Trans R Soc Trop Med Hyg 2022; **0**: 1–10
https://doi.org/10.1093/trstmh/trac004 Advance Access publication 0 2022

Decomposition of socioeconomic inequalities in arboviral diseases in Brazil and Colombia (2007–2017)

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Received 14 May 2021; revised 20 September 2021; editorial decision 6 January 2022; accepted 10 January 2022

Background: We used surveillance data from Brazil and Colombia during 2007–2017 to assess the presence of socioeconomic inequalities on dengue, chikungunya and Zika at the neighborhood level in two Latin American cities.

Methods: To quantify the inequality, we estimated and decomposed the relative concentration index of inequality (RCI) accounting for the spatiotemporal distribution of the diseases.

Results: There were 281 426 arboviral cases notified in Fortaleza, Brazil, and 40 889 in Medellin, Colombia. The RCI indicated greater concentration of dengue cases among people living in low socioeconomic settings in both sites. The RCIs for chikungunya in Fortaleza covered the line of equality during their introduction in 2014, while the RCIs for Zika and chikungunya in Medellin indicated the presence of a small inequality. The RCI decomposition showed that year of notification and age were the main contributors to this inequality. In Medellin, the RCI decomposition showed that age and access to waste management accounted for 75.5%, 72.2% and 54.5% of the overall inequality towards the poor for dengue, chikungunya and Zika, respectively.

Conclusions: Our study presents estimates of the socioeconomic inequality of arboviruses and its decomposition in two Latin American cities. We corroborate the concentration of arboviral diseases in low socioeconomic neighborhoods and identify that year of occurrence, age, presence of healthcare facilities and waste management are key determinants of the heterogenous distribution of endemic arboviruses across the socioeconomic spectrum.

Keywords: Arboviruses, Brazil, Colombia, Collective Effects of Health Disparities, Decomposition of Inequalities, Latin America

Introduction

Dengue, chikungunya and Zika are the main public health concerns in the Americas region.[1–4] These three arboviruses have a similar symptomatology, are illnesses for which specific curative treatments do not exist and diseases for which sufficiently safe and effective vaccines have not yet been introduced.[1,2] Among these three diseases, dengue has the highest incidence worldwide with the Americas region experiencing the second largest burden of notified cases. The largest dengue outbreaks in the region occurred in 2016 and 2019, with 2.38 and 3.1 million cases, respectively.[1,5] Chikungunya and Zika are considered re-emergent diseases and were introduced in the Americas in 2013 and 2015, respectively.[1,5] Chikungunya's outbreak included over a million cases in 2014 and Zika was considered a Public Health Emergency of International Concern (PHEIC) in 2016, due to its association with congenital malformations. In the Americas, Brazil and Colombia account for 40–60% of the overall burden of arboviruses in the South Cone.[1,2,5,6] In Colombia, the burden of dengue is concentrated in 50 out of over 1,000 municipalities, and chikungunya and Zika have been consistently notified by the same 30 municipalities.[7–9] In Brazil, although the distribution of dengue cases varies across the country, the Northwest and Central-Eastern regions report the most cases of Zika and chikungunya as well.[10–13]

Although infectious diseases are well known to demonstrate important social inequalities, the literature on arboviral diseases with the specific focus of health inequalities is limited.[14,15] Having acknowledged the presence of socioeconomic inequalities on arboviruses in Latin America, specifically the heterogeneous distribution of arboviral cases across different strata of socioeconomic status (SES),[1,11,12,14–17] it is imperative to understand what are the main contributors to this inequality. This information is key to contribute to the design and implementation of disease-control strategies that could target the most affected groups, and to promote and adapt interventions aimed at decreasing socioeconomic inequalities at local level.

Therefore, with the objective to identify which social determinants contribute most to socioeconomic inequalities in arboviral diseases in Latin America; we used longitudinal surveillance data of dengue, chikungunya and Zika and assessed the presence of socioeconomic inequality at the neighborhood level in Brazil and Colombia, by estimating and decomposing the relative concentration index of inequality.

Materials and Methods

Study sites

This study was conducted with data from Fortaleza, Brazil and Medellin, Colombia. Municipalities were selected based on the disease burden, knowledge of the context, presence of functioning surveillance system, data availability and expressed interest of the local health agencies in the study. The methods and procedures for this manuscript have been presented elsewhere and are briefly described below.

Fortaleza is the capital of Ceara state in Brazil and it has a population of 2.5 million inhabitants[18] whose healthcare coverage is mainly provided by the Unified Health System national program, which offers healthcare at primary healthcare centers and local hospitals/clinics distributed across the city.[19] Fortaleza has been consistently reporting the presence of dengue over the last decade and, since their introduction, chikungunya and Zika as well.[18–20] The city's altitude is 21 meters above the sea level (m.a.s.l.), the average temperature is 26.6°C, it has one rainy season (January to May) and its area (315 km^2) is distributed across six districts and 119 urban neighborhoods.

Medellin is the second largest city in Colombia with a population of 2.6 million inhabitants.[21] Health coverage of the population is as follows: 70% contributory (employees or self-employees with the capacity to pay for health coverage), 25% government-subsidized and 4% uninsured.[21] Healthcare is provided by different institutions according to the type of coverage. Medellin's altitude ranges from 1460 to 3200 m.a.s.l., and the average temperature is 24°C and two rainy seasons (April and October) can be observed throughout the year. The city has 16 urban districts and 249 urban neighborhoods distributed over 110 km^2. Although 50% of the city belongs to low SES, 98% of the city has access to potable water. Dengue incidence ranged from 161 to 745 cases per 100 000 inhabitants during the last 10 y.[8,9]

Data sources

Notification of dengue, chikungunya and Zika is mandatory in all study sites through each country's national (passive) surveillance system.[22,23] All cases of *Aedes*-transmitted diseases are individually registered in the national surveillance system (SINAN-Brazil and SIVIGILA-Colombia) and our sample included all notified cases in the study areas from 2007 to 2017. Supplementary aggregated information about socioeconomic factors at the neighborhood level was obtained using National Census data and local quality of life and basic needs surveys for socioeconomic data.[18,24]

Outcomes

Clinically and laboratory (e.g. serological and molecular) confirmed cases of dengue, chikungunya and Zika were registered as per the study site's surveillance system.[2,8,10,19,22,23] Given the introduction of chikungunya and Zika in 2014 and 2015 and the possibility of their misclassification with dengue at early stages of their introduction (e.g. chikungunya or Zika could have been misdiagnosed as dengue),[2,25] we also grouped these diseases into a single variable denominated 'all arboviruses'.[17] We estimated the site-specific aggregated and disease-specific spatiotemporally adjusted rate of disease by month and neighborhood and used it as the health outcome for the estimation of the inequality.

Socioeconomic measures

In Brazil, the socioeconomic measure used was the median monthly household income in US$ as a continuous variable.[18] In Colombia, we used the national SES index, which is an administrative summary ordinal measure (range 1–6), with one indicating the lowest SES and six indicating the highest SES.[26] The Colombian SES is a standardized and validated measure constructed by the National Department of Planning, according to the characteristics of the household including construction material, presence of assets and household conditions. Each house has a designated SES level provided by the municipality and each neighborhood in turn possesses an SES designation according to a weighted mode of the household's SES within each block and neighborhood.[26]

Other covariates

To identify and explore the role of individual and area-level social determinants of health (SDH) as contributors of the socioeconomic inequality in the distribution of arboviral diseases, the a priori covariates included into the decomposition were: the proportion of disease-specific female cases and the proportion of cases by age group (<5, 5–9, 10–20, 20–50 and >50 y) per neighborhood and per month. We included the proportion of people with secondary education, the proportion of households with an adequate supply of potable water, waste management, the number of people per household, type of health insurance and number of healthcare facilities per neighborhood, including the number of primary healthcare centers or hospitals/clinics where individuals could receive healthcare attention including diagnosis and treatment, according to the data availability in each study site.

Statistical analysis

Descriptive statistics for the data are presented as mean and SD or median and IQR for continuous variables and as proportions for binary or categorical variables.

Relative concentration index decomposition

The assessment of socioeconomic inequality was conducted by the estimation of crude and adjusted relative index of inequality with a regression-based decomposition of the latter.[27,28] The Relative Concentration Index (RCI) is a measure of relative inequality that allows the identification of differential burden of diseases among the population in different socioeconomic strata.[28] This econometric approach has been widely used in noncommunicable diseases and we propose its use in this field as a tool to assess inequalities in infectious diseases.[27–29] To estimate the RCI, we used disease-specific rates and the measure-specific (e.g. income or SES) socioeconomic rank of the population in each study site to estimate a relative concentration curve, which plots the cumulative fraction of cases on the y-axis against the cumulative fraction of the population ranked by SES on the x-axis. The RCI is twice the area that lies between the 45° line of equality and the concentration curve and the estimates range from −1 to +1.[28] The concentration index equals zero in the absence of inequality, is negative when disease rates are more concentrated among the poor (−1 in the presence of complete inequality towards the people at the bottom of the socioeconomic distribution) and is positive when the rates are more concentrated among the rich (+1 in the presence of complete inequality towards the people at the top of the socioeconomic distribution).[27,28] The regression-based decomposition to identify the contribution of each SDH covariate was conducted using a Bayesian hierarchical Poisson or negative binomial model of notified arboviruses. The regression model, the RCI estimation and the SDH-specific contribution were specified as follows:

$$\text{Disease model}: \log\left(y_{ij}\right) = \log(E_{ij}) + \beta_0 + x_{ij}^n\beta_n + s_i + t_j, \quad (1)$$

$$\text{Relative Concentration Index (RCI)}:$$

$$\text{RCI} = \frac{2cov\left(\hat{y}_{ij},\ R_{ij}\right)}{\mu} = \frac{2}{n^2\mu_y}\sum_{i=1}^{n}\hat{y}_{ij}R_{i,j}, \quad (2)$$

$$\text{SDH contribution}:\ SDH_n = [(\beta_n\bar{x}_n/\mu) * RCI_n]\ /\text{RCI}. \quad (3)$$

Equation 1 models the number of cases y_{ij} in neighborhood i at month j[30]; E_{ij} is the mid-year neighborhood-specific population or offset; β_0 is the intercept indicating the average log rate of disease in all neighborhoods; $x_{ij}^n\beta_n$ is a vector of fixed-effect covariates including gender, age, sanitation and the other neighborhood level covariates listed above. To account for the spatiotemporal distribution of the diseases, we included structured random effects for neighborhoods (s_i) and month of notification (t_j), and indicator variables for the year of notification in the disease model. The RCI and corresponding 95% point-wise intervals were estimated using Equation 2, where $\hat{y}_{ij}$ is the covariates and spatiotemporally adjusted disease rate obtained from Equation 1, R_{ij} is the rank of socioeconomic measure at neighborhood i at time j, specific for each study site. The socioeconomic rank ($R_{ij} = r_{ij} - [(n+1)/2]$) in each study site goes from 0 to 1, with neighborhoods at the lowest income or SES ranked at the bottom (rank 0) and neighborhoods with the highest income or SES ranked at the top (rank 1). And μ is the mean rate of reported cases in each study site. The SDH-specific contribution to the overall inequality was estimated using Equation 3, where the component $\beta_n\bar{x}_n/\mu$ is the elasticity, a parameter that determines the strength of the association between each SDH covariate and the inequality; β_n is the beta coefficient for each SDH covariate fixed-effect in the disease model regression, $\bar{x}_n$ is the covariate-specific mean and RCI_n is the SDH covariate-specific (partial) concentration index. Finally, to obtain the SDH-specific contribution to the overall inequality, the product of the elasticity and the partial SDH-specific concentration index is divided by the overall RCI.[27,29]

Given that the RCI could change over time and that socioeconomic measures could be correlated with the neighborhood, we fit models stratified by year and a set of models without the spatial random effect as sensitivity analysis. To illustrate the magnitude of the inequality in the presence of a monotonic relationship (with concentration of disease rates at the lower end of the SES distribution), we conducted a sensitivity analysis using the same rates from our study but scaling the SES measure. We conducted our analysis for the entire study period, and given that dengue, chikungunya and Zika were circulating simultaneously from 2014 to 2017, we conducted the aggregated arboviruses analysis using only data from these years. We calculated the aggregated and disease-specific RCIs, the point-wise intervals and contributions using modified functions from the 'decomp' R-packages for health inequalities[31] (Supplementary Appendix). All analyses were performed using RStudio (R version 3.6.1, R Core Team, Vienna, Austria).

Results

There were 282 921 arboviral cases notified in Fortaleza, Brazil and 40 889 in Medellin, Colombia. Descriptive characteristics are presented in Table 1 for Fortaleza and in Table 2 for Medellin. Overall, crude and adjusted disease rates showed a non-monotonic relationship with socioeconomic measures. In Fortaleza, we observed higher dengue rates among low-income settings, Zika rates were low across the median household income spectrum and chikungunya rates were highly variable (Figure 1A). In Medellin, dengue rates were higher among middle SES-level neighborhoods while chikungunya and Zika rates were similar across the SES strata (Figure 1B).

RCI estimation and decomposition

In Fortaleza, the overall adjusted RCIs were −0.015 (95% CI −0.018 to −0.012), 0.023 (95% CI 0.017 to 0.029) and −0.028 (95% CI −0.040 to −0.015) for dengue, chikungunya and Zika, respectively (Figure 2). The RCI decomposition showed that the year of notification contributed importantly to the overall inequality, either towards the poor or the rich. For dengue, aside from the year of notification, the 20–49 y age category (i.e. the presence of dengue cases from age 20 to 49 y) was the main contributor to the overall inequality towards the poor with 102.7%,

Table 1. Descriptive characteristics of notified arboviral cases in Fortaleza, Brazil, during 2007–2017

Fortaleza	Dengue	Chikungunya	Zika
Total cases	N=200 832	N=80 408	N=1681
Age, median y (IQR[a])	25 (15, 39)	38 (24, 53)	30 (20, 43)
Crude neighborhood rates per 100 000, median (IQR)	27.6 (10.9, 79.7)	34.9 (11.4, 151.9)	8.4 (4.6, 15.7)
Gender			
Female	110 546 (55.0%)	49 544 (61.6%)	1125 (66.9%)
Male	90 286 (44.9%)	30 864 (38.4%)	556 (33.1%)
Not disclosed	38 (0.02%)	37 (0.05%)	1 (0.06%)
Neighborhood level covariates[b]			
% Water supply, median (IQR)	95.1(91.5, 97.1)	95.0 (91.1, 97.0)	95.0 (91.6, 97.1)
% Literacy, median (IQR)	93.8 (90.8, 95.6)	94.0 (91.0, 95.7)	93.9 (90.8, 95.4)
% Waste management, median (IQR)	99.6 (98.6, 99.9)	99.7 (98.7, 99.9)	99.6 (98.6, 99.9)
Number of healthcare facilities, median (IQR)	2.0 (1.0, 3.0)	2.0 (1.0, 3.0)	2.0 (1.0, 3.0)
Number of educative institutions, median (IQR)	5.0 (2.0, 9.0)	4.0 (2.0, 8.0)	5.0 (2.0, 9.0)
Human development index, median (IQR)	3.4 (2.5, 4.5)	3.4 (2.5, 4.7)	3.4 (2.3, 4.1)

[a]IQR, interquartile range.
[b]Indicates the frequency: number or percentage (%) of households per neighborhood.

Table 2. Descriptive characteristics of notified arboviral cases in Medellin, Colombia, during 2008–2017

Medellin	Dengue	Chikungunya	Zika
Total cases	**N=39 509**	**N=724**	**N=656**
Age, median y (IQR)	28 (16, 45)	34 (24, 49)	29 (21, 42)
Crude neighborhood rates per 100 000, median (IQR)[a]	24.5 (12.3, 127.8)	10.1 (8.9, 17.4)	13.0 (8.9, 20.4)
Gender			
Female	18 973 (48.0%)	433 (59.8%)	402 (61.3%)
Male	20 536 (52.0%)	291 (40.2%)	254 (38.7%)
Insurance[b]			
Subsidized scheme	9275 (23.5%)	144 (19.9%)	137 (20.9%)
Contributory scheme	30 230 (76.5%)	580 (80.1%)	519 (79.1%)
Neighborhood level covariates[c]			
% Electricity, median (IQR)	98.9 (96.4, 100)	97.5 (93.8, 100)	99.2 (95.7, 100)
% Water supply, median (IQR)	98.1 (94.8, 100)	95.8 (91.9, 100)	98.5 (95.1, 100)
% Access to sewage, median (IQR)	97.5 (93.6, 100)	95.4 (92.3, 98.4)	97.7 (93.9, 100)
% Waste management, median (IQR)	95.9 (91.2, 99.2)	93.6 (86.9, 98.6)	97.2 (93.3, 100)
People per household, median (IQR)	4.4 (4.0, 4.7)	3.8 (3.5, 4.3)	3.9 (3.6, 4.4)
Mean monthly US$ household income (proxy), median (IQR)	283 (264, 361)	279 (268, 396)	279 (266, 357)

[a]IQR, interquartile range.
[b]Insurance scheme: contributory insurance (i.e. individuals who are employees or self-employees with the capacity to pay for health coverage) and subsidized insurance (individuals who cannot pay for health coverage whose healthcare is subsidized by the government).
[c]Indicates the frequency: number or percentage (%) of households per neighborhood.

followed by 11.8% from waste management. For chikungunya, we observed that the presence of three to five healthcare units in the neighborhood contributed 23.3% and for Zika the presence of more than six healthcare units contributed 13% to the overall inequality towards the poor. Given that dengue, chikungunya and Zika were circulating simultaneously from 2014 to 2017, we conducted the aggregated arboviruses analysis using only data from these years and the adjusted RCI was 0.058 (95% CI 0.052 to 0.065). The age of cases and presence of healthcare institutions in the neighborhoods contributed 49.3% to the overall socioeconomic inequality towards the poor, while the years 2014 and 2017 contributed 75.1% and 52.3%, respectively, to the overall inequality towards the rich (Figure 3A, Supplementary Appendix).

The stratified analysis by year for chikungunya did not show evidence of socioeconomic inequalities in 2014 and 2015. During 2016 and 2017, the RCIs indicated modest inequality, with most

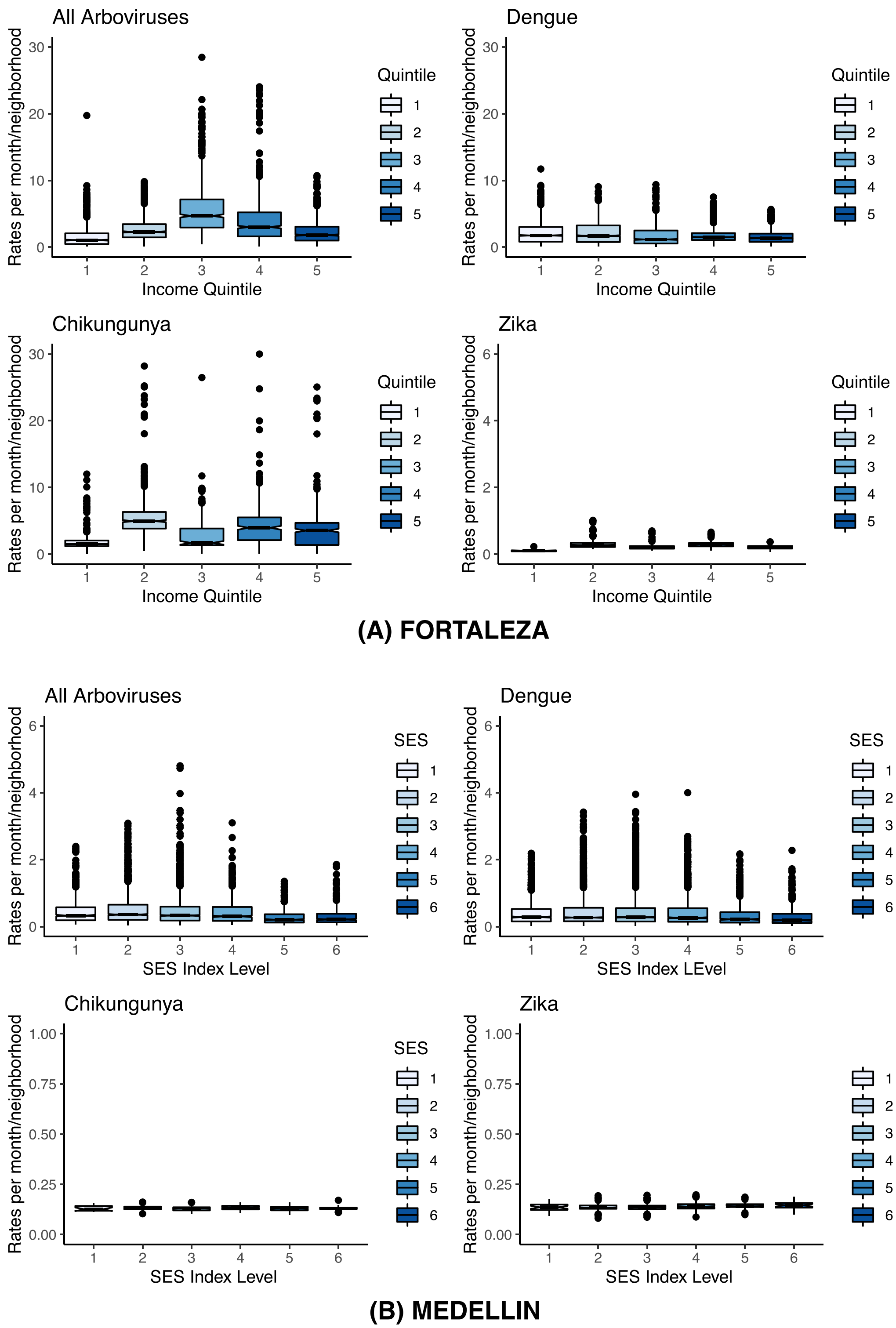

Figure 1. (A) Adjusted disease rates distribution across median household income quintiles in Fortaleza, Brazil (2007–2017). (B) Adjusted disease rates distribution across SES Index level in Medellin, Colombia (2008–2017).

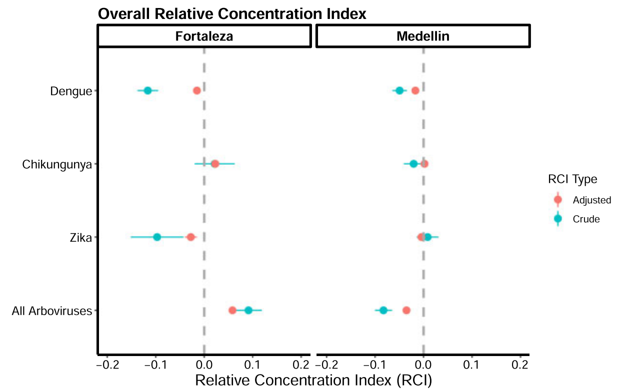

Figure 2. Crude and adjusted RCIs for each arboviral disease in Fortaleza and Medellin, Colombia (2007–2017).

cases concentrated among people in low-income neighborhoods (RCIs −0.03 [95% CI −0.04 to −0.01] and −0.01 [95% CI−0.02 to 0.00], respectively). Age and waste management were the main contributors to the inequalities towards the poor and the presence of healthcare institutions in the neighborhood was the main contributor to the inequality towards the rich. The stratified analysis for aggregated arboviruses showed small RCIs consistently below the line of equality, ranging from −0.01 in 2014 to −0.04 in 2016. As contributors to the inequality towards the poor, waste management accounted for about 10% every year and the presence of healthcare institutions contributed to 43% in 2017 (Supplementary Appendix).

In Medellin, the overall adjusted RCI showed the presence of small inequalities for dengue (−0.017 [95% CI −0.021 to −0.013]) and very small or no inequalities for chikungunya (Figure 2). The decomposition showed that the main contributors to the overall inequality towards the poor for dengue were age and waste management. Contributory insurance accounted for 5.8% and 26.4% of the inequality towards the rich for dengue and chikungunya, respectively. The adjusted RCI for aggregated arboviruses was −0.035 (95% CI −0.041 to −0.030) with age contributing 24.5% of the overall socioeconomic inequality towards the poor (Figure 3B, Supplementary Appendix). In both cities the crude RCIs were larger for all arboviruses than the adjusted estimates (Supplementary Table S3, Supplementary Appendix).

Overall, models fitted without spatial random effects did not change the results for the RCIs but showed larger contributions for age and sanitation covariates. RCIs from the sensitivity analysis using a monotonic relationship between socioeconomic measures and disease rates were on average larger in magnitude than those presented in the main analysis (Supplementary Appendix).

Discussion

We assessed the presence of socioeconomic inequalities (i.e. heterogenous distribution of disease cases across the spectrum of socioeconomic variables) on arboviruses in two cities from Brazil and Colombia using surveillance data from 2007 to 2017, and we estimated quantitatively the contribution of some measured socioenvironmental factors to the presence of the relative socioeconomic inequality.

We observed a constant presence of all arboviruses in both municipalities, but disease rates were higher in Brazil compared with Colombia.[6,9,11] The increased burden of notified arboviruses in Brazil was possibly due to higher temperatures, population density and limited waste management, as previously described.[10,11,13] Despite the observation that chikungunya and Zika affected Colombia significantly, Medellin had fewer cases than the national average and showed a wide disease distribution across the city.[9] Fortaleza, by contrast, presented one of the largest chikungunya outbreaks in Brazil, while the number of Zika cases were comparable with those reported in the country.[10–13] Despite the small magnitude of the RCIs, we consistently observed a greater concentration of dengue and Zika cases among the poor in both municipalities.[17] For dengue, the crude RCI, and for Zika, both the crude and adjusted RCIs (estimates of relative socioeconomic inequality), were larger in Fortaleza than in Medellin. Because the RCI is a function of the disease distribution relative to its share in the socioeconomic distribution of the population, the differences across sites could be attributed to a larger proportion of people living under low socioeconomic conditions (e.g. income or SES) in Fortaleza compared with Medellin, but also to the fact that the absolute number of notified cases and the disease rates were larger in Fortaleza than in Medellin, even when the population sizes were similar.[8–10]

The year of notification impacted the measures of inequality for all outcomes and in both study sites, but was also of larger magnitude in Fortaleza. The yearly stratified analysis for chikungunya and aggregated arboviruses showed RCIs covering the line of equality during 2014 and 2015, indicating a non-differential distribution of disease rates across the socioeconomic distribution. In Medellin, chikungunya and Zika were widely spread across the city and SES strata, with very few cases and small relative inequality. The small relative socioeconomic inequality could be attributed to the fact that chikungunya and Zika were newly introduced arboviruses that started with very few cases, mostly among travelers, and were followed by outbreaks affecting the general population, where it is expected that everyone is similarly susceptible or exposed in the same way, regardless of their SES or other individual and neighborhood-specific characteristics.[4,11,13] The changes across time and magnitude of the relative inequality are also indicators of the epidemic nature of these arboviruses,[6,11] thus indicating that the presence of inequalities (when they exist) is more evident during outbreaks of already established diseases such as dengue, and shows a broader effect across the socioeconomic strata during the introduction of new diseases, as in the case of chikungunya and Zika.[17] These findings stress the need to account for the temporal distribution of the outcome when analyzing the presence of health inequalities of epidemic diseases.

The contributors to the inequality, understood as those social determinant covariates included in the analysis to explain the socioeconomic inequality, varied by setting and disease. The contribution of some age categories and the presence of healthcare facilities (e.g. at least three primary healthcare centers) in the neighborhood accounted for most of the measured inequality in Fortaleza. In Medellin, the main contributors to the overall relative socioeconomic inequality towards the poor were age and waste management. The contribution of some age categories could be attributed to the known differential

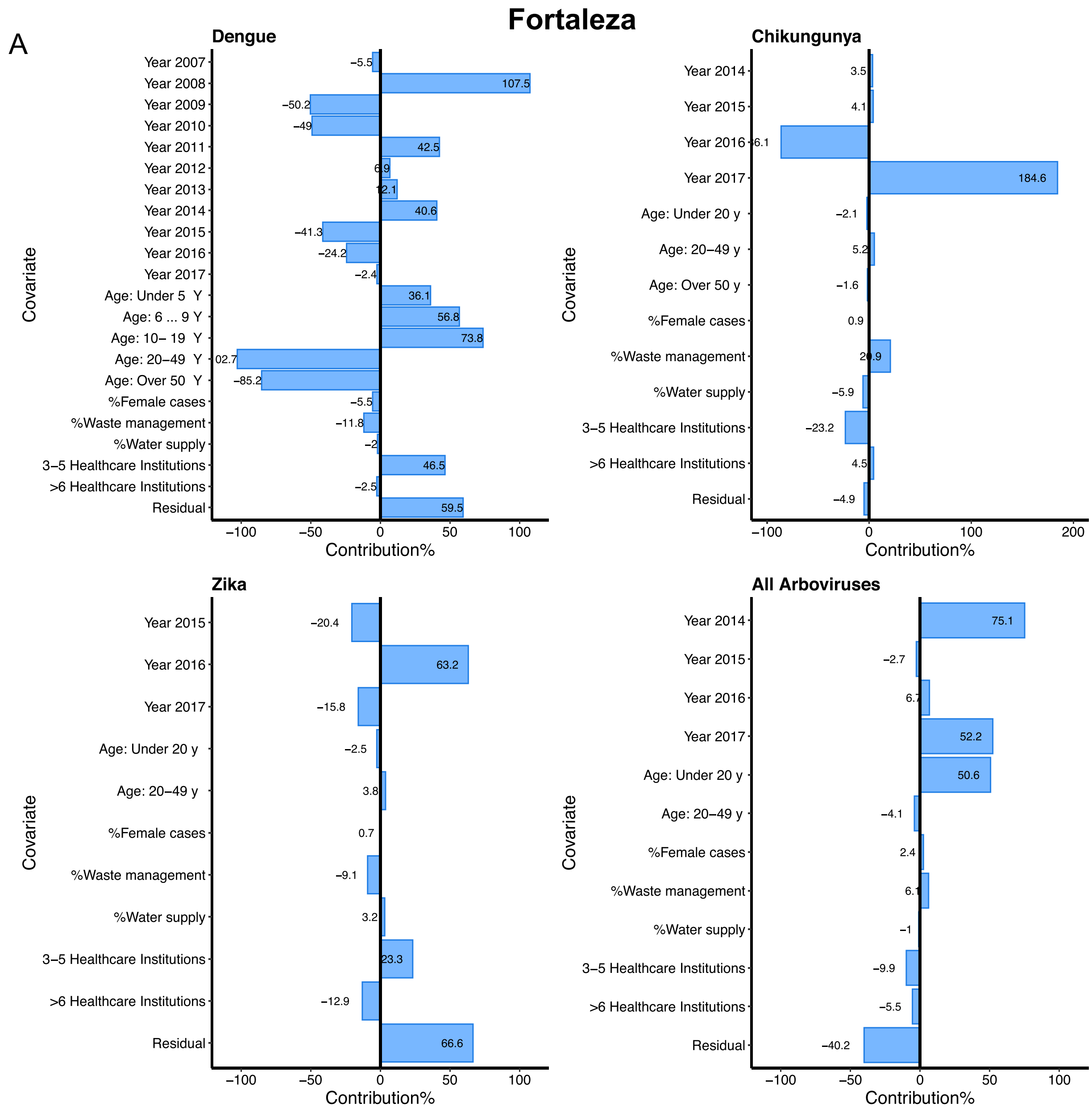

Figure 3. (A) Contribution of covariates to the overall relative inequality of dengue, chikungunya and Zika in Fortaleza, Brazil. (B) Contribution of covariates to the overall relative inequality of dengue, chikungunya and Zika in Medellin, Colombia.

pattern of arboviruses across age groups: dengue is most likely present among children and young adults in endemic populations, which was the case in both study sites.[1,3,6] Chikungunya is known to be more frequent among middle-aged and older adults, and Zika is a concern among women of reproductive age. Hence, given that the contribution of each factor to the overall inequality is a function of the outcome distribution and the strength of the relationship between the specific contributor and the inequality (i.e. elasticity), more cases reported among these populations in low-SES neighborhoods (compared with the distribution in high-SES neighborhoods) could be among the important drivers of the relative socioeconomic inequality.[2,3,5,12]

The contribution of the presence and number of healthcare facilities by neighborhood in Fortaleza, and the contributory insurance scheme in Medellin, to the overall socioeconomic inequality could be explained by their role as healthcare access indicators in each site. It has been reported that physical access (geographical distance and the availability of healthcare facilities) and the type of health system (public vs private) are related to differential outcomes for dengue.[2,4,8,11,15,16,17,32,33] However, we used surveillance data and our study population included

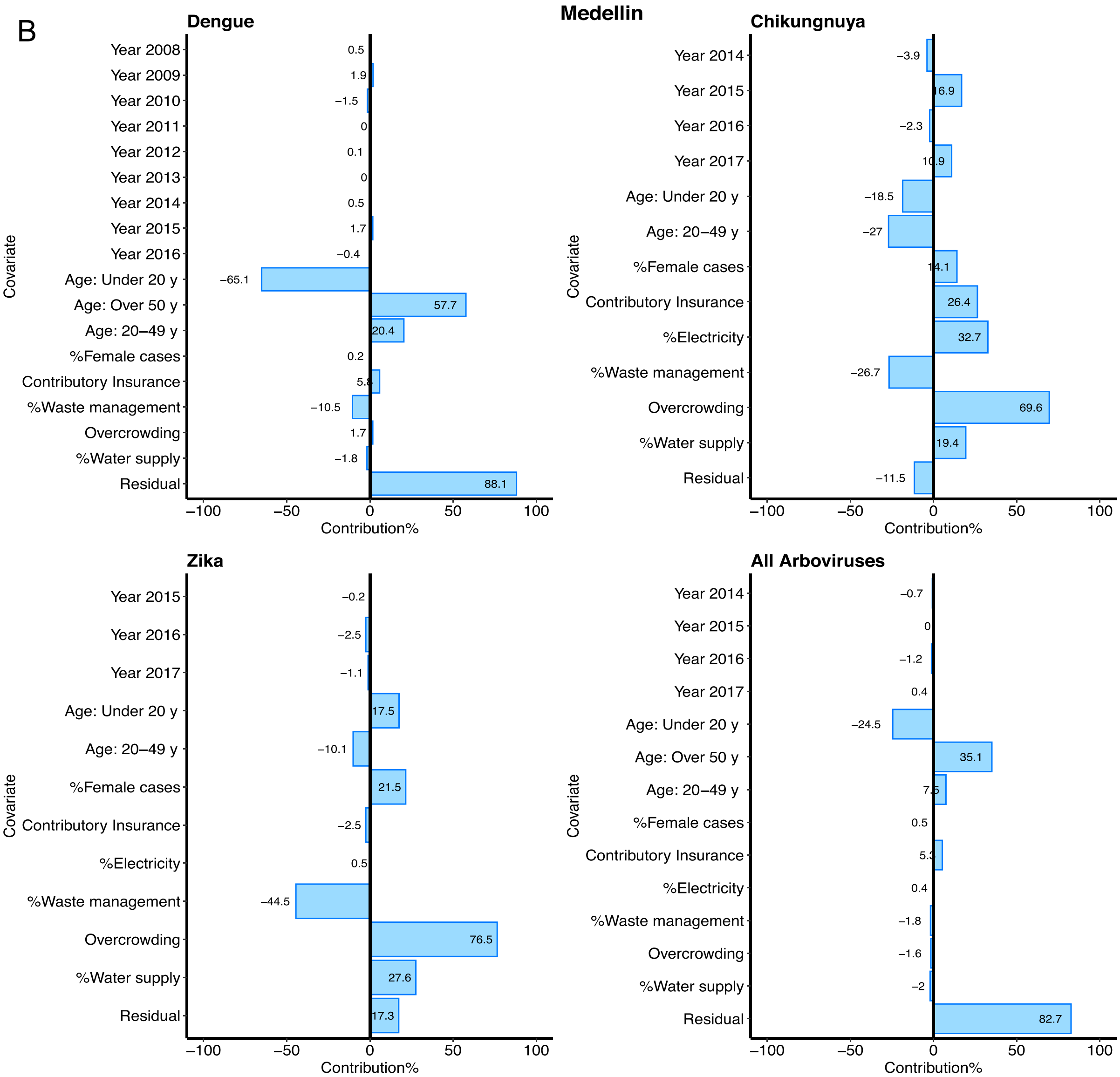

Figure 3. Continued.

individuals who were able to seek and receive care, which could indicate a differential ascertainment and reporting of cases to the national surveillance system.[34] Although the presence of healthcare facilities as an indicator of healthcare access could contribute in either direction to the inequality, the use of surveillance data likely underestimates the true burden of cases among the poor.[20] Similarly, although the contributory insurance (which is similar to a private healthcare system) could contribute to the inequality towards the better-off, the potential underreporting due to the use of surveillance data possibly moves our estimates towards the line of equality.

The contribution of sanitation factors such as waste management and water supply are justified given their main roles in the presence and distribution of *Aedes* mosquitoes.[3,35] The presence of arboviruses in areas of limited waste management and water supply is widely known, given their potential for increasing the breeding sites of *Aedes* mosquitoes.[3,15,33,35] Likewise, the contribution of overcrowding, which is more likely to be seen in low-SES settings, has been associated with disease transmission, even in areas with low entomological indexes, which is the case with Medellin.[3,4,5,6,8,14,15,32] It is worth nothing that vector control strategies and waste-management programs are complementary sanitation measures.[15,33,35] Given their main role in equalizing sanitation conditions, successful vector control strategies and complementary waste management specifically in low socioeconomic settings should contribute to decrease disease rates and potentially push the RCI towards the line of equality.

The small contribution of female cases to the overall inequality could be explained by a differential pattern of health-seeking behavior. Specifically, pregnant women or women of reproductive age may have consulted more, increasing the likelihood of diagnosis and therefore its notification, particularly after the launch of the PHEIC in 2016 for Zika.[4,5,19,36] However, although over-reporting among women is a plausible explanation, an actual increased risk of negative outcomes among women could not be completely ruled out.[4,11,34]

Strengths and limitations

Our study was conducted only in two cities from Colombia and Brazil, and, as indicated above, the use of surveillance data in our analysis limits its generalizability and the interpretation should be conditional on individuals who seek healthcare attention and who were notified to either surveillance system. There is also a concern related to underreporting, mostly due to the lack of notification from private institutions.[25] Although notification is mandatory, private institutions were reported as incompletely compliant in previous studies.[12,34,36] In Fortaleza, we did not have complete information about individuals with access to private healthcare systems and therefore this information was not included in the analysis. Because receiving healthcare at private institutions is positively related to the SES measure evaluated here, conditioning on surveillance in the presence of differential underreporting from private healthcare providers would have resulted in biased estimates towards equality, altogether potentially underestimating the inequality.

The introduction of chikungunya in 2014 and Zika in 2015 presents a risk of misclassification of the outcome. Given the similarity of symptoms between the studied arboviruses and the endemicity of dengue, newly introduced chikungunya and Zika cases could have been misdiagnosed as dengue early during their introduction.[2,34,36] To evaluate the presence of socioeconomic inequality and decompose it using an outcome that could be less likely affected by potential misclassification, we grouped dengue, chikungunya and Zika cases and estimated the aggregated arboviral distributions, RCIs and contributions.

To avoid some methodological issues presented in other analyses of socioeconomic distribution and arboviruses,[11,14,15,16] we used a large sample size, accounted for the spatiotemporal nature of the diseases and tried to account for the use of surveillance data and misclassification. However, it is possible that our models did not completely capture all possible determinants of the inequality, leaving some of the inequality unexplained, which is a well-known limitation of regression-based decompositions.[27–29] Likewise, we observed a non-monotonic disease distribution with instances where more cases were around the middle SES measures, moving the RCIs towards zero, indicating small or no disparity.[14,20,37] This was corroborated with our sensitivity analysis, where we observed that the RCI were indeed larger in magnitude in the presence of monotonic associations between SES and disease rates.

Nonetheless, our approach presents relevant information on the presence of socioeconomic inequalities that would otherwise have been missed by standard analysis.[14,15,33] We consider that our study provides insightful information, offering quantitative estimates of the contribution of some known determinants related to the socioeconomic inequality in arboviral diseases in Latin America, using an inequality-specific metric—the RCI and its decomposition—which have not been presented before in this context.

Conclusion

Our study presents quantitative estimates of the socioeconomic inequality among arboviruses and its decomposition, accounting for the spatiotemporal distribution in two Latin American cities. We corroborate the presence of socioeconomic inequalities with the concentration of arboviral diseases in low socioeconomic neighborhoods and identify that the year of occurrence, age distribution, presence of healthcare facilities and waste management are key determinants of the heterogenous distribution of endemic arboviruses across the spectrum of socioeconomic status. Our results contribute to the body of evidence on health inequalities, which could be used by local public health agencies to design and implement targeted strategies to decrease health inequalities, and for disease control at local level in both the management of ongoing epidemics and preparedness for new outbreaks of emergent and re-emergent pathogens.

Supplementary data

Supplementary data are available at *Transactions* online.

Authors' contributions: MC conceived, designed the study, conducted the analyses. SH and JK participated in the design and analysis plan. ASLN, GdSdS, AC, BNR participated in the epidemiological analysis plan and contribute to data. All authors contributed substantially to the interpretation of the results, manuscript preparation and approved the final version.

Acknowledgements: We acknowledge the collaboration of the Public Health and the Surveillance office in Fortaleza, Brazil, and in Medellin, Colombia. MC holds a CIHR-Banting-Best Doctoral Award fellowship.

Funding: This study did not receive specific funding.

Competing interests: None declared.

Ethical approval: This study analyzed secondary data only. The protocol was reviewed and approved by the respective institutional review boards (study no. A02-E05-18A) and by the ethics committee of the Brazilian Ministry of Health (code: 2.624.599) and Secretary of Health of Medellin, Colombia.

Data availability: Data used in this manuscript can be obtained by official requests to the public health offices/local Ministry of Health from Fortaleza, Brazil and in Medellin, Colombia. The R-script used to conduct the analysis is provided as supplementary material.

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