

## Mathematics

# Temporal dynamics of dengue fever in Rio Grande do Sul: a ten-year analysis of incidence and basic reproduction number (2015–2025)

Dinâmica temporal da dengue no Rio Grande do Sul: uma análise de dez anos da incidência e do número básico de reprodução (2015–2025)

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## ABSTRACT

Dengue fever is one of the main arboviral diseases of public health importance, with a wide global distribution and increasing incidence in historically less affected regions. In Brazil, climate change, accelerated urbanization, and socioeconomic factors have contributed to the intensification and expansion of the disease. In this context, the present study analyzes the trends and patterns of dengue fever in the state of Rio Grande do Sul over a ten-year period, between 2015 and 2025. Official data from the Ministry of Health were used to calculate incidence rates and to analyze the temporal distribution of cases by epidemiological week. In addition, the basic reproduction number  $R_0$  was estimated for years with well-defined epidemic growth, based on the initial exponential growth rate of the case curve, considering epidemiological parameters extracted from the literature. The results show a consistent seasonal pattern, with recurring peaks between epidemiological weeks 10 and 20, as well as a significant increase in the disease burden in recent years, especially in 2022, 2024, and 2025. Estimates of  $R_0$  ranged from approximately 2.2 to 4.8, values consistent with those reported in previous studies conducted in different regions of Brazil. The findings indicate a change in the epidemiological scenario of dengue fever in Rio Grande do Sul, reinforcing the need for more effective surveillance and control strategies adapted to the new epidemiological reality of the state.

**Keywords:** Dengue incidence; Basic reproduction number; Epidemiological data analysis; Applied mathematics

## RESUMO

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A dengue é uma das principais arboviroses de importância em saúde pública, apresentando ampla distribuição global e crescente incidência em regiões historicamente menos afetadas. No Brasil, mudanças climáticas, urbanização acelerada e fatores socioeconômicos têm contribuído para a intensificação e expansão da doença. Neste contexto, o presente estudo analisa as tendências e padrões da dengue no estado do Rio Grande do Sul ao longo de um período de dez anos, entre 2015 e 2025. Foram utilizados dados oficiais do Ministério da Saúde para o cálculo das taxas de incidência e para a análise da distribuição temporal dos casos por semana epidemiológica. Além disso, o número básico de reprodução  $R_0$  foi estimado para os anos com crescimento epidêmico bem definido, a partir da taxa de crescimento exponencial inicial da curva de casos, considerando parâmetros epidemiológicos extraídos da literatura. Os resultados evidenciam um padrão sazonal consistente, com picos recorrentes entre as semanas epidemiológicas 10 e 20, bem como um aumento expressivo da carga da doença nos anos mais recentes, especialmente em 2022, 2024 e 2025. As estimativas de  $R_0$  variaram entre aproximadamente 2,2 e 4,8, valores compatíveis com aqueles reportados em estudos anteriores realizados em diferentes regiões do Brasil. Os achados indicam uma mudança no cenário epidemiológico da dengue no Rio Grande do Sul, reforçando a necessidade de estratégias de vigilância e controle mais eficazes e adaptadas à nova realidade epidemiológica do estado.

**Palavras-chave:** Incidência da dengue; Número básico de reprodução; Análise de dados epidemiológicos; Matemática aplicada

## 1 INTRODUCTION

Dengue fever is one of the most alarming arboviral diseases, representing a significant public health challenge on a global scale (Tauil, 2002). Transmitted by the bite of female *Aedes aegypti* and *Aedes albopictus* mosquitoes, the disease manifests in four serotypes: DENV-1, DENV-2, DENV-3, and DENV-4 (Gubler, 1998).

After being bitten by an infected mosquito, symptoms may appear between 3 and 15 days, with the first 6 days corresponding to the incubation period (Pontes & Ruffino-Netto, 1994).

The spread of dengue has been favored by several factors in different geographic regions, contributing to its endemic character (Valle et al., 2015). Among these factors, climate change, accelerated urbanization associated with high urban mobility, as well as deficiencies in housing, water supply, sanitation, and waste management systems stand out, favoring the proliferation of the vector mosquito (Murray et al., 2013).

World Health Organization (WHO) data reveals that the Americas, Southeast Asia, and Western Pacific regions are the most affected. The Americas region recorded 4.5 million cases of the disease, and a considerable number were reported in Asia, with

Bangladesh accounting for 321,000 cases, Malaysia with 111,400, Thailand with 150,000, and Vietnam with 369,000 (WHO: World Health Organization, 2024).

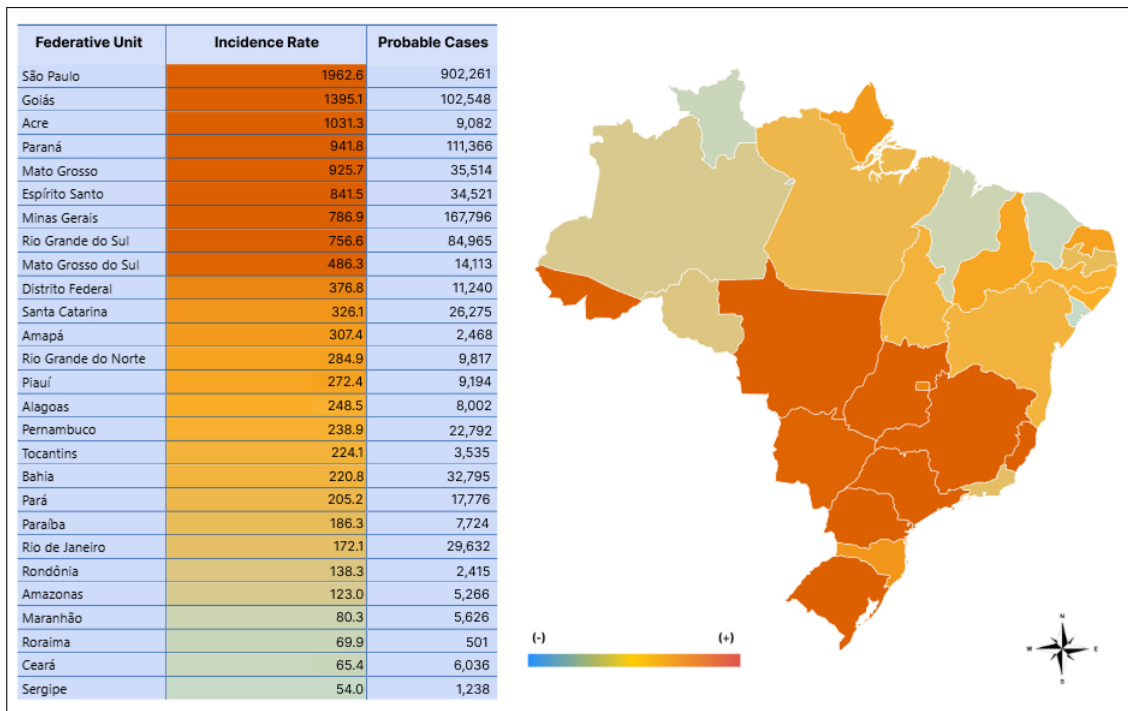
Dengue has become endemic in more than 100 countries, spanning several continents. Although the incidence of the disease is predominantly recorded in tropical and subtropical regions, in recent years a significant increase has been observed in temperate climate areas (Nakase et al., 2024). In the last two decades, cases reported to the World Health Organization (WHO) have increased from approximately half a million in 2000 to more than 6.5 million in 2023 (Target Malaria, 2024).

In Brazil, the first epidemic occurred in 1986, and more recently, a rapid expansion of dengue has been observed. The four serotypes of the virus circulate simultaneously, and the vector mosquitoes are present in all regions of the country (Gurgel-Gonçalves et al., 2024). Furthermore, favorable climatic and socioeconomic conditions in many municipalities promote the proliferation of *Aedes aegypti* and, consequently, dengue outbreaks (Antonio et al., 2017). Previous studies, such as the one by Barcellos & Lowe (2014), identified geographical barriers to dengue transmission in areas of southern Brazil. However, more recent research (Barcellos et al., 2024; Codeço et al., 2022; Lee et al., 2021) shows the expansion and spread of the disease in regions that historically had low incidence.

According to Ministério da Saúde (2025), nine states have high incidence rates, with São Paulo having the highest coefficient. Fourteen other states have moderate incidence. Maranhão, Roraima, Ceará, and Sergipe are the states with rates considered low (Figure 1). The coefficient was determined from the number of new confirmed dengue cases in 2025 per 100,000 inhabitants, using the total population of 2025 as a base.

Given the impact of dengue on public health and its rapid global spread, this study aims to identify the incidence rate of the disease in the last 10 years in the state of Rio Grande do Sul, as well as to calculate the basic reproduction number ( $R_0$ ). The estimated values of  $R_0$  were compared with results presented in the literature for different regions and periods in Brazil.

Figure 1 – Incidence rate of probable dengue cases in 2025 in Brazil



Source: Ministério da Saúde (2025)

From the perspective of Applied Mathematics, this study focuses on the quantitative analysis of epidemiological data and on the estimation of key transmission indicators, providing a mathematical characterization of dengue dynamics at the population level.

## 2 METHODOLOGY

The state of Rio Grande do Sul is located in the extreme south of Brazil, between the parallels 27°03'42" and 33°45'09" south latitude, and the meridians 49°42'41" and 57°40'57" west longitude. With an area of approximately 281,707 km<sup>2</sup> and 10,882,965 inhabitants, the state has a temperate subtropical climate, classified as humid mesothermal (Atlas Socioeconômico do Rio Grande do Sul, 2026; IBGE: Instituto Brasileiro de Geografia e Estatística, 2026).

The data used for this research were taken from Ministério da Saúde (2026), referring to the period from 2015 to 2025. Initially, the dengue incidence rate was calculated. This number is determined from the number of new confirmed cases of dengue, expressed as a proportion per 100,000 inhabitants, in the total resident population during the determined period.

The annual incidence rates were analyzed using logarithmic transformation and min-max normalization in order to improve visualization and allow comparative assessment across years. According to Lee et al. (2021), incidence rates below 100 cases per 100,000 inhabitants are classified as low transmission, between 100 and 300 cases as moderate transmission, and above 300 cases as high transmission.

Since the present analysis was conducted on an annual basis, the epidemiological thresholds of 100 and 300 cases per 100,000 inhabitants were converted to the normalized scale (0–1), subsequently rescaled to the interval (0–3) for visualization purposes using the same logarithmic transformation and the global minimum and maximum values of the annual series. In the analyzed dataset, the threshold of 100 cases per 100,000 corresponds approximately to a normalized index value of 1.68, while 300 cases per 100,000 corresponds to approximately 2.16. It is important to emphasize that these normalized values depend on the temporal window considered and the range of annual incidence observed in the series.

Subsequently, epidemiological weeks 1 through 7 of each year were considered to estimate the basic reproduction number ( $R_0$ ), an important epidemiological parameter representing the risk of an infectious disease spreading within a susceptible population (Rossi & Ternes, 2026).

$R_0$  values greater than 1 indicate that each infectious individual infects, on average, more than one susceptible individual. On the other hand, when  $R_0$  is less than 1, each infectious individual transmits the disease, on average, to less than one person, making the spread of infection slow, which leads to the disease disappearing over time (P. Van Den Driessche & Watmough, 2002).

Massad et al. (2001) estimated the value of  $R_0$  for dengue and yellow fever. The authors propose that  $R_0$  be estimated through:

$$R_0 = \left(1 + \frac{r}{\gamma}\right) \left(1 + \frac{r}{\mu_v}\right) \quad (1)$$

where  $\mu_v$  is the vector mortality rate,  $\gamma$  is the host population recovery rate, and  $r$  is the exponential growth rate of the epidemic curve.

The parameters  $\gamma$  and  $\mu_v$  used were defined and adapted from literature. According to Zhao et al. (2018), the vector's life expectancy is between 4 and 35 days;

therefore, the mortality rate  $\mu_v = 0.2287$  per week was considered. In this work, the recovery rate was defined as  $\gamma = 1/11$  or  $\gamma = 0.6364$  per week, since previous works consider the values  $\gamma = 1/14$  and  $\gamma = 1/8$  (De Almeida, 2014; Jafaruddin et al., 2015).

It is important to note that, in addition to the epidemiological parameters  $\gamma$  and  $\mu_v$  being adopted from values reported in the literature, they are assumed constant throughout the analysis. Although this approach is widely used in epidemiological studies, it does not capture potential local or temporal variability. Therefore, the estimated  $R_0$  values should be interpreted as approximate indicators of transmission intensity, and not as exact measurements.

The value of  $r$ , which represents the weekly exponential growth rate, was estimated using weekly dengue case data from the 1st to the 7th epidemiological weeks of each year, corresponding to the initial exponential growth phase of the epidemic. An exponential growth model of the form  $C(t) = C_0 e^{rt}$  was fitted to the data, where  $C(t)$  denotes the number of reported cases at epidemiological week  $t$ , and  $C_0$  is the initial number of cases. To estimate the model parameters, the equation was linearized by applying a natural logarithmic transformation, and the parameter  $r$  was obtained by linear regression of  $\ln C(t)$  as a function of time, using the least-squares method.

The estimation of the basic reproduction number  $R_0$  was restricted to years presenting a well-defined epidemic growth pattern, characterized by a sustained and approximately exponential increase in reported cases during the initial epidemiological weeks. Years with low incidence were excluded due to the instability of exponential growth rate estimates under sparse data conditions, which could lead to unreliable  $R_0$  values.

### 3 RESULTS AND DISCUSSION

Despite numerous efforts aimed at eradicating the vector mosquito, current control strategies have proven insufficient to prevent the occurrence of the disease. In the state of Rio Grande do Sul, there has been a significant increase in the number of dengue cases registered in recent years, as evidenced in Table 1 and Figure 2. Table 1 presents the total number of annual cases from 2015 to 2025, while Figure 2 illustrates the temporal distribution of these cases across the corresponding epidemiological weeks.

Table 1 shows a significant increase in the number of dengue cases in Rio Grande do Sul throughout the analyzed period. After years with low incidence, such as 2017 and 2018, a gradual increase was observed from 2019 onwards, markedly intensified in subsequent years. This increase culminates in extremely high values in 2022 and, above all, in 2024, when the number of cases reaches an unprecedented level in the historical series considered. Although there is a reduction in relation to the peak in 2023 and 2025, the values remain significantly higher than those recorded for most of the decade, indicating a new level of viral circulation in the state.

Table 1 – Dengue cases in Rio Grande do Sul between 2015 and 2025

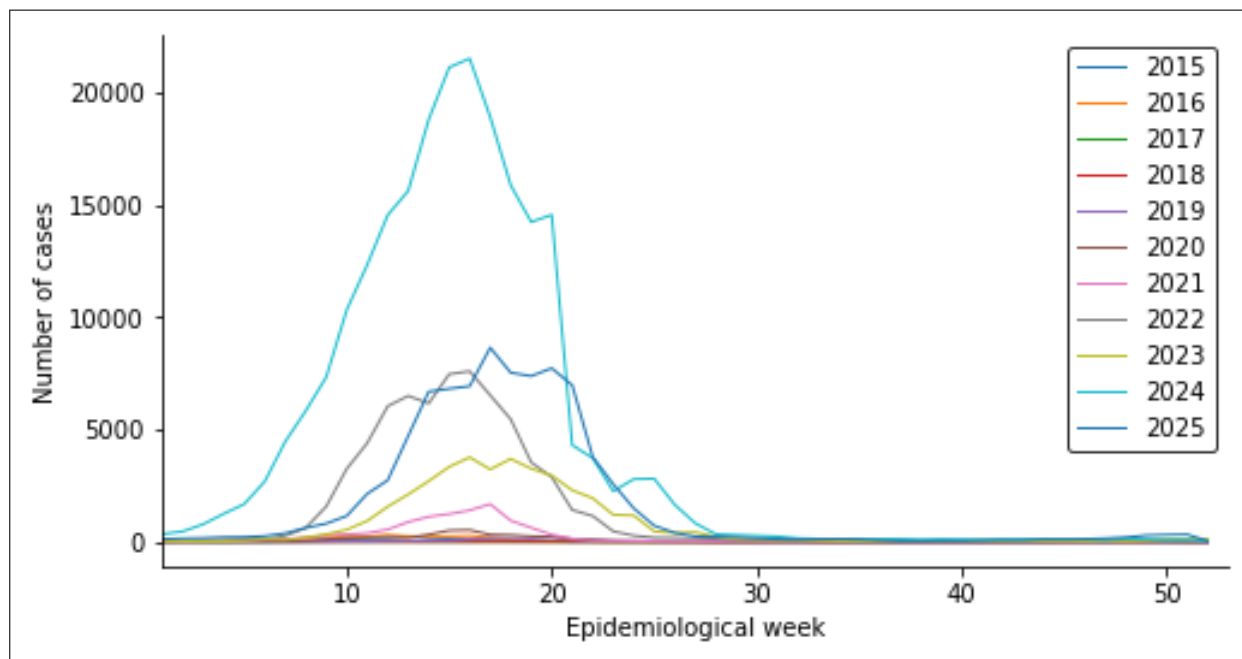
<b>Year</b>	<b>Cases</b>
2015	1,705
2016	3,180
2017	190
2018	130
2019	1,670
2020	4,012
2021	10,878
2022	67,290
2023	38,705
2024	224,774
2025	85,087

Source: Ministério da Saúde (2026)

Figure 2 complements this analysis by presenting the temporal distribution of cases throughout the epidemiological weeks. It is noted that, regardless of the year, dengue peaks consistently occur within a similar interval, mainly concentrated between epidemiological weeks 10 and 20. This recurrence reveals a well-defined seasonal pattern, associated with climatic conditions more favorable to the proliferation of the vector mosquito, such as higher temperatures and greater availability of breeding sites at the end of summer and the beginning of autumn.

Taken together, the results presented in the table and figure point to the coexistence of two relevant phenomena: the persistence of a relatively stable seasonal pattern over time and a consistent increase in the disease burden over the years. This combination reinforces the need for surveillance and control strategies that consider not only the temporal predictability of epidemic peaks, but also the trend of sustained growth of dengue in Rio Grande do Sul.

Figure 2 – Number of dengue cases in Rio Grande do Sul by epidemiological week from 2015 to 2025



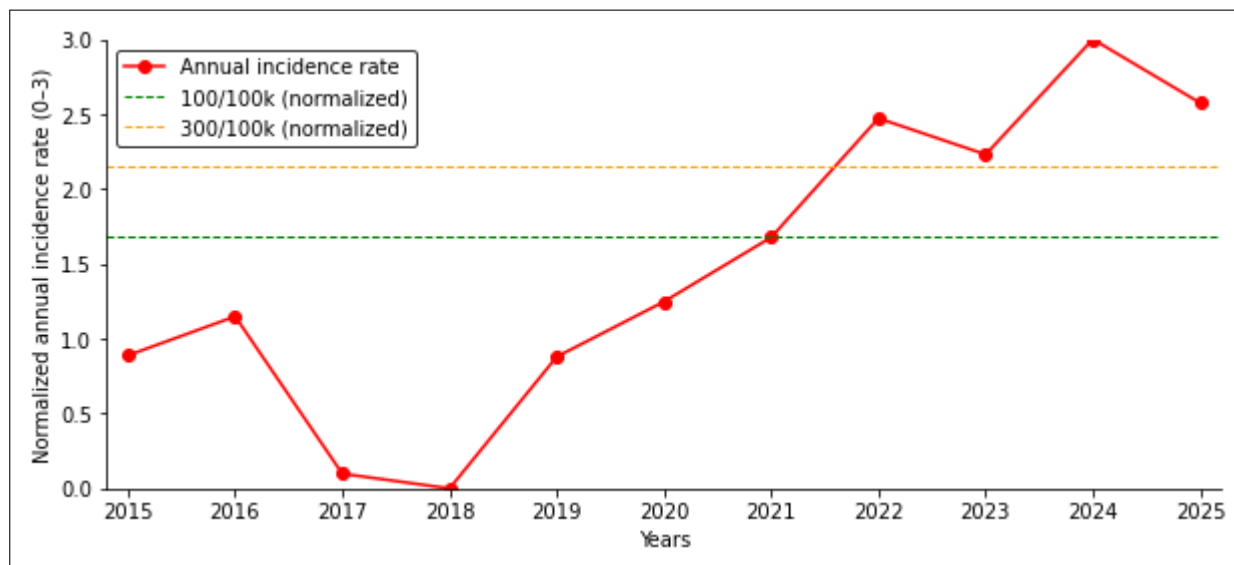
Source: Authors (2026)

One way to estimate the risk of dengue cases occurring in a given time interval is through the dengue incidence rate REDE Interagencial de Informação para a Saúde (2008). This categorization allows for annual monitoring of disease progression and identification of high-transmission areas. Figure 3 shows the evolution of the dengue incidence rate in Rio Grande do Sul from 2015 to 2025.

It was observed that, in most of the years analyzed, the state maintained incidence levels classified as low transmission, remaining below the thresholds associated with moderate or epidemic transmission. This behavior is especially evident in the years prior to 2021, where incidence peaks are of low magnitude and restricted to short time intervals.

In contrast, the years 2022 to 2025 stand out for presenting significant increases in the incidence rate, exceeding the levels associated with moderate transmission and reaching levels compatible with an epidemic situation, indicating a more persistent viral circulation over the years.

Figure 3 – Incidence rate of dengue cases in Rio Grande do Sul per year from 2015 to 2025

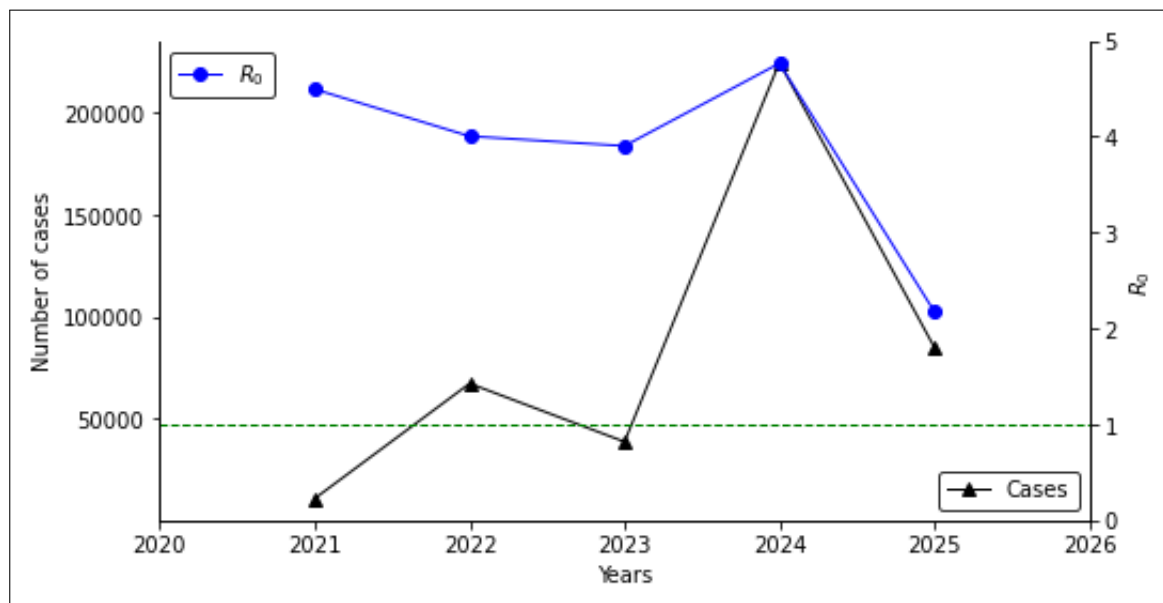


Source: Authors (2026)

This pattern highlights a change in the epidemiological behavior of dengue in the state, suggesting a transition from a scenario historically characterized by low incidence to a context of higher risk and greater pressure on the health system. The occurrence of periods classified as moderate and epidemic in recent years is consistent with data officially reported by Ministério da Saúde (2025). Thus, it is concluded that Rio Grande do Sul has become more consistently integrated into the group of Brazilian states with significant dengue transmission, aligning with the national scenario described in recent epidemiological bulletins.

The basic reproduction number  $R_0$  was estimated only for the years 2021 to 2025, a period in which a well-defined epidemic growth of dengue fever was observed in Rio Grande do Sul. In years of low incidence, the estimation of the initial exponential growth rate becomes unstable and unrepresentative of the transmission dynamics, which is why these periods were not considered. Figure 4 shows the estimated values of  $R_0$  along with the total number of cases registered in each year.

The values of  $R_0$  varied approximately between 2.2 and 4.8, indicating differences in the intensity of transmission throughout the analyzed period. The highest value was observed in 2024, reflecting the rapid growth of cases in the initial weeks of the epidemic. In contrast, despite the high number of cases in 2025, the estimated value of  $R_0$  was lower than in previous years.

Figure 4 – Number of dengue cases and  $R_0$  in Rio Grande do Sul per year from 2021 to 2025

Source: Authors (2026)

It is worth emphasizing that higher values of  $R_0$  reflect a faster initial transmission dynamics rather than the absolute number of cases observed throughout the epidemic. Consequently, years with high case counts may present lower  $R_0$  values if the early growth phase is more gradual.

The estimates obtained are in agreement with values reported in the literature for different regions of Brazil, as shown in the Table 2, which indicates typical ranges of  $R_0$  between approximately 1.0 and 5.6.

The differences between the values observed in this study and those described in previous works may be attributed to contextual factors, such as methodological variations, differences in climatic and geographical conditions, as well as discrepancies in the epidemiological data used.

Table 2 – Estimates of  $R_0$  for different locations in Brazil

<b>Authors</b>	<b>Localization</b>	<b>Analysis period</b>	<b><math>R_0</math></b>
Favier et al. (2006)	Boa Vista (RR)	1999 - 2001	2.7 - 3.3
Favier et al. (2006)	Fortaleza (CE)	2001 - 2003	2.0 - 5.6
Villela et al. (2017)	Rio de Janeiro (RJ)	2002	1.70
Pinho et al. (2010)	Salvador (BA)	2002	2.65
Coelho et al. (2008)	Maringá (PR)	2006 - 2007	5.37
Coelho et al. (2008)	Cascavel (PR)	2006 - 2007	5.63
Coelho et al. (2008)	Londrina (PR)	2006 - 2007	3.04
Sanches & Massad (2016)	Ribeirão Preto (SP)	2009 - 2010	2.67 - 5.44
Sanches & Massad (2016)	Ribeirão Preto (SP)	2009 - 2010	1.78 - 5.41
Codeço et al. (2018)	Foz do Iguaçu (PR)	2010 - 2016	1.05
Codeço et al. (2018)	Foz do Iguaçu (PR)	2010 - 2016	1.02

Source: Authors (2024)

Note: Different estimation methods were reported in Sanches & Massad (2016)

## 4 CONCLUSION

The analysis conducted in this study reveals a significant change in the epidemiological behavior of dengue fever in Rio Grande do Sul over the last decade. Although the state has historically been characterized by a low incidence of the disease, the results show a significant increase in the number of cases from 2019 onwards, culminating in unprecedented levels in 2024 and remaining high in 2025. The temporal distribution of cases reveals the persistence of a well-defined seasonal pattern, with peaks concentrated mainly between epidemiological weeks 10 and 20, suggesting a strong influence of climatic and environmental factors favorable to vector proliferation.

Incidence rates indicate that, in recent years, the state has experienced periods classified as moderate and epidemic transmission, aligning with the scenario observed in other regions of the country. The estimate of the basic reproduction number, restricted to years with well-defined epidemic growth, reinforces this diagnosis by indicating values compatible with those reported in the literature for different Brazilian locations.

Taken together, the results suggest that Rio Grande do Sul is at a new level of dengue viral circulation, requiring continuous epidemiological surveillance, proactive planning of control measures, and integration of public policies aimed at mitigating the environmental and social factors that favor disease transmission. Future studies

incorporating climatic, spatial, and socioeconomic variables may contribute to an even deeper understanding of dengue dynamics in the region.

However, this study has some limitations that should be acknowledged. The analysis was conducted at the state level, without considering spatial heterogeneity among municipalities. In addition, climatic and socioeconomic variables were not explicitly incorporated into the model, and the estimates rely on reported case data, which may be affected by underreporting. Despite these limitations, the results provide valuable insights into the recent dengue transmission dynamics in Rio Grande do Sul.

Future studies may extend this analysis by incorporating climatic variables, spatial modeling approaches, and dynamic transmission models, contributing to a more comprehensive understanding of dengue expansion in southern Brazil.

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