Correlations between urban and demographic data and COVID-19 data: a case study in Fortaleza, Brazil

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Abstract. COVID-19 was a sanitary crisis of international impact. However, its effects weren't experienced equally. In Fortaleza, epidemiological reports (2021;2022) point to different infection patterns between high Human Development Index (HDI) and low HDI neighborhoods, which surfaced the hypothesis that certain territories' characteristics could correlate to COVID-19 data. This article describes a phase of a three-phase research, whose objective is to identify correlations between urban and demographic (UD) data to COVID-19 data. To this, a literature review was done to select seven UD variables and four COVID-19 ones, then, Spearman's correlation was applied in four pandemic time frames (TF). Results show that literacy rates, monthly income and energy have either low or moderate positive correlations with contamination rates in most TF. However, they've shown low or moderate correlations with lethality rates in three TF. Population density showed low positive correlations to either lethality rates or total number of deaths in three TF.

Keywords: COVID-19; Urban Data; Demographic Data; Spearman's Coefficient Correlation; Public Health

1 Introduction

COVID-19 was categorized, at January 2020, as a Public Health Emergency of International Concern (PHEIC) by the World Health Organization (WHO) and, at March of 2020, was characterized as a pandemic. (Pan American Health Organization, 2020) As of March 10th 2023, it had contaminated 676.609.955 people and caused 6.881.955 deaths worldwide. During these three years of pandemic, Brazil, held over 37 million cases and almost 700 thousand deaths. (John Hopkins University, 2023)

Even though it’s clear that the COVID-19 pandemic was a great crisis worldwide, certain territories contexts, such as Brazil and other Global South countries, were more heavily impacted due to social inequalities while trying to instate sanitary protection measures, especially due to lack of infrastructure, such as sanitation and water access. (UNICEF 2020)

Fortaleza’s Municipal Health Department COVID-19 reports (Secretaria Municipal de Saúde & Prefeitura Municipal de Fortaleza, 2023) suggests different contamination and lethality patterns for neighborhoods with unequal Human Development Indexes (HDI) and income. For both the first and second wave of the pandemic in the city studied, it’s perceived that higher HDI neighborhoods tend to start as contamination clusters with significant number of deaths, but lower lethality rate, as the wave develops lower HDI neighborhood tend to consolidate themselves as the most significant contamination clusters, however with a higher lethality rate and total number of deaths.

These facts, sustained by theoretical works involving health and its relationship with environment, such as Barata (2009) ecossocial theory, that states that an individual’s health is inseparable to their psychic, biological, physical and social environment, lead this research to explore further the hypothesis that certain urban and demographic characteristics might affect the dissemination and response against COVID-19. Which resulted in the research question: which urban and demographic characteristics could correlate to COVID-19’s spread and lethality?

The main objective of this paper is to identify correlations among urban and demographic factors and COVID-19 data in the neighborhood scale at four different time frames. The purpose of this is to understand which characteristics need more attention from planners and further investigation, considering the new impacts and challenges the pandemic left regarding the built environment and its relation to health.

2 Methodology

As in previous work yet to published in congress annals, this paper consists on the first phase of a three-phase research. The complete research objective is to develop an algorithmic indicator that can predict COVID-19 impact on a scale inside of the neighborhood, so to mitigate the lack of data in slums and low-income territories.

To achieve this, as detailed in previous work, three phases were planned beforehand. The first phase, that will be detailed in this paper, consists in identifying correlations between urban and sociodemographic factors with COVID-19 data in the neighborhood scale. The second phase consists in testing these correlations in two neighborhoods, one with a higher HDI and the other with a lower HDI, both territories will have a similar number of habitants and need to be considered contamination clusters at one point in the pandemic. The last phase will use the correlations to apply weights so to develop an algorithm that can predict which areas are more vulnerable to COVID-19 to the census sectors scale.

The first phase, explained in this paper, is divided into three steps: the literature review, the variables selection and the correlation matrix.

The main innovation of this paper's methodology, in contrast to the previous work in process of publication, is the application of the Spearman's Correlation Coefficient to four different time frames, instead of one. This decision was made, because, though the application of the correlation coefficient to only one time frame suggested interesting results, its limitation in time made it unable to perceive if the characteristics presented were singular of the specific time frame or if they were connected with the pandemic's dynamic.

2.1 Literature Review

As stated in previous work, this first step goal was to understand which characteristics were usually considered in studies to be analyzed regarding COVID-19. The authors searched for articles that contained the keywords: "correlation", "COVID-19", "urban factors" and "low income areas" in either the title, abstract or keywords. At the end, 13 articles were selected based on the fact that they did in fact connected urban or sociodemographic characteristics to COVID-19 and their studies were situated in low income communities or in the Global South.

Synthetizing the works selected, Lancaster et al. (2022) focused on health care issues and mentioned the number of hospitals as being connected to lower COVID-19 indexes, oppositely, they mentioned the number of registered doctors in the area and COVID-19 testing sites as connected to higher COVID-19 indexes.

Wang et al. (2022) and Qanazi et al. (2022) also focused on health care and consented with Lancaster et al. (2022) regarding the number of hospitals, both of these works also mentioned population density as a factor connected to lower COVID-19 indexes. Qanazi et al. (2022), however, also mentioned population total as a factor with direct correlation with COVID-19 data, which means that the COVID-19 indexes will be higher in territories with higher population.

Silva (2021) and Nunes et al. (2021) also mentioned population density, however, relating it to higher COVID-19 indexes, as in opposition to Wang et al. (2022) and Qanazi et al. (2022). Both the papers also mentioned monthly income as indirect variable to COVID-19, and they seem to focus on a more socioeconomic analysis of COVID-19. Nunes et al. (2021), although, abords some environmental factors as well, by mentioning higher percentages of sanitation and water supply as variables connected with lower indexes of COVID-19, which seems to be the general consensus among all of the authors that mentioned it (Traesel et al, 2021; Aquino, 2020; França, 2020; Amnkwaa & Fischer, 2020)

Other authors that seemed to have a more socioeconomic approach to COVID-19 were Nunes et al. (2020), Sanhueza-Sanzana et al (2021) and Santos et al. (2022). The works of all these authors mentioned income in any way, Nunes et al. (2020) and Santos et al. (2022) agree with Silva (2021) and Nunes et al. (2021) and connect higher income to lower COVID-19 indexes, Sanhueza-Sanzana et al. (2021) agrees with this consensus in a way, but actually mentions extreme poverty as directly connected to COVID-19's lethality rate. Santos et al. (2022) and Sanhueza-Sanzana et al. (2021) also mention higher literacy rates correlates to lower COVID-19 data.

At last, there seems to be a group of three variables connected to environmental and infrastructural approach which all the works that mentioned them associated them as having an opposite relation with COVID-19 indexes, they were: waste collection, sanitation and access to water.

Traesel et al. (2021) and Amnkwaa & Fischer (2020) both mentioned all three of the variables. Beckert and Barros (2022) focused solely on waste collection, as did Aquino (2020) with sanitation access. França (2020) mentioned both sanitation and access to water, as did Nunes et al. (2021), as previously mentioned.

2.2 Variables Selection

This step hasn't changed from previous works and, as the name suggests, its main goal was to select the variables identified in the previous step that would be put through the correlation matrix. At total, 9 variables were identified, they were: Number of Hospitals, Number of registered doctors and COVID-19 testing sites, Population Density, Average Monthly Income, Population, Literacy Rate, Waste Collection, Sanitation Rate and Access to water rate.

It was decided that the two variables related to health care would be eliminated from the study, due to the complexity of the theme and considering Fortaleza's health context, they wouldn't be enough to successfully translate the quality of health facilities, they need to be analyzed with more specific variables such as the number of ICU beds, whose data is not as easily available for this research.

Population was also eliminated, due to low incidence of mentions in articles. (See Figure 1) It seems to be a general preference for the Population Density variable.

Lastly, Electric Energy was added to the variables due to its connection with the infrastructural variables.

All of the selected variables' data was retrieved from the Brazilian Institute of Geography and Statistics (IBGE) 2010 Census, which is the last available census.

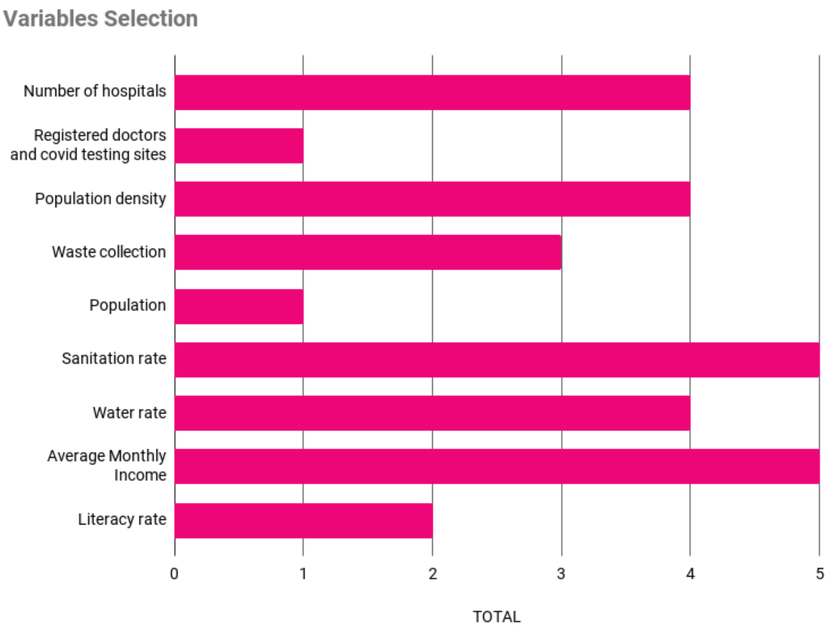

Figure 1. Variables selection: incidence of variables per article. Source: Authors

2.3 Correlation Matrix

The last step was to apply Spearman's correlation coefficient to the seven chosen variables (Population Density, Average Monthly Income, Literacy Rate, Waste Collection, Sanitation Rate, Access to water rate and Electric Energy) and the four COVID-19 variables (Total number of cases, Total number of deaths, Contamination rate and Lethality Rate).

Spearman's coefficient was chosen instead of Pearson's one, due to Pearson's requirement of normally distributed variables, since it isn't the case with the variables of this study, Spearman's, however, allows variables to be skewed or ordinal. (Mukaka, 2012)

The correlation coefficient was applied, differently from previous work to be published yet, to data from four different time frames from the month of the first reported case of the pandemic in Fortaleza, March 2020, till May 2021.

The intervals have four months each except the last that has three, due to data availability, they are: from March 2020 till June till 2020, July 2020 to October 2020, November 2020 till February 2021 and March 2021 till May 2021.

The COVID-19 data was available through Fortaleza's Municipal Health Department pandemic reports. (SMS & PMF, 2023)

To analyze, it was decided to follow Mukaka (2012) interpretation, he states that correlations from 0,00 till ± 0,30 are considered irrelevant, results from ± 0,30 till ±0,50 have low correlations, from ±0,50 to ±0,70 the correlation are considered to be moderate, from ±0,70 till ±0,90 they are considered high, and from ±0,90 till ±1,00 they are considered very high. It was also decided to focus on correlations with p-value < 0,001.

3 Results

From the seven variables, only four shown significant and precise correlations with COVID-19 variables, they were: Access to electric energy (EE), Literacy rate (LitR), Average monthly income (AMI) and Population Density (PD).

As stated in Methodology, the first interval was already discussed in previous works that will be published in congress annals. At this time frame, EE, LitR and AMI variables all showed low negative correlation with COVID-19 lethality rate, with income being the most negative with -0,415, followed by the LitR with -0,317 and then EE with -0,306. Regarding the contamination rate, however the situation inverts itself and LitR and AMI

Correlation Matrix

		Sanitation rate	Access to electric energy rate	Waste collection rate	Access to water rate	Literacy rate	Average monthly income	Population density (hab/km²)	Total number of cases	Total number of deaths	Lethality rate	Contamination rate
Sanitation rate	Spearman's Rho	—										
	p-value	—										
Access to electric energy rate	Spearman's Rho	0.391 ***	—									
	p-value	< .001	—									
Waste collection rate	Spearman's Rho	0.473 ***	0.597 ***	—								
	p-value	< .001	< .001	—								
Access to water rate	Spearman's Rho	0.022	0.128	-0.066	—							
	p-value	0.814	0.174	0.487	—							
Literacy rate	Spearman's Rho	0.511 ***	0.809 ***	0.643 ***	-0.029	—						
	p-value	< .001	< .001	< .001	0.756	—						
Average monthly income	Spearman's Rho	0.342 ***	0.671 ***	0.432 ***	-0.152	0.855 ***	—					
	p-value	< .001	< .001	< .001	0.106	< .001	—					
Population density (hab/km²)	Spearman's Rho	0.445 ***	0.052	0.360 ***	-0.055	0.070	-0.197 *	—				
	p-value	< .001	0.578	< .001	0.556	0.460	0.035	—				
Total number of cases	Spearman's Rho	0.185 *	0.116	-0.050	0.057	0.163	0.108	0.055	—			
	p-value	0.047	0.218	0.593	0.543	0.082	0.249	0.560	—			
Total number of deaths	Spearman's Rho	0.118	-0.079	-0.125	0.040	-0.054	-0.158	0.158	0.858 ***	—		
	p-value	0.208	0.399	0.184	0.672	0.565	0.091	0.091	< .001	—		
Lethality rate	Spearman's Rho	-0.072	-0.306 ***	-0.104	-0.009	-0.317 ***	-0.415 ***	0.187 *	-0.040	0.414 ***	—	
	p-value	0.443	< .001	0.269	0.924	< .001	< .001	0.045	0.669	< .001	—	
Contamination rate	Spearman's Rho	0.167	0.237 *	0.228 *	-0.192 *	0.383 ***	0.380 ***	-0.022	0.430 ***	0.151	-0.418 ***	—
	p-value	0.074	0.011	0.014	0.039	< .001	< .001	0.817	< .001	0.107	< .001	—

Note. * p < .05, ** p < .01, *** p < .001

Low negative correlation   Low positive correlation   Insignificant correlation

Figure 2. Correlation Matrix: 1st timespan. Source: Authors

now show low positive correlations very similar with each other, income had a result of 0,380 while literacy had 0,383. (See Figure 2)

The second time frame, shows that EE, AMI and LitR tend to repeat their dynamics with both the lethality and contamination but with more significant results. The LitR still has low negative correlations with the lethality rate, but now the results are closer to be moderate with -0,442, the correlation with the contamination rate is also still positive, but they are moderate (0,523), instead of low like the first interval. Income has again showed a negative correlation with the lethality rate, a moderate one of -0,531, the correlation with the contamination rate is still positive and has become more significant as well, turning moderate with 0,552.

At last, EE still has a low negative correlation with lethality, although, with a slightly more negative result that consists in -0,415, it also shows a low positive correlation (0,368) that didn't exist in the last timespan. The total number of deaths has, for the first time, shown a negative low correlation with AMI (-0,325) and a low positive one with PD (0,332). (See Figure 3)

Correlation Matrix

		Sanitation rate	Acess to electric energy rate	Waste collection rate	Acess to water rate	Literacy rate	Average monthly income	Population density (hab/km²)	Total number of cases	Total number of deaths	Lethality rate	Contamination rate
Sanitation rate	Rho de Spearman	—										
	p-value	—										
Acess to electric energy rate	Rho de Spearman	0.391 ***	—									
	p-value	< .001	—									
Waste collection rate	Rho de Spearman	0.472 ***	0.599 ***	—								
	p-value	< .001	< .001	—								
Acess to water rate	Rho de Spearman	0.022	0.123	-0.068	—							
	p-value	0.817	0.190	0.471	—							
Literacy rate	Rho de Spearman	0.511 ***	0.811 ***	0.644 ***	0.031	—						
	p-value	< .001	< .001	< .001	0.745	—						
Average monthly income	Rho de Spearman	0.342 ***	0.673 ***	0.433 ***	-0.153	0.855 ***	—					
	p-value	< .001	< .001	< .001	0.102	< .001	—					
Population density (hab/km²)	Rho de Spearman	0.445 ***	0.053	0.359 ***	-0.056	0.069	-0.197 *	—				
	p-value	< .001	0.577	< .001	0.555	0.462	0.035	—				
Total number of cases	Rho de Spearman	0.188 *	0.076	-0.005	0.013	0.106	0.025	0.150	—			
	p-value	0.044	0.421	0.957	0.890	0.262	0.791	0.111	—			
Total number of deaths	Rho de Spearman	0.168	-0.194 *	-0.106	-0.035	-0.182	-0.325 ***	0.332 ***	0.774 ***	—		
	p-value	0.073	0.038	0.260	0.710	0.051	< .001	< .001	< .001	—		
Lethality rate	Rho de Spearman	0.087	0.415 ***	0.159	0.070	0.442 ***	0.531 ***	0.283 **	0.279 **	0.337 ***	—	
	p-value	0.357	< .001	0.091	0.456	< .001	< .001	0.002	0.003	< .001	—	
Contamination rate	Rho de Spearman	0.233 *	0.368 ***	0.244 **	-0.120	0.523 ***	0.552 ***	-0.124	0.399 ***	-0.063	-0.734 ***	—
	p value	0.012	< .001	0.009	0.199	< .001	< .001	0.186	< .001	0.505	< .001	—

Note. * p < .05, ** p < .01, *** p < .001

Low negative correlation; Medium negative correlation; High negative correlation; Low positive correlation; Medium positive correlation; High positive correlation; Insignificant correlation; Correlations important for the analysis

Figure 3. Correlation Matrix: 2nd timespan. Source: Authors

The third time frame show correlations with either the same or slighter lower numbers regarding total number of deaths and lethality, but correlations of the contamination rate show the highest numbers from all the four intervals. PD is the only variable with a significant correlation with total number of deaths with a low positive correlation (0,312), slighter less than the last time frame, this time, this variable also has shown a low positive correlation (0,350) with lethality. PD also had a positive correlation on the second interval; however, it wasn't significant enough (0,283) and didn't have a low enough p-value (0,002). (See Figure 4)

EE and LitR both had a low negative correlation, though, slightly more positive than the last time frame, with the lethality rate, EE with a correlation of -0,384 and LitR with one of -0,401. AMI kept its tendency with the lethality rate, keeping the exact same moderate negative correlation from the last time frame (-0,531).

Regarding correlations between contamination rate, EE, LitR and AMI all kept their tendencies from the last time frames with an increase, EE had again a low positive

Correlation Matrix

		Sanitation rate	Acess to electric energy rate	Waste collection rate	Acess to water rate	Literacy rate	Average monthly income	Population density (hab/km²)	Total number of cases	Total number of deaths	Lethality rate	Contamination rate
Sanitation rate	Rho de Spearman	—										
	p-value	—										
Acess to electric energy rate	Rho de Spearman	0.391 ***	—									
	p-value	< .001	—									
Waste collection rate	Rho de Spearman	0.472 ***	0.599 ***	—								
	p-value	< .001	< .001	—								
Acess to water rate	Rho de Spearman	0.022	0.123	-0.068	—							
	p-value	0.817	0.190	0.471	—							
Literacy rate	Rho de Spearman	0.511 ***	0.811 ***	0.644 ***	-0.031	—						
	p-value	< .001	< .001	< .001	0.745	—						
Average monthly income	Rho de Spearman	0.342 ***	0.673 ***	0.433 ***	-0.153	0.855 ***	—					
	p-value	< .001	< .001	< .001	0.102	< .001	—					
Population density (hab/km²)	Rho de Spearman	0.445 ***	0.053	0.359 ***	-0.056	0.069	-0.197 *	—				
	p-value	< .001	0.577	< .001	0.555	0.462	0.035	—				
Total number of cases	Rho de Spearman	0.139	0.115	-0.021	0.052	0.134	0.072	0.079	—			
	p-value	0.137	0.222	0.821	0.583	0.153	0.446	0.403	—			
Total number of deaths	Rho de Spearman	0.182	-0.142	-0.078	0.000	-0.139	-0.287 **	0.312 ***	0.765 ***	—		
	p-value	0.052	0.131	0.404	0.997	0.139	0.002	< .001	< .001	—		
Lethality rate	Rho de Spearman	0.019	-0.384 ***	-0.098	-0.079	-0.401 ***	-0.531 ***	0.350 ***	-0.337 ***	0.286 **	—	
	p-value	0.842	< .001	0.295	0.399	< .001	< .001	< .001	< .001	0.002	—	
Contamination rate	Rho de Spearman	0.125	0.400 ***	0.223 *	-0.056	0.541 ***	0.601 ***	-0.233 *	0.381 ***	0.124	-0.795 ***	—
	p-value	0.183	< .001	0.017	0.551	< .001	< .001	0.012	< .001	0.188	< .001	—

Note. * p < .05, ** p < .01, *** p < .001

Low negative correlation | Low positive correlation | Insignificant correlation
Medium negative correlation | Medium positive correlation | Correlations important for the analysis
High negative correlation | High positive correlation

Figure 4. Correlation Matrix: 3rd timespan. Source: Authors

correlation (0,400), LitR had another moderate positive correlation (0,541), and AMI also kept a moderate positive correlation (0,601).

The fourth timespan had the most discordant results compared to the other time frames. AMI has kept a negative correlation with lethality, but with far more positive results, leading to a low negative correlation (-0,311), more positive than all of the time frames. The same pattern also happened with its correlation with contamination, AMI has kept its moderate positive correlation but with a more negative result (0,565). (See Figure 5)

PD correlation with lethality, although, kept low and positive (0,403), increased compared to the third interval.

EE and LitR both had no significant correlations with lethality, yet, their correlations with contamination were almost the same from the last timespan. (EE:0,399; LitR:0,542)

Correlation Matrix

		Sanitation rate	Acess to electric energy rate	Waste collection rate	Acess to water rate	Literacy rate	Average monthly income	Population density (hab/km²)	Total number of cases	Total number of deaths	Lethality rate	Contamination rate
Sanitation rate	Rho de Spearman	—										
	p-value	—										
Acess to electric energy rate	Rho de Spearman	0.391 ***	—									
	p-value	< .001	—									
Waste collection rate	Rho de Spearman	0.472 ***	0.599 ***	—								
	p-value	< .001	< .001	—								
Acess to water rate	Rho de Spearman	0.022	0.123	-0.068	—							
	p-value	0.817	0.190	0.471	—							
Literacy rate	Rho de Spearman	0.511 ***	0.811 ***	0.644 ***	-0.031	—						
	p-value	< .001	< .001	< .001	0.745	—						
Average monthly income	Rho de Spearman	0.342 ***	0.673 ***	0.433 ***	-0.153	0.855 ***	—					
	p-value	< .001	< .001	< .001	0.102	< .001	—					
Population density (hab/km²)	Rho de Spearman	0.445 ***	0.053	0.359 ***	-0.056	0.069	-0.197 *	—				
	p-value	< .001	0.577	< .001	0.555	0.462	0.035	—				
Total number of cases	Rho de Spearman	0.112	0.102	-0.033	0.083	0.112	0.024	0.099	—			
	p-value	0.234	0.278	0.724	0.381	0.235	0.798	0.291	—			
Total number of deaths	Rho de Spearman	0.217 *	0.018	0.025	0.029	0.027	-0.147	0.287 **	0.853 ***	—		
	p-value	0.020	0.851	0.787	0.757	0.776	0.118	0.002	< .001	—		
Lethality rate	Rho de Spearman	0.138	-0.128	0.158	-0.062	-0.132	-0.311 ***	0.403 ***	-0.251 **	0.234 *	—	
	p-value	0.142	0.172	0.092	0.513	0.160	< .001	< .001	0.007	0.012	—	
Contamination rate	Rho de Spearman	0.108	0.399 ***	0.208 *	0.001	0.542 ***	0.565 ***	-0.227 *	0.308 ***	-0.043	-0.702 ***	—
	p-value	0.248	< .001	0.025	0.994	< .001	< .001	0.015	< .001	0.650	< .001	—

Note. * p < .05, ** p < .01, *** p < .001

Low negative correlation
Medium negative correlation
High negative correlation
Low positive correlation
Medium positive correlation
High positive correlation
Insignificant correlation
Correlations important for the analysis

Figure 5. Correlation Matrix: 4th timespan. Source: Authors

4 Discussions

Several discussions can be drawn from the results, first one is that the correlation matrix results corroborate with the pattern of dissemination presented in Fortaleza Municipal Health Department epidemiological reports, that states that the higher HDI neighborhoods start the pattern then spread it to lower HDI neighborhoods that reach higher lethality rates. (SMS & PMF, 2023)

According to them, the first timespan of the study corresponds to the apex of the first wave, so, the pattern has started on higher HDI territories and is starting to transfer to the lower HDI neighborhoods, which is why AMI and LitR have a negative correlation with lethality, but still low. The second and third intervals are in a plateau with the number of deaths slowly increasing, which is why EE, LitR and AMI's correlations with the 2^{nd} and 3^{rd} time frame's lethality are more prominent than the first and similar within each other. The fourth interval corresponds to the beginning of a new wave which is why the results tend to be different from the three last intervals' increase.

This work, also points out which factors of the HDI might be actually correlating with COVID-19 and, against what is usually preached, longevity appears to not be the most important factor, but literacy and income do.

Also, AMI brings other reflections. First one is regarding the possibility of higher income neighborhoods to access private health care, as stated in previous works, which would be interesting on the apexes of waves specially (1^{st}/4^{th} intervals), since it's when the public health system tends to be more compromised. However, results show a lower correlation with lethality in the apexes and a stronger correlation in the plateau (2^{nd}/3^{rd} intervals) which, along with the presence of PD's correlations, lead the authors to suspect that problems in a lower scale, such as habitational quality, might be important to investigate in the future.

Finally, the environmental variables' absence might be explained due to the data's age, which is from the 2010's Census, another possibility is that data about quality of certain services (Sanitation, Waste Collection and Access to water) isn't available to analyze and they might be relevant to the pandemic dynamics.

5 Conclusion

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If the conference paper is the continuation of previous work, at least 30% of the content must be original, and the remaining 70% must be entirely rewritten to avoid self-plagiarism.

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