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## International Journal of Infectious Diseases

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## Epidemiology and costs of dengue in Brazil: a systematic literature review

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## ARTICLE INFO

## Article history:

Received 2 February 2022

Revised 2 June 2022

Accepted 29 June 2022

## Keywords:

Dengue

Brazil

Epidemiology

Incidence

Serotype

Economic impact

## ABSTRACT

**Objectives:** Dengue infection is a growing public health problem, with the number of reported cases increasing in the Americas and worldwide. This review characterized the epidemiological and economic burden of dengue in Brazil.

**Methods:** Embase, MEDLINE, evidence-based review databases, and gray literature sources were searched for published literature and surveillance reports on epidemiology (between 2000 and 2019) and costs (between 2009 and 2019) of dengue in Brazil. Studies were included if they reported data on incidence, seroprevalence, serotype distribution, expansion factors, hospitalization, mortality, or costs. Data were summarized descriptively and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.

**Results:** A total of 344 publications were included (167 peer-reviewed and 177 gray literature). Dengue outbreaks increased in incidence and frequency, with the highest incidence observed in 2015 at 807 cases per 100,000 population. Outbreaks were related to alternating predominant serotypes. Dengue was more frequent in young adults (aged 20–39 years) and in the Midwest. Cost and societal impacts are substantial and varied across regions, age, and public/private delivery of healthcare services.

**Conclusion:** The burden of dengue in Brazil is increasing and likely underestimated. Therefore, developing and implementing new strategies, including vaccination, is essential to reduce the disease burden.

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## Introduction

Dengue, a mosquito-borne infection, is a rapidly growing public health problem, and Brazil represents one of the countries with the highest burdens, with over 1.5 million cases reported in 2019 (DATASUS, 2019). Dengue was estimated to have caused over 92,000 disability-adjusted life years (DALYs) in Brazil in 2016, yielding a rate of 44.87 DALYs per 100,000 population (age-standardized). This represents a 4015-fold increase from the burden estimated in 1990, placing dengue as the neglected tropical disease for which burden increased the most in recent decades in Brazil (Martins-Melo *et al.*, 2018).

Dengue can present with common symptoms, including fever, muscle and joint pain, headache, and rash (Castro *et al.*, 2017; Guzman and Harris, 2015). As these symptoms are nonspecific, they may resemble other infections, including SARS-CoV-2, chikungunya, and Zika. Thus, accurate clinical diagnosis of dengue is challenging, which can result in misdiagnosis and under-reporting of the disease (Muller *et al.*, 2017). Furthermore, due to a high prevalence of asymptomatic infection, self-management of symptoms and under-reporting of hospitalized cases, the true burden of dengue is likely underestimated (Martelli *et al.*, 2015; WHO, 2021). Dengue epidemics in Brazil have shown a cyclical pattern, with shifting of the predominant serotypes. Intense epidemic peaks are interspersed with interepidemic periods of 3–4 years, which have decreased in length in recent years (Andrioli *et al.*, 2020).

Cases of dengue are mandatorily notifiable in Brazil through SINAN (Sistema de Informacao de Agravos de Notificacao), the

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national surveillance information system. Until 2014, cases were classified into classic dengue, dengue with complications, dengue hemorrhagic fever, or dengue shock syndrome. In 2014, Brazil adapted the 2009 World Health Organization (WHO) dengue case classification (Nunes et al., 2019; WHO, 2009).

Dengue is associated with a substantial economic burden (Selck et al., 2014; Shepard et al., 2016). Previous reviews show that although data lack standardization, financial impact is particularly relevant in Latin America and Brazil (Laserna et al., 2018; Stahl et al., 2013). During the dengue epidemic season of 2012–2013, the estimated societal cost of dengue in Brazil was \$1212 million US dollars (USD) (when adjusted for under-reporting) (Martelli et al., 2015).

To better characterize the trends and burden of dengue in Brazil, a systematic literature review for the period 2000–2019 (epidemiology) and 2009–2019 (costs) was conducted.

## Methods

The review was conducted according to the Cochrane Handbook for Systematic Reviews and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (Deeks et al., 2011, Moher et al., 2009)

### Information sources and search strategy

Embase, MEDLINE®, and the evidence-based medicine review databases were searched on 6 November 2019. Separate searches were conducted for epidemiologic and cost data in the OVID® search engine. The searches were limited to studies published in English or Portuguese since January 1, 2000 for epidemiology and January 1, 2009 for cost. Search criteria are listed in Supplementary Table 1. Regional scientific databases, such as Latin American and Caribbean Health Sciences Literature and Scientific Electronic Library Online, were also searched. Reference lists, gray literature sources, and major academic websites were searched for additional literature (Supplementary Table 2).

### Eligibility criteria and study selection

Studies were included in the review if they reported incidence, seroprevalence, serotype distribution, expansion factor (EF), hospitalization, mortality, or direct and indirect costs of dengue in Brazil (Supplementary Table 3). The publication with the most recent or complete dataset was included for studies with multiple publications.

The study selection process involved two stages: (i) titles/abstracts were screened and (ii) full texts were screened. Two reviewers independently screened the studies at both stages, and a third reviewer resolved discrepancies. Duplicates and articles not satisfying the inclusion criteria were excluded after a review of the studies.

### Data extraction and synthesis of results

Key data from each included study were collated into a data extraction form. Data were extracted by one reviewer and double-checked by a second reviewer. A third reviewer resolved discrepancies. Overall, data from surveillance sources were prioritized and complemented by peer-reviewed studies where needed. Meta-analyses were not planned in the original protocol. EFs were defined as the multiplication or adjustment factors used to correct under-reporting of dengue cases (Toan et al., 2015; Undurraga et al., 2013). Costs were converted to 2019 USD using the Brazilian consumer price index (IBGE, 2021).

### Risk of bias and quality assessment

Two independent reviewers assessed study risk of bias and quality using the National Institutes of Health (NIH)'s tool for epidemiological studies and the National Health Service Wales' tool for cost studies (National Institutes of Health, 2019). Quality assessment was not performed for gray literature studies or reports that were not peer-reviewed.

## Results

A total of 3585 records were identified; 3425 were from the epidemiology search and 160 from the cost search. After applying limits and deduplication and conducting title and abstract screening on 2858 records, a total of 263 publications were selected for full-text screening. Of these, 164 were selected for data extraction and inclusion in the review. Three additional publications captured from the review of reference lists were included, resulting in 163 publications in epidemiology and four in costs. However, eight publications identified in the epidemiology search also contained cost data and one publication in the cost search contained epidemiology data, yielding a total of 12 publications for the cost analysis and 164 publications for epidemiology analysis (Figure 1, Supplementary Figures 4 and 5). Furthermore, 177 gray literature articles were included in the review (Figure 1).

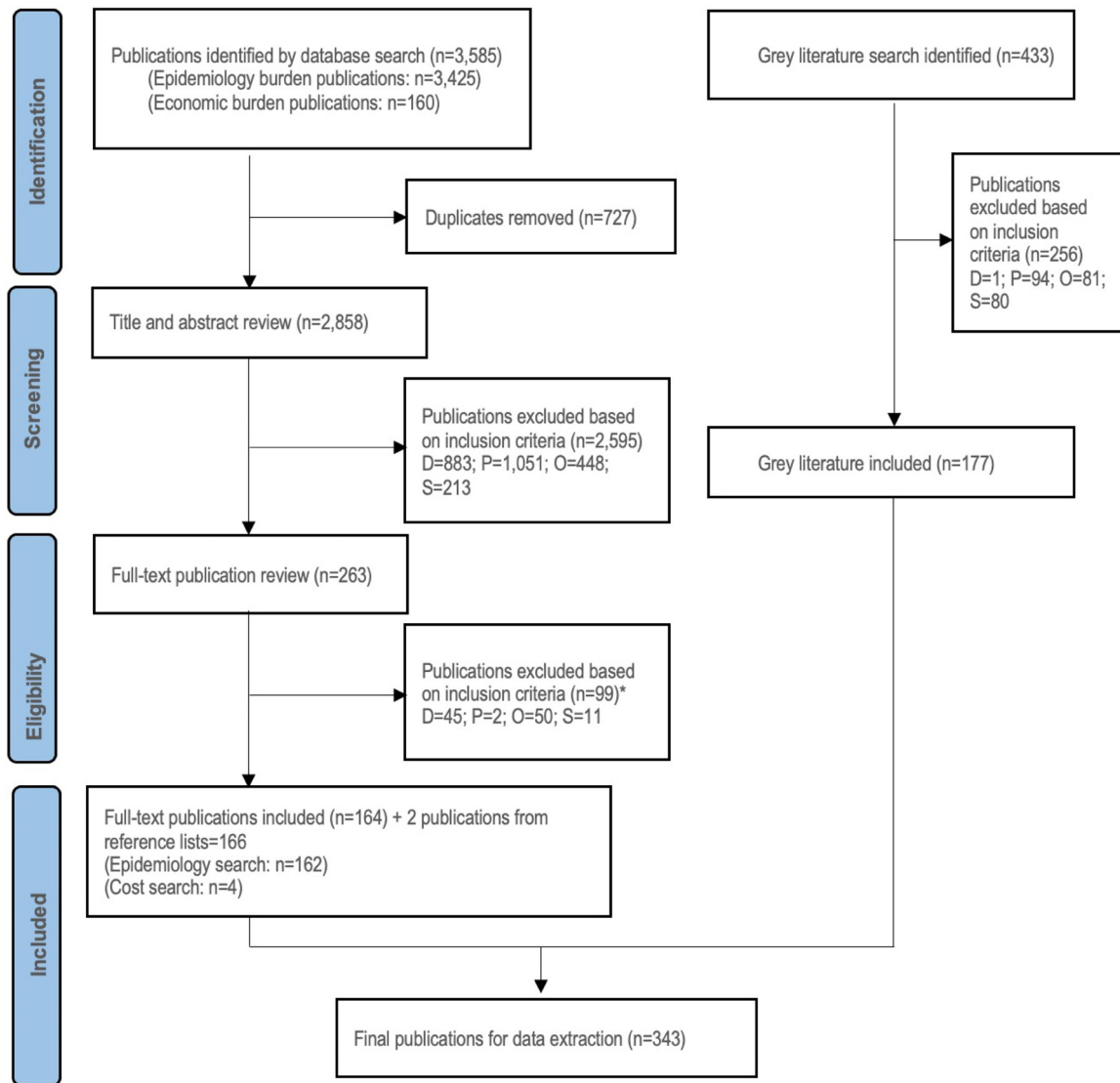
Consensus results of the risk of bias assessment for epidemiology and cost studies are detailed in Supplementary Tables 24 and 25.

### National and regional epidemiology

National incidence data in Brazil are collated by the Ministry of Health (MoH) and reported to the WHO and the Pan American Health Organization (PAHO) Health Information Platform for the Americas Database (PLISA) (Supplementary Tables 6.1 and 6.2). Dengue incidence in Brazil was high during the study period (DATASUS, 2019, PAHO). Major epidemics with over 1,000,000 cases were registered in 2013, 2015, 2016, and 2019. Since 2000, the highest incidence was recorded in 2015 with 806.5 cases per 100,000 population, followed by 2019 with 735.2 cases per 100,000 population (Figure 2). A total of 10 publications generally agreed, with an increasing incidence trend throughout the study period (Supplementary Table 7). However, the studies varied in methodology and the magnitude of the incidence values. One study from the Global Burden of Disease reported a 184.3% increase in incidence from 446.6 per 100,000 population in 2000 to 1269.1 per 100,000 population in 2015. However, this study was based on modelling (Araújo et al., 2017).

Regional incidence of dengue was mostly retrieved from the DATASUS website and the MoH bulletins. The number of probable cases was reported since 2007, but incidence rates were only available from 2013 onwards (Brazil MoH, 2012–2019, DATASUS, 2019). The Southeast had the highest number of reported cases from 2007–2019. Values for this region were more than double those in the second most affected region (Midwest or Northeast) in 2010, 2013, 2015, 2016, and 2019 and reached over 1 million cases in 2015 and 2019. Notwithstanding, the highest incidence rates reported by the MoH between 2013 and 2019 were consistently observed in the Midwest region, ranging between 490.9 (2017) to 1744.2 (2013) cases per 100,000 population. The lowest rates were reported in the South region, with values between 8.5 (2017) and 238.1 (2016) cases per 100,000 population (Figure 2, Supplementary Table 8).

Most publications identified in the review ( $n = 71$ , Supplementary Table 9) reported local incidence by city or Federal District and two key publications reported regional incidence. Böhm et al



**Figure 1.** PRISMA flowchart for epidemiology and cost studies. D: duplicate; O: outcome; P: population; S: study design <sup>a</sup>One full text was not available (Santos *et al.*, 2003)

reported high incidence rates for the Midwest in the periods 2005–2007, 2009–2010, and 2012 (Böhm *et al.*, 2016). Burattini *et al* reported that the total number of cases between 2000 and 2014 was highest in the Southeast region (2,239,451 cases), followed by the Northeast (999,774 cases), Midwest (547,436 cases), North (446,450 cases), and finally, South (90,775 cases) (Burattini *et al.*, 2016). These publications are consistent with the data reported by DATASUS and the MoH.

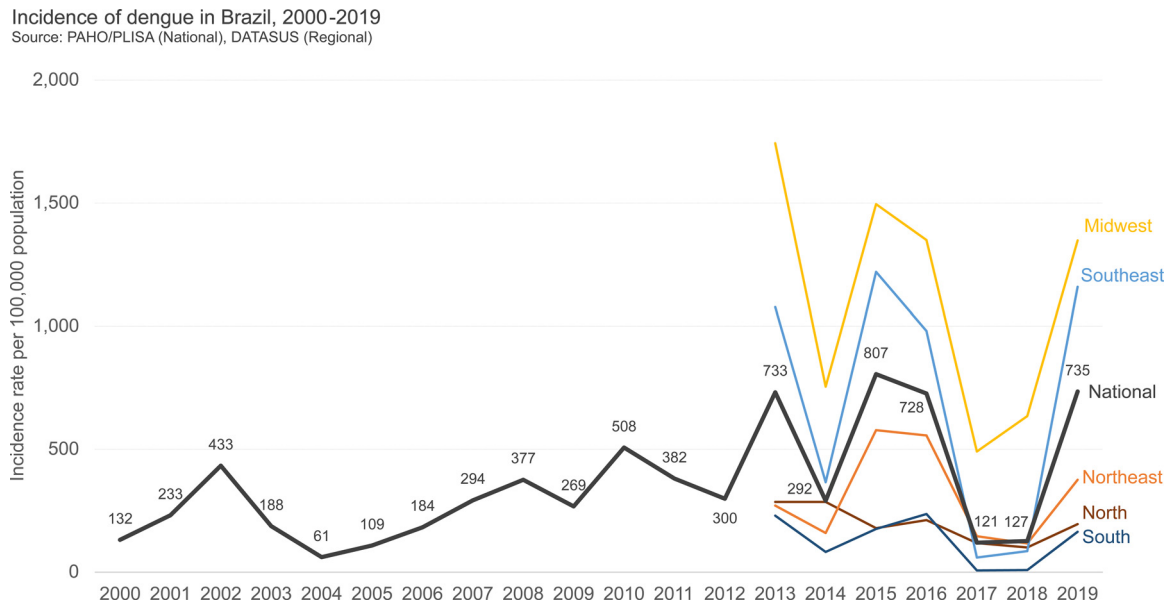
**Seasonality**

A total of 38 publications were reported on dengue seasonality (Supplementary Table 10). Overall, dengue incidence was highest during the rainy season, from October to May. However, the peak incidence months varied across studies, possibly due to regional climatic and environmental differences. An ecologic study in the Northeast (2003–2010) reported highest incidence between April and September, and the peak month varying from year to year (Silva *et al.*, 2016). In the North, the monthly average incidence of dengue between 2001 and 2012 was highest from December to March, with the peak incidence in February (Duarte *et al.*, 2019). Similarly, a cohort study in the Northeast (2007–2013) reported an

increase in dengue cases between January and May (Costa and Calado, 2016). A retrospective study in the Southeast (2008–2015) reported March–May as the period of highest incidence. However, in 2015, dengue cases increased in January (Ferreira *et al.*, 2018). The authors concluded that the seasonal trend in incidence was due to increased rainfall, which led to high mosquito levels (Ferreira *et al.*, 2018). In most publications, increased rainfall and higher temperature were associated with an upsurge in dengue intensity. However, some level of dengue transmission continues throughout the year.

**Age distribution**

The number of dengue cases stratified by age was reported in the period 2007–2013 (DATASUS). Between 2007 and 2013, the most probable dengue cases were identified in the 20–39 age group, followed by the 40–59 age group (Supplementary Table 11). Six publications reported data stratified by age but only three of these reported incidence rates (Supplementary Table 12). These studies identified the age groups 20–39 and 21–35 as the groups with highest number of cases and incidence (Böhm *et al.*, 2016; Burattini *et al.*, 2016; Nascimento *et al.*, 2017). Böhm *et al* reported



**Figure 2.** National incidence rates of dengue per 100,000 in Brazil, 2000-2019. National data from 2000-2018 were from PAHO/PLISA database. Since PAHO data for 2019 were discrepant from the MoH bulletin, the latter was used for 2019 because MoH is the primary data source. Regional incidence data were retrieved for the period 2013-2019 from DATASUS. PAHO, Pan American Health Organization; PLISA, Platform for the Americas Database

yearly incidences by age from 2002-2012. The highest incidence of dengue during this period was reported among those aged 20-39 years (53.0 [2004] to 598.6 [2010] cases per 100,000 population); although, the 10-19 age group had the highest incidence in 2008 (347.0 per 100,000) and in 2011 (418.1 per 100,000). The age groups with the lowest incidence were those aged <5, 5-9, and >60 years (Böhm et al., 2016) (Supplementary Table 11). Burattini et al reported overall number of cases by age in the period 2000-2014. The highest number of cases were observed among those aged 21-35 years (1,270,950 cases) and the lowest number of cases were among those aged 1-5 years (158,616 cases) (Burattini et al., 2016).

A total of 38 studies reported regional incidence by age group. However, the difference in age groups and stratification period makes data summarization challenging (Supplementary Table 13). Most studies reported highest incidences across ages 10-69 years. However, a descriptive study on the basis of surveillance data (2001-2012) from the Northeast showed an increase in incidence over time among children aged <9 years. Dengue incidence was highest in this age group in 2008 (2,331.3 cases per 100,000 population, rising from 406.9 per 100,000 population in 2001) (Oliveira et al., 2018). This trend was supported by Barbosa et al (Barbosa et al., 2012), which showed an increase in the incidence per 100,000 population, from 166.5 in 2000 to 1530.5 in 2008 in the 0-4 age group and from 264.77 in 2000 to 1580.8 in 2008 in the 5-14 age group.

*Hospitalizations and deaths*

The overall nationwide number of hospitalizations for dengue was obtained from the Brazilian Hospitalization Information System (SIH-SUS). In the period 2008-2019, the highest number of hospitalizations was registered in 2010 (95,008), followed by 2008, 2011 and 2015 (>70,000). The lowest number was reported in 2018 (17,858) (Figure 3) (DATASUS, 2019). Hospitalization rates from the identified studies ranged from <1-25.52%, with the latter associated with DENV2 serotype (Supplementary Table 14). Burattini et al reported the number and hospitalization rates of dengue by age group from 2000-2014. In this period, the number of hospitaliza-

tions was highest in age groups 21-35 (25,142) and 11-20 (23,897) and lowest in age groups 1-5 (7,485) and >65 (7,782). However, the percentage of hospitalizations among dengue cases was highest in the 6-10 age group (17.47%). From a regional perspective (Supplementary Table 15), the Southeast region registered the highest number of hospitalizations (55,275) but had the lowest hospitalization rate (4.91%). The highest hospitalization rates were observed in the Northeast (13.47%, 30,000 hospitalizations), followed by the South (9.7%, 2,483 hospitalizations) and North (9.2%, 10,506 hospitalizations) (Burattini et al., 2016). It should be noted that this study used data from SINAN, which was previously shown to underreport dengue hospitalizations (Coelho et al., 2016).

The national case fatality rates (CFRs) and deaths due to dengue for the period 2000-2019 were retrieved from the PAHO database (PAHO, 2020). The CFR was highest in 2014 (0.069%) and in 2010 (0.066%), but the highest numbers of deaths due to dengue were registered in 2015 (863) and in 2019 (789) (Figure 3). Seven publications reporting nationwide data (Supplementary Table 16) found that the CFR for DF ranged from 0.01-5.8%. However, the highest value was registered for people with comorbid renal failure.

According to the 2019 MoH bulletin (up to epidemiologic week 47), the highest CFR for dengue by age group was registered in the group aged >80 years (0.92%), followed by the 60-79 years (0.16%) (Brazil MoH, 2012-2019). The age group with the lowest CFR was the group aged 1-4 years (0.01%) (Supplementary Table 17). In the same bulletin, the regional CFRs of probable dengue cases were 0.04% in the North and Northeast, 0.05% in the Southeast, 0.06% in the South, and 0.07% in the Midwest. No publications reported regional CFR; although, 21 studies identified CFR within specific cities or federal districts (Supplementary Table 18).

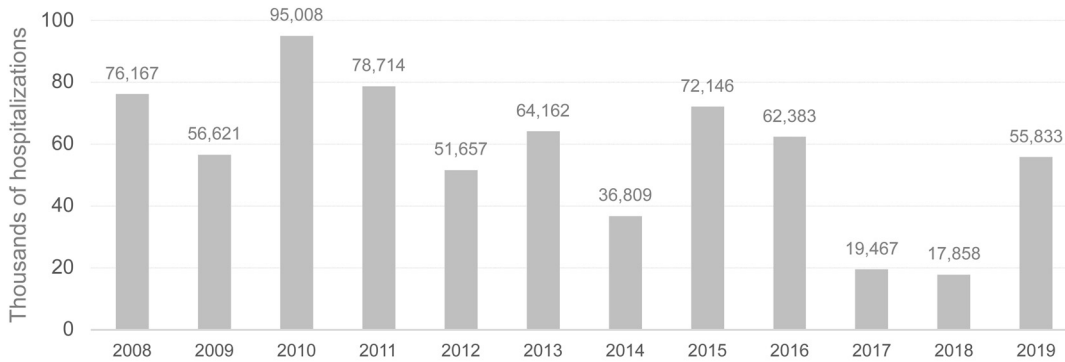
*Seroprevalence*

Seroprevalence was not reported at a national level. From 20 publications reporting data at a regional level, seroprevalence varied depending on age, sex, region, and testing method (Supplementary Table 19). Overall, seroprevalence increased with age (Chiaravalloti-Neto et al., 2019; Sacramento et al., 2018). High rates were observed in those aged 5-14 years (69.9-84%) in three set-



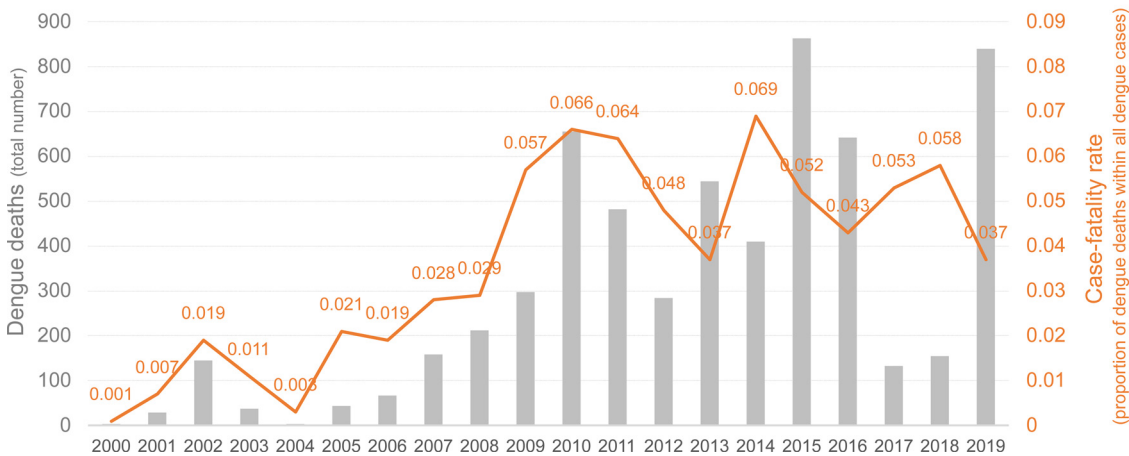
### Dengue hospitalizations in Brazil

Source: SIH-SUS (Hospitalizations Information System)



### Dengue deaths in Brazil

Source: PAHO PLISA database



**Figure 3.** Dengue severity in Brazil. Top: Dengue-related hospitalizations, 2008–2019. Source SIH-SUS. Bottom: Deaths due to dengue and case-fatality rate in Brazil, 2000–2019. Source: PAHO/PLISA database. PAHO, Pan American Health Organization; PLISA, Platform for the Americas Database

tings in Northeast Brazil (2005–2006) but still lower than those aged  $\geq 15$  years (77.7–96.8%) (Braga *et al.*, 2010).

#### Serotype distribution

According to data from the PAHO database, DENV1–3 have cocirculated in Brazil between 2000 and 2009 and all serotypes have been cocirculated in Brazil since 2010 (PAHO, 2020). The Brazilian MoH reported serotype distribution in weekly bulletins. However, the reports are inconsistent throughout time and challenging to interpret because yearly distributions do not add up to 100%. Nonetheless, the data suggest an overall predominance of DENV4 in 2012, DENV1 from 2014–2016, and DENV2 in 2018 but with regional variation (Supplementary Table 20) (Brazil MoH, 2012–2019).

A total of 56 publications reported serotype distributions within different regions and states of Brazil and are generally consistent with MoH reports (Supplementary Table 21). Three key studies report results from  $>100,000$  notified dengue cases; although, not all cases were serotyped. In the Northeast, one study showed that DENV1 predominated and cocirculated with DENV2 between 1995 and 2001, with DENV3 becoming predominant between 2002 and 2006 (Cordeiro *et al.*, 2007). Another study showed that the predominant serotypes were DENV1 in 2001, DENV3 in 2003 and 2007, and DENV2 in 2008 (Barbosa *et al.*, 2012). A study in the Southeast reported DENV1 (52.2%) and DENV4 (47.8%) as the

most frequent serotypes between November 2012 and July 2013 (Amâncio *et al.*, 2014).

#### Expansion factors

Five studies reported EFs to account for dengue under-reporting in Brazil (Supplementary Table 22). Two of these studies, on the basis of the same data, reported higher EF for ambulatory (EF 3.2) than for hospitalized cases (EF 1.6) (Boiron *et al.*, 2018; Martelli *et al.*, 2015). On the basis of these EFs, an estimated 18.2 million ambulatory cases and 366,934 hospital cases were likely underreported from 2008–2017 (Boiron *et al.*, 2018). Duarte *et al* estimated that 37% of suspected dengue cases identified in the SIH-SUS (from 1996–2002, Southeast) were not reported to SINAN (Duarte and França, 2006). Similarly, Coelho *et al* reported a 33% increase in the number of hospitalizations recorded in SIH-SUS (48,174 cases) compared with SINAN (36,145 cases) between 2008 and 2013 in 10 municipalities in Brazil. Notwithstanding, the hospitalizations registered in SINAN are underreported because the database is limited to cases from public health systems only (Coelho *et al.*, 2016). Coudeville *et al* compared the incidence data from a dengue vaccine phase III trial with a national surveillance system and reported an EF of 1.8 (Coudeville *et al.*, 2016). In comparison, Sarti *et al* reported higher EFs at the national (26.7), state (16.9), and local (19.4) levels. However, the authors analyzed limited study locations and age ranges (9–19 years) (Sarti *et al.*, 2016).

### Dengue costs: direct medical and nonmedical

A total of 12 publications reported the costs of dengue in Brazil between 2005 and 2017. All costs were adjusted to 2019 USD, except for three studies because they did not report the year's valuation.

From a societal perspective, the estimated costs of dengue, including ambulatory, hospital, and fatal cases, varied from \$516.79 million (2009) to \$1688.3 million (2013) USD after adjusting for under-reporting (Martelli et al., 2015). Other studies reported 2010 as the year of higher total cost of dengue hospitalizations or direct medical costs (Amaral et al., 2014; Camasmie Abe and Miraglia, 2018; Godói et al., 2018). Shepard et al reported an overall annual aggregated cost of \$1014.3 million USD, with more than half of the cost related to ambulatory cases (\$678.56 million USD) and indirect costs (\$859.77 million USD) (Shepard et al., 2016).

Overall, hospitalized cases had higher total costs per case (mean  $\pm$  standard deviation: \$3416.27  $\pm$  2,188.35 USD) than ambulatory cases (\$1472.24  $\pm$  1,695.50 USD). When stratified, all cost categories were also higher for hospitalized than for ambulatory cases: direct medical (\$1465.92  $\pm$  775.08 vs \$187.45  $\pm$  128.48 USD), direct nonmedical (\$183.24  $\pm$  136.90 vs \$67.40  $\pm$  82.14 USD) and indirect (\$1769.21  $\pm$  2,036.70 vs \$1213.18  $\pm$  1663.90 USD) (Suaya et al., 2009). This was supported by Shepard et al, who reported an overall average cost per case of \$531.63 USD (Shepard et al., 2016).

The total direct medical cost per case was generally higher in private than in the public healthcare sector (\$1671.16  $\pm$  3,786.79 vs. \$713.93  $\pm$  1,590.22 USD, respectively) and among those aged >60 years (\$1882.49  $\pm$  4,431.11 USD) than those aged <15 years (\$1011.69  $\pm$  748.40 USD). However, in the public sector, the cost was highest among aged <15 years (\$1189.05  $\pm$  2492.67 USD) and lowest among those aged 15–60 years (\$452.80  $\pm$  890.45 USD) (Vieira Machado et al., 2014). Additionally, the average cost of dengue deaths in children (\$449,924.12 USD) was higher than in adults (\$293,913.28 USD) (Shepard et al., 2016).

Over a 16-year period (2000–2015), costs for dengue treatment were highest in the Southeast (21% of the total national costs, \$34.16 million USD) and Northeast regions (48% of the total national costs, \$81.12 million USD) (Godói et al., 2018). The higher rates/number of cases and hospitalizations in the regions may be partly responsible (Godói et al., 2018). The total cost per case also varied by region, public versus private sector, and healthcare setting (Martelli et al., 2015).

### Societal impact

Six studies reported on the societal impact of dengue between 2010 and 2017, but data were limited (Supplementary Table 23). Most studies reported the number of hospital days as the proxy for societal impact because they imply school/work absenteeism. Overall, patients showing dengue with warning signs, severe dengue, or requiring a platelet transfusion had the highest number of hospital days (Machado et al., 2019; Vieira Machado et al., 2014). As expected, hospitalized patients also had a higher number of work-days lost (10.7  $\pm$  5.2 vs 7.1  $\pm$  5.1) or school days (6.8  $\pm$  5.4 vs 5.2  $\pm$  3.9), a higher number of days of illness (17.4  $\pm$  8.4 vs 15.0  $\pm$  8.4), and higher number of ambulatory visits (4.0  $\pm$  2.7 vs 3.6  $\pm$  2.7) than a patient who was not hospitalized.

For patients of economically active age, the average number of hospital days was estimated at 3.89 days per patient (Pereira et al., 2014). However, in Vieira Machado et al, the longest hospital stay (15  $\pm$  2.8 days) was reported for laboratory-confirmed dengue in the public healthcare system for patients who did not meet the WHO dengue platelet transfusion criteria (Vieira Machado et al., 2014). As expected, the average number of hospital days was lower

for classical dengue (3.2 days) than dengue hemorrhagic fever (5 days) (Silva et al., 2013).

### Discussion

This review summarizes the trends and burden of dengue in Brazil in the past 10–20 years. Information retrieved from surveillance data and publications shows that the burden of dengue has been increasing in recent years, with incidence reaching over 500 cases per 100,000 population in 2010, 2013, 2015, and 2019 (DATASUS, 2019; PAHO, 2020). Except for 2015, these peak years coincided with outbreak years in neighboring countries, such as Colombia (Gutierrez-Barbosa et al., 2020).

Although the highest number of cases were reported in more populous regions (Southeast), the highest incidence rates in the past decade were consistently recorded in the Midwest (Andrioli et al., 2020, Brazil MoH, 2012–2019, DATASUS, 2019). Evident in this review and corroborated by previous analyses, dengue incidence and hospitalizations are underreported in surveillance databases due to the high rate of asymptomatic infections, self-management of symptoms, or misdiagnosis of cases. In addition, public databases fail to report episodes from private health institutions (Bhatt et al., 2013; Boiron et al., 2018; Coelho et al., 2016; Undurraga et al., 2013; WHO, 2021; Wichmann et al., 2011). For public health officials to understand the disease burden and appropriately assess the cost-benefit of interventions, accurate reporting of dengue is essential (Undurraga et al., 2013).

Dengue cases were primarily concentrated in the rainy season, with varied peak incidence months each year (Silva et al., 2016). The seasonal surges could overwhelm healthcare systems and negatively impact the management and outcomes of other diseases during crucial periods (Clark et al., 2005; García et al., 2011). This could be further exacerbated when seasonal peak of dengue coincides with other diseases, as observed in 2020 with COVID-19 (Lorenz et al., 2020). Brazil is one of the countries most affected by the COVID-19 pandemic, with about 21 million cases reported by September 7, 2021 (Pan American Health Organization 2021). Because the occurrence of COVID-19 overlapped with a higher incidence of dengue in Brazil in 2020, the burden of dengue on the national healthcare system is expected to increase as the infection curve of COVID-19 grows and dengue serotypes are reintroduced (Nacher et al., 2020; Rabiú et al., 2021). Furthermore, cocirculation and coinfection of COVID-19 with dengue could affect disease management; the quality of patient care; and increase the risk of morbidity, mortality, and socioeconomic impacts (Ridwan, 2020; Tsheten et al., 2021). COVID-19 outbreaks coinciding with dengue outbreaks may profoundly impact Brazil's already strained healthcare system (Nacher et al., 2020; Rabiú et al., 2021). These impacts may affect specific regions differently, as reported for Valle del Cauca in Colombia (Cardona-Ospina et al., 2021). Early-stage clinical manifestations of dengue are similar to those of COVID-19 and other viral infections, complicating diagnosis and confounding surveillance.

All four DENV serotypes fluctuated in frequency throughout the study period. DENV1 re-emerged in 2009 and became predominant in 2010 in most states in the Midwest, Southeast, and South (Brazil MoH, 2010). DENV1 cocirculated with DENV4 between 2011 and 2013 (Colombo et al., 2016; Rocha et al., 2017) and predominated between 2014 and 2016, whereas in 2018, predominance shifted to DENV2 (Brazil MoH, 2012–2019). Major dengue outbreaks appear to be related to shifting of predominant serotypes. The exchange in serotypes between regions of Brazil and other neighboring countries, such as Colombia or Panama, may play a role in the occurrence of local outbreaks (Díaz et al., 2019; Gutierrez-Barbosa et al., 2020). This highlights the need to monitor

serotype distributions at the regional and national levels because this may help predict the occurrence of an upcoming outbreak.

Mortality due to dengue has also increased; tens of thousands of hospitalizations have been registered yearly since 2008, reflecting an increase in severity (DATASUS, 2019; PAHO, 2020). This may be partly due to the predominance of DENV2, which has been associated with the highest risk of mortality and hospitalization due to dengue (Vicente et al., 2016). Furthermore, this serotype was identified as a cause of the high incidence and increased disease severity observed in children in 2008 (Barbosa et al., 2012; Böhm et al., 2016; Oliveira et al., 2018). Though young adults (20–39 years) have the highest incidences (Böhm et al., 2016; Burattini et al., 2016; DATASUS, 2019; Nascimento et al., 2017), some studies suggest that dengue incidence has increased in children (Barbosa et al., 2012; Oliveira et al., 2018) and that severe dengue cases and hospitalizations due to dengue were higher among children (6–10 years) (Burattini et al., 2016), suggesting that broad age groups should be targeted to reduce both disease burden and those at risk of more severe outcomes.

Summarizing seroprevalence data was challenging due to the varying testing methods, regions, and populations analyzed. Overall, studies agreed that seroprevalence increases with age, with specific adult populations of hyperendemic areas in the Northwest and Southwest reaching >85% seropositivity (Braga et al., 2010; Chiaravalloti-Neto et al., 2019).

Dengue was shown to cause a significant and increasing economic burden; although, its true burden is likely underestimated. Hence, using EFs to adjust for under-reporting is necessary (Coelho et al., 2016; Martelli et al., 2015; Sarti et al., 2016). After adjusting for under-reporting, total national costs of dengue were estimated to be over \$2,586.42 million USD in 2013. Although the costs for treating a hospitalized case were higher, overall outpatient treatment and indirect costs contributed the largest portion of the cost (Martelli et al., 2015; Shepard et al., 2016), and it is expected to increase after an increase in dengue cases and changing serotypes likely to result in future outbreaks.

This review has several important strengths, which lie in the methodology and broad study period: 2000–2019 for epidemiology and 2009–2019 for cost/burden. To the best of our knowledge, this is the first systematic review analyzing dengue costs in Brazil. However, there are several limitations, some of which have been reported in an earlier analysis (Teixeira et al., 2013). Incidence and hospitalization of dengue cases are underreported. Classification and reporting of disease severity are inconsistent through the years; data quality is inconsistent across the country and age group data for overall incidence has been limited since 2014. National seroprevalence data were rarely reported. This information is required to understand the overall exposure to dengue. Furthermore this review did not focus on the coevolution of dengue with other arboviral diseases, such as chikungunya and Zika, which have been shown to influence dengue epidemiology (Perez et al., 2019). In the economic burden analysis, studies identified were heterogeneous in definitions, source data, and methodology and did not allow comparison of the data across the studies. Costs associated with long-term persistent effects of dengue were not identified, which, if reported, could significantly increase the economic burden of dengue. In Mexico, these effects were estimated to increase the total economic burden of dengue by 13% (Tiga et al., 2016). Although this study did not capture the costs of vector control methods, different studies have reported that these account for 40–72% of the overall economic burden and have questionable efficacy (Castañeda-Orjuela et al., 2012; Castro et al., 2017). On the other hand, a pilot vaccination program has uncovered potential challenges in achieving high vaccination coverage (Preto et al., 2021). As such, the success of dengue vaccination depends on using different approaches.

## Conclusion

Dengue incidence has been increasing in magnitude and frequency in recent years, causing a significant economic and societal burden in Brazil. However, due to under-reporting, the true burden of dengue may be substantially underestimated. It is, therefore, crucial to implement public health interventions, such as vaccination and improved vector control, that will prevent the multiplication of dengue cases.

## Conflicts of interest

JBSJ is a speaker and part of the board for Takeda Brazil. EM has no competing interests to declare. EG, RK, and AL are employees of Takeda. RK owns stocks in Takeda. LO is an employee of Adelphi Values and has served as a paid consultant for Takeda Pharmaceuticals.

## Acknowledgments

The authors acknowledge Egbe Ubamadu and Ana Goios (P95 Epidemiology and Pharmacovigilance, Leuven, Belgium) for their assistance in data extraction and critical review of the systematic literature review, writing, and preparing figures, which was funded by Takeda Pharmaceuticals.

## Funding

This study was funded by Takeda Pharmaceuticals.

## Ethical approval

Not required

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijid.2022.06.050.

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