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RESEARCH ARTICLE

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The occurrence of COVID-19 is associated with air quality and relative humidity

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Abstract

The association between meteorological factors and COVID-19 is important for the prevention and control of COVID-19. However, similar studies are relatively rare in China. This study aims to investigate the association between COVID-19 and meteorological factors, such as average temperature, relative humidity, and air quality index (AQI), and average wind speed. We collected the daily confirmed cases of COVID-19 and meteorological factors in Shanghai China from January 10, 2020 to March 31, 2020. A generalized additive model was fitted to quantify the associations between meteorological factors and COVID-19 during the study period. A negative association between average temperature and daily confirmed cases of COVID-19 was found on lag 13 days. In addition, we observed a significant positive correlation between meteorological factors (AQI, relative humidity) and daily confirmed cases of COVID-19. A 10 increase in AQI (lag1/7/8/9/10 days) was correlated with a 4.2%–9.0% increase in the daily confirmed cases of COVID-19. A 1% increase in relative humidity (lag1/4/7/8/9/10 days) was correlated with 1.7%–3.7% increase in the daily confirmed cases of COVID-19. However, the associations between average wind speed and the daily confirmed cases of COVID-19 is complex in different lag days. In summary, meteorological factors could affect the occurrence of COVID-19. Reducing the effects of meteorological factors on COVID-19 may be an important public health action for the prevention and control of COVID-19.

KEYWORDS
AQI, average temperature, COVID-19, generalized additive model, relative humidity, time series

1 | INTRODUCTION

Novel coronavirus pneumonia (COVID-19) is a respiratory infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which was identified in Wuhan, China, in December 2019 and then led to a pandemic all over the world.[1] The mainly clinical features of COVID-19 include fever, cough, chest tightness, dyspnoea, myalgia, fatigue and imaging manifestations of pneumonia by computed tomography.[2,3] Person to person transmission of COVID-19 mainly takes place through droplets from coughing or sneezing or direct contact.[4] It has been shown that SARS-CoV-2 is more infectious than SARS-CoV and MERS-CoV.[5,6] Thus, strong measures have been taken to control the spread and improve the curative rate of COVID-19 in the world. However, as of June 22, 2020, a total of 8 860 331 confirmed cases and 465 740 deaths have been reported in the world, affecting more than 200 countries.

Meteorological factors, such as average temperature, relative humidity (ARH), air quality index (AQI), and average wind speed, may

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directly or indirectly influence the occurrence and development of infectious diseases by affecting the survival and transmission of pathogens and the susceptibility of a person. Cui et al.,[7] investigated the relationship between air pollution and death of SARS. The results showed that the mortality of SARS was higher in areas with air pollution.[7] In addition, some evidences showed that ARH, and air pollution are related to COVID-19.[8–10] However, the relationship between other meteorological factors and COVID-19, such as average wind speed, has never been discussed. Furthermore, most studies on the relationship between meteorological factors and COVID-19 are finished in February, whose time span is not long enough. Thus, this study investigated the relationship between meteorological factors and daily confirmed cases of COVID-19 in shanghai China from January 10, 2020 to March 31, 2020, so that we could get authentic results.

2 | MATERIALS AND METHODS

2.1 | Data collection

The daily confirmed cases of COVID-19 in Shanghai, China from January 10, 2020 to March 31, 2020 were collected from the official website of Shanghai health commissions (http://wsjkw.sh.gov.cn/) and all imported cases from other countries were excluded. The daily meteorological data for Shanghai between January 10, 2020 to March 31 were collected from china meteorological network (http://www.weather.com.cn), including daily high temperature, low temperature, ARH, AQI, and average wind speed. All the abovementioned data is freely accessible.

2.2 | Data analysis

2.2.1 | Statistical description and simple correlation analysis

SPSS 20.0 software was used to calculate the mean, *SD*, and quartile of daily high temperature, low temperature, average temperature, average wind speed, ARH, AQI and confirmed cases of COVID-19. The Spearman method was applied to analyze the simple correlation between meteorological factors and COVID-19. All statistical tests were two-sided, and a value $p < 0.05$ was considered statistically significant.

2.2.2 | Generalized additive model (GAM)

The GAM is a nonparametric regression method, and independent observation is not an essential condition in GAM. It is suitable for various distribution types and widely used to evaluate the effects of environmental factors on health. COVID-19 is a little probability event for the whole population. Thus, we used the GAM with a Poisson distribution family and natural splines to fit the association of COVID-19 and meteorological factors (lag0–15). The core model was fitted as follows:

$$\log[E(Y_k)] = ns(X_1, df_1) + ns(X_2, df_2) + ns(X_3, df_3) + ns(X_4, df_4) + ns(X_5, df_5) + \alpha,$$

where $E(Y_k)$ is the expected daily confirmed cases of COVID-19 at day k; X_1 is the average temperature; X_2 is the average wind speed; X_3 is ARH; X_4 is AQI; X_5 is time; df_1, df_2, df_3, df_4, and df_5 were defined according to the minimum Akaike information criterion and other studies[11,12]; α is the intercept. β Values of all variables were estimated by the model. On the basis of the core model, variables and the lag effects (lag0–15) were added. GAM analysis was realized by R software (version 3.6.3) with the “mgcv” package, and a value $p < 0.05$ was considered statistically significant.

2.2.3 | Sensitivity analysis

Sensitivity analyses were conducted to look at the stability of the model with different variables. We applied different models to examine whether other meteorological factors, such as rains, air pressure were robust after controlling the temperature, ARH, AQI and wind speed in the core model.

3 | RESULTS

3.1 | Description of daily confirmed cases of COVID-19 and meteorological factors

A total of 338 cumulative confirmed cases of COVID-19 in Shanghai, China had been reported by Shanghai health commissions from January 10, 2020 to March 31, 2020. During the observation period, the average daily confirmed cases of COVID-19 was 4.12. The average daily high temperature, low temperature, average temperature, ARH, AQI and average wind speed were 12.72°C, 7.34°C, 10.03°C, 74.96%, 56.55 and 2.57 m/s, respectively (Table 1). Figure 1 shows the time series of confirmed cases of COVID-19 in Shanghai, China from January 10, 2020 to March 31, 2020.

3.2 | Simple correlation between meteorological factors and COVID-19

Spearman correlation coefficients between confirmed cases of COVID-19 and meteorological factors have been summarized in Table 2. We observed that high temperature, low temperature and average temperature were negatively correlated with daily confirmed cases of COVID-19 on lag 0/5/10/15 days, and Spearman correlation coefficients ranged from −0.660 to −0.327 ($p < 0.05$). In addition, there was a positive association between ARH and daily confirmed

TABLE 1 Descriptive statistics of daily confirmed cases and meteorological factors in Shanghai

	Mean ± *SD*	Percentile					Range
		P_{10}	P25	P50	P75	P_{90}	
Confirmed cases	4.12 ± 7.14	0	0	0	7	15	0–27
High temperature (℃)	12.72 ± 4.84	7	9	12	16	20	5–25
Low temperature (℃)	7.34 ± 3.43	3	4.75	7.5	10	12	0–17
Average temeprature (℃)	10.03 ± 3.93	5.15	7	9.5	12.625	16.2	2.5–19.5
ARH (%)	74.96 ± 13.57	54.6	62.75	75.5	85.25	93.7	44–97
AQI	56.55 ± 33.02	27	34	46	72.25	101.5	19–163
Average wind speed (m/s)	2.57 ± 0.82	1.4	1.9	2.7	3.125	3.67	1.1–4.4

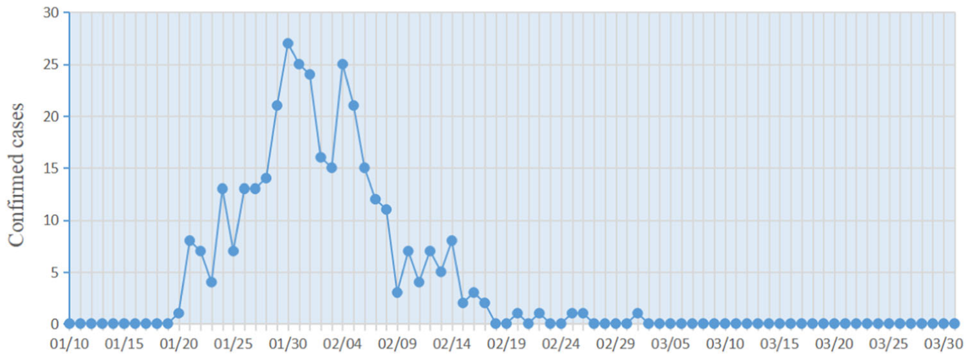

FIGURE 1 The time series of confirmed cases of COVID-19 in Shanghai, China

TABLE 2 Spearman correlation coefficients between meteorological factors and COVID-19

		High temperature	Low temperature	Average temperature	ARH	AQI	Average wind speed
lag0	*r*	−0.327*	−0.410*	−0.384*	0.238*	0.031	−0.044
lag5	*r*	−0.531*	−0.529*	−0.557*	0.294*	0.103	−0.063
lag10	*r*	−0.645*	−0.587*	−0.645*	0.309*	0.225*	−0.054
lag15	*r*	−0.66*	−0.541*	−0.63*	0.263*	0.309*	−0.034

Abbreviations: AQI, air quality index; ARH, average temperature, relative humidity.
*$p < 0.05$.

cases of COVID-19 on lag 0/5/10/15 days, and Spearman correlation coefficients ranged from 0.238 to 0.309 ($p < 0.05$). Moreover, a positive association between AQI and daily confirmed cases of COVID-19 was observed on lag 10/15 days, and Spearman correlation coefficients ranged from 0.225 to 0.309 ($p < 0.05$). However, no significant association was found between average wind speed and daily confirmed cases of COVID-19.

3.3 | GAM analysis

The estimated relative risk and 95% confidence interval of all variables by GAM are listed in Table 3 and Figure 2. There were an association between the daily confirmed cases of COVID-19 and average temperature, AQI, ARH, average wind speed after controlling other meteorological factors and time trend. A negative association between average temperature and daily confirmed cases of COVID-19 was found on lag 13 days after controlling AQI, ARH, average wind speed and time trend. A 1℃ increase in average temperature was associated with a 9.7% reduction in the daily confirmed cases of COVID-19 ($p < 0.05$). A positive association between AQI and daily confirmed cases of COVID-19 was found on lag 1/7/8/9/10 days, and a 10 increase in AQI was associated with a 4.2%–9% increase in the daily confirmed cases of COVID-19 ($p < 0.05$). In addition, a positive association between ARH and daily confirmed cases of COVID-19 was founded on lag 1/4/7/8/9/10 days after controlling other meteorological factors and time trend, and a 1% increase in ARH was associated

TABLE 3 The significantly estimated RR and 95% CI for the relationship between meteorological factors and the daily confirmed cases of COVID-19 by GAM analysis on different lag days

	RR	95% CI	p
Average temperature			
Lag13	0.9033	0.8210–0.9939	0.0370
AQI			
Lag1	1.009	1.0045–1.0134	0.0012
Lag7	1.0087	1.0049–1.0124	0.0002
Lag8	1.007	1.0034–1.0106	0.0017
Lag9	1.0061	1.0027–1.0096	0.0044
Lag10	1.0042	1.0009–1.0076	0.0447
ARH			
Lag1	1.018	1.0010–1.0343	0.3724
Lag4	1.017	1.0041–1.0302	0.0345
Lag7	1.0376	1.0236–1.0518	0.0001
Lag8	1.0285	1.0147–1.0426	0.0009
Lag9	1.0239	1.0095–1.0385	0.0076
Lag10	1.0207	1.0058–1.0358	0.0255
Average wind speed			
Lag3	1.1950	1.0230–1.3959	0.0246
Lag6	1.1881	1.0185–1.3860	0.0283
Lag11	0.7683	0.6527–0.9045	0.0098
Lag12	0.8094	0.6895–0.9501	0.0348
Lag13	0.6201	0.5182–0.7419	0.0001

Abbreviations: CI, confidence interval; GAM, generalized additive model; RR, relative risk.

with a 1.7%–3.7% increase in the daily confirmed cases of COVID-19 ($p < 0.05$). However, the relationship between the daily confirmed cases of COVID-19 and average wind speed is more complicated than other meteorological factors on different lag days. On lag 3/6 days, a positive association was observed between average wind speed and the daily confirmed cases of COVID-19, but a negative association was observed on lag 11/12/13 days.

3.4 | Sensitivity analysis

Sensitivity analyses were conducted to explore the stability of the model with different meteorological factors. We found that other meteorological factors, such as rains, air pressure were insignificant for the occurrence of COVID-19 in Shanghai, China, after controlling other meteorological factors and time trend. However, ARH, and AQI, and average wind speed were significant. Thus, these meteorological factors were introduced into the core model.

4 | DISCUSSION

Our study revealed that average temperature, AQI, ARH and average wind speed may influence the occurrence of COVID-19 in Shanghai, China, after controlling other meteorological factors and time trends, which seem important to prevent and control the COVID-19 in the future.

In this study, whether analyzed by Spearman correlation or GAM, a negative association between average temperature and daily confirmed cases of COVID-19 was found. A 1°C increase in average temperature was associated with a 9.7% reduction in the daily confirmed cases of COVID-19 on lag 13 days. Other studies have reported similar results. A study in Wuhan, China, revealed that average temperature was significantly negatively associated with COVID-19.[9] Another study investigated the effects of temperature on the daily new cases and new deaths of COVID-19 in 166 countries, which observed that temperature was negatively related to daily new cases and deaths of COVID-19.[10] Although, these studies revealed similar trend between temperature and occurrence of COVID-19, the reduction of new cases of COVID-19 followed by temperature increase and the lag effect was not totally identical, which may be due to the different participants and differently observed time, and different models used in different studies.

Air pollution may increase the cases of COVID-19. Studies have shown that air pollution may lead to the occurrence and development of some common respiratory diseases, especially asthma and chronic obstructive pulmonary disease (COPD).[13] $PM_{1.0}$ and $PM_{2.5}$ are closely related to the increase in the number of hospitalized patients with pneumonia and COPD. The risk in the cold season is significantly higher than that in warm season.[14] The evidences that air pollution is related to chronic respiratory system have been confirmed. At the same time, there are many pieces of evidences that air pollution is related to infectious diseases of respiratory system. For example, the increase of $PM_{2.5}$ was associated with the increase of measles incidence,[15] which is more obvious when it is lagged for 1–3 days, indicating that air pollution has certain lag effects on disease. In our study, AQI and daily confirmed cases of COVID-19 is positively correlated. A 10 increase in AQI (lag1/7/8/9/10 days) was correlated with a 4.2%–9.0% increase in the daily confirmed cases of COVID-19, which is similar to other studies. Some studies demonstrated that $PM_{2.5}$, PM_{10}, CO, NO_2 and O_3 may increase new cases and deaths of COVID-19.[14,16] As masks can effectively reduce the harm of air pollution to health,[17,18] wearing a mask is an indispensable measure to prevent COVID-19.

Physiologically, the most comfortable humidity for the human body ranges from 40% to 60%. When the humidity is too high or too low, it will cause adverse effects on human. Unlike a negative association between ARH and new cases of COVID-19 or SARS in previous studies,[9,10,19] we found a positive correlation between ARH and new cases of COVID-19 (lag1/4/7/8/9/10 days). The reason for this divergence is probably that Shanghai, as a coastal city of China, has a relatively high ARH in winter. It has been shown that the increase of relative humidity in the air aids in the propagation of

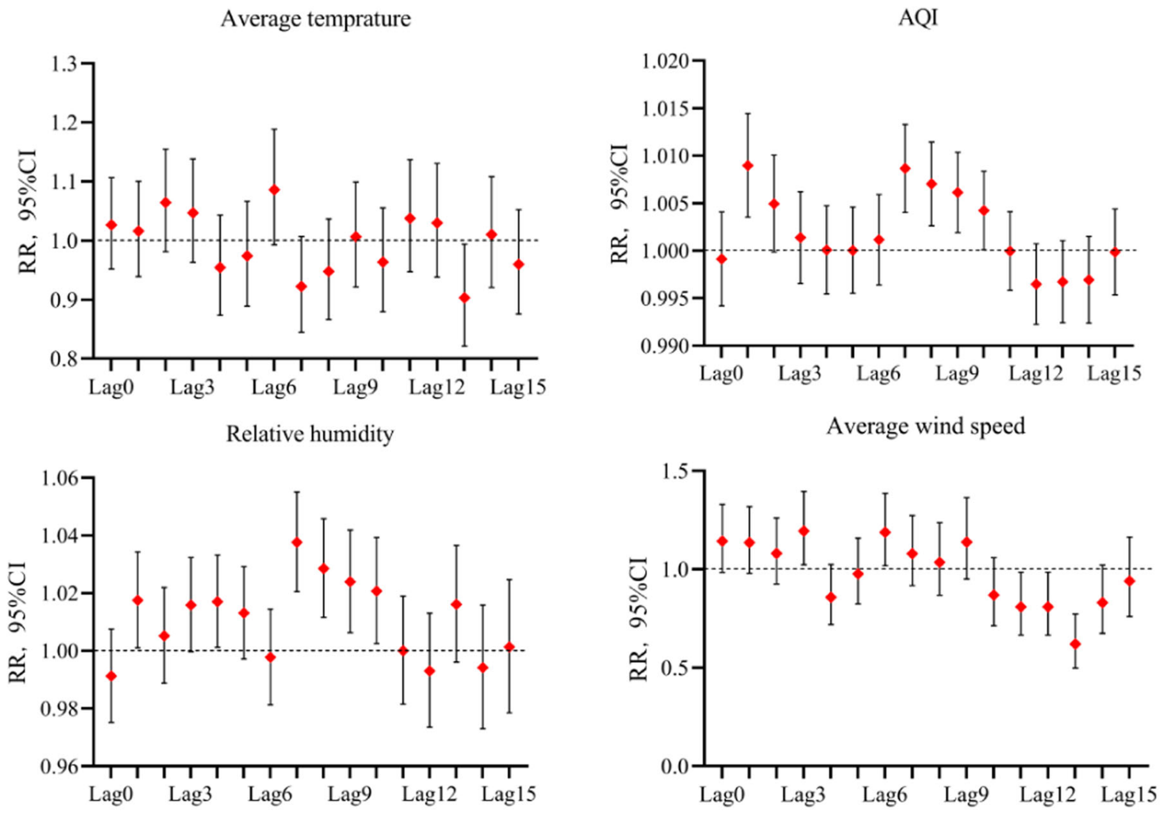

FIGURE 2 All estimated RR and 95% CI for the relationship between meteorological factors and the daily confirmed cases of COVID-19 by GAM analysis in different lag days. CI, confidence interval; GAM, generalized additive model; RR, relative risk

pathogens. When the humidity was more than 70%, the virus activity significantly increased. When humidity was between 60% and 80%, the detection rate of Mycoplasma pneumoniae and influenza virus was the highest.[20]

However, the associations between average wind speed and the daily confirmed cases of COVID-19 is complex on different lag days. On lag 3/6 days, a positive association was observed between average wind speed and the daily confirmed cases of COVID-19, but a negative association was observed on lag 11/12/13 days. So far, the relationship between average wind speed and the daily confirmed cases of COVID-19 is not enough, thus we just presumed that more air circulation was followed by increased wind speed. More air circulation may dilute the concentration of SARS-CoV-2 in the air, and then reduce the occurrence of COVID-19. One study reported that increasing wind speed was followed by a decrease in cases of COVID-19, but there is no statistical significance.[21] On the other hand, increased wind speed, especially in cold season, would elevate the body's susceptibility to disease. However, the sample size of this study is limited. For all these reasons, the exact relationship between average wind speed and occurrence of COVID-19 needs further study.

Regarding daily confirmed cases of COVID-19 in Shanghai China as the research subjects, we mainly considered the adequate medical resources in Shanghai. Patients with COVID-19 in Shanghai can be confirmed in time, which ensured the accuracy of daily new cases and reduced the confounding effects of social factors such as medical resources. However, due to the adequacy of medical resources in Shanghai and the effective prevention and control measures that had been taken, the total cases of COVID-19 are relatively limited (a total of 338 cases excluding imported cases from other countries). Moreover, the meteorological data we collected was the external environmental monitoring data, not the actual personal exposure data. For example, the outside ambient temperature in winter is generally lower than the indoor environment. In addition to meteorological factors, community and family isolation measures may affect the occurrence of COVID-19, but the authors believe that this effect is consistent during the study period. Although the above limitations may partially weaken the persuasion of our results, this study still provides some clues for future research. Furthermore, AQI is used in this study instead of single air pollutant. It is because AQI may reflect air quality more comprehensively and easier to obtain and understand than a single pollutant. Therefore, AQI can be regarded as more important in terms of early disease monitoring in a population.

5 | CONCLUSION

In conclusion, meteorological factors may influence the occurrence of COVID-19 in different degrees, and average temperature, AQI and ARH are significant meteorological factors for

COVID-19. Thus, reducing the effects of meteorological factors on health, including wearing a mask and going out less frequently, may be important public health actions for the prevention and control of COVID-19.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the official website of Shanghai health commissions at http://wsjkw.sh.gov.cn/ and in the China meteorological network at http://www.weather.com.cn.

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