



香港城市大學  
City University of Hong Kong

專業 創新 胸懷全球  
Professional · Creative  
For The World

## CityU Scholars

### Meteorological Factors Facilitated Increased Legionnaires' Disease Notifications and Mortality Pre-COVID-19 and COVID-19 in Hong Kong

Zhang, Yin; Chen, Frank Y.; Tso, Geoffrey K.F.; Yang, Lin

**Published in:**

Journal of Infectious Diseases and Treatment

**Published:** 01/01/2022

**Document Version:**

Final Published version, also known as Publisher's PDF, Publisher's Final version or Version of Record

**License:**

CC BY

**Publication record in CityU Scholars:**

[Go to record](#)

**Publication details:**

Zhang, Y., Chen, F. Y., Tso, G. K. F., & Yang, L. (2022). Meteorological Factors Facilitated Increased Legionnaires' Disease Notifications and Mortality Pre-COVID-19 and COVID-19 in Hong Kong. *Journal of Infectious Diseases and Treatment*, 8(8), Article 040. <https://www.primescholars.com/articles/meteorological-factors-facilitated-increased-legionnaires-disease-notifications-and-mortality-precovid19-and-covid19-in-hong-kong-114297.html>

**Citing this paper**

Please note that where the full-text provided on CityU Scholars is the Post-print version (also known as Accepted Author Manuscript, Peer-reviewed or Author Final version), it may differ from the Final Published version. When citing, ensure that you check and use the publisher's definitive version for pagination and other details.

**General rights**

Copyright for the publications made accessible via the CityU Scholars portal is retained by the author(s) and/or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights. Users may not further distribute the material or use it for any profit-making activity or commercial gain.

**Publisher permission**

Permission for previously published items are in accordance with publisher's copyright policies sourced from the SHERPA RoMEO database. Links to full text versions (either Published or Post-print) are only available if corresponding publishers allow open access.

**Take down policy**

Contact [lbscholars@cityu.edu.hk](mailto:lbscholars@cityu.edu.hk) if you believe that this document breaches copyright and provide us with details. We will remove access to the work immediately and investigate your claim.



# Meteorological Factors Facilitated Increased Legionnaires' Disease Notifications and Mortality Pre-COVID-19 and COVID-19 in Hong Kong

Yin Zhang<sup>1</sup>, Frank Y. Chen<sup>1\*</sup>, Geoffrey K.F. Tso<sup>1</sup>, Lin Yang<sup>2</sup>

<sup>1</sup>Department of Management Sciences, City University of Hong Kong, Hong Kong

<sup>2</sup>Department of Health and Social Sciences, The Hong Kong Polytechnic University, Hong Kong

## ABSTRACT

Annual notification number of Legionnaires' disease (LD) increased from 66 cases in 2015 to 104 cases in 2020 in Hong Kong, with a case fatality rate (CFR) of 17.3% in 2020. This study investigated possible meteorological factors associated with confirmed LD cases and deaths. The negative binomial regression model was used for monthly LD confirmed cases and the Poisson regression model was used for monthly LD mortality cases. A decision tree model was adopted to identify the thresholds of meteorological factors if any. The confirmed LD cases were highest in July while the LD mortality was highest in August. A negative binomial regression model confirmed that maximum air temperature ( $P=0.081$ ,  $RR=1.3$ ,  $95\% CI=0.97-1.75$ ) and rainfall ( $P=0.009$ ,  $RR=1.02$ ,  $95\% CI=1.0004-1.003$ ) were positively correlated with the increase in confirmed LD cases. A Poisson regression model confirmed that maximum air temperature ( $P=0.034$ ,  $RR=1.71$ ,  $95\% CI=1.04-2.80$ ) was positively correlated with the surge in LD mortality. When rainfall exceeds 78.8 mm, the public should be alerted of the increased risk of contracting LD. Temperature and rainfall were positively associated with the confirmed LD cases in Hong Kong.

**Keywords:** Legionnaires' disease; Meteorological causes; Negative binomial regression; Poisson regression; Decision tree

## INTRODUCTION

Legionnaires' disease (LD) ranked fourth (17.3%) in terms of Case Fatality Rate (CFR) among the 13 notifiable diseases with all other causes (AOC) in Hong Kong in 2020 (**Supplementary Table S1**). The associations of environmental factors with confirmed Legionnaires' disease (LD) cases have been reported in the literature; Tanimoto, et al. found apparent evidence of *Legionella* spp. bacteria being transmitted via water mist in hot spring spas among the ageing populations in Japan [1]. Lam, et al. found that *Legionella* spp. bacteria widely colonized in cooling towers in Singapore, which has abundant high rise buildings [2]. With the COVID-19 lockdown and subsequent reopening, Rhoads, et al. expressed concern that extended water stagnation in buildings would increase the number of confirmed LD cases, and Palazzolo, et al. reported that an Italian male aged 40 years who worked as

a restaurant dishwasher contracted LD 3 days after the COVID-19 lockdown restriction was eased in Rome [3,4]. O'Connor, et al. developed a PCR test kit to detect bacteria in the *Legionella* genus in water with a single test. Hozalski, et al. suggested that flushing of stagnant water after the COVID-19 shutdown could reduce the *Legionella* infection risk, and Lancaster, et al. encouraged building management personnel to monitor water stagnancy before reopening to reduce morbidity and mortality [5-7].

The literature reports clinical epidemiological evidence of LD and COVID-19 pneumonia coinfection, with *Legionella* spp. being the main species isolated in Europe, the United States (US), and Canada [8-12]. Dey, et al. reported LD and COVID-19 coinfection in patients, similar to that of "1918 Spanish flu" bacterial coinfection. Lai, et al. warned that up to 50% of patients with LD and COVID-19 coinfection do not survive [13,14].

<b>Received:</b>	27-September-2022	<b>Manuscript No:</b>	IPJIDT-22-14441
<b>Editor assigned:</b>	29-September-2022	<b>PreQC No:</b>	IPJIDT-22-14441 (PQ)
<b>Reviewed:</b>	13-October-2022	<b>QC No:</b>	IPJIDT-22-14441
<b>Revised:</b>	18-October-2022	<b>Manuscript No:</b>	IPJIDT-22-14441 (R)
<b>Published:</b>	25-October-2022	<b>DOI:</b>	10.36648/2394-9988-8.8.40

**Corresponding author** Frank Y. Chen, Department of Management Sciences, City University of Hong Kong, Hong Kong, E-mail: youhchen@cityu.edu.hk

**Citation** Zhang Y, Chen FY, Tso GKF, Yang L (2022) Meteorological Factors Facilitated Increased Legionnaires' disease Notifications and Mortality Pre-COVID-19 and COVID-19 in Hong Kong. J Infect Dis treat. 8:40.

**Copyright** © 2022 Zhang Y, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited

Other works in the literature identified climatic variables and seasons associated with the number of confirmed LD cases. Ricketts, et al. explored quarterly and annual data and found some evidence suggesting that the effect of the interaction of relative humidity and temperature on the increased number of confirmed LD cases in England was highly significant. Precipitation increased the confirmed LD cases in Taiwan. Brandsema, et al. found an association of warm and wet weather with an increased number of confirmed LD cases in the summer of 2010 in the Netherlands [15-17]. Oda, et al. reported a male aged 62 years contracting LD after the Heavy Rain Event of July 2018 in Japan [18]. Temperature, rainfall, and atmospheric pressure have been associated with the numbers of confirmed LD cases in Denmark, Germany, Italy and the Netherlands [19]. The average temperature was significantly associated with the number of confirmed LD cases in South Korea [20]. Simmering, et al. analyzed LD cases in the middle Atlantic region and confirmed that LD cases were more common in summer in the US [21]. Falconi, et al. observed a seasonal pattern from mid-September to mid-August in the number of confirmed LD cases after 2003 in the US [22]. Ozeki, et al. found two seasonal peaks of confirmed LD cases between June and November 2005-2009 in both Tokyo and Saitama, Japan [23].

Previous literature focused on the association of the number of confirmed LD cases with environmental factors, epidemiological factors, or meteorological factors in Asia, Europe, or North America. Accordingly, our research aims to fill the knowledge gap and analyze the number of confirmed LD cases and deaths in association with potential meteorological factors in HK.

## METHODS

### Data

We obtained

- Daily death micro-data sets from the Census and Statistical Department of HK from 2015-2020,
- Monthly meteorological variables from the HK Observatory Department from 2015-2021 and
- Monthly number of confirmed LD cases from the Department of Health from January 2015 to November 2021 [24-25]. We retrieved LD deaths by using the International Classification of Disease, 10<sup>th</sup> revision (ICD-10) A48.1 in the death registry data from the Census and Statistics Department of Hong Kong. All methods were performed in accordance with the relevant guidelines and regulations.

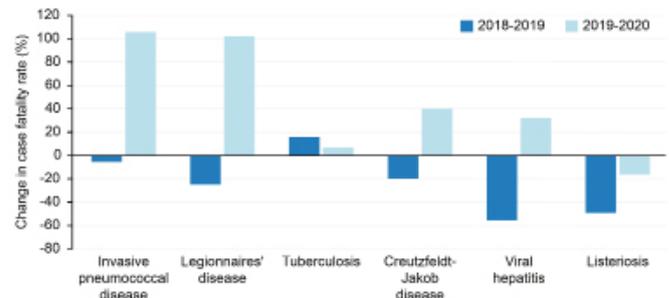
### Statistical Analysis

We employed negative binomial regression to model our raw monthly confirmed LD case as the dependent variable considering raw meteorological factors as independent variables since we found that the raw monthly confirmed LD cases are over dispersed counts variables where the mean of the confirmed LD cases does not equal the variance confirmed LD cases. While, we used Poisson regression to model raw monthly LD deaths with raw meteorological variables, because the mean and variance of the LD deaths are almost the same. Finally, we constructed a decision tree to identify possible weather thresholds for public policy decision making regarding LD.

## RESULTS

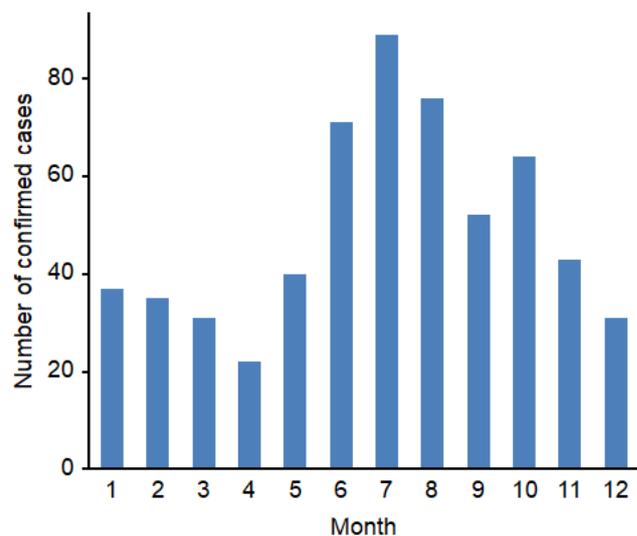
### Confirmed Cases Mortality

LD ranked the fourth (17.3%) in terms of CFR among the 13 notifiable diseases with all other cause (AOC) mortality data in HK in 2020. The CFR of LD more than doubled (101.9%) in HK from 2019-2020 (**Figure 1**), when the COVID-19 outbreak began.



**Figure 1:** Annual change in the case fatality rate of the 6 leading causes of death from 2018-2020 in Hong Kong.

A total of 591 confirmed LD cases were reported in HK from January 2015 to November 2021. We found that the confirmed LD cases increased in HK during this time (**Figure 2**).



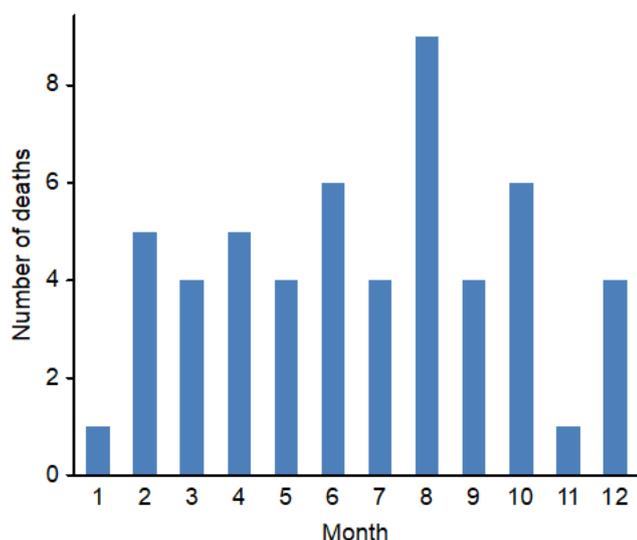
**Figure 2:** The bar chart shows the accumulated monthly number of confirmed LD cases. We can see that July had the largest accumulated number of confirmed LD cases in HK, 2015-2020.

June to August had the largest number of confirmed LD cases (40%), and the summer month of July accounted for the largest number of accumulated confirmed LD cases (15%).

The annual rate of confirmed LD cases increased from 0.88 to 1.4 per 100,000 standard populations from 2015 to 2018 and remains 1.4 PTSP in 2018, 2019 and 2020, respectively. An abnormal surge in the number of monthly confirmed LD cases (21 cases) in February 2020 is shown in **Supplementary Figure S1**. This was the month immediately after the first case of COVID-19 case was reported in HK in January 2020.

53 LD deaths (case fatality rate 10.1%) were identified in HK from 2015 to 2020. We found that the annual increase in LD CFR doubled from 2019 to 2020 in HK after the COVID-19 outbreak. Leung, et al. found a more than 4-fold increase in the number of confirmed LD cases from 2005 to 2015 [26]. August had the larg-

est number of accumulated LD deaths in our study period (Figure 3).



**Figure 3:** The bar chart shows the accumulated monthly number of LD-related death cases. We can see that August had the largest number of accumulated LD-related deaths in HK, 2015-2020.

## Descriptive Analysis of Confirmed LD Cases and Mortality with Monthly Weather Variables

We now examined the associations of confirmed LD cases and mortality in HK with the city's meteorological variables, described

**Table 1:** Negative binomial model results for the number of confirmed LD cases associated with monthly weather variables. CI, confidence interval; RR, relative risk; S.E., Standard Error; 95% CI, 95% Confidence Interval of relative risk. \*p<0.1, \*\*p<0.05, \*\*\*p<0.01. N=591 number of confirmed LD cases.

Variable	Coefficient	S.E.	Pr(>z)	RR	95% CI
Intercept	0.478	1.625	0.769	1.61	0.07-39
Maximum air temperature	0.264	0.151	0.081*	1.3	0.97-1.75
Average air temperature	-0.231	0.154	0.135	0.79	0.60-1.075
Relative humidity	0.493	1.871	0.792	0.61	0.02-23
Rainfall	0.002	0.001	0.009***	1.02	1.0004-1.003

The relative risk associated with the maximum air was 1.3 while the relative risk associated with the rainfall amount was 1.02. This confirmed that monthly maximum air temperature was the most important factor positively correlated to the number of monthly confirmed LD cases, followed by rainfall. To examine the effect of the month of July, we defined the month of July of every year as a categorical variable (true/false, true if the confirmed case occurred in July, false if otherwise). The July effect was statistically significant (P=0.025), as shown in Supplementary This quantitatively confirmed our visual finding that July had the largest number of accumulated monthly confirmed LD cases, as shown in Figure 3. Furthermore, to examine the February 2020 spike in confirmed LD cases, we defined February 2020 as a categorical variable (true/false, true if the confirmed case occurred in Feb-

below. **Supplementary Table S2** shows the monthly number of confirmed LD cases with meteorological variables covering 83 months in HK from 2015-2021. **Supplementary Table S3** shows monthly LD mortality with meteorological variables covering 72 months in HK from 2015-2020. Since the LD mortality data we retrieved were daily data, we stratified the LD-related mortality into months per year. We aimed to determine whether the number of confirmed LD confirmed cases and related deaths in HK were associated with monthly meteorological variables, including maximum air temperature (in °C), average air temperature (in °C), relative humidity and rainfall (in mm)

## Negative Binomial Regression for LD Confirmed Cases

Previous studies used Poisson regression to model confirmed LD cases. On the basis of their approach, we conducted the goodness of fit and Wald's statistics tests, which rejected the null hypothesis (**Supplementary Appendix D**). Then, we constructed a negative binomial regression model, and the results were confirmed by the t test, log-likelihood ratio test, and  $\chi^2$  tests (**Supplementary Appendix E**).

Using the number of confirmed LD cases in the 83 month dataset from January 2015 to November 2021, we constructed a negative binomial regression model to study the marginal effects of air temperature, relative humidity, and rainfall on confirmed numbers. **Table 1** shows that the maximum air temperature and rainfall amount were statistically associated, but the relative humidity and average air temperature were not [22,27,28].

ruary 2020, false if otherwise). Similarly, the February 2020 spike was statistically significant (P=0.016) (**Table S4-S7**).

The relative risk associated with the February 2020 spike was 3.27 (95% CI 1.24-8.58). This further confirmed the abnormally large number of confirmed LD cases in February 2020 amid the COVID-19 pandemic, as shown in **Supplementary Figure S1**.

## Poisson Regression for LD Mortality

The 72 month monthly LD-related mortality data had a Poisson distribution because the mean (0.74) almost equaled the variance (0.79). We also confirmed the hypothesis by the goodness of fit test (**Supplementary Appendix F**). Poisson regression (**Supplementary Appendix G**) was applied to study the marginal effects

of air temperatures, relative humidity, and rainfall on mortality numbers. **Table 2** shows that the factors of maximum air temperature, average air temperature, and rainfall amount were statistically significant, but relative humidity was not. The relative

risk associated with the maximum air temperature equaled 1.71. This confirmed that monthly maximum air temperature was the most important factor positively related to the number of monthly LD deaths (**Table S8 -S9**).

**Table 2:** Poisson model results for the number of LD-related deaths associated with monthly weather variables. CI, confidence interval; RR, relative risk; S.E., Standard Error; 95% CI, 95% Confidence Interval of relative risk. \*p<0.1, \*\*p<0.05, \*\*\*p<0.01. N=53 number of LD-related deaths.

Variable	Coefficient	S.E.	Pr(>z)	RR	95% CI
Intercept	-6.585	2.622	0.012**	0.001	8×10 <sup>-6</sup> -0.24
Maximum air temperature	0.536	0.252	0.034*	1.71	1.04-2.80
Average air temperature	-0.424	0.253	0.093*	0.65	0.40-1.07
Relative humidity	3.14	2.397	0.19	23.11	0.21-2537
Rainfall	-0.002	0.001	0.035**	0.997	0.9957-0.9998

## Decision Management for LD

Considering that maximum monthly air temperature and rainfall amount were important factors that were positively associated with the number of monthly confirmed LD cases, we built a decision tree model [29] (**Supplementary Appendix G**). When rainfall reaches the “danger” zone, i.e., when the amount of rainfall is above 78.8 (in mm) and the Gini impurity of rainfall equals 3.4%, public messaging should alert the general public and healthcare providers to the risk of new-onset LD (**Supplementary Figure S2**). We found that a large number of confirmed LD cases occurred when rainfall was higher than or equal to 334.8 (in mm) on the right side of the tree in **Supplementary Figure S3**.

## DISCUSSION

Our retrospective study analyzed a total of 591 confirmed LD cases in HK from 2015-2021 and 53 LD-related deaths in HK from 2015-2020. The LD case fatality rate remained high, at over 10%. An abnormal increase in the number of confirmed LD cases occurred in February 2020, which was the month immediately following that of the first reported COVID-19 case in HK (January 2020). An increase in the LD notification number was observed from 2015 to 2020 (157%), and the annual increase of CFR of LD doubled (101.9%), from 2019 to 2020, after the COVID-19 outbreak. Overall, June to August had the largest number of confirmed LD cases (40%), which is in accordance with that of Ricketts, et al., 15 and the summer month of July accounted for the largest number of accumulated confirmed LD cases (15%) from 1 January 2015 to 30 November 2021. In addition to HK, North America, Europe, and Australia also experienced increases in the number of confirmed LD cases amid the COVID-19 pandemic [30]. We also found that the number of confirmed LD cases and related deaths had a lag of approximately one month, from July to August, which is in accordance with Riddell, et al. who stated that the incubation period of *Legionella spp.* is 2-10 days. We also found that the LD-related death characteristics by gender and age are highly consistent with that of the confirmed LD cases in Leung, et al. [26].

As reported in the previous study [17], warm weather is an important factor in LD development [22]. Regarding the number of monthly confirmed LD cases in HK from January 2015-November 2021, our study data quantitatively supplements that of Leung, et al. in terms of the number of confirmed LD cases in HK (**Supple-**

**mentary Table S4**). Furthermore, we are the first to report that the February 2020 spike was positively correlated with an abnormally large number of confirmed LD cases in HK in 2020; February 2020 was the month immediately following that of the first reported case of COVID-19 in HK (January 2020). In recent years, there has been increasing interest in studying the meteorological factors potentially associated with the increase in the number of confirmed LD cases. Unexpectedly, our study found that in HK, relative humidity ( $P>0.05$ ) was not significantly associated with the number of confirmed LD cases or related deaths; these results are in contrast with those of Ricketts, et al. who found a significant association with humidity in England and Wales, but in accordance with those of Chen, et al. in Taiwan [15,16]. Temperature and amount of rainfall, on the other hand, are related to the confirmed LD cases in HK, which is in accordance with studies in Scotland, Netherlands, Taiwan, Denmark, and Seoul Korea [17,19,20,26,27].

Strong seasonal patterns were observed in the monthly data for maximum air temperature, average air temperature, relative humidity, and rainfall, though the two air temperature variables were highly correlated visually, which is in accordance with Ozeiki, et al. Our initial simple analysis using 83 month average (83 MA) and relative risk found that the probability of contracting LD was inconclusive; for example, the relative risks associated with the monthly maximum air temperature above the 83 MA (26.9°C, RR=0.98, 95% CI=0.88-1.07), the monthly average air temperature above the 83 MA (24.2°C, RR=1.03, 95% CI=0.93-1.13), relative humidity and rainfall were inconclusive. Likewise, we found that the probabilities of dying from LD were increased by 72% and 62% when exposed to a monthly maximum air temperature above the 72 MA (26.7°C, RR=1.72, 95% CI=1.06-2.79) and a monthly average air temperature above the 72 MA (24.05°C, RR=1.62, 95% CI=1.014-2.595); however, the results of relative humidity and rainfall were inconclusive (RR=0.65, 95% CI=0.416-1.018; RR=1.03, 95% CI=0.658-1.620), respectively (**Supplementary Appendix H**). Therefore, we further used more appropriate statistical models to analyze the raw number of confirmed LD cases (instead of transformed variable) as the response variable and raw weather variables (instead of transformed variables) as the explanatory variables to achieve conclusive results. Our study is the first to use negative binomial regression to model the number of confirmed LD cases and confirm that maximum air tem-

perature is a robust risk factor positively related to the number of monthly confirmed LD cases ( $P=0.081$ ,  $RR=1.3$ ,  $95\% CI=0.71-1.75$ ). Rainfall was also positively related to the number of monthly confirmed LD cases with a relative risk marginally higher than one ( $P=0.009$ ,  $RR=1.02$ ,  $95\% CI=1.0004-1.003$ ). Furthermore, our Poisson regression model confirmed that maximum air temperature was positively related to the number of LD-related deaths ( $P=0.034$ ,  $RR=1.71$ ,  $95\% CI=1.04-2.80$ ) [31,32].

From a public healthcare management policy perspective, our retrospective study suggests that the local government should inform the general public more about LD risk in HK. Frequent disinfection of water pipes in buildings during COVID-19 lockdowns should be implemented before reopening to prevent LD. Testing for LD and COVID-19 coinfection are also suggested to avoid missing a potential LD case in a COVID-19 patient. These are ongoing public health concerns. Rainfall exceeding 78.8 (in mm) is likely to increase the likelihood of contracting LD in HK, which is in accordance with Oda, et al. [18]. We hypothesized that during the hot summer months (June-August) and rainy days in Hong Kong, more people tend to stay indoors longer with the air conditioning turned on in the office or at home in a typical summer month [29]. This could potentially result in people inhaling contaminated water aerosols released from the air conditioning [33]. As such, this could potentially increase the risk of contracting and dying from LD during the hot summer months. However, this hypothesis should be tested by future study. Weather related risk alerts should be disseminated from the HK Observatory Department to the general public and healthcare professionals when the weather risk threshold identified in our study is reached to prevent LD in HK; government should also educate people on regular air conditioning maintenance during hot summers to minimize confirmed LD cases and deaths in HK.

## CONCLUSION

The annual case fatality rate of LD doubled from 2019 to 2020 in HK after the COVID-19 outbreak. The risk of contracting LD in July ( $P=0.025$ ,  $RR=1.81$ ) was 81% higher than the risk in any other month. Negative binomial regression confirmed that maximum air temperature ( $P=0.081$ ,  $RR=1.3$ ) and rainfall ( $P=0.009$ ,  $RR=1.02$ ) were positively related to the number of confirmed LD cases. Poisson regression found that maximum air temperature ( $P=0.034$ ,  $RR=1.71$ ) was positively correlated to the number of LD-related deaths. From a public policy perspective, the general public and healthcare professionals should be alerted when the amount of rainfall increases above 78.8 (in mm), which will increase the likelihood of contracting LD in HK because people would be highly likely or likely to stay indoors longer during rainy days and hot summers with air conditioning on for potential inhalation of contaminated air aerosols.

## AUTHOR CONTRIBUTIONS STATEMENT

Y.Z. conceived and designed the analysis; contributed analysis tools; conducted the analysis; drafted the paper and revised the paper. F.C. conceived and designed the analysis; reviewed and revised the paper; and managed the project. G.T. conceived and designed the analysis; collected data; reviewed and revised the paper. L.Y. reviewed and revised the paper; checked compliance. All authors reviewed the manuscript.

## DECLARATION OF COMPETING INTEREST

The authors declare that there are no competing interests.

## DATA AVAILABILITY DECLARATION

Some examples of data availability statements are given below: The data that support the findings of this study are available:

- From [the Census and Statistical Department, Hong Kong, SAR, China]: Daily mortality per person micro data sets from the Census and Statistical department in HK 2015-2020,. Restrictions apply to the availability of these data, which were used under license for this study. Such data can be obtained *via* a direct request to the Census Department (with a certain fee).
- From the Department of Health: Monthly legionaries' disease numbers from January 2015 to November 2021 are available. The number of notifiable infectious diseases by month is available from the Department of Health, The Government of the Hong Kong Special Administrative Region. January 2015 to December 2021.

## DECLARATION OF FUNDING SOURCES

This research did not receive any specific grant from funding agencies in the public, commercial, or not for profit sectors.

## ACKNOWLEDGEMENTS

We thank the Census and Statistical Department, Government of Hong Kong Special Administrative Region, for providing the micro data sets used in our research. We thank American Journal Experts (AJE) for English language editing on this paper.

## REFERENCES

1. Tanimoto T, Takahashi K, Crump A (2021) Legionellosis in Japan: A self-inflicted wound? *Intern Medicine* 60(2): 173-180.
2. Lam MC, Ang LW, Tan AL, James L, Goh KT (2011) Epidemiology and control of legionellosis, Singapore. *Emerg Infect Dis* 17(7): 1209-15.
3. Rhoads WJ, Hammes F (2021) Growth of *legionella* during COVID-19 lockdown stagnation. *Environ Sci Water Res Technol* 7: 10-15.
4. Palazzolo C, Maffongelli G, Abramo A, Lepore L, Mariano A, et al. (2020) *Legionella* pneumonia: Increased risk after COVID-19 lockdown? Italy, may to june. *Euro Surveill* 25(30): 2001372 (2020).
5. O'Connor O, Minogue E (2021) Urgency of rapid *legionella* detection post-COVID-19 lockdowns: An interview with elizabeth minogue. *Biotechniques* 71(5): 547-549.
6. Hozalski RM, LaParaet TM, Zhao X, Kim T, Waak MM, et al. (2020) Flushing of stagnant premise water systems after the covid-19 shutdown can reduce infection risk by *legionella* and mycobacterium spp. *Environ Sci Technol* 54(24): 15914-15924.
7. Lancastern EC, Lee J (2022) Potential environmental and health risk when returning to normal amidst COVID-19 vaccination. *Curr Opin Environ Sci Heal* 26: 100328.

8. Fattorini L, Creti R, Palma C, Pantosti A (2020) Bacterial coinfections in COVID-19: An underestimated adversary. *Ann Ist Super Sanita* 56 (3): 359-364.
9. Chalker VJ, Adler H, Ball R, Naike F, Day J, et al. (2021) Fatal co-infections with SARS-COV-2 and *legionella* pneumophila, England. *Emerg Infect Dis* 27(11): 2950.
10. Allam C, Gaymard A, Descours G, Ginevra C, Josset L, et al. (2021) Co-infection with *legionella* and sars-cov-2, france, march 2020. *Emerg Infect Dis* 27(11): 2864-2868.
11. Subedi Y, Haas C J (2021) *Legionella* coinfection in a patient with COVID-19 pneumonia. *Cureus* 13(8): e17356.
12. Chaudhary R, Bondy L, Zeeshan N, Mrkobrada M (2020) *Legionella* co-infection in a patient with covid-19. *Off J Assoc Med Microbiol Infect Dis Can* 5(4): 261-263.
13. Dey R, Ashbolt NJ (2020) *Legionella* infection during and after the COVID-19 pandemic. *ACS ES T Water* 1(1): 13-14.
14. Lai CC, Wang CY, Hsueh PR (2020) Co-infections among patients with COVID-19: The need for combination therapy with non-anti-sars-cov-2 agents? *J Microbiol Immunol Infect* 53(4): 505-512.
15. Ricketts KD, Charlett A, Gelb D, Lane C, Lee JV, et al. (2009) Weather patterns and legionnaires' disease: A meteorological study. *Epidemiol Infect* 137(7): 1003-1012.
16. Chen NT, Chen MJ, Guo CY, Chen KT, Su HJ (2014) Precipitation increases the occurrence of sporadic legionnaires' disease in Taiwan. *PLoS One* 9: e114337.
17. Brandsema P, Euser S, Karagiannis I, Boer JWD, Hoek WVD (2014) Summer increase of legionnaires' disease 2010 in the Netherlands associated with weather conditions and implications for source finding. *Epidemiol Infect* 142(11): 2360-2371.
18. Oda N, Hirahara T, Fujioka Y, Mitani R, Takata I (2019) *Legionella* pneumonia following the heavy rain event of July 2018 in Japan: A case report. *Intern Medicine* 58(19): 2825-19.
19. Beauté J, Sandin S, Uldum A, Rota MC, Brandsema P, et al. (2016) Short-term effects of atmospheric pressure, temperature, and rainfall on notification rate of community-acquired legionnaires' disease in four European countries. *Epidemiol Infect* 144(16): 3483-3493.
20. Park SH, Jin YH, Ahn MJ, Han SH, Kim HS, et al. (2019) Epidemiology of *legionella* and climatic variables in Seoul, Korea. *J Bacteriol Virol* 49(2): 59-68.
21. Simmering JE, Polgreen LA, Hornick DB, Sewell DK, Polgreen PM (2017) Weather-dependent risk for legionnaires' disease, United States. *Emerg Infect Dis* 23(11): 1843-1851.
22. Falconi TA, Cruz M, Naumova E (2018) The shift in seasonality of legionellosis in the USA. *Epidemiol Infect* 146 (14): 1824-1833.
23. Ozeki Y, Yamada F, Saito A, Kishimoto T, Tannoet S, et al. (2012) Seasonal patterns of legionellosis in saitama, 2005-2009. *J Infect Dis* 65(4): 330-333.
24. Monthly weather summary (January 2015-December 2021) data sets (2021).
25. Number of notifiable infectious diseases by month (January 2015-December 2021) data sets (2021).
26. Leung YH, Lam CK, Cheung YY, Chan CW, Chuang SK (2020) Epidemiology of legionnaires' disease, Hong Kong, China, 2005-2015. *Emerg Infect Dis* 26(8): 1695-1702.
27. Dunn CE, Rowlingson B, Bhopal R, Diggle P (2013) Meteorological conditions and incidence of legionnaires' disease in Glasgow, Scotland: Application of statistical modelling. *Epidemiol Infect* 141(4): 687-696.
28. Lawless JF (1987) Negative binomial and mixed poisson regression. *The Can J Stat Revue Can de Stat* 15(4): 209-225.
29. Tso GK, Yau KK (2007) Predicting electricity energy consumption: A comparison of regression analysis, decision tree and neural networks. *Energy* 32(9): 1761-1768.
30. Recent legionnaires' disease outbreaks (2021).
31. Riddell S, Goldie S, Hill A, Eagles D, Drew TW (2020) The effect of temperature on persistence of SARS-COV-2 on common surfaces. *Virol J* 17(1): 1-7.
32. Ranganathan P, Aggarwal R, Pramesh C (2015) Common pitfalls in statistical analysis: Odds versus risk. *Perspect Clin Res* 6(4): 222-4.
33. Dondero TJ, Rendtorff RC, Mallison GF, Weeks RM, Levy JS, et al. (1980) An outbreak of legionnaires' disease associated with a contaminated air-conditioning cooling tower. *New Engl J Med* 302(7): 365-370.