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COVID-19 mortality in Brazil: socioeconomic determinants across age groups

Mortalidade por COVID-19 no Brasil: determinantes socioeconômicos segundo faixas etárias

Mortalidad por COVID-19 en Brasil: determinantes socioeconómicos según grupos de edad

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Abstract

Introduction: COVID-19 mortality is known to be higher among older populations, but determinants across different age groups remain poorly understood in countries with significant social inequalities. Objective: To evaluate the association between socioeconomic inequalities, primary healthcare availability, and COVID-19 mortality across age groups in Brazil during 2020. Methods: A population-based ecological study was conducted using data from the Ministry of Health and the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística* – IBGE. COVID-19 mortality rates were analyzed in three age groups (<30, 30–59, and ≥60 years) across 26 states and the Federal District. Negative Binomial Regression models adjusted for population size were fitted. Results: Mortality varied significantly by state and age group. Higher income inequality (Gini Index) was consistently associated with increased mortality ($p<0.05$), while greater availability of primary healthcare teams was linked to lower mortality ($p<0.05$). Conclusions: Social inequalities were associated with higher COVID-19 mortality in Brazil, underscoring the need for equitable public health policies and stronger primary healthcare systems.

Keywords: COVID-19; Mortality; Health Inequalities; Primary Health Care; Social Determinants of Health.

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Resumo

Introdução: A mortalidade por COVID-19 é maior em populações idosas, mas os determinantes entre diferentes faixas etárias permanecem pouco compreendidos em países com desigualdades sociais marcantes. Objetivo: Avaliar a associação entre desigualdades socioeconômicas, disponibilidade de atenção primária e mortalidade por COVID-19 segundo faixas etárias no Brasil em 2020. Métodos: Estudo ecológico de base populacional com dados do Ministério da Saúde e do Instituto Brasileiro de Geografia e Estatística (IBGE). Foram analisadas as taxas de mortalidade em três grupos etários (<30, 30–59 e ≥60 anos) nos 26 estados e no Distrito Federal, por meio de modelos de Regressão Binomial Negativa ajustados pelo tamanho da população. Resultados: A mortalidade variou significativamente entre estados e faixas etárias. Maior desigualdade de renda (Índice de Gini) associou-se a maior mortalidade em todas as faixas etárias (p<0,05), enquanto maior disponibilidade de equipes de atenção primária esteve associada a menor mortalidade (p<0,05). Conclusões: As desigualdades sociais se associaram a maior mortalidade por COVID-19 no Brasil, reforçando a necessidade de políticas públicas equitativas e do fortalecimento da atenção primária à saúde.

Palavras-chave: COVID-19; Mortalidade; Desigualdades de Saúde; Atenção Primária à Saúde; Determinantes Sociais da Saúde.

Resumen

Introducción: La mortalidad por COVID-19 es mayor en poblaciones de edad avanzada, pero los determinantes entre diferentes grupos etarios siguen siendo poco conocidos en países con marcadas desigualdades sociales. Objetivo: Evaluar la asociación entre desigualdades socioeconómicas, disponibilidad de atención primaria y mortalidad por COVID-19 según grupos etarios en Brasil durante 2020. Métodos: Estudio ecológico de base poblacional con datos del Ministerio de Salud y del Instituto Brasileño de Geografía y Estadística (IBGE). Se analizaron las tasas de mortalidad en tres grupos etarios (<30, 30–59 y ≥60 años) en los 26 estados y el Distrito Federal, mediante modelos de Regresión Binomial Negativa ajustados por el tamaño de la población. Resultados: La mortalidad varió significativamente entre estados y grupos etarios. Una mayor desigualdad de ingresos (Índice de Gini) se asoció consistentemente con mayor mortalidad (p<0,05), mientras que una mayor disponibilidad de equipos de atención primaria se vinculó a menor mortalidad (p<0,05). Conclusiones: Las desigualdades sociales se asociaron a mayor mortalidad por COVID-19 en Brasil, destacando la necesidad de políticas públicas equitativas y del fortalecimiento de la atención primaria de salud.

Palabras clave: COVID-19; Mortalidad; Inequidades en Salud; Atención Primaria de Salud; Determinantes Sociales de la Salud.

INTRODUCTION

The first report of the severe acute respiratory syndrome virus 2 (SARS-CoV-2) was in December 2019 in Wuhan, China.[1] The transmission of the virus around the world occurred quickly, and on 11 March 2020, the World Health Organization (WHO) declared the pandemic status of coronavirus disease 2019 (COVID-19).[2] The risk factors for greater severity of the disease are male sex, age, and the presence of comorbidities such as hypertension, diabetes, respiratory diseases, cancer, stroke, chronic kidney disease, and obesity.[3,4] However, substantial heterogeneity in COVID-19 morbidity and mortality was observed across and within countries, reflecting not only biological risk factors but also differences in socioeconomic conditions, healthcare infrastructure, and public health responses.

Since the first case of infection in Brazil on 26 February 2020, the rate of disease progression in the national territory has grown rapidly.[5] The Brazilian health system, which was already weakened in 2020 due to the high number of hospitalizations of patients who developed severe forms of COVID-19, was overwhelmed shortly after the new variant of the virus was initially found in Manaus, a city in Amazonas, Brazil, in 2020.[6]

On 31 December 2020, the country had recorded more than 194,000 deaths from the disease, and this number increased in the first 3 months of 2021 to 300,000 deaths.[7] In this scenario, there are still several questions regarding the behavior of the virus in different populations, especially in developing countries such as Brazil, that need to be addressed to assist in the design and implementation of an effective health system.

An important study in Brazil found that existing socioeconomic inequalities have affected the course of the epidemic, leading to a disproportionate adverse burden on states and municipalities. It also showed that there are significant differences in policy responses across municipalities.[8] However, although previous analyses have explored social vulnerability and pandemic preparedness, less is known about the independent role of income inequality, primary health care (PHC) structure, and other contextual determinants in COVID-19 mortality across different age groups in Brazil.

Understanding these associations may help clarify how structural socioeconomic and healthcare factors influenced pandemic outcomes beyond biological vulnerability alone.

In this ecological study, we assessed whether public healthcare structure indicators and socioeconomic factors were associated with COVID-19 mortality across age groups in Brazilian federative units, using cumulative mortality rates in 2020. The analysis focused on the first year of the pandemic, before the introduction of COVID-19 vaccination in Brazil.

METHODS

Number of COVID-19 cases and deaths in Brazilian states

The database with death records for the 26 Brazilian states and the Federal District was obtained from the online platform of the civil registry[7] which updates the number of cases and deaths daily. The number of deaths in 2020 was used in this analysis to evaluate the impact of COVID-19.

Socioeconomic, demographic, and health service structure data in Brazilian States

To determine which variables were associated with mortality, we first collected several different indices available in the country from different sources:

- Demographic density and estimated population for each Brazilian state, as estimated by the Brazilian Institute of Geography and Statistics;[9]
- Gini coefficient in 2020;[10]
- The Human Development Index (HDI), last registered in 2017 by the *Programa das Nações Unidas para o Desenvolvimento*,[11] which is based on three human dimensions — longevity, education, and income — and was classified as very low (0–0.499), low (0.5–0.599), medium (0.6–0.699), high (0.7–0.799), and very high (0.8–1.0);
- The social vulnerability index calculated by the Institute for Applied Economic Research (*Instituto de Pesquisa Econômica Aplicada* – IPEA)[12] in 2017, which analyzed 16 variables that were organized into three vulnerability dimensions: urban infrastructure, human capital, and income and work. Vulnerable categories were classified as very low (0–0.2), low (0.2–0.3), medium (0.3–0.4), high (0.4–0.5), and very high (>0.5);
- Percentages of the population with piped water and with sewage collection;[13]
- Number of primary care teams, hospital beds, and doctors per 100,000 inhabitants.[14]

Statistical analysis

All statistical analyses were performed using RStudio (‘2024.12.1.563’), employing packages such as MASS, AER, car, ggplot2, and DHARMa. The outcome variable was the number of COVID-19 deaths

per state, analyzed separately for three age groups: <30 years, 30–59 years, and ≥60 years. To account for differing population sizes across states and age groups, we included the natural logarithm of the population as an offset in all regression models.

Initial Poisson regression models showed significant overdispersion in all age groups (dispersion tests: $p<0.001$). Residual diagnostics and formal overdispersion tests suggested deviations from Poisson assumptions. The estimated dispersion parameter ($\alpha=1/\theta$) ranged from 0.083 to 0.156 across age-specific models, further supporting the presence of extra-Poisson variability. To account for extra-Poisson variability, negative binomial regression models were fitted. Model fit was substantially improved, as demonstrated by lower Akaike information criterion (AIC) values and likelihood ratio tests favoring the negative binomial specification in all age groups.

Independent variables were selected based on theoretical relevance, exploratory correlation analyses, and multicollinearity assessment using the variance inflation factor (VIF). To improve interpretability of the regression coefficients, the Gini Index and Social Vulnerability Index were rescaled by dividing each by 0.05 units. This allows mortality rate ratios (MRRs) to reflect the effect of a 0.05-point increase, representing a meaningful change in the scale of both indices. PHC teams and churches were also rescaled (per 2,000 and 40 units, respectively). Variables with VIF <5 were retained in the final models. The final variables included the Gini Index (income inequality), Social Vulnerability Index, PHC teams, and number of churches per 100,000 inhabitants.

Diagnostic evaluation of the final models included analysis of standardized residuals, Q-Q plots, and residuals *vs*. predicted values using the DHARMa package. We also tested the linearity assumption for all continuous variables using natural cubic splines (df=3). As detailed in the results and supplementary material, no substantial evidence of non-linearity was detected, and spline models did not significantly improve model fit. Given the ecological design and the limited number of observational units (n=27 federative units), variable inclusion was restricted to avoid overfitting, maintaining a ratio of observations to predictors above the commonly recommended minimum of 5:1.

This study used only publicly available, aggregated secondary data at the state level, without individual identification of participants. According to Brazilian National Health Council Resolution No. 510/2016, ethical review by a Research Ethics Committee was waived.

RESULTS

There was a large difference in mortality rates by age group among the Brazilian states (Figure 1).

Regarding death rates per 100,000 inhabitants, in the <30 age group, Roraima had the highest rate (9.91), while Minas Gerais had the lowest rate (1.74). In the 30–59 age group, Roraima had the highest rate (128.54), while Maranhão had the lowest rate (28.31). Among individuals aged ≥60 years, mortality was highest in Roraima (1,913.41) and lowest in Rondônia (294.27) (Figure 1).

The correlation plot (Figure 2) showed a positive correlation between income inequality (Gini index) and mortality rates, particularly among younger populations, while higher healthcare infrastructure indicators, such as doctors and hospital beds, were negatively correlated with mortality.

After adjusting for population size and selected covariates, the negative binomial models identified consistent associations between income inequality and COVID-19 mortality across all age groups. A 0.05-point increase in the Gini Index was associated with a 35% increase in mortality in the <30 age group (MRR=1.35; 95% Confidence Interval (95%CI): 1.14–1.60), a 22% increase in the 30–59 group

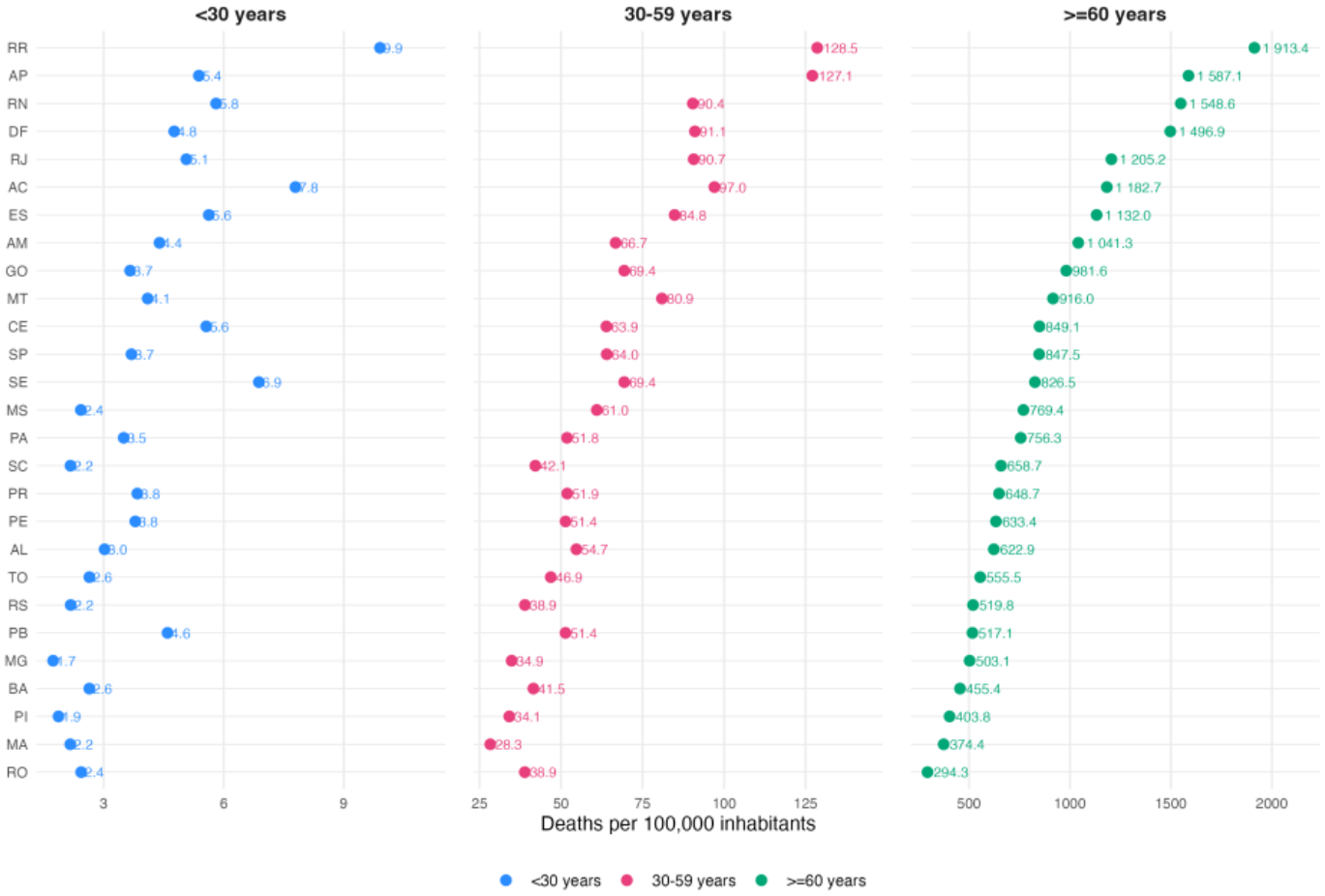

Figure 1. Mortality rate by age group across Brazilian states.

(MRR=1.22; 95%CI: 1.03–1.46), and a 24% increase in the ≥60 group (MRR=1.24; 95%CI: 1.01–1.53) (Table 1).

The availability of PHC teams showed a protective association with mortality in all age groups. After rescaling the PHC variable (per 2,000 PHC teams), each increase in PHC team availability was associated with a 16-17% reduction in mortality (MRRs ranging from 0.83 to 0.84, all p<0.05).

The Social Vulnerability Index (scaled per 0.05-point increase) and the number of churches (per 40 units) were not significantly associated with mortality in any age group after adjustment.

Linearity assessment

We tested the linearity assumption for all continuous predictors using natural cubic splines (df=3) in each of the three age-specific models. Comparisons between the linear and spline-based models were performed using the AIC and likelihood ratio tests. As shown in Supplemental Figure 1, spline terms did not significantly improve model fit for any variable in any age group.

For example, while the PHC teams variable showed a slight improvement in model fit in the 30–59 age group (ΔAIC=+1.83; p=0.054), this difference did not reach statistical significance. Similarly, the churches variable in the 60+ age group yielded a p-value of 0.079, suggesting only a modest, non-significant trend toward non-linearity.

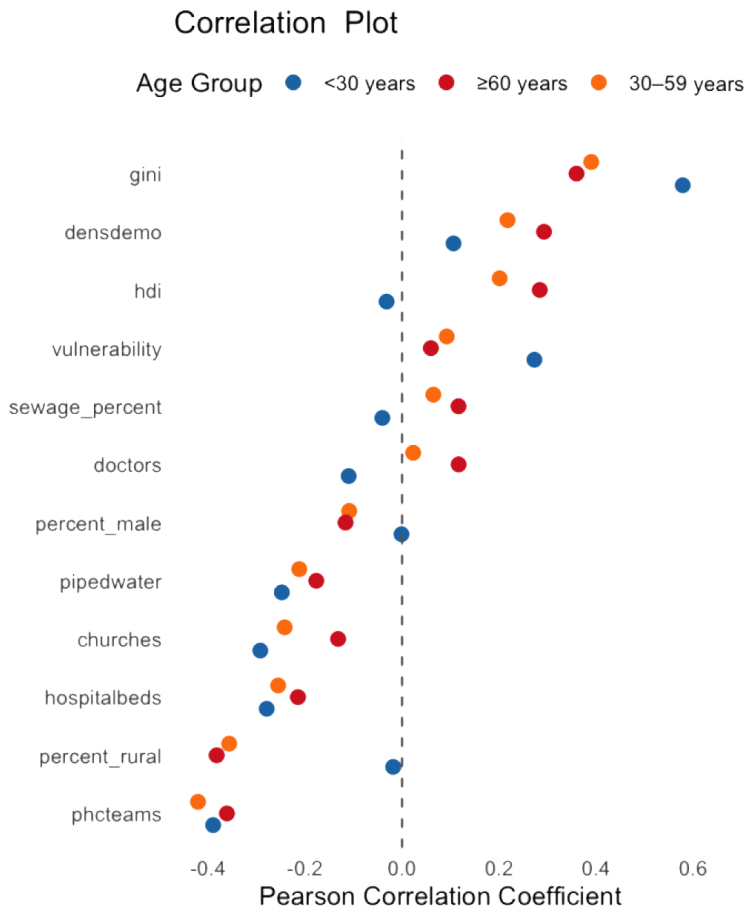

Figure 2. Correlation Plot.

Table 1. Negative Binomial Regression Models for COVID-19 Mortality According to Age Groups in Brazilian States, 2020.

Variable	MRR (<30y) [95%CI]	MRR (30–59y) [95%CI]	MRR (≥60y) [95%CI]
Gini Index	1.35* [1.14–1.60]	1.22* [1.03–1.46]	1.24* [1.01–1.53]
PHC Teams	0.83* [0.73–0.96]	0.84* [0.73–0.97]	0.83* [0.70–0.99]
Vulnerability	1.02 [0.89–1.17]	0.96 [0.83–1.10]	0.96 [0.80–1.14]
Churches	1.06 [0.92–1.21]	1.02 [0.89–1.17]	1.05 [0.90–1.24]

*p<0.05. MRR: Mortality Rate Ratio; 95%CI: 95% Confidence Interval; PHC: Primary Health Care.
Note: Variables were rescaled for interpretability (see Methods).

To address potential concerns regarding model assumptions, we performed diagnostic evaluations using the DHARMa package. All models demonstrated adequate fit, with no evidence of overdispersion or systematic deviation in residuals (Supplemental Figure 2).

DISCUSSION

This study found that income inequality was consistently associated with higher COVID-19 mortality across all age groups in Brazil, even after adjustment for social vulnerability and healthcare structure indicators. Conversely, greater availability of PHC teams showed a protective association with mortality.

Similar patterns were observed in previous health crises, such as the H1N1 pandemic, where accumulating evidence showed racial and ethnic minorities being disproportionately affected, suggesting that health inequities amplify the risk of severe clinical outcomes.[15] Likewise, during the COVID-19 pandemic, U.S. counties with higher concentrations of non-Hispanic Black populations experienced disproportionately higher morbidity and mortality rates,[16] reflecting how socioeconomic determinants, including access to healthcare, significantly shaped pandemic outcomes.

Income inequality, frequently measured by indicators such as the Gini Index, is strongly associated with poorer health status, higher prevalence of chronic diseases, and reduced life expectancy, particularly in low- and middle-income countries and among vulnerable populations such as those in Brazil.[17] Multiple mechanisms may explain these associations, including overcrowded housing conditions, limited capacity for social distancing, dependence on informal labor, higher prevalence of chronic diseases, and delayed access to healthcare services. Consequently, addressing socioeconomic inequalities through integrated policies aimed at reducing disparities and enhancing healthcare accessibility and quality has become essential for future health emergencies worldwide.[18]

Although older adults presented substantially higher absolute mortality rates, the persistence of the association between income inequality and mortality across all age groups suggests that structural socioeconomic determinants influenced COVID-19 outcomes beyond biological vulnerability alone. These findings reinforce the hypothesis that unequal social conditions may intensify exposure, susceptibility, and barriers to timely healthcare access throughout the population.

Brazil's public health system, established under the 1988 Federal Constitution as the Unified Health System (*Sistema Único de Saúde* – SUS), is one of the world's largest universal public healthcare systems.[19] Its decentralized structure allows municipalities and states to organize healthcare delivery according to local needs, while primary healthcare services play a central role in surveillance, prevention, community-based care, and longitudinal follow-up of vulnerable populations.[20,21] During the COVID-19 pandemic, these characteristics may have contributed to early case detection, monitoring of high-risk individuals, and continuity of care, particularly in socially vulnerable regions.

However, decentralization may also have contributed to heterogeneous pandemic responses across Brazilian states and municipalities. Differences in local governance capacity, healthcare infrastructure, testing availability, implementation of social distancing measures, and hospital bed expansion likely intensified regional disparities in COVID-19 outcomes.[8,22] In a context of chronic underfunding of SUS[23,24] and unequal distribution of healthcare resources, decentralization may have amplified existing structural inequalities, limiting the ability of poorer regions to adequately respond to the pandemic.

These findings further support the concept of the social gradient in health, which postulates that health outcomes improve progressively with increasing socioeconomic position rather than differing only between the most and least disadvantaged groups. In highly unequal societies, adverse health effects tend to extend across the entire population, reflecting cumulative differences in living conditions, educational opportunities, employment stability, income distribution, and access to resources that promote health.[25,26] The persistence of the association between income inequality and COVID-19 mortality across all age groups suggests that the pandemic disproportionately affected populations positioned lower along this social gradient, reinforcing the role of structural social determinants in shaping health outcomes.

In this context, the protective association observed between PHC availability and lower mortality gains additional relevance. While income inequality reflects broader structural conditions that increase vulnerability to adverse outcomes, strong PHC systems may help mitigate part of these effects by reducing

barriers to healthcare access, strengthening territorial surveillance, supporting early identification of cases, coordinating care, and maintaining continuity of services during health emergencies. Thus, PHC may function as an important mechanism for attenuating the health consequences of social inequalities, even when broader socioeconomic disparities persist.

This study has limitations, particularly its ecological design, which precludes establishing rigorous causal inferences regarding the association between COVID-19 mortality and PHC resource availability. In addition, the ecological design may be subject to ecological fallacy, since associations observed at the state level may not necessarily reflect individual-level relationships. The relatively small number of observational units (27 federative units) may also have limited statistical power and constrained the number of variables that could be simultaneously included in the models. Furthermore, the official databases used in the analysis may have underreported actual COVID-19 mortality figures due to delays or inconsistencies in reporting. Despite these limitations, the consistency of the associations across age groups reinforces the relevance of socioeconomic inequalities and PHC structure as key determinants of COVID-19 mortality in Brazil.

CONCLUSION

COVID-19 differentially impacted the Brazilian population according to age and geographic region. Despite inherent challenges in addressing historical underfunding and systematic undervaluation of public healthcare, this study underscores the potential role of PHC in mitigating the pandemic's effects and promoting health equity in Brazil. The results emphasize the need to address socioeconomic disparities and strengthening PHC systems as foundational strategies for reducing the health impacts of current and future pandemics.

Given the global prevalence of inequality and the importance of resilient health systems, these findings may also inform strategies in other low- and middle-income countries facing similar structural challenges.

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CONFLICTS OF INTEREST

Nothing to declare.

AUTHORS' CONTRIBUTIONS

TLDLK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. LDL: Investigation, Methodology, Validation, Writing – review & editing. LHOE: Data curation, Investigation, Validation, Writing – review & editing. DCP: Validation, Writing – review & editing. MHGP: Data curation, Investigation, Writing – review & editing. BE: Data curation, Investigation, Writing – review & editing. TPM: Validation, Writing – review & editing. MS: Formal analysis, Methodology, Validation, Writing – review & editing. MO: Writing – review & editing. JFN: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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