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# ***Examining the correlation between the weather conditions and COVID-19 pandemic in Galicia***

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## ***5.1 Introduction***

In December 2019, a new severe respiratory coronavirus infection was detected for the first time in Wuhan, capital of Hubei Chinese province [1–3,17]. Initially, most cases were found around the Huanan Seafood Wholesale Market in Jiangnan District, where live animals are also traded [4]. However, in the space of a month and a half, COVID-19 spread to all Chinese provinces and the rest of the world. On 17 March 2020, the World Health Organization (WHO) officially declared COVID-19 as a pandemic caused by an epidemic. The disease is an RNA virus belonging to the Coronaviridae family and of the order Nidovirales, known as SARS-COV-2 [5,6], and the main symptoms of the infection include viral pneumonia, fever, dry cough, fatigue, pain, nasal congestion, respiratory problems or even a variety of nonspecific symptoms [7,1,8,9]. The infection is sufficiently severe, with an estimated mortality rate in the order of 1% [10–13], meaning that the virus has become a priority public health problem, given the expected scale of the pandemic due to the absence of preexisting immunity. According to dashboard reports provided by COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) of John Hopkins University (JHU), until 11 January, the number of reported infected cases, the number of documented deaths and the number of documented recoveries reached almost 90.435.754; 1.938.004; and 50.118.270, respectively, worldwide [14]. In most countries, the epidemic is taken seriously from the first day, with appropriate public health measures being implemented, including nonpharmaceutical interventions. Out of 185 countries, the United States of America (22.429.685 cases), India (10.466.595 cases), Brazil (8.105.790 cases), Russia (3.389.733 cases), United Kingdom (3.081.368 cases), France (2.840.864 cases), Turkey (2.326.256 cases), Italy (2.276.491 cases), Spain (2.050.360 cases), Germany (1.938.668 cases), Colombia (1.786.900 cases),

Argentina (1.722.217 cases), Mexico (1.534.039 cases), Poland (1.390.385 cases), Iran (1.292.614 cases), South Africa (1.231.597 cases), Ukraine (1.154.850 cases), and Peru (1.033.648 cases) face worse epidemic situations, with almost 77.5% of the total number of cases. The first country to introduce the quarantine strategy was China in Wuhan on 23 January 2020. At present, China has 96.882 confirmed cases with the number of documented deaths and recovered being 4.792 and 90.751, respectively. The same strategy was also applied by other countries, i.e., the implementation of the national lockdown to limit the transmission of the disease, as did, for example, France on 17 March, Spain on 13 March, the UK on 23 March and even India on 25 March. For the third time this century, the zoonotic human coronavirus has spread. Previous to this, in 2002, the severe acute respiratory syndrome coronavirus (SARS-CoV) spread to 37 countries and in 2012, the Middle East respiratory syndrome coronavirus (MERS-CoV) also circulated to 27 countries. In Spain, the disease was first detected on 31 January 2020, when a German tourist tested positive for SARS-CoV-2 in La Gomera, Canary Islands. Subsequent post-hoc genetic analysis suggested that at least 15 different strains of the virus had been imported, and community transmission initiated in mid-February. By 13 March, cases had been confirmed in all 50 provinces of the country. According to the Centro de Coordinación de Alertas y Emergencias Sanitarias (CCAES), in Spain, there are a total of 2,024,904 confirmed cases, 150,376 recovered, and 51,675 deaths reported in the country up to 8 January 2021 [15]. Spanish government, adopted a 15-day state of national alert on 13 March, which will take effect the day after its approval by the Council of Ministers. The nationwide lockdown due to the state of alert became effective on 15 March. All residents were obliged to remain in their normal residence, except for the purchase of basic necessities. The lockdown restrictions also required the temporary closure of nonessential shops and businesses, including bars, restaurants, cafes, cinemas, and retail activities, while announcing that the government will be able to take over private healthcare providers if necessary. The announcement followed a significant increase in the number of confirmed cases of COVID-19 in Spain, which rose from 3146 to 5232 cases on 13 March 2020, an increase of 66%. On 22 March, the Spanish Government decided to submit a petition to regional leaderships to extend the state of alert in the country until 11 April. The Government announced on 28 April a plan to alleviate the lockdown restrictions. The plan included four phases, numbered 0 to 3, and each of phases 1 to 3 should last at least two weeks. The state of alert ceased at midnight on Sunday 21 June, and Spain moved into a *new normal* phase, in which restrictions such as maximum occupancy in shops are managed independently. In this work, we pretend to analyze the influence of weather conditions in the transmission of COVID-19 in Galicia. Precisely, we examine the correlation between weather conditions considering temperature and humidity and epidemiological variables such as active cases, recovered, and deceased. The structure of the following document is as follows: Section 5.2 contains the description of the concept of fuzzy sets. Section 5.3 illustrates the results obtained by applying the methodology described to the Santiago de Compostela-Barbanza health area. A short conclusion is given in the last section.

## 5.2 Fuzzy sets

A fuzzy set is a set that may contain elements in a partial way, that is, the property that an element  $x$  belongs to a set  $A$  may be true with a partial degree of truth. This degree of belonging is measured with a real number  $\mu_A(x)$  and takes values in  $[0, 1]$ . A natural extension of these sets, made in [16], includes the measurement of the degree of nonmembership of an element by another function  $\nu_A(x)$  so that it is always verified  $0 \leq \mu_A(x) + \nu_A(x) \leq 1$ . Using these two functions, the degree of uncertainty of an element can also be defined by a third function  $\pi_A(x) = 1 - (\mu_A(x) + \nu_A(x))$ . Using these measures, Borah et al. [18] calculate the correlation coefficient between two fuzzy variables as the average of the correlation coefficients between the degrees of membership, nonmembership and uncertainty of the climatological and epidemiological variables:

$$r(A, B) = \frac{1}{3}(r_1(A, B) + r_2(A, B) + r_3(A, B))$$

where  $A$  and  $B$  are two intuitionistic fuzzy soft sets (IFSS) and  $r_1(A, B)$ ,  $r_2(A, B)$ , and  $r_3(A, B)$  are the correlation coefficients for the degrees of membership, nonmembership, and uncertainty, respectively, of the climatological and epidemiological variables.

## 5.3 Results

The idea was to study the correlation between the variables by applying such methodology to several municipalities instead of health areas or regions in order to obtain a reliable correlation between the climatological and epidemiological variables. However, the data by municipality are not available for consultation and/or downloading by the population and we were only able to collect data on active cases, deaths, and recovered cases in the health area of Santiago during the whole month of September by consulting many sources. In the rest of the health areas we only have the data of active cases and, in some cases, of deaths. Concerning the meteorological data, we used the Meteo Galicia database. Specifically, we made use of the maximum, average, and minimum temperature and humidity measurements for the 7 sanitary areas, taking the most important city as a reference (for example, for the health area of Santiago de Compostela – Barbanza we took the data from Santiago de Compostela, for the health area of Coruña – Cee we took the data from A Coruña). Once the data collection was finished and contrasting between the different sources to ensure their reliability, we decided to study the influence of the meteorological variables considering the epidemiological data of the health area of Santiago de Compostela – Barbanza. This health area is made up of the 46 municipalities shown in Fig. 5.1 and has approximately 450,000 inhabitants (2014).

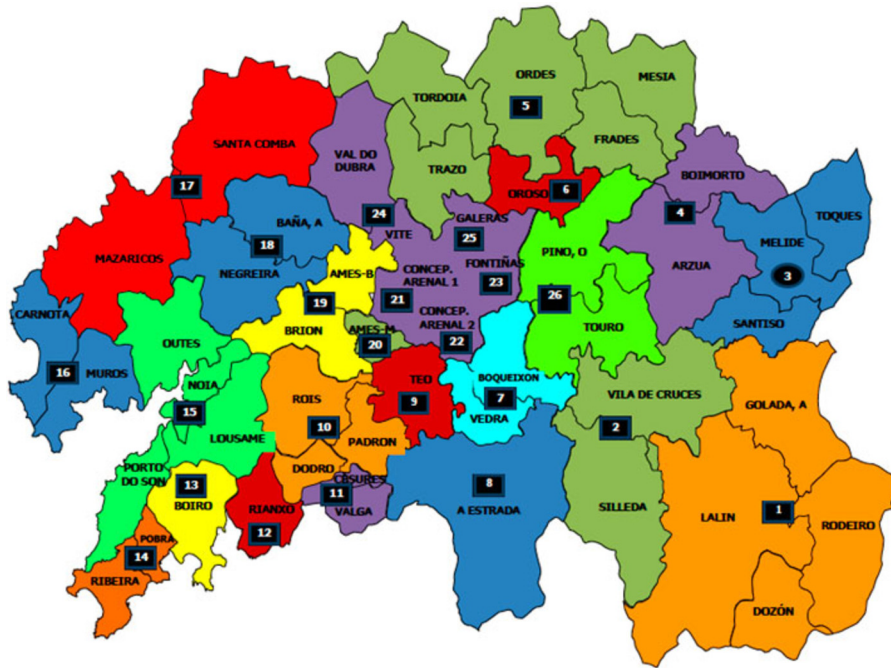


Figure 5.1: Town councils included in the Health Area of Santiago de Compostela – Barbanza.

In order to apply the methodology described above, we have considered the data of maximum, average, and minimum temperature and humidity in the city of Santiago de Compostela during the month of September (see Table 5.1). We have allocated the degrees of membership, nonmembership, and uncertainty, respectively, to the maximum, minimum, and average value of the climatological variables and to the number of active, recovered, and dead cases of the epidemiological variables. Our results indicate that the only variable with significant correlation is humidity. Specifically, maximum humidity has a positive correlation with the number of active and deceased cases and a negative correlation with the number of recovered cases. This correlation indicates that an increase in humidity leads to an increase in active and deceased cases and a decrease in recoveries. In all cases, the absolute value of the correlation is approximately 0.6 which is quite significant.

Fig. 5.2 shows the maximum, average, and minimum temperature as a function of date with superimposed the number of active cases for Santiago de Compostela from the start of the pandemic to October 2020. Likewise, Fig. 5.3 presents the maximum (dashed red line), average (dashed orange line), and minimum (dashed blue line) humidity as a function of date with superimposed the number of active cases (solid black line) for Santiago de Compostela from the start of the pandemic to October 2020.

Table 5.1: Data available for the health area of Santiago de Compostela-Barbanza for the period 1 September to 10 September 2020.

Date	Temperature (°C)			Humidity (%)			Epidemiological		
	Maximum	Average	Minimum	Maximum	Average	Minimum	Active	Recovered	Deceased
01/09/2020	22.9	17.1	12.2	96.0	77.0	50.0	607	1927	98
02/09/2020	24.6	17.6	12.2	93.0	77.0	54.0	644	1933	99
03/09/2020	31.7	21.8	13.5	94.0	69.0	31.0	659	1963	99
04/09/2020	28.8	21.7	15.9	91.0	68.0	20.0	673	1993	99
05/09/2020	22.6	18.7	16.5	92.0	79.0	61.0	677	2023	99
06/09/2020	23.1	18.0	14.2	84.0	69.0	52.0	688	2066	99
07/09/2020	24.6	18.3	13.6	83.0	66.0	44.0	688	2098	100
08/09/2020	27.8	20.0	13.5	83.0	62.0	34.0	662	2153	100
09/09/2020	30.3	21.4	14.4	86.0	63.0	26.0	659	2207	101
10/09/2020	29.4	21.3	14.1	87.0	67.0	36.0	658	2276	101

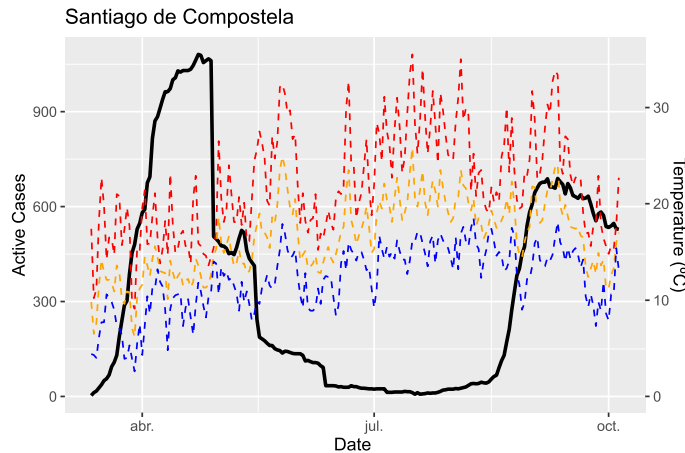


Figure 5.2: Maximum (dashed red line), average (dashed orange line), and minimum (dashed blue line) temperature in function of date with superimposed number of active cases (solid black line) for Santiago de Compostela from the beginning of the pandemic to October 2020.

Following the algorithm presented in [18], we collected the data in tabular form. As described above, we have assigned degrees of membership, nonmembership, and uncertainty, respectively, to the maximum, mean, and minimum values of the climatological variables and to the number of active, recovered and deceased cases of the epidemiological variables.

Following the same algorithm, we converted the data into decimal form (see Table 5.2). By making a correlation between meteorological and epidemiological data we obtain the following results (see Table 5.3).

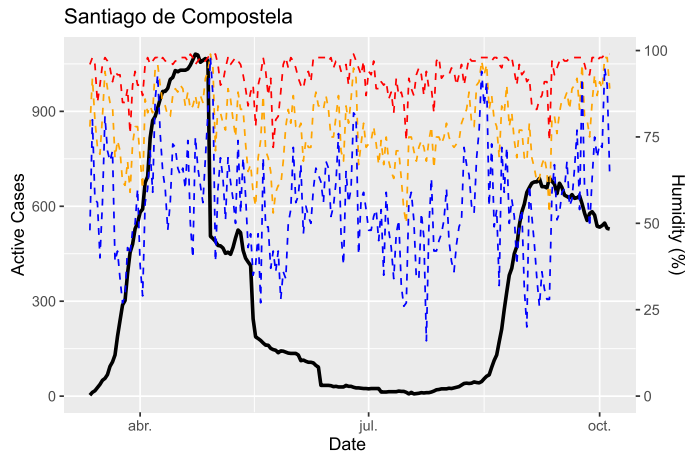


Figure 5.3: Maximum (dashed red line), average (dashed orange line), and minimum (dashed blue line) humidity in function of date with superimposed number of active cases (solid black line) for Santiago de Compostela from the beginning of the pandemic to October 2020.

Table 5.2: Data available for the Santiago de Compostela health area for the period 1 September to 10 September 2020 in decimal form.

Date	Temperature (°C)			Humidity (%)			Epidemiological		
	Maximum	Average	Minimum	Maximum	Average	Minimum	Active	Recovered	Deceased
01/09/2020	0.4387	0.3276	0.2337	0.4305	0.3453	0.2242	0.2306	0.7321	0.0372
02/09/2020	0.4522	0.3235	0.2243	0.4152	0.3438	0.2411	0.2407	0.7223	0.0370
03/09/2020	0.4731	0.3254	0.2015	0.4845	0.3557	0.1598	0.2422	0.7214	0.0364
04/09/2020	0.4337	0.3268	0.2395	0.5084	0.3799	0.1117	0.2434	0.7208	0.0358
05/09/2020	0.3910	0.3235	0.2855	0.3966	0.3405	0.2629	0.2419	0.7228	0.0354
06/09/2020	0.4177	0.3255	0.2568	0.4098	0.3366	0.2537	0.2411	0.7242	0.0347
07/09/2020	0.4354	0.3239	0.2407	0.4301	0.3420	0.2280	0.2384	0.7270	0.0347
08/09/2020	0.4535	0.3263	0.2202	0.4637	0.3464	0.1899	0.2271	0.7386	0.0343
09/09/2020	0.4584	0.3238	0.2179	0.4914	0.3600	0.1486	0.2221	0.7438	0.0340
10/09/2020	0.4537	0.3287	0.2176	0.4579	0.3526	0.1895	0.2168	0.7499	0.0333

Table 5.3: Correlation matrix between weather and epidemiological variables.

	Active	Recovered	Deceased
Temperature (maximum)	0.2148720	-0.2179535	0.2423024
Temperature (average)	-0.2353762	0.2273507	-0.1370719
Temperature (minimum)	-0.1532617	0.1586790	-0.2090688
Humidity (maximum)	0.6207839	-0.6198863	0.5897007
Humidity (average)	0.1479555	-0.1468946	0.1310120
Humidity (minimum)	-0.5753772	0.5743762	-0.5446649



## 5.4 Conclusions

In December 2019, Coronavirus or Covid-19 was first detected in China, but currently has spread worldwide in the form of a pandemic. Current situation reports reveal that almost 89 million people are infected with the virus worldwide. Although governments and doctors in each country are trying to provide protective measures for people, the infection rate is still quite high, as the right antidote for this virus is still unknown, although the vaccination campaign has recently begun. The United States has the most confirmed cases with the number 21,870,427, based on data up to 9 January 2021 provided by the dashboard of CSSE at John Hopkins University. Official reports indicate that in the US a total of almost 368,908 people have died, the highest number among 185 countries or religions. In Spain, according to CCSAE reports, there are 2,050,360 confirmed cases, 51,874 deaths, and 150,376 recovered cases are reported up to 9 January 2021. Taking this pandemic situation into account, in this paper we have studied the influence that climatic conditions can have on the evolution of COVID-19 in Galicia. In order to study this influence, we have followed the line of work proposed in [18]. The aim of this work, which is still in the process, is to study the relationship that may exist between climatic conditions (temperature and humidity) and certain epidemiological variables (number of active cases, recovered cases, and deaths) in the five regions most affected by COVID-19 in India. Specifically, the authors employ a generalization of the Pearson coefficient,  $r$ , applied to a diffuse set (fuzzy sets), originally proposed in [19]. This may be of particular interest in regions with high humidity such as Galicia, however, these results have been obtained by comparing the climatological data of the city of Santiago with its entire health area so there may be some variation from the actual correlation.

## References

- [1] N. Chen, M. Zhou, X. Dong, J. Qu, F. Gong, Y. Han, Y. Qiu, J. Wang, Y. Liu, Y. Wei, J. Xia, T. Yu, X. Zhang, L. Zhang, Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study, *The Lancet* 395 (10223) (2020) 507–513.
- [2] W. Chen, P.W. Horby, F.G. Hayden, G.F. Gao, A novel coronavirus outbreak of global health concern, *The Lancet* 395 (10223) (2020) 470–473.
- [3] R. Li, S. Pei, B. Chen, Y. Song, T. Zhang, W. Yang, J. Shaman, Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV2), *Science* 368 (6490) (2020) 489–493.
- [4] D. Juan, Wuhan wet market closes amid pneumonia outbreak, <https://www.chinadaily.com.cn/a/202001/01/WS5e0c6a49a310cf3e35581e30.html>, 2020.
- [5] Coronaviridae Study Group of the International Committee on Taxonomy of Viruses, The species Severe acute respiratory syndromerelated coronavirus: classifying 2019-nCoV and naming it SARS-CoV2, *Nature Microbiology* 5 (4) (2020) 536–544.
- [6] D.D. Richman, R.J. Whitley, F.G. Hayden, *Clinical Virology*, Wiley, Hoboken, 2016.
- [7] Centers for disease control and prevention, 2019 novel coronavirus, <https://www.cdc.gov/coronavirus/2019-ncov>, 2019.



- [8] K. Gaythorpe, N. Imai, G. Cuomo-Dannenburg, M. Baguelin, S. Bhatia, A. Boonyasiri, A. Cori, Z. Cucunubá, A. Dighe, I. Dorigatti, R. FitzJohn, H. Fu, D. Laydon, G. Nedjati-Gilani, L. Okell, S. Riley, H. Thompson, S. van Elsland, H. Wang, Y. Wang, C. Whittaker, X. Xi, C.A. Donnelly, A. Ghani, Report 8: Symptom progression of COVID-19, 2020, p. 10.
- [9] X. Yang, Y. Yu, J. Xu, H. Shu, J. Xia, H. Liu, Y. Wu, L. Zhang, Z. Yu, M. Fang, T. Yu, Y. Wang, S. Pan, X. Zou, S. Yuan, Y. Shang, Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study, *The Lancet Respiratory Medicine* 8 (5) (2020) 475–481.
- [10] I. Dorigatti, L. Okell, A. Cori, N. Imai, M. Baguelin, S. Bhatia, A. Boonyasiri, Z. Cucunubá, G. Cuomo-Dannenburg, R. FitzJohn, H. Fu, K. Gaythorpe, A. Hamlet, N. Hong, M. Kwun, D. Laydon, G. Nedjati-Gilani, S. Riley, S. van Elsland, H. Wang, R. Wang, C. Walters, X. Xi, C. Donnelly, A. Ghani, Report 4: severity of 2019-novel coronavirus (nCoV), Imperial College London COVID-19 Response Team, 2020.
- [11] M. Famulare, 2019-nCoV: preliminary estimates of the confirmed case-fatality-ratio, and infection-fatality-ratio and initial pandemic risk assessment, 2020.
- [12] R. Verity, L.C. Okell, I. Dorigatti, P. Winskill, C. Whittaker, N. Imai, G. Cuomo-Dannenburg, H. Thompson, P.G.T. Walker, H. Fu, A. Dighe, J.T. Griffin, M. Baguelin, S. Bhatia, A. Boonyasiri, A. Cori, Z. Cucunubá, R. FitzJohn, K. Gaythorpe, W. Green, A. Hamlet, W. Hinsley, D. Laydon, G. Nedjati-Gilani, S. Riley, S. van Elsland, E. Volz, H. Wang, Y. Wang, X. Xi, C.A. Donnelly, A.C. Ghani, N.M. Ferguson, Estimates of the severity of coronavirus disease 2019: a model-based analysis, *Lancet. Infectious Diseases* 20 (2020) 669–677.
- [13] J.T. Wu, K. Leung, M. Bushman, N. Kishore, R. Niehus, P.Md. Salazar, B.J. Cowling, M. Lipsitch, G.M. Leung, Estimating clinical severity of COVID-19 from the transmission dynamics in Wuhan, China, *Nature Medicine* 26 (2020) 506–510.
- [14] Coronavirus COVID-19 global cases by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU), <https://coronavirus.jhu.edu/map.html>.
- [15] Centro de Coordinación de Alertas y Emergencias Sanitarias (CCAES), <https://www.mscbs.gob.es/profesionales/saludPublica/ccayes/alertasActual/nCov/situacionActual.htm>.
- [16] Krassimir T. Atanassov, Intuitionistic fuzzy sets, *Fuzzy Sets and Systems* 20 (1) (1986) 87–96.
- [17] S. Saha, G.P. Samanta, J.J. Nieto, Epidemic model of COVID-19 outbreak by inducing behavioural response in population, *Nonlinear Dynamics* 102 (1) (2020) 455–487.
- [18] M.J. Borah, B. Hazarika, S.K. Panda, J.J. Nieto, Examining the correlation between the weather conditions and COVID-19 pandemic in India: a mathematical evidence, *Results in Physics* 19 (103587) (2020), <https://doi.org/10.1016/j.rinp.2020.103587>, Epub 2020 Nov 18. PMID: 33224720; PMCID: PMC7672333.
- [19] L.A. Zadeh, Fuzzy sets, *Information and Control* 8 (3) (1965) 338–353.