Socioeconomic vulnerability and natural disasters: an exploratory analysis of floods and their effects on education in Rio Grande do Sul[1]

Jéssica Antunes de Oliveira[2]
Kamila da Silva Baum[3]
Renata Pereira Cardoso[4]
Luan Marca[5]
Marco Túlio Aniceto França[6]

Abstract: This study aims to investigate the association between the 2024 floods and education in Rio Grande do Sul. We used data from the Rio Grande do Sul State Department of Education (SEDUC-RS) and the National Institute of Educational Studies and Research Anísio Teixeira (INEP). The results from a spatial analysis show that schools of low socioeconomic status located in municipalities prone to flooding were closed for longer, revealing inequalities in access to education in disaster situations. We stress the urgent need to develop and implement public policies that strengthen the resilience of schools in vulnerable areas, mitigating the adverse effects of these natural disasters on the continuity and quality of education.

Keywords: education, floods, Rio Grande do Sul, schools.

Resumo: Este estudo tem como objetivo investigar a associação entre as enchentes de 2024 e a educação no Rio Grande do Sul. Utilizamos dados da Secretaria Estadual de Educação do Rio Grande do Sul (SEDUC-RS) e do Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira (INEP). Os resultados de uma análise espacial mostram que escolas de baixo nível socioeconômico, localizadas em municípios suscetíveis a inundações, permaneceram fechadas por mais tempo, revelando desigualdades no acesso à educação em situações de desastre. Destacamos a necessidade urgente de desenvolver e implementar políticas públicas que fortaleçam a resiliência das escolas em áreas vulneráveis, mitigando os efeitos adversos desses desastres naturais sobre a continuidade e a qualidade da educação.

Palavras-chave: educação, enchentes, Rio Grande do Sul, escolas.

Submission Area 7: Urban Issues and Metropolises

JEL CODE: C21, I25, Q54

[1] The author would like to thank CAPES for the fellowship at the School of Agricultural and Environmental Science, Newcastle University, during the second semester of 2024. Special thanks are extended to Bruno Walter for extracting the dataset, and to Dr. Rogério Duenhas for his insightful comments and suggestions.
[2] Pontifical Catholic University of Rio Grande do Sul (PUCRS)
[3] Pontifical Catholic University of Rio Grande do Sul (PUCRS)
[4] Pontifical Catholic University of Rio Grande do Sul (PUCRS)
[5] Pontifical Catholic University of Rio Grande do Sul (PUCRS)
[6] Pontifical Catholic University of Rio Grande do Sul (PUCRS)

1 Introduction

Climate change, as well as its effects, is a reality in different regions of the world. According to the *AR6 Synthesis Report: Climate Change 2023 Intergovernmental Panel on Climate Change* (IPCC)[7], the increase in extreme weather and climate events has exposed millions of people to food insecurity and reduced water security, with the most significant adverse impacts observed in many locations and/or communities in Africa, Asia, Central and South America, and globally for Indigenous peoples.

The report emphasizes that communities that have historically contributed the least to current climate change and face significant development constraints are disproportionately affected. Between 2010 and 2020, human mortality from floods, droughts, and storms was 15 times higher in regions with high vulnerability to climate risks due to socioeconomic constraints and poor infrastructure, compared to areas that are less vulnerable to these risks.

In Brazil, the scenario is no different. The country is highly exposed to the risks of climate change[8] and has been experiencing extreme events such as floods with increasing frequency. Santos et al. (2020) point out that climate change projected for different levels of global warming indicates significant changes in the regional climate. In the South of Brazil, projections point to an increase in heavy rainfall, with an increase in minimum and maximum temperatures. These changes demonstrate the region's vulnerability to extreme weather events such as floods, which may become more frequent and severe (Santos et al., 2020).

A report prepared by the World Bank found that between 1995 and 2019, losses reported across the country from climate-related events cost an average of more than R$13.33 billion annually. Drought is the climate risk with the highest cost in the country (R$ 199.8 billion between 1995 and 2019), followed by floods (R$ 55 billion) and inundation in riverside regions (R$ 32.2 billion). Rio Grande do Sul is among the states that reported the most significant losses, and floods were responsible for 88% of deaths from disasters between 2000 and 2018[9].

The World Weather Attribution report reveals that the rainfall totals in Rio Grande do Sul in 2024 are the highest they have been since 1979. The study points out that three of the four worst floods ever recorded in Porto Alegre occurred in the last nine months. The most severe flood happened in May 2024, and the second largest occurred in 1941[10].

The floods in April and May 2024 in Rio Grande do Sul were one of the most devastating natural disasters in the state's history, highlighting a recurring issue in the region. During this period, the Guaíba River reached a level of 5.33 meters, surpassing previous records and resulting in floods that affected 446 municipalities (89.56%) out of a total of 498 that are part of the state. According to the Civil Defense of Rio Grande do Sul, more than 2.1 million people were affected, with 79,494 homeless, 538,245 displaced, and 149 recorded deaths[11].

---

[7] https://www.ipcc.ch/report/sixth-assessment-report-cycle/

[8] https://openknowledge.worldbank.org/server/api/core/bitstreams/af026935-5f2d-4edd-b19e-d8fb66f6e9da/content

[9] https://documents1.worldbank.org/curated/en/099050123155511882/pdf/P1761580a79b5b0c80b34c01afa40534151.pdf

[10] See figure 1.5 of the report: https://noticias.paginas.ufsc.br/files/2024/06/Scientific-report-Brazil-RS-floods.pdf. Retrieved from https://www.worldweatherattribution.org/climate-change-made-the-floods-in-southern-brazil-twice-as-likely/

[11] https://www.estado.rs.gov.br/defesa-civil-atualiza-balanco-das-enchentes-no-rs-14-5-18h. Access to the list of affected municipalities: https://www.estado.rs.gov.br/upload/arquivos/202405/lista-de-municipios-afetados-14-05-18h.pdf

In this context, one of the groups most affected by the floods is the children and adolescents of school age. Schools are directly impacted by floods, which damage infrastructure and disrupt the school calendar, hindering student access to classes and leading to a loss of qualified teachers, thus affecting the quality of education (Munsaka and Mutasa, 2021; Mudavanhu, 2014; Marchezini, Muñoz and Trajber, 2017).

The consequences for students are diverse. School dropout rates tend to increase in affected regions, worsening student learning outcomes and resulting in slower school grade progression (Mudavanhu, 2014; Khalid et al., 2024, Marin, Schwarz and Sabarwal, 2024). Children and adolescents who experience these traumatic events can be affected by waterborne diseases and are more exposed to negative externalities, such as conflicts and violence, physical and mental health problems, food insecurity and nutrition, even increased family conflicts and alcohol and drug use, which further aggravates the vulnerability to which these communities are exposed (Mudavanhu, 2014, Convery, Balog and Carroll, 2010; Stanke et al, 2012; Marin, Schwarz and Sabarwal, 2024).

These events highlight educational inequalities, as schools in poorer areas are more vulnerable to flood damage. Marchezini, Muñoz, and Trajber (2017) define educational vulnerability as the level of fragility of school communities, including students, teachers, staff, residents in the surrounding area, and tangible and intangible assets of the school. This fragility is influenced by the environmental context in which they are located and the types of threats to which they are exposed, among other factors.

Students with greater purchasing power often have access to alternative forms of education, such as online classes or private tutoring. However, for many students from low-income families, school plays a role beyond education. School is also a place for food and social support, which are essential for their well-being and development (Yoon and Nozue, 2022; Drake et al, 2017; Zhao, Chen and Song, 2024; Cardoso et al, 2019).

The closure of schools in Rio Grande do Sul due to flooding began on April 29, 2024, and many became shelters for families affected by the flooding. Mudavanhu (2014) highlights the importance of schools as safe environments since they can become shelters in times of emergency. The return to classes occurred gradually, with some institutions resuming in-person activities while others adopted hybrid, remote, or rotation models[12]. According to Maese et al. (2012), flood risk poses various challenges for economies and individuals, particularly jeopardizing children's access to quality education.

Within this scenario, the study investigates how the floods may have affected education in Rio Grande do Sul. Using data from the Rio Grande do Sul State Department of Education (SEDUC-RS) on the days schools were closed during the floods of May 2024 and the Indicator of Socioeconomic Level of Primary Education Schools (INSE), the relationship between the socioeconomic level of schools and the time of interruption of school activities is analyzed. The results indicate that schools in more vulnerable areas remained closed for longer periods, suggesting structural inequalities in access to education in natural disasters.

Furthermore, the study includes an analysis of the correlation between the days of closure and the socioeconomic level of schools, seeking to identify spatial patterns that can guide public policies to mitigate the effects of floods on education. For this purpose, univariate and bivariate Moran's I were performed. By pointing out the differences in school closure times according to socioeconomic status, our results indicate the need for policies that increase the resilience of schools in poorer areas, promoting equitable education even in adverse contexts.

The manuscript is organized into four sections, in addition to this introduction. The Methodology section explains the data sources and the analysis methods used. The Results section presents the findings on the effects of floods on schools according to their

[12] https://educacao.rs.gov.br/mapa-do-retorno

socioeconomic level. Finally, in the final considerations, the implications of the results for public policies and future research are discussed.

2 Conceptual Framework and Mechanisms

The objective of this study is to understand the impacts of the May 2024 floods on educational conditions in Rio Grande do Sul through a theoretical model based on the life cycle theory developed by Currie et al. (2014). This theory builds upon the previous studies of Grossman (1972), Cunha and Heckman (2007), and Currie and Almond (2011) on human capital accumulation and investment. The model seeks to highlight how living conditions at different stages of life can be affected by adverse events and how these events can generate long-term impacts on children's and adolescents' education. This theory was inspired by the epidemiological literature, where the fetal origins hypothesis[13] asserts that chronic and degenerative health conditions in adulthood may be triggered by inadequate development during the intrauterine period. Economists expanded this hypothesis by investigating a broader range of shocks and circumstances, identifying a wealth of long-term effects on educational attainment, income, and health outcomes (Almond & Currie, 2011).

This model can be applied to environmental shocks, such as floods, which, as adverse events, compromise human capital accumulation. In the case of the floods in Rio Grande do Sul, such events may directly hinder students' development, affecting their living conditions and access to education. This impact tends to be more severe for students from schools with lower socioeconomic status, who face greater difficulties in recovering from the effects of these adversities. The model divides life into three phases: i) early childhood, which begins in the womb and extends up to age five; ii) middle childhood, which encompasses the school years, from age five through adolescence; and iii) adulthood, seen as the post-school period when individuals typically enter the workforce. In the context of this study, within this life cycle, most affected children are in the final years of elementary school or in high school, as the analysis is based on data from state schools. Thus, it is crucial to investigate the impact of floods on middle childhood, a phase marked by intense human capital accumulation that can significantly shape young people's future trajectories.

The study assumes that early childhood human capital (Hp) is influenced by adverse circumstances (Cp), which can be either positive or negative, and that children are exposed to these circumstances from gestation to age five. Family characteristics (X), which are time-invariant—such as genetic factors—also play an important role. Floods represent an adverse circumstance that can affect students' health, well-being, and access to education, limiting their immediate development opportunities and shaping their long-term life trajectories.

$$H_p = f_p(C_p, X) \tag{1}$$

Human capital in middle childhood (Hs) depends on the living conditions of early childhood, Is(Hp), as well as exposure to adverse circumstances in middle childhood (Cs). The term Is, which appears as a multiplier of early childhood human capital, refers to the investments made by the family in their children during middle childhood, based on the outcomes obtained in the previous stage (Hp). Thus, given the resulting condition from early childhood (Hp), the necessary and feasible investments (Is) are made in the subsequent stage, depending on each family's constraints.

[13] This hypothesis is associated with David J. Barker; for more details, see Barker (1995).

$$H_s = f_s[I_s(H_p), C_s] \quad (2)$$

Equations (1) and (2) imply that the impacts of exposure to adverse circumstances in early childhood on human capital in later periods depend both on the short-term effects of this exposure and on the propagation of these effects throughout the individual's life cycle. Floods, by interrupting the educational process and hindering access to school, affect learning and can exacerbate educational inequality.

Nguyen and Pham (2018) assess the impact of natural disasters on early childhood education by comparing countries with different economic contexts and education levels. The authors find that floods have more harmful effects on children's education compared to other extreme weather events, such as droughts, frosts, and hailstorms. Exposure to floods decreases the number of grades completed by children aged 12 to 15 in Ethiopia, India, and Vietnam, and in the case of Vietnam, it also reduces enrollment rates and mathematics test scores.

Segarra-Alméstica et al. (2022) analyze the impact of consecutive natural events on educational outcomes in Puerto Rico, focusing on school disruptions caused by Hurricane Maria and the 2020 earthquakes. Using econometric methodologies such as Difference-in-Differences (DD) and Heckman-Copula, the authors find that students in affected areas, especially those whose schools were permanently closed, had a higher likelihood of experiencing academic performance declines and school dropout. Notably, vulnerable students—due to poverty or disability—were disproportionately affected. The authors recommend the implementation of mitigation strategies, such as efficient school response protocols, support for students with disabilities, and improvements in hybrid teaching models to ensure educational continuity during crises.

The mechanisms through which adverse weather events affect school-age children and adolescents are diverse. Natural disasters can reduce household income, making children's education a lower priority. Additionally, school accessibility and infrastructure can be severely damaged, making it difficult for students to attend school and extending the disruption of academic activities. There is also a direct impact on children's health, which hinders their academic performance and progress. In the long run, children from the most vulnerable families, who experience these consequences more intensely, suffer even greater disadvantages, further amplifying social and educational inequalities. The following studies support these assertions.

First, economic losses disproportionately affect families. Arouri, Nguyen, and Youssef (2015) estimate the effect of natural disasters on the well-being and poverty levels of rural families in Vietnam. The authors find that all three types of disasters considered in the study—storms, floods, and droughts—negatively impact household income and expenditures. Furthermore, living in flood-prone areas over the past two years increases the likelihood of being poor. The authors highlight that families with a higher proportion of working-age members are more resilient to disasters. Therefore, families with school-age children are more affected, as they cannot increase their labor supply to mitigate the impact of disasters.

Khan and Hussain (2023) assess the impact of the 2010 floods on children's education in Pakistan. The disaster destroyed approximately 11,000 schools, leaving around half a million children without access to education. The results indicate that the floods led to an increase in school dropout rates and a decline in literacy levels. The main mechanisms behind these effects include a sharp drop in employment and income levels. The authors highlight that this forced families to adopt self-insurance strategies, such as withdrawing children from school and putting them into child labor.

Second, children's health and school infrastructure are also critical mechanisms. Palacios and Rojas-Velásquez (2023) evaluate the impact of climate shocks on educational outcomes in Colombian municipalities, identifying asymmetric effects between excess and deficit rainfall shocks. The authors find that excessive rainfall increases school dropout rates,

reduces educational coverage, and harms academic performance. While they emphasize the income channel—represented by tax revenues, intergovernmental transfers, and agricultural income—as the main transmission mechanism of these effects, factors such as infant mortality and infrastructure damage also play a significant role. The results suggest that public policies should prioritize maintaining school and road infrastructure, as well as implementing income compensation mechanisms to mitigate the negative effects of climate shocks on education.

Furthermore, effective adaptation to floods is a key factor in mitigating their impact on household well-being and, consequently, on educational outcomes. Factors such as access to credit, previous experience with floods, and early warning systems can enhance families' ability to implement adaptation strategies (Ndue, Baylie, and Goda, 2023), which can help reduce the negative effects of floods on education.

3 Database

The study utilized data from the Rio Grande do Sul State Department of Education (SEDUC-RS). This data pertained to the time period during which state schools were closed due to the floods. Classes in state schools were first suspended on April 29, 2024, and all activities were halted on May 3, 2024. The return to classes occurred gradually, depending on each school and community's situation.

In this context, the number of days that schools were closed was calculated based on the dates for schools to reopen, published by SEDUC-RS, considering the closing on 05/01/2024.The 2021 Indicator of Socioeconomic Level of Primary Education Schools (INSE) database was also used in this study[14]. The INSE[15] is based on students' responses to contextual questionnaires from the SAEB assessments (Aneb and Prova Brasil) and ENEM (Exame Nacional do Ensino Médio - National High School Exam). The questions concern family income, asset ownership, the hiring of domestic employees, and the educational level of parents or guardians. INSE only includes data from students who responded to more than three questions and is calculated for schools with more than 15 responding students. It includes a scale from level I to level VII, with level I representing the lowest socioeconomic status and level VII representing the highest.

The State of Rio Grande do Sul has 2,516 state schools, according to the 2023 School Census. The INSE database contains the indicators for 1,858 state schools in Rio Grande do Sul. The database for the present study includes 452 municipalities based on data released by SEDUC-RS

Information on school performance was included to complement the analysis. Data from the SAEB (Basic Education Assessment System) were gathered for both the early and late years of elementary and high school through the IDEB (Basic Education Development Index) database. Data on age-grade distortion were also included, allowing us to assess the percentage of students lagging behind the expected school year for their age.[16] Frame 1 describes the data and its sources.

---

[14] The last year available for analysis is 2021.

[15] Retrieved from https://download.inep.gov.br/educacao_basica/prova_brasil_saeb/resultados/2013/nota_tecnica_ondicador_de_nivel_socioeconomico_das_escolas_de_educacao_basica_inse.pdf

[16] Access to data in https://www.gov.br/inep/pt-br/acesso-a-informacao/dados-abertos/indicadores-educacionais

Frame 1. Description and data source

Variable	Description	Source
Lost Days	Number of days the school was closed due to the floods.	SEDUC-RS
INSE	Socioeconomic Level of Primary Education Schools in 2021.	INEP
SAEB Score	Average performance in Portuguese and mathematics for students in the early (EY) and late (LY) years of elementary school and high school (HS) in 2023	INEP
Age-Grade Distortion Rate	Relationship between the number of students enrolled in a specific grade and the age of students in that grade in 2023. This measures the percentage of students who are two or more years behind in school.	INEP

Source: Prepared by the authors.

4 Method

Exploratory Spatial Data Analysis (ESDA) consists of a set of techniques for visualizing a phenomenon's spatial distribution and identifying outliers and spatial clusters. This methodology helps to determine whether there is a systematic spatial pattern or if the variable of interest is randomly distributed across the territory (Almeida, 2012). For the current study, which examines the effects of the May 2024 floods on schools in Rio Grande do Sul, ESDA was essential for investigating the correlation between school closures due to the floods and the socioeconomic status of these institutions. Additionally, it helped in exploring whether there are any geographical patterns in the distribution of these impacts. To implement the methodology, the GeoDa software was used, which has powerful capabilities for performing spatial analysis, multivariate exploratory data analysis, and global and local spatial autocorrelation.

The first step was to test the hypothesis that spatial data (e.g., the number of days schools remained closed) are randomly distributed. For this purpose, the spatial autocorrelation coefficient was used to measure the relationship between the values of a variable and their spatial locations (Almeida, 2012). Two spatial autocorrelation statistics were used: the Global Univariate Moran's I and the Local Univariate Moran's I. These statistics help assess the spatial dependence in the distribution of the mean number of days of closure per municipality and identify clusters of municipalities with similar closure patterns.

Algebraically, the Global Moran's I statistic, according to Almeida (2012), is given by:

$$I = \left(\frac{n}{\sum_{i=1}^{n} W_{ij}}\right)\frac{z\prime Wz}{z\prime z} \quad (3)$$

Where, I is the global Moran's index; n is the number of municipalities (spatial units); $\sum_{i=1}^{n} W_{ij}$ is the sum of the elements of the contiguity matrix; z is the vector of n observations; W is the contiguity matrix itself (queen contiguity was chosen because it considers all connections in the territory).

A significant positive value of Global Moran's I indicates spatial similarity, meaning that municipalities with longer school closures tend to be near other municipalities exhibiting the same behavior (High-High cluster). On the other hand, negative autocorrelation indicates dissimilarity. Municipalities with schools closed for many days tend to be surrounded by those with schools closed for a few days (High-Low cluster).

Furthermore, Local Indicators of Spatial Association (LISA), as proposed by Anselin in 1995, were utilized to identify local spatial autocorrelation patterns. Local Moran's I is given by:

$$I_i = z_i \sum_{j=1}^{j} w_{ij} z_j \quad (4)$$

Where, I is the local Moran's index; w_{ij} are the elements of the contiguity matrix; z_j is the vector of observations (number of closing days).

This statistic enables us to identify local clusters of spatial autocorrelation, revealing the geographical areas where the effects of floods were most concentrated. This allows for breaking down the global indicator to identify clusters of schools that experienced varying impacts (more or fewer days closed) in specific areas of the state. The visualization of these clusters on the generated maps, categorized as High-High, Low-Low, High-Low, and Low-High, contributed to a detailed analysis of the floods' effects, revealing critical patterns of vulnerability that vary according to the socioeconomic context of the schools.

In addition to the univariate autocorrelation statistics, the **Bivariate Moran's I** was also calculated, which allows investigation of the spatial correlation between two distinct variables: the mean number of days closed per school due to flooding and educational institutions' Socioeconomic Index (INSE). Bivariate Moran's I measures the relationship between a variable observed in a given location and a second variable observed in neighboring regions (ALMEIDA, 2012).

The Bivariate Moran's I formula can be written as:

$$I_{xy} = z_x' w_{zy} \quad (5)$$

Where, I_{xy} is the bivariate Moran's index between variables x (the mean number of days closed per municipality) and y (INSE), z_x is the vector of observations of the first variable (mean of closure days); z_y is the vector of observations of the second variable (INSE); W is the spatial contiguity matrix that shows the relationships between the municipalities where schools are located.

Assessing the Bivariate Moran's I helps determine if there is spatial dependence between floods (closure days) and the socioeconomic status of schools. A negative and significant value would indicate that municipalities located in areas with a higher socioeconomic level tend to be surrounded by municipalities that experienced less closure due to flooding. In contrast, municipalities in areas with a lower socioeconomic level are situated near municipalities that experienced more closures. This result indicates a spatial dissimilarity where the impact of floods and socioeconomic status do not align geographically, highlighting inequalities in educational vulnerability related to floods.

5 Results

5.1 Descriptive Data Analysis

Table 2 below shows the distribution of the mean number of schools per municipality according to socioeconomic level (INSE). The INSE level ranges from one to seven, based on the INSE score scale[17]. It is possible to observe that:

[17] https://download.inep.gov.br/areas_de_atuacao/Indicadores_de_nivel_Nota_tenica_2021.pdf

Table 2. Mean of variables according to socioeconomic level

INSE	Level IV[18]	Level V	Level VI	Level VII	General state values
No. of Municipalities	21	264	164	3	452[19]
Mean Closed Schools	9.7	10.75	8.88	6	9.95
Mean Saeb EY	6.37	6.35	6.81	7.51	6.51
Mean Saeb LY	5.12	5.38	5.76	5.90	5.52
Mean Saeb HS	4.54	4.83	5.17	5.21	4.95
Mean AGD EY	4.06	4.59	3.13	1.6	4.06
Mean AGD LY	17.98	17.69	13.06	10.1	15.95
Mean AGD HS	28.80	22.45	17.85	14.03	21.04

Source: prepared by the authors.

- Level I, II, and III (0 municipalities): The absence of municipalities at Levels I and II indicates that there are no institutions located in the lowest socioeconomic level areas or that the number is too small to be reported. This could suggest that there is exclusion or a lack of schools in highly vulnerable communities.
- Level IV (21 municipalities): There is a significant increase at this level, with 21 municipalities located in regions of intermediate socioeconomic status.
- Level V (264 municipalities): The largest number of municipalities is concentrated at Level V, indicating that the institutions are mainly located in middle or lower-middle-class areas with relatively better economic conditions but are still not the most favored.
- Level VI (164 municipalities): In regions with higher socioeconomic levels, there is still a high number of municipalities, indicating a good distribution in areas with better financial conditions.
- Level VII (3 municipalities): In areas with higher socioeconomic status, the number of schools decreases significantly. This may suggest that despite being wealthy, these areas might have fewer public schools, or private schools could be more widespread.

The data indicate a higher concentration of municipalities at intermediate levels (V and VI), implying that state schools are more prevalent in middle and upper-middle-class areas. The absence of municipalities at the lowest levels (I, II, and III) may indicate unequal access to education in vulnerable areas, exacerbating social disparities. This may indicate the necessity for public policies to increase the presence of schools in poorer areas in order to ensure educational equity.

The analysis of the mean number of days that schools remained closed by municipality, according to their socioeconomic level, reveals a clear trend that institutions in more vulnerable areas are more affected by natural disasters, as the mean number of days closed decreases as the INSE increases. Moreover, there is a noticeable correlation between socioeconomic status and educational achievement. The average scores in the Basic Education Assessment System (Saeb) for the early years (EY) and late years (LY) of elementary school, as well as for high school (HS), indicate that students from municipalities with higher INSE scores achieve higher grades. It is noted that the age-grade distortion rate (AGD) tends to decrease as the INSE

[18] Level I: INSE SAEB scale ranging from zero to 3. Level II: between 3 and 4. Level III: 4 to 4.5. Level IV: between 4.5 and 5. Level V: between 5 and 5.5. Level VI: between 5.5 and 6. Level VII: between 6 and 7. Level VIII: above 7. For more information, see < https://download.inep.gov.br/areas_de_atuacao/Indicadores_de_nivel_Nota_tenica_2021.pdf >

[19] This last column refers to general information about the state of Rio Grande do Sul.

increases, indicating a positive relationship between improved socioeconomic conditions and proper school progression (Patrinos and Psacharopoulos, 1996). Pontili and Kassouf (2008) demonstrate the advantages of policies aimed at enhancing school infrastructure and improving family socioeconomic status, leading to a reduction in age-grade distortion.

Table 3 below presents the results of estimating the correlation between INSE and the number of days the schools remained closed. To ensure the robustness of the findings, three different correlation techniques were employed: Pearson, Spearman, and Kendall. The Pearson correlation assesses the linear relationship between continuous variables under the assumption of normality. The Spearman and Kendall coefficients, in turn, are non-parametric methods that evaluate monotonic associations and are more appropriate when the data may not meet parametric assumptions or contain tied ranks. All three methods revealed a statistically significant negative correlation between the INSE and the number of days schools remained closed.

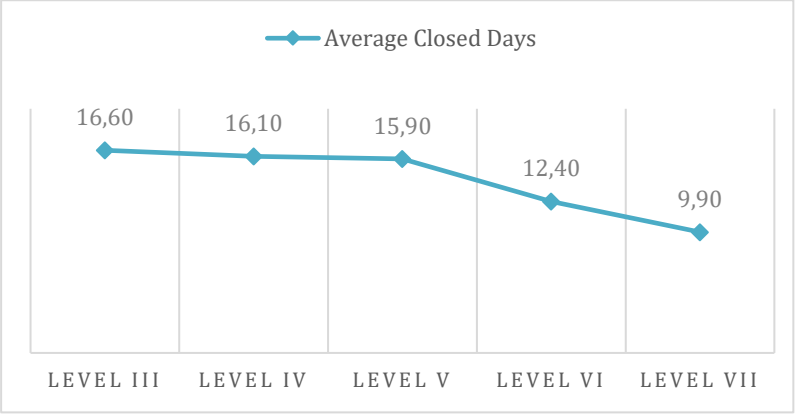
Table 3. Correlation Results

Correlation between INSE and the number of days the schools remained closed	
Pearson Correlation Coefficient	-0.1436
p-values	0.0000
Spearman Correlation Coefficient	-0.1517
p-values	0.0000
Kendall Correlation Coefficient	-0.1110
p-values	0.0000

Source: Prepared by the authors

The negative correlation indicates that as the socioeconomic level of the school decreases (i.e., in areas with worse socioeconomic conditions), the number of days the school remains closed tends to increase. However, the correlation between these factors is weak, suggesting that other significant factors likely contribute to the number of closure days. Figure 1 below illustrates the correlation between the socioeconomic level of schools, measured by the Socioeconomic Level Index (INSE), and the mean number of days schools were closed due to flooding in Rio Grande do Sul.

Figure 1 – Relationship between INSE and mean number of closing days.



Source: Prepared by the authors.

There is a clear relationship between INSE and the duration of school closures. Schools in lower socioeconomic levels (III, IV, and V) have more days closed compared to those in higher socioeconomic levels (VI and VII).

The data appear to support the hypothesis that schools with lower socioeconomic status are more likely to remain closed for longer periods during floods, especially at levels III, IV, and V compared to levels VI and VII. This pattern suggests that schools in less privileged areas may have fewer resources or infrastructure to effectively deal with natural disasters, resulting in extended periods without classes. This analysis emphasizes the need for public policies that aim to enhance the resilience of schools in low-income areas, reducing the impact of natural disasters on students' education.

We also examined the connection between the socioeconomic status of schools and the duration of their closures. Additionally, we investigated the relationship between the number of days of closure and academic performance, as measured by SAEB scores in the Early Years of Elementary School (EY), the Late Years of Elementary School (LY), and in High School (HS) (see Table 4).

Table 4. Correlation Results

Correlation between the number of days the school was closed and the Saeb Score					
Pearson Saeb Score EY 2023	-0.4080	**Spearman Saeb Score EY 2023**	-0.3773	**Kendall Saeb Score EY 2023**	-0.2773
p-values	0.0000	**p-values**	0.0000	**p-values**	0.0000
Pearson Saeb Score LY 2023	-0.2433	**Spearman Saeb Score LY 2023**	-0.2297	**Kendall Saeb Score LY 2023**	-0.1686
p-values	0.0000	**p-values**	0.0000	**p-values**	0.0000
Pearson Saeb Score HS 2023	-0.1707	**Spearman Saeb Score HS 2023**	-0.1324	**Kendall Saeb Score HS 2023**	-0.0990
p-values	0.0003	**p-values**	0.0046	**p-values**	0.0044

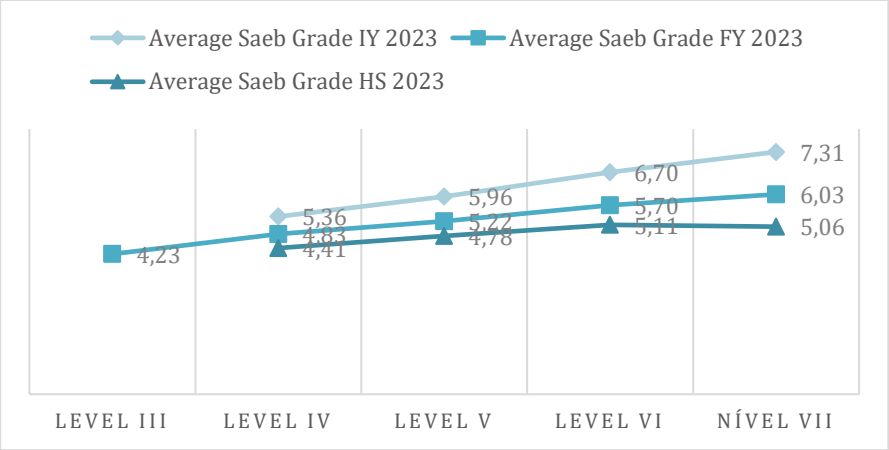
Source: Prepared by the authors

The correlation observed was negative, suggesting that as the number of days the school was closed decreased, students' grades increased. This correlation reflects previous analyses, indicating that schools with lower socioeconomic status, typically those that have been closed for longer periods, have lower academic performance.

This relationship is more evident in the early years of elementary school, indicating that younger students are more impacted by prolonged school closures. This can be attributed to the greater need for pedagogical support during these years, as children have not yet fully developed independent study skills and depend more on school as a safe and structured learning environment (Sindique, 2021).

Figure 2 below illustrates the correlation between INSE and SAEB scores, indicating that students' proficiency increases with higher socioeconomic levels (INSE).

Figure 2 – Relationship between INSE and Saeb Score



Source: Prepared by the authors

Another important aspect to consider is the correlation between the number of days the school was closed and the age-grade distortion rate. The schools that have been closed for the longest duration are those with the highest age-grade distortion and the lowest socioeconomic status. Ferrão et al. (2017) found a negative correlation between socioeconomic status and the likelihood of age-grade distortion. Furthermore, according to Brito, Melo and Sampaio (2022), parental unemployment increases age-grade distortion, especially for older children. It is worth noting that this distortion reduces the opportunity cost for individuals entering the job market (Eide; Showalter, 2001). The negative correlation between age-grade distortion and school performance (Ferrão et al., 2017, Gonçalves and França, 2008; Ferrão et al., 2001) shows that children do not learn more when retained in a specific grade or year (Manacorda, 2012; Mccoy; Reynolds, 1999). This result suggests that students, particularly those from more vulnerable backgrounds, encounter significant challenges in keeping up with the school curriculum.

In this case, the effect is more pronounced in the early years of elementary school, where the correlation is more significant. This suggests that extended periods of school suspension have a more significant impact on younger children, who struggle to follow the school curriculum without regular support.

Table 5. Correlation Results

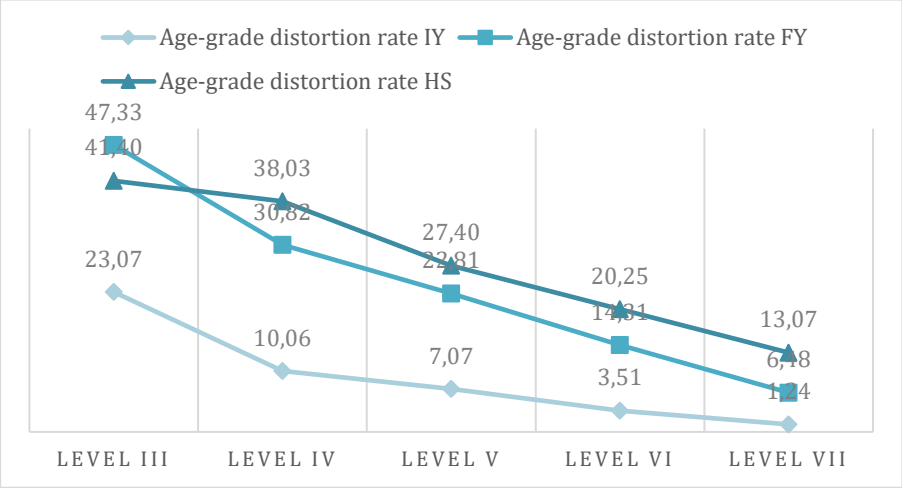
Correlation between the number of days the school was closed and the age-grade distortion					
Pearson Age-Grade Distortion EY	0.3965	**Spearman Age-Grade Distortion EY**	0.3981	**Kendall Age-Grade Distortion EY**	0.2931
p-values	0.0000	**p-values**	0.0000	**p-values**	0.0000
Pearson Age-Grade Distortion LY	0.3654	**Spearman Age-Grade Distortion LY**	0.3569	**Kendall Age-Grade Distortion LY**	0.2601
p-values	0.0000	**p-values**	0.0000	**p-values**	0.0000
Pearson Age-Grade Distortion HS	0.3481	**Spearman Age-Grade Distortion HS**	0.3522	**Kendall Age-Grade Distortion HS**	0.2588
p-values	0.0000	**p-values**	0.0000	**p-values**	0.0000

Source: Prepared by the authors

Figure 3 illustrates the relationship between INSE and the age-grade distortion rate, showing that, as the socioeconomic level increases, the age-grade distortion rate tends to

decrease. This reinforces the notion that schools in more affluent areas not only experienced shorter closure periods but also tend to enroll students with a reduced age-grade distortion.

Figure 3 – Relationship between INSE and Age-Grade Distortion Rate



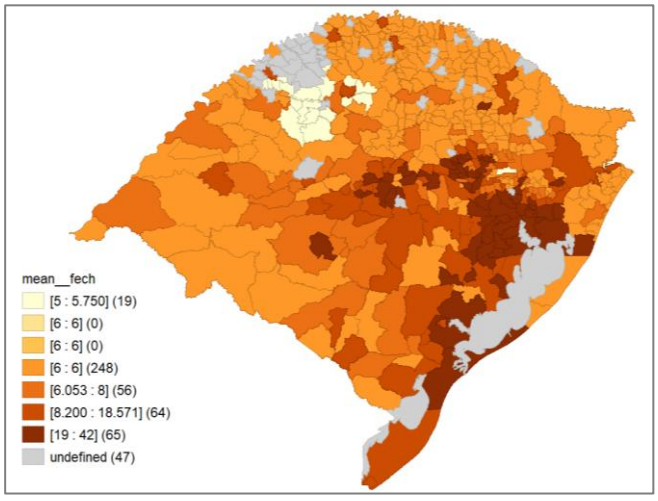
Source: Prepared by the authors.

5.2 Exploratory Spatial Data Analysis (ESDA)

Figure 4 shows the spatial distribution of the mean number of days that state schools in each municipality were closed due to the flooding in May 2024. It highlights the concentration of closures in the most affected regions, including the metropolitan region of Porto Alegre and the cities along Lagoa dos Patos. This pattern is associated with geographic and hydrological factors that exacerbated the impacts of heavy rains in these areas. The metropolitan region of Porto Alegre, including several densely populated cities, is at risk of flooding due to the convergence of multiple rivers flowing into the Guaíba River, such as the Gravataí, Sinos, Caí, and Jacuí Rivers. The Guaíba River serves as a natural recipient for this large volume of water, which has a tendency to overflow during prolonged periods of rain.

This may explain why schools in these regions remained closed for longer. The waters took a long time to recede because of the extensive drainage basin that converged toward the Guaíba River, the flat topography, and the limited drainage capacity of the areas near Lagoa dos Patos.

Figure 4. Spatial distribution of mean number of closing days/municipality

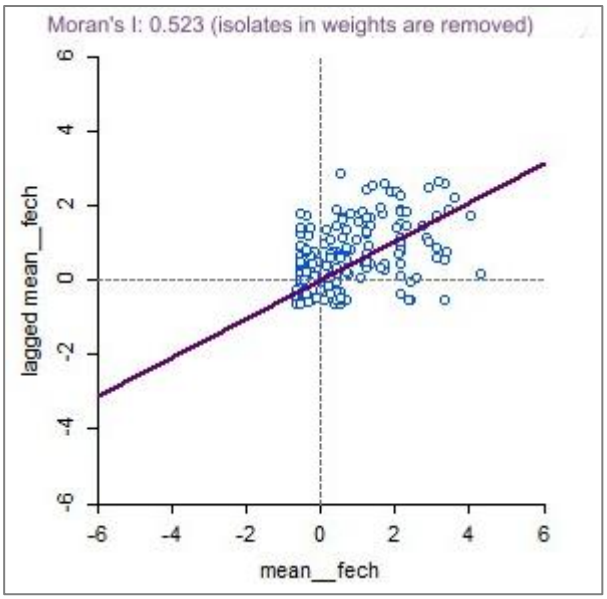


Source: prepared by the authors.

We used the exploratory spatial data analysis (ESDA) methodology to determine the presence of spatial autocorrelation in the mean number of days that schools remained closed due to flooding in Rio Grande do Sul municipalities. The first step in this approach is to define the spatial weight matrix, also known as the contiguity matrix. We chose the queen contiguity because it considers all connections between territories, better representing spatial interaction. The results of the Global Moran's I were positive and significant at 1%, with a value of 0.523. This indicates a positive spatial autocorrelation in the distribution of school closure days, allowing us to reject the null hypothesis of spatial randomness. The obtained value was higher than the critical statistic[20].

This result suggests the presence of uniform areas in Rio Grande do Sul, where municipalities with a high (or low) number of days of school closures due to floods are typically surrounded by municipalities exhibiting similar behavior. This suggests that floods cause geographic patterns of educational vulnerability, impacting entire regions differently based on their physical and socioeconomic characteristics.

Figure 5. Moran's I - mean number of closing days/municipality



Source: prepared by the authors

Figures 5 and 6 present the Univariate Local Moran's Index, represented in LISA cluster maps, to analyze spatial patterns and identify regions with the highest concentration of days in which schools remained closed due to flooding.

These clusters are formed based on four distinct spatial patterns: high-high, low-low, high-low, and low-high. The more vibrant colors on the map indicate statistically significant clusters, while gray areas represent the absence of clusters. The red color, representing high-high clusters, indicates that municipalities with a high number of days of school closures are near other cities with a similar pattern, suggesting a geographic concentration of schools most affected by the floods. The low-low pattern, represented by the dark blue color, indicates that municipalities with few days of school closures are grouped, forming areas of lesser impact.

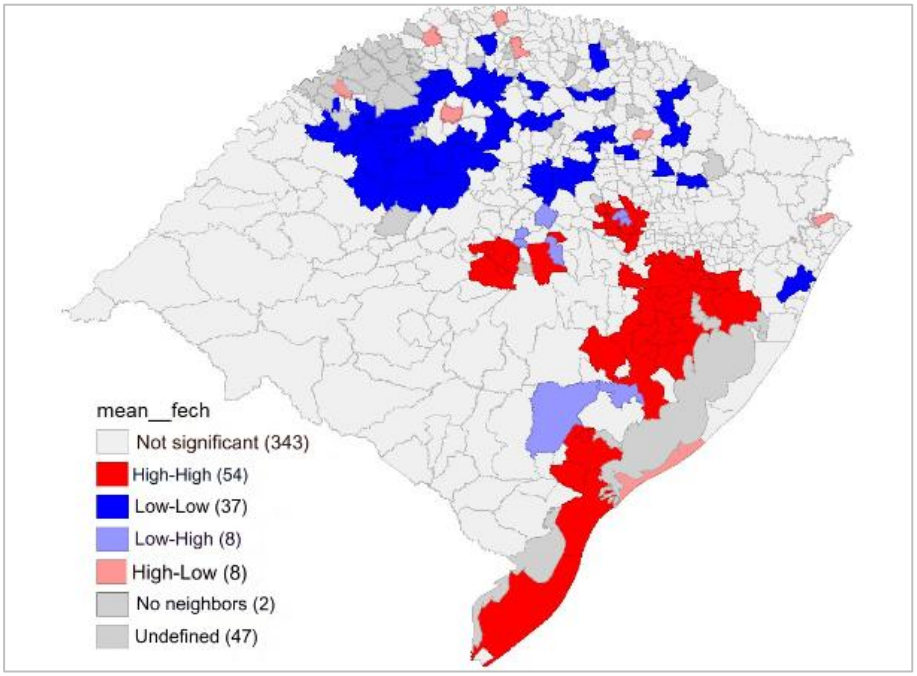
A significant high-high cluster of schools affected by floods was identified in the Porto Alegre Metropolitan Region (PAMR), resulting in many days of closure. In contrast, the state's

[20] The critical statistic (c) of Moran's I is given by $c = -[1/(n-1)] \approx -0.001$, where n is the number of municipalities.

northwest region presents a low-low cluster, indicating that schools in this area experienced fewer closure days.

These patterns reflect contrasting regional dynamics. The PAMR is a hydrologically more vulnerable area, while the northwest region of the state was less affected by the floods, which explains the low-low cluster in this area.

Figure 6. Cluster Map - mean number of closing days/municipality

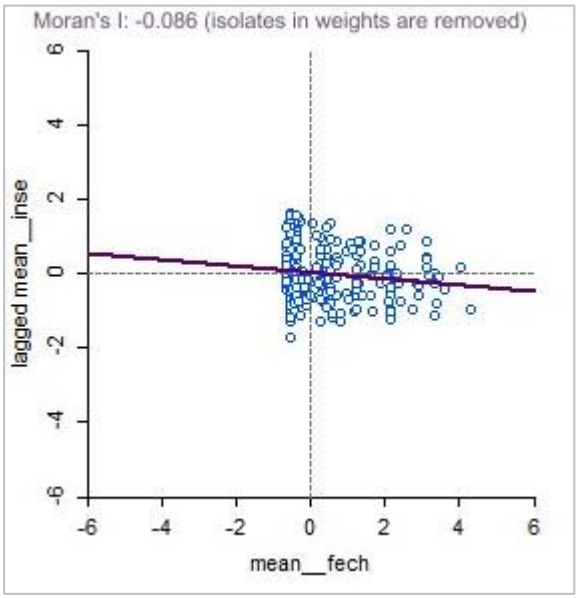


Source: prepared by the authors.

Figure 7 shows the negative and significant result of the Bivariate Moran's Index, with a value of -0.086. This indicates an inverse spatial autocorrelation between the mean number of days that schools were closed due to flooding and the Socioeconomic Level Index (INSE) by municipality. Therefore, municipalities with a lower socioeconomic level (low INSE) tend to be close to other cities with more days of school interruption, and vice versa.

This negative correlation suggests that schools in more socioeconomically vulnerable areas were disproportionately affected by the floods, experiencing more days of activity interruption. However, municipalities with higher socioeconomic levels tend to be in less affected areas and have fewer closure days. This spatial pattern confirms previous findings, highlighting disparities in school resilience and infrastructure across regions.

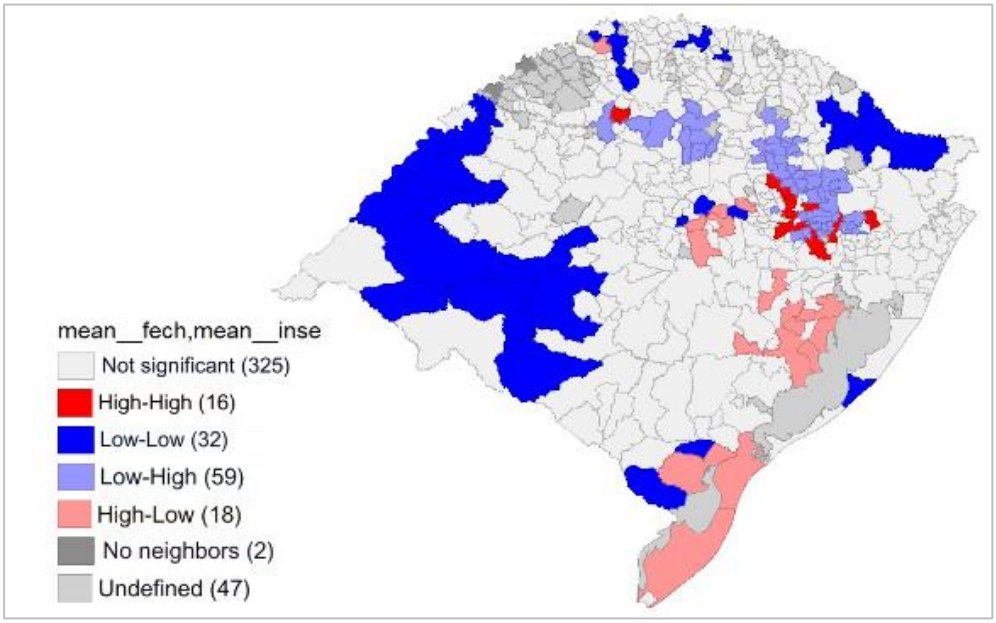
Figure 7. Bivariate Moran's I – mean number of closure days/municipality and INSE



Source: prepared by the authors

The high-low (pink) and low-high (purple) patterns demonstrate a spatial contrast, with cities experiencing many closure days being near others with few closure days, and vice versa, highlighting local variations within the same region.

Figure 8. Bivariate Cluster Map



Source: prepared by the authors

Figure 8 shows distinct spatial concentration patterns in different regions of Rio Grande do Sul. A significant high-low cluster encompasses 18 municipalities, located mainly in the Porto Alegre Metropolitan Region and in the microregions of Jaguarão and Litoral Lagunar.

This high-low pattern suggests that these municipalities experience a high number of school closure days while being surrounded by regions with a lower Socioeconomic Level Index (INSE). This suggests that schools in areas most impacted by flooding are located in adjacent regions with lower INSE, which may reflect disparities in the capacity to respond to climate events.

Children enrolled in schools located in areas with lower environmental resilience require a more robust support network, both at the individual and family levels, as they are more likely to experience the consequences of learning loss (Segarra-Almestica et al., 2022), as well as long-term effects on health and well-being throughout the life cycle (Currie *et al*., 2014).

Furthermore, the loss of family income caused by floods can have a direct impact on students' school retention. Families facing financial difficulties may be forced to withdraw their children from school to enter the labor market or to reduce education-related costs (Khan & Hussain, 2023). In this context, strengthening conditional cash transfer programs that link school attendance to benefit eligibility may be an effective strategy to ensure that students remain in school and continue their education.

On the other hand, there is a low-high cluster involving 59 municipalities, which are partially concentrated in the northeast and northwest regions. This pattern suggests that these municipalities with a low number of school closure days are surrounded by areas with a higher INSE.

6 Final Considerations

In May 2024, Rio Grande do Sul experienced devastating floods that impacted 90% of its 497 municipalities. This tragic event underscored the need to address climate change, which often does not receive adequate attention. In this study, the research examined the effects of floods and severe weather on education, emphasizing the susceptibility of students in low-income areas.Analysis of the data shows that the frequency of school closures is linked to socioeconomic factors. Schools in vulnerable areas experience more inactivity, which worsens social disparities and restricts development opportunities for children in these areas.

Given this scenario, the increasing incidence of extreme weather events and their repercussions on education requires an integrated approach that mitigates the immediate impacts of floods and promotes the resilience of vulnerable communities and schools. Public policies aimed at constructing and repairing school infrastructure and providing post-disaster educational support programs are crucial to prevent setbacks in education.The analysis of the spatial distribution of days when schools were closed due to the floods in May 2024 showed a significant concentration in the most affected regions, including the Porto Alegre Metropolitan Region and areas near Lagoa dos Patos. This reflects geographic and hydrological factors that intensified the effects of the heavy rains. The vulnerability of this region results from the convergence of multiple rivers into the Guaíba River, which serves as a natural receptor, causing overflow during extended periods of rainfall.

The results of the Exploratory Spatial Data Analysis (ESDA) indicated a significant positive spatial autocorrelation in the mean number of days of school closure. This suggests that municipalities with either high or low numbers of days with school closures are clustered together, highlighting geographic patterns of educational vulnerability. LISA cluster maps identified a high-high cluster in the Porto Alegre Metropolitan Region, where schools faced many days of closure. This is in contrast to the northwest region of the state, which presented a low-low cluster, evidencing fewer disruptions.Furthermore, the results indicate that municipalities with lower socioeconomic status have more days of closure, exacerbating inequality in school resilience. School performance deteriorates with prolonged school closures, especially impacting students in flood-prone areas. These findings emphasize the

impact of floods on education in Rio Grande do Sul and the necessity for tailored mitigation strategies based on regional characteristics.

Based on our results, we recommend that policies be formulated to develop municipal education contingency plans that include rapid actions to resume classes, internet access, and equipment for emergency remote learning. For the initial grades, it is important that schools maintain close contact with students' families so that, in an emergency situation, parents or guardians are informed about how to support their studies at home.

Learning recovery programs and psychosocial support for students and teachers should also be implemented in the most affected schools, especially those located in municipalities with low INSE. These actions are essential to mitigate the adverse effects of climate events on the right to education, especially among the most vulnerable populations. The need for public policies aimed at the adaptation and rapid recovery of school infrastructure is also highlighted, ensuring that school buildings are more resistant to disasters and can be quickly reactivated after extreme events.

In addition to educational and school infrastructure measures, investment in preventive structural and environmental actions is essential to reduce the frequency and severity of floods. This includes strengthening urban drainage systems, expanding the mapping of risk areas, controlling the occupation of flood zones, and encouraging environmental preservation through reforestation and sustainable soil management. Integration between educational, environmental, and civil defense policies is essential for municipalities to be better prepared to face natural disasters, protecting both schools and the communities in which they are located.

There are a few limitations to this study. Our approach focuses on exploring factors associated with floods and their effects on education without seeking to establish causal relationships. Furthermore, there is a lack of updated data on age-grade distortions, socioeconomic index, and school performance, which may restrict the depth of the analysis. These gaps make it challenging to fully comprehend how these variables impact students' resilience and academic performance during natural disasters.

References

ALMEIDA, E. Econometria Espacial Aplicada. Campinas, SP: Alínea Editora , 2012.

AROURI, Mohamed; NGUYEN, Cuong; YOUSSEF, Adel Ben. Natural disasters, household welfare, and resilience: evidence from rural Vietnam. **World development**, v. 70, p. 59-77, 2015.

CARDOSO, Sónia Goulart et al. School meals and food poverty: Children's views, parents' perspectives and the role of school. **Children & Society**, v. 33, n. 6, p. 572-586, 2019.

CONVERY, Ian; BALOGH, Ruth; CARROLL, Bob. 'Getting the kids back to school': education and the emotional geographies of the 2007 Hull floods. **Journal of flood risk management**, v. 3, n. 2, p. 99-111, 2010.

CUNHA, Flavio; HECKMAN, James. The technology of skill formation. American Economic Review, v. 97, n. 2, p. 31-47, 2007

CURRIE, Janet et al. What do we know about short-and long-term effects of early-life exposure to pollution?. Annu. Rev. Resour. Econ., v. 6, n. 1, p. 217-247, 2014.

CURRIE, Janet; ALMOND, Douglas. Human capital development before age five. In: Handbook of Labor Economics. Elsevier, 2011. p. 1315-1486.

Drake L, Fernandes M, Aurino E, et al. School Feeding Programs in Middle Childhood and Adolescence. In: Child and Adolescent Health and Development. 3rd ed. The International

Bank for Reconstruction and Development / The World Bank, Washington (DC); 2017.Disponível em: https://pubmed.ncbi.nlm.nih.gov/30212132/

EIDE, Eric R.; SHOWALTER, Mark H. The effect of grade retention on educational and labor market outcomes. **Economics of Education review**, v. 20, n. 6, p. 563-576, 2001.

FERRÃO, M. E. et al. O SAEB - Sistema Nacional de Avaliação da Educação Básica: objetivos, características e contribuições na escola eficaz. **Revista Brasileira de Estudos de População**, v. 18, n. ½, p. 111-130, 2001.

Ferrão, M. E., Costa, P. M., & Matos, D. A. S. (2017). The relevance of the school socioeconomic composition and school proportion of repeaters on grade repetition in Brazil: a multilevel logistic model of PISA 2012. Large-Scale Assessments in Education, 5(1), 7. https://doi.org/10.1186/s40536-017-0036-8

GONÇALVES, Flávio de Oliveira; FRANÇA, Marco Túlio Aniceto. Transmissão intergeracional de desigualdade e qualidade educacional: avaliando o sistema educacional brasileiro a partir do SAEB 2003. **Ensaio: Avaliação e Políticas Públicas em Educação**, v. 16, p. 639-662, 2008

GROSSMAN M. On the concept of health capital and the demand for health. The Journal of Political Economy, 80(2): 223-255, 1972.

KHALID, Nazar et al. Floods and Children's Education in Rural India. **RSF: The Russell Sage Foundation Journal of the Social Sciences**, v. 10, n. 1, p. 230-254, 2024.

KHAN, Qaisar; HUSSAIN, Karrar. Gone with the Flood: Natural Disasters and Children's Schooling in Pakistan. **The BE Journal of Economic Analysis & Policy**, v. 23, n. 1, p. 271-283, 2023.

MANACORDA, Marco. The cost of grade retention. Review of Economics and Statistics, v. 94, n. 2, p. 596-606, 2012.

MARCHEZINI, Victor; MUÑOZ, Viviana Aguilar; TRAJBER, Rachel. Vulnerabilidade escolar frente a desastres no Brasil. **Territorium**, n. 25 (II), p. 161-178, 2018.

MCCOY, Ann R.; REYNOLDS, Arthur J. Grade retention and school performance:: An extended investigation. **Journal of school psychology**, v. 37, n. 3, p. 273-298, 1999.

MUDAVANHU, Chipo. The impact of flood disasters on child education in Muzarabani District, Zimbabwe. **Jamba: Journal of Disaster Risk Studies**, 2014.

MUNSAKA, Edson; MUTASA, Sebia. Flooding and its impact on education. **Natural Hazards-Impacts Adjustments and Resilience**, 2021.

NDUE, Kennedy; BAYLIE, Melese Mulu; GODA, Pál. Determinants of rural households' intensity of flood adaptation in the Fogera Rice plain, Ethiopia: evidence from generalised Poisson regression. **Sustainability**, v. 15, n. 14, p. 11025, 2023.

NGUYEN, Cuong Viet; MINH PHAM, Nguyet. The impact of natural disasters on children's education: Comparative evidence from Ethiopia, India, Peru, and Vietnam. **Review of development Economics**, v. 22, n. 4, p. 1561-1589, 2018.

PALACIOS, Paola; ROJAS-VELÁSQUEZ, Libardo. Impact of weather shocks on educational outcomes in the municipalities of Colombia. **International Journal of Educational Development**, v. 101, p. 102816, 2023.

PATRINOS, Harry Anthony; PSACHAROPOULOS, George. Socioeconomic and ethnic determinants of age-grade distortion in Bolivian and Guatemalan primary schools. **International Journal of Educational Development**, v. 16, n. 1, p. 3-14, 1996.

PONTILI, R.; KASSOUF, A. Is Age-Grade distortion in Brazil's primary public education system more closely associated to school infrastructure or to family characteristics. **Well-being and social policy**, v. 4, n. 1, p. 29-54, 2008.

SANTOS, Diego Jatobá dos; PEDRA, George Ulguim; SILVA, Marcelo Guatura Barbosa da; GUIMARÃES JÚNIOR, Carlos Augusto; ALVES, Lincoln Muniz; SAMPAIO, Gilvan; MARENGO, José Antônio. Future rainfall and temperature changes in Brazil under global warming levels of 1.5ºC, 2ºC and 4ºC. **Sustainability in Debate**, *[S. l.]*, v. 11, n. 3, p. 57–90, 2020. DOI: 10.18472/SustDeb.v11n3.2020.33933. Disponível em: https://periodicos.unb.br/index.php/sust/article/view/33933. Acesso em: 21 aug. 2024.

SEGARRA-ALMÉSTICA, Eileen et al. The effect of consecutive disasters on educational outcomes. **International Journal of Disaster Risk Reduction**, v. 83, p. 103398, 2022.

SINDIQUE, Cláudio. O uso das metodologias activas de aprendizagem para a promoção de autonomia no estudante: uma análise a partir de Paulo Freire. **Tecnologias, sociedade e conhecimento**, v. 8, n. 2, p. 48-68, 2021.

STANKE, Carla et al. The effects of flooding on mental health: Outcomes and recommendations from a review of the literature. **PLoS currents**, v. 4, 2012.

Yoon J, Nozue M. The Role of School Meal Service Programs. J Nutr Sci Vitaminol (Tokyo). 2022;68(Supplement):S87-S88. doi: 10.3177/jnsv.68.S87. PMID: 36437030.

ZHAO, Chunkai; CHEN, Boou; SONG, Zhiyong. School nutritious feeding and cognitive abilities of students in poverty: Evidence from the nutrition improvement program in China. **Children and Youth Services Review**, v. 159, p. 107519, 2024.