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CONFERENCE PAPER

Does High Population Density Catalyze the Spread of COVID-19?

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Abstract: *COVID-19 represents not only public health emergency but has become a global economic problem. It has affected all economic sectors threatening global poverty. The important question that arises is what catalyses the spread of the disease? In this paper the relationship between population density and spread of COVID-19 is observed which is goal of the paper. For the purpose of the analysis the correlation between the population variables and COVID-19 variables on a global country level (209 countries) and regional level of individual countries with the most cases of infection is observed. The results have shown that on a country level variable population is statistically significant in all regression models for total cases, deaths and total tests variables whereas variable population density was not. The research results from this paper can be important and relevant for economic and health policy makers to guide COVID-19 surveillance and public health decision-making.*

Keywords: Population density; spread of the disease; COVID-19; World; Croatia

JEL Classification: I19, J1

Introduction

COVID-19 represents not only public health emergency but has become an international economic crisis surpassing the global financial crisis of 2008-2009, Loayza and Pennings (2020). It has affected almost all aspects of human life threatening with the global poverty. From the economic aspect sectors that have been the hardest hit with the global pandemic are sports and entertainment industry, travel industry, hos-

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pitality industry, oil industry and financial markets, Peterson and Thankom (2020). In order to prevent catastrophic suffering and loss of human lives an immediate and adequate measures have been taken. The important question that arises is what accelerates the spread of the disease? According to the US Department of Health and Human Services/Centers for Disease Control and Prevention (2020) COVID-19 is primarily transmitted by respiratory droplets so population density might play a significant role in the acceleration of transmission. In this paper the impact of population density on global spread of COVID-19 will be analysed. Investigations on link between population density and propagation and magnitude of epidemics so far have been proved inconclusive, Li et al (2018). There is an evidence that high population density catalyses the spread of disease. A main control-strategy of COVID-19 is contact tracing while contact rate is proportional to population density, Rocklöv and Sjödin (2020). The main goal of this paper is to investigate the relationship between population density and spread of COVID-19 disease. For that purpose, the correlation between COVID-19 variables and population size is observed on a sample of 209 countries. In addition, countries with the most total cases of infection (the United States of America, Spain, Italy, France, Germany and the United Kingdom) are inspected in more details. Therefore, for those countries, the relation between COVID-19 and population variables is observed at a region level as well. In addition to those countries, the situation in Croatia is inspected in the same way. Paper is structured in five chapters. After the introduction, short literature review elaborates on relationship between high population density and spread of the disease. In the methodology and data section the methodology of the paper is explained and descriptive statistics of data is presented. In the results and discussion section the main results of the analysis are displayed, both on a country level and individual countries regions level. Final chapter presents concluding remarks.

Short literature review

In this chapter the short literature review about link between population density and spread of the disease will be presented an elaborated. High population densities catalyse the spread of COVID-19. Controlling contact rates is key to outbreak control, and such a strategy depends on population densities, Rocklöv and Sjödin (2020). Tarwater and Martin (1999) evaluated the effect of population density on the epidemic outbreak of measles or measles-like infectious diseases in four different population densities scenarios. Using average-number of contacts with susceptible individuals per infectious individual as a measure of population density, they found that there was a decrease in a susceptible contact rate from four to three in different scenarios. Kraemer et al. (2015) investigated the transmission of dengue disease across Pakistan in relation to population density and contact rates. Population density was identified as an important factor that affects the spread of the disease.

Li et al. (2018) has shown that there is a weak but clearly defined relationship between population density and a death rate of epidemics. It was also shown that population density determines the time dependence of the death rate. Mazharul et al. (2020) developed a model to measure the risk of coronavirus outbreak in four countries (United States, Australia, Canada and China). The model underlined the hypothesis that higher the population density, higher the risk of transmission of infectious disease from human to human. The authors recommended avoiding mass gatherings, maintaining recommended physical distance and restricting inbound and outbound flights as well. Hu, Nigmatulina and Eckhoff (2013) investigated the scaling of contact rates with population density for the infectious disease models. They highlighted that contact rates tend to increase with density and saturate at higher density. On the other side, Barr and Tassier (2020) provided the answer to question are crowded cities the reason for the COVID-19 pandemic and conclude that placing too much blame on urban density is a mistake.

Methodology and data

In the paper correlation between COVID-19 variables and population size is observed. COVID-19 variables are total cases, total deaths and total tests. However, it has to be emphasized that there are no available data for all observed countries for all three COVID-19 variables. Those three variables will be compared with population size in absolute sense and population size per km^2 (population density).

In the first step of the analysis COVID-19 variables will be compared with population variables for all countries in the World for which data are available. In the second step, countries with the most total cases (the United States of America, Spain, Italy, France, Germany and the United Kingdom) will be inspected in more details. Also, for those countries, the relationship between COVID-19 and the population variables will be observed at a regional level as well. In addition to those countries, situation in Croatia will be inspected in the same way. In the analysis the most recent data will be used and that could be different in the case when regions of a country are observed. In the analysis the main focus will be given to correlation and regression analysis. In the simple linear regression model, the role of dependent variable is going to have a certain COVID-19 variable whereas independent variable will be one from the population variables group. In that way it will be possible to detect the size and impact of correlation between COVID-19 and population variables. In addition, the actual and estimated (regression) values will be compared and discussed in order to detect which countries may have high residual values.

Table 1: Descriptive statistics results for the observed COVID-19 and population variables

Statistics	COVID-19 variables			Population variables	
	Total cases	Total deaths	Total tests	Population	Population density (P/km²)
Number of countries	209	163	162	209	209
Mean	10,444	901	112,689	37,059,910	566
Standard deviation	52,945	3,969	352,795	142,842,565	3,177
Coefficient of variation	507%	441%	313%	385%	561%
Median	394	15	15,272	6,948,445	94
Minimum	1	1	10	3,480	0.14
1st quartile	43	4	1,543	895,312	35
3rd quartile	2,605	119	76,322	26,378,274	237
Maximum	678,144	34,641	3,411,394	1,439,323,776	39,242
Skewness	10	6	7	9	10
Kurtosis	124	42	52	82	116

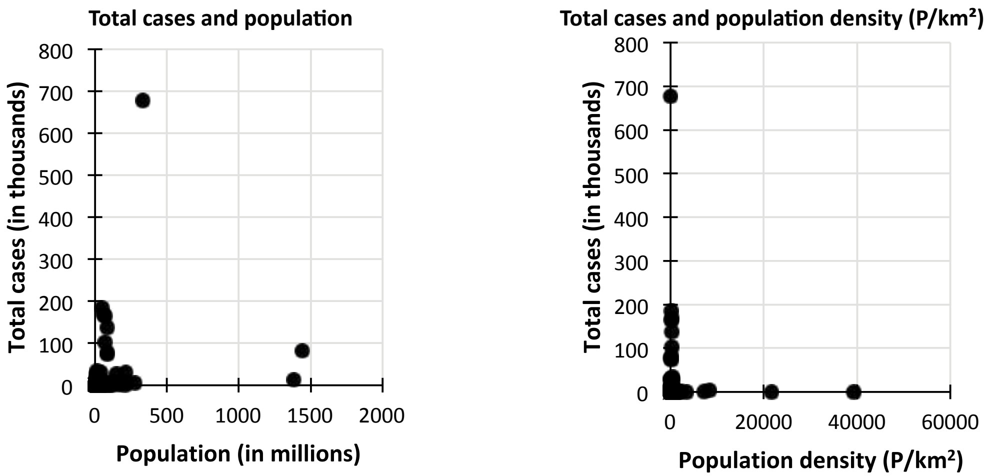
Source: Worldometer (2020a, b), authors.

In Table 1 descriptive statistics results for the observed variables are presented. All COVID-19 variables refer to the state on April 17, 2020 whereas population variables are estimations related to year 2020. The data are analysed for overall 209 countries worldwide. The data related to total deaths cases are available for 163 countries and the data for total tests are available for 162 countries. There are 10,444 cases, 901 deaths and 112,689 tests on average per observed country. However, high values of standard deviations and of coefficients of variations are suggesting that those average values are not representative. Therefore, median values should be used as representative ones. On that way, it can be concluded that 50% of observed countries have 394 total cases or less whereas the other 50% of countries have more total cases. Similarly, it can be concluded that 50% of observed countries had 15 or less deaths due to the COVID-19. Also, half of observed countries had conducted 15,272 tests in total.

Results and discussion

In Figure 1 the scatter diagrams for total cases of infection and population on the left side and total cases and population density on the right side are shown. In both diagrams there are some cases which are quite far away from others so the vast majority of cases or dots are placed in the left bottom corner. Consequently, it was hard to determine the shape of relation between those variables. It is expected that those cases will have large deviations from the regression line, because the linear regression modelling will be conducted.

Figure 1: Scatter diagrams of total cases and population variables, 209 countries



Source: Worldometer (2020a, b), authors.

The decision that such cases will not be omitted from the analysis is brought. What's more, such cases will be emphasized and listed separately. In Table 2 results of two simple linear regression models are given. According to the model A results, it appears that the correlation between total cases and population is positive but weak (coefficient of correlation is 0.2328). On the other hand, according to the model B results, there is no significant correlation between total cases and population density. Those conclusions are supported by regression coefficients estimates. In the model A regression coefficient is highly statistically significant whereas in the model B it is not.

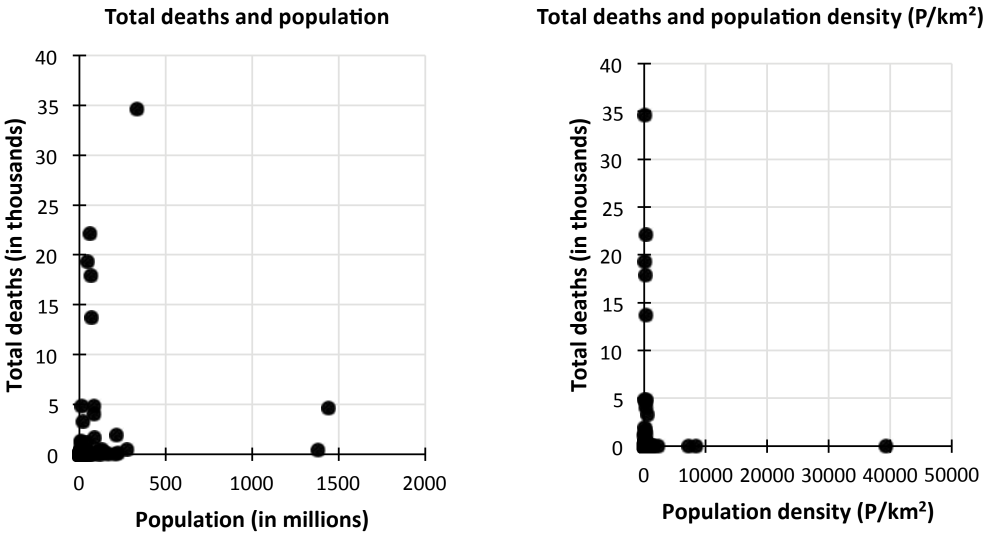
Table 2: Linear regression results, dependent variable total cases

Statistics		**Model A**	**Model B**
Independent variable		Population	Population density (P/km2)
Coefficient of correlation		0.2328	0.0261
Coefficient of determination		0.0542	0.0007
Standard error of the model		51,615	53,054
Observations		209	209
Empirical F-value		11.858	0.141
Constant term	Estimate	7,246.23	10,690.10
	Standard error	3,689.02	3,727.97
	P-value	0.0508	0.0046
Regression coefficient	Estimate	8.63E-05	-0.44
	Standard error	2.51E-05	1.16
	P-value	0.0007	0.7074
Countries with large standardized residuals (less than -2.0 or above 2.0)		USA (12.47), Spain (3.37), Italy (3.04), France (2.95), Germany (2.39), India (-2.19)	USA (12.61), Spain (3.29), Italy (2.99), France (2.92), Germany (2.40)

Source: Worldometer (2020a, b), authors.

Accordingly, it can be concluded that an increase of 100 thousand persons in population on average leads to the increase in total cases by about 9 persons (8.63). In the last row of Table 2 countries with absolute standardized residual values higher than 2 are listed. Obviously in those countries there is no such pattern and relation between total cases and population variables as for other countries. Therefore, those countries should be inspected in more detail.

Figure 2: Scatter diagrams of total deaths and population variables, 163 countries



Source: Worldometer (2020a, b), authors.

Scatter diagrams of total deaths and population variables are shown in Figure 2. Again, there are some countries which have much higher values of the observed variables. Consequently, it is difficult to see real pattern there because majority of cases (dots on Figure 2) are placed on the small area. Results from Table 3, for simple linear regression models, should be more helpful in detection the relation between the observed variables.

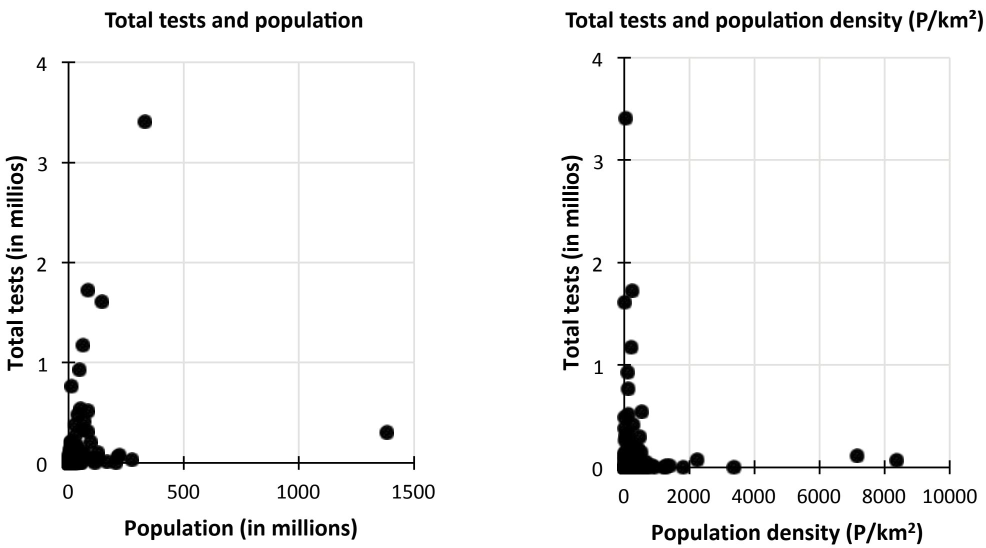
Table 3: Linear regression results, dependent variable total deaths

Statistics		Model C	Model D
Independent variable		Population	Population density (P/km2)
Coefficient of correlation		0.1784	0.0276
Coefficient of determination		0.0318	0.0008
Standard error of the model		3,917	3,980
Observations		163	163
Empirical F-value		5.295	0.123
Constant term	Estimate	701.25	919.08
	Standard error	318.87	316.07
	P-value	0.0293	0.0042
Regression coefficient	Estimate	4.41E-06	-0.03
	Standard error	1.92E-06	0.10
	P-value	0.0227	0.7265
Countries with large standardized residuals (less than -2.0 or above 2.0)		USA (8.32), Italy (5.43), Spain (4.71), France (4.34), United Kingdom (3.26)	USA (8.50), Italy (5.36), Spain (4.64), France (4.29), United Kingdom (3.23)

Source: Worldometer (2020a, b), authors.

According to Table 3, there is a weak, but positive, correlation between variables total deaths and population (coefficient of correlation is 0.1784) whereas no statistically significant correlation is between total deaths and population density variables. According to the regression estimate in the model C, it can be concluded that increase of one million in population on average leads to increase of about 4 total deaths (4.41).

Figure 3: Scatter diagrams of total cases and population variables, 162 countries



Source: Worldometer (2020a, b), authors.

Similarly, as previous scatter diagrams presented on Figures 1 and 2, scatter diagrams given in Figure 3 are revealing that there are some countries which have much higher total tests or population variables values compare to the rest of observed countries.

Table 4: Linear regression results, dependent variable total tests

Statistics		Model E	Model F
	Independent variable	Population	Population density (P/km2)
Coefficient of correlation		0.2623	0.0345
Coefficient of determination		0.0688	0.0012
Standard error of the model		341,508	353,685
Observations		162	162
Empirical F-value		11.819	0.191
Constant term	Estimate	84,950.56	116,916.07
	Standard error	28,018.27	29,424.96
	P-value	0.0028	0.0001
Regression coefficient	Estimate	0.0008	-13.10
	Standard error	0.0002	30.00
	P-value	0.0007	0.6628
Countries with large standardized residuals (less than -2.0 or above 2.0)		USA (9.01), Germany (4.63), Russia (4.15), Italy (3.07), Spain (2.38), India (-2.54)	USA (9.35), Germany (4.58), Russia (4.24), Italy (3.02), Spain (2.31)

Source: Worldometer (2020a, b), authors.

Results of linear regression models given in Table 4 are confirming previous conclusions. Namely, in linear regression model, in which a COVID-19 variable is dependent variable, it turned out that variable population is statistically significant whereas variable population density is not. The situation is the same here. When variable total tests is dependent one, variable population is statistically significant (the model E) whereas variable population density is not (the model F). So, it can be concluded that an increase in population of 10 thousand on average leads to an increase of 8 conducted total tests.

Table 5: Linear regression results, the United States of America states (with District of Columbia)

Statistics USA 1		**Regression models**					
		USA 2	**USA 3**	**USA 4**	**USA 5**	**USA 6**	
Dependent variable		Total cases	Total cases	Total deaths	Total deaths	Total tests	Total tests
Independent variable		Population	Population density	Population	Population density	Population	Population density
Coeff. of correlation		0.4342	0.0158	0.3520	0.0107	0.7123	0.0319
Coeff. of determination		0.1885	0.0002	0.1239	0.0001	0.5073	0.0010
Sta. error of the model		30,114	33,425	2,163	2,311	62,238	88,626
Observations		51	51	51	51	51	51
Regression coefficient	Estimate	0.0020	0.8680	0.0001	0.0408	0.0086	-4.6597
	Sta. error	0.0006	7.8590	4.22E-05	0.5434	0.0012	20.8379
	P-value	0.0015	0.9125	0.0113	0.9405	4.58E-09	0.8240

Note: the regression models include constant term but the estimates are omitted from the table.

Source: United States Census Bureau (2017), Wikipedia (2020a), Worldometer (2020c), authors.

One of countries for which the standardised residual value was larger than 2 standard deviations in Models A-E is the United States of America (USA). Therefore, the USA were inspected more closely. Instead of observing countries, here the analysis was conducted on lower level by observing states of the USA (District of Columbia included). However, even at lower level the same conclusions are valid as before (Table 5). In cases when the dependent variable was one of COVID-19 variables, variable population was statistically significant (Models USA 1, USA 3 and USA 5) whereas variable population density was not (Models USA 2, USA 4 and USA 6).

Table 6: Linear regression results, Spanish regions

Statistics ESP 1		**Regression models**			
		ESP 2	**ESP 3**	**ESP 4**	
Dependent variable		Total cases	Total cases	Total deaths	Total deaths
Independent variable		Population	Population density	Population	Population density
Coeff. of correlation		0.7271	0.1695	0.6751	0.1241
Coeff. of determination		0.5286	0.0287	0.4558	0.0154
Sta. error of the model		9,122	13,094	1,254	1,687
Observations		19	19	19	19
Regression coefficient	Estimate	0.0037	-1.2181	0.0004	-0.1141
	Sta. error	0.0008	1.7175	0.0001	0.2213
	P-value	0.0004	0.4878	0.0015	0.6129

Note: the regression models include constant term but the estimates are omitted from the table.

Source: Centro de Coordinación de Alertas y Emergencias Sanitarias (2020), Statista (2020c), Wikipedia (2020b), authors.

Another country which was outlined in Models A-E as a country with too high standardized residual value is Spain. Unfortunately, there were no available data for total tests for Spanish regions. Therefore, in Table 6 the results only for four regression models are given. The conclusions are in relation to previous findings. Again, variable population is statistically significant in the regression models (Models ESP 1 and ESP 3) whereas variable population density is not (Models ESP 2 and ESP 4).

Table 7: Linear regression results, Italian regions

Statistics ITA 1		**Regression models**					
		ITA 2	**ITA 3**	**ITA 4**	**ITA 5**	**ITA 6**	
Dependent variable		Total cases	Total cases	Total deaths	Total deaths	Total tests	Total tests
Independent variable		Population	Population density	Population	Population density	Population	Population density
Coeff. of correlation		0.7624	0.5651	0.7112	0.5261	0.7780	0.6137
Coeff. of determination		0.5812	0.3193	0.5058	0.2768	0.6053	0.3766
Sta. error of the model		9,299	11,855	1,822	2,205	40,391	50,760
Observations		20	20	20	20	20	20
Regression coefficient	Estimate	0.0042	69.0532	0.0007	11.5985	0.0192	335.5386
	Sta. error	0.0008	23.7636	0.0002	4.4189	0.0037	101.7464
	P-value	9.33E-05	0.0094	0.0004	0.0172	5.38E-05	0.0040

Note: the regression models include constant term but the estimates are omitted from the table.

Source: Ministero della Salute (2020), Statista (2020d), Wikipedia (2020d), authors.

In Table 7 linear regression results for Italian regions are given. The results have shown that, not only variable population, but population density variable is statistically significant in all regression models. So, here can be concluded that population and population density have positive impact on the COVID-19 variable values. There was lack of data for COVID-19 variables for French regions. Only available data related to COVID-19 variables were the ones regarding the number of hospitalised persons. In Table 8 the results of linear regression models for hospitalised persons variable as dependent one, are presented.

Table 8: Linear regression results, French regions

Statistics FRA 1		Regression models FRA 2	
Dependent variable		Hospitalised	Hospitalised
Independent variable		Population	Population density
Coeff. of correlation		0.8391	0.9343
Coeff. of determination		0.7040	0.8729
Sta. error of the model		1,982	1,299
Observations		13	13
Regression coefficient	Estimate	0.0010	12.6795
	Sta. error	0.0002	1.4589
	P-value	0.0003	2.95E-06

Note: the regression models include constant term but the estimates are omitted from the table.

Source: Sante publique France (2020), Statista (2020e), Wikipedia (2020c), authors.

According to the results, variables population and population density have positive and statistically significant impact on the number of hospitalised persons.

Table 9: Linear regression results, German regions

Statistics DEU 1		Regression models DEU 2	DEU 3	DEU 4	
Dependent variable		Total cases	Total cases	Total deaths	Total deaths
Independent variable		Population	Population density	Population	Population density
Coeff. of correlation		0.9160	0.1357	0.8838	0.1763
Coeff. of determination		0.8390	0.0184	0.7810	0.0311
Sta. error of the model		4,592	11,340	168	354
Observations		16	16	16	16
Regression coefficient	Estimate	0.0021	-1.3499	0.0001	-0.0551
	Sta. error	0.0002	2.6343	8.79E-06	0.0822
	P-value	6.33E-07	0.6163	5.62E-06	0.5137

Note: the regression models include constant term but the estimates are omitted from the table.

Source: City Population (2020b), Robert Koch Institut (2020), Wikipedia (2020e), authors.

Like for Spanish regions, the values for variables total cases and total deaths were available for German regions. According to the results from Table 9, variable population is statistically significant in both regression models (Models DEU 1 and DEU 3) whereas variable population density is not statistically significant in both models in which it was used as independent variable (Models DEU 2 and DEU 4). Still, the positive correlation between COVID-19 variables and population is confirmed again.

Table 10: Linear regression results, the United Kingdom's regions with Northern Ireland

Statistics		Regression models	
GBR 1		GBR 2	
Dependent variable		Total cases	Total cases
Independent variable		Population	Population density
Coeff. of correlation		0.8016	0.8323
Coeff. of determination		0.6425	0.6928
Sta. error of the model		2,925	2,712
Observations		12	12
Regression coefficient	Estimate	0.0017	2.4997
	Sta. error	0.0004	0.5264
	P-value	0.0017	0.0008

Note: the regression models include constant term but the estimates are omitted from the table.

Source: City Population (2020c), Statista (2020a, b), authors.

For United Kingdom regions (alongside with the Northern Ireland) data for total cases were available only. Therefore, in Table 10 results of only two regression models are given. However, in both regression models it has been shown that population variables are statistically significant. Also, those two regression models have shown that there is a positive correlation between total cases of infection and population variables.

Table 11: Linear regression results, Croatia counties

Statistics		Regression models			
CRO 1		CRO 2	CRO 3	CRO 4	
Dependent variable		Total cases	Total cases	Total deaths	Total deaths
Independent variable		Population	Population density	Population	Population density
Coeff. of correlation		0.9162	0.7262	0.8933	0.8522
Coeff. of determination		0.8394	0.5273	0.7980	0.7262
Sta. error of the model		47.11	80.81	1.52	1.77
Observations		21	21	21	21
Regression coefficient	Estimate	0.0006	0.3171	1.74E-05	0.0107
	Sta. error	0.0001	0.0689	2.01E-06	0.0015
	P-value	5.58E-09	0.0002	5.04E-08	9.44E-07

Note: the regression models include constant term but the estimates are omitted from the table.

Source: Croatian Bureau of Statistics (2018), City Population (2020a), GDi (2020), authors.

Finally, the situation in Croatia according to 21 counties is observed. At county level data for total tests were not available. Therefore, in Table 11 the results of regression models where total cases (Models CRO 1 and CRO 2) and total deaths

(Models CRO 3 and CRO 4) variables are dependent variables are shown. The results suggest that there are positive and statistically significant correlations between COVID-19 variables and population variables.

The results of the analysis point out to the conclusion that larger population and higher population density lead to higher possibility of infection to COVID-19 due to the consequent greater number of contacts between the people. On a country level the population density variable has not been statistically significant in all regression models. This can be explained with heterogeneity in data (characteristics of individual countries), various health measures being implemented (full, some or no quarantine in different countries) and different stages of infection in observed countries. For example, the countries in Africa or India have not reached a critical stage of infestation yet so the achieved results at the world level cannot be taken as conclusive. On the other side, the results obtained from the regional or state level of some countries with the most total cases of infection suggest that population and population density variables have positive impact on spread of the disease. This can be explained with more possible contacts in population leading to catalysing spread of the COVID-19 disease. It would be interesting to investigate the relationship between population variables and COVID-19 variables on a city level in which case similar results should be obtained as well.

Conclusions

Goal of the paper was to investigate the relationship between population density and spread of the disease, COVID-19 specifically. For that purpose, the correlation between population and population density and total cases, deaths and test conducted was inspected firstly on global sample of 209 countries and after that on regional or county level for countries with the most cases of infection. The case of Croatia was also analysed. The results on the whole sample have shown that variable population is statistically significant in the regression model for total cases, deaths and total tests whereas variable population density was not. This conclusion was also valid when USA states, Spanish and German regions were observed. On the other side, in the case of Italian, French and United Kingdom's regions the results have shown that, not only variable population, but variable population density is statistically significant in all regression model also. It can be concluded that population and population density have positive impact on the COVID-19 variable values.

Limitations of the paper are related to the fact that there is unavailability of data for some observed countries for some COVID-19 variables. The possible future directions of the research conducted in this paper could go in the way of analysing the correlation between population density and spread of COVID-19 on a city level or for different settlement sizes. The results from this paper can be important and relevant for economic and health policy makers to guide Covid-19 surveillance and public health decision-making.

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