Climate Change in the Sanitation Sector

How droughts, storms and heat waves impact water consumption?

Trata Brasil Institute

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PROJECT **INSTB24A**

DELIVERABLE Climate Risk in the Sanitation Sector Report

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1. Introduction

Climate change poses a growing threat to the sanitation sector in Brazil, intensifying existing challenges and creating risks for the operation of water and sewage systems. Climate phenomena such as heat waves, heavy storms and prolonged droughts have a direct impact on the ability of sanitation companies to guarantee an adequate supply of drinking water and the correct management of effluents, and consequently, impact the quality of life of the population and the water security of communities.

Effects can be seen in heat waves that exacerbate the demand for water, putting pressure on systems that are already operating at the limit of their capacity. At the same time, severe droughts affect water sources, reducing water availability and leading to rationing, or the use of alternative sources, often of lower quality. Droughts directly affect the population, as the lack of water limits access to basic sanitation services and increases the risk of disease transmission.

Furthermore, storms and heavy rains overload drainage and sewage treatment systems, causing flooding, burst pipes and contamination of drinking water sources. These events can lead to flooding and contamination of residential areas, exposing certain areas to untreated effluents and health risks.

These changes of the climate not only affect the physical infrastructure of supply companies, but also highlight the need for strategic planning based on future climate scenarios. For the population, these climate risks increase the inequality of access to basic sanitation services, especially in peripheral urban and rural areas, as they face infrastructure challenges. This context highlights the need for adaptation policies that ensure access to water and sanitation in extreme climate scenarios, increasing the resilience of the most affected communities.

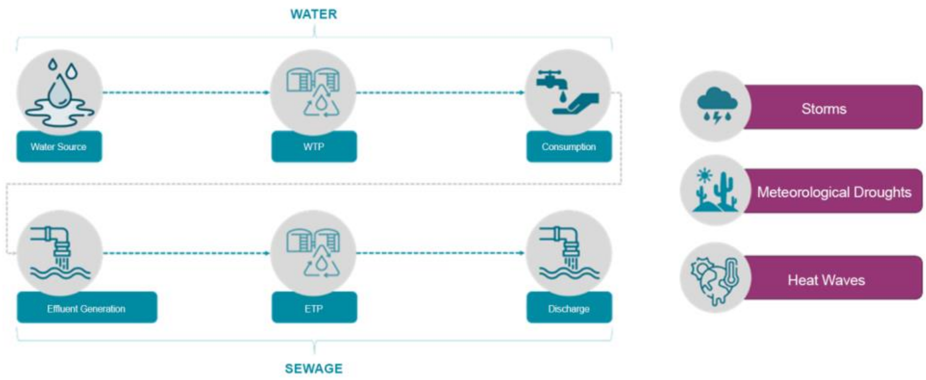
The trends of worsening climate events and their impacts on the sanitation sector in Brazil can be assessed through scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). These scenarios project different trajectories of global warming and climate change that, in the long term, could intensify extreme events, such as severe droughts and more frequent storms.

2. Technical Scope

The climate risk assessment for the sanitation sector in Brazil includes water and sewage systems, each based on three main stages. The water system is made up of springs, WTPs (Water Treatment Plants) and consumption points. The sewage system is made up of effluent generation points, ETPs (Sewage Treatment Plants) and the final discharge of treated or untreated effluent into the environment. Climate threats assessed according to future scenarios consider the effects of storms, meteorological droughts and heat waves.

Figure 1 presents a summary of the scope of the climate risk assessment for the sanitation sector in Brazil.

Figure 1 - Scope of climate risk assessment in the sanitation sector

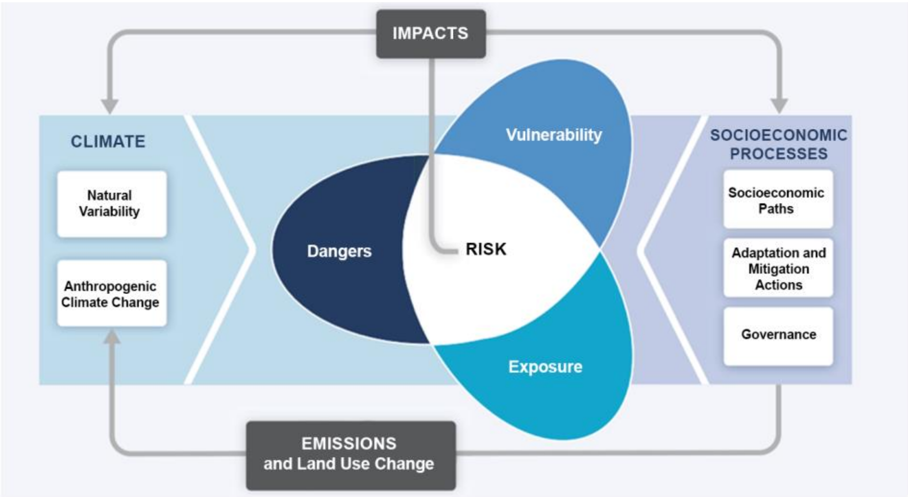


3. Methodology

The risk of climate-related impacts results from the interaction of climate threats (or hazards) such as heat waves and meteorological droughts with the vulnerability and exposure of human and natural systems.

The project is based on the main concepts associated with climate risks, according to the IPCC, illustrated in Figure 2. Changes in both the climate system (left) and social and economic processes, including adaptation and mitigation (right), are drivers of climate threats, exposure and vulnerability (IPCC).

Figure 2 - Illustration of the main concepts associated with climate risks (AR6 IPCC).



The concepts involved are presented below:

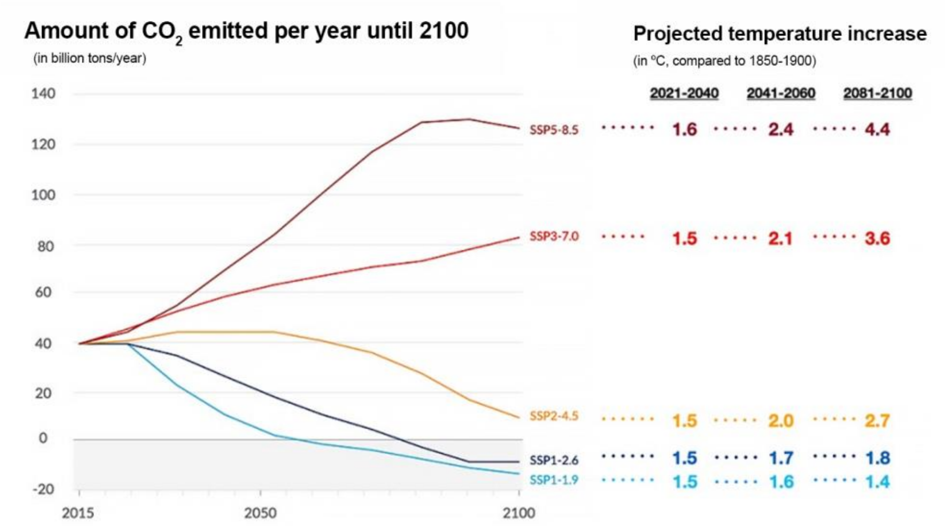
- **Climate Threat/Hazard:** The potential tendency for a natural event to occur that could cause damage or impact the health, infrastructure, the provision of public and private services, ecosystems and natural resources. In the context of the study, it refers to future trends of occurrence of impacts associated with climate change that may impact sanitation services and the population.
- **Exposure:** The presence of people, ecosystems, environmental functions, sanitation sector infrastructure that could be adversely affected. The indicators used to represent exposure are based on the main system under analysis, which in this case is the sanitation sector. In this sense, information from Water Treatment Plants (WTP) and Sewage Treatment Plants (ETP) and effluent discharge points were considered.
- **Vulnerability:** Propensity or predisposition to be adversely affected by the impacts of climate change. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to damage and the lack of capacity to respond or adapt. Sensitivity corresponds to the level at which the evaluated system is affected by the impacts of climate change. For example, regions that have a qualitative water balance are more sensitive and would be more vulnerable to the effects of droughts.

3.1. IPCC Climate Models and Scenarios

Climate models are essential tools for projecting climate change and its potential impacts. These models consider a wide range of factors, including atmospheric and oceanic circulation, ice cover and the carbon cycle (EYRING et al., 2019) among many others specific to each climate model. Efforts to understand and represent the climate are centralized on the CMIP (Coupled Model Intercomparison Project) (STOTT; FOREST, 2007). CMIP is a project of the World Climate Research Programme (WCRP) that uses different global models to analyze climate change, and is currently in its sixth phase (CMIP6).

CMIP 6 is used as a benchmark for the climate scenarios presented in the IPCC Assessment Report 6 (AR6), which introduces the Shared Socioeconomic Pathways (SSPs). Figure 3 shows the SSP scenarios presented by the IPCC, which relate GHG emissions to the respective temperature increase.

Figure 3 – IPCC's SSP Climate Scenarios



These scenarios consider both Greenhouse Gas (GHG) emission trajectories and variations in socioeconomic factors, creating projections with different warming intensities until the end of the 21st century.

For the study of climate risks in the sanitation sector, the SSP3-7.0 scenario was selected, due to its close match with the trends currently observed in global GHG emissions. This scenario represents an intermediate-high trajectory, in which emissions increase considerably by the end of the century, reflecting a lack of global coordination for mitigation and a high dependence on fossil fuels, leading to global warming between 3ºC and 4ºC. This emissions trajectory, observed in several countries with climate policies that are considered inefficient, makes the chosen scenario suitable for modeling physical climate risks in the sanitation sector.

Regarding the horizons under analysis, the reference period (1895-1994) is defined, which aims to understand the historical conditions considered normal in the region and, based on this climate, describe the behavior of the recent historical scenario (1995-2014), already under the effects of climate change, and the climate projections for the 2030 (2021-2040) and 2050 (2041-2060) periods.

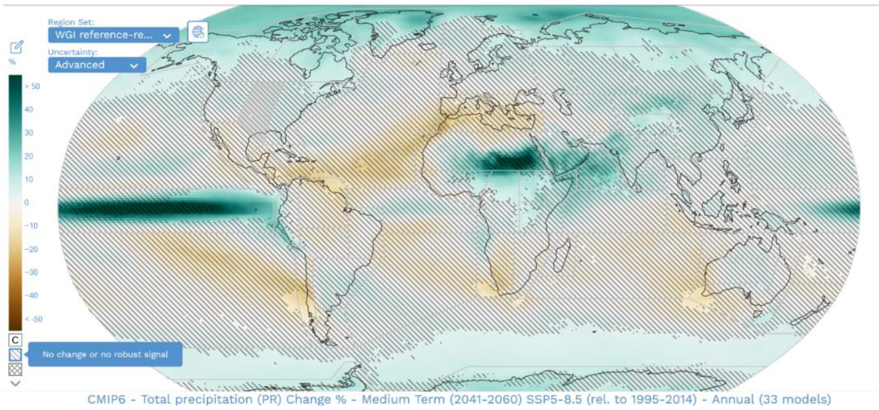
3.1.1. Limitations and Uncertainties

Although CMIP climate models have advanced significantly, there are still inherent uncertainties in the projections, especially at the regional level. The precision of the projections is limited by the complexity of atmospheric processes and the spatial resolution of the models, which makes it difficult to represent local and regional phenomena in detail.

The divergence between models is traditionally considered in the analysis of results, emphasizing the uncertainty of projections and the importance of using sets of models (ensembles) instead of a single projection to support political and economic decisions (STAINFORTH et al., 2007). The members of an ensemble are, in general, different models that share similar input parameters. By comparing results one can understand the range of possibilities and uncertainties of a specific model or set of assumptions.

Climate projections are then presented as ensembles, which consist of several simulations of the Earth's climate system. For example, Figure 4 illustrates the areas of uncertainty, highlighted in hatching, based on the average ensemble of 33 CMIP6 models for precipitation between 2041 and 2060, taking the period 1995 to 2014 as a reference and considering the IPCC pessimistic scenario (SSP5-8.5).

Figure 4 - Representation of the CMIP6 Ensemble for precipitation in the period 2041 to 2060, in the SSP5-8.5 scenario.



Source: IPCC-WGI Interactive Atlas: Regional information, 2021.

We highlight that, for a large part of the region analyzed in this study, in Brazil, there is no agreement between all the models. Therefore, techniques for selecting models that best represent the climate of a specific region or that provide more concise projections are essential to support decision making. Discussions in this sense are recurrent in the literature (HERGER et al., 2018; STOTT; FOREST, 2007) and emphasize the construction of ensembles in regional studies.

3.1.2. Selection of Models and Reanalysis of Data

In the process of ensemble construction, the main objective is to reduce the uncertainty associated with the premises of each model and assist in risk management, providing a theoretical basis to guide decision making by the public or private sector, whether in the formulation of broad policies or for directing private investments. To achieve this, it is essential to use the best available information in a considerate and assertive manner, balancing processing costs and the need to minimize risks of exposure to climate events.

The product of building an assertive ensemble is not an end in itself, but an intermediate step in the process of evaluating climate projections. In this context, direct results from the CMIP6 dataset (STOTT; FOREST, 2007), compiled and made available by the ESGF (Earth System Grid Federation), were used. The complete set of climate data and variables is extensive (over 30 terabytes (THRASHER et al., 2022)), therefore it was necessary to pre-select the models to be evaluated. The models considered in this study are presented in Table 1.

Table 1 – Climate Models selected for the study, references and resolution

Models and references	Research Center	Resolution (LAT x LON)
ACCESS-ESM1-5 (ZIEHN et al., 2020)	Commonwealth Scientific and Industrial Research Organisation (Australia)	1.25° × 1.25°
GFDL-ESM4 (DUNNE et al., 2020)	National Oceanic and Atmospheric Administration (USA)	1.11° × 1.11°
IPSL-CM6A-LR (BOUCHER et al., 2020)	Institut Pierre Simon Laplace (France)	1.3° × 2.5°
MIROC6 (TATEBE et al., 2019)	Japan Agency for Marine-Earth Science and Technology (Japan)	1.4° × 1.4°
MRI-ESM2-0 (YUKIMOTO et al., 2019)	Meteorological Research Institute (Japan)	1.1° × 1.1°
NorESM2-MM (SELAND et al., 2020)	Bjerknes Centre for Climate Research (Norway)	1.1° × 1.1°

Source: Adapted from MORADIAN; AKBARI; IGLESIAS, 2022

Another useful tool for validating and calibrating the projection analyses are reanalysis models, such as CHIRPS (Climate Hazards group InfraRed Precipitation with Station data) and ERA5 from the European Centre for Medium-Range Weather Forecasts (ECMWF). These models integrate historical data with climate simulations, complementing climate model data and helping to calibrate the projections considered in this study.

CHIRPS comprises a precipitation dataset that combines satellite-based measurements with data from *in situ* stations to provide a long-term record of precipitation in regions around the world where locally collected data are scarce. This dataset is produced by the Climate Hazards Group at the University of California, Santa Barbara and is considered one of the best representations of the observed reality regarding precipitation (PAREDES-TREJO; BARBOSA; KUMAR, 2017).

ERA5, produced by the European Centre for Medium-Range Weather Forecasts, provides high-resolution climate data, combining satellite observations with numerical modeling to provide a detailed record of meteorological variables such as precipitation, temperature, wind and atmospheric pressure. This dataset covers the period from 1950 to the present and is widely used in climate and meteorological research due to its coverage and accuracy. ERA5 is considered one of the best data sources for studying the climate and atmospheric phenomena, and is frequently used to validate climate models and study extreme events (HERSBACH et al., 2020).

3.1.3. Model Treatment, Downscaling and Ensemble

Based on the set of available models, it is necessary to evaluate the performance of these projection models in relation to the reality observed in the reanalysis models (MCAVANEY et al., 2001) with the objective of combining information from the best adjusted models and refining the resolution of the climate models based on the reanalysis data (downscaling) (BRANDS et al., 2011).

Initially, all models were reprojected, using the bilinear extrapolation model (HOSSAIN et al., 2021), into a 0.25º x 0.25º grid (latitude x longitude). In this process, there is no gain in representation or error reduction, only a return to the original resolution of the data reanalysis model (PAREDES-TREJO; BARBOSA; KUMAR, 2017), which was used as a reference to evaluate the models listed in Table 3 and build the ensemble.

3.1.4. Climate Variables

In this study, three climate threats related to material risks for the sanitation sector were analyzed and are presented in Table 2.

Table 2 – Description of climate threats in the study

Climate Threat	Description
Storm	Meteorological phenomenon characterized by severe atmospheric conditions, such as strong winds, heavy rain, and, in some cases, hail. They can vary in intensity and duration, from short-lived local storms to large-scale tropical cyclones and are influenced by several climate factors (IPCC, 2021).
Heat Wave	Defined as a prolonged period of extreme and abnormal heat, usually lasting several days to weeks. (IPCC, 2021).
Meteorological Drought	Defined as prolonged periods of insufficient precipitation, leading to a significant water deficit depending on the intensity and duration (IPCC, 2021).

To assess the incidence of storms, two climate variables were considered: maximum precipitation in one day and maximum precipitation in five consecutive days. To evaluate the incidence of heat waves, two climate variables were also considered: number of heat waves and evapotranspiration. In addition, to assess the incidence of meteorological droughts, the climate variable of number of consecutive days without rain was considered. Table Table 3 presents the evaluated climate indicators that represent each climate threat in the study of climate risks for the sanitation sector.

Table 3 – Climate variables used to represent the effects of climate threats

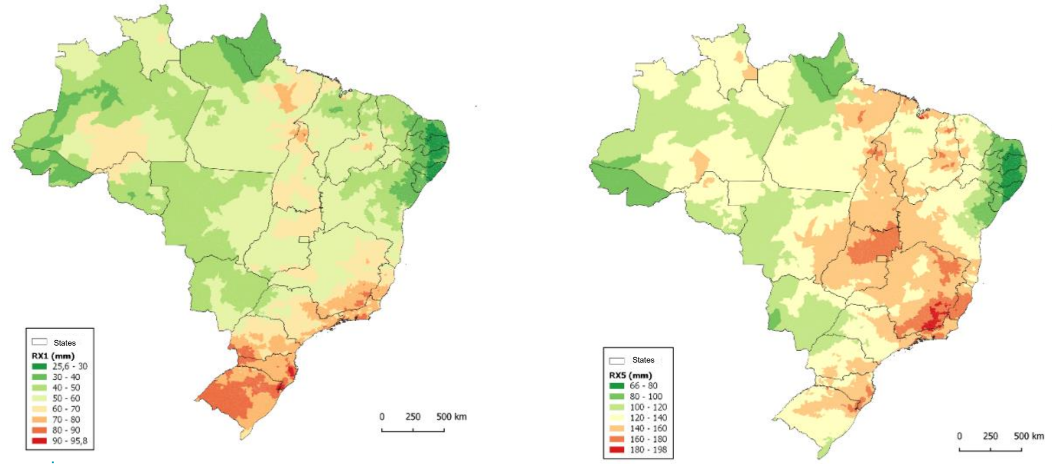
Climate Threat	Climate Indicator Assessed	Reference
Heat Waves	**HW.N** = Number of heat waves recorded in the year	AR6 - IPCC (2021)
	EVAP = Maximum potential evaporation in the year	
Meteorological Droughts	**CDD** = Maximum sequence of dry days	
Storms	**Rx1day** = Maximum precipitation in one day	
	Rx5day = Maximum accumulated precipitation in 5 consecutive days	

Source: WayCarbon

Figures 5 to 7 below show the spatialization of each climate variable analyzed in the 2050 horizon and SSP3-7.0 scenario.

3.1.4.1. Storms

Figure 5 – Rx1day and Rx5day - Maximum precipitation in one day and in five days in the 2050 horizon and SSP3-7.0



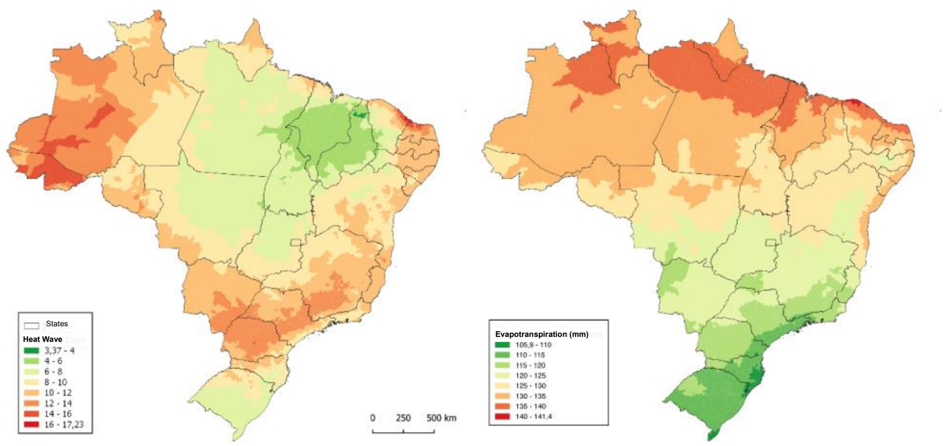
scenario

Preparation: WayCarbon based on CMIP6 climate models

The results highlight areas of Brazil with a greater likelihood of worsening, in terms of frequency and intensity, of severe precipitation events. The RX1day variable, which projects the maximum precipitation in a single day, shows higher values in the South, especially in Rio Grande do Sul, Santa Catarina and west of Paraná. In the Southeast, the highest RX1day values occur mainly on the coast of São Paulo, Rio de Janeiro and south of Espírito Santo. The RX5day variable, which considers the accumulated rainfall over five consecutive days, shows patterns of prolonged precipitation especially in the Southeast region, with higher values in the south of Minas Gerais, Espírito Santo and Rio de Janeiro. In contrast, Northeast Brazil shows the lowest values for both variables, reflecting the region’s drier climate.

3.1.4.2. Heat waves

Figure 6 – HW.N and EVAP - Number of heat waves and evapotranspiration in the 2050 horizon and SSP3-7.0 scenario



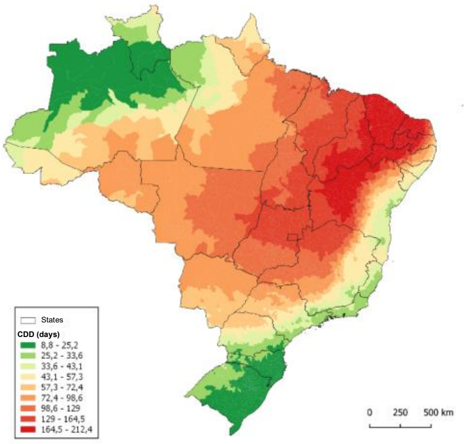
Preparation: WayCarbon based on CMIP6 climate models

These results reveal temperature and humidity patterns that reflect Brazil’s distinct climatic characteristics. The number of heat waves (HW.N) show the highest projected values for Acre, western Amazonas and part of the Northeast, mainly in the states of Rio Grande do Norte and Ceará. These regions, in addition to already being subject to high temperatures, are also expected to see an increase in the number of heat waves. Other regions such as the south of Mato Grosso do Sul, Paraná, and certain regions of São Paulo and Minas Gerais show intermediate to high values, indicating a high frequency of heat waves.

The EVAP variable, which represents evapotranspiration, shows the highest values in the North region, especially in the states of Amazonas and Roraima, northern Pará and southern Amapá. In the Northeast, the phenomenon is more pronounced in the states of Maranhão, Piauí, Ceará, and Rio Grande do Norte.

3.1.4.3. Meteorological Droughts

Figure 7 – CDD - Consecutive days without rain in the 2050 horizon and SSP3-7.0 scenario



Preparation: WayCarbon based on CMIP6 climate models

The results of the CDD variable reflect Brazil's climate characteristics, with emphasis on the *sertão* and *agreste* regions in the Northeast, where the highest projected values are identified, especially in the states of Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, and Bahia. Some regions in Tocantins, Goiás and Minas Gerais also show high values. The effect is reduced in the Zona da Mata region, close to the coast, due to the influence of oceanic humidity.

3.2. Exposure and Vulnerability

In order to assess climate risks, the analysis of indicators that describe the exposure and vulnerability of the affected regions and the systems involved is also considered. These indicators are used to understand the degree of susceptibility of municipalities to extreme climate events and the adaptability of sanitation infrastructure.

For example, regarding exposure, factors such as population density may be considered, as places with high population density have a larger number of people dependent on sanitation services and are therefore more exposed to interruptions or system failures due to climate events. Furthermore, the number and distribution of WTPs and ETPs in the municipalities allow us to identify those most exposed to drought and storm events.

Vulnerability, in turn, includes factors that influence the sensitivity of the evaluated systems. Water balance, both quantitative and qualitative, is an important factor, as it allows assessing the quantity and quality of available water resources, especially in contexts of water stress, such as prolonged drought events or due to contamination from heavy rains.

Furthermore, the water supply index shows the drinking water coverage in the different regions of the country, while the sewage collection and treatment index reflects the environmental vulnerability of the regions. Municipalities with low sewage collection rates, for example, may face greater risks of water contamination during storm events, increasing sanitation challenges in more sensitive areas.

3.2.1. Selected Indicators

The list of indicators that represent the exposure and vulnerability parameters of sanitation systems in climate risk modeling are presented in Table 4.

Table 4 – Indicators selected to represent exposure and vulnerability of sanitation systems

Variable	Description	Reference
Geographic density	Number of inhabitants per unit area (inhab./km^2)	IBGE (2022)
Population	Absolute number of inhabitants (inhab.)	IBGE (2022)

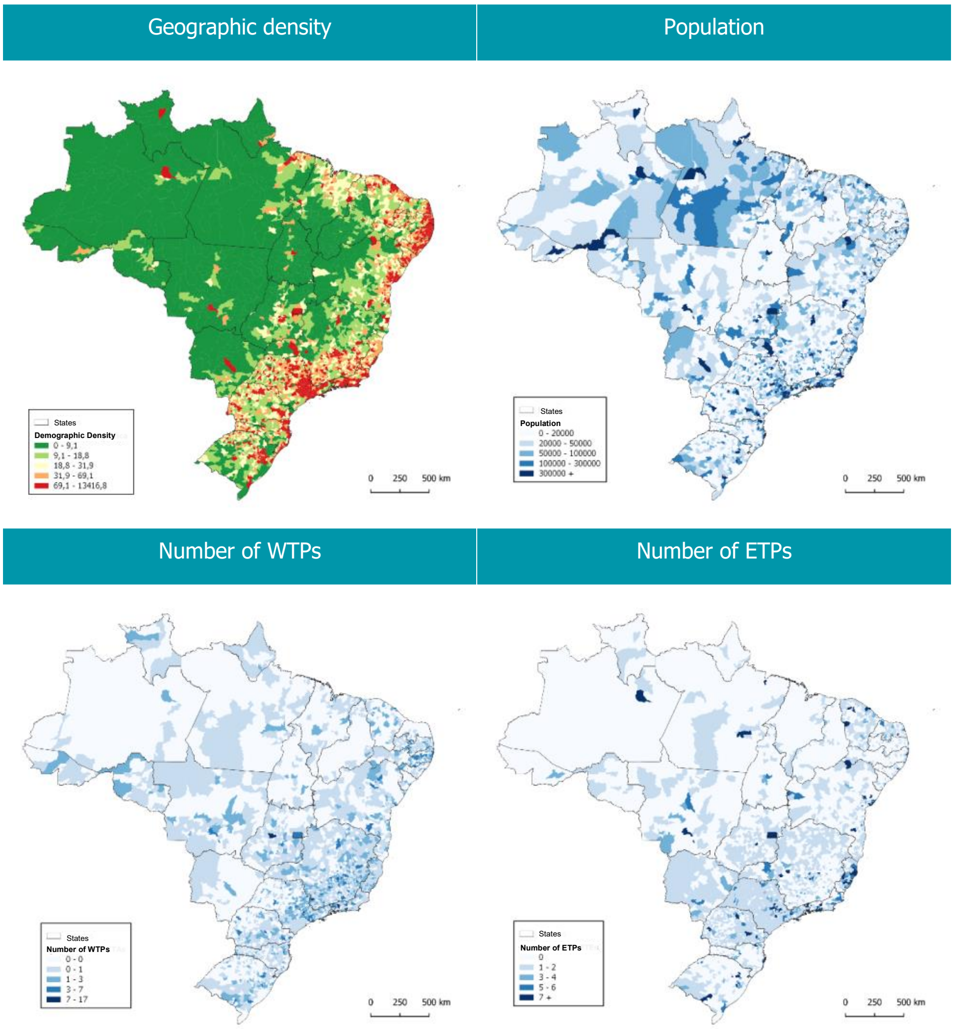
Number of WTPs	Number of WTPs (Water Treatment Plants) with conventional treatment supplying the municipality	Water Atlas (2021)
Number of ETPs	Number of ETPs (Sewage Treatment Plants) that treat municipal sewage	Sewage Atlas (2020)
Qualitative Water Balance	Estimates the current self-purification capacity of rivers, considering the flow and the load received. The value scale corresponds to the following: 0-0.5 (excellent), 0.5-1.0 (good), 1.0-5.0 (fair), 5.0-20.0 (poor) and >20 (bad).	ANA (2016)
Quantitative Water Balance	Estimates how impaired is the river flow considering its different uses. It classifies the impairment level of river sections as: low (below 5%), medium (5% to 30%), high (30% to 70%), very high (70% to 100%), critical (above 100%) and intermittent (zero supply).	ANA (2016)
Sewage collection index	Percentage of population served by sewage collection (%)	Sewage Atlas (2013)
Water supply index	Percentage of population supplied with treated water (%)	Water Atlas (2021)
Type of water source	Type of water source that supplies the municipality (ground, surface or mixed)	Water Atlas (2021)
Sewage load generated	Sewage load generated in the municipality (kg BOD/day)	Sewage Atlas (2013)
Sewage load sent to an ETP	Sewage load sent to an ETP (kg BOD/day)	Sewage Atlas (2013)
Sewage load discharged	Sewage load discharged in the municipality (kg BOD/day)	Sewage Atlas (2013)
Coverage by individual solution index	Percentage of population supplied by individual sewage treatment solutions (%)	Sewage Atlas (2013)
Urban Water Security Index	The Urban Water Security Index (ISH-U) is calculated from the water production efficiency and the water distribution efficiency (minimum, low, medium, high, maximum)	ANA (2021)

Preparation: WayCarbon

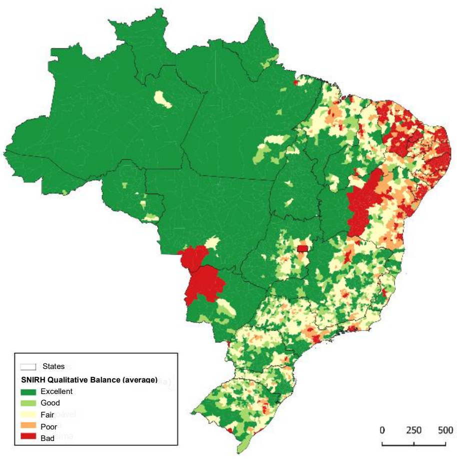
Some indicators are available at the municipal level, such as population density and the number of WTPs and ETPs, while others, such as the quantitative and qualitative water balance, are available at the watershed level, which need to be adapted to be used. To ensure the consistency and applicability of the selected indicators, the entire database was duly processed and consolidated at the municipal level.

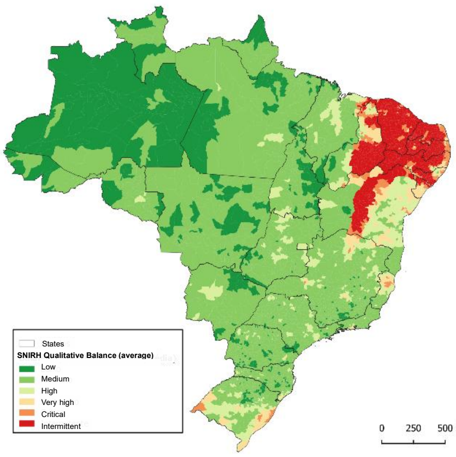
Figure 8 shows maps with the spatial distribution of each indicator of Table 4.

Figure 8 - Graphical representation of support variables

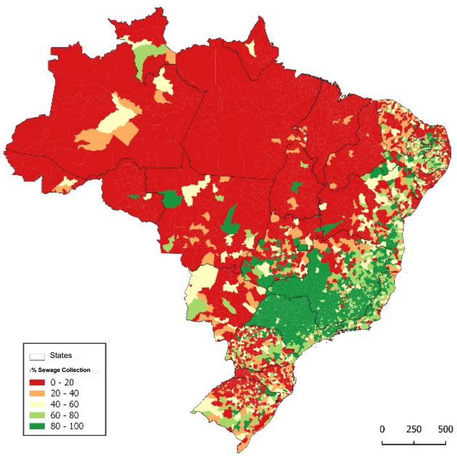


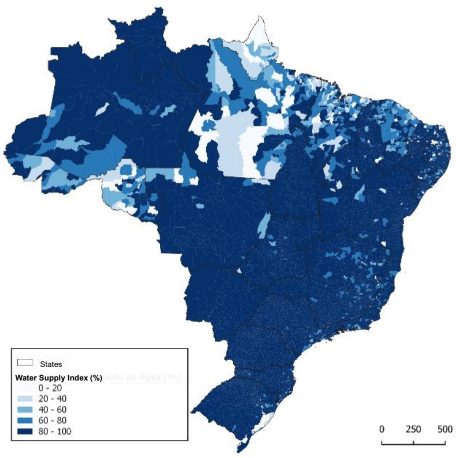
ANA Qualitative Balance	ANA Quantitative Balance



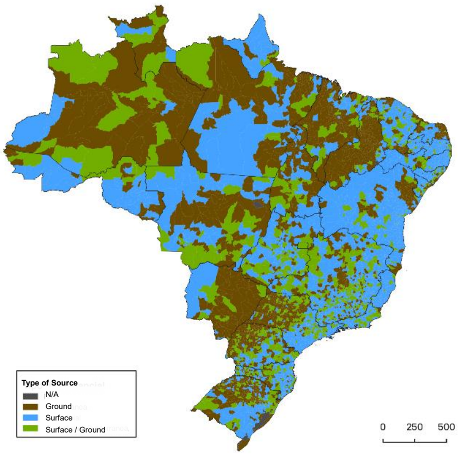


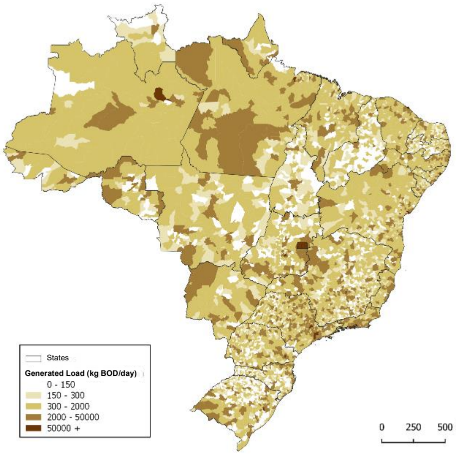
Sewage collection index	Water supply index



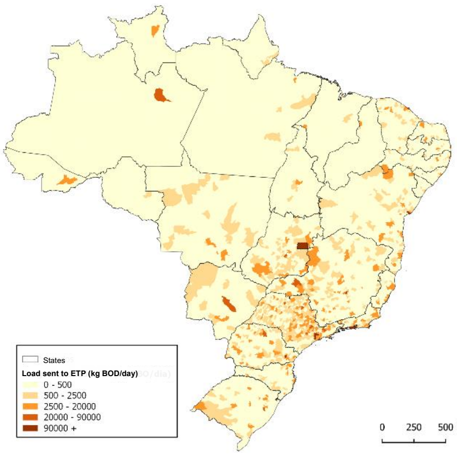


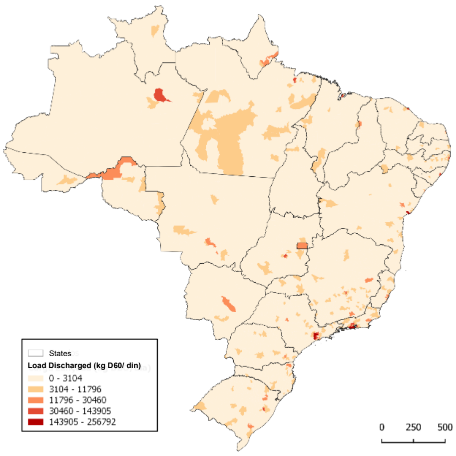
Type of water source	Sewage load generated



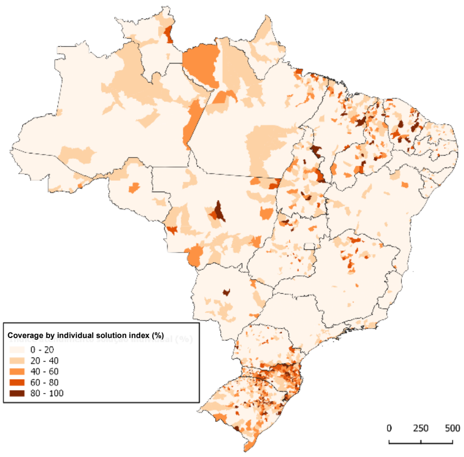


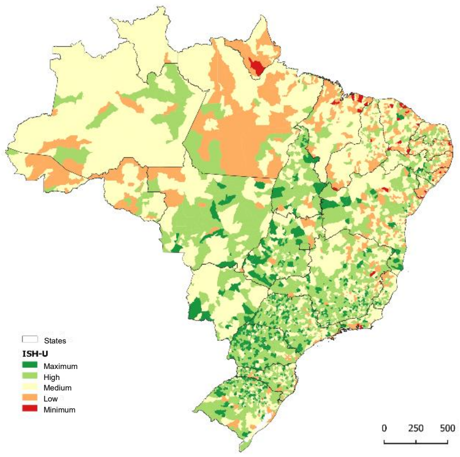
Sewage load sent to an ETP	Sewage load discharged





Coverage by individual solution index	Urban water security index





Preparation: WayCarbon, adapted from references

3.3. Impact identification

The objective of this stage was to identify the main consequences from climate threats for the sanitation sector, understanding the potential effects of the extreme climate events evaluated, such as droughts, storms and heat waves, which impact water and sewage systems directly and indirectly.

Impact identification was conducted through previously performed studies in the sector and querying national and international literature with the key words: climate change, sanitation, water treatment, effluent treatment, storms, droughts, heat waves, water supply, sewage. After reviewing and validating the impact survey, these were consolidated based on the availability of relevant data and information to model each identified climate risk.

The complete list of impacts mapped for each climate threat to water and sewage systems is presented in ANNEX II – Identification of Climate Risks with GT.

3.4. Climate Risk Modeling

Climate risk modeling combined projections of climate variables from the IPCC SSP3-7.0 scenario with previously selected and processed exposure and vulnerability indicators. The database used is at the municipal level.

To ensure a coherent analysis of the parameters, they were normalized to comparable intervals. This normalization process is important so that the different indicators can be combined without distortions, facilitating the interpretation of the results. Normalization allows variables with different units and scales, such as population density, sewage collection index and projected variations in precipitation, to be adjusted to the same relative scale, ranging from 0 to 1, considering the extremes of the national territory. This approach ensures that each parameter contributes in a balanced way to the risk composition.

Thus, the risk index was calculated according to the equation below:

$$Risco\ Climático = (AC_1 . IS_1 . IS_2 \ldots IS_n)^{\left(\frac{1}{n+1}\right)}$$

Where:

- AC_1: Normalized climate threat variable;
- $IS_{1,2 \ldots n}$: Normalized support variable;
- n: Number of support indicators used in the modeling

As a result of this relationship, a climate risk value ranging from 0 to 1 was obtained, which was classified into 5 risk levels, from very low to very high, as presented in Table 5.

This analysis was performed for all municipalities according to the IBGE classification. It is noted that in the State of Rio Grande do Sul, 2 additional municipalities are presented, due to the inclusion of two lagoons in the IBGE coding, Lagoa Mirim and Lagoa dos Patos.

Table 5 - Climate risk modeling classification

Risk Level	Range
Very low	0 – 0.2
Low	0.2 – 0.4
Intermediary	0.4 – 0.6
High	0.6 – 0.8
Very high	0.8 – 1.0

Source: Authors

The ranges defined for each variable used in the study are presented in ANNEX I – Normalization of study variables.

4. Results and Discussion

This section presents the results obtained during the process of identification of climate risks and impacts for the sanitation sector, in addition to the climate risk modeling performed according to the methodology described above.

4.1. Impact Identification

This section presents the results of the identification of impacts associated with each assessed climate threat, and their effects on water and sewage systems.

4.1.1 Water System

For the water supply system, 16 major impacts were identified, 6 for the heat wave threat, 6 for meteorological droughts and 4 for storms. The results are presented according to the stage of the system where the impact occurs (Table 6).

Table 6 – Identification of climate impacts to the Water Supply system

Threat	Stage	Impact	Impact sphere
Heat Waves	Water Source	• **Reduction of water volume** and **increase in pollutant concentration**: Heat waves increase the evaporation of reservoirs, thus reducing the stored volume and increasing the concentration of pollutants, which can make treatment and supply more difficult. • **Cyanobacteria bloom:** Rising temperatures cause cyanobacteria to bloom in water sources, compromising water quality and requiring more complex treatment processes	Sanitation infrastructure / Population
Heat Waves	Water Treatment Plant	• **Infrastructure damage and equipment overload:** Extreme heat accelerates the deterioration of WTP components, such as piping and pumps, and increased equipment use raises overload, leading to mechanical failures and the need for premature replacement. • **Increased energy demand:** During heat waves, increased use of pumping systems can overload the electric system, causing water supply failures.	Sanitation Infrastructure

Heat Waves	Consumption	• **Contamination and spread of diseases:** High temperatures favor the survival and proliferation of pathogens in the supply system, increasing the risk of contamination. • **Increased water demand:** Water consumption increases significantly during periods of extreme heat, which can exceed the capacity of supply systems and cause temporary shortages.	Population
Droughts	Water Source	• **Increase in pollutant concentration:** The reduction of the flow rate of rivers and springs concentrates pollutants, compromising the quality of the water sent to the WTPs. • **Increased demand for groundwater:** Reduced surface water availability may increase dependence on groundwater. • **Conflict over the use of water resources:** In drought-affected regions, competition for water use intensifies.	Sanitation infrastructure / Population
Droughts	Water Treatment Plant	• **Increased operating costs:** The use of alternative water sources during droughts, such as drilling wells or transporting water, increases the operating costs of sanitation companies. • **Reduction in treatment efficiency:** The low water flow rate during dry periods compromises the efficiency of WTPs, which operate below their designed capacity, impairing treatment.	Sanitation infrastructure / Population
Droughts	Consumption	• **Rationing and use of alternative sources:** Rationing can prompt the population to seek alternative and sometimes inadequate sources, increasing the risk of contamination and the spread of diseases.	Sanitation Infrastructure / Population
Storms	Water Source	• **Increased sediment accumulation:** Intense and prolonged storms can increase the amount of sediment carried to springs and reservoirs, thus reducing the storage capacity and making water treatment more difficult.	Sanitation infrastructure
Storms	Water Treatment Plant	• **Physical damage to structures and impediment to water flow:** Storms can cause significant damage to WTPs, pressurization structures, and impact water flow. • **Reduction in treatment efficiency:** WTPs may receive water flows above their design capacity during storms, thus compromising treatment efficiency. • **Power outages:** Storms can cause power failures, affecting the operation of WTPs.	Sanitation infrastructure / Population

Source: Authors, based on literature review and working group discussions.

4.1.2 Sewage System

Considering the sewage system, 9 major impacts were identified, 3 resulting from heat waves, 2 from meteorological droughts and 4 from storms. The impacts were subsequently consolidated according to the modeled risks and the stage of the system where the impact occurs (Table 7).

Table 7 - Consolidated impacts to the Sewage System

Threat	Stage	Impact	Impact sphere
Heat Waves	Effluent generation	• **Increased odor generation:** High temperatures intensify the decomposition of organic matter and the elevated concentration of sewage in the networks can increase the generation of odors, impacting the surrounding population.	Population
Heat waves	Effluent treatment plant	• **Reduction in treatment efficiency and infrastructure overload:** Heat waves can affect the operation of biological treatment units, which depend on specific temperatures, and the greater water consumption can increase the volume of effluent received, thus overloading the designed capacity of the ETPs. • **Physical damage to infrastructure:** High temperatures accelerate the deterioration of pipes and pumping equipment, increasing the maintenance and operating costs of ETPs.	Sanitation Infrastructure
Droughts	Effluent treatment plant	• **Reduction in treatment efficiency:** The reduction in the entry flow at ETPs during dry periods harms the balance of the treatment processes.	Sanitation Infrastructure
Droughts	Discharge	• **Surface water contamination:** Receiving bodies of water will have a lower dilution capacity.	Sanitation Infrastructure
Storms	Effluent generation	• **Surface water contamination:** Intense storms can cause the overflow of canals without sewage collection and treatment networks, with the consequent release of untreated effluents directly into water bodies.	Sanitation Infrastructure / Population

Comentado [OA1]: Acho que seria melhor tirar essa parte, , pq teoricamente com mais calor, teríamos uma melhora na eficiência.

Storms	Effluent treatment plant	• **Physical damage to structures and impediment to sewage flow:** Storms can cause significant damage to sewage treatment plants, pumping stations and discharge lines, making sewage flow more difficult. • **Reduction in treatment efficiency:** ETPs may receive water flows above their design capacity during storms, thus compromising treatment efficiency. • **Power outages:** Storms can cause power failures, affecting the operation of pumps and other equipment of ETPs.	Sanitation Infrastructure

Source: Authors, based on literature review and working group discussions.

4.2. Climate Risk Modeling

This section presents the results of climate modeling, to the water and sewage systems, for each of the climate threats assessed. The risks are presented in climate sheets, followed by tables with the distribution of municipalities in each state, according to the modeled level of climate risk.

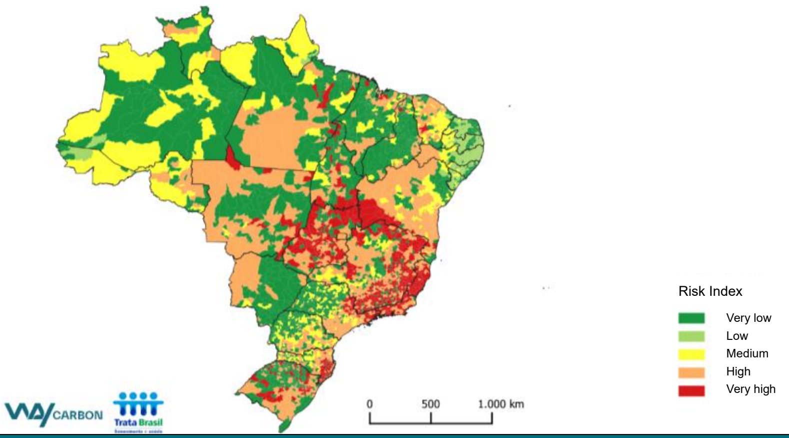
4.2.1. Water Supply System

4.2.1.1. Storms

The climate risks from storms to water supply systems are presented in Tables 8 to 11.

Table 8 – Results of Climate Risk Modeling 1

Climate Threat	Storms
System	Water Supply
System stage	Water Source
System impacts	Increased sediment accumulation
Impact Sphere	Sanitation Infrastructure
Climate Risk Parameters	
Climate Variable	**RX5day** - Maximum precipitation in 5 days
Support Variable	Type of water source (ground, surface or mixed)
Modeling Result	



Discussion

Brazil, with its great climatic and geographic diversity, faces increasing challenges from intense storms, especially with the worsening of climate change. The accumulation of sediments resulting from intense rainfall can compromise the water storage and filtration capacity, affecting the continuity and quality of sanitation services.

The municipalities found to have the highest risk index are those supplied with water exclusively from surface sources, exposed to the effect of sediment accumulation, and those located in regions with a worsening trend of maximum 5 days precipitation in future climate scenarios. The highest risk indices can be observed in Espírito Santo, Rio de Janeiro and Goiás. In addition to these states, the south and southeast regions of Minas Gerais, southwest of Bahia and the coastal region of Santa Catarina also have high risk indices.

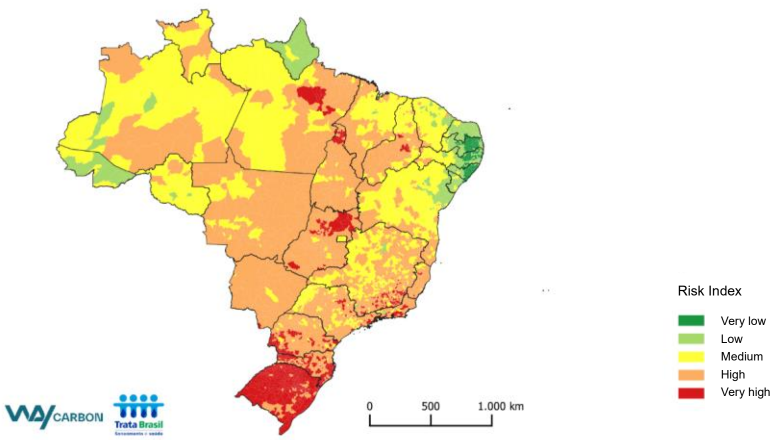
Table 9 – Distribution results of Climate Risk 1 by State

State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
ES	78	0.84	0%	0%	0%	22%	78%
RJ	92	0.66	1%	0%	1%	27%	71%
GO	246	0.64	24%	0%	0%	24%	52%
MG	853	0.60	25%	0%	3%	35%	37%
TO	139	0.26	61%	0%	4%	16%	19%
SC	295	0.51	26%	0%	18%	39%	17%
RS	499	0.28	63%	0%	0%	24%	14%
SP	645	0.32	52%	0%	15%	26%	8%
MT	141	0.40	44%	0%	3%	46%	7%
PA	144	0.19	74%	0%	10%	10%	6%
MA	217	0.18	74%	0%	6%	18%	2%
BA	417	0.53	18%	1%	25%	53%	2%
PI	224	0.17	78%	0%	4%	17%	0%
DF	1	0.75	0%	0%	0%	100%	0%
MS	79	0.15	80%	0%	4%	16%	0%
AL	102	0.23	35%	57%	8%	0%	0%
CE	184	0.43	29%	2%	32%	38%	0%
PB	223	0.29	25%	50%	24%	0%	0%
PE	184	0.34	7%	71%	9%	13%	0%
RN	167	0.22	44%	35%	21%	0%	0%
SE	75	0.26	27%	63%	11%	0%	0%
AC	22	0.22	18%	14%	68%	0%	0%
AM	62	0.21	71%	2%	27%	0%	0%
AP	16	0.34	19%	19%	63%	0%	0%
RO	52	0.42	19%	0%	37%	44%	0%
RR	15	0.27	33%	0%	47%	20%	0%
PR	399	0.26	61%	0%	21%	19%	0%

Table 10 - Results of Climate Risk Modeling 2

Climate Threat	Storms
System	Water Supply
System stage	Water Treatment Plants (WTP)
System impacts	Physical damage to structures and impediment of water flow; Reduction in treatment efficiency; Power outages
Impact Sphere	Sanitation Infrastructure
Climate Risk Parameters	
Climate Variable	**RX1day** - Maximum precipitation in 1 day
Support Variable	Number of WTPs

Modeling Result



Discussion

Brazil faces a growing threat of intense storms with impacts on infrastructure, given the worsening of climate change. Storms can cause significant physical damage to the infrastructure of WTPs, in addition to impacts on operations, such as reduced water treatment efficiency, especially due to damage to facilities or power supply outages.

The municipalities found to have the highest risk indices are those located in regions projected to receive large volumes of maximum 1-day precipitation. With fewer WTPs to guarantee the distribution and proper treatment of water, the population would be more exposed to risks of shortages and loss of quality of the water supplied. There is a notable predominance of very high risk across the state of Rio Grande do Sul, where in May 2024, heavy rains damaged two of the six WTPs in Porto Alegre, forcing them to shut down. Furthermore, Santa Catarina, Paraná, Rio de Janeiro, Goiás and Pará were also found to have regions with a high risk index.

Table 11 – Distribution results of Climate Risk 2 by State

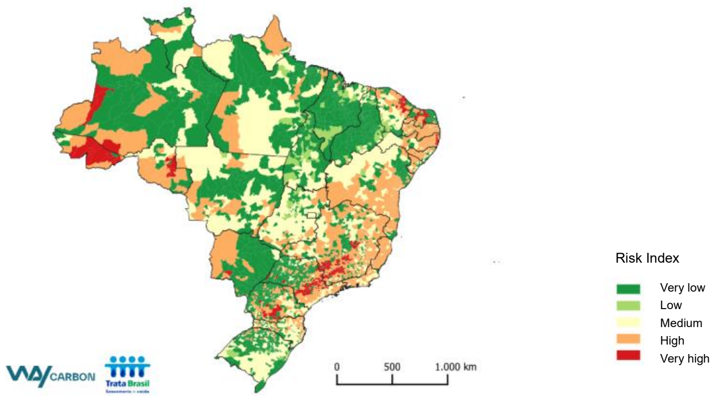
State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
RS	499	0.88	0%	0%	0%	8%	92%
SC	295	0.81	0%	0%	2%	49%	49%
RJ	92	0.72	0%	2%	4%	72%	22%
PR	399	0.74	0%	0%	5%	76%	19%
GO	246	0.73	0%	0%	2%	89%	10%
MG	853	0.67	0%	0%	21%	69%	9%
TO	139	0.69	0%	0%	5%	86%	9%
PA	144	0.64	0%	0%	19%	76%	5%
PI	224	0.62	0%	0%	42%	55%	3%
SP	645	0.66	0%	0%	25%	72%	2%
ES	78	0.70	0%	0%	6%	92%	1%
DF	1	0.58	0%	0%	100%	0%	0%
MS	79	0.70	0%	0%	3%	97%	0%
MT	141	0.66	0%	0%	12%	88%	0%
AL	102	0.21	54%	41%	5%	0%	0%
BA	417	0.51	0%	20%	60%	19%	0%
CE	184	0.49	0%	12%	81%	7%	0%
MA	217	0.58	0%	0%	58%	42%	0%
PB	223	0.24	47%	37%	16%	0%	0%
PE	184	0.28	31%	47%	19%	3%	0%
RN	167	0.29	5%	80%	15%	0%	0%
SE	75	0.32	4%	85%	11%	0%	0%
AC	22	0.46	0%	64%	36%	0%	0%
AM	62	0.55	0%	10%	69%	21%	0%
AP	16	0.69	0%	94%	6%	0%	0%
RO	52	0.49	0%	4%	83%	13%	0%
RR	15	0.64	0%	0%	67%	33%	0%

4.2.1.2. Heat Waves

The climate risks from heat waves to water systems are presented in Tables 12 to 17.

Table 12 – Results of Climate Risk Modeling 3

Climate Threat	Heat Waves
System	Water Supply
System stage	Water Source
System impacts	Reduction of water volume and increase in pollutant concentration; Cyanobacteria bloom
Impact Sphere	Sanitation Infrastructure
Climate Risk Parameters	
Climate Variable	**HW.N** - Number of heat waves recorded in the year
Support Variable	Type of water source (ground, surface or mixed)
Modeling Result	



Discussion	
Brazil is facing an increase in the frequency and intensity of heat waves, with direct consequences for the sanitation sector and the population that depends on the services provided. These events intensify water evaporation, reducing the available volume in water sources and worsening the concentration of pollutants. Heat waves also promote cyanobacteria bloom, which can compromise water quality. The municipalities that showed the highest risk indices are those supplied with water exclusively from surface sources and that are located in regions with a worsening trend of heat wave events. The highest values are found in the interior of São Paulo, southwest of Minas Gerais, coastal region of Pernambuco and some municipalities in the states of Ceará, Rio Grande do Norte, Acre and Amazonas.	

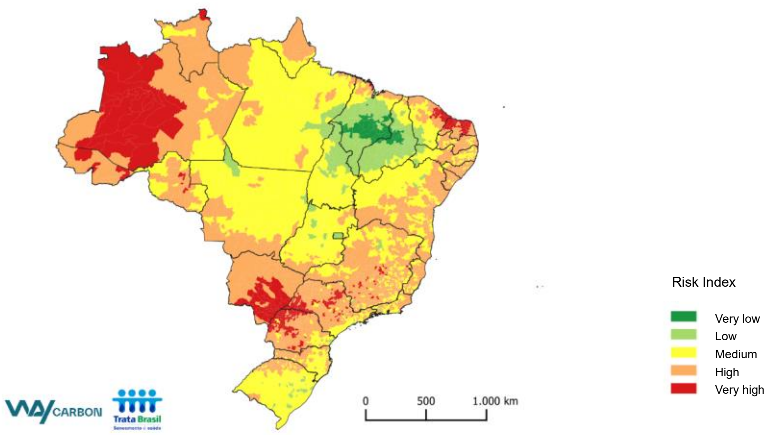
Table 13 – Distribution results of Climate Risk 3 by State

State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
AC	22	0.65	18%	0%	5%	32%	45%
RO	52	0.57	19%	0%	10%	52%	19%
CE	184	0.44	29%	7%	30%	21%	14%
RN	167	0.41	44%	0%	4%	38%	13%
MG	853	0.52	25%	0%	17%	47%	11%
SP	645	0.33	52%	0%	10%	28%	10%
PE	184	0.65	5%	2%	17%	67%	9%
AM	62	0.20	71%	0%	6%	15%	8%
PR	399	0.26	61%	0%	10%	25%	4%
PB	223	0.66	8%	0%	7%	83%	3%
MS	79	0.14	80%	0%	3%	15%	3%
SC	295	0.45	26%	0%	43%	31%	0%
DF	1	0.44	0%	0%	100%	0%	0%
GO	246	0.40	24%	4%	58%	14%	0%
MT	141	0.32	44%	1%	32%	23%	0%
AL	102	0.58	16%	0%	16%	69%	0%
BA	417	0.53	18%	0%	20%	62%	0%
MA	217	0.09	78%	11%	9%	2%	0%
PI	224	0.09	79%	9%	9%	2%	0%
SE	75	0.49	27%	0%	13%	60%	0%
AP	16	0.52	19%	0%	31%	50%	0%
PA	144	0.13	74%	4%	15%	6%	0%
RR	15	0.39	33%	0%	53%	13%	0%
TO	139	0.17	61%	17%	19%	3%	0%
ES	78	0.72	0%	0%	9%	91%	0%
RJ	92	0.63	1%	0%	25%	74%	0%
RS	499	0.19	63%	4%	27%	6%	0%

Table 14 – Results of Climate Risk Modeling 4

Climate Threat	Heat Waves
System	Water Supply
System stage	Water Treatment Plant (WTP)
System impacts	Damage to infrastructure and equipment overload; Increased demand for water and energy
Impact Sphere	Sanitation Infrastructure
Climate Risk Parameters	
Climate Variable	**HW.N** - Number of heat waves recorded in the year
Support Variable	Number of WTPs

Modeling Result



Discussion

The intensification of heat wave events in Brazil also brings relevant challenges to sanitation infrastructures. These events increase the demand for water, which can overload existing infrastructure, increasing energy consumption and putting additional pressure on equipment whose performance may be compromised.

The municipalities that showed the highest risk indices are those located in regions with a worsening trend of heat waves and which have fewer WTPs, as the capacity to respond to increased demand becomes limited. With fewer stations to treat and distribute water, the pressure on the sanitation system is accentuated, posing a greater risk of shortages. The highest risk index values are found in regions such as Amazonas, south of Mato Grosso do Sul, northwest of Paraná and west of São Paulo, Rio Grande do Norte and Ceará.

Table 15 – Distribution results of Climate Risk 4 by State

State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
MS	79	0.79	0%	0%	0%	49%	51%
AM	62	0.75	0%	0%	11%	48%	40%
RN	167	0.77	0%	0%	2%	60%	38%
PR	399	0.74	0%	1%	8%	56%	35%
AC	22	0.77	0%	0%	0%	68%	32%
SP	645	0.71	0%	1%	13%	67%	19%
CE	184	0.63	0%	7%	41%	34%	17%
RO	52	0.68	0%	0%	23%	65%	12%
RR	15	0.67	0%	0%	7%	87%	7%
MG	853	0.66	0%	0%	20%	75%	4%
PB	223	0.66	0%	0%	25%	73%	2%
MA	217	0.35	23%	43%	18%	14%	2%
PE	184	0.61	0%	5%	43%	49%	2%
SC	295	0.61	0%	1%	44%	54%	1%
DF	1	0.36	0%	100%	0%	0%	0%
GO	246	0.52	0%	2%	83%	15%	0%
MT	141	0.55	0%	2%	70%	28%	0%
AL	102	0.67	0%	0%	13%	87%	0%
BA	417	0.62	0%	1%	37%	62%	0%
PI	224	0.34	12%	59%	27%	3%	0%
SE	75	0.67	0%	0%	11%	89%	0%
AP	16	0.62	0%	0%	31%	69%	0%
PA	144	0.52	0%	10%	74%	16%	0%
TO	139	0.41	1%	45%	53%	1%	0%
ES	78	0.64	0%	0%	27%	73%	0%
RJ	92	0.59	0%	2%	47%	51%	0%
RS	499	0.56	0%	4%	64%	31%	0%

Table 16 – Results of Climate Risk Modeling 5

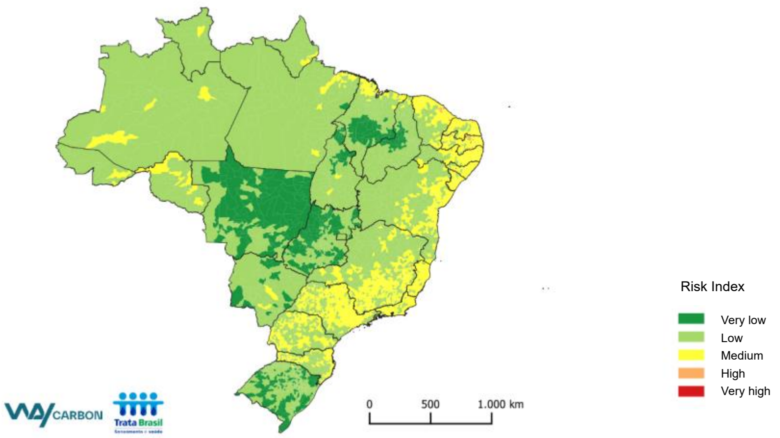
Climate Threat	Heat Waves
System	Water Supply
System stage	Consumption
System impacts	Contamination and spread of diseases; Increased demand for water
Impact Sphere	Sanitation Infrastructure and Society
Climate Risk Parameters	
Climate Variable	**HW.N** - Number of heat waves recorded in the year
Support Variables	Population density; water coverage index; ISHU (Urban Water Security Index)
Modeling Result	
	
Discussion	
Heat waves can pose a growing threat to the sanitation system in Brazil, with direct impacts on water demand and public health. Heat waves can drive the spread of diseases, especially in areas where the water coverage rate is insufficient, population density is high and the Urban Water Security Index (ISHU) is low, which increases the risk of contamination. Although no areas of high or very high risk were identified, in general terms, for the country, the Southeast region had medium risk for São Paulo, Espírito Santo and regions of Minas Gerais and Rio de Janeiro, a large part of the Northeast coast and in areas of the southern states, such as Paraná and Santa Catarina.	

Table 17 – Distribution results of Climate Risk 5 by State

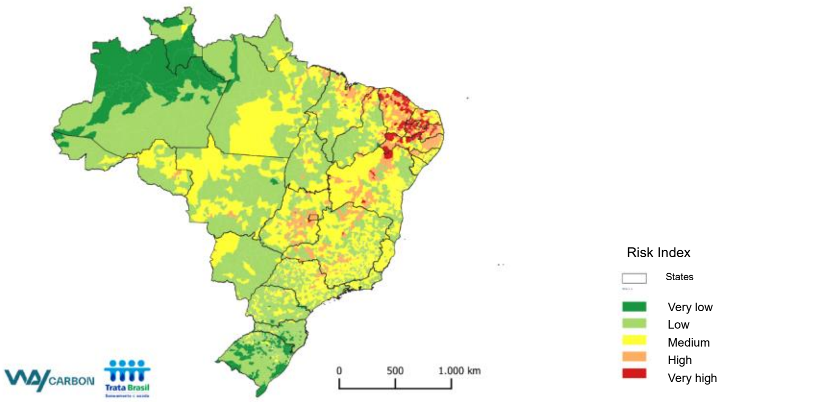
State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
PB	223	0.44	0%	35%	57%	8%	1%
DF	1	0.30	0%	100%	0%	0%	0%
GO	246	0.29	0%	100%	0%	0%	0%
MS	79	0.39	0%	54%	46%	0%	0%
MT	141	0.31	0%	99%	1%	0%	0%
AL	102	0.40	0%	46%	53%	1%	0%
BA	417	0.36	0%	83%	17%	0%	0%
CE	184	0.38	0%	67%	33%	0%	0%
MA	217	0.25	39%	49%	12%	0%	0%
PE	184	0.39	0%	46%	54%	0%	0%
PI	224	0.25	28%	71%	1%	0%	0%
RN	167	0.42	0%	46%	53%	2%	0%
SE	75	0.40	0%	51%	49%	0%	0%
AC	22	0.43	0%	23%	77%	0%	0%
AM	62	0.40	0%	47%	53%	0%	0%
AP	16	0.26	0%	56%	44%	0%	0%
PA	144	0.33	1%	96%	3%	0%	0%
RO	52	0.41	0%	67%	31%	2%	0%
RR	15	0.35	0%	80%	20%	0%	0%
TO	139	0.25	27%	73%	0%	0%	0%
ES	78	0.38	0%	63%	37%	0%	0%
MG	853	0.37	0%	79%	21%	0%	0%
RJ	92	0.38	0%	76%	24%	0%	0%
SP	645	0.36	0%	78%	22%	0%	0%
PR	399	0.35	0%	89%	11%	0%	0%
RS	499	0.30	0%	99%	0%	0%	0%
SC	295	0.34	0%	92%	8%	0%	0%

4.2.1.3. Meteorological Droughts

Climate risks from meteorological droughts are presented in tables 18 to 23.

Table 18 – Results of Climate Risk Modeling 6

Climate Threat	Meteorological Droughts
System	Water Supply
System stage	Water Sources
System impacts	Increased concentration of pollutants; Increased demand for groundwater; Conflict over the use of water resources
Impact Sphere	Sanitation Infrastructure
Climate Risk Parameters	
Climate Variable	**CDD** – Consecutive days without rain in the year
Support Variables	Type of water source (ground, surface or mixed); Population density
Modeling Result	



Discussion

Droughts pose major challenges for the sanitation sector in Brazil, such as the reduction of the water volume in water sources, which can increase the concentration of pollutants and compromise water quality, requiring more complex and costly treatments.

In addition to operational impacts, droughts worsened by climate change directly affect the population, which faces supply restrictions and, in some situations, possible health crises. On the other hand, increased dependence on groundwater during dry periods can lead to depletion and have negative impact on water security.

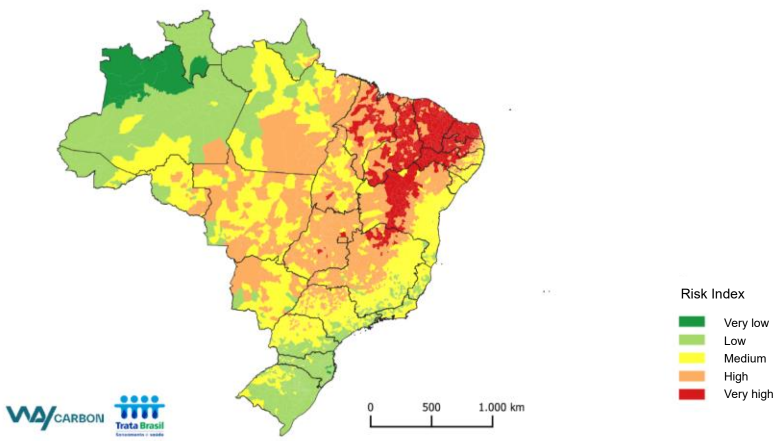
The municipalities with the highest risk indices are those with a worsening trend of consecutive days without rain, supplied by surface water sources and located in regions with high population density, particularly states in the Northeast region.

Table 19 – Distribution results of Climate Risk 6 by State

State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
PB	223	0.75	0%	0%	15%	43%	40%
RN	167	0.68	1%	0%	44%	19%	36%
CE	184	0.71	0%	0%	32%	35%	33%
PE	184	0.67	0%	0%	20%	62%	16%
PI	224	0.45	0%	0%	46%	10%	4%
MA	217	0.48	0%	0%	52%	15%	2%
BA	417	0.49	0%	0%	57%	15%	2%
GO	246	0.52	0%	0%	36%	34%	2%
MG	853	0.44	0%	0%	52%	9%	0%
DF	1	0.67	0%	0%	0%	100%	0%
MS	79	0.30	0%	0%	11%	1%	0%
MT	141	0.37	1%	0%	43%	2%	0%
AL	102	0.52	0%	0%	61%	24%	0%
SE	75	0.47	0%	0%	73%	0%	0%
AC	22	0.33	14%	0%	14%	0%	0%
AM	62	0.20	55%	0%	0%	0%	0%
AP	16	0.37	0%	0%	31%	0%	0%
PA	144	0.39	2%	0%	42%	6%	0%
RO	52	0.40	0%	0%	56%	4%	0%
RR	15	0.22	47%	0%	7%	0%	0%
TO	139	0.38	0%	0%	35%	4%	0%
ES	78	0.44	0%	0%	90%	0%	0%
RJ	92	0.44	0%	0%	74%	0%	0%
SP	645	0.41	0%	0%	47%	2%	0%
PR	399	0.34	2%	0%	21%	1%	0%
RS	499	0.25	26%	0%	5%	0%	0%
SC	295	0.30	9%	0%	4%	0%	0%

Table 20 – Results of Climate Risk Modeling 7

Climate Threat	Meteorological Droughts
System	Water Supply
System stage	Water Treatment Plants (WTP)
System impacts	Increased operating costs; Reduced treatment efficiency
Impact Sphere	Sanitation infrastructure/Society
Climate Risk Parameters	
Climate Variable	**CDD** – Consecutive days without rain in the year
Support Variables	ANA Qualitative Balance; Number of WTPs
Modeling Result	



Discussion

In Brazil, droughts also pose an increasing risk to sanitation infrastructures, such as WTPs. Long periods of drought, especially in areas with poor qualitative balance, can affect harvesting volumes and compromise the quality of water that reaches the treatment stations, increasing operating costs. Regions with fewer WTPs or with already overloaded treatment systems may face even greater risks, due to the lack of alternatives for load redistribution or water supply.

The highlighted areas with the highest level of risk are those that show a worsening trend of periods with no rainfall, with poor qualitative water balance and that have a smaller number of WTPs. There is a concentration of municipalities with very high risk in the *agreste* and *sertão* regions in the Northeast, and specially in the states of Paraíba, Rio Grande do Norte, Ceará, Piauí, and Bahia. The effect is reduced in the Zona da Mata region, close to the coast. Some municipalities with high risk also stand out in Goiás, Mato Grosso and, Mato Grosso do Sul, northern Minas Gerais, Tocantins, and Pará.

Table 21 – Distribution results of Climate Risk 7 by State

State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
RN	167	0.88	0%	0%	1%	16%	83%
CE	184	0.87	0%	0%	3%	21%	76%
PB	223	0.78	0%	0%	8%	48%	44%
PI	224	0.70	0%	0%	30%	50%	20%
PE	184	0.65	0%	2%	40%	47%	11%
BA	417	0.55	0%	8%	65%	16%	11%
MA	217	0.65	0%	0%	34%	59%	7%
PA	144	0.47	0%	20%	65%	13%	1%
MG	853	0.43	0%	42%	50%	7%	1%
DF	1	0.63	0%	0%	0%	100%	0%
GO	246	0.54	0%	1%	72%	26%	0%
MS	79	0.42	0%	54%	39%	6%	0%
MT	141	0.44	0%	17%	81%	2%	0%
AL	102	0.54	0%	2%	80%	18%	0%
SE	75	0.53	0%	4%	95%	1%	0%
AC	22	0.33	0%	100%	0%	0%	0%
AM	62	0.28	13%	82%	5%	0%	0%
AP	16	0.37	0%	69%	31%	0%	0%
RO	52	0.41	0%	42%	56%	2%	0%
RR	15	0.26	7%	93%	0%	0%	0%
TO	139	0.49	0%	0%	95%	5%	0%
ES	78	0.34	0%	79%	21%	0%	0%
RJ	92	0.37	0%	67%	33%	0%	0%
SP	645	0.45	0%	34%	60%	6%	0%
PR	399	0.40	0%	50%	50%	0%	0%
RS	499	0.30	2%	95%	3%	0%	0%
SC	295	0.28	11%	89%	0%	0%	0%

Table 22 – Results of Climate Risk Modeling 8

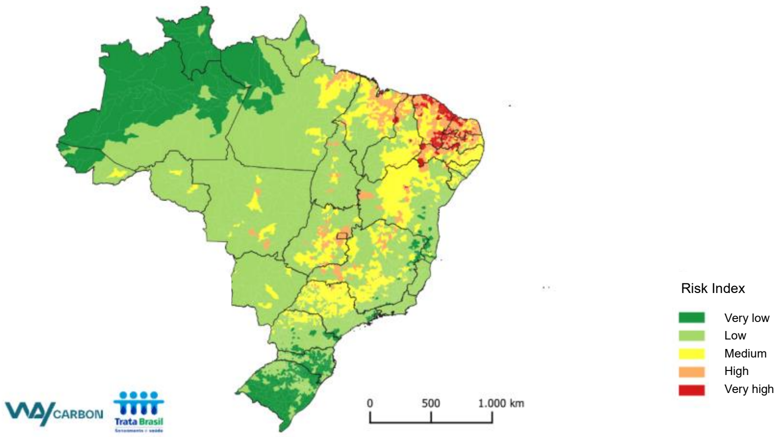
Climate Threat	Meteorological Droughts
System	Water Supply
System stage	Consumption
System impacts	Rationing and use of alternative sources
Impact Sphere	Society
Climate Risk Parameters	
Climate Variable	**CDD** – Consecutive days without rain in the year
Support Variables	Demographic Density
Modeling Result	
	
Discussion	
In Brazil, droughts directly impact the water supply for the population in certain regions of Brazil. In cases of prolonged drought, some regions may experience rationing or have to resort to alternative water sources, such as drilling wells or transporting water from increasingly distant regions. The impact on the population often translates into limited access to drinking water, which can result in risks to health and general well-being. The areas highlighted with the highest risk index are those that combine worsening of consecutive days without rain with high population densities. There is a notable concentration of very high risk areas in the Northeast region, such as in the interior of Pernambuco, Paraíba, Rio Grande do Norte, and Ceará, in addition to municipalities with medium and high risk in Minas Gerais, Bahia, Goiás, São Paulo, Tocantins, Pará, and the Federal District.	

Table 23 – Distribution results of Climate Risk 8 by State

State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
CE	184	0.78	0%	0%	13%	39%	49%
RN	167	0.74	0%	0%	9%	59%	32%
PB	223	0.70	0%	2%	24%	51%	24%
PE	184	0.59	0%	1%	69%	21%	9%
PI	224	0.52	0%	29%	46%	21%	4%
MA	217	0.55	0%	19%	41%	37%	3%
BA	417	0.39	3%	62%	29%	5%	0%
DF	1	0.78	0%	0%	0%	100%	0%
GO	246	0.47	0%	47%	33%	20%	0%
MS	79	0.29	0%	91%	9%	0%	0%
MT	141	0.32	0%	90%	7%	3%	0%
AL	102	0.44	0%	25%	73%	2%	0%
SE	75	0.40	0%	47%	53%	0%	0%
AC	22	0.22	32%	64%	5%	0%	0%
AM	62	0.16	76%	24%	0%	0%	0%
AP	16	0.27	6%	81%	13%	0%	0%
PA	144	0.42	8%	44%	26%	21%	0%
RO	52	0.30	0%	94%	6%	0%	0%
RR	15	0.16	93%	7%	0%	0%	0%
TO	139	0.37	0%	83%	11%	6%	0%
ES	78	0.31	0%	100%	0%	0%	0%
MG	853	0.37	2%	67%	28%	3%	0%
RJ	92	0.32	0%	100%	0%	0%	0%
SP	645	0.41	2%	49%	48%	1%	0%
PR	399	0.33	6%	74%	20%	0%	0%
RS	499	0.20	47%	53%	0%	0%	0%
SC	295	0.21	37%	63%	0%	0%	0%

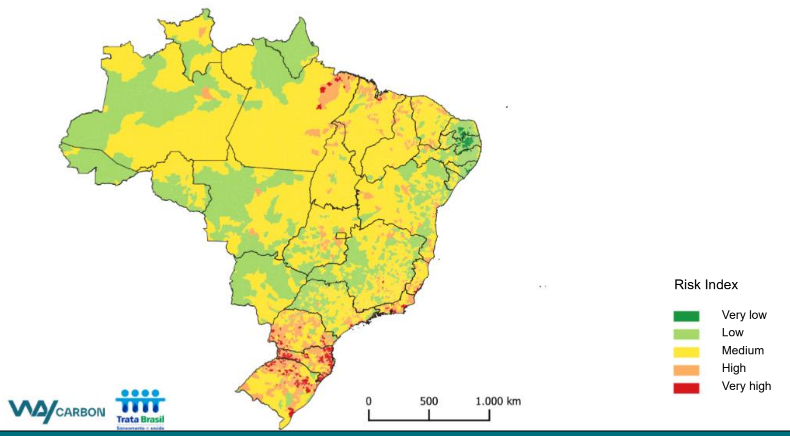
4.2.2. Sewer System

4.2.2.1. Storms

The climate risks from storms to sewage systems are presented in Tables 24 to 27.

Table 24 - Results of Climate Risk Modeling 9

Climate Threat	Storms
System	Sanitary sewer
System stage	Generation of raw effluent
System impacts	Surface water contamination
Impact Sphere	Sanitation infrastructure; Population
Climate Risk Parameters	
Climate Variable	**RX1day** - Maximum precipitation in 1 day
Support Variable	Sewage collection index; Population density
Modeling Result	



Discussion	
Intense storms also present a challenge to the country's sewage systems. These rains concentrated in a single day intensify the risk of overloading sewage systems, especially in areas where collection rates are insufficient. The sudden accumulation of water in the networks can result in the overflow of raw effluents, contaminating watercourses and negatively impacting local ecosystems and the population's quality of life. The municipalities found to have the highest risk indices are those with high population density, lower sewage collection rates and that are located in regions with worsening trend of maximum rainfall in a single day. It is possible to observe a medium-risk patch that extends across a large part of the country, however, the highest indices are concentrated in the states of the South region, mainly Rio Grande do Sul and Santa Catarina, in addition to part of the states of Rio de Janeiro and Pará.	

Table 25 – Distribution results of Climate Risk 9 by State

State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
SC	295	0.76	0%	1%	12%	46%	42%
RS	499	0.70	0%	2%	20%	57%	21%
RJ	92	0.62	0%	0%	48%	39%	13%
PA	144	0.57	0%	6%	53%	33%	8%
PR	399	0.64	0%	2%	31%	59%	7%
ES	78	0.57	0%	3%	62%	32%	4%
MA	217	0.55	0%	1%	69%	29%	1%
SP	645	0.44	0%	37%	53%	9%	1%
MG	853	0.45	0%	29%	63%	8%	0%
DF	1	0.46	0%	0%	100%	0%	0%
GO	246	0.50	0%	16%	63%	21%	0%
MS	79	0.45	0%	41%	53%	6%	0%
MT	141	0.41	0%	47%	51%	2%	0%
AL	102	0.33	11%	66%	24%	0%	0%
BA	417	0.46	0%	31%	58%	11%	0%
CE	184	0.53	0%	7%	70%	24%	0%
PB	223	0.30	23%	52%	24%	0%	0%
PE	184	0.35	2%	74%	21%	3%	0%
PI	224	0.51	0%	3%	78%	19%	0%
RN	167	0.36	6%	63%	30%	1%	0%
SE	75	0.39	0%	53%	47%	0%	0%
AC	22	0.34	0%	91%	9%	0%	0%
AM	62	0.40	0%	55%	44%	2%	0%
AP	16	0.30	0%	88%	13%	0%	0%
RO	52	0.42	0%	42%	58%	0%	0%
RR	15	0.44	0%	20%	73%	7%	0%
TO	139	0.50	0%	1%	86%	13%	0%

Table 26 - Results of Climate Risk Modeling 10

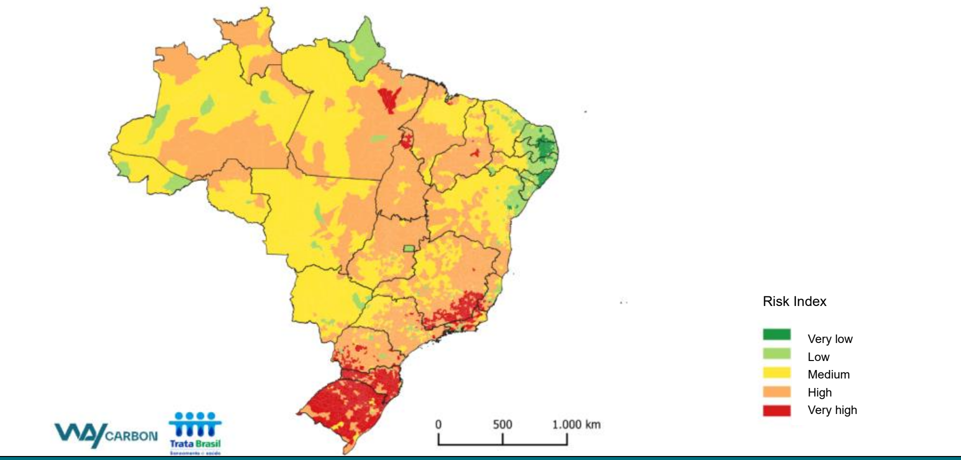
Climate Threat	Storms
System	Sanitary sewer
System stage	Effluent Treatment Plant
System impacts	Physical damage to structures; reduction in treatment efficiency; power outages.
Impact Sphere	Population
Climate Risk Parameters	
Climate Variable	**RX1day** - Maximum precipitation in 1 day
Support Variable	Number of ETPs
Modeling Result	
	
Discussion	
Storms worsened by climate change also create challenges for ETPs. In these events, overload and damage to ETPs can result in lower quality effluent treatment, with potential impact on the quality of local water bodies and public health. Regions with fewer ETPs or with already overloaded treatment systems may face greater risks due to the lack of alternatives for responding to extreme events. The municipalities that showed the highest risk indices are those that have fewer ETPs and that are located in regions with a worsening trend of maximum precipitation events in 1 day in future climate scenarios. There is a high-risk patch extending across Brazil, with the highest indices concentrated in the southern region, especially in the states of Rio Grande do Sul and Santa Catarina, in addition to the south and southeast regions of Minas Gerais and part of the state of Rio de Janeiro.	

Table 27 – Distribution results of Climate Risk 10 by State

State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
RS	499	0.85	0%	0%	2%	12%	86%
SC	295	0.84	0%	1%	1%	15%	83%
RJ	92	0.74	0%	8%	4%	45%	43%
MG	853	0.72	0%	1%	11%	60%	28%
ES	78	0.66	0%	12%	10%	59%	19%
PR	399	0.72	0%	1%	5%	75%	19%
TO	139	0.71	0%	0%	4%	88%	9%
PA	144	0.68	0%	1%	16%	77%	6%
PI	224	0.62	0%	0%	36%	61%	3%
SP	645	0.62	0%	2%	32%	64%	2%
MA	217	0.59	0%	0%	54%	45%	1%
DF	1	0.31	0%	100%	0%	0%	0%
GO	246	0.65	0%	0%	20%	80%	0%
MS	79	0.53	0%	4%	75%	22%	0%
MT	141	0.55	0%	2%	70%	28%	0%
AL	102	0.22	50%	43%	7%	0%	0%
BA	417	0.52	0%	18%	50%	31%	0%
CE	184	0.48	1%	14%	80%	5%	0%
PB	223	0.26	39%	41%	21%	0%	0%
PE	184	0.31	11%	65%	18%	5%	0%
RN	167	0.28	14%	72%	14%	0%	0%
SE	75	0.30	4%	87%	9%	0%	0%
AC	22	0.41	0%	45%	55%	0%	0%
AM	62	0.53	0%	10%	68%	23%	0%
AP	16	0.33	0%	94%	6%	0%	0%
RO	52	0.55	0%	2%	77%	21%	0%
RR	15	0.63	0%	0%	33%	67%	0%

4.2.2.2. Heat waves

The climate risks from heat waves to sewage systems are presented in Tables 28 to 31.

Table 28 - Results of Climate Risk Modeling 11

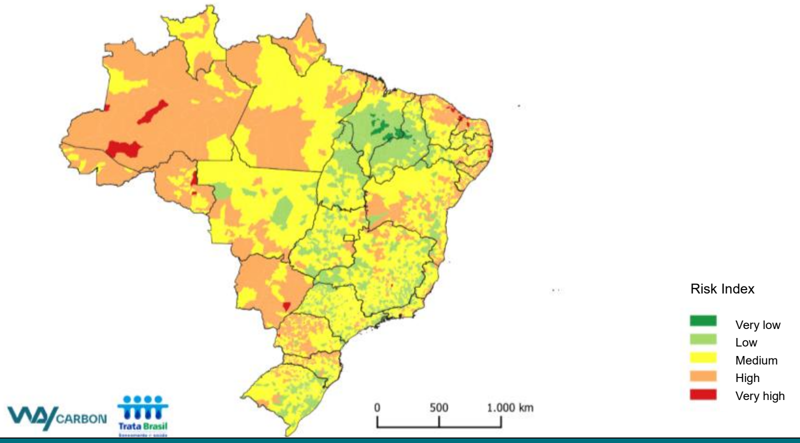
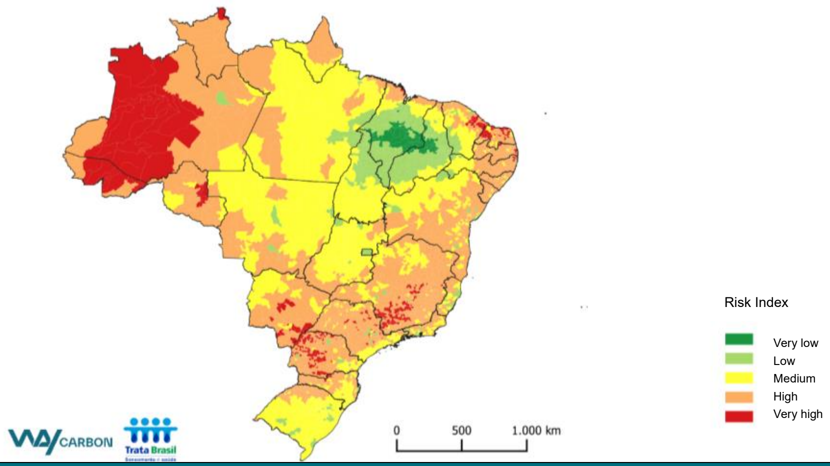
Climate Threat	Heat waves
System	Sanitary sewer
System stage	Effluent generation
System impacts	Increased odor generation
Impact Sphere	Population
Climate Risk Parameters	
Climate Variable	**HW.N** - Number of heat waves recorded in the year
Support Variable	Sewage load generated; Sewage collection index
Modeling Result	
	
Discussion	
Heat waves in Brazil also pose risks to the sewage system, with direct effects on the population. After heat wave events, the accelerated decomposition of organic matter in effluents generates a significant increase in the release of odors, which can directly impact the population's quality of life, especially in areas with a high sewage load and insufficient collection indices. The municipalities found to have the highest risk indices are those with the highest sewage load, lowest sewage collection rates and that are located in regions with a worsening trend of heat waves. There is a notable predominance of high and very high risk in the northern region, especially in the state of Amazonas. Furthermore, other states in the country stand out, such as Ceará, Rio Grande do Norte, Alagoas, Sergipe, Mato Grosso do Sul, and Paraná.	

Table 29 – Distribution results of Climate Risk 11 by State

State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
CE	184	0.58	0%	9%	49%	36%	6%
PE	184	0.54	0%	14%	58%	23%	5%
AM	62	0.69	0%	0%	13%	82%	5%
RO	52	0.60	0%	0%	40%	56%	4%
RN	167	0.58	0%	6%	47%	44%	2%
PB	223	0.51	0%	17%	63%	19%	1%
MS	79	0.67	0%	0%	20%	78%	1%
PR	399	0.58	0%	2%	49%	49%	1%
MG	853	0.42	0%	45%	50%	6%	0%
DF	1	0.40	0%	0%	100%	0%	0%
GO	246	0.46	0%	34%	60%	7%	0%
MT	141	0.52	0%	9%	73%	18%	0%
AL	102	0.60	0%	5%	39%	56%	0%
BA	417	0.53	0%	13%	59%	29%	0%
MA	217	0.39	8%	48%	33%	11%	0%
PI	224	0.33	5%	72%	21%	2%	0%
SE	75	0.56	0%	5%	59%	36%	0%
AC	22	0.67	0%	0%	23%	77%	0%
AP	16	0.60	0%	0%	44%	56%	0%
PA	144	0.55	0%	6%	69%	25%	0%
RR	15	0.57	0%	0%	73%	27%	0%
TO	139	0.38	0%	66%	34%	0%	0%
ES	78	0.49	0%	23%	60%	17%	0%
RJ	92	0.49	0%	25%	63%	12%	0%
SP	645	0.42	0%	36%	60%	4%	0%
RS	499	0.45	0%	28%	67%	5%	0%
SC	295	0.53	0%	8%	66%	26%	0%

Table 30 - Results of Climate Risk Modeling 12

Climate Threat	Heat waves
System	Sanitary sewer
System stage	Effluent treatment plant
System impacts	Reduced treatment efficiency and overloading of infrastructure; physical damage to infrastructure
Impact Sphere	Population
Climate Risk Parameters	
Climate Variable	**HW.N** - Number of heat waves recorded in the year
Support Variable	Number of ETPs
Modeling Result	



Discussion

Heat waves in Brazil, aggravated by the effects of climate change, pose direct challenges to the operation of ETPs. In these high temperature events, the higher water consumption by the population generates a larger volume of effluents to be processed, and the plants may suffer with lower treatment efficiency due to overload. The physical wear and tear of equipment and infrastructure due to high temperatures can also lead to the need for more frequent maintenance and increased costs.

The municipalities that showed the highest risk indices are those with fewer effluent treatment plants and that are located in regions where there are more heat waves per year. There is a notable predominance of high risk in much of Brazil, but there is a concentration of very high risk areas in parts of Amazonas, Santa Catarina, Mato Grosso do Sul, Minas Gerais, Rio Grande do Norte, and Ceará.

Table 31 – Distribution results of Climate Risk 12 by State

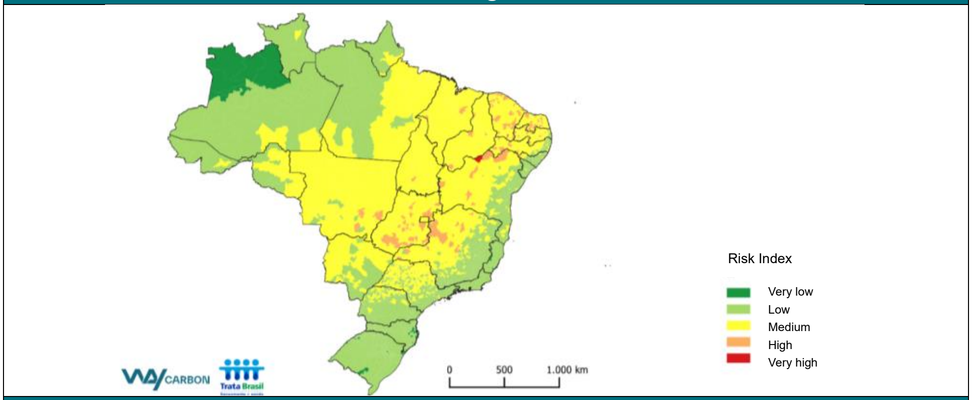
State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
AC	22	0.80	0%	0%	0%	45%	55%
AM	62	0.75	0%	2%	6%	48%	44%
PR	399	0.73	0%	1%	9%	64%	26%
RN	167	0.74	0%	1%	9%	65%	25%
MS	79	0.72	0%	0%	10%	67%	23%
RO	52	0.70	0%	0%	6%	75%	19%
CE	184	0.60	0%	11%	41%	36%	13%
MG	853	0.71	0%	1%	8%	79%	12%
RR	15	0.71	0%	0%	0%	93%	7%
PE	184	0.68	0%	4%	14%	77%	5%
PB	223	0.72	0%	0%	5%	91%	4%
SP	645	0.67	0%	1%	14%	81%	4%
MA	217	0.36	22%	41%	20%	15%	2%
SC	295	0.64	0%	1%	35%	62%	1%
DF	1	0.25	0%	100%	0%	0%	0%
GO	246	0.54	0%	1%	78%	20%	0%
MT	141	0.57	0%	3%	60%	38%	0%
AL	102	0.70	0%	1%	7%	92%	0%
BA	417	0.63	0%	2%	25%	73%	0%
PI	224	0.35	12%	55%	29%	4%	0%
SE	75	0.68	0%	0%	7%	93%	0%
AP	16	0.65	0%	0%	31%	69%	0%
PA	144	0.53	0%	11%	70%	19%	0%
TO	139	0.41	1%	44%	52%	3%	0%
ES	78	0.61	0%	12%	26%	63%	0%
RJ	92	0.60	0%	9%	28%	63%	0%
RS	499	0.57	0%	3%	63%	34%	0%

4.2.2.3. Meteorological Droughts

The climate risks from meteorological droughts to sewage systems are presented in Tables 32 to 35.

Table 32 - Results of Climate Risk Modeling 13

Climate Threat	Meteorological droughts
System	Sanitary sewer
System stage	Effluent treatment plant
System impacts	Reduction in treatment efficiency
Impact Sphere	Population
Climate Risk Parameters	
Climate Variable	**CDD** – Consecutive days without rain in the year
Support Variable	Sewage load generated; Number of ETPs
Modeling Result	



Discussion

In the Brazilian context, the intensification of drought periods can compromise the quality and availability of water resources used to dilute and treat discharged effluents. These dry periods may require operational adjustments and a reduction in the efficiency of ETPs. In regions with higher sewage load and an insufficient number of ETPs, the population may be affected by increased contamination of watercourses and possible public health problems.

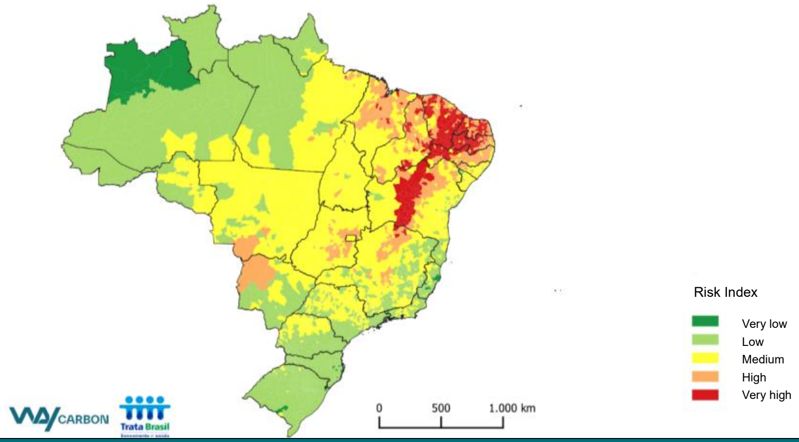
The municipalities found to have the highest risk indices are those with the highest sewage load, the lowest number of ETPs and that are located in regions with a worsening trend of drought periods. There is a notable predominance of medium to high risk in the central region of the country, especially in the northwest of Minas Gerais, Goiás, northwest of Bahia, Ceará, and Rio Grande do Norte.

Table 33 – Distribution results of Climate Risk 13 by State

State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
CE	184	0.56	0%	0%	81%	18%	1%
BA	417	0.40	0%	58%	40%	2%	0%
DF	1	0.50	0%	0%	100%	0%	0%
GO	246	0.52	0%	0%	89%	11%	0%
MS	79	0.39	0%	58%	42%	0%	0%
MT	141	0.46	0%	6%	92%	2%	0%
AL	102	0.35	0%	86%	13%	1%	0%
MA	217	0.50	0%	0%	99%	1%	0%
PB	223	0.52	0%	6%	90%	4%	0%
PE	184	0.45	0%	38%	59%	3%	0%
PI	224	0.54	0%	0%	98%	2%	0%
RN	167	0.55	0%	1%	88%	11%	0%
SE	75	0.34	0%	99%	1%	0%	0%
AC	22	0.35	0%	95%	5%	0%	0%
AM	62	0.27	0%	82%	5%	0%	0%
AP	16	0.40	0%	63%	38%	0%	0%
PA	144	0.44	0%	18%	82%	0%	0%
RO	52	0.41	0%	23%	77%	0%	0%
RR	15	0.28	0%	93%	7%	0%	0%
TO	139	0.48	0%	0%	99%	1%	0%
ES	78	0.29	0%	96%	0%	0%	0%
MG	853	0.38	0%	66%	33%	1%	0%
RJ	92	0.30	0%	99%	0%	0%	0%
SP	645	0.40	0%	52%	48%	0%	0%
PR	399	0.34	0%	85%	15%	0%	0%
RS	499	0.25	0%	98%	0%	0%	0%
SC	295	0.24	0%	93%	0%	0%	0%

Table 34 - Results of Climate Risk Modeling 14

Climate Risk 14	
Climate Threat	Meteorological droughts
System	Sanitary sewer
System stage	Discharge
System impacts	Surface water contamination
Impact Sphere	Population
Climate Risk Parameters	
Climate Variable	**CDD** – Consecutive days without rain in the year
Support Variable	ANA Qualitative Balance; Number of ETPs
Modeling Result	



Discussion
Prolonged droughts are a critical challenge for the sanitation sector in Brazil, also affecting the population's quality of life. In these events, the flow of rivers and bodies of water may be reduced, impairing their dilution capacity and increasing the concentration of pollutants in surface waters. The risk of contamination and environmental degradation is even greater in areas where the qualitative water balance is already unfavorable and where treatment infrastructure is limited, with an insufficient number of ETPs. The municipalities found to have the highest risk indices are those with the worst qualitative balance, the fewer ETPs and that are located in regions with more consecutive days without rain. There is a notable predominance of high risk areas in the central region of the country, especially in the Pantanal, in addition to municipalities in Goiás, northern Minas Gerais, Maranhão, and Piauí. However, the predominance of municipalities with very high risk occurs in the states of Bahia, Ceará, Rio Grande do Norte, Paraíba, and Pernambuco.

Table 35 – Distribution results of Climate Risk 14 by State

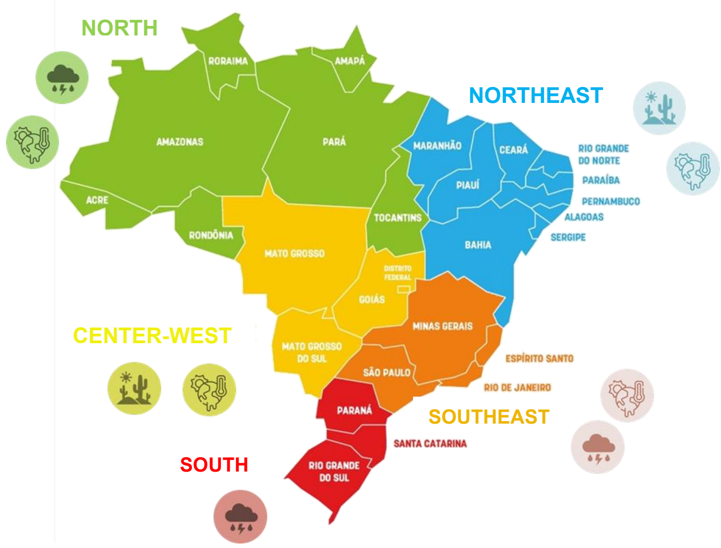
State	Number of municipalities	Average Risk Index	Percentage of municipalities at risk in the State				
			Very Low	Low	Medium	High	Very high
CE	184	0.85	0%	0%	5%	23%	72%
RN	167	0.85	0%	0%	2%	27%	71%
PB	223	0.83	0%	0%	5%	31%	64%
PI	224	0.70	0%	0%	30%	46%	24%
PE	184	0.69	0%	2%	16%	61%	21%
BA	417	0.56	0%	9%	62%	15%	13%
MA	217	0.66	0%	0%	30%	63%	7%
PA	144	0.47	0%	18%	68%	13%	1%
MG	853	0.45	0%	32%	59%	8%	1%
DF	1	0.50	0%	0%	100%	0%	0%
GO	246	0.55	0%	0%	70%	30%	0%
MS	79	0.40	0%	63%	29%	8%	0%
MT	141	0.45	0%	9%	88%	3%	0%
AL	102	0.56	0%	3%	69%	28%	0%
SE	75	0.54	0%	4%	95%	1%	0%
AC	22	0.34	0%	100%	0%	0%	0%
AM	62	0.28	13%	82%	5%	0%	0%
AP	16	0.39	0%	69%	31%	0%	0%
RO	52	0.42	0%	23%	75%	2%	0%
RR	15	0.27	0%	100%	0%	0%	0%
TO	139	0.49	0%	1%	95%	4%	0%
ES	78	0.32	4%	78%	18%	0%	0%
RJ	92	0.37	2%	52%	46%	0%	0%
SP	645	0.43	0%	37%	62%	1%	0%
PR	399	0.40	0%	51%	49%	0%	0%
RS	499	0.31	1%	95%	4%	0%	0%
SC	295	0.29	4%	96%	0%	0%	0%

5. Conclusions

The study of climate risks to the sanitation sector in Brazil reveals a situation that requires attention and adaptation in the face of climate change, especially in regions that already face social, environmental and sanitation infrastructure vulnerabilities.

The IPCC climate scenarios indicate that the country will be increasingly impacted by heatwave events, prolonged droughts and heavy storms, which put at risk the efficiency of water supply and sanitation systems and, consequently, the health and water security of the population. According to the results presented, some climate threats stand out in each region of the country, highlighted in Figure 9.

Figure 9 - Main climate threats to the sanitation sector in Brazil by region



In prolonged droughts, there is a reduction in the quantity and quality of available water, which overloads the harvesting and treatment systems and can increase risks to the population. In heat wave events, the effects can be aggravated by increased water demand and evaporation losses in water sources, with risks of rationing or limited access to basic sanitation services by the population. During storms, water resources are more likely to be contaminated, which can increase the incidence of waterborne diseases; in addition to overloading treatment plants and distribution infrastructure, with the risk of interruption of these services.

To address climate risks, both public authorities and sanitation companies need to adopt climate adaptation strategies. Actions that reduce risks include strengthening the water harvesting infrastructure and water and sewage treatment, modernizing water quality monitoring and control systems, and investing in technology, such as reuse, contributing to the diversification of water sources. Furthermore, public policies that promote the integrated and sustainable management of water resources and encourage water conservation and reuse practices are essential to mitigate the impacts of climate change and guarantee water security for the population.

6. References

BRANDS, S.; HERRERA, S.; SAN-MARTÍN, D.; GUTIÉRREZ, J. M. Validation of the ENSEMBLES global climate models over southwestern Europe using probability density functions, from a downscaling perspective. Climate Research, v. 48, n. 2-3, p. 145-161, 2011.

EYRING, V. et al. Taking climate model evaluation to the next level. Nature Climate Change, v. 9, n. 2, p. 102–110, jan. 2019. Available at: ⟨https://doi.org/10.1038/s41558-018-0355-y⟩.

HERGER, N. et al. Selecting a climate model subset to optimize key ensemble properties. Earth System Dynamics, v. 9, n. 1, p. 135–151, fev. 2018. Available at: ⟨https://doi.org/10.5194/esd-9-135-2018⟩.

HERSBACH, H. et al. The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, v. 146, n. 730, p. 1999-2049, 2020.

IPCC. Climate Change 2021: The Physical Science Basis. Cambridge: Cambridge University Press, 2021.

IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Cambridge: Cambridge University Press, 2022. 3-33 p. (Summary for Policymakers). ISBN 9781009325844.

MCAVANEY, B. J. et al. Model evaluation. In: Climate change 2001: the scientific basis. Contribution of WG1 to the third assessment report of the IPCC (TAR). Cambridge: Cambridge University Press, 2001. p. 471-523.

MORADIAN, S.; AKBARI, M.; IGLESIAS, G. Optimized hybrid ensemble technique for CMIP6 wind data projections under different climate-change scenarios. Case study: United Kingdom. Science of The Total Environment, v. 826, p. 154124, jun. 2022. Available at: ⟨https://doi.org/10.1016/j.scitotenv.2022.154124⟩.

PAREDES-TREJO, F. J.; BARBOSA, H.; KUMAR, T. L. Validating CHIRPS-based satellite precipitation estimates in Northeast Brazil. Journal of Arid Environments, v. 139, p. 26–40, abr. 2017. Available at: ⟨https://doi.org/10.1016/j.jaridenv.2016.12.009⟩.

STAINFORTH, D. A. et al. Issues in the interpretation of climate model ensembles to inform decisions. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, v. 365, n. 1857, p. 2163–2177, jun. 2007. Available at: ⟨https://doi.org/10.1098/rsta.2007.2073⟩.

STOTT, P. A.; FOREST, C. E. Ensemble climate predictions using climate models and observational constraints. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, v. 365, n. 1857, p. 2029–2052, jun. 2007. Available at: ⟨https://doi.org/10.1098/rsta.2007.2075⟩.

THRASHER, B. et al. NASA global daily downscaled projections, CMIP6. Scientific Data, v. 9, n. 1, jun. 2022. Available at: ⟨https://doi.org/10.1038/s41597-022-01393-4⟩.

ANNEX I – Normalization of study variables

The water supply index was classified considering that higher coverage represents lower risks (Table 36).

Table 36 - Classification of Water Supply Index Ranges

Range	Risk
0 – 20%	1.0
20% - 40%	0.8
40% - 60%	0.6
60% - 80%	0.4
80% - 100%	0.2

Source: Authors

Regarding the urban water security index, the higher the index, the lower the risk (Table 37).

Table 37 – ISHU Classification

Value	Risk
Maximum	0.2
High	0.4
Medium	0.6
Low	0.8
Minimum	1.0

Source: Authors.

The idea of assessing the number of Water Treatment Plants is related to the capacity that the municipality would have to deal with extreme events, without interrupting the service completely, therefore, those municipalities with a larger number of WTPs would have a lower associated risk (Table 38).

Table 38 - Classification of the number of WTPs

Range	Risk
0	1.0
1	0.8
2 – 4	0.6
4 – 8	0.4
8 - maximum	0.2

Source: Authors.

The classification of the supply source varied according to the impact being analyzed. For the risk of cyanobacteria bloom, value zero was adopted for ground sources, due to the impossibility of cyanobacteria blooming in groundwater (Table 39). On the other hand, for other impacts the value adopted for groundwater was not zero (Table 40).

Table 39 - Classification of water supply sources for the risk of cyanobacteria bloom

Type of source	Risk
Surface	1.0
Surface / Ground	0.6
Ground	0

Source: Authors.

Table 40 - Classification of water supply sources for other impacts

Type of source	Risk
Surface	1.0
Surface / Ground	0.6
Ground	0.2

Source: Authors.

Population density is associated with a greater concentration of people in the municipality, which can pose problems in the event of extreme weather events, thus the values were reclassified, with higher densities associated with higher risks. It is important to note that the last interval is quite high, with the purpose of reducing the discrepancies of most municipalities with large urban centers, such as the metropolitan region of São Paulo and Rio de Janeiro, which have very high population densities (Table 41).

Table 41 - Classification of population density

Interval (inhab/km^2)	Risk
0 – 9.1	0.2
9.1 – 18.8	0.4
18.8 – 31.9	0.6
31.9 – 69.1	0.8
69.1 – 13416.8	1.0

Source: Authors

Regarding sewage load, whether discharged (Table 42) or generated (Table 43), the risk index was associated with higher values of organic load.

Table 42 - Classification of discharged sewage load

Range (kg BOD/day)	Risk
0 – 3,104	0.2
3,104 – 11,796	0.4
11,796 – 30,460	0.6
30,460 – 143,905	0.8
143,905 – maximum	1.0

Source: Authors.

Table 43 - Classification of generated sewage load

Range (kg BOD/day)	Risk
0 – 150	0.2
150 – 300	0.4
300 – 2,000	0.6
2,000 – 50,000	0.8
50,000 – maximum	1.0

Source: Authors.

The qualitative balance was classified based on the organic load value that can be assimilated (Table 44). Increasingly higher values indicate overload of the receiving water body, indicating a lower capacity for self-purification of new discharges of organic load.

Table 44 - Classification of ANA's qualitative balance

Range	Risk
0 – 0.5 (Excellent)	0.2
0.5 – 1.0 (Good)	0.4
1.0 – 5.0 (Fair)	0.6
5.0 – 20.0 (Poor)	0.8
20.0 – maximum (Bad)	1.0

Source: Authors.

The quantitative balance was classified in relation to the impairment of the water source, with higher values representing the level of impairment of the Q95 flow of the source and the consumption demand (Table 45). Higher values represent a lower capacity of the source to meet the demand for water in response to certain climate events.

Table 45 - Classification of ANA's quantitative balance

Value	Risk
1 (Low)	0.2
2 (Medium)	0.4
3 (High)	0.6
4 (Very high)	0.8
5 and 6 (Critical and Intermittent)	1.0

Source: Authors.

The sewage collection index was reclassified following the same logic as the water supply index, the greater the service, the lower the associated risks (Table 46).

Table 46 - Sewage collection index classification

Range	Risk
0 – 20%	1.0
20% - 40%	0.8
40% - 60%	0.6
60% - 80%	0.4
80% - 100%	0.2

Source: Authors

The absolute population was reclassified considering that locations with larger populations would be more susceptible to risks from an extreme event (Table 47).

Table 47 - Population classification

Range	Risk
0 – 20,000	0.17
20,000 – 100,000	0.33
100,000 – 200,000	0.50
200,000 – 500,000	0.67
500,000 – 1,000,000	0.83
1,000,000 - maximum	1.00

Source: Authors

The classification based on the number of effluent treatment plants (ETP) followed the same logic as the number of water treatment plants, considering that municipalities with a larger number of ETPs would be better adapted to extreme climate events (Table 48).

Table 48 - Classification of the number of effluent treatment plants

Range	Risk
0	1.0
1	0.8
2 - 4	0.6
4 - 6	0.4
7 - maximum	0.2

Source: Authors

Finally, the coverage rate by individual sewage solutions was classified considering that locations that depend more on these solutions, as they are generally simplified solutions, present greater inherent risks, as shown in Table 49.

Table 49 - Classification of service index by individual sewage solution

Range	Risk
0 – 20%	0.2
20% – 40%	0.4
40% - 60%	0.6
60% - 80%	0.8
80% - 100%	1.0

Source: Authors

ANNEX II – Identification of Climate Risks with WG

Table 50 presents the list of impacts identified for the water sanitation system in the WG meetings before consolidation in the final material.

Table 50 – Result of discussion with the WG on the survey of climate risks to the water system

CLIMATE THREAT	IMPACT DESCRIPTION
Heat Waves	Sudden increases in energy demand may cause an interruption of this service.
Heat Waves	Increased deterioration of infrastructure
Heat Waves	Overloading of structures, with increased use of pumps, for example, above the equipment capacity.
Heat Waves	Favoring the survival of pathogens in the water supply network.
Heat Waves	Bloom of cyanobacteria in lakes and reservoirs.
Heat Waves	Increase in the concentration of pollutants due to the reduction in the volume of water in the reservoirs.
Heat Waves	Increased evaporation from water reservoirs.
Droughts	Higher demand for groundwater, above recharge capacity.
Droughts	Conflict over water use
Droughts	Increased demand for water for agricultural activities
Droughts	Increased demand for water for power generation
Droughts	Bloom of cyanobacteria in lakes and reservoirs.
Droughts	Reduction of flow in water bodies can lead to an increase in the concentration of pollutants directed to WTPs.
Droughts	Rationing in the water supply network may lead consumers to seek unsuitable alternatives for consumption
Droughts	Low-pressure flows or interruption of supply may lead to intrusion of groundwater into the distribution networks.
Droughts	Isolation of communities and changes to the standard of care in remote regions and/or regions dependent on transport by water.

Droughts	Treatment plants receive flows below their designed capacity.
Droughts	Increased cost of production (activation of alternative sources, increased network maintenance)
Droughts	Reduction in the availability of water for harvesting
Droughts	Increased cost of production
Droughts	Change in customer behavior: search for alternative sources, reduction in consumption after savings campaign
Droughts	Reduction in the supply of treated water, loss of revenue due to reduced production (Rotation)
Storms	Change in population behavior due to system failures, leading to health risks
Storms	Low-pressure flows or interruption of supply may lead to intrusion of groundwater into the distribution networks.
Storms	Contamination of water resources by mixing components during floods
Storms	Destruction of sanitation structures, such as the harvesting network or WTP units.
Storms	Erosion of areas and compromise of structures
Storms	Increased deterioration of infrastructure
Storms	Interruption of operation and even disabling of equipment not prepared to operate at higher flood levels
Storms	Dam collapse
Storms	Interruption of the treatment system
Storms	Treatment plants receive flows that exceed their design capacities
Storms	Increased suspended solids content in raw water
Storms	Loss of revenue due to the inability to supply treated water due to damage to infrastructure

Table 51 presents a list of impacts identified for the sewage system in the WG meetings before consolidation in the final material.

Table 51 – Result of discussion with the WG on the survey of climate risks to the sewage system

CLIMATE THREAT	IMPACT DESCRIPTION
Heat Waves	Increased deterioration of infrastructure
Heat Waves	Overloading of structures, with increased use of pumps, for example, above the equipment capacity.
Heat Waves	Sudden increases in energy demand may cause an interruption of this service.
Heat Waves	Overloading of structures due to increased water consumption, above the designed capacity of the equipment.
Heat Waves	Increased generation of odors in the sewage system
Droughts	Receiving bodies of water will have a lower dilution capacity.
Droughts	Increased corrosion of sewage networks.
Droughts	Preventing systems that use water as a transport agent
Droughts	Isolation of communities and changes to the standard of care in remote regions and/or regions dependent on transport by water.
Droughts	Reduction in the quality of the final effluent after treatment due to increased concentration and/or variability of the entry flow rate.
Storms	Spillage from open sewage channels and increased incidence of diseases, either due to overloading of the network or physical obstruction.
Storms	Overflow of effluent treatment plants
Storms	Collapse of individual sewage treatment structures
Storms	Destruction of sanitation structures, such as collection system pipes and ETP units.
Storms	Increased deterioration of infrastructure
Storms	Impediment of the arrival of supplies to treatment units and/or operators.
Storms	Change in population behavior due to system failures, leading to health risks
Storms	Damage/obstruction of pressurized structures (lifting stations/discharge lines).
Storms	Impediment of the collection of sludge and/or the material to be treated
Storms	Deposition of coarse solids in sewage systems and consequent reduction in the cross-sectional area of the pipes.
Storms	Breakage in sewage pipes due to changes in soil moisture.
Storms	Interruption of the treatment system
Storms	Reduction of detention time in sewage treatment units

ANNEX III – Climate Variation Analysis

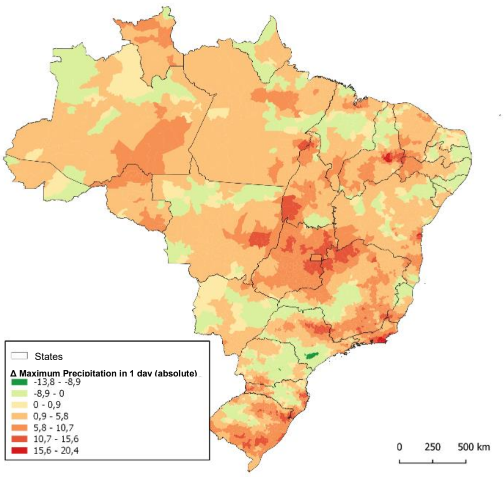
In addition to modeling considering the absolute values of the projections of climate variables, some regions present greater variations in climate patterns between the historical period and the evaluated scenario, for the 2050 horizon, which are identified below.

Storms

Maximum precipitation in one day (RX1)

We observe a significant increase of up to 20.4 millimeters of maximum precipitation in one day in several regions of Brazil, with emphasis on the States of Goiás, Rio Grande do Sul, Rio de Janeiro, Tocantins and Minas Gerais (Figure 10). This increase could have significant impacts, as many municipalities are not prepared to receive large volumes of precipitation in such a short period of time, as has been observed in recent years in Brazil.

Figure 10 - Variation in maximum precipitation in one day between the historical period and the 2050 scenario.



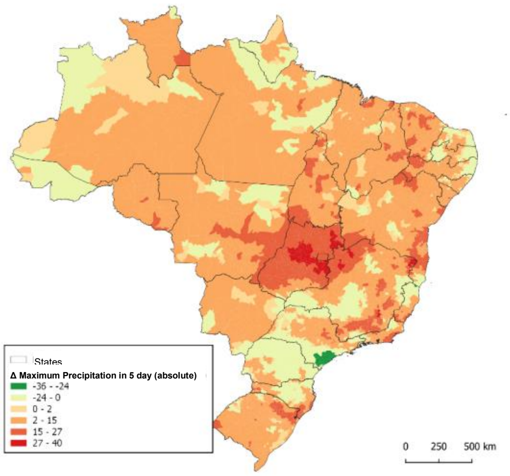
Source: Adapted from CMIP6 by authors

Maximum precipitation in five days (RX5)

From the perspective of maximum precipitation in five days, the state that presents the greatest variations is Goiás, with an increase of up to 40 millimeters of accumulated precipitation in 5 days. Other regions also stand out, with variations of up to 27 millimeters in the Zona da Mata of Minas Gerais, Rio Grande do Sul and Bahia (Figure 11).

This increase in the volume of accumulated precipitation in 5 days may require additional efforts of water treatment, given the constant transport of particles to water sources, increasing turbidity and the amount of suspended solids in raw water.

Figure 11- Variation in maximum precipitation in five days between the historical period and the 2050 scenario



Source: Adapted from CMIP6 by authors

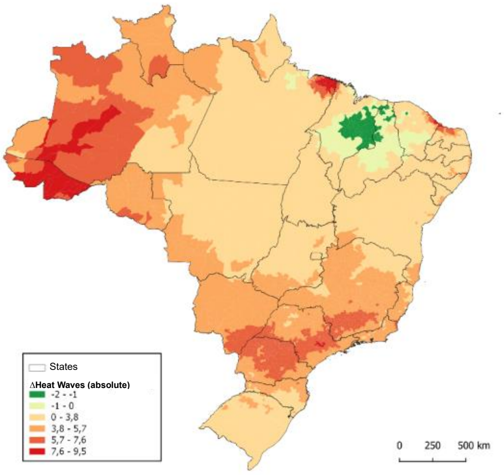
Heat waves

When looking at the variation in the incidence of heat waves (

Figure 12), we notice a reduction in the central part of the states of Maranhão and Piauí and an increase, almost throughout Brazil, of up to 4 heat waves per year. The states of Amazonas, Acre and a large part of Mato Grosso do Sul, Paraná, São Paulo and Minas Gerais and the northeast region of Pará and north of Ceará and Rio Grande do Norte stand out with increases of up to 9 heat waves per year.

This increase may represent greater water consumption in these regions and increased deterioration of water and sewage infrastructure, worsening the problems already observed, such as the generation of odors in sewage systems and the proliferation of cyanobacteria in water sources.

Figure 12 - Variation in the number of heat waves between the historical period and the 2050 scenario



Source: Adapted from CMIP6 by authors

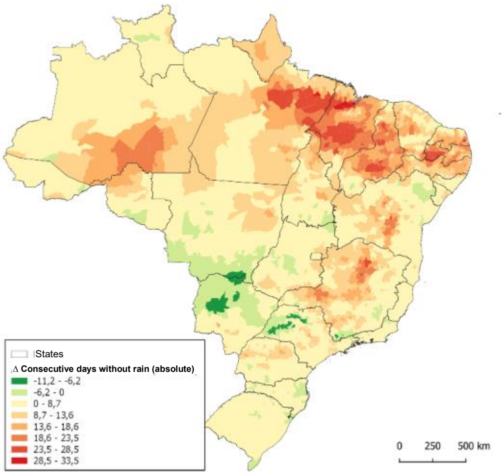
Meteorological Droughts

When looking at the variation in consecutive days without rain (

Figure 13), we notice a reduction in the dry period in part of the center-west and interior of São Paulo. However, a large part of the country may have up to 9 more days without rain during the dry season, in addition to a large part of the northeast and north and regions of the states of Minas Gerais, São Paulo and Santa Catarina that experience an increase of up to 30 additional days without rain per year.

This result will lead to a reduction in the availability of water from sources and an increase in conflicts over the use of water resources, increasing the costs of producing water, food and energy.

Figure 13 - Variation in consecutive days without rain between the historical period and the 2050 scenario



Source: Adapted from CMIP6 by authors

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