in Western Liaoning. Journal of Nanjing Institute of Meteorolog, 27: 632-640.
[8] Guo.J.L, Wang.Y.B. (2005) Temperature Change and Urbanization in Harbin in Recent 40 years. Meteorology, 31: 74-76.
[9] Guo.J.X, Ding.Y.H, Du.J.W et al. (2004) A Numerical Simulation of the Impact of Afforestation and Desertification on Summer Rainfain in Northern Shanxi. Climate and Environmental Research, 9: 527-538.
[10] Tang.Q.Y, Feng.M.G. (2006) DPS Data Processing System-Experimental Design, Statistical Analysis and Model Optimization. Beijing: Science Press.
[11] Robaa S M. (2006) A study of solar radiation climate at Cairo urban area, Egypt and its environs. International Journal of Climatology, 26: 1913-1928.