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The Impact of Public Health, Socioeconomic, and Environmental Factors on SARS-CoV-2 Infection and Mortality Rates in Peru: Exploring the Role of Obesity

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ABSTRACT

Introduction: Although several factors contributed to the rates of infection and mortality of the SARS-CoV-2 pandemic, obesity seemed to have played a larger role than most within the first several months of the pandemic. In addition, both preexisting health conditions and poor environmental conditions seemed to have added to higher levels of infection and mortality in several regions of the country. This study aimed to explore the impact of public health, socio-economic and environmental factors on the rate of infection and mortality of SARS-CoV-2 on gender and age groups in Peru.

Methods: We explored the relationships, using Pearson's correlation and stepwise linear regression, between the infection and mortality cases per 100,000 individuals with public health data (obesity prevalence, total number of health infrastructure, hypertension prevalence, active smokers, tuberculosis cases freely available from the Ministry of Health of Peru), socio-economic data (health needs not met, childhood malnutrition, access to potable water, access to chlorinated water system from National Institute of Statistics and Informatics of Peru) and environmental data (NO_2 concentration from the Sentinel-2 satellite) in Peru. We used confirmed cases from the 26 department level jurisdictions from 2020, before known variants were registered within the country and focused on gender and age groups, as well as case-fatality rate.

Results: Multiple linear regression models indicate obesity, air quality, access to chlorinated water system, and prevalence of smoking are influential factors in the distribution of infection and mortality for middle-age and elderly female and male groups, but prevalence of TB and health needs not met were more important for children and young adults in Peru. Case-fatality rate was weakly associated with NO_2 concentration.

Conclusions: Obesity, exposure to poor air quality, and socio-economic conditions are significant factors in the morality of individuals above the age of 40 for both men and women, while other health factors appear to be more important to those younger than 40. The combination of these factors played a significant role during the first wave of SARS-CoV-2 infection in Peru in 2020.

KEYWORDS

Air quality, age groups, COVID-19, gender, obesity, public health infrastructure.

INTRODUCTION

The current public health situation involving SARS-CoV-2 has been labeled as a collision of pandemics and health crisis[1,2], where the likelihood of negative outcomes significantly increases in magnitude when multiple risk factors are present[1]. Among the early identified major risk factors was obesity, an increasingly prevalent pandemic to pediatric and older

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age groups that seemed to increase the development of severe symptoms and mortality[3,4]. In previous decades obesity had been described as a risk condition for AH1N1 influenza[5,6] and is now linked to an increased number of infections[5].

Socio-economic factors are extensively associated with the prevalence of diseases and mortality, and is now reflected in the outcomes of the newly emerged coronavirus disease (i.e. SARS-CoV-2) [7]. It has become increasingly important to determine the roles of different socio-economic factors in the spread of current pandemic[8], where the unequal demographic and clinical presentations of SARS-CoV-2 patients, allude to the importance of socio-economic factors in the transmission, disease severity and outcomes[9].

The interconnection between different pre-existing health conditions, environmental factors and the susceptibility of individuals to SARS-CoV-2 infection and death continues to be explored as the pandemic reaches its second year and continues to evolve. There is currently wide documentation exploring the rate of infection and mortality to various factors, including obesity[7], air quality[10,11], climate variables[12], and socio-economic inequality[9]. It appears that obesity and prolonged exposure to poor air quality are among the most significant factors associated with the total infection and mortality rate[7,13], at least in the first waves of infections of 2020 and reaching into early 2021. Studies have also documented the apparent differences in rate of infection and mortality based on gender[14] and broad age groups[15]. However, few studies have explored which factors, within a larger data set of underlying health conditions, environmental and socio-economic factors, could help determine the infection and mortality rate within different gender-based age groups.

Understanding which factors are the most important to the rate of infection and mortality of SARS-CoV-2 continues to be an important activity as more data on case totals, outcomes, and cofactors become available. The main objective of this study was to explore the impact of obesity, public health, including pre-existing conditions and infrastructure, socio-economic and environmental factors on the rate of infection, mortality and case fatality rates of SARS-CoV-2 on the different gender and age groups in Peru during the first wave of infections in 2020.

MATERIALS AND METHODS

We obtained SARS-CoV-2 confirmed cases by department from official data provided by the Peruvian Ministry of Health (MINSA), through an official government open data portal (https://datosabiertos.gob.pe/), which was recently updated to include deaths reported in the National Information Systems of Deaths (SINADEF). This combined database may now approach a more accurate number of deaths from SARS-CoV-2 during the length of the pandemic. We used the cumulative number of confirmed cases of infection and confirmed cases of mortality of the 24 departments of Peru, 1 constitutional province of Callao, and the metropolitan city of Lima, registered within the year 2020 (i.e March to December 2020). For the purpose of categorization, we are naming all political entities presented here as departments. No SARS-CoV-2 variants were registered by MINSA in Peru before December 31, 2020. Under this criteria, the number of positive SARS-CoV-2 cases were 776,518 and 93,543 deaths by the end of the year. Most, if not all of these cases would be considered part of the first wave of infections and deaths associated with SARS-CoV-2 that occurred in Peru before new variants were detected. Available data of infection included data of confirmation and data on mortality included sex and date registered. The number of infections and deaths per 100,000 population within the general population, by sex, and age group per department were analyzed for this study.

In addition, we analyzed case-fatality rates, which indicates the severity of the condition by estimating the proportion of cases that die from the given condition[16]. The case-fatality rate was estimated by dividing the number of SARS-CoV-2 specific deaths among the incidence cases by the total number of incidence cases multiplied by 100 [17].

Public health and socio-economic data

The set of public health and socioeconomic data were obtained from the National Institute of Statistics and Informatics (INEI; https://inei.gob.pe). Public health data layers included obesity prevalence (% of the population), total number of health infrastructure (i.e. total number of hospitals, clinics, medical outposts), % of the population with hypertension, % of the population that are active smokers, number of tuberculosis (TB) cases per 100,000 population, and mean NO_2 density. We estimated air quality through mean and maximum tropospheric NO_2 density (µmol m^{-2}) for the year 2020, which is a health-relevant air pollutant monitored by the Copernicus Sentinel-5P satellite. We extracted the zonal statistics by department (i.e. average value per department polygon) for NO_2 mean and maximum across the department using ArcPro (version 2.2). Socio-economic data included the percent of the population indicating at least one health related need not met, percent of child population under 5 years of age with malnutrition, percent of population that do not have access to potable water, and percent of population with access to a chlorinated water system.

Data analysis

We used JASP version 0.15.0.0 for all statistical analysis. Bivariate covariance with the subset of public health and socioeconomic data were estimated with Pearson's correlation, where the correlation of the order of 0.9 or larger were determined to have a high covariance. As a result, maximum NO_2 across departments for 2020 and percent of population that do not have access to potable water were not used in this study. The final data set used in this study were 9 data layers, including 6 public health layers and 3 socioeconomic layers (Table 1). The public health and socioeconomic data were normalized (following 10, 18), due to different units used in each variable, through the following equation:

$$X = X_n - X_{an}/S_n \qquad (1)$$

Where X is the normalized data, X_n is the raw data for the factor, X_{an} is the mean value of the raw data, and S_n is the standard deviation of X_n.

We used stepwise linear regression to explore the association between public health and socioeconomic variables with data of infection per 100k population, mortality per 100k population, and case-fatality rate across the departments of Peru. The number of cases were used as dependent variables and the public health and socioeconomic factors were selected as independent variables. The predictive models used one or multiple variables that best explain the dependent variables in a statistically significant association. The percentage of all factors that explain the distribution of cases is indicated by the adjusted R^2 from model fitting. The magnitude of the standardized β indicates the influence of a particular variable in the predictive model. Collinearity diagnostics, within the stepwise linear regression analysis, were used to identify model variables that were highly correlated. A one-way ANOVA, followed by a Tukey test, was used to evaluate the significant differences between means.

RESULTS

Metropolitan Lima had the most number of infections and case fatalities of SARS-CoV-2, with 265,505 total infections and 38,957 total fatalities, within the year 2020. However, the department of Moquegua had the highest rate of infection of 7,888 per 100,000 population and the second highest rate of fatalities of 457.1 per 100,000. Callao had a slightly higher rate of fatalities of 460.2 per 100,000.

The total number of registered female fatalities was 33,250 (35.5%) and that of males were 60,292 (64.5%). The average age of total female fatalities was 67.4 (SD ± 15.9) and males was 66.0 (SD ± 15.1). We found a significant difference between the average age of female and male fatalities ($F= 182$, $p = <0.001$). Mortality by 100,000 population was highest in the departments of Callao (460.2), Moquegua (457.1), and Lima (402.7). In addition, the department of Callao had the highest female and male mortality by 100,000 population. It was notable that Moquegua had among the highest mortality by 100,000 population despite being ranked 25th out of 26 departments according to total population in the year 2020.

Correlation analysis indicated a significant positive correlation of the number of infections per 100,000 with percentage of population with obesity ($\rho = 0.591$), percentage of population who have a chlorinated water system ($\rho = 0.439$) and percentage of active smokers ($\rho = 0.391$), and a negative cor-

Table 1. Pearson's correlation between public health and socioeconomic factors and infection and mortality per 100,000 population, and case-fatality rate (CFR). Only statistically significant correlations are shown

Factors	Infection	CFR	Mortality		
			All	Male	Female
Public health					
Obesity prevalence	0.591**	–	0.804***	0.795***	0.771***
Total health infrastructure	–	–	–	–	–
% pop. with hypertension	–	–	–	–	0.403*
% pop. active smokers	0.391*	–	0.488*	0.477*	0.471*
TB cases per 100k	–	–	0.557**	0.568**	0.501**
Mean NO_2 density	–	0.476*	0.603**	0.628***	0.561**
Socio-economic					
% pop. health care need not met	–	–	–	–	–
% pop. under 5 years with child malnutrition	–0.495*	–	–0.689***	–0.674***	–0.683***
% pop. with access to chlorinated water system	0.439*	–	0.554**	0.568**	0.490*

* p<0.05, ** p<0.01, and ***p<0.001.

relation with percentage of child malnutrition (ρ = –0.495). With regards to mortality from SARS-CoV-2, a significant positive correlation coefficient between registered mortality per 100,000 population and obesity (ρ = 0.804), NO_2 mean (ρ = 0.603), percentage of active smokers (ρ = 0.488), percentage of population who have access to a chlorinated water system (ρ = 0.554) and a negative correlation with percentage of child malnutrition (ρ = –0.689). Similar positive and negative correlations were also found between mortality in the male and female population, with the exception that hypertension was also positively correlated with female mortality (ρ = 0.403; Table 1).

In stepwise linear regression model fitting, only obesity was indicated as the parameter that explained the cumulative number of infections per 100,000 population across the Peruvian departments (R^2 = 0.35; p = 0.001). This indicates an increase in the number of infections per 100,000 individuals with the increase in the percentage of the population that are classified as obese. The highest percentage of obesity were in the departments of Tacna, Moquegua, and Madre de Dios, which were ranked 4th, 1st and 2nd in the rate of infection, respectively.

Model fitting for mortality cases per 100,000 population indicated a positive correlation of obesity (β = 0.887), NO_2 mean (β = 0.572), and a negative correlation with percentage of population who have a chlorinated water system (β = –0.461). Obesity was the most influential factor for mortality across the departments, as well as in the female and male population. An adjusted R^2 indicated the models included at least 73% of the factors that affect the difference in all mortality and across sexes (Table 2).

However, when we disaggregate female and male mortality by age groups, there is change in influential factors below 40 years of age. For women, the percent of population with health care needs not met (β = 0.663) and number of tuberculosis (TB) cases per 100,000 population (β = 0.764) were the most influential factor for ages 0 to 19 and 20 to 39, respectively. Male mortality per 100,000 population had a similar set of predictors for the 0 to 19 age range (R^2 = 0.62, p = <0.001) and included % of the population that are active smokers for the 20 to 39 age range (R^2 = 0.64, p = <0.001). Predicting factors for age groups above 40 years of age were similar to the predictive models for overall mortality across all populations.

A positive correlation from model fitting was also found between case fatality rate and NO_2 mean (β = 0.476), and a relatively low explanatory factor (R^2 = 0.23; p-value = 0.014) compared to most predictive models performed in this study (Table 2). Disaggregated by sex and age groups, the case fatality rate models provided low explanatory factors ($R^2 \leq 0.40$). However, it is worth noting that both female and male groups below 40 years of age did not have NO_2 mean as the most influential factor for the development of the model (Table 5).

Table 2. Predictive models of the relationship of SARS-CoV-2 incidents per 100,000 population and public health and socioeconomic factors

Dependent	Predictors	Standardized β	R^2	Adj. R^2	p-Value
Infections across populations	Obesity	0.591	0.35	0.32	0.001
Mortality across populations	Obesity	0.887	0.8	0.78	0.014
	NO_2 mean	0.572	–	–	–
	Chlorinated water system	–0.461	–	–	–
Overall male mortality	Obesity	1.215	0.84	0.81	0.037
	NO_2 mean	0.672	–	–	–
	Chlorinated water system	–0.424	–	–	–
	Child malnutrition	0.455	–	–	–
Overall female mortality	Obesity	0.91	0.76	0.73	0.008
	NO_2 mean	0.583	–	–	–
	Chlorinated water system	–0.549	–	–	–
Case fatality rate	NO_2 mean	0.476	0.23	0.2	0.014

Table 3. Table 3. Predictive models of the relationship of age of female mortality from SARS-CoV-2 per 100,000 population and public health and socioeconomic factors.

Female age range	Predictors	Standardized β	R^2	Adj. R^2	p-Value
0 to 19	Health care needs	0.663	0.44	0.42	<0.001
20 to 39	TB	0.764	0.58	0.57	<0.001
40 to 59	Obesity	0.838	0.81	0.77	<0.001
	NO_2 mean	0.538	–	–	–
	Chlorinated water system	–0.561	–	–	–
	Smoking	0.253	–	–	–
60 to 79	Obesity	0.843	0.74	0.71	<0.001
	NO_2 mean	0.656	–	–	–
	Chlorinated water system	–0.550	–	–	–
≥80	Obesity	0.742	0.64	0.59	<0.001
	NO_2 mean	0.671	–	–	–
	Chlorinated water system	–0.532	–	–	–

Table 4. Predictive models of the relationship of age of female mortality from SARS-CoV-2 per 100,000 population and public health and socioeconomic factors.

Male age range	Predictors	Standardized β	R^2	Adj. R^2	p-Value
0 to 19	TB	0.525	0.62	0.59	<0.001
	Health care needs	0.496	–	–	–
20 to 39	TB	0.482	0.64	0.61	<0.001
	Smoking	0.384			
40 to 59	Obesity	0.825	0.87	0.84	<0.001
	NO_2 mean	0.45	–	–	–
	Chlorinated water system	–0.416	–	–	–
	Smoking	0.256	–	–	–
60 to 79	Obesity	1.25	0.82	0.78	<0.001
	NO_2 mean	0.618	–	–	–
	Child malnutrition	0.504	–	–	–
	Chlorinated water system	–0.376	–	–	–
≥80	Obesity	0.751	0.56	0.55	<0.001

Table 5. Predictive models of the relationship of case fatality rates from SARS-CoV-2 per 100,000 population and public health and socioeconomic factors. Only statistically significant correlations are shown

Age range	Predictors	Standardized β	R^2	Adj. R^2	p-Value
Females					
0 to 19	Chlorinated water system	–0.441	0.2	0.16	0.024
20 to 39	TB	0.706	0.4	0.34	0.014
	Chlorinated water system	–0.493	–	–	–
40 to 59	NO_2 mean	0.428	0.18	0.15	0.029
60 to 79	NO_2 mean	0.448	0.2	0.17	0.022
≥80	–	–	–	–	–
Males					
0 to 19	Child malnutrition	0.389	0.15	0.12	0.049
20 to 39	TB	0.655	0.36	0.3	0.014
	Chlorinated water system	–0.513	–	–	–
40 to 59	–	–	–	–	–
60 to 79	NO_2 mean	0.486	0.24	0.2	0.012
≥80	NO_2 mean	0.615	0.38	0.35	<0.001

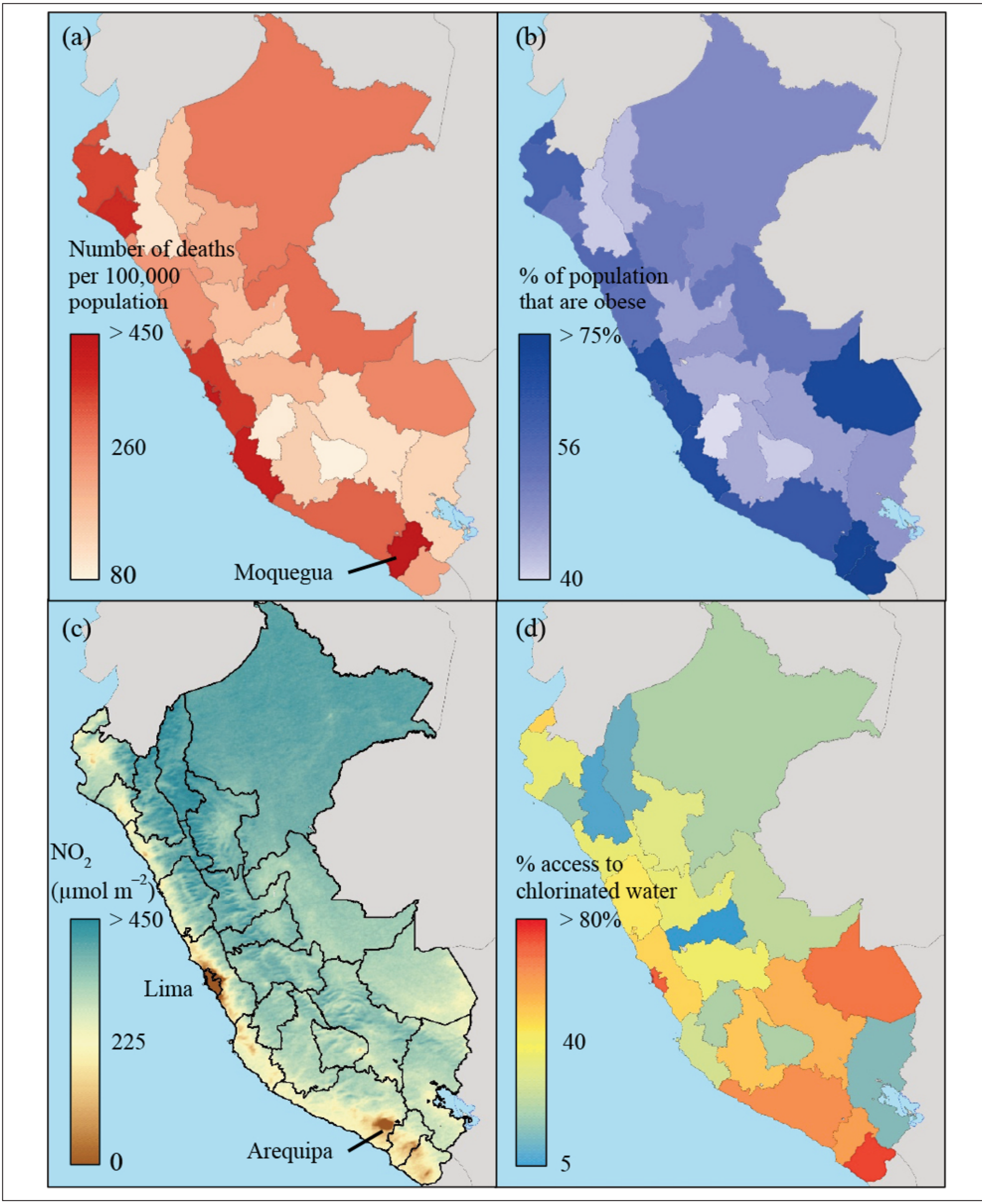
DISCUSSION

Our study found a clear relationship between obesity and the rate of mortality per 100,000 population, particularly for the portion of the female and male population above 40 years of age. Generally, the higher rate of obesity seems to significantly increase the probability of mortality in the middle-age to older adults, both female and male, but with other environmental and socio-economic factors having significant roles. Indeed, obesity was found to be an important SARS-CoV-2 mortality factor early in the pandemic[1,2,19]. It was a very strong predictor for mortality rates in Peru, followed by air quality. But to our surprise, it was not a significant predictor of mortality for children or young adults for either gender.

By looking at the mortality per 100,000 population from different age groups and gender, it becomes clearer that other factors, such as access to healthcare and sanitary conditions become increasingly important. The percent of population who have been infected by tuberculosis, another respiratory disease, reflects both public health status and socio-economic conditions, as TB infections are both preventable and treatable with proper public health infrastructure and investment. Although our study was not able to obtain specific data on the percentage of TB infections for each age group in Peru, poorer populations in Peru, particularly young age groups, are known to experience a high degree of respiratory infections due to location and environmental conditions of dense population settlements in the outskirts of major cities, such as Lima[20]. Nonetheless, obesity rates of young individuals in Peru are growing, but it does not seem to be a factor in the same magnitude as for older individuals.

It is worth noting the additional factors that seem to contribute to the rate of mortality across gender and age group, particularly air quality, access to a chlorinated water system and the percentage of the population that are smoking. Air quality, measured through mean NO_2 concentration, was poorest in the major metropolitan cities of Lima and Arequipa, and Moquegua, which had the highest rate of infection and the second highest rate of fatalities per 100,000. The unusually high rate of mortality for the relatively small population of Moquegua has not been previously reported, particularly in the context of Peru where it is reported as the country with among the highest rate of mortality in the world[21]. This seemingly extreme hotspot for SARS-CoV-2 mortality has a collision of factors, including the higher than usual percentage of obesity, where populations in the Sierra have a significantly higher consumption of carbohydrates compare to other regions[22], and lower mean air quality throughout the year, apparently due to heavy mining activity.

Figure 1. a) SARS-CoV-2 deaths per 100,000 population per department, b) percent (%) of population that are classified as obese per department, c) mean tropospheric NO2 density (μmol m^{-2}) for 2020, and d) percent (%) of population per department that has access to a chlorinated water system.



In addition, the percentage of population that are smoking was a significant factor for middle-aged female and male populations. The susceptibility of the smoking population may be similar to those exposed to continued poor air quality, as smoking is an additional factor that complicates tissue recovery from infection, allergic exposure, and many other chronic health conditions[23].

Our study not only supports a growing body of studies that signal obesity affects SARS-CoV-2 infection and mortality rates, but significant differences between factors are affecting female and male age groups separately. Most importantly, obesity was the most statistically significant contributor to the predictive models for middle-age and older populations, but not for children and young females and males, where other disease and public health metrics were significant. This is important to understand the heterogeneous effect of SARS-CoV-2 to different portions of the population and the post-SARS-CoV-2 response developing nations should take to rebuild the public health infrastructure.

Limitations

We were able to obtain public health metrics at the department level, but disaggregated public health data at the district level or sub-divided to additional age groups and gender are not publically available. In addition, although Peru has recently taken great strides to improve the estimation of mortality, including cross-validating official government databases, the number of total infections throughout the SARS-CoV-2 pandemic may be underestimated due to the lack of resources, particularly early in the pandemic and up to December 2020. No statistically structured testing regime is being conducted in Peru to adequately estimate the number of infections.

CONCLUSIONS

Obesity and poor air quality were among several factors that determined the high number of infections and mortality per 100,000 population in Peru during the first wave of SARS-CoV-2 through the end of 2020. In particular, obesity and poor air quality were the most significant factors for mortality for middle-aged to elderly female and male portions of the population. However, other public health factors were more significant predictors of mortality for children and young adults. As new data becomes available and SARS-CoV-2 variants become prevalent, this study can be compared to new findings to determine if different relationships determine the rate of infection and mortality with the new variants.

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