

# **Future Vulnerability and Population Dynamics in Brazil**

## **Introduction**

Climate change and its related disasters have been increasingly analyzed by approaches that go beyond physical aspects, including social and institutional dimensions of risk. Furthermore, there is an implicit demand to include temporal aspects, as indicators projections can better inform impacts of future trajectories and scenarios. This aspect influences both IPCC assessments and the Shared Socioeconomic Pathways (Riahi et al., 2017), but few future indicators (of vulnerability and adaptation, for instance), are still available (Huisman et al., 2025).

Within this, this article tackles how demography contributions can play a central role in projecting future climate change vulnerability indicators. We depart from SSPs trajectories to estimate future population at subnational level by age, sex, educational attainment and state of residence in Brazil until 2050. Once population is projected, we combine existing indicators of risk to landslide, floods and water stress at the same temporal scale, presenting an unprecedented indicator of future vulnerability that encompasses social and physical dimensions of vulnerability. The case of Brazil, a Latin America country officially taken as “in development”, synthesizes both current challenges related to climate change knowledge in different disciplines, as well as the myriads of spatial inequalities and risks in which climatic changes will affect populations.

## **Theoretical focus**

Multiple disciplines are involved with the “future studies” field. Demographic science plays a central role in this, as population projections quantify future population structures in a tangible and reliable way. As this practice relies on different methods covering demographic dynamics, a relevant theory underlying this is based on demographic transition, demographic metabolism and the topic of societal change related to the generations problem (Lutz, 2021).

In this, a multidimensional demography approach goes beyond age and sex analysis, including  $n$ -dimensions (as labor force composition and education). This is particularly important for population and environment studies, as heterogeneities are key to adaptation, vulnerability and mitigation. In here we focus on vulnerability, understood as a set of contextual and structural conditions that expose socioecological systems to harm, encompassing susceptibility, fragility, and lack of capacity (Cardona et al., 2012). Adaptation, in turn, is a continuous process shaped by resilience and vulnerability, requiring the activation of adaptive capacities (Adger, Arnell and Tompkins, 2005).

Demographic dynamics (including aging, urbanization, mobilities, composition and others) directly influence vulnerability and adaptation. To ensure more effective responses to future transformations, these factors must be integrated into climate policies across different countries (Schensul and Dodman, 2013; Martine and Schensul, 2013), including Brazil (Martine et al., 2015). The challenges to adaptation, as defined by the IPCC and SSP frameworks, involve both socioeconomic and biophysical dimensions, and so, the link among education, demographic trends and environmental conditions is essential for building resilient societies (O’Neill et al., 2014; Rothman et al., 2014).

Education plays a pivotal role in enhancing adaptive capacity. It influences individuals’ agencies (by improving cognition, decision-making, and risk assessment), and social

process, by strengthening institutions, reducing disaster-related losses, and enhancing preparedness. Societies with higher average education levels are better equipped to anticipate and respond to climate risks, build social capital, and promote sustainable development (Lutz and Mutarak, 2017; Striessnig et al., 2013; Witter et al., 1984).

## **Data**

The composite index of future vulnerability relies on population and environmental data.

The population data sources used were the Brazilian Demographic Censuses (2000, 2010, and 2022), the most recent official population projections (IBGE, 2024), and data from the Human Capital Data Explorer of the Wittgenstein Centre for Brazil (KC et al., 2024).

Environmental data consider the present and future estimations of risk do landslide, floods and water stress elaborated by the AdaptaBrasil project, which uses IPCC approach (Brazil, 2022).

## **Methods**

Population was estimated by age, sex, and educational attainment for Brazil's 27 states. A multidimensional cohort-component model was applied, following the approach used in the Shared Socioeconomic Pathways (SSPs) demographic component (KC et al., 2024). Calculations were performed at five-year intervals, starting in 2022 (the reference year of the Demographic Census) and extending to 2052.

Age and sex distributions were taken from official IBGE projections (2024a), since Census data are affected by under enumeration by age and sex. The educational structure was directly derived from Census data. Educational attainment was classified into six ISCED-consistent categories: (e1) No schooling, (e2) Incomplete primary, (e3) Primary, (e4) Lower secondary, (e5) Upper secondary, and (e6) Post-secondary education.

Projections of educational attainment for the 15–34 age group were based on SSP trajectories (KC et al., 2024). Fertility projections by state was done with data from Census and National Vital Statistics System (SINASC), to estimate and project age- and education-specific fertility rates consistent with SSP scenarios.

Internal migration followed IBGE (2024) assumptions: gradually declining net flows under SSP2, lower mobility under SSP1, and constant rates under SSP3. International migration was assumed negligible, except for states receiving inflows from Venezuela. Mortality trajectories were derived from IBGE survival rates, adjusted by educational differentials from the WCDE, reflecting scenario-specific improvements in life expectancy.

Overall, the projections align with the SSP framework: slower demographic and educational progress under SSP3, moderate continued advances under SSP2, and accelerated gains in human capital and longevity under SSP1.

The method used to derive vulnerability indicators incorporates the demographic dimensions of the Global Vulnerability Index, which has undergone validation analyses against other indices and was projected using global SSP parameters (Huisman et al., 2025). Specifically, we estimated three demographic indicators for 2050: proportion of adults with post-secondary education, life expectancy at birth by sex, and the total

dependency ratio. These indicators were normalized and classified into five categories, ranging from *very low* to *very high* vulnerability.

The three environmental risk assessments were also available using the same categorical scale, which enabled the construction of a composite vulnerability index. This was done by applying the matrix presented in Table 1, in which environmental risks were cross-classified with the socio-demographic dimensions of vulnerability.

Table 1. Matrix of Vulnerability categories by environmental risks and social dimensions.

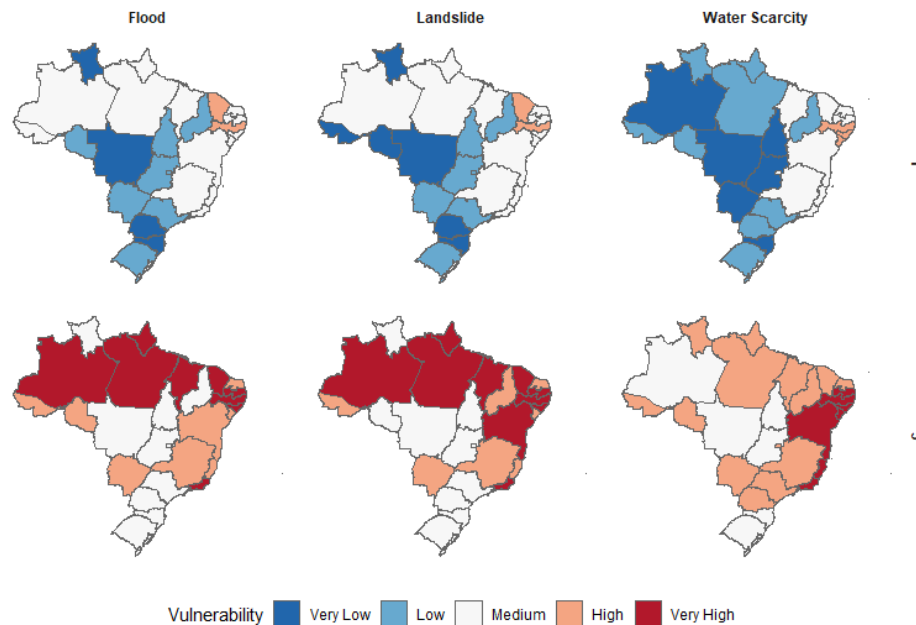
Environmental risks	Social dimensions of vulnerability				
	Very Low	Low	Medium	High	Very High
Very Low	Very Low	Low	Low	Medium	Medium
Low	Low	Low	Medium	Medium	High
Medium	Low	Medium	Medium	High	High
High	Medium	Medium	High	High	Very High
Very High	Medium	High	High	Very High	Very High

## Findings

Brazil total population was of 210,9 million people by 2022, where 10.4% were above 60 years and 21.1% of adults (aged 25 and more) had post-secondary education. In summary, SSP1 and SSP3 scenarios projects an “optimistic” path in terms of development, as SSP3 is more “pessimistic”. Nevertheless, population is expected to decline by 2050 in any scenario: by the end of the 2030 decade at SSP1 or by the end of 2040 decade at SSP3. The maximum population varies from 215 (SSP1) to 224 million (SSP3). At SSP1, the population of elderly represents 24.7% and of adults with post-secondary education of 43.4%. At SSP3, the same values are 19.5% and 30.7%. Although growth at education levels and aging are disseminated throughout the country, this considerably varies at different states. For instance, by 2050 the DC area presents the higher value of adults with post-secondary education (57% at SSP1), and Maranhão (a state located at the East of Amazon forest) a value of 24.8%.

The vulnerability index (Figure 1) represents a comparison approach among scenarios and risks.

Figure 1. Vulnerability index by risk and state, Brazil, 2050



Comparatively, vulnerability will be higher when both climate change and underdevelopment are higher, under SSP3 assumptions. The 3 risks will be present almost all regions in this context, but with different intensities. The most affected places are in the Northeast and North of the country, where the biomes of Amazon and Semiarid are. If SSP1 are followed, social and environmental conditions will present significantly lower levels of risk. Nevertheless, some states of Northeast are of great concern, as even in SSP1 they have high levels of vulnerability.

These findings can better guide the prioritization of future adaptation challenges by integrating social and environmental dimensions. Demographic research offers valuable tools and knowledge to strengthen this understanding and support more informed decision-making processes. However, significant challenges remain in translating this knowledge into actionable strategies.

The next steps and expected findings of this research include the disaggregation of projections for Brazil's 5,570 municipalities and a deeper understanding of the vulnerability index construction. This represents an advancement toward developing a more detailed and policy-relevant tool to inform local decision-makers about future adaptation challenges, translating projections into actionable scales for planning and resilience-building. However, several uncertainties remain — stemming from methodological assumptions, data limitations, and the inherent complexity of social dynamics. These challenges highlight the need for continued refinement of integrated demographic–environmental models, improved data quality, and collaborative approaches across disciplines. Strengthening these aspects will foster the use of future vulnerability indicators to better support evidence-based adaptation policies at the local level and contribute to climate-resilient development pathways.

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