Effect of ambient air pollutants and meteorological factors on COVID-19 transmission

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Research article

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Abstract

Background

Since its first appearance in Wuhan China in December 2019, the coronavirus disease 2019 (COVID-19) has become a worldwide pandemic. Although the COVID-19 is known to cause by human-to-human transmission, it remains largely unclear whether ambient air pollutants and meteorological factors could promote its transmission process.

Methods

We conducted a retrospective cohort study to understand the correlation between COVID-19 incidence and eight ambient air pollutants ($PM_{2.5}$, PM_{10}, SO_2, CO, NO_2, and O_3-8 h) and three meteorological variables (temperature, humidity and wind level) in China's two worst-hit cities, Wuhan and XiaoGan, between Jan 25th to Feb 29th in 2020.

Results

Our data showed that the COVID-19 incidence was constantly correlated with $PM_{2.5}$, NO_2 and local temperature in both cities. Specifically, in Wuhan, the tightest correlation was observed between NO_2 and COVID-19 incidence ($R^2 = 0.329$, $p < 0.01$). The $PM_{2.5}$ and CO also present tight correlation with the incidence number, whose R^2 equaled 0.174 ($p < 0.01$) and 0.203 ($p < 0.05$), respectively. In XiaoGan, in addition to the $PM_{2.5}$ ($R^2 = 0.23$, $p < 0.01$) and NO_2 ($R^2 = 0.158$, $p < 0.05$), a notable correlation was also observed between the PM_{10} and incidence cases ($R^2 = 0.158$, $p < 0.05$). Moreover, temperature is the only meteorological factors that constantly correlated well with COVID-19 incidence in both Wuhan and XiaoGan, but in a negative pattern ($R^2 = 0.126$ and 0.13, respectively, both $p < 0.05$).

Conclusion

Our data concludes that ambient air pollutants, especially $PM_{2.5}$ and NO_2, and temperature are three variables that could potential promote the sustained transmission of COVID-19. Thus, personal protective devices, especially the facial mask and eye goggle, shall be suggested to residents for SARS-CoV-2 protection in highly polluted regions.

Background

Since its first appearance in Wuhan China in December 2019, the coronavirus disease 2019 (COVID-19) has become a worldwide pandemic [1–3]. The Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) is the pathogen of the COVID-19, which is now a big threat to global health. As of Mar 31st, 2020, 785,979 confirmed cases and 37,810 death related to COVID-19 had been recorded from 204 countries [4].

Ambient air pollutant is a well-known threat to human health, as sufficient evidence become available to generate the tight correlation between pollutant and increased risks of numerous diseases [5–7]. Among pollution related health issues, ambient air pollutant has raised concerns over its association with infectious diseases, some of which have previously caused local epidemic [8–10]. It is speculated that the airborne air pollutants provide “condensation nuclei” for virus to attach. This hypothesis was supported by the studies based on the observation of influenza-PM2.5 correlation [10–12]. Although the COVID-19 is known to cause human-to-human transmission by infectious secretions [3], these secretions can be transferred in many different ways. Thus, whether the ambient air pollutants could promote the transmission of SARS-CoV-2 becomes an urgent question in the current pandemic scenario. Additionally, meteorological factors such as humidity and temperature had also been suggested to enhance air pollution [13, 14] and promote transmission of infection disease[14]. However, their role in SARS-CoV-2 transmission also remains largely unknown.

Wuhan is one of the most populated cities in china, which has a subtropical humid monsoon climate. Due to rapid industrialization and urbanization, both the concentration and composition of air pollutants become higher and more complicated [15, 16], respectively, which caused severe health problems to local population[17]. Previous study demonstrated a mycobacterium surge in Wuhan as being fueled by local worsen air pollution and weather[18]. Nevertheless, no study so far has studied the correlation between Wuhan local air quality/ meteorological data and COVID-19 incidence.

Due to its sever air pollution and COVID-19 incidence, Wuhan provided a good research object to investigate this issue. Thus, we hypothesized a potential role of air pollutants and meteorological variables in promoting SARS-CoV-2 transmission, aiming to provide clues of influencing factors for SARS-CoV-2 pandemic. We have also enrolled XiaoGan into the current study, which is the seconded worst COVID-19-affect city located in the same province of Wuhan.

Methods

Study Population

The study population included a retrospective cohort of coronavirus infected patients in two China cities, Wuhan and XiaoGan between Jan 25th to Feb 29th in 2020. The incidence data of coronavirus subjects were obtained from the Health Commission of Hubei Province[19].

The daily air quality index (AQI) and average concentrations of six ambient air pollutants data were collected from the website Platform AQI (https://www.aqistudy.cn). These pollutants included $PM_{2.5}$, PM_{10}, SO_2, CO, NO_2, and O_3-8 h (maximum 8-h moving average concentrations for O_3), whose daily concentration were calculated by averaging the concentrations of all stations in the city to represent the citywide pollution exposure. The daily temperature, relative humidity, and wind (in Beaufort number) were also obtained from the Platform AQI.

Data analysis

A time-series analysis was applied to examine the associations between the pollutants and COVID-19 incidence. We conducted the Pearson regression coefficient analysis to estimate the association between various pollutants concentration and COVID-19 incidence in Wuhan and XiaoGan, China on a daily base. All analyses were conducted using GraphPad Prism® 6.0. The statistical tests were two-sided, and p-value < 0.05 was considered as statistically significant.

Results

Previous epidemiological study demonstrated that the median incubation period of SARS-CoV-2 infection was 4 days [20]. Thus, the Pearson correlation was applied to analyze the relationships of COVID-19 incidence numbers with air pollution data from four days ago.

Table 1 presents the descriptive statistics for daily COVID-19 incidence numbers and the air pollutants value in Wuhan. In Wuhan, on Jan 26th, 80 cases of COVID-19 were newly diagnosed, which appeared to be the lowest incidence number during the entire study period. Meanwhile, the highest incidence number showed up on Feb 12th, which were 13,436 cases. The daily means of weather factors in Wuhan were as follows: temperature 7.11 ± 0.67°C, humidity 79.33 + 1.47%, wind (Beaufort No.) 0.75 ± 0.14. Additionally, the daily means of air pollution factors in Wuhan were as follows: $PM_{2.5}$ 45.53 ± 3.84 μg/m^3, PM_{10} 53.08 ± 3.99 μg/m^3, SO_2 7.36 ± 0.38 μg/m^3, CO 0.89 ± 0.03 μg/m^3, NO_2 22.25 ± 1.42 μg/m^3, O_3-8 h 75.39 ± 3.6 μg/m^3. Similarly, Table 2 presents the descriptive statistics in XiaoGan. From 25th Jan to 29th Feb 2020, the minimal and maximum incidence of COVID-19 incidence was − 15 and 424 cases, respectively. The daily means of weather factors in XiaoGan were as follows: temperature 6.86 ± 0.63°C, humidity 81.69 ± 1.96%, wind (Beaufort No.) 1.17 ± 0.07. In addition, the air pollution factions in XiaoGan were as follows: : $PM_{2.5}$ 50.28 ± 4.27 μg/m^3, PM_{10} 59.58 ± 4.69 μg/m^3, SO_2 7.03 ± 0.44 μg/m^3, CO 1.15 ± 0.04 μg/m^3, NO_2 11.69 ± 0.81 μg/m^3, O_3-8 h 78.72 ± 3.7 μg/m^3.

Table 1

Descriptive statistics of daily COVID-19 incidences numbers and meteorological data /air pollution conditions from 25th Jan to 29th Feb 2020 in Wuhan, China (total 36 days).

Factors (Wuhan)	**Minimum**	**Maximum**	**Mean**	**S.E.M.**
Incidence (cases)	80	13436	1386	373.5
Meteorological Data				
Temperature (ºC)	2	18	7.11	0.67
Humidity (%)	58	95	79.33	1.47
Wind (Beaufort No.)	0	3	0.75	0.14
Ambient Air Pollutants (μg/m^3)				
$PM_{2.5}$	11	97	45.53	3.84
PM_{10}	20	103	53.08	3.99
SO_2	5	13	7.361	0.38
CO	0.5	1.3	0.8861	0.03
NO_2	10	47	22.25	1.42
O_3-8 h	45	110	75.39	3.64

Table 2
Descriptive statistics of daily COVID-19 incidences numbers and meteorological data /air pollution conditions from 25th Jan to 29th Feb 2020 in XiaoGan, China (total 36 days).

Factors (XiaoGan)	**Minimum**	**Maximum**	**Mean**	**S.E.M.**
Incidence (cases)	-15	424	98.94	16.17
Meteorological Data				
Temperature (ºC)	2	17	6.86	0.63
Humidity (%)	58	98	81.69	1.96
Wind (Beaufort No.)	1	3	1.17	0.07
Ambient Air Pollutants (μg/m^3)				
$PM_{2.5}$	12	108	50.28	4.27
PM_{10}	22	122	59.58	4.69
SO_2	4	14	7.03	0.44
CO	0.8	1.6	1.15	0.04
NO_2	4	26	11.61	0.81
O_3-8 h	40	120	78.72	3.70

Next, the presence of linear relationship was evaluated between air pollutants/meteorological data and the COVID-19 incidence numbers in each city (Table 3, Fig. 1.). Due to the change of case definition on Feb 12th, there existed a surge of COVID-19 incidence on Feb 12th and 13th[21, 22]. Additionally, XiaoGan shows a negative number in COVID-19 incidence on Feb 19th. Thus, we excluded the data on these date in our study. First, in Wuhan (Table 3), among six air pollutants, the negative linear relationship was only revealed between O_3-8 h and incidence number, while the rest pollutants showed positive correlation. The tightest correlation was observed between NO_2 and COVID-19 incidence ($R^2 = 0.329$, $p < 0.01$). The $PM_{2.5}$ and CO also present tight correlation with the incidence number, whose R^2 equaled 0.174 and 0.203, respectively ($p < 0.01$ and 0.05, respectively). In addition, we also studied the correlation between three meteorological variables and COVID-19 incidence. The temperature was the only factor that predominantly correlated with the incidence cases ($R^2 = 0.126$, $p < 0.05$), but in a negative pattern. Neither the humidity nor wind level had linear correlation with the COVID-19 incidence.

Table 3
The correlation between the COVID-19 transmission and eight ambient air pollution and three meteorological variables from 25th Jan to 29th Feb 2020 in Wuhan and XiaoGan, China.

	Wuhan			**XiaoGan**		
	Slope	**R^2**	**P**	**Slope**	**R^2**	**P**
Meteorological Data						
Temperature	-0.002 + 0.001	0.126	< 0.05	-0.014 + 0.007	0.130	< 0.05
Humidity	0.003 + 0.003	0.040	0.27	-0.019 + 0.022	0.025	0.40
Wind	0.00 + 0.00	0.001	0.84	0.00 + 0.00	0.003	0.75
Ambient Air Pollutants						
$PM_{2.5}$	0.015 + 0.006	0.174	0.02	0.117 + 0.046	0.23	< 0.01
PM_{10}	0.117 + 0.006	0.105	0.07	0.105 + 0.044	0.158	0.03
SO_2	0.00 + 0.00	0.008	0.64	0.009 + 0.005	0.101	0.08
CO	0.00 + 0.00	0.203	< 0.01	-0.0003 + 0.0004	0.022	0.42
NO_2	0.007 + 0.002	0.329	< 0.001	0.015 + 0.007	0.158	0.03
O_3-8 h	-0.005 + 0.006	0.023	0.41	0.034 + 0.043	0.021	0.43

In XiaoGan, among six air pollutants (Fig. 2), the negative linear relationship was only revealed between CO and incidence number, which however showed no statistical significance. Similar to that of Wuhan, the $PM_{2.5}$ (R^2 = 0.23, $p < 0.01$) and NO_2 (R^2 = 0.158, $p < 0.05$) had tight correlation with COVID-19 incidence. Moreover, a notable correlation was also observed between the PM_{10} and incidence cases (R^2 = 0.158, $p < 0.05$). Among three meteorological factors, the COVID-19 incidence only correlated well with the temperature, but in a negative pattern (R^2 = 0.13, $p < 0.05$).

Discussion

Ambient air pollution and meteorological variables can impact viral transmission (e.g., influenza) but have not yet been examined for the SARS-CoV-2. In the current study, we provided an initial assessment of ambient air pollutants and meteorological variables on the incidence of COVID-19 day by day from Jan 25th to Feb 29th in 2020. Overall, the results, based on data from China's two worst-hit cities, we showed that the COVID-19 incidence was tightly correlated with $PM_{2.5}$, NO_2 and local temperature, indicating their potential role in promoting viral transmission.

The PM is a mixture of both solid particles and liquid droplets suspended in the air. $PM_{2.5}$ and PM_{10} is identified as the PM diameter cut off at 2.5 and 10 μm, respectively. Although it is not the sole cause of respiratory illness, previous studies had provided some evidence to support the hypothesis that ambient air pollutant is a strong environmental determinant of viral transmissions. For example, tight correlation was discovered between human influenza cases and $PM_{2.5}$ concentrations in epidemical studies based in big cities, such as Beijing[23], Hong Kong[24] and Brisbane[25]. Its potential mechanisms are believed to the increased oxidative stress caused by ambient air pollutants that damage bronchial immunity[26] and epithelial cells integrity [27] and thus enhance viral attachment. However, it remains particularly unclear whether the ambient air pollutant could assist SARS-CoV-2 transmission. In the current study, we observed that among six ambient air pollutants, the $PM_{2.5}$ concentration is constantly and positively correlated with the COVID-19 incidence, which agreed with the data from previous influenza study. Moreover, although not statistically significant in Wuhan, the correlation between PM_{10} concentration and COVID-19 incidence is prominent in XiaoGan. We tend to believe that $PM_{2.5}$ and PM_{10} could both promote coronavirus transmission based on following reason: The receptor for both SARS-CoV-2 and SARS-CoV binding is the angiotensin-converting enzyme 2, which concentrates on the type II alveolar cells [28]. However, the type II alveolar cells locates in the alveoli, which is only reachable to particles with a diameter less than 5 micrometers[29]. Thus, small airborne pollutants, such as $PM_{2.5}$, are particularly harmful as they are more likely to penetrate the respiratory tract all the way to the alveolar region unfiltered[30, 31]. For larger PM, penetration ability decreased dramatically when its size rise. We believe PM_{10} is also harmful respiratory tract to some extent as starts at 20 μm and beyond, PM is not able to penetrate below the trachea[31]. This might also explain our finding that $PM_{2.5}$ is more tightly correlated with the COVID-19 incidence than that of the PM_{10}. The safety guideline concentration of $PM_{2.5}$ of PM_{10} are 15 and 50 μg/m^3 by US EPA[32], respectively. Meanwhile, both Wuhan and XiaoGan were constantly suffered from particularly higher than safe $PM_{2.5}$ and PM_{10} levels during our study period. Future epidemiological study in other world regions with similar population density but different $PM_{2.5}$ and PM_{10} concentration could be used to verify this result.

There are a number of studies demonstrate the adverse health effects of NO_2 exposure. For example, short-term increase of outdoor NO_2 concentration can significantly increase the risk of upper respiratory tract infection[33]. This phenomenon is was particularly notable in children, as this subpopulation is highly susceptible to NO_2 induced lung injury [34–36]. Viral infection was common after NO_2 exposure. According to Chauhan et al.[37], four viruses were frequently detected in NO_2-related respiratory tract infection and coronavirus was one of them. Previous study indicated that preceding NO_2 exposure can decrease host immunity and thus significantly increase infection risk of cytomegalovirus in mice[38]. Moreover, recovered mice tended to be re-infected after re-exposing to NO_2[39]. In the current study, although the NO_2 level was constantly lower than the US EPA standards[40], our data revealed that

COVID-19 incidence were highly correlated with the ambient NO_2 concentration. This finding agreed to epidemiological studies from other regions of the world [35, 37].

So far, epidemiological studies had identified at least nine viruses categories that are capable of infecting respiratory tract [41, 42]. Although all feature seasonal oscillation of outbreaks, only three viruses show peak incidences in the winter months, which are the Influenza, human coronavirus, and human respiratory syncytial virus[43, 44]. Although the epidemiological characteristics of SARS-CoV-2 is not clear, recent study predicted the SARS-CoV-2 transmits more efficiently in winter than summer[45], indicating the importance of temperature. In current study, our data agreed with previous findings as we demonstrated that temperature is an important metrological variable that is negatively correlated with COVID-19 incidence, indicating lower temperature promote the SARS-CoV-2 transmission. This phenomenon might be related to life-style as people tend to huddle indoors together during winter season. Future study needs to investigate the direct effect of temperature on viral activity as well.

There also exist some discrepancies between the results current and previous studies. For example, it had been shown that low humidity could increase the viability and thus promote viral transmission [29, 46]. However, we failed to observe the role of humidity on COVID-19 incidence. This issue might be related to the high humidity (constantly > 50%) of Wuhan and XiaoGan during the entire period. Without proper shifting of humidity for comparison, we believe our data could not properly reveal the importance of humidity on viral transmission.

The current study has some limitations. First, as the ambient PM2.5 is a mixture of solid particles and liquid droplets, the exact components of PM2.5 that could promote coronavirus transmission remain unknown. Second, due to the relatively short study period since the current outbreak and imperfect daily reporting practices, our results are vulnerable to changes as the emerging of more detailed data.

Conclusions

In conclusion, we found that $PM_{2.5}$, NO_2 and temperature are three variables that could potential promote the sustained transmission of SARS-CoV-2. Personal protective devices, especially the facial mask, shall be suggested to residents for coronavirus protection in highly polluted regions.

Abbreviations

COVID-19	Coronavirus Disease 2019
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus-2

Declarations

Ethics approval and consent to participate

The current study has been approved by the ethics committee of Shanghai Rui-Jin Hospital, which had also ruled that no formal ethics approval was required in this particular case.

Since all data were already publically available to the public, the need for participates' consent was waived by the ethics committee of Shanghai Rui-Jin Hospital and deemed unnecessary according to national regulations.

Consent for publication

Not applicable.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

We state that there is no conflict of interest and ethical adherence in this study.

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Authors' contributions

Dr. YJ and YJG designed the original study. Dr. YJ analyzed the data and drafted the manuscript independently. All authors participated in modifying the final manuscript

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References

1. Zhu N, Zhang D, Wang W, Li X, Yang B, Song J, Zhao X, Huang B, Shi W, Lu R, et al. A Novel Coronavirus from Patients with Pneumonia in China, 2019. N Engl J Med. 2020;382(8):727–33.
2. Rodríguez-Morales AJ, MacGregor K, Kanagarajah S, Patel D, Schlagenhauf P. Going global – Travel and the 2019 novel coronavirus. Travel Medicine Infectious Disease. 2020;33:101578.
3. Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, Ren R, Leung KSM, Lau EHY, Wong JY, et al. Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus-Infected Pneumonia. N Engl J Med. 2020;382(13):1199–207.
4. **Cases**. & **Latest Updates** [https://.
5. Liu C, Chen R, Sera F, Vicedo-Cabrera AM, Guo Y, Tong S, Coelho M, Saldiva PHN, Lavigne E, Matus P, et al. Ambient Particulate Air Pollution and Daily Mortality in 652 Cities. N Engl J Med. 2019;381(8):705–15.
6. Rückerl R, Schneider A, Breitner S, Cyrys J, Peters A. Health effects of particulate air pollution: A review of epidemiological evidence. Inhal Toxicol. 2011;23(10):555–92.
7. Zhao B, Johnston F, Salimi F, Kurabayashi M, Negishi K. Short-term exposure to ambient fine particulate matter and out-of-hospital cardiac arrest: a nationwide case-crossover study in Japan. Lancet Planet Health. 2020;4(1):e15–23.
8. You S, Tong Y, Neoh K, Dai Y, Wang C. On the association between outdoor PM(2.5) concentration and the seasonality of tuberculosis for Beijing and Hong Kong. Environ Pollut. 2016;218:1170–9.
9. Horne BA-O, Joy EA, Hofmann MG, Gesteland PH, Cannon JB, Lefler JS, Blagev DP, Korgenski EK, Torosyan N, Hansen GI, et al. Short-Term Elevation of Fine Particulate Matter Air Pollution and Acute Lower Respiratory Infection. Am J Respir Crit Care Med. 2018;198(6):759–66.
10. Su W, Wu X, Geng X, Zhao X, Liu Q, Liu T. The short-term effects of air pollutants on influenza-like illness in Jinan, China. BMC Public Health. 2019;19(1):1319.
11. Liang Y, Fang L, Pan H, Zhang K, Kan H, Brook JR, Sun Q. PM2.5 in Beijing - temporal pattern and its association with influenza. Environ Health. 2014;13:102.
12. Feng C, Li J, Sun W, Zhang Y, Wang Q. Impact of ambient fine particulate matter (PM2.5) exposure on the risk of influenza-like-illness: a time-series analysis in Beijing, China. Environ Health. 2016;15:17.
13. Xiang H, Mertz K, Arena V, Brink L, Xu X, Bi Y, Talbott E. Estimation of short-term effects of air pollution on stroke hospital admissions in Wuhan, China. PLoS One. 2013;8(4):e61168.
14. Moriyama M, Hugentobler W, Iwasaki A. **Seasonality of respiratory viral infections**. *Annu Rev Virol* 2020.
15. Zeng P, Lyu XP, Guo H, Cheng H, Jiang F, Pan W, Wang Z, Liang S, Hu Y. **Causes of ozone pollution in summer in Wuhan, Central China**. *Environ Pollut* 2018, **241**(852 – 61).
16. Xing X, Chen Z, Tian Q, Mao Y, Liu W, Shi M, Cheng C, Hu T, Zhu G, Li Y, et al: **Characterization and source identification of PM(2.5)-bound polycyclic aromatic hydrocarbons in urban, suburban, and rural ambient air, central China during summer harvest**. *Ecotoxicol Environ Saf* 2020, 191(110219).

17. Qian Z, He Q, Lin H, Kong L, Liao D, Dan J, Bentley C, Wang B. Association of daily cause-specific mortality with ambient particle air pollution in Wuhan, China. Environ Res. 2007;105(3):380–9.
18. Yang X, Duan Q, Wang J, Zhang Z, Jiang G. Seasonal variation of newly notified pulmonary tuberculosis cases from 2004 to 2013 in Wuhan, China. PLoS One. 2014;9(10):e108369.
19. **The realtime coronovirus epidemiological situationof Hubei province**. .
20. Guan W-J, Ni Z-Y, Hu Y, Liang W-H, Ou C-Q, He J-X, Liu L, Shan H, Lei C-L, Hui DSC, et al. Clinical Characteristics of Coronavirus Disease 2019 in China. N Engl J Med. 2020. .
21. **COVID-19**: **China once again changes case definition in Hubei province** [https://.
22. **How Many Coronavirus Cases in China? Officials Tweak the Answer** .
23. Liang Y, Fang L, Pan H, Zhang K, Kan H, Brook J, Sun Q. PM2.5 in Beijing - temporal pattern and its association with influenza. Environ Health. 2014;13:102.
24. Qiu H, Yu I, Tian L, Wang X, Tse L, Tam W, Wong T. Effects of coarse particulate matter on emergency hospital admissions for respiratory diseases: a time-series analysis in Hong Kong. Environ Health Perspect. 2012;120(4):572–6.
25. Xu Z, Hu W, Williams G, Clements A, Kan H, Tong S. Air pollution, temperature and pediatric influenza in Brisbane, Australia. Environ Int. 2013;59:384–8.
26. Ma J, Song S, Guo M, Zhou J, Liu F, Peng L, Fu Z. **Long-term exposure to PM2.5 lowers influenza virus resistance via down-regulating pulmonary macrophage Kdm6a and mediates histones modification in IL-6 and IFN-β promoter regions**. *Biochem Biophys Res Commun* 2017 **493**(2):1122–1128.
27. Jaspers I, Ciencewicki J, Zhang W, Brighton L, Carson J, Beck M, Madden M. Diesel exhaust enhances influenza virus infections in respiratory epithelial cells. Toxicol Sci. 2005;85(2):990–1002.
28. Zhou P, Yang X, Wang X, Hu B, Zhang L, Zhang W, Si H, Zhu Y, Li B, Huang C, et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature. 2020;579(7798):270–3.
29. Brankston G, Gitterman L, Hirji Z, Lemieux C, Gardam M. Transmission of influenza A in human beings. Lancet Infect Dis. 2007;7(4):257–65.
30. Tellier R. Aerosol transmission of influenza A virus: a review of new studies. J R Soc Interface. 2009;6(Suppl 6):783–90.
31. Hinds W. Aerosol technology. **2nd edn**. New York: John Wiley and Sons, Inc.; 1999.
32. **What are the Air Quality Standards for PM?** [.
33. Martini C, Buxbaum S, Rodrigues M, Nilica B, Scarpa L, Holzner B, Virgolini I, Gamper EM. **Quality of life in patients with metastatic gastroenteropancreatic neuroendocrine tumors receiving peptide receptor radionuclide therapy: information from a monitoring program in clinical routine**. *J Nucl Med* 2018.
34. Moshammer H, Hutter H, Hauck H, Neuberger M. Low levels of air pollution induce changes of lung function in a panel of schoolchildren. Eur Respir J. 2006;27:1138–43.

35. Lin Y, Chang C, Chang S, Chen P, Lin C, Wang Y. Temperature, nitrogen dioxide, circulating respiratory viruses and acute upper respiratory infections among children in Taipei, Taiwan: a population-based study. Environ Res. 2013;120:109–18.
36. Ghosh R, Joad J, Benes I, Dostal M, Sram RJ, Hertz-Picciotto I. Ambient nitrogen oxides exposure and early childhood respiratory illnesses. Environ Int. 2012;39(1):96–102.
37. Chauhan A, Inskip H, Linaker C, Smith S, Schreiber J, Johnston S, Holgate S. Personal exposure to nitrogen dioxide (NO2) and the severity of virus-induced asthma in children. Lancet. 2003;361(9373):1939–44.
38. Rose R, Fuglestad J, Skornik W, Hammer S, Wolfthal S, Beck B, Brian J. The pathophysiology of enhanced susceptibility to murine cytomegalovirus respiratory infection during short-term exposure to 5 ppm nitrogen dioxide. Am Rev Respir Dis. 1988;137:912–7.
39. Rose R, Pinkston P, Skornik W. **Altered susceptibility to viral respiratory infection during short-term exposure to nitrogen dioxide**. *Res Rep Health Eff Inst* 1989(24):1–24.
40. **NAAQS Table**. .
41. Nichols W, Campbell A, Boeckh M. Respiratory viruses other than influenza virus: impact and therapeutic advances. Clin Microbiol Rev. 2008;21(2):274–90.
42. Pavia A. Viral infections of the lower respiratory tract: old viruses, new viruses, and the role of diagnosis. Clin Infect Dis. 2011;52(Suppl 4):284–9.
43. Midgley C, Haynes A, Baumgardner J, Chommanard C, Demas S, Prill M, Abedi G, Curns A, Watson J, Gerber S. **Determining the seasonality of respiratory syncytial virus in the United States: the impact of Increased molecular testing**. *J Infect Dis* 2007, 216(345 – 55).
44. Killerby M, Biggs H, Haynes A, Dahl R, Mustaquim D, Gerber S, Watson J. Human coronavirus circulation in the United States 2014–2017. J Clin Virol. 2018;101:52–6.
45. **Seasonality of SARS-CoV-2: Will COVID-19 go away on its own in warmer weather?** [.
46. Reiman J, Das B, Sindberg G, Urban M, Hammerlund M, Lee H, Spring K, Lyman-Gingerich J, Generous A, Koep T, et al. Humidity as a non-pharmaceutical intervention for influenza A. PLoS One. 2018;13(9):e0204337.

Figures

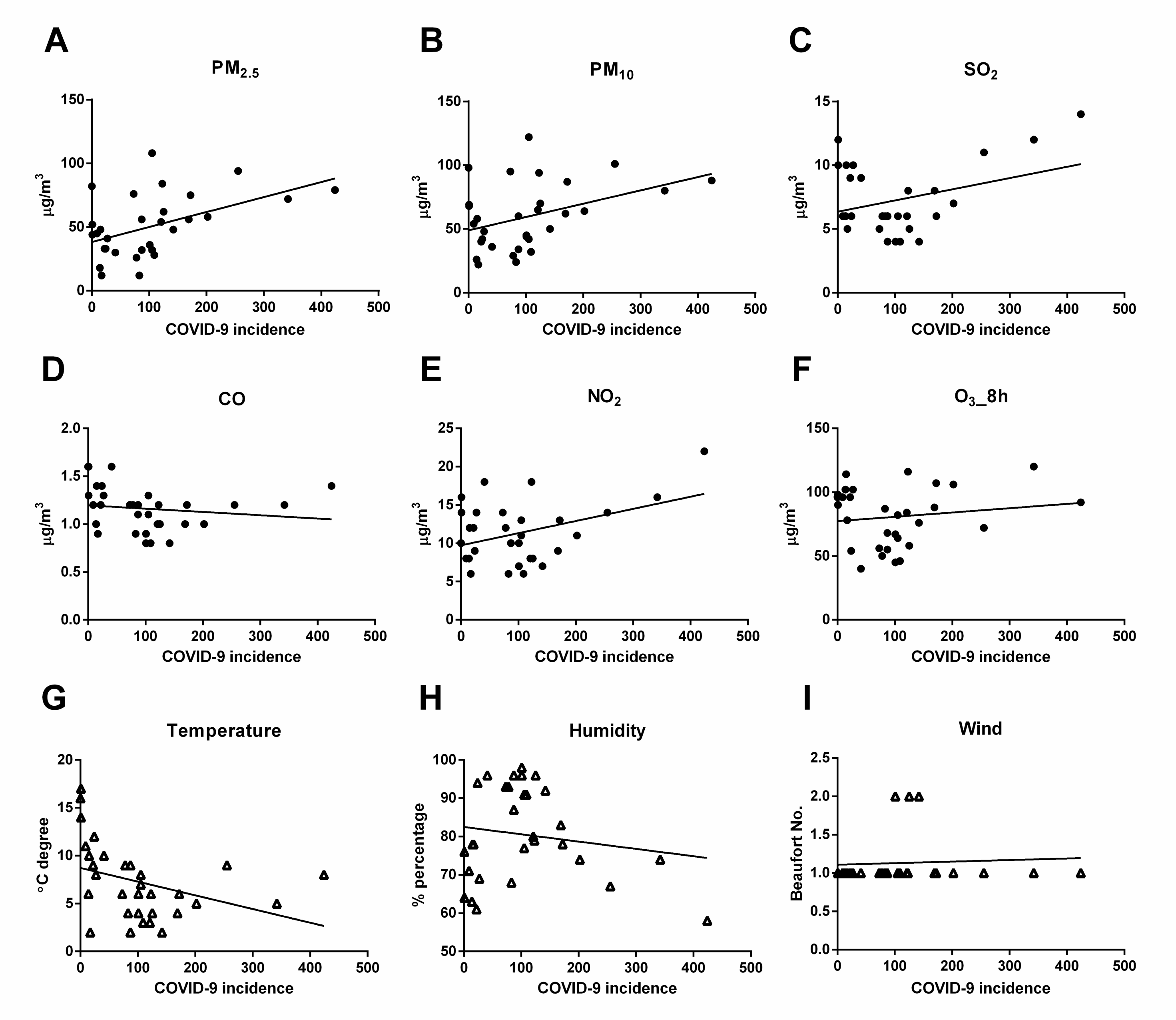

Figure 1

The correlation between the COVID-19 incidence and six ambient air pollution and three meteorological variables in Wuhan.

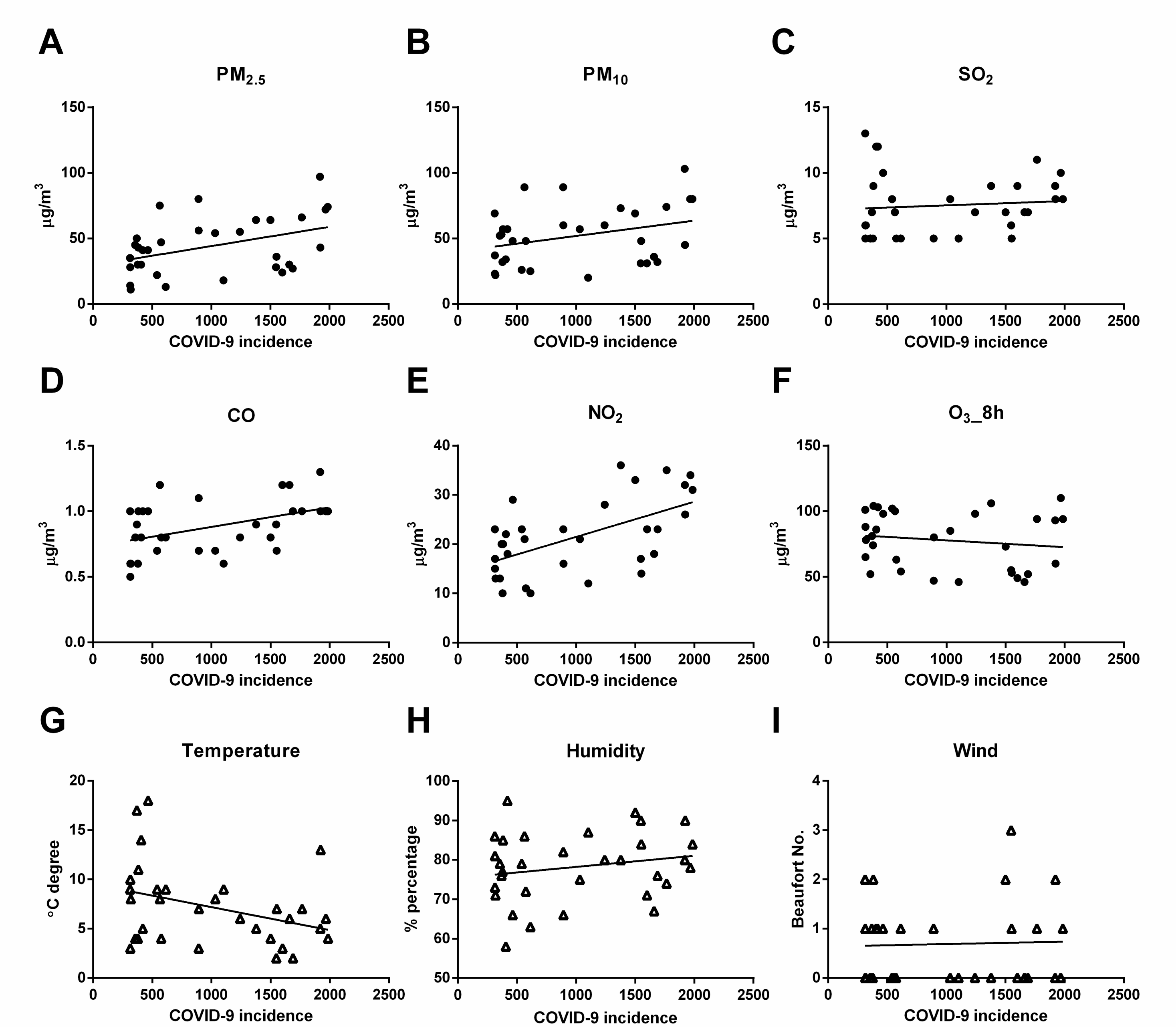

Figure 2

The correlation between the COVID-19 incidence and six ambient air pollution and three meteorological variables in XiaoGan.