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Impact of Air Pollution on Residents' Health in China: Moderating Effect Analysis Based on a Hierarchical Linear Model

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Abstract: *Background*: Air pollution is an important factor affecting residents' health. *Methods*: Based on the health data of 9959 residents from 28 provinces in China in the 2017 Chinese General Social Survey (CGSS), this paper uses a hierarchical linear model (HLM) to scientifically analyze the impact of air pollution on residents' health and to explore the moderating role of air pollution in various factors influencing residents' health. *Results*: Air pollution has significant negative effects on residents' health (coef. −0.103, $p < 0.01$), while frequency of exercise (coef. 0.070, $p < 0.01$), education level (coef. 0.012, $p < 0.1$) and income level (coef. 0.383, $p < 0.01$) have positive effects on residents' health. Air pollution has a negative moderating effect on the positive impact of exercise frequency on residents' health (coef. −0.015, $p = 0.004$). *Conclusions*: Air pollution causes serious damage to residents' health and it is necessary to control air pollution. Increasing residents' income, education level and exercise frequency can help improve residents' health level. Air pollution significantly reduce the positive impact of exercise frequency on residents' health. In order to effectively improve their own health, it is a better choice for residents to exercise when the air quality is good.

Keywords: air pollution; resident health; HLM; moderating effect

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1. Introduction

In the past 10 years, China's economy has maintained rapid development, but air pollution problems are still severe [1]. According to the evaluation of SO_2, NO_2, PM_{10}, $PM_{2.5}$ and other indicators listed in the 2021 China Ecological Environment Status Bulletin, only 218 of the 339 cities at prefecture level and above in China have air quality within the limits of standard, and 35.7% of them still exceed the standard (Date source: 2021 China Ecological Environment Status Bulletin issued by the Ministry of Ecological Environment of the People's Republic of China. https://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/202205/P020220608338202870777.pdf. Accessed on 28 October 2022). The previous literature demonstrated that air pollution had a negative impact on residents' happiness [2–4]. It is indicated that health is a vital factor that affects residents' happiness and plays an important mediating role in the relationship between air pollution and happiness [5]. Accordingly, this study aims to discuss the relationship between air pollution and residents' health on the basis of the previous literature.

Health is an important indicator affecting the quality of residents' life and a basic guarantee for national development [6]. Speaking at the National Congress on Health and Wellness in August 2016, President Xi indicated that only when people were healthy could they realize a well-off society. If air pollutants enter the atmosphere with enough concentration and over enough time, they will have a serious effect on the physical and mental health of residents. The impact of air pollution on residents' health is both physical and psychological. Air pollution causes serious damage to human health by inducing various respiratory diseases [7]. Scholars have demonstrated that air pollution will increase the rate of disease and mortality, reducing the life expectancy of residents [8–10]. The impact of air pollution on residents' health is not only reflected at the physiological level, but also causes mental health problems. Air pollution influences residents' health by affecting their mood [11]. Poor air quality will cause the subjective pollution of residents to deteriorate, and damage the well-being of residents [12,13]. The previous literature has shown that air pollution increases the probability that residents will suffer from depression, anxiety and other mental diseases [14]. Severe air pollution can even affect residents' mood, sleep quality and social evaluation, thus inducing potential criminal behaviors and increasing crime rates [15].

There is a significant amount of literature focusing on the relationship between air pollution and residents' health. Previous studies used traditional regression models, such as the panel threshold effect, generalized additive model and least square method, to directly study the impact of air pollution on residents' physical and mental health. Yuan Zhang (2022) [1] applied the panel threshold effect to analyze the impact of air pollution on healthy capital at different stages of economic development. Ying Zhang et al. (2022) [16] estimated the exposure–response relationship coefficient of the impact of changes in air pollution concentration on residents' deaths from disease in Chengdu from 2014 to 2016 using the generalized additive model and the distribution lag nonlinear model (DLNM) in epidemiology. Rong-rong Qu et al. (2022) [17] adopted the generalized estimation equation to analyze the effect of air pollutant concentration on biomarkers of nerve injury in healthy elderly people. Shu-chang Chen et al. (2021) [18] utilized the generalized additive model (GAM) of the Pearson regression to analyze the effect of increased single pollutant concentration on the health of primary school students. Dan Fan et al. (2022) [19] used the least squares method to evaluate the impact of air pollution on the cognitive ability of middle-aged and elderly people in China, and its transmission path. However, considering that air pollution variables and residents' health variables belong to provincial variables and individual variables respectively, it is difficult to separate group effects using traditional regression models.

In this paper, a hierarchical linear model (HLM) is used to conduct empirical analysis. Accordingly, this study aims to: (1) analyze the impact of air pollution on residents' health; and (2) explore the moderating role of air pollution in various influencing factors of residents' health. Unlike the prior studies that explored the relationship between air pollution and residents' health, this paper uses HLM to better analyze the relationship between variables at different levels and to reduce the error value of the model. The results of this study verified the negative effect of air pollution on residents' health, and proved the moderating role of air pollution on the relationship between exercise frequency and residents' health. The conclusions of this paper provide evidence for public participation in air pollution control to improve residents' health.

2. Research Methods

2.1. Variable Selection and Data Sources

The dependent variable is the health level of residents, and the data for the dependent variable are drawn from the 2017 Chinese General Social Survey (CGSS). The CGSS is the earliest national, comprehensive and continuous academic survey project in China, which investigates individuals in more than 10,000 families across China every two years. We selected the 16th question from the 2017 CGSS: "How often have your work or other daily activities been affected by health problems in the past week?" The data from this question are taken as the data for residents' health level.

The provincial-level variable is air pollution, which is the main independent variable of this study. SO_2 is one of the major air pollutants and has a direct negative impact on human health [20]. Nowadays, China's air pollution mainly comes from the production activities of industrial enterprises, since China's current energy structure is still dominated by fossil energy, and fossil fuel combustion will produce a large amount of SO_2 [21]. Compared with $PM_{2.5}$, PM_{10} and NO_2, the increase of SO_2 concentration will lead to higher death rates and years of life lost [22]. The previous literature indicates that SO_2 will cause greater damage to residents' health. Therefore, when exploring the relationship between air pollution and residents' health, this study intends to use SO_2 emissions in 2017 to represent air pollution in that year, and the data are from the 2018 China Statistical Yearbook in the National Bureau of Statistics (http://www.stats.gov.cn/tjsj/ndsj/2018/indexch.htm. Accessed on 28 October 2022).

Among individual-level variables, people with lower income levels and educational background are more likely to have poor health [23], and physical exercise can improve people's physical and mental health [24]. Therefore, education level, income and exercise status are considered as important variables to explain health differences. Age and gender are used as control variables. Relevant data are from the 2017 Chinese General Social Survey (CGSS).

2.2. Model Specification

A hierarchical linear model is used in this study. The traditional linear regression model generally assumes that random errors among individuals are independent of each other [25]. However, the health of residents in the same province is affected by the provincial variables. Therefore, it is difficult to guarantee the independence of individual health. It is hard for the traditional linear regression model to separate the group effect in the individual level variables and provincial level variables. This leads to an increase in the error item value in the traditional linear regression model. Therefore, the traditional model is not applicable in this study. We use an HLM to incorporate provincial-level air pollution variables and analyze the mechanism of the impact on residents' health. Its decomposition of regression error includes two parts: individual differences and provincial differences. Compared with the traditional linear model, the error value of HLM is smaller.

The basic equations of the HLM are as follows, where j represents the *j*th organization and i represents the *i*th individual, β_{0j} is the intercept of Equation (1), β_{pj} ($p \neq 0$) is the regression coefficient related to the first level prediction variable, X_p. γ_{p0} means average value of β_{pj}, γ_{pq} ($q \neq 0$) represents the regression coefficient related to the second level predictive variable Wqj, and μ_{pj} represents the random component of β_{pj}. The model in Level 1 describes the development trend of an individual feature over time. Unlike the traditional linear model, the intercept parameter β_{0j} and slope parameters β_p ($p \neq 0$) are no longer constants, but random variables that change with the second-level variable. In Level 2, we take the intercept and slope in Level 1 as dependent variables and the second-level variable as independent variables to analyze the differences between individuals of these random variables [26]. According to the different variable additions in Level 1 and Level 2, different random components and fixed components can be set to build various analysis models. The HLM in this paper includes a zero model, random coefficient regression model, intercept model and complete model.

$$\text{Level 1}: \; Y_{ij} = \beta_{0j} + \beta_{1j}X_{1ij} + \beta_{2j}X_{2ij} + \cdots + \beta_{pj}X_{pij} + r_{ij} \tag{1}$$

$$\text{Level 2}: \; \beta_{pj} = \gamma_{p0} + \gamma_{p1}W_{1j} + \gamma_{p2}W_{2j} + \cdots + \gamma_{pq}W_{qj} + \mu_{pj} \tag{2}$$

2.3. Descriptive Analysis

The data from 2017 Chinese General Social Survey (CGSS) were screened according to the respondents' answers, and the samples with incomplete and illogical answers were eliminated. Finally, 9959 valid samples were obtained. The respondents cover the residents of 28 provinces across the country, of whom 48% are men. The age range is from 18 to 103 years old. The average annual income of the residents is 4259 thousand yuan and the income level is a maximum of 9.9936 million yuan every year. The respondents' self-reported health levels are divided into five levels, with an average of 3.88, and self-reported exercise frequency is divided into five levels: every day, every week, every month, every year and never. The coefficient of average exercise level is 2.502. It is concluded that the average frequency of residents participating in physical exercise is low. The average emissions of SO_2 in the 28 provinces covered by the survey are 265.39 million tons, with the highest emissions up to 739.1 million tons (Table 1).

Table 1. Descriptive statistics.

Variables	Measures	Mean	S.D.	Min	Max
HEALTH	The levels of respondents' self-reported health (1–5)	3.880	1.151	1	5
AGE	The age of respondents	51.290	16.770	18	103
GENDER	Male = 1, Female = 0	0.480	0.499	0	1
SPORT	Five levels of exercise frequency reported by respondents (1–5)	2.502	1.597	1	5
EDU	Self reported educational level of respondents (1–13)	5.161	3.269	1	13
INCO	Income of respondents (Ten thousand yuan)	4.259	25.392	0	999.360
SO_2	SO_2 emissions (Ten thousand tons)	26.539	19.191	1.850	73.910

3. Empirical Results

In this study, HLM is used to explore the impact of air pollution and individual-level variables on the health of residents in each province. The detailed empirical results are shown in Table 2.

Table 2. Results of multilevel analysis of the health effects of air pollution on residents.

Variable	Model 1 Coefficient (Standard Error)	Model 2 Coefficient (Standard Error)	Model 3 Coefficient (Standard Error)	Model 4 Coefficient (Standard Error)
AGE (γ_{10})		−0.017 *** (0.001)	−0.023 *** (0.001)	−0.017 *** 0.001)
GENDER (γ_{20})		0.072 *** (0.017)	0.146 *** (0.017)	0.072 *** (0.017)
SPORT (γ_{30})		0.070 ** (0.009)		0.063 *** (0.008)
EDU (γ_{40})		0.012 * (0.006)		0.015 ** (0.005)
INCO (γ_{50})		0.383 ** (0.033)		0.374 ** (0.030)
SO_2 (γ_{01})			−0.103 *** (0.036)	−0.150 *** (0.038)
SO_2 * SPORT (γ_{31})				−0.015 *** (0.005)
SO_2 * EDU (γ_{41})				0.008 (0.006)
SO_2 * INCO (γ_{51})				0.030 (0.039)
Random effects	Variance	Variance	Variance	Variance
Second Floor (τ_{00})	0.081 ***	0.298 ***	0.045 ***	0.028 **
First Floor (σ^2)	1.174	0.978	1.036	0.977
Deviance	29,945.679	28,187.722	28,740.475	28,214.191

Note: The asterisk represents the significance of p value, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

3.1. Zero Model (Model 1)

The zero model is the basis of the HLM analysis, which includes only the explained variables and the group variables. It is used to test whether the health of residents will be different in the different provinces. If the difference is significant between the provinces, it indicates that the provincial variables have a significant impact on residents' health. Therefore, it is necessary to use the HLM to analyze the variables at different levels. The specific models are as follows:

$$\text{Level 1}: \ \text{HEALTH}_{ij} = \beta_{0j} + r_{0j} \tag{3}$$

$$\text{Level 2}: \ \beta_{0j} = \gamma_{00} + \mu_{0j} \tag{4}$$

In the zero model, HEALTH_{ij} represents the health level of residents with the number i in the j province. r_{ij} is the error item of the individual level, μ_{0j} is the error item of the provincial level and γ_{00} is the average value of the health level of residents in the provinces. The intra-group correlation coefficient (ICC) can be calculated using the zero model. ICC = inter-group variance/(intra-group variance + inter-group variance), which represents the proportion of the differences between the units in the second layer in total variance of the first-layer dependent variable. In general, if the ICC is too small, it indicates that the relative difference in the dependent variable between units in the second layer is not large, and the HLM is not required. The HLM is recommended only when ICC > 0.059.

According to the results of the zero model in Table 2, the inter-group variance is 0.081 and the intra-group variance is 1.174 (Table 2). It is also necessary to explain the variance within and between groups by adding the variables of Level 1 and Level 2 respectively. According to the inter-group variance and intra-group variance of the zero model, ICC = 0.065, greater than 0.059, and its reliability is 0.945. This indicates that there is a significant difference in health between the provinces, and it is necessary to use the HLM for analysis.

3.2. Random Coefficient Regression Model (Model 2)

In the random coefficient regression model, only the individual-level variables are introduced into Level 1, and no variables are introduced into Level 2. This model reflects the impact of individual-level differences on the health of residents, and is set as follows:

$$\begin{aligned} \text{Level 1}: \ \text{HEALTH}_{ij} = \beta_{0j} + \beta_{1j}(\text{AGE}_{ij}) + \beta_{2j}(\text{GENDER}_{ij}) + \\ \beta_{3j}(\text{SPORT}_{ij}) + \beta_{4j}(\text{EDU}_{ij}) + \beta_{5j}(\text{INCO}_{ij}) + r_{ij} \end{aligned} \tag{5}$$

$$\text{Level 2}: \ \beta_{mj} = \gamma_{m0} + \mu_{mj}(m = 0, 1, 5) \tag{6}$$

$$\beta_{nj} = \gamma_{n0}(n = 2, 3, 4) \tag{7}$$

As can be seen from Table 2 (Model 2), in the random-coefficient model, the within-group variance decreases from 1.174 of the zero model to 0.978, and the variance improved by 16.695% after increasing the independent variables at the individual level. This shows that the first-level variables can effectively explain the intra-group differences in the health of the residents.

As for the results of the control variables, the age coefficient γ_{10} is -0.017 ($p < 0.001$), indicating that the health level of the older residents is low, and the gender coefficient γ_{20} is 0.072 ($p < 0.001$), which is significant at the 1% level, indicating that the overall health level of women is lower than that of men.

As for the results of individual-level variables, the coefficient of exercise frequency γ_{30} is 0.070 ($p < 0.001$), since obviously regular physical exercise will improve the health level of residents. The coefficient of education level γ_{40} is 0.012 ($p = 0.07$), which is significant at the 10% level, suggesting that the health level of residents is affected by their educational level to some extent, i.e. residents with more education might be more healthier. The income level coefficient γ_{50} is 0.383 ($p < 0.001$), indicating that income significantly affects the health level of residents, i.e. high-income people tend to be healthier than low-income people.

3.3. Intercept Model (Model 3)

In the intercept model, only the control variable is added to Level 1, and in Level 2, the intercept term of Level 1 is taken as the dependent variable, and the explanatory variable of the second level is added to test the effect of the second-level variable on residents' health. The model is set as follows:

$$\text{Level 1}: \ \text{HEALTH} = \beta_{0j} + \beta_{1j}(\text{AGE}_{ij}) + \beta_{2j}(\text{GENDER}_{ij}) + r_{ij} \tag{8}$$

$$\text{Level 2}: \ \beta_{0j} = \gamma_{00} + \gamma_{01}(\text{SO}_2 - \text{ME}_j) + \mu_{mj} \tag{9}$$

$$\beta_{1j} = \gamma_{10} + \mu_{1j} \tag{10}$$

$$\beta_{2j} = \gamma_{20} \tag{11}$$

According to Table 1 (Model 3), in the model without intercept, the between-group variance is 0.045, which decreases by 0.036 compared with the zero model, and the variance improved by 44.444%, indicating that provincial variables can effectively explain the between-group differences in residents' health. The difference in the health level of residents is affected by the level of air pollution in their provinces. The air pollution coefficient γ_{01} is -0.103 ($p = 0.009$), meaning that the result of the study is the same as the conclusion of previous literature [7,9,14], that is, air pollution will significantly reduce the health level of residents. The higher the degree of air pollution, the lower the health level of residents.

3.4. Complete Model (Model 4)

In the complete model, the intercept and slope terms of the first-layer equation are used as dependent variables, and the second-layer explanatory variables are added to analyze the moderating effect of air pollution in each province on the effect of individual variables on residents' health. In Level 2, γ_{31}, γ_{41} and γ_{51} are regression coefficients of the moderating effect of air pollution on the positive impact of exercise frequency, education level and income on residents' health. The model is set as follows:

$$\text{Level 1}: \ \text{HEALTH}_{ij} = \beta_{0j} + \beta_{1j}(\text{AGE}_{ij}) + \beta_{2j}(\text{GENDER}_{ij}) + \beta_{3j}(\text{SPORT}_{ij} - \overline{\text{SPORT}}_{.j}) + \beta_{4j}\left(\text{EDU}_{ij} - \overline{\text{EDU}}_{.j}\right) + \beta_{5j}(\text{INCO}_{ij} - \overline{\text{INCO}}_{.j}) + r_{ij} \tag{12}$$

$$\text{Level 2}: \ \beta_{0j} = \gamma_{00} + \gamma_{01}(\text{SO}_2 - \text{ME}_{.j}) + \mu_{mj} \tag{13}$$

$$\beta_{1j} = \gamma_{10} + \mu_{1j} \tag{14}$$

$$\beta_{2j} = \gamma_{20} \tag{15}$$

$$\beta_{3j} = \gamma_{30} + \gamma_{31}(\text{SO}_2 - \text{ME}_{.j} - \overline{\text{SO}_2 - \text{ME}_{.j}}) \tag{16}$$

$$\beta_{4j} = \gamma_{40} + \gamma_{41}(\text{SO}_2 - \text{ME}_{.j} - \overline{\text{SO}_2 - \text{ME}_{.j}}) \tag{17}$$

$$\beta_{5j} = \gamma_{50} + \gamma_{51}(\text{SO}_2 - \text{ME}_{.j} - \overline{\text{SO}_2 - \text{ME}_{.j}}) + \mu_{5j} \tag{18}$$

According to the results in Table 2 (Model 4), the between-group variance of the complete model decreases to 0.028 and the within-group variance decreases to 0.977. Compared with the zero model, the variance improvement rates are 65.432% and 16.780%, respectively. This shows that the complete model can effectively explain the differences in residents' health. The statistical adaptability of the complete model is good.

The coefficient γ_{31} is -0.015 ($p = 0.004$) for the moderating effect of air pollution on exercise frequency, which is significant at the 1% level, indicating that air pollution has a negative moderating effect on the relationship between exercise frequency and residents' health. With the increase of air pollution, the positive effect of exercise frequency on residents' health would be weakened. When air pollution is serious, reducing outdoor exercise will be good for residents' health. Regarding the moderating effect of air pollution on education level and income level, the coefficient for γ_{41} is 0.008 ($p = 0.162$) and for γ_{51} is 0.030 ($p = 0.450$). This shows that a change in air pollution does not significantly affect the impact of education level and income level on residents' health: neither of these two moderating effects is significant.

4. Discussion

Based on data from the 2017 Chinese General Social Survey (CGSS) and 2018 China Environmental Statistics Yearbook, combined with a HLM, this paper analyzes the influencing factors of the health of 9959 residents in 28 provinces of China. We make several findings.

Air pollution has a significant negative impact on residents' health. In this paper, a HLM is used to avoid the problem that it is difficult to separate the group effect in the analysis of variables at different levels when using traditional linear regression models. A more scientific method is used to verify the negative impact of air pollution on residents' health. The conclusion is consistent with the previous literature [7,9,14]. Air pollution affects residents' health in both physiological and psychological aspects. Long-term exposure to poor air quality increases the risk of air pollution-related diseases [9]. Serious air pollution not only directly affects residents' emotions [27], but also indirectly enhances residents' negative emotions by harming residents' physical health and creates inconvenience to their daily life [28,29]. As people pay more and more attention to air quality, air pollution abatement is extremely urgent. Although government measures on air pollution are effective [30], but we still need to continue spending time and energy on air pollution control [31]. Against the current background of advocating for the whole of society to participate in air pollution control [32], residents should actively participate in air pollution control in order to improve their health.

The education level, exercise frequency and income level of residents will have a positive impact on the health level of residents. Education has a positive effect on mental health and daily life self-care ability [33]. Residents with high education levels tend to have higher health literacy [34]. Therefore, they will pay more attention to personal health and are more likely to choose a healthy lifestyle in daily life. When the income level of residents is higher, their ability to invest in maintaining their health economically is also higher [35]. It appears that high-income residents have the ability to choose healthier and more expensive products in their daily life, such as green food, environment-friendly furniture, etc. When they have problems with their health, they also have better economic resources to invest in medical treatment to minimize the damage to their physical health [36]. When it comes to physical exercise, it is the consensus and common sense that the whole of society should improve physical health level through physical exercise. Physical exercise has a significant positive impact on the physical and mental health of residents [24]. Among residents who exercise frequently, the level of health is higher.

Air pollution has negative moderating effect on the positive impact of exercise frequency on residents' health. When air pollution is serious, the positive effect of exercise frequency on the health level of residents will be weakened. The reason is that residents breathe more frequently during exercise and inhale more air [37]. When the air quality in the space is poor during exercise, they inhale more harmful gases, which undermines the positive impact of exercise on health. The previous literature has also confirmed that air pollution increases the risk of outdoor physical exercise [38]. In order to ensure positive effects from exercise, we conclude that exercising at a time or place with good air quality is a better choice for residents' health.

5. Conclusions

This study uses a HLM to demonstrate the negative impact of air pollution on the health of residents. The education level, exercise frequency and income level of residents will have a positive impact on their health. Significantly, we show that air pollution will have a negative adjustment effect on the positive impact of residents' exercise frequency. The results of this study have important policy implications. First of all, in order to improve the level of residents' health, the government should increase the health awareness of residents with a low education level, and provide more medical benefits for low-income people. With the support of the government, more residents will have health awareness and economic ability to maintain their health level. In addition, the government should do a good job in information transmission and pay attention to current air quality. In order to avoid the reduction of exercise effect caused by air pollution, the government also should encourage residents to exercise in high air quality or choose indoor exercise. Finally, to completely solve the problem of air pollution and increase the level of residents' health, the government should widely publicize the harm of air pollution to residents' health and make residents fully aware of the urgency of air pollution control. In the meantime, the government should put forward reasonable suggestions on the behavior of residents, so that the public can participate in the process of air pollution control and play an important role.

In general, in the HLM model, the ICC is 0.065. This shows that residents' health is affected more by individual factors than by provincial factors. However, after adding individual-level variables, the improvement of intraclass variance can be further improved. It is indicated that there are other variables at the individual level that affect residents' health. In the future, it is necessary to explore other influencing factors of residents' health at the individual level.

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