Hydrological Disasters and Learning Losses in Brazil*

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Abstract

This study provides the first comprehensive evidence on how hydrological disasters in recent years have affected elementary education outcomes in Brazil, combining innovative data construction with modern causal inference techniques. Using nationally representative administrative records, the analysis links municipal disaster notifications from the Integrated Disaster Information System (S2ID) to both aggregate and individual-level performance data from the Basic Education Assessment System (SAEB) for the period 2013–2017. Two complementary empirical strategies are employed: a municipality-level panel estimated with the staggered difference-in-differences methodology of Callaway and Sant'Anna (2021), and a novel individual-level pseudo-panel built through probabilistic matching and corrected for attrition using inverse probability weighting.

The results show that hydrological disasters significantly reduce student proficiency in Portuguese and Mathematics for 5th-grade students, with effects that persist over the medium run. The impacts are particularly pronounced in the South and Southeast regions, where the frequency and intensity of hydrological events are highest. Crucially, the individual-level analysis reveals learning losses that are substantially larger than those suggested by municipality-level averages, indicating that aggregate models underestimate the true magnitude of disaster-induced educational harm.

The study also uncovers important heterogeneous effects. Boys experience greater losses in Mathematics, girls in Portuguese, and white students show the largest absolute declines across both subjects. Despite these substantial drops, the relative performance gaps between social groups remain largely unchanged. This pattern is consistent with evidence that students with higher baseline achievement levels may experience larger absolute learning losses when exposed to educational shocks, while structurally disadvantaged groups—already constrained by chronic inequalities—exhibit more limited margins for further deterioration.

By combining high-frequency disaster data with standardized learning measurements and rigorous quasi-experimental methods, this research advances the literature on climate shocks and human capital in several ways. It is the first study in Brazil to estimate heterogeneous disaster effects using individual-level educational data and demonstrates the value of integrating staggered DiD estimators with pseudo-panel methods to uncover impacts that would otherwise remain concealed. The findings highlight hydrological disasters as significant drivers of learning inequalities and reinforce the urgency of targeted policies—such as remedial instruction, psychosocial support, and resilient school infrastructure—to protect educational trajectories in a context of increasing climate-related risk.

Overall, the study underscores that natural disasters in Brazil are not only environmental and economic events, but also critical forces shaping educational inequality. By documenting how exposure to hydrological events impairs learning and disproportionately affects specific demographic groups, the research provides actionable evidence to inform more equitable and climate-resilient education policies.

Keywords: climate shocks; education; learning outcomes.

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1 Introduction

Natural disasters represent a persistent and growing challenge to development, with implications that reach far beyond physical infrastructure, economic stability, and immediate humanitarian concerns. Among their most enduring effects are disruptions to human capital accumulation, particularly through the educational system. Although events such as floods, landslides, droughts, and storms often draw public attention to visible damage, it is their less visible, long-term consequences on learning trajectories that raise critical concerns. Educational disruptions can reverberate through children's cognitive, social, and economic development, shaping outcomes well after the disaster itself has ended.

A substantial body of literature documents how natural disasters interfere with education. Physical damage to schools can force prolonged closures or reduce classroom capacity, transportation networks may become unusable, and school buildings are frequently repurposed as emergency shelters, displacing regular activities (Sacerdote, 2008; Kousky, 2016). Even where direct structural damage does not occur, broader community effects—including income shocks, health burdens, and psychological distress—can reduce household investment in schooling and compromise children's ability to focus or attend school consistently (Mani et al., 2013; Nguyen and Pham, 2018). Children in disaster-affected areas may also assume additional household responsibilities, such as caregiving or informal labor, which further impairs attendance and academic performance (UNICEF, 2013).

Importantly, these effects are not uniform across populations. Scholars have shown that pre-existing inequalities, rooted in race, gender, income, geography, and institutional access, shape both disaster exposure and the capacity to recover. Disasters act not merely as environmental shocks but as social accelerators, intensifying structural disparities (Cutter et al., 2003; Marino and Faas, 2020). Black and Indigenous communities, for example, are disproportionately represented in high-risk areas due to patterns of spatial marginalization, and they face systemic barriers to recovery resources that prolong educational disruptions and exacerbate intergenerational inequality (Luft, 2016). Gendered dynamics also play a critical role: in many contexts, girls face increased caregiving burdens after disasters, resulting in reduced attendance and higher dropout rates (Nguyen and Pham, 2018; Marchetta et al., 2018).

These vulnerabilities are particularly pronounced in lower-income countries, where institutional responses to disasters are constrained. Noy (2009) and Loayza et al. (2012) demonstrate that the severity of disaster impacts is closely linked to socioeconomic development and governance capacity. In Brazil, these patterns are evident in the geographic distribution and recurrence of extreme events. According to the Integrated Disaster Information System (S2ID), more than 1,600 municipalities per year are affected by disasters, with over 27,000 events recorded between 2007 and 2019. Droughts and dry spells prevail in the Northeast, while hydrological disasters are more frequent in the South, Southeast, and North. Prior research has shown that Brazilian municipalities affected by disasters tend to experience declines in average student performance and increases in school dropout rates (Alves, 2021). However, the literature offers limited analysis of how these impacts vary across social groups within the same disaster event and has not, to date, explored these differences using individual-level data.

The present study contributes to filling these gaps. It provides the first analysis for Brazil estimating the heterogeneous educational impacts of hydrological disasters using individual-level data from the Basic Education Assessment System (SAEB), linked to municipal disaster records from S2ID. By constructing both a municipality-level panel (2013–2017) and an innovative individual-level pseudo-panel, the study employs econometric strategies suited for longitudinal data with staggered treatment timing. This dual approach strengthens causal identification and allows for a direct comparison between aggregate and individual outcomes, revealing that municipality-level estimates tend to underestimate the true extent of learning losses. These data and methods make it possible to uncover patterns that remain obscured in aggregate analyses, highlighting the importance of micro-level variation for understanding how climate shocks shape educational trajectories.

This study also advances the literature by examining how disaster impacts differ by gender and race-two critical dimensions of inequality in Brazil. By integrating insights from research on social vulnerability, climate resilience, and educational inequality, the analysis detects heterogeneity that aligns with broader patterns identified in international studies but has not yet been systematically documented in the Brazilian context. Understanding these differences is essential for identifying which groups are most disadvantaged by extreme events and for designing policies that mitigate long-term educational harm.

Natural disasters do not affect all individuals equally. Exposure, vulnerability, and recovery capacity vary substantially across socioeconomic, racial, and geographic lines (Marino and Faas, 2020). A growing body of research highlights that pre-existing disadvantages, such as poverty, rural residence, low parental education, and limited access to public services, amplify the negative effects of climate shocks on education (Takasaki, 2017; Heltberg et al., 2009). Disasters often intensify economic fragility, pushing households to reallocate labor and withdraw children from school or overburden them with domestic tasks (Maccini and Yang, 2009; Sawada and Takasaki, 2017). These mechanisms interact with gender, age, and family composition in complex ways. Girls may face disproportionate caregiving expectations; boys may be pressured into paid work; and younger children may be more sensitive to disruptions in routine and support systems.

Evidence also shows that institutional responses shape the degree to which disasters exacerbate or mitigate educational inequalities. Weak or poorly coordinated recovery and compensation policies tend to entrench existing disparities (Sawada, 2007; Skoufias, 2003), while communities with stronger institutional capacity and higher levels of social capital can better protect children's learning. Analyzing heterogeneous effects is therefore essential for understanding how extreme events generate new forms of exclusion or deepen existing ones. Disaggregated evidence by race, gender, geography, and socioeconomic status allows researchers and policymakers to identify the groups most at risk and to design interventions that more effectively promote equity and resilience.

By situating Brazil's educational system within this broader framework of climate-related vulnerability, structural inequality, and institutional fragility, this study contributes new empirical evidence to an expanding field. It provides a clearer understanding of how natural disasters shape educational outcomes across intersecting social categories and offers insights that can inform more equitable and context-sensitive public policy. In doing so, it advances the literature on climate shocks and human capital, highlighting the need for targeted strategies to promote educational justice in an era of accelerating environmental risk.

2 Data

The data used in this study come from two official sources. Information on natural disasters in Brazilian municipalities was obtained from the Integrated Disaster Information System (S2ID). This platform was developed by the Center for Disaster Studies and Research at the Federal University of Santa Catarina (CEPED/UFSC), in partnership with the Ministry of National Integration through the National Secretariat of Civil Defense (SEDEC). S2ID provides access to the full set of records related to federal recognition processes for emergency situations and public calamities, covering municipalities across all five regions of the country. Its nationally standardized structure enables the consistent identification and categorization of different types of disasters, as well as the monitoring of all recorded notifications. This standardization is one of the system's primary strengths, ensuring comparability across time and space.

Educational indicators were constructed using data from the Basic Education Assessment System (SAEB), managed by the National Institute for Educational Studies and Research Anísio Teixeira (INEP), an agency linked to the Ministry of Education. SAEB is a large-scale census assessment conducted every two years in public primary and secondary schools throughout Brazil. It includes standardized tests in Portuguese Language and Mathematics, along with detailed socioeconomic questionnaires. The resulting indicators allow for the evaluation of learning levels and school performance across municipalities, states, and regions, providing a comprehensive view of the quality of basic education in the country.

The integration of disaster information from S2ID with educational data from SAEB makes it possible to assess, in a systematic and nationally comparable way, how natural disasters affect student learning outcomes in Brazil. This combined dataset forms the foundation for the empirical strategy employed in this research.

2.1 Floods in Brazil

Floods are classified as hydrological disasters and constitute one of the most frequent and destructive natural hazards in Brazil, affecting both urban and rural areas across multiple regions. According to data from the Disaster Information System (S2ID), between 2009 and 2019, floods accounted for roughly 40% of the 27,457 extreme weather events officially recorded in the country (S2ID, 2024). These events arise from a combination of climatic factors, such as heavy rainfall and extreme weather episodes, and anthropogenic processes, including deforestation, inadequate land use planning, and unregulated urban expansion. Brazil displays marked regional variation in flood incidence, with particularly high concentrations in the Southeast and South throughout the year (Mendes et al., 2018).

The socioeconomic consequences of floods are substantial and tend to fall disproportionately on socially vulnerable populations. Direct and indirect economic losses include damage to housing and public infrastructure, reductions in agricultural productivity, and disruptions to commercial and industrial activities (Mendes et al., 2018). In the education sector, floods commonly force temporary school closures, degrade infrastructure, and impede students' physical access to classrooms. These disruptions contribute to higher absenteeism and increased dropout rates. The problem is particularly acute in low-income communities, where limited access to digital resources and remote learning alternatives exacerbates educational inequality and deepens learning losses (UNICEF, 2021).

This study focuses exclusively on hydrological disasters, including floods, flash floods, and inundations, based on both conceptual and empirical considerations. These events are the type of disaster most directly linked to immediate disruptions in school functioning, such as infrastructure damage and prolonged interruptions in teaching activities. Their recurrent nature and well-documented connection to educational interruptions make them especially pertinent for analyzing student performance. Moreover, restricting the analysis to a single, clearly defined disaster category enhances the ability to isolate causal mechanisms and provides a more consistent framework for examining how disaster exposure contributes to learning losses.

2.2 Educational data

In the SAEB assessment, students are evaluated in Portuguese Language, with an emphasis on reading comprehension, and in Mathematics, focusing on problem-solving skills. The exams are administered biennially to students in the 5th and 9th grades of primary education in schools with at least 20 eligible students. SAEB uses Item Response Theory (IRT), which ensures comparability of results over time and across test editions. Scores range from 0 to 500 within each subject and school stage.

Using the microdata for public school students in urban and rural areas during the study period, the average 5th-grade score in Portuguese was 191.09 points (SD = 47.85), compared to 206.96 points in Mathematics (SD = 48.04). Among 9th-grade students, the average was 240.91 points in Portuguese (SD

= 47.61) and 245.48 points in Mathematics (SD = 46.17). These descriptive statistics reflect performance at the individual level and serve as the foundation for the empirical analyses.

In addition to cognitive tests, SAEB includes detailed socioeconomic questionnaires that gather information on students, their family environment, and characteristics of teachers and school administrators. These data were used to construct the matrix of control variables, given that individual background, social context, and school conditions play an important role in academic performance. The literature consistently demonstrates that these factors explain a substantial share of achievement differences. Costa et al. (2024) emphasize the relevance of gender, race, and cognitive skills for explaining proficiency gaps. International evidence shows that boys tend to outperform girls in Mathematics, while girls usually score higher in reading-related subjects, such as Portuguese (Stoet & Geary, 2013). Racial disparities are also well documented, with white students performing better on average than Black students.

The dataset used in this study reproduces these patterns. Girls score higher than boys in Portuguese Language (198.48 versus 186.98), while boys slightly outperform girls in Mathematics (209.26 versus 207.70). Standard deviations are similar across genders, indicating comparable variability. At the lower end of the distribution, the 5th percentile is higher for girls in both subjects, suggesting that the lowest-performing girls still score better than the lowest-performing boys. At the top of the distribution, the 95th percentile favors girls in Portuguese and boys in Mathematics, mirroring the differences observed in the means.

Racial disparities are equally pronounced. White students achieve the highest average scores in both Portuguese (197.96) and Mathematics (214.54). Mixed-race students perform worse than white students and similarly to Black students. Asian students record the lowest mean score in Portuguese (186.21) but improve noticeably in Mathematics. Indigenous students show relatively low averages in both subjects (191.23 in Portuguese and 204.89 in Mathematics). Score dispersion is relatively homogeneous across groups, ranging from 45 to 50 points. At the upper tail, white and Asian students exhibit the highest P95 values, while the lowest P5 values are concentrated among mixed-race, Black, and Indigenous students. Among 9th-grade students, the gender differences remain consistent: boys perform better in Mathematics and girls perform better in Portuguese.

Socioeconomic conditions also play a central role in shaping student achievement and may influence the estimated disaster effects. Although SAEB does not directly collect household income, it provides information that allows the construction of a socioeconomic status (SES) index. Following the methodology adopted by INEP in the 2015 Basic Education Schools Socioeconomic Level Indicator (INSE), we derived an SES measure based on students' questionnaire responses.

SES indicators constructed from questionnaire items are widely used in large-scale assessments and serve as effective proxies for living standards and family background in the absence of direct income data. This approach captures dimensions such as asset ownership (television, refrigerator, car, computer), housing conditions (number of bedrooms and bathrooms), and parents' or guardians' educational attainment—all of which are strong predictors of academic performance. The INSE methodology relies on psychometric modeling to extract a latent socioeconomic construct from these observable variables.

Using this framework, we constructed an individual SES indicator for all students in the dataset. The index was standardized to have a mean of 50 and a standard deviation of 10, separately for each year and educational stage, ensuring comparability across cohorts and facilitating the interpretation of socioeconomic differences in learning outcomes.

3 Methodology

To estimate the effects of hydrological disasters on elementary education outcomes in Brazil, this study employs two complementary empirical strategies. The first is a municipality-level panel analysis using the generalized difference-in-differences estimator proposed by Callaway and Sant'Anna (2021). The second involves the construction of an individual-level pseudo-panel, which allows the identification of heterogeneous impacts across different demographic groups and captures within-municipality variation that aggregate data may conceal.

3.1 Identification Strategy

Given the observational nature of the data and the non-random occurrence of natural disasters, the study adopts a quasi-experimental framework to estimate causal effects. Several methodological decisions were required concerning the definition of the analytical sample, the construction of the comparison group, and the treatment of potential threats to identification.

A central decision was to restrict the analysis to the period 2013–2017. This choice is motivated by two main considerations. First, the Integrated Disaster Information System (S2ID), which serves as the primary source of information on disaster occurrences, became fully standardized only after 2012, following the implementation of federal regulations governing disaster recognition and classification. Including earlier years would risk introducing measurement error due to inconsistent reporting practices. Second, the socioeconomic questionnaires administered as part of the Basic Education Assessment System (SAEB) underwent a major redesign in 2019. Several key variables used for constructing the pseudo-panel and for controlling for student demographic and household characteristics were modified or removed, making longitudinal comparability unfeasible. Restricting the sample to 2013–2017 therefore ensures consistent measurement of both disaster exposure and socioeconomic covariates.

The subsequent sections describe in detail the econometric procedures used in the municipality-level panel analysis and the individual-level pseudo-panel, outlining the assumptions required for identification and the strategies adopted to mitigate potential bias.

3.2 Municipality-Level Panel Analysis

In the municipality-level panel analysis, aggregated data from the Basic Education Assessment System (SAEB) were used, containing information on the average proficiency of 5th- and 9th-grade students in Portuguese and Mathematics between 2013 and 2017. These data were merged with municipal disaster records from the Integrated Disaster Information System (S2ID), producing a panel that includes municipalities exposed and not exposed to hydrological disasters.

The treatment group consists of municipalities that experienced at least one hydrological disaster - flood, flash flood, or inundation - during the study period. To strengthen internal validity, two exclusion criteria were applied to define the control group. First, municipalities that did not register any disaster of any type during the study period or in the three preceding years were removed to avoid selecting units that may have been indirectly affected by recent shocks. Second, neighboring municipalities of treated units were excluded to reduce the risk of spatial spillovers, such as shared school infrastructure, population displacement, or resource reallocation.

To improve comparability between treated and control municipalities, we implemented a Mahalanobis distance matching procedure in which each municipality exposed to a hydrological disaster was matched to municipalities in the control group with similar pre-treatment characteristics. Matching was based on two structural variables measured prior to the disaster: municipal GDP per capita and the degree of urbanization. These variables capture, respectively, local economic development and urban structure, which are strongly associated with both disaster vulnerability and educational performance. After matching, standard balance diagnostics were conducted, indicating satisfactory covariate balance between treated and control municipalities. Additional municipal-level covariates, including unemployment rates and average educational attainment, were included in the regression models to account for any remaining observable heterogeneity.

The empirical strategy follows the generalized difference-in-differences estimator proposed by Callaway and Sant'Anna (2021), which is particularly suited for settings with staggered treatment timing and heterogeneous treatment effects. The method estimates the average treatment effect on the treated (ATT) for each cohort of municipalities defined by the year in which they first experienced a hydrological disaster, comparing them to the matched control group across the entire period. This framework accounts for observable differences through weighting and bias correction and controls for unobservable time-invariant characteristics via the panel structure.

The Callaway and Sant'Anna (2021) estimator offers several advantages over traditional two-way fixed-effects models. Standard fixed-effects difference-in-differences approaches implicitly assume homogeneous treatment effects and can yield biased estimates when treatment adoption is staggered, when treatment effects evolve differently across cohorts, or when already-treated units are used as controls. By contrast, the Callaway and Sant'Anna approach explicitly allows treatment effects to vary across cohorts and over time, addressing the identification challenges inherent in contexts, such as natural disasters, where exposure occurs at different moments and in a non-systematic manner. This makes the method particularly appropriate for analyzing the educational consequences of hydrological disasters in Brazil.

3.3 Individual-Level Panel Analysis

The public microdata from SAEB do not allow students to be followed longitudinally, as they lack unique identifiers capable of tracking the same individuals over time. To overcome this limitation and construct an individual-level panel, a probabilistic matching strategy was implemented, following the approach of Kassouf et al. (2020). Students who were in the 5th grade in 2013 were matched to students in the 9th grade in 2017 within the same school, using time-invariant characteristics such as sex, month of birth, and year of birth, in order to approximate the likelihood that they represent the same individual.

This procedure, however, introduces important methodological challenges. Imperfect matching may occur when multiple students share the same set of invariant characteristics, and attrition may arise due to school dropout, grade repetition, or transfers between schools over the 2013–2017 period. Only students who followed a regular progression through the education system remained in the constructed panel, which naturally restricts the sample and raises concerns about selection bias.

To address these issues, an inverse probability weighting (IPW) approach was adopted to correct for the non-random probability of remaining in the panel. Following Wooldridge (2002), we estimate a selection equation in which the probability that a student remains in the same school between 2013 and 2017 is modeled using a probit specification. This equation includes only baseline characteristics observed in 2013, such as 5th-grade test scores and sociodemographic information. The predicted probabilities derived from this model form the basis for the inverse probability weights.

These weights were incorporated into the estimations so as to assign greater weight to students with a higher predicted probability of attrition, thereby adjusting the estimates to more accurately reflect the original student population. In this individual-level panel, the treatment group consists of students residing in municipalities that experienced at least one hydrological disaster during the period, while the control group includes students living in municipalities with no recorded disasters. To ensure comparability, the same exclusion criteria used in the municipality-level analysis were applied, removing municipalities that had not experienced any hydrological events in the three years preceding the analysis period.

Following Wooldridge (2002), we estimate a sample selection model in which the probability that a student remains enrolled in the same school between 2013 and 2017 is modeled using a maximum-likelihood probit specification. The selection equation includes only baseline covariates observed in 2013, such as 5th-grade test scores and sociodemographic characteristics, ensuring that identification relies exclusively on pre-treatment information. The predicted probabilities from this model are then used to construct inverse probability weights, which adjust the outcome regressions for non-random sample attrition.

These weights are incorporated into all estimations to correct for the non-random likelihood of attrition. Students with a higher predicted probability of leaving the sample receive larger weights, allowing the estimates to more closely approximate the characteristics of the original student population. In this pseudo-panel, the treatment group consists of students residing in municipalities affected by at least one hydrological disaster during the period, while the control group includes students living in municipalities with no recorded disasters. To ensure comparability, the same exclusion criteria applied in the municipality-level analysis were also used here, removing municipalities that had not experienced any hydrological events in the three years preceding the baseline year.

The individual-level model estimated using the pseudo-panel can be expressed as:

$$Y_i = \alpha + \beta D_i + X'\delta + \varepsilon_i$$

where Y_i represents the student's test score, D_i is a treatment indicator equal to 1 if the student was exposed to at least one hydrological disaster between 2013 and 2017; X_i is a vector of baseline covariates observed in 2013 (including prior achievement, gender, age, and race), and ε_i is the error term. The model is estimated using inverse probability weights defined as $w_i = 1/\hat{p}_i$, where $\hat{p}_i$ is the predicted probability that student i remains in the sample across both periods.

To reinforce the credibility of the identification strategy, placebo tests were conducted by randomly assigning treatment years to municipalities in the control group. The absence of statistically significant effects in these falsification exercises provides additional support for the internal validity of the empirical design.

4 Results

This section presents the findings from the two empirical strategies employed in the paper: the municipality-level panel and the individual-level pseudo-panel. It then examines the underlying mechanisms and the heterogeneous impacts across regions, gender, and race.

4.1 Municipality level panel

Table 5 reports the results for the municipality-level panel in Brazil. The estimates indicate persistent and economically meaningful negative effects of hydrological disasters on 5th-grade educational performance. On average, Language and Math scores decline by approximately 4 points in the post-treatment period, suggesting that disasters generate significant and widespread learning losses. The absence of statistically significant differences in the pre-treatment period reinforces the credibility of the difference-in-differences strategy: treated and control municipalities followed parallel trends prior to exposure.

In the contemporaneous year of the disaster, a significant effect is detected only for Language, with an average drop of 1.75 points (approximately -0.003 standard deviations). This may reflect the heightened sensitivity of language acquisition to emotional stress, domestic instability, and disruptions to household routines, conditions commonly associated with natural disasters. Math performance does not decline immediately in the disaster year, consistent with the cumulative nature of mathematical learning, which may experience a delayed but progressive deterioration.

Two years after the disaster, the effects become substantially larger: reductions of 6.5 points in Language and 6.6 points in Math (approximately -0.13 standard deviations each). These results indicate that the negative impacts not only persist but intensify over time, likely due to mechanisms such as student dropout or repetition, teacher turnover, infrastructure damage, accumulated learning deficits, and prolonged socioeconomic hardship. The convergence of effect sizes across subjects in the medium term suggests that, although the timing of impacts differs between Language and Math, both domains are ultimately equally compromised. These findings highlight the need for longer-term educational responses such as tutoring programs, psychosocial support, and investments in resilient infrastructure. No statistically significant effects are observed for 9th-grade outcomes.

Table 5: Hydrological disasters and educational outcomes - Brazil

Hydrological disaster	(1) (Language 5th grade)	(2) (Math 5th grade)	(3) (Language 9th grade)	(4) (Math 9th grade)
Pre-treatment Average	-0.291	-0.453	1.678	2.052
	(1.107)	(1.720)	(1.939)	(1.390)
Post-treatment Average	-4.168***	-4.154***	0.331	0.559
	(1.496)	(1.520)	(1.547)	(1.273)
Two years before treatment	-0.291	-0.453	1.678	2.052
	(1.107)	(1.720)	(1.939)	(1.390)
Year of treatment	-1.752*	-1.663	0.482	1.031
	(0.996)	(1.052)	(1.165)	(1.116)
Two years after treatment	-6.584***	-6.644***	0.180	0.087
	(2.127)	(2.184)	(2.396)	(1.847)
Municipalities fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Observations	2,175	2,175	2,183	2,183

Note: *significance of 10%, **significance of 5%, ***significance of 1%.
Robustness standard errors between parentheses.
Controls include: GDP per capita, unemployment rate, elementary school enrollment, socioeconomic level index, mother's education and school dropout rate.

4.2 Mechanisms

There are several interconnected mechanisms through which natural disasters can negatively affect the educational trajectories of children and adolescents. One of the most direct channels is the disruption of school provision. Events such as floods, landslides, and severe droughts can damage school infrastructure, interrupt transportation, or lead to school buildings being used as temporary shelters for displaced populations. These disruptions often result in class suspensions, shortened school years, and difficulties in maintaining pedagogical continuity. Sacerdote (2008), examining the aftermath of Hurricane Katrina, demonstrates that extended school closures can have substantial and lasting effects on student achievement, even after schools reopen.

Beyond the physical interruption of classes, disasters generate significant psychological and emotional stress within affected households. Exposure to loss—including destruction of housing, family separation, the death of loved ones, or displacement—can undermine children's mental well-being. Such stress compromises cognitive and socioemotional skills that are essential for learning, such as memory, attention, self-regulation, and motivation. Mani et al. (2013) argue that scarcity and instability temporarily impair cognitive functioning due to the mental load imposed by adverse circumstances. Consistent with this perspective, Nguyen and Pham (2018) find that exposure to floods is associated with significant declines in children's cognitive test scores, regardless of whether they remain enrolled in school.

Another prominent mechanism involves income shocks experienced by affected households. In developing countries, natural disasters frequently reduce family productive capacity by damaging crops, destroying small businesses, interrupting informal employment, or disrupting local services. Families may be forced to reallocate expenditures away from education or require children and adolescents to contribute economically, whether through formal or informal labor or by assuming additional domestic responsibilities. Kousky (2016) highlights that shifts in children's time use are a key pathway through which disasters affect educational outcomes, especially among the poorest. Empirical evidence supports this mechanism: Jensen (2000) in Côte d'Ivoire and Marchetta et al. (2018) in Madagascar document significant declines in school enrollment following extreme weather events, particularly among boys who are more likely to be pulled into the labor force. At a broader scale, Cuaresma (2010) shows a robust negative correlation between geological disasters and secondary school enrollment across countries, reinforcing the macro-level association between disasters and schooling disruptions.

These impacts can also extend well beyond the short term. An important, though still understudied, dimension in the Brazilian context concerns the long-term and intergenerational effects of disasters on human capital formation. Caruso and Miller (2015), studying the 1970 Ancash earthquake in Peru, find that individuals exposed to the disaster at birth achieved significantly lower educational attainment more than three decades later. This evidence suggests that disasters can initiate persistent cycles of vulnerability, with consequences that endure across generations.

4.3 Heterogeneous effects

The analysis of heterogeneous impacts focuses on the South and Southeast regions of Brazil. They are the most economically developed areas of the country. The Southeast is the wealthiest region, responsible for roughly half of Brazil's total GDP, while the South ranks as the second richest, with high levels of economic diversification and social development. Together, these two regions concentrate more than half of the Brazilian population, with the Southeast alone accounting for over 40%. Both regions are highly urbanized, marked by dense metropolitan areas and extensive infrastructure networks. Despite their relative prosperity, the Southeast and South are also among the most vulnerable to hydrological disasters. Their high population density, intense urbanization, and widespread occupation of flood-prone areas increase exposure to extreme weather events. As a result, these regions consistently register some of the highest frequencies of floods and flash floods in the country, amplifying the potential for disruptions in public services, including education.

Table 6 presents the estimates for the South. The results show that disasters produce larger learning losses in this region compared to the national average. In the post-treatment period, Language and Math scores decline by approximately 5.9 points (around -0.11 standard deviations), indicating a stronger overall effect. Two years after the disaster, the impacts become even more pronounced: -9.4 points in Language and -9.6 points in Math (around -0.18 and -0.19 standard deviations, respectively). These substantial medium-term effects suggest a slower or more uneven recovery trajectory. The similarity of effect sizes across subjects implies that the disruption extends to general learning conditions rather than skills specific to one domain. No significant effects are detected for 9th-grade outcomes.

Table 6: Hydrological disasters and educational outcomes - South region

Hydrological disaster	(1) (Language 5th grade)	(2) (Math 5th grade)	(3) (Language 9th grade)	(4) (Math 9th grade)
Pre-treatment Average	-0.896	-1.788	2.936	2.570
	(2.220)	(2.266)	(3.669)	(3.379)
Post-treatment Average	-5.989***	-5.951***	-0.693	1.165
	(2.217)	(2.265)	(2.313)	(1.421)
Two years before treatment	-0.896	-1.788	2.936	2.570
	(2.220)	(2.266)	(3.669)	(3.379)
Year of treatment	-2.509	-2.269	-0.537	2.596
	(1.563)	(1.806)	(2.521)	(1.967)
Two years after treatment	-9.468***	-9.633***	-0.848	-0.265
	(3.294)	(3.252)	(2.660)	(1.743)
Municipalities fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Observations	796	796	787	787

Note: *significance of 10%, **significance of 5%, ***significance of 1%.
Robustness standard errors between parenthesis.

Table 7 presents the results for the Southeast. The region also exhibits negative impacts, though of smaller magnitude relative to the South. The average post-treatment effect is -2.47 points in Math, while the reduction in Language is of similar magnitude but not statistically significant. This corresponds to approximately -0.05 standard deviations in Math, indicating a meaningful but more moderate loss. Dynamic effects show no significant pre-treatment differences, reinforcing the parallel-trends assumption. In the disaster year, no immediate effects are detected for either subject. Two years after exposure, the impacts become sizable: -6.76 points in Math (around -0.13 standard deviations) and -4.40 points in Language (around -0.08 standard deviations). The larger effect for Math may reflect the difficulty of compensating for cumulative content losses in this subject. Although the Southeast benefits from relatively stronger infrastructure and institutional capacity, the results demonstrate that disaster impacts remain persistent and non-negligible, reinforcing the need for coordinated mitigation and long-term educational recovery policies.

Overall, the municipality-level panel shows that hydrological disasters generate persistent learning losses in Language and Math, with significant regional variation. The South experiences the strongest impacts, while the Southeast faces smaller but still meaningful medium-term losses. Because these averages may mask internal inequalities, the next section turns to an individual-level pseudo-panel to examine how the effects distribute across students with different characteristics.

Table 7: Hydrological disasters and educational outcomes - Southeast region

Hydrological disaster	(1) (Language 5th grade)	(2) (Math 5th grade)	(3) (Language 9th grade)	(4) (Math 9th grade)
Pre-treatment Average	-2.599	-2.821	-4.975	-3.151
	(2.967)	(2.868)	(2.836)	(3.300)
Post-treatment Average	-2.465	-4.263**	-2.889	-1.971
	(1.687)	(1.347)	(2.181)	(2.132)
Two years before treatment	-2.599	-2.821	-3.151	-2.821
	(2.967)	(2.868)	(2.836)	(3.300)
Year of treatment	-0.536	-1.769	0.202	1.163
	(1.501)	(1.720)	(2.078)	(1.790)
Two years after treatment	-4.395*	-5.982	-5.106	-6.756**
	(2.334)	(2.963)	(2.999)	(3.004)
Municipalities fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Observations	532	532	545	545

Note: *significance of 10%, **significance of 5%, ***significance of 1%.
Robustness standard errors between parenthesis.
Controls include: GDP per capita, unemployment rate, elementary school enrollment, socioeconomic level index, mother's education and school dropout rate.

4.4 Individual level panel

Table 8 reports the estimates from the individual-level panel analysis and indicates substantial educational impacts associated with exposure to hydrological disasters. Students who were in the 5th grade in 2013 and reached the 9th grade in 2017, and who lived in municipalities affected by disasters during this period, scored significantly lower on Saeb assessments. The estimated reductions of -15.4 points in Language and -10.4 points in Math correspond to approximately 0.3 and 0.2 standard deviations, respectively. Given that Saeb scores have a mean near 250 and a standard deviation around 50, these magnitudes reflect severe learning losses similar to those observed in contexts of extended school closures or major public health crises. The results underscore that disasters disrupt not only the school routine but also the processes through which students acquire and consolidate learning.

The larger effects observed in the individual panel compared to municipal averages can be explained by three factors. First, the individual-level specification controls for fixed student characteristics—such as socioeconomic environment and unobserved ability—yielding more precise estimates. Second, the measure of exposure is defined at the student level rather than averaged across municipalities, avoiding the masking of within-municipality inequalities. Third, the estimates capture the cumulative effects of disruptions across the entire educational cycle, revealing how the consequences of disasters build over time.

The difference in magnitudes between Language and Math is also informative. Language losses are larger, likely reflecting this subject's reliance on continuous exposure to reading materials, emotional stability, and consistent interaction with teachers and peers—all conditions easily disrupted during disasters. Math, while negatively affected, may initially appear more resilient due to its structured and cumulative nature, though this resilience may diminish as disruptions persist.

The findings point to the need for policy responses that extend beyond emergency assistance. Medium- and long-term initiatives—such as remedial education, psychosocial support, curricular adjustments, and targeted interventions for students most affected—are essential to counteract the persistent and compounding nature of disaster-related learning losses. These results align with international evidence documenting substantial educational setbacks following extreme events.

Table 8: Hydrological disasters in Brazil- Individual analysis

Disaster	(1) (Language Score)	(2) (Math Score)
Hydrological disaster	-15.368***	-10.394***
	(0.506)	(0.458)
Individuals fixed effect	Yes	Yes
Controls	Yes	Yes
Observations	260,595	260,595

Note: *significance of 10%, **significance of 5%, ***significance of 1%.
Robustness standard errors between parenthesis.
Controls include: gender, race, parental education, and socioeconomic status.

4.5 Heterogeneous Effects

Table 9 presents heterogeneous effects by gender and race. All sociodemographic groups experienced significant learning losses, though the magnitudes differ. For race classification, White and Asian students were grouped as "White," while Black, Mixed-race, and Indigenous students were grouped as "Non-White."

Among boys, exposure to a disaster reduced Language scores by 15.5 points and Math scores by 11.7 points (approximately 0.31 and 0.23 standard deviations). Girls also experienced significant losses -14.7 points in Language and 8.6 in Math (0.29 and 0.17 standard deviations). The larger Math losses among boys may relate to higher dropout rates, earlier entry into the labor market, or reduced educational support within the household during crises.

The race-disaggregated estimates show that white students experienced declines of 24.3 points in Language and 17.0 in Math (0.49 and 0.34 standard deviations), whereas non-white students experienced reductions of 14.7 and 8.5 points (0.29 and 0.17 standard deviations). The finding of larger learning losses among white students may appear counterintuitive at first glance. However, this pattern is consistent with differences in baseline achievement levels across racial groups. White students in Brazil, on average, start from higher levels of academic performance, which implies greater absolute losses when schooling is disrupted. Students who accumulate learning at a faster pace under normal conditions have more to lose when instructional time and curricular continuity are interrupted, as documented in Kuhfeld et al. (2020).

In contrast, non-white students disproportionately face structurally disadvantaged educational conditions, including higher age-grade distortion, lower access to educational resources, and more frequent exposure to disruptions even in non-disaster periods. As a result, additional shocks may generate smaller measured declines in test scores, partly reflecting ceiling effects (Reardon, 2012) and partly reflecting already constrained learning trajectories.

Moreover, differential attrition and compositional changes may also play a role. If more vulnerable non-white students are more likely to drop out or fail to appear in the constructed pseudo-panel following disasters, the estimated average losses among those who remain observed may be attenuated, even after applying inverse probability weights. Finally, it is possible that schools serving predominantly non-white populations have developed coping mechanisms in response to chronic adversity, which could partially mitigate the marginal impact of additional shocks.

Table 9: Hydrological disasters in Brazil- Individual analysis

Group Treated	(1) (Language Score)	(2) (Math Score)
Boys	-15.522***	-11.656***
	(0.850)	(0.786)
Girls	-14.732***	-8.516***
	(0.754)	(0.670)
White	-24.288***	-16.990***
	(1.198)	(1.059)
Non-white	-14.732***	-8.516***
	(0.754)	(0.670)
Individuals fixed effect	Yes	Yes
Controls	Yes	Yes
Observations	260,595	260,595

Note: *significance of 10%, **significance of 5%, ***significance of 1%.
Robustness standard errors between parenthesis.
Controls include: parental education, and socioeconomic status.

4.6 Robustness Check

To reinforce the robustness of the identification strategy, a placebo test was conducted in which hypothetical treatment years were randomly assigned to municipalities that were never exposed to disasters. The purpose of this exercise is to assess whether the model would erroneously detect effects in a context where no intervention actually occurred. Under correct model specification and valid identification assumptions, no statistically significant effects should appear around the placebo treatment dates.

The randomization was applied exclusively to municipalities that remained untreated throughout the entire analysis period, with simulated treatment years assigned based on predetermined probabilities. Using this setup, an event-study model was estimated employing the Callaway and Sant'Anna (2021) estimator for both the 5th and 9th grades in the municipality-level panel, treating the simulated year as the treatment indicator.

Table 10 reports the results. As expected, no statistically significant effects were detected in either the pre-treatment or post-treatment periods. These findings support the validity of the empirical strategy by confirming that the model does not generate spurious treatment effects in the absence of actual disasters.

Table 10: Hydrological disasters and educational outcomes - Robustness check

Hydrological disaster	(1) (Language 5th grade)	(2) (Math 5th grade)	(3) (Language 9th grade)	(4) (Math 9th grade)
Pre-treatment Average	-3.517	-1.501	8.294	9.387
	(4.714)	(4.844)	(4.441)	(5.483)
Post-treatment Average	0.501	0.480	-1.294	-4.492
	(4.243)	(3.325)	(3.978)	(3.325)

Two years before treatment	-3.517	-1.501	8.294	9.387
	(4.714)	(4.844)	(4.441)	(5.483)
Year of treatment	-4.418	-2.413	-5.379	-6.269
	(5.002)	(3.718)	(5.744)	(5.776)
Two years after treatment	5.421	3.374	2.789	-2.716
	(6.512)	(5.691)	(5.707)	(4.140)
Municipalities fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Observations	181	181	196	196

Note: *significance of 10%, **significance of 5%, ***significance of 1%.
Robustness standard errors between parenthesis.

These findings provide strong support for the empirical strategy, particularly for the parallel trends assumption. The absence of statistically significant placebo effects shows that the model is accurately isolating the treatment effect rather than capturing noise from unobserved municipal heterogeneity or time-specific shocks. The fact that no artificial effects emerge in periods without treatment substantially increases confidence in the internal validity of the main estimates. This diagnostic test also aligns with contemporary best practices for staggered difference-in-differences designs (Athey & Imbens, 2018).

5 Conclusion

This study presents novel evidence on the educational impacts of hydrological disasters in Brazil,. Using complementary methodological strategies, a municipality-level panel and an individual-level panel constructed from Saeb data, the results indicate that natural disasters significantly reduce student performance in Portuguese and Math, with effects that persist in the medium term.

Learning losses are more pronounced at the individual level, suggesting that aggregate analyses may underestimate the extent of the impacts. All groups analyzed were negatively affected, but with important variations. Boys experienced greater losses in Math, while white students showed the largest absolute declines in both subjects. One possible explanation for this pattern is that students with higher prior achievement may experience greater absolute losses when faced with educational shocks, as they have a larger "stock" of accumulated learning. In contrast, historically vulnerable students may already face such adverse structural conditions that their room for further deterioration is limited.

These findings underscore the need for mitigation and recovery policies that go beyond emergency responses. Medium and long-term strategies, such as remedial education programs, continuous psychosocial support, and investments in resilient infrastructure, are essential to address learning losses and prevent the deepening of educational inequalities. Moreover, such policies must be sensitive to race and gender disparities to ensure equitable and effective responses.

This work also contributes to the literature as one of the first to estimate the heterogeneous effects of natural disasters on education in Brazil using individual-level data. Future research can deepen the understanding of the mechanisms underlying these effects, such as the role of school interruptions, family reorganization, and economic pressures on students following extreme events.

Among the study's limitations is the fact that disaster exposure is assigned based on the municipality of residence, which may not fully capture the student's individual experience. Additionally, while the construction of the pseudo-panel is methodologically grounded, it relies on probabilistic matching assumptions that may be subject to selection bias. Even so, the findings presented here provide a solid foundation for the debate on the educational impacts of climate change and for the formulation of public policies aimed at educational justice in risk-prone contexts.

Future research may further explore the mechanisms behind these effects, including the role of school disruptions, family restructuring, and economic pressures on students following extreme events. Additionally, it may investigate which students are more likely to recover from educational shocks and what factors are associated with such resilience. Tracking student trajectories in the years following a disaster would allow researchers to understand not only the immediate impacts but also recovery capacity and inequalities in the pathways to overcoming these effects.

Overall, the evidence presented here reinforces the urgency of integrating educational policy into climate adaptation strategies. As extreme events become more frequent, protecting students' learning, especially those already at risk, must be a central component of equitable and forward-looking public policy in Brazil.

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