

Assessment of weather and atmospheric pollution as a co-factor in the spread of SARS-CoV-2

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Summary. *Background and aim:* COVID-19 is a persistent and ongoing global pandemic caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Non-anthropogenic factors, such as weather conditions and air quality are possible predictors of respiratory diseases, such as COVID-19. Weather conditions may also be a direct cause of biological interactions between SARS-CoV-2 and humans and vary widely between regions. The course of an epidemic is determined by several factors, including demographic and environmental parameters, many of which have an unknown correlation with COVID-19. The goal of this study is to assess the influence of ground surface particulate matter and weather parameters on the dissemination of COVID-19 in Ljubljana, Slovenia. *Methods:* Data on average, minimum and maximum daily temperature, relative humidity; precipitation; sun duration in hours; and daily particle matter (PM10 and PM2.5) was obtained from the Slovenian Environmental Agency. The dataset on the number of daily COVID-19 cases in Ljubljana was obtained from the National Institute of Public Health. Data was divided into three groups: entire dataset; partial lifting of measures (from 1st of June to 30th of September); and less stringent containment measures (from 1st of July to 30th of September). Spearman rank correlation was used to investigate the association between new daily COVID-19 cases and weather data. *Results:* The weather data and the daily new COVID-19 cases did not show any significant correlation during the entire period under investigation, except for PM 10 (0.30). With the beginning of the less stringent containment measures, five of the six weather parameters correlated significantly with the daily cases of COVID-19. Relative humidity showed the highest correlation coefficient (0.48). *Conclusions:* The correlations observed are highly dependent on the local policies that were in force during the period under study. The interaction between weather conditions and human behaviour may also be an important factor in understanding the relationship between weather and the spread of COVID-19. (www.actabiomedica.it)

Key words: SARS-CoV-2, COVID-19; Coronavirus; Weather; Air quality; PM.

Background and aim of the work

The Coronavirus Disease 2019 (COVID-19) is a persistent and ongoing global pandemic that is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Patients of COVID-19 have symptoms that include dry cough, myalgia, fatigue, fever, shortness of breath, diarrhea, anosmia and ageusia (1–5). After its first report in Wuhan, China, it led to a massive loss of life in Europe, especially in Italy, France

and Spain. Due to the lack of available treatment options, attempts have been made worldwide to stem its spread through national lockdowns, quarantines and other similar sanitary measures (6). SARS-CoV-2 has spread to nearly all countries and areas of the world with more than 34 million confirmed cases and more than 1 million deaths (7). The virus is highly transmissible, and the rapid spread of the new SARS-CoV-2 causing COVID-19 is a clear current example of how pathogens can have devastating consequences for health, and to the

economy by overstressing the capacity of intensive care units and the healthcare system (8). The main recommendations for preventing the spread of the infection include regular hand washing, covering the mouth and nose, when coughing and sneezing, and avoiding close contact with persons showing symptoms of respiratory illness (9). The new coronavirus has been reported to spread faster than SARS-CoV and MERS-CoV (10) and it often spreads via coughing, sneezing, touching and breathing (11).

The new dynamics of the outbreaks seem to be highly variable among countries (12). The course of an epidemic is determined by several factors, including demographic and environmental parameters, many of which have an unknown correlation with COVID-19 (13).

Among the non-anthropogenic factors, weather conditions and air quality are possible predictors of respiratory disease, such as COVID-19. Weather conditions may also be a direct cause of biological interactions between SARS-CoV-2 and humans (14) and vary widely between regions. The goal of this study is to access the influence of ground surface particulate matter and weather parameters on the dissemination of COVID-19 in Ljubljana.

Methods

Study area

Ljubljana is the capital of Slovenia and the country's largest city. Ljubljana is located in the centre of Slovenia at the Ljubljana Basin, with an altitude of 285-310 m and a population of approximately 260 000 inhabitants. The area of Ljubljana consists of 168.8 km² on a latitude of 46° 03' 3.89" N and longitude of 14° 30' 18.47" E.

Data Collection

Data on average, minimum and maximum daily temperature, relative humidity; precipitation; sun duration in hours; and daily particle matter (PM₁₀ and PM_{2.5}) was obtained from Slovenian Environmental Agency, Ministry of the Environment and Spatial Planning, Slovenia (<https://meteo.arso.gov.si/met/sl/archive/>).

The dataset represents the period between 4th of March 2020 and 30th of September 2020 in Ljubljana, Slovenia. The dataset on the number of daily COVID-19 cases in Ljubljana was obtained from the National Institute of Public Health, Slovenia (<https://www.nijz.si/sl/dnevno-spremljanje-okuzb-s-sars-cov-2-covid-19>).

Data analysis

The normality of the data was evaluated using Shapiro Wilk's test. As the data on new daily cases of COVID-19 showed non-normal distribution, Spearman rank correlation was used to investigate the association between new daily COVID-19 cases and weather data, using R Studio (version 1.3.1093) with the R package ggplot2 (version 3.3.2).

Results

The number of new daily COVID-19 cases and the total number of cases that have occurred in Ljubljana over time are shown in Fig. 1. The dissemination of COVID-19 started slowly in Ljubljana, with the first case detected in 4th of March, followed by an increase, reaching a total of 175 reported cases by the end of March. The containment of the SARS-CoV-2 epidemic was strongly influenced by the rapid expansion of efforts by health authorities, who adopted strategies to contain the spread in the population. Among the unprecedented containment and mitigation strategies implemented were strict travel restrictions, screening and testing of travellers, isolation and quarantine, and the closure of schools and universities, resulting in an average of three daily cases between 4th of March and 30th of May (Fig. 1 - dark grey zone). From 1st to 30th June, the containment policy was partially lifted and there was an average of 1 new case per day (Fig. 1 - grey zone). With less stringent containment measures, there was an increase in daily cases from 1st of July, with an average of 9 new cases per day and a maximum of 52 new cases on the 24th of September (Fig. 1 - light grey zone).

The daily average temperature was lowest at the end of March at 0.8°C and rose until August, with a maximum average temperature of 26.7°C in July. The

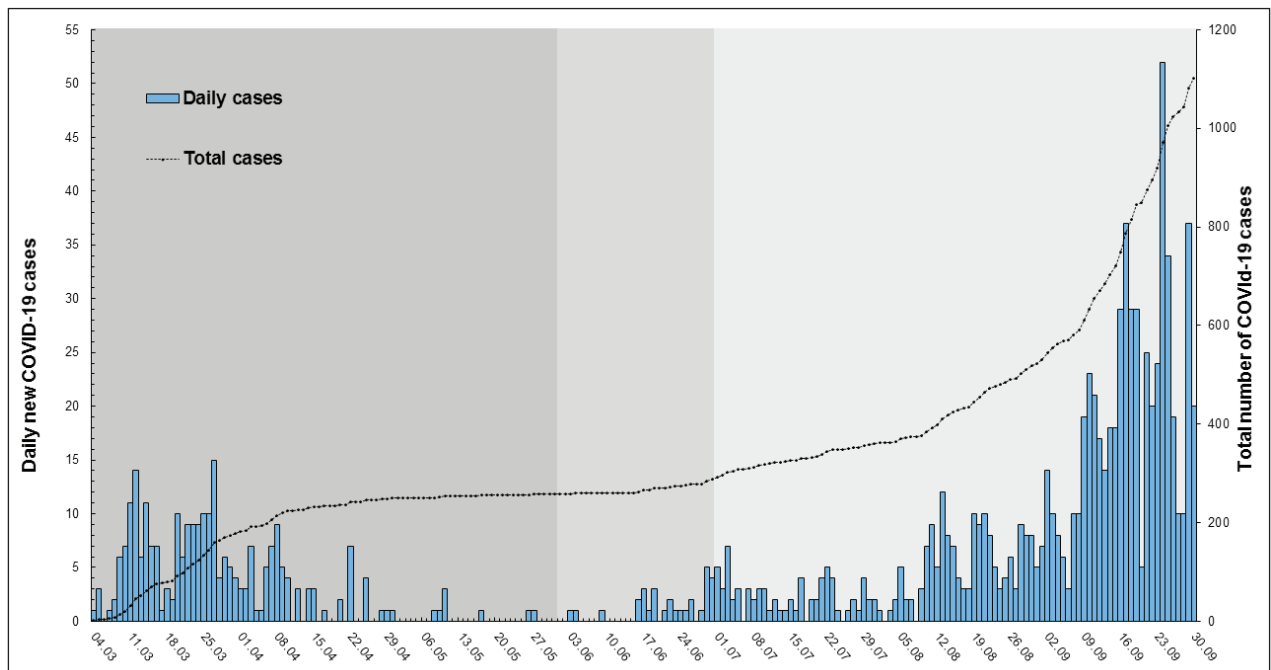


Figure 1. Daily new cases of COVID-19 and total number of COVID-19 cases in Ljubljana, Slovenia from March to September 2019.

average temperature decreased continuously until September. Average relative humidity was lowest during March and April (60.4 % and 50.0 %, respectively) and highest in June (69.3 %). Rainfall did not show significant temporal variation. July was the month with the highest sun duration, with an average of 10.5 hours, while March was the month with the lowest sun duration (6.0 hours). Concentration of PM₁₀ and PM_{2.5} was highest in March (31 $\mu\text{g}/\text{m}^3$ and 17 $\mu\text{g}/\text{m}^3$, respectively) and lowest in June (12 $\mu\text{g}/\text{m}^3$ and 7 $\mu\text{g}/\text{m}^3$, respectively).

Data was divided into three groups: entire dataset; partial lifting of measures (from 1st of June to 30th of September); and less stringent containment measures (from 1st of July to 30th of September). The Spearman rank correlation was used to investigate the association between the new daily COVID-19 cases and six weather parameters. The correlation levels were classified according to Evans, 1996: 0.00 to 0.17 as very weak, 0.20 to 0.39 as weak, 0.40 to 0.59 as moderate, 0.60 to 0.79 as strong and 0.80 to 1.0 as very strong.

The correlation coefficients are summarized in Table 1. The weather data and the daily new COVID-19 cases did not show any significant correlation during the entire period under investigation (from 3th of

March to 30th of October). Significant correlations were not found after the first containment measures were lifted (from 1st of June to 30th of September). With the beginning of the less stringent containment measures (from 1st of July to 30th of September), five of the six weather parameters investigated correlated significantly with the daily cases of COVID-19. The

Table 1. Spearman Rank Correlation coefficients between COVID-19 daily new cases with weather and air quality variables.

Studied variables	Spearman correlation coefficient		
	All months	After 1st of June	After 1st of July
Average daily temperature ($^{\circ}\text{C}$)	0,03	-0,09	-0,35 ***
Minimum daily temperature ($^{\circ}\text{C}$)	0,07	-0,04	-0,31 **
Maximum daily temperature ($^{\circ}\text{C}$)	0,04	-0,04	-0,32 **
Relative Humidity (%)	0,129	0,30	0,48 *
Precipitation (mm)	-0,109	-0,16	-0,06
Sun duration (h)	-0,062	-0,17	-0,28 **
PM 10 [$\mu\text{g}/\text{m}^3$]	0.30 **	0.35 ***	0.35 ***
PM 2.5 [$\mu\text{g}/\text{m}^3$]	0.27	0.28 **	0.28 **

Correlation is significant at the * 0.05 level (2-tailed), ** 0.01 level (2-tailed) and *** 0.001 level (2-tailed)

average, minimum and maximum daily temperatures and the duration of sun showed a negative significant correlation with the daily cases of COVID-19, which implies that as the temperature and sun duration decrease, the number of cases of COVID-19 increased. Relative humidity showed the highest correlation coefficient (0.48) with a significant moderately positive correlation with the daily cases of COVID-19.

Discussion

The observed correlations are consistent with previous studies that found an association between weather variables and the transmission of Respiratory Syncytial Virus (RSV) (16), SARS (17), and recently SARS-CoV-2. These studies have shown associations between the cases of COVID-19 and temperature, relative humidity and wind speed (14,18–20). Topsepu et al. (2020) reports that minimum and maximum temperature, and humidity are not associated with new cases of COVID-19, however the present study has found correlations with the above factors. In the present study, correlations were found with similar coefficients as reported by ahin, 2020. The average daily temperature showed the largest negative correlation coefficient (-0,35), suggesting lower temperatures contribute to higher new daily cases of COVID-19. Sun duration has a correlation coefficient of -0,28. It is possible that sun duration influences human behaviour, as people might spend more time indoors and in social gatherings with shorter daily sun duration periods. Other studies have used solar radiation as a variable and have shown statistically significant correlations (19). While the connection between solar radiation intensity and duration are not explored in the current study, these variables could complement each other considering people are more likely to gather outside in social events during sunny weather and inside during cloudy weather (21).

Studies of how meteorological parameters affect the spread of COVID-19 at national and regional level have become an important line of research recently. In many of these studies, the results differ. The differences are likely to be due to local dynamics, differences in data collection procedure and imposed restrictions

in each studied site. Data on the current epidemic is subject to a large degree of uncertainty and there is a global underestimation of the number of confirmed cases (22). Briz-Redón and Serrano-Aroca, 2020 highlighted the need to consider non-meteorological factors, including population density and age structure of each region. Especially population density as well as movement of people within a certain geographical area are important factors contributing to the spread of COVID-19 as was shown in other studies (21). Non-meteorological factors might aid to explain the difference in results different studies. In the current study, the correlation between daily concentration of particulate matter (PM) in the air (PM_{10} and $PM_{2.5}$) and the number of daily reported infections was also investigated. PM particles were previously associated with viral transmission of viruses including the avian influenza virus and measles virus (23). PM particles enter into the lungs and any attached SARS-CoV-2 particles can therefore invade the lower part of the respiratory tract directly (24). In this study, daily PM concentrations have also shown a significant correlation with new daily reported cases of COVID-19 in the three data groups analysed (TABLE 1). The observed positive correlation for PM_{10} and $PM_{2.5}$ supports previous studies showing similar results (25–27). The fine PM particles can affect the upper respiratory pathways, causing inflammation and thus increasing the risk of infection and possible worse disease outcomes(28,29). A recent study performed in 33 European countries also showed that high levels of particulate and greenhouse gases are associated with SARS-CoV-2 and that nitrogen oxides and PM_{10} are the pollution factors with the strongest correlation with COVID-19 cases and related deaths (30).

The current study has some limitations. The study was conducted in a single geographical region (Ljubljana, Slovenia) and the findings might be site specific. The study period is relatively short, however it encompasses three sub-periods with different policies. It is also important to stress that association does not mean causation. Despite the limitations, the current study contributes to the growing literature on the associations between COVID-19 cases and weather/pollution factors.

Conclusion

Weather and concentrations of PM particles in the air seem to be an important factor in determining the incidence rate of COVID-19 in Ljubljana, Slovenia. The authors of the current study have found correlations between weather variables and PM particles with new cases of COVID-19. The correlations between the different studies vary and further research is needed to investigate the role of meteorological and air quality variables in the spread of the COVID-19 epidemic. The associations observed are highly dependent on the local policies that were in force during the period under study. The interaction between weather conditions and human behaviour may also be an important factor in understanding the relationship between weather and the spread of COVID-19.

Availability of data and materials: The data used in this publication can be found at <https://www.nijz.si/> and <https://www.arso.gov.si/>.

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