African Educational Research Journal
Vol. 10(1), pp. 72-83, March 2022
DOI: 10.30918/AERJ.101.22.013
ISSN: 2354-2160
Full Length Research Paper

Urban air pollution characteristics and associations with pre-school children respiratory health in four cities of Central China

Yinghong Cao* and Yue Cai

Hubei Preschool Teachers College, Gaoxin East Road No. 1, Gedian Economic and Technological Development Zone, Hubei Province, Hubei Province, 436032, China.

Accepted 4 March, 2022

ABSTRACT

The focus of this study was on the associations between air pollution, outdoor activities and symptoms of wheeze and rhinitis for pre-school children over Wuhan and surrounding cities. Air pollutants had downward trends over the study region from 2015 to 2020. Sulfur dioxide (SO_2) content decreased significantly. Particulate matter was concentrated on the north side of the study area and nitrogen dioxide (NO_2) was concentrated near Wuhan urban, while the distribution of ozone (O_3) was relatively uniform. Odds Ratio (OR) showed that an increase in NO_2 was associated with a high incidence of rhinitis, with an OR of 1.043 (1.025, 1.062 95% confidence interval). Reduction of O_3 was associated with remissions of rhinitis symptoms in spring and autumn. The living environment is an important factor. Living near lakes was associated with the incidence of wheeze and living near roads was associated with the incidence of wheeze rhinitis, respectively. Additionally, appropriate outdoor activities showed association with a low incidence of wheeze and rhinitis symptoms in this region. This research improved our understanding of air pollution, outdoor activities and pre-school children's respiratory health. It was also a guide on the design of outdoor activities and outdoor courses for pre-school children during the process of urban construction.

Keywords: Air pollution, pre-school children, wheeze, rhinitis, outdoor activities.

*Corresponding author. E-mail: 494716637@qq.com.

INTRODUCTION

In recent decades, due to the rapid developments of the economy and industry, air pollution events have occurred frequently and have been received increasing attention (Huang et al., 2014). Air pollutants can generally be divided into particulate pollutants and gaseous pollutants. The particulate pollutant usually refers to an aerosol particle with an aerodynamic diameter of less than 10, 2.5, and 1 micron (PM_{10}, $PM_{2.5}$, and PM_1 respectively). The gaseous pollutant includes sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3), etc. Under some specific conditions, such as high temperature and high humidity, they can transform each other to produce secondary pollutants and induce more serious air pollution events (Schichtel et al., 2001; Hennigan et al., 2008). In addition to the impact on nature, such as the greenhouse effect and extreme precipitation (Rosenfeld et al., 2008), the rapidly increasing air pollutants can also cause harm to human health (Tie et al., 2009). Therefore, the study of the characteristics of air pollution and related outdoor air exposure is a meaningful topic in process of urban construction (Ulutaş et al., 2021a).

The World Health Organization (WHO) found that about 92% of people in the world live in an environment where air pollution exceeds the recommended standards (Lelieveld et al. 2015). Subsequently, one-ninth of the total global mortality caused by exposure to air pollution was reported (Lelieveld et al. 2015). In China, due to the acceleration of urbanization and economic growth, the anthropogenic emission of air pollutants has greatly increased in the last decades. Exposure to air pollution has become one of the major concerns for the government and people (Zou et al., 2020). At present, through a series of effective measures by the government, such as pollution-related industry closures, traffic reductions and clean air actions, air quality has been continuously improved (Gao et al., 2017). In the meantime, a large number of studies using measurements from satellite and ground-based stations have verified the fact that air pollution events have been alleviated in recent years (Zheng et al., 2018; Li et al., 2019; Tao et al., 2020; Ulutaş et al., 2021b).

The respiratory system is the primary target of air pollution, including nasal passages, respiratory tract and lungs. Due to the interaction of the air pollutants with epithelial cells and professional immune cells in the system, perturbation of these stimulated cells can cause disease (Glencross et al. 2020). For instance, birth cohort studies have pointed out relationships between $PM_{2.5}$, NO_2 and carbonaceous particles and the incidence of asthma (Clark et al., 2010; Hsu et al., 2015). Panel studies have found associations between outdoor air pollutants and airway inflammation (Lin et al., 2011). Additionally, other longitudinal studies have demonstrated that indoor air pollutants, such as tobacco smoke and cooking gas, are also related to childhood asthma or wheezing at home (Mendell 2007; Burke et al. 2012). A cross-sectional questionnaire survey, the Chinese Children Health Home study, has been launched in recent years (Zhang et al., 2013). It focused on air exposure risk for respiratory health among pre-school children in China and aroused wide concerns.

MATERIALS AND METHODS

Study area

Wuhan is a megacity located in the eastern part of the Jianghan Plain and the middle reaches of the Yangtze River (Figure 1). As the economic and cultural center of Central China, this area has also been facing severe air pollution and frequent haze incidents in recent years (Zhang et al., 2021). This study was dedicated to investigating regional variations of air pollutants and their impacts on respiratory health for pro-school children during the period from 2015 to 2020. The purpose is to enhance the understanding of the regional air pollution characteristics and to provide guidance for pre-school children in the design of outdoor activities and outdoor courses when they have to face the existing air pollution problem.

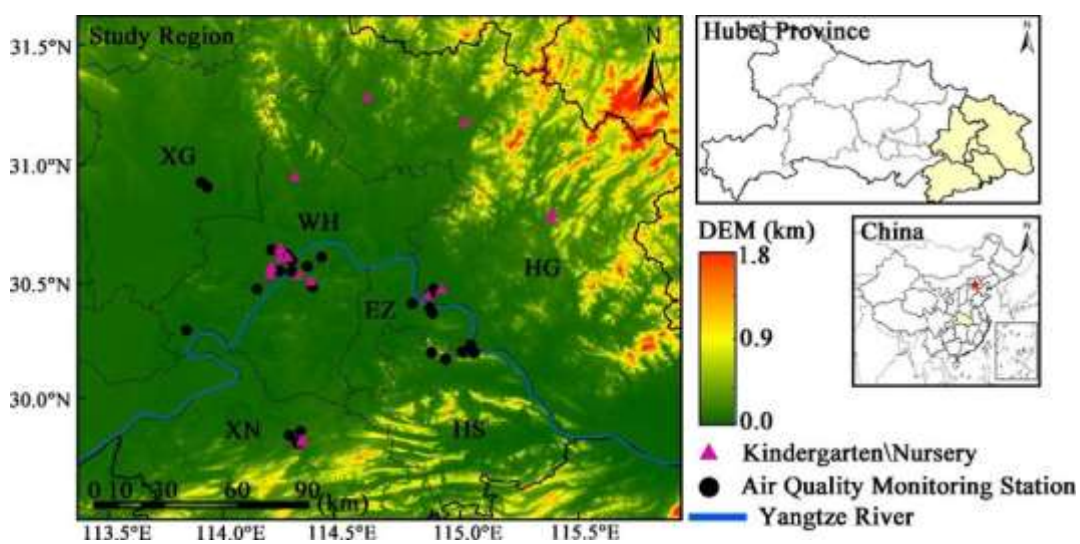

Figure 1. Topographic map and the distribution of experimental sites in the study area.

The study area selected the urban agglomeration centered on Wuhan in the eastern part of Hubei Province, including Wuhan (WH), Ezhou (EZ), Huanggang (HG), and Xianning (XN). These regions have cold winters (~0°C) and hot summers (~30°C), with relatively high humidity (>50%) throughout the year (Jin et al., 2019). Southwesterly winds prevail in summer and northerly winds prevail in winter. The topography of the north-south mountains makes it difficult for air pollutants to be discharged and thus also contributes to forming large-region and long-term air pollution events, especially in winter. Benefiting from the plain terrain and developed transportation and construction, the eastern cities are the economic and population centers of the province.

Air quality monitoring station

The air pollution data were acquired from air quality monitoring stations constructed by the China National Environmental Monitoring Center. In the study area, over 26 monitoring stations were selected. These monitoring stations released hourly and daily air pollution data, including $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and carbon monoxide (CO). $PM_{2.5}$ and PM_{10} data are measured by the gravimetric method, whereas the gaseous air pollutants are estimated by spectrophotometry (GB3095-2012). The accuracy and validity of the data can refer to HJ630-2011.

Study design

A retrospective survey was applied in this study to collect the occurrence of wheeze and rhinitis symptoms for pre-school children (3-6) in the past year (2020) and since birth. As shown in Table S1, the design of the questionnaire was based on Phase One of the ISAAC (International Study of Asthma and Allergies in Childhood) study (Asher et al., 1995). For more details about the ISAAC can refer to the official website (http://isaac.auckland.ac.nz/). The survey is distributed by kindergarten teachers to the open online platform and filled out by guardians voluntarily. Finally, 3223 valid reports were obtained from 16 kindergartens (or nurseries) in Wuhan and surrounding cities.

Table S1. Demographic information among pre-school children in the study.

	Num	Percent
Total	3223	100
Sex		
Boys	1765	54.76
Girls	1458	45.24
Age		
3	883	27.40
4	1286	39.90
5	736	22.84
6	318	9.87
Birth season		
Spring	792	24.57
Summer	933	28.95
Autumn	775	24.04
Winter	723	22.43
Birth weight (kg)		
< 2.5	97	3.01
≥ 2.5	3126	96.99
Outdoor activities time (h)		
< 0.5	806	25.01
≥ 0.5, < 1.0	1648	51.13
≥ 1.0, < 2.0	669	20.76
≥ 2.0	99	3.07
Traffic time (min)		
< 10	1794	55.66
≥ 10, < 30	1222	37.92
≥ 30, < 60	195	6.05
≥ 60	12	0.37
Living environment		
Near Roads	56	1.74
Near Lakes	286	8.87
Commercial District	1184	36.74
Industrial District	15	0.47
Other	1681	52.16

Statistical and analytical methods

In order to estimate personal exposure to outdoor air pollution for the pre-school children, an Ordinary Kriging interpolation was used, based on temporal and spatial attributes of kindergarten. In addition to the study area, the air quality monitoring stations in surrounding areas were also considered in the interpolation process to make the results more continuous and reasonable. All calculations of the interpolation process were performed by ArcGIS 10.2 (Esri Inc., USA).

Multiple logistic regression was used to study associations between air pollution exposure and incidence of wheeze and rhinitis among pre-school children. Conditions that occurred since birth but have not been in the past year are defined as remissions. In addition, due to the influence of COVID-19 and partially local lockdown, the number and frequency of people outings have reduced sharply in the past year (2020) in the Wuhan region. Therefore, this is also a good opportunity to investigate the relationship between the reduction of outdoor activities and respiratory health for pre-school children. The processes of statistical analysis were performed by SPSS 25 (IBM Inc., USA).

RESULTS AND DISCUSSION

Characteristics and variations of regional air pollution

Interannual variations of the six air pollutants over all stations of the study area are shown in Figure 2. Average values of $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and CO during the study period were 48.92 μg/m^3, 79.03 μg/m^3, 12.07 μg/m^3, 33.36 μg/m^3, 112.49 μg/m^3, and 1.09 mg/m^3, respectively. Among interannual variations of air pollution, CO was the most obvious. The average values of CO decreased from 1.31 mg/m^3 in 2015 to 0.90 mg/m^3 in 2020, with the highest determination coefficient (R^2) of 0.24. Additionally, the average concentrations of $PM_{2.5}$, PM_{10} and SO_2 also showed downward trends from 2015 to 2020. However, this downward trend has not been observed in the remaining two pollutants, NO_2 and O_3. The corresponding R^2 was small. Nevertheless, the slopes of the interannual fitting lines for all pollutants were negative. This implied that the air quality showed improvement in the last years, which can be owing to the joint efforts of the local government and the public to reduce aerosol emissions (Ma et al., 2019).

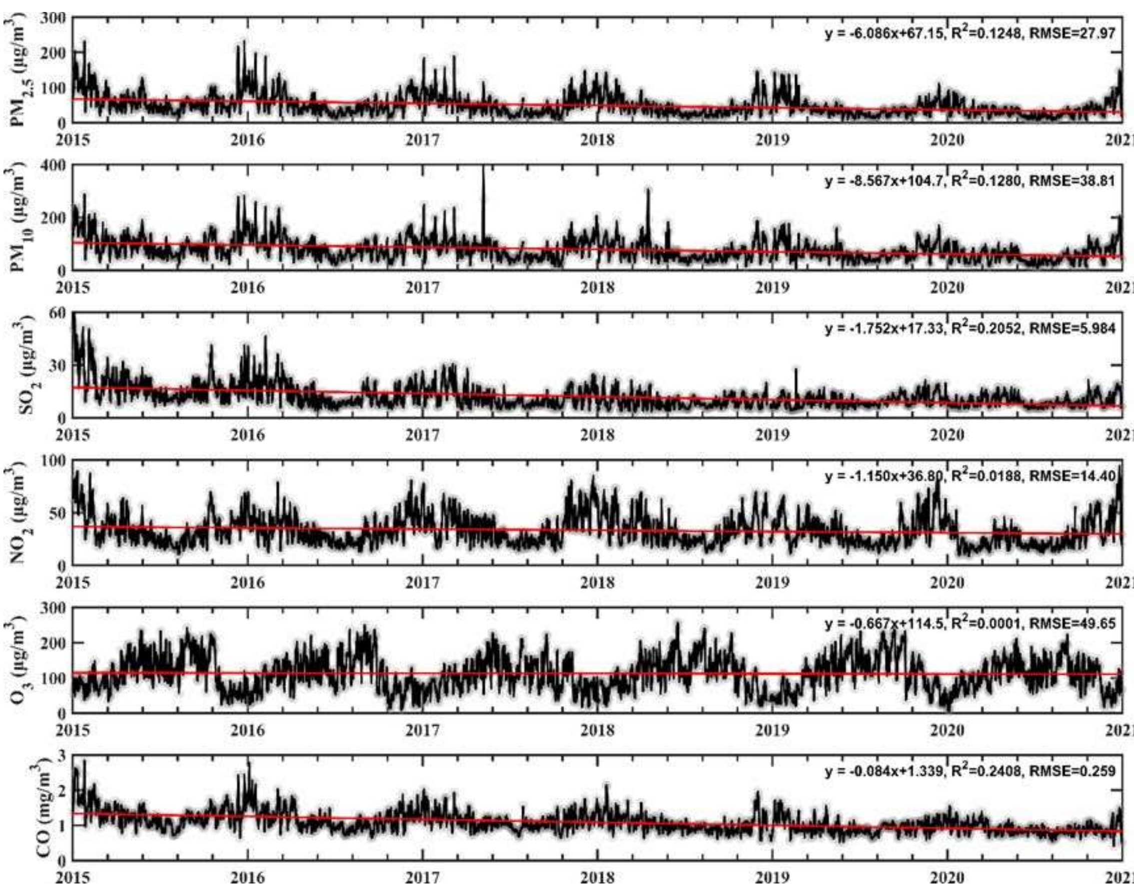

Figure 2. Interannual variations and trends of air pollutants over the study region. The red lines represent linear fitting lines and the specific parameters are displayed in the upper right corner of each subplot.

It was worth noting that the air pollutants showed similar fluctuation in each year, which represented their seasonal variation. This also meant that the exposure to air pollution changed with the season cycle. Figure 3 showed spatial and seasonal distributions of air pollution in the study area during the period from 2015 to 2020.

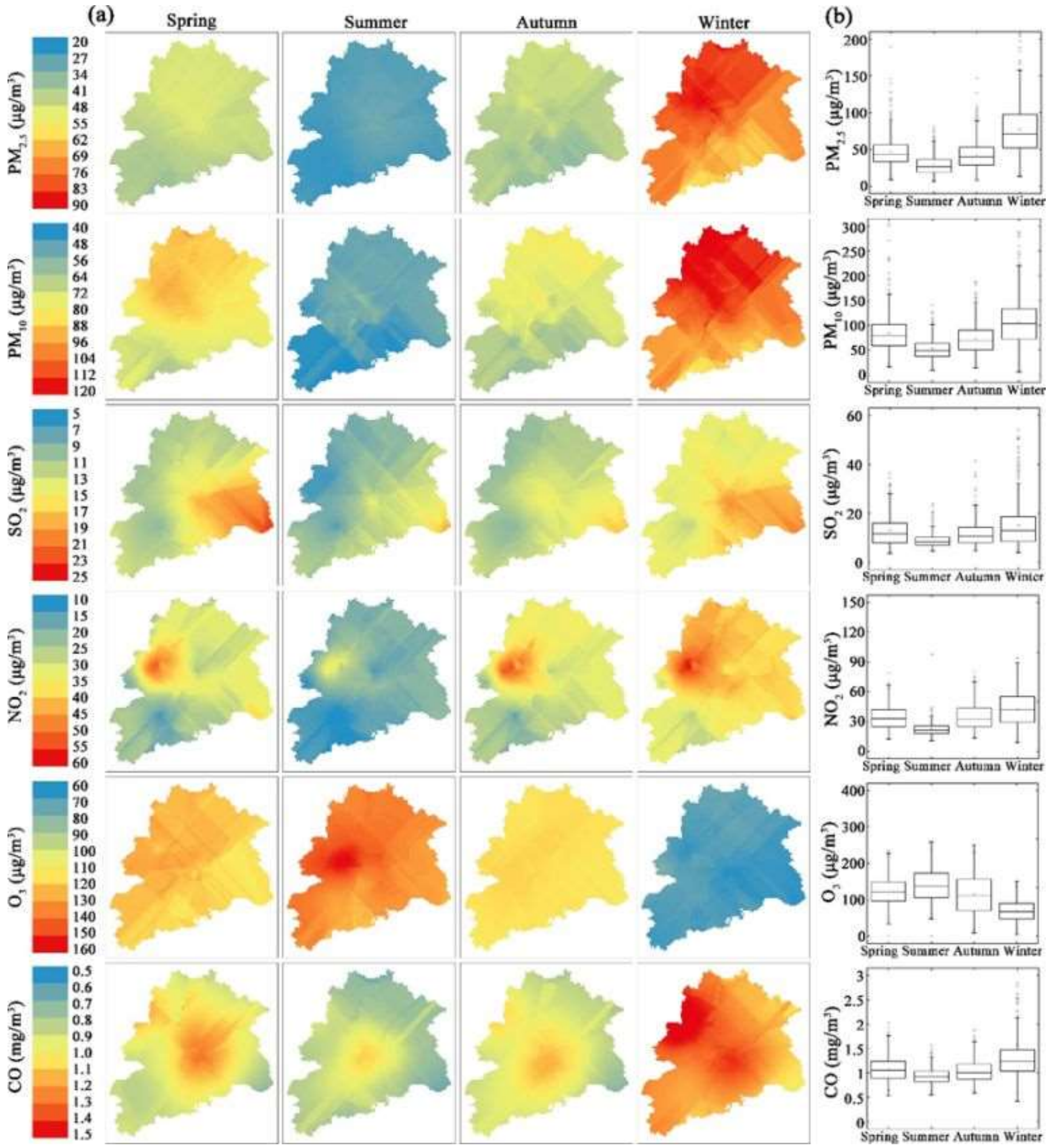

Figure 3. Spatial and seasonal distributions of air pollutions from 2015 to 2020. (a) Spatial distribution characteristics of pollutants in different seasons by using ordinary Kriging interpolation in the study area. (b) Box-plots of seasonal changes in air pollutants. Gray dots represent outliers.

Except for O_3, air pollutants present seasonal characteristics of high in winter and low in summer. The pollutant with the most obvious seasonal change is $PM_{2.5}$. The winter average is 76.79 μg/m^3, which is nearly three times the summer average of 28.90 μg/m^3. While, the second is PM_{10}, which is approximately 106.65 μg/m^3 in winter and 52.53 μg/m^3 in summer. The significant variation in concentrations of air pollutants has been proven to be greatly controlled by atmospheric and meteorological conditions and pollution sources (Guo et al., 2014). For example, the stagnant atmospheric conditions and the lower planetary boundary layer in winter promoted the deposition of particulate pollutants near the surface, making it difficult to diffuse to the outside (Liu et al., 2013). As a result, this contributed to the formation of urban haze events and increased the exposure risk of particulate pollutants for people. In addition to unfavorable atmospheric conditions to diffusion, the increase in heating in winter also leads to an increase in the concentrations of SO_2, NO_2, and CO. The water-soluble pollutants will also be transferred with changes in humidity (Curci et al., 2015). The O_3 is an exception, high in summer and low in winter, generally due to increasing photochemical reaction under high temperature and humidity in summer. A study reported that the local photochemical formation accounted for 75% of the daytime O_3 during summer over the Wuhan region (Zeng et al., 2018). In addition, due to a lower titration of O_3 by NO, the low concentration of local NO_x can also increase the concentration of O_3 (Sicard et al., 2020).

Air pollution showed significant spatial distribution characteristics, as displayed in Figure 3a. In addition to local emissions, meteorological conditions and external input sources also affect the distribution of pollutants (Jin et al., 2021). The concentration of particulate pollutants in the north of the study area (WH and HG) was generally higher than that in the south. Due to the transport of haze and dust particles, this phenomenon was most obvious in winter and spring (Tao et al., 2012). The value of SO_2 was higher in the western part of the study area (HG and HS). The NO_2 was concentrated near Wuhan throughout the year, showing a higher value (~46.24 μg/m^3) compared with other regions (~27.41 μg/m^3). The highest O_3 was also found in Wuhan during summer, while in other seasons, the O_3 was evenly distributed. The distribution of CO was mainly concentrated in the middle of the study area (EZ), but in winter, the CO in the Wuhan area also increased significantly. The spatial distribution of air pollutants affects exposure to air pollutants for people in different cities. Except for SO_2, the air pollution in Wuhan was the most serious during study periods. The detailed values of exposure to air pollution for pre-school children were shown in Table S2.

Respiratory health and exposure to air pollution

To understand the basic situation in this study area, the prevalence of wheeze and rhinitis symptoms for pre-school children in different cities in the past year and since birth was investigated, as shown in Figure 4. There are obvious differences between different cities. The average occurrence percent of wheeze and rhinitis symptoms is 9.9 and 37.4% since birth and 6.4 and 30.6% in the past year. These results showed that the incidence of rhinitis symptoms was higher than surrounding cities, such as Nanjing and Chongqing, whereas the wheeze occurred was lower among pre-school children in this area (Norback et al., 2019). The incidence of wheeze was highest in XN and lowest in HG, with 12.7% and 8.5% respectively. By contrast, the incidence of rhinitis symptoms was highest in WH (39.7%) and lowest in EZ (22.4%). Details can be found in Table S3.

Table S2. Exposure to outdoor air pollution for kindergarten children (aged 3-6) since birth and in the past year over study region.

	Mean	25%	50%	75%	IQR
Total (since birth)					
$PM_{2.5}$	46.96	42.34	44.72	48.69	6.35
PM_{10}	79.18	70.32	74.74	84.65	14.33
SO_2	11.56	9.62	11.50	13.66	4.04
NO_2	40.62	34.31	43.81	48.34	14.03
O_3	110.17	108.55	111.06	112.67	4.12
CO	1.06	0.99	1.07	1.11	0.12
In the past year (2020)					
$PM_{2.5}$	36.02	34.30	37.44	37.58	3.28
PM_{10}	60.71	58.49	61.46	61.78	3.29
SO_2	9.63	7.62	10.22	11.54	3.92
NO_2	33.38	30.12	33.14	40.76	10.64
O_3	107.88	106.82	107.85	110.71	3.89
CO	0.94	0.89	0.93	1.06	0.17

$PM_{2.5}$, PM_{10}, SO_2, NO_2, and O_3: μg/m^3; CO: mg/m^3.

Compared to since birth, results showed that the average incidence of wheeze and rhinitis symptoms decreased (remission) obviously in the past year, about 3.5 and 6.8%. The relationship between high and low

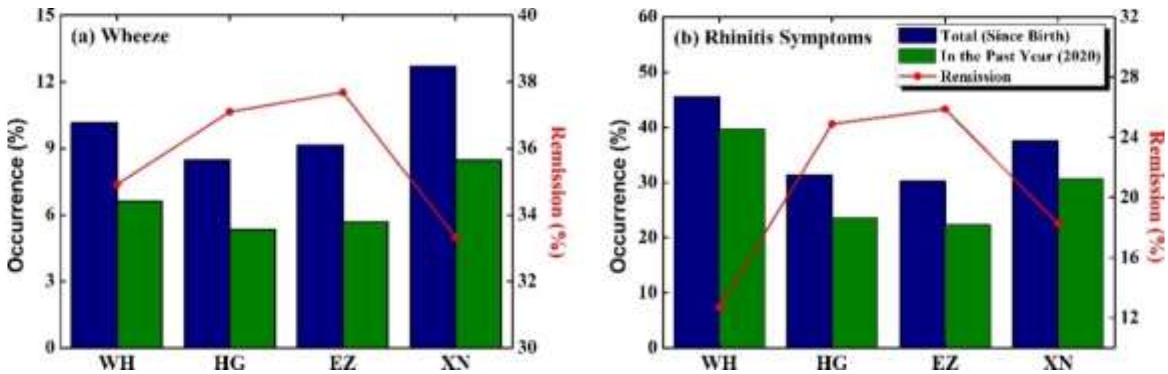

Figure 4. Incidence and remission of wheeze and rhinitis symptoms for pre-school children in four cities during the period from 2015 to 2020.

Table S3. Incidence of wheeze and rhinitis symptoms for pre-school children at four cities during period from 2015 to 2020.

	Wheeze		Rhinitis symptoms		Total
	Num	Percent	Num	Percent	
Total (Since Birth)					
WH	126	10.15	565	45.53	1241
HG	62	8.48	229	31.33	731
EZ	69	9.14	228	30.20	755
XN	63	12.7	186	37.5	496
In the past year (2020)					
WH	82	6.61	493	39.73	1241
HG	39	5.34	172	23.53	731
EZ	43	5.70	169	22.38	755
XN	42	8.47	152	30.65	496

incidence rates in different cities has not changed. The highest remissions of wheeze and rhinitis symptoms were found in EZ (37.7 and 25.9%). Whereas, the lowest remissions of wheeze and rhinitis symptoms were respectively found in XN (33.3%) and WH (12.7%). The decline in the incidence of wheeze and rhinitis symptoms for pre-school children was probably attributed to the reduction in outgoing and the improvement in air quality in the past year. Due to the influence of COVID-19 and local lockdown, the number of people outings and emissions of air pollutants has reduced sharply over the Wuhan region. The average values of exposure to air pollution respectively decreased by 10.94 μg/m^3, 18.47 μg/m^3, 1.93 μg/m^3, 7.24 μg/m^3, 2.29 μg/m^3 and 0.12 mg/m^3 for $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3 and CO in 2020.

The odds ratio (OR) with 95% confidence interval (CI) was calculated by using the logistic regression model. $PM_{2.5}$, SO_2, and CO were excluded from the model, due to the co-linearity problems as shown in Table S4. The $PM_{2.5}$ and PM_{10} were related with a correlation coefficient (R) of -0.773. The CO and SO_2 were related to NO_2, with R of -0.792 and 0.902 respectively. It was worth noting that the increase of NO_2 concentration has a significant promoting effect on the onset of rhinitis symptoms, with an OR of 1.043 (1.025, 1.062 95% CI) (Table 1). This was agreed with a previous study in six major cities in China (Norback et al., 2019). Another analysis pointed out that childhood exposure to NO_2 can increase the onset of wheeze and childhood asthma (Takenoue et al., 2012). However, OR showed that the increase in PM_{10} did not increase the risk of wheeze (0.937) and rhinitis symptoms (0.942) in this region. But the decrease in PM_{10} seems to help remission of wheeze, with an OR of 1.056 (0.854, 1.307 95% CI). A satellite data-based study showed that ground concentration of $PM_{2.5}$ was related to rhinitis and doctor-diagnosed asthma for pre-school children (Chen et al., 2018). In addition, the decrease in O3 was found to be significantly hinder the remission of rhinitis symptoms, as the OR was 0.842 (0.727, 0.974 95% CI). This is possibly due to the photochemical reaction between O_3 and NO_2 as mentioned above, i.e. decreasing NO_2 will increase O_3.

Another concerned problem is whether the time spent outdoors will impact wheeze and rhinitis symptoms for

Table S4. Co-linear correlation between pollutant parameters during study period.

	PM_{10}	$PM_{2.5}$	NO_2	SO_2	O_3	CO
PM_{10}		-0.773	0.481	0.196	-0.127	-0.729
$PM_{2.5}$			-0.731	-0.537	-0.350	0.75
NO_2				0.902	0.02	-0.792
SO_2					0.165	-0.715
O_3						-0.115

Table 1. Odds ratio (95% confidence interval) of wheeze and rhinitis symptoms in relation to pre-school children exposed to air pollution by using the logistic regression model.

	Wheeze		**Rhinitis Symptoms**	
	Occurrence	**Remission**	**Occurrence**	**Remission**
PM_{10}	0.937 (0.885, 0.993)*	1.056 (0.854, 1.307)	0.942 (0.913, 0.971)***	0.879 (0.767, 1.008)
NO_2	0.985 (0.953, 1.017)	0.992 (0.764, 1.286)	1.043 (1.025, 1.062)***	0.876 (0.753, 1.019)
O_3	1.139 (0.927, 1.400)	1.003 (0.803, 1.253)	1.050 (0.941, 1.171)	0.842 (0.727, 0.974)*

In the cases of remission, PM_{10}, NO_2, and O_3 represented the specific reduced amounts of air pollution. * $p < 0.05$, ** $P < 0.01$, *** $p < 0.001$.

pre-school children in this region. Therefore, we made the same assessment of outdoor activities time for pre-school children from three aspects: average outdoor activity time after kindergarten, average traffic time between home and kindergarten, and living environment. Since children in Chinese cities usually go to a kindergarten near the home, their exposure to air pollution is considered consistent. Results showed that 1-2 hours of activity time after kindergarten could significantly reduce the incidence of rhinitis symptoms, with an OR of 0.588 (0.372, 0.930 95% CI) (Table 2). As activity time after kindergarten went up, OR of occurrence of wheeze and rhinitis gradually decreased, which meant that enough outdoor activities might have a potential relieving effect. However, no matter what the situation was, there was no significant association between traffic time and wheeze and rhinitis.

Table 2. Odds ratio (95% confidence interval) of wheeze and rhinitis symptoms in relation to outdoor activities and living environment for pre-school children by using the logistic regression model.

	Wheeze		**Rhinitis Symptoms**	
	Occurrence	**Remission**	**Occurrence**	**Remission**
Average outdoor activity time after kindergarten (h)				
[0, 0.5]	1.875 (0.659, 5.333)	0.426 (0.077, 2.359)	0.729 (0.464, 1.146)	3.145 (0.925, 10.70)
[0.5, 1]	1.480 (0.528, 4.148)	0.478 (0.089, 2.562)	0.677 (0.437, 1.050)	3.103 (0.928, 10.37)
[1, 2]	1.047 (0.358, 3.063)	0.656 (0.116, 3.707)	0.588 (0.372, 0.930)*	2.561 (0.739, 8.877)
[2, 5]				
Average traffic time between home and kindergarten (min)				
[0, 10]	1.065 (0.132, 8.604)	0.687 (0.030, 15.77)	0.720 (0.224, 2.316)	1.133 (0.128, 10.06)
[10, 30]	1.029 (0.127, 8.318)	0.812 (0.036, 18.39)	0.665 (0.206, 2.140)	1.438 (0.162, 12.73)
[30, 60]	1.276 (0.150, 10.86)	0.977 (0.040, 23.92)	0.840 (0.253, 2.793)	1.058 (0.112, 10.03)
[60, 120]				
Living environment				
Near road	1.751 (0.664, 4.616)	1.977 (0.484, 8.067)	1.988 (1.142, 3.461)*	0.492 (0.144, 1.682)
Near lakes	2.023 (1.283, 3.190)**	0.194 (0.065, 0.577)**	1.159 (0.877, 1.531)	0.855 (0.504, 1.449)
Commercial	1.235 (0.864, 1.706)	0.737 (0.426, 1.275)	0.975 (0.997, 0.842)	0.828 (0.590, 1.163)
Industrial	1.421 (0.180, 11.20)		0.870 (0.270, 2.800)	0.984 (0.103, 9.368)
Other				

The input parameters are categorical variables, and the last item is reference in each category. * $p < 0.05$, ** $P < 0.01$, *** $p < 0.001$.

One of the main reasons is that the transportation and route are difficult to determine. OR of 2.023 (1.283, 3.190 95% CI) and 0.194 (0.065, 0.577 95% CI) showed that living near a lake promoted the occurrence of wheeze and hindered the relief of the symptoms. And, living near the road increased the incidence of rhinitis, as the OR was 1.988 (1.142, 3.461 95% CI). The values of OR showed that living near commercial and industrial areas seems to reduce these symptoms. This may be affected by the economic level of the city because a lower economic level of the city is generally associated with the increased onset of wheeze (Norback et al., 2019). In addition, it is reported that indoor air pollution is also an important factor affecting the health of the respiratory system (Franck et al., 2014; Deng et al., 2016), such as tobacco smoke and volatile organic compounds.

Given that air pollution had obvious seasonal characteristics in the study region, the probability of wheeze and rhinitis symptoms was also counted in different seasons (Figure 5). Wheeze and rhinitis usually occurred in autumn (29.07 and 35.59%), followed by winter (13.42 and 16.15%). Summer is the least, only 3.83 and 1.86% correspondingly. However, the air pollution in winter was worst, with average values of PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3, and CO of 93.13 μg/m^3, 67.94 μg/m^3, 10.56 μg/m^3, 40.40 μg/m^3, 66.49 μg/m^3, and 1.29 μg/m^3 (Table S5). In addition, another important seasonal factor is temperature. Some guardians reported that wheeze and rhinitis are more likely to occur when the temperature drops rapidly, by the questionnaire. The impact of air pollutants in different seasons on the occurrence of wheeze and rhinitis among patients can be found in Table 3. Since the high interaction of NO_2 and O_3 in summer was excluded, the decrease of O_3 showed a significant promotion effect on the alleviation of rhinitis symptoms in spring and autumn. The OR were correspondingly 1.164 (1.032, 1.313 95% CI) and 1.092 (1.007, 1.184 95% CI). In addition, the PM_{10} and NO_2 had potential positive associations with incidence of wheeze and rhinitis symptoms during autumn respectively, with the OR of 1.075 (0.993, 1.163 95% CI) and 1.017 (0.997, 1.038 95% CI).

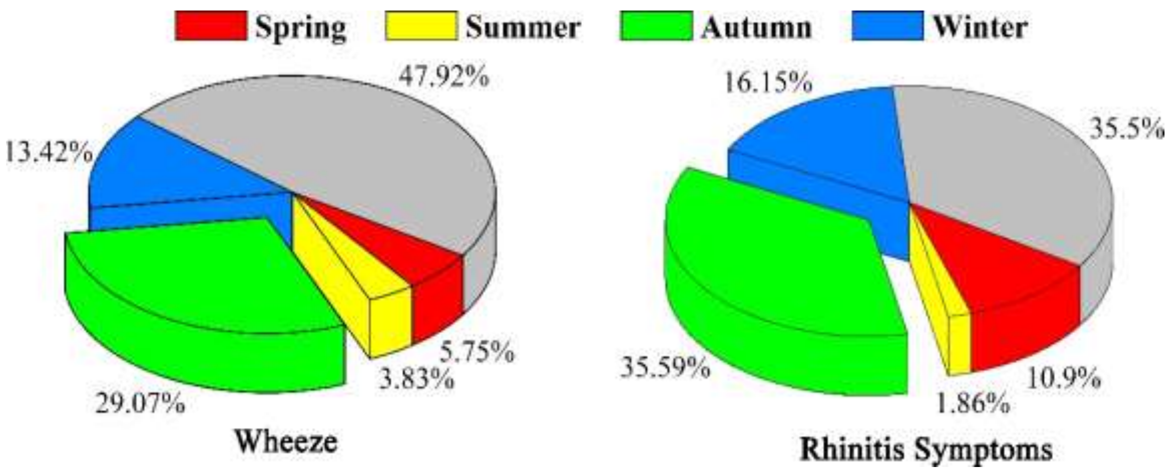

Figure 5. Seasonal distributions of incidence of wheeze and rhinitis symptoms for pre-school children during the period from 2015 to 2020. The gray area represents that the appearance of symptoms is reported as seasonal in-dependence.

Table S5. Exposure to outdoor air pollution for kindergarten children (aged 2-6) during different seasons over Wuhan region.

	Spring		Summer		Autumn		Winter	
	Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**
$PM_{2.5}$	41.21	4.26	24.55	2.85	38.29	2.69	67.94	6.43
PM_{10}	78.45	8.28	46.84	4.91	67.42	5.34	93.13	8.95
SO_2	10.49	2.35	7.49	1.77	9.73	1.20	10.56	1.87
NO_2	33.57	11.31	21.85	8.64	35.40	11.25	40.40	9.74
O_3	122.66	3.86	142.95	7.65	117.57	3.97	66.49	4.35
CO	0.98	0.11	0.88	0.07	0.93	0.06	1.29	0.25

$PM_{2.5}$, PM_{10}, SO_2, NO_2, and O_3: μg/m^3; CO: mg/m^3. **Std** represents standard deviation.

Table 3. Odds ratio (95% confidence interval) of wheeze and rhinitis symptoms in relation to pre-school children exposed to air pollution during different seasons by using the logistic regression model.

	Wheeze		Rhinitis Symptoms	
	Occurrence	**Remission**	**Occurrence**	**Remission**
Spring				
PM_{10}	1.088 (0.941, 1.259)		1.008 (0.968, 1.049)	0.983 (0.880, 1.099)
NO_2	0.878 (0.713, 1.081)		1.021 (0.964, 1.082)	0.949 (0.754, 1.195)
O_3	1.434 (0.775, 2.653)		0.986 (0.818, 1.188)	1.164 (1.032, 1.313)*
Summer				
PM_{10}	0.857 (0.378, 1.945)		0.901 (0.667, 1.218)	
NO_2	1.077 (0.802, 1.446)		0.972 (0.867, 1.090)	
O_3	0.922 (0.628, 1.354)		1.068 (0.925, 1.234)	
Autumn				
PM_{10}	1.075 (0.993, 1.163)	0.876 (0.588, 1.305)	0.977 (0.951, 1.005)	0.948 (0.889, 1.011)
NO_2	0.963 (0.904, 1.025)	0.983 (0.564, 1.713)	1.017 (0.997, 1.038)	1.066 (0.985, 1.153)
O_3	0.859 (0.593, 1.244)	0.583 (0.209, 1.627)	1.117 (0.983, 1.286)	1.092 (1.007, 1.184)*
Winter				
PM_{10}	0.979 (0.921, 1.041)	1.025 (0.907, 1.159)	0.999 (0.975, 1.024)	0.998 (0.950, 1.048)
NO_2	1.019 (0.893, 1.162)	0.872 (0.664, 1.146)	1.010 (0.964, 1.058)	0.985 (0.890, 1.089)
O_3	0.942 (0.488, 1.817)	1.117 (0.944, 1.321)	1.002 (0.782, 1.284)	0.939 (0.846, 1.043)

In the cases of remission, PM_{10}, NO_2, and O_3 represented the specific reduced amounts of air pollution. The vacancy is because the sample size is too small, the model cannot complete robust fitting. * $p < 0.05$, ** $P < 0.01$, *** $p < 0.001$.

CONCLUSIONS

This study focused on investigating regional characteristics of air pollutants and their potential impacts on outdoor activities for pre-school children over the Wuhan area from 2015 to 2020. Incidence and remission of wheeze and rhinitis symptoms were indicators used to estimate the impact of air pollution and outdoor activities on pre-school children. The main purpose of the study was to provide guidance on the design of outdoor activities and outdoor courses for pre-school children who have to face the existing air pollution problem during the process of urban construction.

The characteristics of air pollutants were noticeable in this region. The PM_{10}, $PM_{2.5}$, SO_2, and CO showed downward trends year by year, implying a partial improvement in air quality. In terms of spatial distribution, $PM_{2.5}$ and PM_{10} presented the characteristics of high in the south and low in the north. SO_2 was mostly concentrated in the southeast of the study area. NO_2 had obvious peaks throughout the year in Wuhan. Except for the high value in Wuhan in summer, the distribution of O_3 was relatively uniform. CO was concentrated in the middle of the study area. Except for ozone, all other pollutants showed a seasonal feature that was high in winters and low in summers.

A retrospective questionnaire was used to collect the occurrence of wheeze and rhinitis for pre-school children (3-6) in the past year and since birth. Among the four cities studied, WH showed a higher incidence of rhinitis, while XN had a higher incidence of wheeze. The values of OR (1.043) showed NO_2 had a significant positive association with the occurrence of rhinitis. The reduction of O_3 was significantly associated with the remissions of rhinitis symptoms in spring and autumn. Whereas, PM_{10} was associated with a lower incidence of wheeze and rhinitis. In addition, appropriate outdoor activities (1-2h) were associated with the low incidence of rhinitis with an OR of 0.588 (0.372, 0.930 95% CI), but it was not conducive to the relief of symptoms. Living near lakes showed association with high incidence and low remission of wheeze. Living near roads was associated with a high incidence of rhinitis symptoms. This means that consideration of the local air pollution distribution when selecting a kindergarten site can alleviate the occurrence of respiratory diseases in young children to a certain extent. This research enhanced our understanding of the associations between air pollution, outdoor activities and pre-school children's respiratory health. Increasing appropriate outdoor exercise while reducing exposure risk to O_3 and NO_2 was encouraged for pre-school children over the Wuhan region.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGEMENTS

This work was supported by the Hubei Province Educational Science Planning 2019 Key Project (Grant No. 2019GA069). We are grateful to the China National Environmental Monitoring Center for their air pollution data. We would like to thank Jun Xia and Dan Liu from the Hubei Experimental Kindergarten, Mang Yuan from the Third Kindergarten of Hubei Provincial Government, Guoping Mou and Yanfang Wen from the Wuhan Evergreen Dream Kindergarten, Yang Ding from Wuhan Jianghan District Qihui Kindergarten, Xiaolin Xu from Huanggang Education Bureau of Hubei Province, Jing Wang Hubei Province Luotian County Chengdong Kindergarten, and Hongxia Wu from Hubei Wuhan Arhat Central Kindergarten for their assistance in the investigation. Finally, we thank all anonymous reviewers for their constructive comments.

REFERENCES

Asher, M. I., Keil, U., Anderson, H. R., Beasley, R., Crane, J., Martinez, F., Mitchell, E. A., Pearce, N., Sibbald, B., Stewart, A. W., Strachan, D., Weiland, S. K., and Williams, H. C. (**1995**). International Study of Asthma and Allergies in Childhood (ISAAC): Rationale and methods. European Respiratory Journal, 8: 483-491.

Burke, H., Leonardi-Bee, J., Hashim, A., Pine-Abata, H., Chen, Y., Cook, D. G., Britton, J. R., and McKeever, T. M. (**2012**). Prenatal and passive smoke exposure and incidence of asthma and wheeze: Systematic review and meta-analysis. Pediatrics, 129: 735.

Chen, F. E., Lin, Z., Chen, R., Norback, D., Liu, C., Kan, H., Deng, Q., Huang, C., Hu, Y., Zou, Z., Liu, W., Wang, J., Lu, C., Qian, H., Yang, X., Zhang, X., Qu, F., Sundell, J., Zhang, Y., Li, B., Sun, Y., and Zhao, Z. (**2018**). The effects of PM2.5 on asthmatic and allergic diseases or symptoms in preschool children of six Chinese cities, based on China, Children, Homes and Health (CCHH) project. Environmental Pollution, 232: 329-337

Clark, N. A., Demers, P. A., Karr, C. J., Koehoorn, M., Lencar, C., Tamburic, L., and Brauer, M. (**2010**). Effect of early life exposure to air pollution on development of childhood asthma. Environmental Health Perspectives, 118: 284-290

Curci, G., Ferrero, L., Tuccella, P., Barnaba, F., Angelini, F., Bolzacchini, E., Carbone, C., Denier van der Gon, H. A. C., Facchini, M. C., Gobbi, G. P., Kuenen, J. P. P., Landi, T. C., Perrino, C., Perrone, M. G., Sangiorgi, G., and Stocchi, P. (**2015**). How much is particulate matter near the ground influenced by upper-level processes within and above the PBL? A summertime case study in Milan (Italy) evidences the distinctive role of nitrate. Atmospheric Chemistry and Physics, 15, 2629-2649

Deng, Q., Lu, C., Ou, C., Chen, L., and Yuan, H. (**2016**). Preconceptional, prenatal and postnatal exposure to outdoor and indoor environmental factors on allergic diseases/symptoms in preschool children. Chemosphere, 152: 459-467

Franck, U., Weller, A., Röder, S. W., Herberth, G., Junge, K. M., Kohajda, T., von Bergen, M., Rolle-Kampczyk, U., Diez, U., Borte, M., and Lehmann, I. (**2014**). Prenatal VOC exposure and redecoration are related to wheezing in early infancy. Environment International, 73: 393-401.

Gao, J., Woodward, A., Vardoulakis, S., Kovats, S., Wilkinson, P., Li, L., Xu, L., Li, J., Yang, J., Li, J., Cao, L., Liu, X., Wu, H., and Liu, Q. (**2017**). Haze, public health and mitigation measures in China: A review of the current evidence for further policy response. Science of the Total Environment, 578: 148-157

Glencross, D. A., Ho, T. R., Camina, N., Hawrylowicz, C. M., and Pfeffer, P. E. (**2020**). Air pollution and its effects on the immune system. Free Radical Biology & Medicine, 151: 56-68.

Guo, S., Hu, M., Zamora, M. L., Peng, J. F., Shang, D. J., Zheng, J., Du, Z. F., Wu, Z., Shao, M., Zeng, L. M., Molina, M. J., and Zhang, R. Y. (**2014**). Elucidating severe urban haze formation in China. Proceedings of the National Academy of Sciences of the United States of America, 111: 17373-17378.

Hennigan, C. J., Bergin, M. H., Dibb, J. E., and Weber, R. J. (**2008**). Enhanced secondary organic aerosol formation due to water uptake by fine particles. Geophysical Research Letters, 35: 102-102

Hsu, H. H. L., Chiu, Y. H. M., Coull, B. A., Kloog, I., Schwartz, J., Lee, A., Wright, R. O., and Wright, R. J. (**2015**). Prenatal particulate air pollution and asthma onset in urban children: Identifying sensitive windows and sex differences. American Journal of Respiratory and Critical Care Medicine, 192: 1052-1059.

Huang, R. J., Zhang, Y., Bozzetti, C., Ho, K. F., Cao, J. J., Han, Y., Daellenbach, K. R., Slowik, J. G., Platt, S. M., and Canonaco, F. (**2014**). High secondary aerosol contribution to particulate pollution during haze events in China. Nature, 514: 218.

Jin, S., Ma, Y., Gong, W., Liu, B., Lei, L., and Fan, R. (**2021**). Characteristics of vertical atmosphere based on five-year microwave remote sensing data over Wuhan region. Atmospheric Research, 260: 105710.

Jin, S., Ma, Y., Zhang, M., Gong, W., Lei, L., and Ma, X. (**2019**). Comparation of aerosol optical properties and associated radiative effects of air pollution events between summer and winter: A case study in January and July 2014 over Wuhan, Central China. Atmospheric Environment, 218: 117004.

Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D., and Pozzer, A. (**2015**). The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature, 525: 367-371.

Li, H., Cheng, J., Zhang, Q., Zheng, B., Zhang, Y., Zheng, G., and He, K. (**2019**). Rapid transition in winter aerosol composition in Beijing from 2014 to 2017: Response to clean air actions. Atmospheric Chemistry and Physics, 19: 11485-11499.

Lin, W., Huang, W., Zhu, T., Hu, M., Brunekreef, B., Zhang, Y., Liu, X., Cheng, H., Gehring, U., Li, C., and Tang, X. (**2011**). Acute respiratory inflammation in children and black carbon in ambient air before and during the 2008 Beijing Olympics. Environmental Health Perspectives, 119: 1507-1512.

Liu, X.G., Li, J., Qu, Y., Han, T., Hou, L., Gu, J., Chen, C., Yang, Y., Liu, X., Yang, T., Zhang, Y., Tian, H., and Hu, M. (**2013**). Formation and evolution mechanism of regional haze: A case study in the megacity Beijing, China. Atmospheric Chemistry and Physics, 13: 4501-4514.

Ma, Y., Zhang, M., Jin, S., Gong, W., Chen, N., Chen, Z., Jin, Y., and Shi, Y. (**2019**). Long-term investigation of aerosol optical and radiative characteristics in a typical megacity of Central China during winter haze periods. Journal of Geophysical Research: Atmospheres, 124: 12093-12106.

Mendell, M. J. (**2007**). Indoor residential chemical emissions as risk factors for respiratory and allergic effects in children: A review. Indoor Air, 17: 259-277.

Norback, D., Lu, C., Zhang, Y., Li, B., Zhao, Z., Huang, C., Zhang, X., Qian, H., Sun, Y., Sundell, J., Juan, W., Liu, W., and Deng, Q. (**2019**). Onset and remission of childhood wheeze and rhinitis across China - Associations with early life indoor and outdoor air pollution. Environment International, 123: 61-69.

Rosenfeld, D., Lohmann, U., Raga, G.B., O'Dowd, C.D., Kulmala, M., Fuzzi, S., Reissell, A., and Andreae, M.O. (**2008**). Flood or drought: How do aerosols affect precipitation? Science, 321: 1309-1313.

Schichtel, B. A., Husar, R. B., Falke, S. R., and Wilson, W. E. (**2001**). Haze trends over the United States, 1980-1995. Atmospheric Environment, 35(30): 5205-5210.

Sicard, P., De Marco, A., Agathokleous, E., Feng, Z., Xu, X., Paoletti, E., Rodriguez, J. J. D., and Calatayud, V. (**2020**). Amplified ozone pollution in cities during the COVID-19 lockdown. Science of the Total Environment, 735: 139542.

Takenoue, Y., Kaneko, T., Miyamae, T., Mori, M., and Yokota, S. (**2012**). Influence of outdoor NO_2 exposure on asthma in childhood: Meta-analysis. Pediatrics International, 54: 762-769.

Tao, M. H., Chen, L. F., Su, L., and Tao, J. H. (**2012**). Satellite observation of regional haze pollution over the North China Plain. Journal of Geophysical Research-Atmospheres, 117: 16.

Tao, M., Wang, L., Chen, L., Wang, Z., and Tao, J. (**2020**). Reversal of aerosol properties in Eastern China with rapid decline of anthropogenic emissions. Remote Sensing, 12(3)

Tie, X.X., Wu, D., and Brasseur, G. (**2009**). Lung cancer mortality and exposure to atmospheric aerosol particles in Guangzhou, China. Atmospheric Environment, 43: 2375-2377.

Ulutaş, K., Abujayyab, S. K., & Karaş, İ. R. (**2021**). Evaluation of particulate matter (PM10) distributions in İZMIR using geographic information systems for smart cities applications. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 46: 545-555.

Ulutaş, K., Abujayyab, S. K., and Salem, A. B. U. (**2021**). Major air pollutants, levels, temporal changes and interactions with meteorological variables in Ankara. Mühendislik Bilimleri ve Tasarım Dergisi, 9(4): 1284-1295.

Zeng, P., Lyu, X. P., Guo, H., Cheng, H. R., Jiang, F., Pan, W. Z., Wang, Z. W., Liang, S. W., and Hu, Y. Q. (**2018**). Causes of ozone pollution in summer in Wuhan, Central China. Environmental Pollution, 241: 852-861.

Zhang, M., Jin, S., Ma, Y., Fan, R., Wang, L., Gong, W., and Liu, B. (**2021**). Haze events at different levels in winters: A comprehensive study of meteorological factors, Aerosol characteristics and direct radiative forcing in megacities of north and central China. Atmospheric Environment, 245: 118056.

Zhang, Y., Li, B., Huang, C., Yang, X., Qian, H., Deng, Q., Zhao, Z., Li, A., Zhao, J., Zhang, X., Qu, F., Hu, Y., Yang, Q., Wang, J., Zhang, M., Wang, F., Zheng, X., Lu, C., Liu, Z., Sun, Y., Mo, J., Zhao, Y., Liu, W., Wang, T., Norbäck, D., Bornehag, C.-G., & Sundell, J. (**2013**). Ten cities cross-sectional questionnaire survey of children asthma and other allergies in China. Chinese Science Bulletin, 58: 4182-4189.

Zheng, B., Tong, D., Li, M., Liu, F., Hong, C., Geng, G., Li, H., Li, X., Peng, L., Qi, J., Yan, L., Zhang, Y., Zhao, H., Zheng, Y., He, K., and Zhang, Q. (**2018**). Trends in China's anthropogenic emissions since 2010 as the consequence of clean air actions. Atmospheric Chemistry and Physics, 18: 14095-14111.

Zou, B., Li, S., Lin, Y., Wang, B., Cao, S., Zhao, X., Peng, F., Qin, N., Guo, Q., Feng, H., Matthew, C.J., Xu, S., and Duan, X. (**2020**). Efforts in reducing air pollution exposure risk in China: State versus individuals. Environmental International, 137: 105504.

Citation: Cao, Y., and Cai, Y. (2022). Urban air pollution characteristics and associations with pre-school children respiratory health in four cities of central China. African Educational Research Journal, 10(1): 72-83.