Humidity is a consistent climatic factor contributing to SARS-CoV-2 transmission

Michael P. Ward | Shuang Xiao | Zhijie Zhang

INTRODUCTION

The global spread of severe acute respiratory coronavirus 2 (SARS-CoV-2), causing the novel coronavirus disease (COVID-19) pandemic, has been linked to climatic factors. This has a plausible biological basis. The spread of SARS-CoV-2 among people is predominantly via respiratory droplets and aerosols, as well as fomites (Cai et al., 2020) and possibly faecal–oral (Yeo, Kaushal, & Yeo, 2020). Temperature and relative humidity can affect coronavirus transmission (Casanova, Jeon, Rutala, Weber, & Sobsey, 2010) through virus survival (at lower temperatures coronaviruses survive longer) and the length of time infectious respiratory matter stays suspended in the air (at lower humidity more material stay suspended for longer) (Casanova et al., 2010; Chan et al., 2011; Guionie et al., 2013).

In previous observational research, a negative relationship between relative humidity and SARS cases has been found (Cai et al., 2007; Tan et al., 2005), and a similar negative relationship with Middle East respiratory syndrome coronavirus (MERS-CoV) cases has been described (Altamimi & Ahmed, 2020; Gardner, Kelton, Poljak, Van Kerkhove, & von Dobcschez, 2019). However, the relationship with temperature is inconsistent: a positive relationship has been described for SARS (Gardner et al., 2019) and MERS-CoV (Altamimi & Ahmed, 2020), but a negative relationship has also been observed for MERS-CoV (Gardner et al., 2019). Specifically for SARS-CoV-2, a negative relationship between COVID-19 cases in China and temperature and humidity has recently been described (Qi et al., 2020), and more recently in the state of New South Wales (NSW), Australia we described a significant negative association between COVID-19 cases during the initial exponential phase of the epidemic and relative humidity (Ward, Xiao, & Zhang, 2020). In the current study, we extend this research to examine the effect of a greater number of climatic factors on the occurrence of COVID-19 cases during both exponential and descending phases of the epidemic and investigate whether there are regional and temporal differences in this relationship. This knowledge is needed to guide public health interventions to successfully control the spread of SARS-CoV-2.
2 | METHODS

Case reports in NSW, Australia from the beginning of the epidemic in January to the end of May 2020 were accessed. Those whose infection source was determined to be locally acquired, and whose postcode of residence was reported, were included. A daily time series of cases was created, from which separate series preceding and following the epidemic peak (31 March) and for individual NSW public health units (PHUs) were created. Based on the reported postcode the closest weather observation station was identified. Daily observations of the following factors were downloaded: rainfall (mm) and temperature (°C), relative humidity (%) and wind speed (m/s). The mean values for each day were estimated to create time series of weather data. Additional series of daily differences between 9 a.m. and 3 p.m. temperature, relative humidity and wind speed were created. Thus, 10 predictor time series were created for modelling.

The data was analysed based on the exponential and descending phases of the epidemic overall, and for 6 PHUs (those PHUs reporting <100 cases were excluded), to determine the effect of epidemic phases and locations on the association between climatic factors and case reports. Thus, 14 separate time series analyses were performed.

A PHU-average Spearman correlation coefficient matrix was first calculated to avoid multicollinearity among variables. Then, univariate quasi-Poisson generalized additive models (GAMs) were fit to the cases time series as the outcome and the climatic factors time series as the predictors. Climatic factors with \( P \) value < .1 in univariate analysis in all the PHUs were selected for multivariate analysis. A standard two-stage approach was then applied to evaluate the PHU-specific and NSW-average associations between short-term exposure to climate factors and cases. In the first stage, a quasi-Poisson GAM was used to estimate the association between PHU-specific climate factors and the daily count of cases. A 14-day exponential moving average (EMA) was used to represent the effects of climate factors on cases during the 14 days preceding case reporting. Natural splines of time were included to control short-term temporal trend; its optimal degrees of freedom (df) was chosen based on Quasi AIC (QAIC). In the second stage, a meta regression model with random effects were used to obtain NSW-average risk estimate of meteorological factors.
on cases. To estimate the overall relationship, exposure-response curves were plotted using the GAM with natural spline’s knot set - ting at its median ($df = 2$). A sensitivity analysis was performed by modifying the EMA (14 days to 13 or 15 days), and changing $df$ for natural splines of time (3 to 2 or 4). R4.0.1 software (R Foundation for Statistical Computing) was used to perform all analyses.

3 | RESULTS

The first COVID-19 case in which infection was locally acquired was notified on 26 February 2020. Between 26 February and 31 May, 1,203 locally acquired cases with a residence postcode were notified. Cases were reported from 11 PHUs (range 3–357; Figure 1a); 6 of these reported >100 cases, and climatic data were acquired from 27 weather observation stations within these PHUs.

Based on correlation coefficients, 3 p.m. temperature and relative humidity, and temperature and relative humidity range were excluded from univariate modelling (Figure 1b). Overall, only 9 a.m. temperature (range: 8.05–26.6°C) and 9 a.m. relative humidity (35–100%) entered the final model (Figure 1c). Mean temperature range was higher during the exponential epidemic phase than the descending epidemic phase, whereas the reverse occurred for relative humidity range (Table 1).

Overall, we observed a negative association between COVID-19 cases and relative humidity in both epidemic phases (Table 2), but no association with temperature. A 1% decrease in relative humidity was associated with a 7.7% (95% CI: 0.04–14.8%) and 6.8% (95% CI: 0.4%–12.2%) increase in the pooled estimate of daily counts of COVID-19 in the two epidemic phases, respectively. Heterogeneous effects across PHUs were obvious: a significant positive association between temperature and cases in South Eastern Sydney PHU during the descending epidemic phase (Figure 2a,c), whereas a significant negative association between humidity and cases in Sydney PHU during the exponential epidemic phase (Figure 2b,d), were noted. However, the association between humidity and cases was consistently negative in the epidemic phase- and location-specific analyses (Table 2 and Figure 2).
The exposure-response curves showed that the negative association between cases and relative humidity was more pronounced above 79% and 75% relative humidity in the exponential and descending epidemic phases, respectively (Figure 3). The sensitivity analysis indicated that the associations between cases and relative humidity were robust (Table 3).

4 | DISCUSSION

We found that throughout the epidemic of COVID-19 in NSW, Australia—both during the exponential and descending phases of the epidemic—there was a consistent negative relationship between relative humidity and case occurrence: a 1% decrease in relative humidity was associated with an incidence rate ratio decrease of 1.06 and 1.11 in the exponential and descending phases, respectively.
humidity was predicted to increase cases about 7–8%, with a more pronounced effect at a relative humidity <75–79%. In almost all PHUs this negative relationship between relative humidity and cases was found.

Given that SARS-CoV-2 transmission is thought to be primarily via the respiratory route (Cai et al., 2020), and that coronaviruses are known to be susceptible in the environment (Casanova et al., 2010), the finding of an association with relative humidity is expected. This association might occur via the effect on respiratory aerosols and therefore infectious material remaining airborne for longer; or it could be a more direct effect on the survivability of the virus in the environment. The lack of a consistent association between temperature and COVID-19 cases in this and other studies (Qi et al., 2020)—as well as for SARS-CoV-1 and MERS-CoV cases (Altamimi & Ahmed, 2020; Gardner et al., 2019; Tan et al., 2005)—suggests that it is the former that influences SARS-CoV-2 transmission. This raises an interesting question, and one with potentially profound importance for public health: could increasing relative humidity contribute to a reduction in SARS-CoV-2 infections when infectious individuals mix with susceptible individuals? In the current study—as with other studies conducted to date on SARS-CoV-1, SARS-CoV-2 and MERS-CoV—we used data collected from meteorological recording stations under the assumption that either cases were infected in an outdoors setting, or that ambient outdoors weather conditions are a proxy for the indoors environment (if that is where most infections occur). Measuring the indoors environment is not possible when retrospectively analysing hundreds of disease cases that have occurred in an epidemic across an entire country or state. The conduct of controlled studies of the relationship between COVID-19 cases and factors such as relative humidity is challenging.

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CONFLICT OF INTEREST
Not applicable.

ETHICAL APPROVAL
The authors confirm that the ethical policies of the journal, as noted on the journal’s author guidelines page, have been adhered to. No ethical approval was required as the case notification data was accessed from the public (NSW Government) domain.

ORCID
Michael P. Ward https://orcid.org/0000-0002-9921-4986
Zhijie Zhang https://orcid.org/0000-0002-1276-787X

ENDNOTES
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