

RIVER BASINS AND THE SPATIAL DISTRIBUTION OF DENGUE IN THE SÃO FRANCISCO HYDROGRAPHIC REGION: A GEOPROCESSING APPROACH

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Abstract

Dengue is an arboviral disease of major public health relevance, influenced by environmental, biological, and socio-spatial determinants. This study aimed to analyze the spatial distribution of probable dengue cases in the São Francisco Hydrographic Region in 2024. This is an ecological, descriptive study employing a quantitative approach and geoprocessing. Epidemiological data were obtained from the Notifiable Diseases Information System/Department of Informatics of the Unified Health System (Sistema de Informação de Agravos de Notificação/Departamento de Informática do Sistema Único de Saúde – SINAN/DATASUS), while cartographic data were obtained from the National Water and Basic Sanitation Agency (Agência Nacional de Águas e Saneamento Básico – ANA) (2020) and the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística – IBGE) (2025). Processing was performed using the open-source software QGIS 3.40, including the harmonization of six- and seven-digit municipal codes and the spatial clipping of the 505 municipalities in the basin. The results showed cases in 498 municipalities, with the highest incidence concentrated in the urban centers of the Upper and Middle São Francisco, such as Montes Claros/MG, Pirapora/MG, Petrolina/PE, and Juazeiro/BA, associated with unplanned urbanization and intermittent water supply. Lower incidences predominated in the Sub-Middle and Lower São Francisco, although household water storage continued to pose a risk. It is concluded that the river basin is a strategic unit for health surveillance and that interdisciplinary integration between Geography and Biology, mediated by geoprocessing, is essential for targeting prevention and control measures.

Keywords: Arboviral disease, Dengue, Geoprocessing, São Francisco River Basin, Socio-environmental vulnerability.

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INTRODUCTION

Brazil holds approximately 12% of the planet's surface freshwater, distributed across twelve Hydrographic Regions established by Resolution No. 32/2003 of the National Water Resources Council (Conselho Nacional de Recursos Hídricos – CNRH). This division, formally established by the National Water and Basic Sanitation Agency (Agência Nacional de Águas e Saneamento Básico – ANA), was defined on the basis of the natural, social, and economic characteristics of each region and constitutes the primary basis for water-resource planning and management at the national level, as provided for in Law No. 9,433/1997. However, this abundance of water, combined with a predominantly tropical climate, historical social inequalities, and chronic basic-sanitation deficits, creates conditions conducive to the persistence and spread of various neglected tropical diseases, constituting a major public health problem in the country.

The relationship between water and health is recognized by the World Health Organization (WHO) as one of the principal environmental determinants of health and is responsible for a significant share of the global burden of disease. Diseases such as malaria, whose transmission is associated with bodies of stagnant water in forested areas and with deforestation and unplanned settlement processes in the Amazon; schistosomiasis, which depends on lentic water bodies containing host snails of the genus *Biomphalaria*, commonly found in reservoirs and floodplains in the Northeast and the São Francisco River Valley; leptospirosis, whose incidence rises dramatically during flood and inundation events in densely populated urban basins; and arboviral diseases such as dengue, Zika, and Chikungunya, which proliferate in areas characterized by intermittent water supply, improper storage in water tanks and drums, and irregular solid-waste disposal, clearly demonstrate how hydrographic and climatic dynamics directly shape the population's epidemiological profile and socio-environmental vulnerability.

In this regard, the river basin, defined as a territorial planning unit by Law No. 9,433/1997, is therefore not merely a water-management unit, but also a fundamental and strategic unit of analysis for

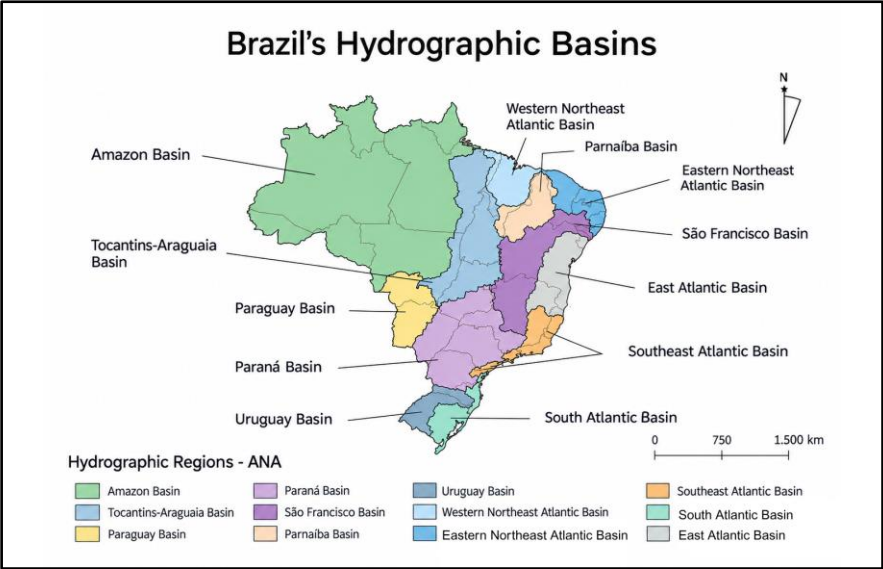
health geography. Analyzing the distribution of diseases by basin makes it possible to understand spatial patterns and transmission corridors that are not revealed by the traditional political-administrative division into states and municipalities. Examples include the continuity of schistosomiasis transmission along the entire main channel and tributaries of the São Francisco Basin, which functions as an axis for the spread of the disease from Minas Gerais to Pernambuco, and the concentration of leptospirosis outbreaks on the floodplains of the Southeast Atlantic and Paraná Basins, where the country's largest metropolitan regions are located, including São Paulo, Rio de Janeiro, and Porto Alegre, all marked by high levels of soil sealing and the occupation of risk areas.

In this context, geoprocessing emerges as an essential, low-cost, and highly applicable tool for spatial analysis in health. The use of Geographic Information Systems (GIS), such as the open-source software QGIS, allows hydrographic layers to be overlaid with epidemiological data obtained from DATASUS, enabling the identification of risk areas, the delimitation of transmission corridors, correlations with climate and sanitation variables, and analysis of the effects of extreme climatic events on population health. This integrated approach is essential to support decision-making and the formulation of more effective, territorially targeted public policies aimed at reducing health inequities and socio-environmental vulnerability in critical basins such as the São Francisco and Tucunduba Basins. From this perspective, recent studies such as Muniz et al. (2026), conducted in peripheral neighborhoods of Ananindeua/PA, show that the low recyclable-material recovery rate (1.11%) and high community perception of vectors (96.3%) create scenarios of environmental racism that intensify the proliferation of *Aedes aegypti*, reinforcing the river basin as a strategic unit of health analysis.

Figure 1 presents the territorial basis of this study, namely Brazil's twelve Hydrographic Regions, which will serve as a reference for cross-referencing the epidemiological data, as detailed in the methodology below.

Figure 1

Brazil's River Basins: 12 Hydrographic Regions.



Source: ANA (2024) and IBGE (2025). Prepared by the authors, 2026.

As shown in Figure 1, the twelve Hydrographic Regions cover different portions of the national territory and extend beyond state boundaries. Their composition by Federative Unit is detailed in Chart 1.

Chart 1

Composition of Brazil's 12 Hydrographic Regions by Federative Unit.

Hydrographic Region	Federative Units (FU) Covered
Amazon	AC, AM, RO, RR, PA, AP, MT
Tocantins-Araguaia	GO, TO, PA, MA, MT, DF
Paraguay	MT, MS
Paraná	PR, SP, MG, GO, MS, SC, DF
São Francisco	MG, BA, PE, AL, SE, GO, DF
Parnaíba	PI, MA, CE
Uruguay	RS, SC
Western Northeast Atlantic	MA, PA
Eastern Northeast Atlantic	CE, RN, PB, PE, AL
Southeast Atlantic	MG, ES, RJ, SP
South Atlantic	RS, SC, PR, SP
East Atlantic	BA, MG, SE, ES

Source: ANA. Prepared by the authors, 2026.

The general objective of this chapter is to analyze the spatial distribution of dengue cases by municipality in the São Francisco Hydrographic Region in 2024, using geoprocessing as a

methodological approach. The specific objectives are: a) to spatially situate the São Francisco Hydrographic Region within the National Hydrographic Division; b) to map dengue incidence by municipality in that basin in 2024; and c) to discuss how the basin's hydrological, climatic, and urbanization characteristics influence the disease's epidemiological profile.

THEORETICAL FRAMEWORK

This theoretical framework seeks to underpin the discussion of the spatial distribution of dengue in the São Francisco Hydrographic Region from an interdisciplinary perspective, integrating knowledge from Geography and Biology. Geography contributes to an understanding of the river basin as a unit of systemic territorial planning and management, while Biology provides the foundation for understanding vector ecology and the socio-environmental determinants of the health-disease process.

To this end, the chapter is structured around five themes: first, the river basin is discussed as a management unit; next, the Brazilian legal framework is presented; academic and management challenges are then analyzed; and, finally, case studies from the Amazon are presented as an analytical paradigm of socio-environmental vulnerability for understanding the conditions of the São Francisco Basin.

THE RIVER BASIN AS A PLANNING AND MANAGEMENT UNIT

According to Souza et al. (2022), the river basin has repeatedly been identified in the literature as a basic unit for environmental and water-resource management, a locus of urban planning, and an environmental planning unit.

The authors emphasize that a basin constitutes a natural territorial unit delimited according to geomorphological structure and water-resource generation, integrating all natural components involved in generating those resources. This systemic condition makes its landscape unique because of the systemic relationship among its components.

Also according to Souza et al. (2022), academic approaches to the subject can be grouped into two main perspectives: 1) the river basin as an environmental planning unit; and 2) the river basin as a territorial planning and/or management unit.

Environmental planning is understood as an instrument focused on the biophysical environment and the effects of human activities upon it. Territorial planning, in turn, is broader and is understood as a means of organizing the territory with a view to balanced socioeconomic development, improved quality of life, responsible management of natural resources, and environmental protection.

THE RIVER BASIN IN THE BRAZILIAN LEGAL FRAMEWORK

In analyzing six Brazilian environmental laws, Souza et al. (2022) identified a significant gap. Only the National Water Resources Policy (Política Nacional de Recursos Hídricos – PNRH), Law No. 9,433/1997, officially adopts the river basin as the territorial unit for policy implementation and for the activities of the National Water Resources Management System (Sistema Nacional de Gerenciamento de Recursos Hídricos – SINGREH).

Chart 2

The river basin in Brazil's principal environmental laws, according to Souza et al. (2022).

Laws	Treatment of the River Basin
Law No. 6,902/1981 – Environmental Protection Areas (APA)	Does not mention the river basin
Law No. 6,938/1981 – National Environmental Policy (PNMA)	Focuses on federative entities, without mentioning the basin
Law No. 9,433/1997 – National Water Resources Policy (PNRH)	Defines the basin as the territorial unit for policy implementation
Law No. 9,985/2000 – National System of Nature Conservation Units (SNUC)	Does not mention the river basin
Law No. 12,651/2012 – Forest Code	The basin is a guideline to be considered in Legal Reserve plans
Law No. 11,445/2007 – Basic Sanitation	The basin is a reference unit for planning measures

Source: Adapted from Souza et al. (2022).

For the authors, this framework demonstrates that, although Brazil has a sophisticated legal apparatus for water-resource management that adopts the river basin as a planning and management unit grounded in the integration of all components of nature, there is a gap regarding the practical application of the basin for this purpose.

ACADEMIC UNDERSTANDING AND MANAGEMENT CHALLENGES

In their integrative systematic review, Souza et al. (2022) analyzed eleven studies and narrowed the selection to seven directly related to the issue of the basin as a planning unit.

Chart 3

Studies addressing the basin as a planning unit, according to Souza et al. (2022).

Authors	Reference to the Subject
Matos and Dias (2012)	Intermunicipal cooperation in the Paraopeba River Basin
Wolkmer and Pimmel (2013)	PNRH: water governance
Araújo Júnior (2015)	River basin in the title; planning in the keywords
Demajorovic, Caruso and Jacobi (2015)	Basin in the title and abstract, associated with water-resource management
Araújo Júnior (2016)	Environmental information systems
Fontes Filho and Anjos (2016)	Basin and water management in Brazil
Carvalho (2016)	River basin plan in the title, abstract, and keywords

Source: Adapted from Souza et al. (2022).

The central conclusion reached by Souza et al. (2022) is that the studies notably lack a strong theoretical foundation capable of defining whether and how the river basin can serve as a planning and/or management unit.

Furthermore, the authors note that basin committees, theoretically collegiate bodies with regulatory, advisory, and deliberative authority, have faced operational difficulties because of multisectoral economic interests and unequal access to information. In 2016 specifically, there were only 213 basin committees, and approximately 51% of the country had no active committees, particularly in the North, Northeast, and Central-West regions.

Thus, there is a gap in the practical adoption of the river basin as a planning and/or management unit, both in academic production and in effective territorial implementation under Brazilian environmental laws (Souza et al., 2022). Despite this management challenge, the river basin appears preferable for planning purposes because it has been used as the territorial unit of geo-environmental studies, given its systemic nature.

This chapter adopts precisely the systemic conception proposed by Souza et al. (2022), applying the 12 Hydrographic Regions as units for the spatial analysis of tropical diseases.

THE INFLUENCE OF THE RIVER BASIN ON THE INCIDENCE OF PARASITIC DISEASES: THE
CASE OF THE TUCUNDUBA BASIN IN BELÉM, PARÁ, ACCORDING TO TEIXEIRA ET AL.
(2024)

According to Teixeira et al. (2024), water resources are important to the physical environment, but they are easily compromised in terms of quality and/or quantity, as well as by changes in watercourses or reductions in drainage channels, making the current degradation scenario a cause for concern.

From this perspective, water may be considered a potential health risk, making constant monitoring of its quality essential, especially in locations where the population is not served by sanitation companies and water is obtained from alternative systems, generally without treatment. Water quantity and quality are key factors in reducing the incidence and prevalence of various parasitic diseases, which are among the leading causes of death in children under 5 years of age.

The Tucunduba River Basin is one of the most precarious areas in the Belém Metropolitan Region. It contains an extensive area of substandard settlements, mostly located in flood-prone zones that extend across more than 50% of the basin's territory. With a population of approximately 300,000 inhabitants, it is characterized by unplanned settlement and is regarded as one of the basins with the most severe environmental and sanitation problems on the outskirts of Belém; it is inhabited by a low-income population (Teixeira et al., 2024).

Methodological Procedures of the Study

For this analysis, the approach used by Teixeira et al. (2024) involved quantitative research, which seeks and enables the identification of indicators and trends present in reality, as well as a qualitative approach, which enables the study of the specific characteristics of each society. It is therefore a mixed-methods approach, combining quantitative and qualitative methods, of an applied and descriptive nature and employing a cross-sectional design. The study was conducted on the outskirts of Belém, in a

floodplain area characterized by unplanned settlement and environmental and sanitation problems, inhabited by a low-income population (Teixeira et al., 2024).

Regarding the procedures, the research was structured into three interdependent stages: a) a bibliographic and documentary survey on sanitation, water resources, and environmental health in the Tucunduba River Basin; b) a field assessment involving the collection of drinking-water samples from three different points at Fonte Viva School, located in the Terra Firme neighborhood, an area directly influenced by the basin; and c) a health-education initiative. Laboratory tests were performed on 50 students between 8 and 12 years of age to identify possible waterborne intestinal parasitic infections, after their guardians had provided free and informed consent.

Finally, an Educational Booklet was produced using a more playful approach to the subject in order to reduce the incidence of cases among students at Fonte Viva School, in the Terra Firme Basin. The booklet was prepared in accessible language, with visual resources and interactive activities addressing the water cycle, proper solid-waste disposal, safe water storage, and the prevention of arboviral and parasitic diseases. It thus constituted a low-cost social technology applicable to other critical urban basins.

Results: Water Quality and Prevalence of Parasitic Infections

The values obtained in the field study for the physicochemical and bacteriological variables were compared with those stipulated in Ministry of Health ordinances. Ordinance No. 2,914/2011 was repealed and is currently incorporated into Consolidation Ordinance No. 5/2017, Annex XX, which regulates the integrity of water-distribution systems and the control and surveillance of water quality for human consumption.

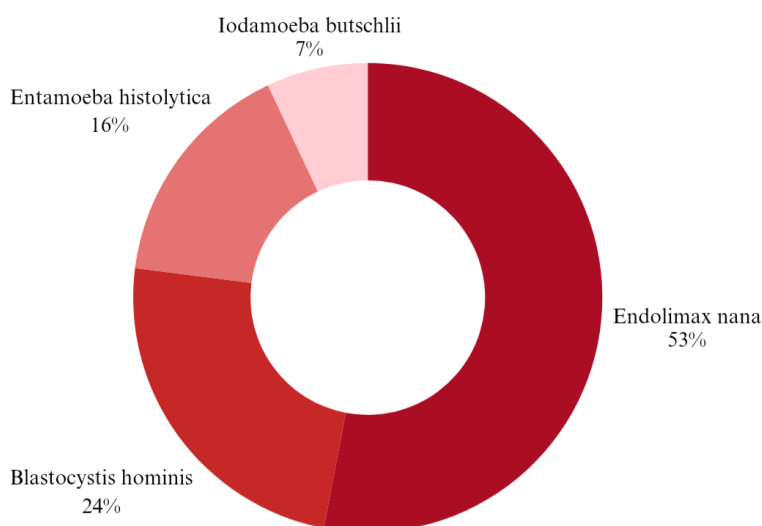
The samples collected from drinking fountains and cisterns showed levels well below the maximum thresholds permitted by the Ministry of Health, meaning that they met drinking-water standards for the parameters analyzed. Of particular note was the complete absence of thermotolerant

indicators at all three collection points. When detected in water, fecal coliforms, or thermotolerant coliforms, may indicate possible contamination by pathogenic microorganisms that cause waterborne diseases such as typhoid fever, paratyphoid fever, bacillary dysentery, and cholera (Teixeira et al., 2024).

Regarding the investigation into the prevalence of parasitic diseases, the survey focused on identifying intestinal parasites and revealed concerning findings. The analysis highlighted the occurrence of different species, with varying prevalence among the students.

Graph 1

Prevalence of parasites found among students at Fonte Viva School, according to Teixeira et al. (2024).



Source: Adapted from Teixeira et al. (2024).

According to the authors, *Endolimax nana* had the highest prevalence, consistent with areas characterized by poor sanitation and inadequate access to safe drinking water. In socioeconomically vulnerable regions such as the Terra Firme neighborhood, water contamination is one of the principal routes of transmission. The second most prevalent parasite was *Blastocystis hominis*, recognized as one of the most prevalent parasites in children. The presence of this protozoan reflects continuous exposure to contaminated water sources and inadequately washed food, indicating a strong correlation between inadequate sanitation and the proliferation of these organisms.

Another noteworthy protozoan was *Entamoeba histolytica*, identified in approximately 16% of the students. It causes amebiasis, with severe gastrointestinal symptoms such as diarrhea and cramps. Its significant presence highlights the urgent need for sanitation and educational interventions. *Iodamoeba butschlii* had the lowest prevalence, occurring in approximately 7% of the individuals. Although it is considered less pathogenic, its detection indicates the persistence of inadequate hygiene practices and a lack of effective control over sources of contamination.

Table 1, adapted from Graph 2 in Teixeira et al. (2024), presents the overall picture: 62% of students had parasitic diseases, while 38% had no parasites. Of all confirmed cases, male children accounted for 60% and female children for 40%.

Table 1

Distribution of intestinal parasitic infection cases among students at Fonte Viva School, Tucunduba Basin, according to Teixeira et al. (2024).

Variable Analyzed	Frequency (%)
Parasitological status (n=50)	
Positive for parasitic infection	62%
Negative for parasitic infection	38%
Distribution of Positive Cases by Sex	
Male	60%
Female	40%

Source: Adapted from Teixeira et al. (2024).

The results suggest that, although contamination may occur at multiple points of exposure, such as the household environment, the school, and the community at large, the Tucunduba Basin plays a significant role in contaminating the water sources used by the students. Proximity to contaminated water bodies is one of the principal risk factors for the proliferation of intestinal parasites in peripheral urban areas, which applies to the context of the Terra Firme neighborhood.

Another factor contributing to their spread is direct contact with contaminated water from the Tucunduba Basin. According to the Belém Municipal Health Department, this basin is severely polluted,

receiving large quantities of untreated domestic and industrial sewage and thus becoming a potential source of infection, particularly for children who use the area for leisure and recreation (Teixeira et al., 2024).

Conclusions of the Study

The results demonstrate the urgent need to improve sanitation conditions and the quality of water consumed by the local population, since the water supplied by the school was found to be safe, but the children remain exposed to risks in their household and community environments (Teixeira et al., 2024).

In view of this, the authors recommend that future studies investigate in greater depth the relationship between the quality of water supplied to Terra Firme residents and the prevalence of parasitic diseases, proposing practical solutions such as implementing sewage-treatment systems, improving the water supply, and developing public policies focused on environmental health, in addition to strengthening environmental and health-education programs.

SOCIO-ENVIRONMENTAL VULNERABILITY AND SOLID WASTE AS DETERMINANTS OF ARBOVIRAL DISEASES

The study by Muniz et al. (2026), conducted in peripheral Amazonian neighborhoods of Ananindeua/PA, such as Tapanã and Coqueiro, provides empirical evidence of the concept of socio-environmental vulnerability discussed in this chapter. The authors demonstrated that, although 100% of households had waste collection according to the 2022 IBGE Census, only 98.15% of waste is effectively collected and just 1.11% is recovered. This rate is lower than the national average of 3.36% and reflects conditions in the state of Pará, which has the lowest recycling rate in the country (0.48%) and disposes of 66.7% of its waste in open-air dumps, contrary to the National Solid Waste Policy (Política Nacional de Resíduos Sólidos – PNRS), Law No. 12,305/2010.

Although 60.6% of the 109 respondents considered collection adequate, 90.8% reported environmental problems such as blocked storm drains and polluted streams, while 96.3% observed disease vectors, especially rats and cockroaches, in locations where waste accumulated. This finding supports the biological understanding that irregular solid-waste disposal, including plastics, tires, and containers, creates artificial breeding sites for *Aedes aegypti*, the dengue vector.

The study also introduces the discussion of environmental racism by reporting that peripheral communities such as Vila da Barca were affected by the disposal of construction debris from COP 30 projects, while affluent areas received cosmetic infrastructure improvements. This socio-spatial inequality, described by Muniz et al. (2026), in which 94.5% negatively assessed government measures and 86.2% reported the absence of recycling programs, is analogous to that observed in the urban centers of the Upper and Middle São Francisco, namely Montes Claros/MG and Juazeiro/BA, where unplanned urbanization and shortcomings in waste management increase the risk of arboviral diseases.

Thus, the Amazonian experience demonstrates that both intestinal parasitic infections and dengue share the same socio-environmental determinants related to the inadequate management of waste and water resources, justifying the adoption of the river basin as a unit of integrated health and environmental management.

METHODOLOGY

This is an ecological study with a quantitative, descriptive approach, emphasizing the spatial analysis of the distribution of dengue cases. Ecological studies are appropriate for assessing patterns in the distribution of health conditions across large geographic areas, allowing correlations with environmental and territorial variables.

STUDY AREA

The study area corresponds to the São Francisco Hydrographic Region, as established by the National Hydrographic Division instituted by Resolution No. 32/2003 of the National Water Resources Council (CNRH). The São Francisco River Basin is the third-largest river basin in Brazil, with a drainage area of approximately 639,219 km² (8% of the national territory), encompassing 505 municipalities distributed across seven Federative Units: Minas Gerais, Goiás, Bahia, Pernambuco, Alagoas, Sergipe, and the Federal District.

From a physiographic perspective, the basin is subdivided into four regions: the Upper São Francisco, from its headwaters in Minas Gerais to Pirapora; the Middle São Francisco, from Pirapora to Remanso; the Sub-Middle São Francisco, from Remanso to Paulo Afonso; and the Lower São Francisco, from Paulo Afonso to the river mouth in the Atlantic Ocean. The basin exhibits considerable climatic diversity, ranging from a humid tropical climate in the Upper São Francisco to a semiarid climate in the Sub-Middle region, a factor that directly influences the vector dynamics of *Aedes aegypti*.

Table 2

Physiographic characterization of the São Francisco Hydrographic Region

Physiographic Region	Approximate Area	No. of Municipalities	Predominant Climate
Upper São Francisco	39%	240	Humid tropical/Cerrado
Middle São Francisco	39%	94	Semi-humid tropical
Sub-Middle São Francisco	17%	92	Semiarid
Lower São Francisco	5%	79	Agreste/Humid coastal
Total	639.219 km ²	505	—

Source: Adapted from ANA (2020) and IBGE (2025).

DATA COLLECTION AND PROCESSING

Epidemiological data concerning probable dengue cases by municipality of residence and year of notification (2024) were obtained from the Notifiable Diseases Information System (Sistema de Informação de Agravos de Notificação – SINAN), made available by the Department of Informatics of the Unified Health System (Departamento de Informática do Sistema Único de Saúde – DATASUS). The

data were tabulated in a CSV-format spreadsheet containing the IBGE municipal code and the total number of cases.

The vector cartographic data used were: a) the boundaries of Brazil's 12 Hydrographic Regions, in shapefile format, obtained from the official database of the National Water and Basic Sanitation Agency (ANA, 2020); b) Brazil's 2024 digital municipal boundary dataset, obtained from the Brazilian Institute of Geography and Statistics (IBGE), in shapefile format; and c) the Geocentric Reference System for the Americas (Sistema de Referência Geocêntrico para as Américas – SIRGAS 2000), the official standard for Brazil.

GEOPROCESSING AND SPATIAL ANALYSIS

Processing and spatial analysis were performed using the open-source software QGIS, version 3.40. When harmonizing the databases, an incompatibility was identified between the linkage keys: the IBGE municipal boundary dataset (2025) uses a seven-digit code, whereas the SINAN/DATASUS case table uses a six-digit code. To correct this, a new column was created in the attribute table of the municipal shapefile using the QGIS Field Calculator and the expression `to_string(left("CD_MUN",6))`, thereby generating the six-digit code. Following this procedure, the vector layer and the dengue CSV table were joined using the common six-digit field.

Next, spatial clipping was performed to extract the 505 municipalities belonging to the São Francisco Hydrographic Region from the shapefile of ANA's 12 Hydrographic Regions (2020).

For the choropleth representation, dengue cases in 2024 were classified into five intervals: 0–51, 51–201, 201–1001, 1001–5001, and 5001→ cases. The final layout, containing the map, legend, graphic scale, north arrow, and SIRGAS 2000 coordinate system, was exported at a resolution of 300 dpi.

ETHICAL CONSIDERATIONS

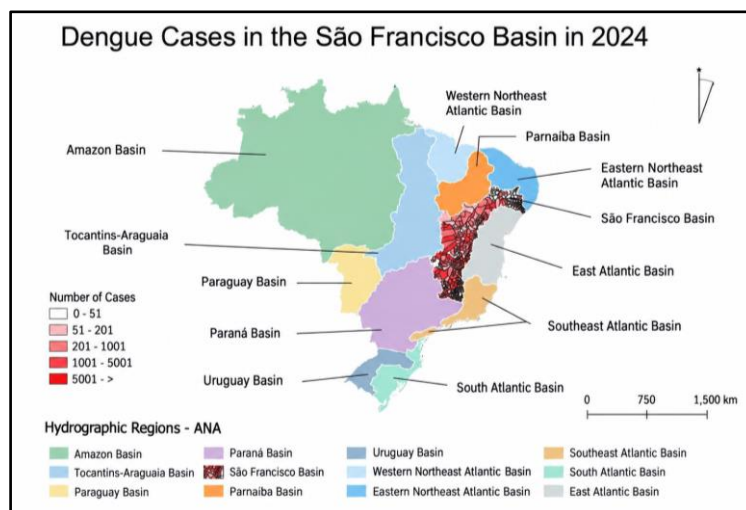
Because this study used publicly available secondary data aggregated by municipality, with no possibility of individual identification, submission to a Research Ethics Committee was not required, in accordance with Article 1, sole paragraph, of Resolution No. 510/2016 of the National Health Council.

RESULTS AND DISCUSSION

Based on geoprocessing of SINAN/DATASUS data for 2024, it was possible to map dengue cases in the São Francisco Hydrographic Region (Figure 2). Cases were recorded in 498 of the 505 municipalities comprising the basin, demonstrating the widespread distribution of dengue throughout the territory.

Figure 2

Spatial distribution of probable dengue cases by municipality in the São Francisco Hydrographic Region, Brazil, 2024.



Source: DATASUS (2024), ANA (2020), and IBGE (2025). Prepared by the authors, 2026.

Cases in the highest-incidence classes (>1001 cases) were concentrated in the most populous municipalities located in the Upper and Middle São Francisco, particularly in Minas Gerais and Bahia. The municipalities of Montes Claros/MG, Pirapora/MG, Juazeiro/BA, and Petrolina/PE stand out; together, they accounted for more than 35% of the basin's cases. These municipalities are characterized

by unplanned urbanization, high population density, and intermittent water supply, factors that favor the proliferation of *Aedes aegypti* and the persistence of the dengue transmission chain.

By contrast, municipalities located in the Sub-Middle and Lower São Francisco, within the semiarid region, had the lowest incidences, falling within the ranges of 0–51 and 51–201 cases. This pattern may be related to climatic conditions unfavorable to the vector during the period, including low rainfall, although improper water storage in cisterns continues to maintain the risk of dengue transmission.

The climatic gradient observed across the basin, transitioning from humid tropical conditions in the Upper region to semiarid conditions in the Sub-Middle region, corroborates the descriptions provided by the World Health Organization (WHO, 2024) and the IPCC (2023), according to which climate change and hydrological variability act as environmental determinants of dengue expansion. The river basin therefore constitutes a strategic territorial unit not only for water management but also for dengue surveillance.

Spatial analysis using QGIS proved effective in identifying priority areas for dengue control and prevention measures, reinforcing the importance of geoprocessing as a tool to support public health decision-making.

CONCLUSION

The spatial analysis of probable dengue cases in the São Francisco Hydrographic Region in 2024, conducted through geoprocessing in QGIS 3.40, made it possible to identify the pattern of disease distribution across the basin's four physiographic regions. Cases were found in 490 of the 505 municipalities comprising the hydrographic unit, demonstrating the endemic nature of the arboviral disease and its relevance as a public health problem throughout the territory.

From an interdisciplinary perspective, the study demonstrates the intrinsic relationship between Geography and Biology in understanding dengue dynamics. Geography, as the science of space, made it possible, through geoprocessing and analysis of the river basin as a territorial unit, to understand the influence of factors such as unplanned urbanization, population density, sanitation deficiencies, and the climatic gradient that transitions from humid tropical conditions in the Upper São Francisco to semiarid conditions in the Sub-Middle region. These geographic elements shape the territory's socio-environmental vulnerability.

Biology, in turn, provides the basis for understanding the ecology of the *Aedes aegypti* vector, its reproductive biology associated with artificial breeding sites containing stagnant water, its adaptation to the urban environment, and its dependence on temperature and rainfall conditions to complete its life cycle. Integrating knowledge of vector bioecology with the geographic mapping of cases makes it possible to understand why the urban centers of Montes Claros/MG, Pirapora/MG, Petrolina/PE, and Juazeiro/BA have the highest numbers of cases, as the interaction between biological factors and geographic settlement is most intense in these locations.

The results demonstrated a concentration of cases in the highest-incidence classes (>1001 cases) in the most populous municipalities located in the Upper and Middle São Francisco, especially in Minas Gerais and Bahia. Fewer cases were recorded in the Sub-Middle and Lower São Francisco regions, situated within the semiarid context. Nevertheless, the risk of transmission associated with household water storage in cisterns and drums remains, as this common practice creates artificial microhabitats for the vector even during periods of drought.

The study reinforces that the river basin constitutes a strategic territorial unit for integrated health and environmental management, moving beyond an analytical framework based solely on states and municipalities, as advocated by Law No. 9,433/1997, the National Water Resources Policy. The use of secondary data from SINAN/DATASUS and official cartographic databases from ANA and IBGE,

combined with the open-source software QGIS, proved effective, low-cost, and replicable for other health conditions and other Brazilian river basins.

The study's limitations include the use of secondary data subject to underreporting and the time lag inherent in information systems. Future studies should incorporate climatic variables, including precipitation and temperature, sanitation indicators, and temporal analyses of historical series in order to examine more deeply the correlation between environmental, biological, and geographic determinants in dengue dynamics.

It is concluded that the interdisciplinary approach integrating Biology and Geography, mediated by geoprocessing, is a fundamental tool for health surveillance. It enables the identification of priority areas and the targeting of dengue prevention and control measures in a more equitable, effective, and territorially contextualized manner throughout the São Francisco Hydrographic Region.

The analysis of the Tucunduba Basin and the case study conducted in Ananindeua/PA (MUNIZ et al., 2026) demonstrate that the problem of solid waste extends beyond the technical dimension of collection. As shown, even with formal collection coverage, the low recovery rate of recyclable materials (1.11%) and the predominant disposal of waste in dumps (66.7% in Pará) create a scenario of socio-environmental vulnerability in which 96.3% of the population reports the presence of disease vectors. These conditions are analogous to those in municipalities of the Upper and Middle São Francisco, where waste accumulation in peripheral areas intensifies the proliferation of *Aedes aegypti*.

It is concluded that government neglect and environmental racism, expressed through the prioritization of affluent areas to the detriment of peripheral communities, heighten the risk of arboviral diseases. Hope for change lies in the community's willingness (94.5%) to participate in collective cleanup initiatives, as noted by Simoncini et al. (2023), reinforcing the need for integrated public policies encompassing environmental education, recycling, and infrastructure, with the river basin serving as the management unit.

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