The long-term impact of in-utero exposure to natural disasters: Evidence from the 2010 Pakistan flood

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Abstract

This paper uses the 2010 flood as a natural experiment to measure the long-term impacts on human capital. Microdata from the years 2019 and 2021 indicate that cohorts in utero during the flood displayed reduced rates of functional and cognitive development, decreased educational attainment, and increased learning losses compared with other birth cohorts and unaffected children. In addition, the exposed households to the flood have lower income, lower housing conditions, and higher food insecurity compared with non-exposed households.

Keywords: Flood 2010, Natural Disaster, In-Utero Exposure, Children Development, Economic Outcomes
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1 Introduction

In recent years, scholarly interest has burgeoned around the intricate nexus between environmental stressors and human development, as global climatic challenges become more pronounced. This study contributes to this discourse by rigorously investigating the repercussions of flooding during the in-utero period on child development, educational outcomes, and household well-being. Grounded in empirical evidence drawn from Pakistan Social Living Measurement (PSLM) & Annual Statistics of Education Report (ASER) microdata and geocoded data of the 2010 flood, our research integrates advanced statistical methods to yield nuanced insights into the multifaceted impacts of floods.

There is a growing literature on the impacts of natural disasters on socioeconomic outcomes. Several within-country studies examine the effect of natural disasters on household income, expenditures, and poverty using micro-data such as in Vietnam by (Bui et al., 2014), in Sri Lanka by (Keerthiratne and Tol, 2018), in South Asian countries by (Kumar et al., 2021), etc. These disasters have a number of negative consequences on climate change, food security, nutrition, and socioeconomic conditions.

Natural disasters are believed to directly impact national income, and socio-economic status and exacerbate poverty (Almond, 2006) & (Case et al., 2002); however, little is known about to what extent they affect children's and socioeconomic outcomes in the longer run. In the case of Pakistan, the 2010 flood impact in the longer run is not yet answered, particularly in the case of educational outcomes, functional abilities, cognitive development, income, housing conditions, and food security.

Structured across distinct panels, our analysis scrutinizes various dimensions, beginning with child development indices. Consistent with the findings of (Lee, 2014; Black et al., 2007; Currie, 2011; Dunkel Schetter, 2011; Du et al., 2010; Ahern et al., 2005), our results reveal a significant negative association between flood exposure during the in-utero period and indices of overall child development, functional development, and cognitive development. This echoes the growing body of literature highlighting the susceptibility of early-life developmental trajectories to environmental perturbations (Mallett and Etzel, 2018; Reynolds et al., 2013; Tong et al., 2011; Barker, 1992).

Transitioning to educational outcomes, our study aligns with the findings of (Caruso, 2017; Figlio et al., 2014; Hynes et al., 2013; Black et al., 2007), elucidating the multifaceted impact of floods on enrollment ratios, early childhood enrollment delays, and grade levels. These results underscore the pertinence of considering environmental factors in educational policy formulations in emphasizing the need for climate-resilient education systems.

Expanding the scope to household economic dimensions, our research resonates with seminal works by Hart (2009) and Edwards et al. (2021), which stress the far-reaching consequences of environmental stressors on economic well-being. We observe discernible causation between flood exposure and diminished financial capacity, housing conditions, and monthly income, adding granularity to the understanding of household resilience in the face of environmental adversities.

2 Pakistan 2010 Flood

The flood in Pakistan began in late July, resulting in the brunt of the damage and loss. It affected more than 20 million people, caused between 1,800 and 2,000 causalities, and damaged or destroyed approximately 1.7 million houses, making it the worst flood in Pakistan's modern history (Fair et al., 2017). The women of childbearing age in lower socioeconomic status families were most affected by the flood (Nasir, 2021). A Fall 2010 survey of 1,769 households in 29 severely flood-affected districts found that 54.8% of households reported damage to their homes, 77% reported at least one household member with health problems, and 88% reported a significant reduction in household income (Kirsch, 2012). In Figure 1, we can observe the extent of the Pakistan 2010 flood. This figure, based on data from United Nations (UN) Office for the Coordination of Humanitarian Affairs (OCHA)[1], illustrates the flood-affected regions as of August 27, 2010.

While the scale of the disaster was unprecedented, it was not nearly as bad as many observers predicted at the time. By mid-August the death toll from the floods was

[1]Source: UN OCHA (https://www.unocha.org/publications/map/pakistan/pakistan-flood-extent-27-aug-2010-and-flood-affected-districts-26-aug-2010)

estimated to be about 1,600 people. An editorial in The Economist on August 21 expected that number to increase dramatically, arguing that "it is no more than the plain truth that the worst is yet to come–in terms of hunger, disease, looting, and violence as victims scramble to save themselves and their families."

The 2010 disaster was a significant outlier in Pakistan's flood history. Figure 2 shows standardized values for the number affected, displaced, and killed by floods over the past few decades. The upper part of the figure presents data from the International Disaster Database (EM-DAT) hosted by the Center for Research on the Epidemiology of Disasters (2013) (data range 1975–2012), and the lower graph draws on data from the Global Active Archive of Large Flood Events of the Dartmouth Flood Observatory (DFO) (2013) (data range 1988–2012). In terms of the number affected and the number temporarily displaced, the 2010 flood was the largest in the history of Pakistan by several orders of magnitude, and almost twice as devastating as the next largest flood according to the EM-DAT[2].

Despite extensive and concerted efforts at local, national, and global levels to address the aftermath of the 2010–11 floods, their lasting impact on various socioeconomic indicators persists. In response to the unprecedented devastation, the Pakistani government, civil society, and the international community rallied together to coordinate relief efforts. The National Disaster Management Agency (NDMA) played a pivotal role in directing these initiatives, collaborating closely with federal ministries, armed forces, and donors (Ahmed, 2010; Khan and Mughal, 2010; UN OCHA, 2010).

International support, exemplified by the United Nations' appeal for $460 million in immediate assistance, garnered a substantial commitment of nearly $1.792 billion by November 2010. Key contributors included the United States, private entities, and Saudi Arabia. The subsequent increase in total commitments to over $2.653 billion by April 2013 reflected sustained global engagement in addressing the crisis (UN OCHA, 2010, 2013).

Additionally, spontaneous self-help initiatives emerged at the local level, with affected individuals and communities taking proactive measures to salvage belongings and un-

[2]The next largest was the 1992 flood which affected 12.8 million, temporarily displaced 4.3 million, and killed at least 1,446 people.

dertake essential repairs. Civil society, operating at grassroots levels, organized relief efforts, collecting and distributing resources. Despite the commendable local response, documented by scholars from Pakistan's Sustainable Development Policy Institute, the long-term consequences of the flood on socioeconomic factors, such as child development, health, education, income, and food security, persist. This enduring impact is revealed through a robust causal methodology, highlighting the resilience of the flood's adverse effects despite extensive collaborative endeavors (Shahbaz et al., 2012; Halvorson and Parker Hamilton, 2010).

3 Methodology

3.1 Data Sources

We leverage three data sources in our analysis: (1) geocoded data on the floods; (2) nationally representative microdata collected by the Pakistan Board of Statistics (PBS) as PSLM 2019-20 & ASER 2021; and (3) a range of geospatial variables that predict ex-ante flood risk.

3.1.1 Data on Flood

Geo-spatial data on the 2010 and 2011 floods come from the United Nations Institute for Training and Research's (UNITAR) Operational Satellite Applications Program (UNOSAT) (United Nations Institute for Training and Research, 2003). These data combine multiple different sources and are the most precise data we know of on those floods, providing estimates of flood extent at 100 m×100 m resolution. We overlapped various UNOSAT images to generate a layer of maximal flood extent in 2010, 2011, and 2012.

We measure flood exposure with objective measures based on geo-spatial data. Using the 2010 Landscan gridded (5 km × 5 km resolution) population data (Oak Ridge National Laboratory, 2008), we calculate the percent of the population exposed to the floods for each of the districts. The UNOSAT data underestimate the floods' impacts in steep areas where the flood waters did not spread out enough to be identified with overhead imagery but where contemporaneous accounts clearly show there was major damage at the bottom of river valleys.

3.1.2 Data on Outcome Variables

The PSLM data stands as a vital resource in our study, offering a comprehensive examination of various social and economic aspects across the nation. Conducted by PBS, this nationally representative survey captures a wide array of indicators related to household demographics, income, employment, education, health, and housing conditions. With an annual frequency, the PSLM provides a valuable snapshot of living standards, allowing for the exploration of trends and changes over time. Particularly pertinent to our study, the education module of PSLM contributes critical insights into educational attainment, learning outcomes, and other factors for cohorts affected by the 2010 flood.

On the other hand, the ASER, an annual national assessment facilitated by Idara-e-Taleem-o-Aagahi (ITA) and collaborative partners, holds a distinct focus on evaluating the status of education in both rural and urban areas of Pakistan. ASER uniquely prioritizes the assessment of learning levels in reading and arithmetic, providing a nuanced understanding of the effectiveness of the education system. Its emphasis on rural regions, where educational challenges may be more pronounced, aligns with our study's interest in exploring the impacts of the 2010 flood on diverse communities. The active involvement of community-based volunteers in conducting assessments fosters community engagement and ensures a grassroots perspective in the evaluation process.

In our study, the integration of these two datasets becomes paramount. The PSLM data, with its broad coverage and household-level insights, complements the ASER data, which hones in on learning assessments and educational quality. By leveraging both datasets, we aim to offer a comprehensive analysis of the long-term impacts of the 2010 flood on human capital. Specifically, the education-focused lens provided by PSLM and ASER enhances our understanding of cognitive development and educational attainment among cohorts exposed to natural disasters. Together, these datasets provide a robust foundation for unraveling the multifaceted consequences of the 2010 flood on individuals and households in Pakistan, shedding light on both the immediate and enduring effects on human capital.

3.1.3 Treatment Variable

In Tables 1, 2, and 3, the treatment variables are formed through interaction terms. Specifically combining birth cohorts and a flood dummy variable in Panel A of the tables and flood exposure in Panel B of the tables. Birth cohorts represent groups of children born in different timeframes before, during & after the flood, and the flood dummy variable indicates whether the districts were exposed to the 2010 flood. The control group includes neighboring cohorts of the treatment group as well as all cohorts from unaffected districts by the flood, ensuring a comprehensive analysis by comparing both directly impacted and proximate cohorts and districts for contextual understanding of in utero group. To account for potential age-related influences on outcome variables, age fixed effects are introduced at the levels of months and years, allowing for a nuanced examination of age-related variations within the dataset.

$$\text{Flood Dummy} = \begin{cases} \text{Cohorts} & \begin{cases} = 1 & \text{if Child is exposed to flood in-utero} \\ = 0 & \text{if Child is not exposed to flood in-utero} \end{cases} \\ \text{Flood} & \begin{cases} = 1 & \text{if District is exposed to flood} \\ = 0 & \text{if District is not exposed to flood} \end{cases} \end{cases}$$

$$\text{Flood Intensity} = \begin{cases} \text{Cohorts} & \begin{cases} = 1 & \text{if Child is exposed to flood in-utero} \\ = 0 & \text{if Child is not exposed to flood in-utero} \end{cases} \\ \text{Flood} & \begin{cases} = & \text{Flood Intensity to the District} \\ = 0 & \text{if District is not exposed to flood} \end{cases} \end{cases}$$

An innovative addition to the analysis is the inclusion of functional abilities, a crucial aspect not extensively measured in prior literature. Functional abilities serve as a pivotal component in assessing the long-term effects of in-utero exposure to the 2010 flood, extending the evaluation beyond typical educational & cognitive metrics. The negative impact observed in these functional abilities provides an additional layer of understanding the flood's enduring implications on child development.

In Tables 4 and 5, Panel A, the treatment variable takes the form of the interaction of the flood time period with the flood dummy. Panel B, an additional treatment variable is - the interaction of flood exposure with affected districts. This variable delves into the heterogeneity of impacts within districts that experienced the flood. It helps unravel localized effects, capturing variations in outcomes among districts based on their level of exposure and the subsequent response to the flood. This interaction provides insights into the temporal evolution of the flood's impact, exploring how effects may vary across different phases of the post-flood period.

By incorporating these treatment variables, Tables 4 and 5 offer a detailed exploration of the temporal dynamics and district-specific nuances in the aftermath of the 2010 flood. This comprehensive approach enhances the robustness and depth of the study's findings, providing valuable insights into the evolving impact of natural disasters on various outcomes.

3.1.4 Control Variables

Control variables in the study encompass a range of demographic and contextual factors. Gender, age, and education serve as fundamental demographic controls, ensuring a critical examination of outcomes. Migration and displacement factors provide insights into population movements and potential disruptions caused by the flood. The variable "flood risk" contributes to understanding the predisposition of certain areas to flooding. Employment status is included to gauge the economic stability of households. Moreover, the educational backgrounds of both fathers and mothers are controlled for, offering a comprehensive view of the familial influence on outcomes. These control variables collectively enhance the study's analytical depth, allowing for a more rigorous and robust exploration of the long-term impacts of the 2010 flood on various dimensions of human capital. The control variables for each of the regression model is given in the table notes.

3.2 Specification

$$Y_{ihdpt} = \beta_0 + \beta_1 \text{Treat}_{ihdp} + \beta_2 \text{Post}_t + \beta_3 (\text{Treat}_{ihdp} \times \text{Post}_t) + \gamma_{ihdp} + \tau_t + \delta X_{ihdpt} + \epsilon_{ihdpt} \quad (1)$$

where:

Y_{ihdpt} is the outcome for individual i in household h in district d in province p at time t,
Treat_{ihdp} is the treatment indicator for individual i in household h in district d in province p,
Post_t is the indicator of the time of the flood,
for the children's outcomes it is the period of in-utero during the flood, and
for the other outcomes it is the time period of the flood.
γ_{ihdp} is the district and province fixed effects for individual i in household h,
τ_t is the time (year–month) fixed effects for individual i,
X_{ihdpt} represents control variables,
ϵ_{ihdpt} is the error term.

4 Findings

4.1 Health Outcomes

In the past few decades flooding has been the most common type of disaster globally, responsible for almost half of all victims of natural disasters and economic losses (Alderman et al., 2012). The health consequences of floods depend on geographic and socioeconomic factors, as well as the baseline vulnerability of the populations affected (Ahern et al., 2005; Du et al., 2010). Research across various disciplines suggests that in utero exposure to negative health shocks has strong and persistent effects on health and socioeconomic outcomes at older ages (Lee, 2014). Health at birth is predictive of important child outcomes including educational attainment and adult earnings. Hence, economists are increasingly concerned with understanding the impacts of conditions during pregnancy on birth outcomes (Black et al., 2007; Currie, 2011). One intriguing hypothesis is that stress during pregnancy could have negative effects on the fetus through neuroendocrine changes, changes in immune function, and/or behavioral channels (Dunkel Schetter, 2011). The findings of this study align with the papers cited above.

4.1.1 Child Development

According to the fetal programming hypothesis, in-utero exposure to several maternal factors, such as depression, anxiety, major life events, and/or stressors, can have potentially permanent and long-lasting effects on postnatal development (Laplante et al., 2018; Barker, 1992). Natural disasters like floods can have a significant impact and indicate an association between high levels of prenatal stress and poor pregnancy outcomes, such as preterm birth and lower birth weight, stunting, and negative health outcomes in children (Mallett and Etzel, 2018). The severity of exposure affects the mental/physical health of the mother which itself influences offspring development independently of prenatal stress (Reynolds et al., 2013). By affecting the physical and mental health of pregnant mothers and their ability to access health services, floods may impact the health of newborns (Tong et al., 2011). A study conducted with women who became pregnant within six months following Katrina showed that severe hurricane exposure was significantly associated with worse birth outcomes (Xiong et al., 2008).

In light of the existing literature, the the column 1 of Table 1, extend the evidence on the dynamics between flood exposure during the in-utero period and child development. In Panel A, focusing on Child Development indices, the binary treatment indicator 'Flood' exhibits a statistically significant negative coefficient on Child Development (-0.038, $p < 0.001$). These findings suggest a robust association between in-utero flood exposure and reduced child development, aligning with prior research on early-life environmental stressors.

Moving to Panel B, where 'Flood Exposure' serves as a continuous index of flooding severity, the negative coefficients persist, albeit with varying magnitudes. Notably, the cognitive development dimension is particularly sensitive to the intensity of flooding, as evidenced by a coefficient of (-0.019, $p = 0.003$).

Crucially, the inclusion of controls for key covariates including age, gender, area type (rural or urban), level of education, distance to school, mobility, displacement, & past flood risk to the district, area fixed effects including province & district, and time fixed effects enhances the robustness of these findings. The persistence of statistically significant coefficients even after accounting for these factors reinforces the argument for the independent influence of in-utero flood exposure on child development, bolstering the findings on the lasting impact of early-life adversities.

Further, the considerable sample size (N = 19091), spanning across 133 districts and 11864 clusters, lends statistical power to these results. The clustering of standard errors at the household level (11864) ensures the reliability of the presented estimates. The meticulous attention to methodological details, such as controlling for past flood risk and employing area and time-fixed effects, aligns with the methodological rigor contributing to the robustness and generalizability of our findings.

4.1.2 Functional Development

Evidence suggests that prenatal maternal stress (PNMS) is associated with sub-optimal development in children (Van den Bergh et al., 2020). Low birth weight and preterm birth are associated with higher risks of significant physical and mental impairments (Saigal et al., 1991; Reichman et al., 2008; Goosby and Cheadle, 2009). Our findings align with the literature, in Column 2 of Table 1, we extend our exploration of the impact of in-utero flood exposure, focusing on Functional Development outcomes. Panel A reveals a significant negative coefficient associated with the 'Flood' binary treatment indicator (-0.014, $p = 0.006$). This result emphasizes the adverse effects of flood exposure on functional aspects, which is a unique finding of this paper, encompassing hearing, seeing, and walking. The statistical significance persists in Panel B, where 'Flood Intensity' displays a coefficient of (-0.0062 $p = 0.043$). This suggests that the intensity of flooding during the in-utero period contributes to measurable impairments in functional development.

4.1.3 Cognitive Development

The origins of many behavioral and health outcomes in life can be traced back to the period in-utero when rapid alterations in the structure and function of the brain and body of the fetus take place (Barker, 2002; Glover, 2011; Gluckman et al., 2005). Many human studies have shown that mothers' exposure to disaster and stress alters the structure and function of offspring's brain (Babenko et al., 2015; Glover, 2011; Buss et al., 2010). Hong et al. (2021), found that fetal exposure to the 1974 Tornado Super Outbreak during later stages of pregnancy raised the probability of having at least one cognitive difficulty. Laplante et al. (2018), results suggest that prenatal maternal stress was related to lower cognitive abilities in 30-month-old toddlers who were exposed to Lowa Flood in-utero. Rosales-Rueda (2018), finds that children in utero during the 1997–1998 El Niño floods exposure during the first trimester results in cognitive deficits. Chang et al. (2022), finds that children who are exposed to rainfall shocks in-utero have lower cognitive skills at age 5 and age 15. Majid (2015) showed that children in Indonesia exposed to Ramadan in-utero scored 7.8% lower on cognitive tests. Many studies in medical sciences and psychology suggest that low birth weight and early malnutrition may lead to impaired cognitive development (Linnet et al., 2006; Mara, 2003; Shenkin et al., 2004).

In Column 3 of Table 1, we present the realm of Cognitive Development outcomes, shedding light on the relationship between in-utero flood exposure and cognitive abilities. In Panel A, the 'Flood' binary treatment indicator exhibits a negative coefficient of (-0.024 $p = 0.000$), signaling a statistically significant association between flood exposure during the in-utero period and compromised cognitive development. This aligns with existing literature emphasizing the vulnerability of cognitive functions to early-life development.

Panel B refines our understanding by introducing the continuous index 'Flood Intensity.' The negative coefficient of (-0.013 $p = 0.003$) highlights that, beyond binary exposure, the severity of in-utero flooding plays a discernible role in shaping cognitive outcomes. This key exploration underscores the importance of considering the intensity of environmental stressors in assessing their impact on cognitive development.

4.2 Educational Outcomes

The relationship between poor health at birth and negative educational outcomes is well documented (Fuller, 2014). There is a growing concern among economists and policymakers that negative conditions experienced early in life may have persistent effects (Caruso, 2017). Some studies have found evidence that health at birth measured by birthweight or gestational age is positively correlated with educational outcomes, and income in adult life (Figlio et al., 2014; Black et al., 2007; Moster et al., 2008). Exposure in utero to natural disasters generates an average reduction of 0.3 years of education. The results show that the children of women exposed to natural disasters are negatively affected by increased child labor and decreased education (Caruso, 2017). Caruso and Miller (2015) estimate that exposure in utero to the Ancash earthquake of 1970 generated a loss of 0.7 years of education. Caruso (2017) finds that exposure in utero to earthquakes in general generates a loss of 0.2 years of education. Children whose mothers had UIC < 150 μg/L had reductions of 10.0% in spelling, 7.6% in grammar, and 5.7% in English literacy performance compared with children whose mothers' UICs > 150 μg/L (Hynes et al., 2013). Similarly, the analysis of this paper in Table 2 & 3 provides evidence of in-utero flood exposure, presenting a nuanced examination of its impact on various dimensions of children's educational outcomes and learning levels using data from ASER.

Panel A of Table 2 examines children's educational trajectories, the 'Flood' variable in Column 1 reveals a statistically significant negative coefficient of (-0.040 $p = 0.000$), indicating a decreased likelihood of enrollment for those exposed to in-utero floods. Column 2, addressing the delay in enrollment, presents a noteworthy positive coefficient of (0.15 $p = 0.000$), signifying a substantial delay linked to early-life environmental stressors. Moving to Column 3, which assesses enrollment in Grade 5, the 'Flood' variable displays a statistically significant negative coefficient of (-0.0079 $p = 0.000$), underscoring a lasting impact on educational attainment.

Similarly, Panel B utilized flood exposure as a treatment variable. Column 1 reveals a statistically significant negative coefficient of (-0.032 $p = 0.000$), indicating a decreased likelihood of enrollment for those exposed to in-utero floods. Column 2, addressing the delay in enrollment, presents a noteworthy positive coefficient of (0.10 $p = 0.000$), signifying a substantial delay linked to early-life environmental stressors. Moving to Column 3, which assesses enrollment in Grade 5, the 'Flood' variable displays a statistically significant negative coefficient of (-0.0072 $p = 0.000$), underscoring a lasting impact on educational attainment.

Crucially, the inclusion of controls for key covariates including age, gender, area type (rural or urban), level of education, distance to school, mobility, displacement, & past flood risk to the district, area fixed effects including province & district, and time fixed effects enhances the robustness of these findings. The persistence of statistically significant coefficients even after accounting for these factors reinforces the argument for the independent influence of in-utero flood exposure on child development, bolstering the findings on the lasting impact of early-life adversities.

Further, the substantial sample size (N = 128519, 97422), spanning 133 district and 13474 & 11871 clusters, lends statistical power to these results. The clustering of standard errors at the household level ensures the reliability of the presented estimates. The meticulous attention to methodological details, such as controlling for past flood risk and employing area and time-fixed effects, aligns with the methodological rigor contributing to the robustness and generalizability of our findings.

Panel A of Table 3 examines children's educational trajectories using data from ASER, the 'Flood' variable in Column 1 reveals a statistically significant negative coefficient of enrollment (-0.015 $p = 0.029$) which seconds the findings from PSLM data in Table 2, Column 2 indicating a decreased language test score by standard deviation (-0.10 $p = 0.000$). Column 3, addressing the standard deviation score of maths, presents a negative coefficient of (-0.11 $p = 0.003$), signifying a substantial loss associated with early-life environmental stressors. Moving to Column 4, which assesses english scores, the 'Flood' variable displays a statistically significant negative coefficient of standard deviations (-0.072 $p = 0.003$), underscoring a lasting impact on educational attainment.

Similarly, Panel B utilized flood exposure as a treatment variable. Column 1 reveals a statistically significant negative coefficient of enrollment (-0.013 $p = 0.004$) which seconds the findings from PSLM data in Table 2 and improves the results of Panel A, Column 2 indicating a decreased language test score by standard deviation (-0.11 $p = 0.000$). Column 3, addressing the standard deviation score of maths, presents a negative coefficient of (-0.11 $p = 0.000$), signifying a substantial loss associated with early-life environmental stressors. Moving to Column 4, which assesses english scores, the 'Flood' variable displays a statistically significant negative coefficient of standard deviations (-0.078 $p = 0.000$), underscoring a lasting impact on educational attainment.

Crucially, the inclusion of controls for key covariates including age, gender, area type (rural or urban), level of education, distance to school, mobility, displacement, & past flood risk to the district, area fixed effects including province & district, and time fixed effects enhances the robustness of these findings. The persistence of statistically significant coefficients even after accounting for these factors reinforces the argument for the independent influence of in-utero flood exposure on child development, bolstering the findings on the lasting impact of early-life adversities.

Further, the substantial sample size (N = 227707, 194550), spanning 152 districts and 4406 villages & 79334 clusters at the household level, lends statistical power to these results. The clustering of standard errors at the household level ensures the reliability of the presented estimates. The meticulous attention to methodological details, such as controlling for past flood risk and employing area and time-fixed effects, aligns with the methodological rigor contributing to the robustness and generalizability of our findings.

4.3 Economic Outcomes

Weather shocks might affect crop production and the related changes in prices and income consequently would affect the consumption of food and other health inputs (Hoddinott, 2013; Skoufias and Vinha, 2013). Flood severely disrupts the livelihood in low-resource settings. Natural disasters like floods and tsunamis cause direct economic losses, physical injuries, and long-term psychological impacts, including post-traumatic stress disorder and anxiety in the affected population (Dai et al., 2017; Van Griensven et al., 2006). Natural disasters, particularly floods, affect millions of people, damage millions of hectares of agricultural land, and damage or destroy millions of houses and health facilities which ultimately lower the income of populations associated with agriculture (Maheen and Hoban, 2017). Since Pakistan's major share of the population is associated with agricultural income, we can relate the long-term security risks with the damaged crops and lower crop production. In Table 4, we investigate the impact of flood exposure on various dimensions of household well-being, focusing on financial capacity, housing conditions, and monthly income. Panel A, the coefficient for 'Flood' on the financial capacity of households is (-0.074 $p < 0.000$), indicating a statistically significant negative association similarly in panel B it is (-0.067 $p < 0.000$). This suggests that households exposed to floods experienced a reduction in financial capacity compared to those unexposed.

The housing condition is adversely affected by flood exposure, with a coefficient of (-0.13 $p < 0.000$) and for panel B it is (-0.080 $p < 0.000$). This implies that households exposed to floods during the specified year exhibit lower housing standards. The monthly income of households is significantly reduced following flood exposure, as indicated by the coefficient of (-1009.1 rupees per month $p = 0.014$). This highlights the economic strain experienced by households with floods. The results are robust utilizing the sample size (N = 770738), spanning 141286 clusters and 133 districts. In addition, the time-fixed effects and area-fixed effects consisting of the province and district have been used for a more conservative approach.

The persistent economic repercussions of the 2010 Pakistan flood extend far beyond the immediate aftermath, shaping the livelihoods of a predominantly agrarian population. With agriculture serving as the backbone of Pakistan's economy, the devastation wrought upon crops and arable land during the flood has had enduring consequences. According to estimates, the flood adversely affected over 2 million hectares of cultivated land, causing a substantial decline in agricultural productivity (International Federation of Red Cross and Red Crescent Societies, 2010). The economic impact on households, particularly those reliant on farming, is pronounced. The loss of crops and livestock has translated into a prolonged struggle for financial recovery, reflected in Table 4's examination of financial capacity, housing conditions, and monthly income. The negative coefficients associated with 'Flood' and 'Flood Intensity' underscore the enduring economic challenges faced by households exposed to the 2010 flood. Despite the passage of time, the economic scars of the flood persist, underscoring the need for targeted policies aimed at restoring and fortifying the agricultural backbone of Pakistan's economy.

4.4 Food Insecurity

Floods in developing countries have been associated with maternal and child malnutrition, food shortages, and decreased levels of breastfeeding in rural areas (Choudhury and Bhuiya, 1993; Barrios et al., 2000; Del Ninno and Lundberg, 2005; Adhisivam et al., 2006; Jayatissa et al., 2006). Flood-related destruction of crops resulted in a decrease in food supply (Mallett and Etzel, 2018). Climate change affects the health of children and pregnant women through an escalation in weather-related disasters, leading to decreased water quality and quantity, food shortages, and greater exposure to toxicants (Xu et al., 2012; Mallett and Etzel, 2018). Further, the effect of disasters on food insecurity was also studied by Hart (2009) & Edwards et al. (2021). We present similar findings with the evidence from causal method and microdata by examining the repercussions of flood exposure on household food security, financial constraints, access to nutritious food, variety in food consumption, and instances of meal skipping, we present the results in Table 5. The binary treatment indicator 'Flood' in Panel A and the continuous index 'Flood Intensity' in Panel B provide insights into the nuanced dynamics of how floods impact household food-related outcomes.

The coefficient on the overall food insecurity experience scale in Column 1 is (0.10 $p < 0.000$) and (0.047 $p < 0.000$). This positive coefficient suggests a statistically significant association between exposure to floods in 2010 and an elevated level of food insecurity within households.

Similarly, Flood exhibits a positive coefficient of (0.037 $p < 0.000$) and (0.023 $p < 0.000$) regarding concerns about food due to financial constraints. Similarly, the coefficient on limited access to nutritious food is (0.032 $p < 0.001$) and (0.009 $p < 0.001$). Further in column 4, the association between flood and limited variety in food consumption is indicated by a coefficient of (0.031 $p < 0.001$) and (0.007 $p < 0.016$). Last, contrary to the previous outcomes, the coefficient on meal skipping instances is (0.0026 $p = 0.408$), and the result is not statistically significant, however, the coefficient for flood exposure on meal skipping is highly significant (0.0079 $p < 0.000$).

The continuity of the positive coefficients in Panel B reinforces the robustness of the findings. 'Flood Intensity' exhibits positive coefficients across all outcomes, indicating that the severity of flooding contributes to adverse impacts on household food-related conditions.

All models include controls for key covariates, such as income, age, gender, area type, education, mobility, displacement, and past flood risk. The inclusion of area and time fixed effects enhances the reliability and generalizability of the results. The substantial sample size (N = 770738) and clustering of standard errors at the household level (141286) contribute to the statistical power of the estimates. The findings highlight the multifaceted challenges faced by households exposed to flooding, particularly in the realm of food security and consumption.

5 Research Relevance and Contribution

The findings of this study bear significant policy relevance and make significant contributions to the existing literature, providing valuable insights for policymakers and practitioners. First, the observed negative association between in-utero flood exposure and child development, as well as educational outcomes, highlights the importance of early-life interventions, particularly in the flood-risk areas of Pakistan. Policymakers should consider targeted programs focusing on maternal and child health during and after natural disasters, aiming to mitigate the potential long-term consequences on children's well-being and educational trajectories.

Second, the study emphasizes the need for enhanced disaster preparedness and response strategies, particularly for pregnant women and young children. Integrating maternal and child health considerations into disaster management plans can help minimize the impact of adverse events on developmental outcomes.

Given the substantial influence of in-utero flood exposure on educational outcomes, policymakers should prioritize the implementation of educational support programs for affected children. Tailored interventions, such as remedial classes, counseling services, and targeted learning resources, can help mitigate the negative effects on academic performance.

The research reveals that flood exposure disproportionately affects households with lower financial capacity and housing conditions. Policies aimed at reducing socioeconomic disparities, providing financial assistance, and improving housing conditions can contribute to breaking the cycle of intergenerational vulnerabilities exacerbated by environmental stressors.

Methodologically, this study contributes to the literature by controlling for key covariates, utilizing area and time-fixed effects, and employing a large and diverse dataset. Such methodological rigor enhances the robustness and reliability of the findings, providing a template for future research exploring the intersection of environmental stressors and developmental outcomes.

Finally. this study not only sheds light on the lasting impact of in-utero flood exposure on child development and education but also offers actionable insights for policymakers. By addressing the identified policy implications, stakeholders can work towards building resilient communities that prioritize the well-being and educational success of the youngest and most vulnerable members.

6 Conclusion

This study comprehensively investigates the enduring impacts of the 2010 flood on human capital, employing a rich dataset that integrates Pakistan Social and Living Standards Measurement and Annual Status of Education Report data. The findings, meticulously presented in Tables 1 through 5, unveil critical patterns in educational and child development outcomes, shedding light on persistent consequences.

We present the multifaceted and lasting effects of the 2010 flood, employing interaction terms of birth cohorts and flood exposure. The inclusion of functional abilities as a novel metric provides a deeper understanding of the flood's impact beyond traditional educational indicators. Key coefficients consistently reveal adverse outcomes, emphasizing reduced rates of functional and cognitive development, decreased educational attainment, and heightened learning losses among exposed cohorts.

Temporal dynamics are explored through the interaction of the flood time period with the flood dummy. Negative coefficients across different time periods underscore the prolonged impact of the flood on the studied outcomes. Meanwhile, Panel B delves into district-specific variations, emphasizing the heterogeneity in outcomes within districts that experienced the flood.

Extending the analysis, reaffirming the negative coefficients over time and providing critical insights into district-specific impacts. Control variables, encompassing gender, age, education, migration, displacement, flood risk, employment, and parental education, contribute to the depth of our analysis, revealing the intricate interplay of demographic and contextual factors in shaping post-flood outcomes.

The key coefficients unveiled throughout this study consistently highlight the remaining and multifaceted impacts of the 2010 flood on human capital in Pakistan. The incorporation of innovative metrics and detailed control variables enhances the depth and robustness of our analysis, contributing valuable insights for both academic research and policy formulation in the domain of disaster resilience and recovery. As we navigate the complex landscape of post-disaster recovery, these findings present the necessity of holistic approaches that consider various dimensions of human capital to foster resilient communities in the face of natural disasters.

7 Figures

Figure 1: Pakistan 2010 Flood Extent

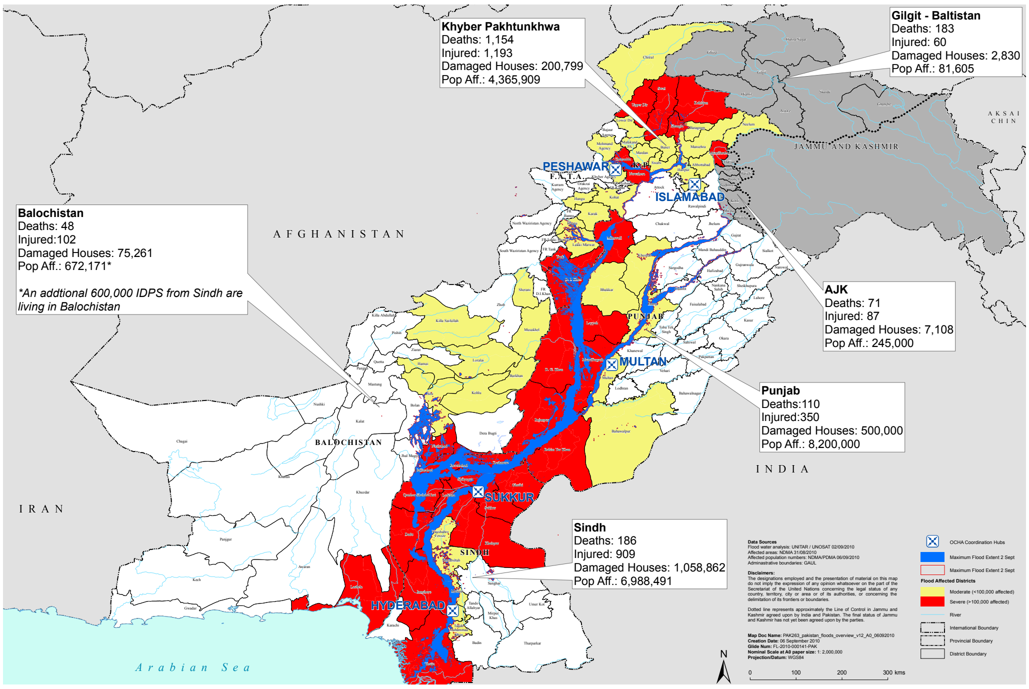
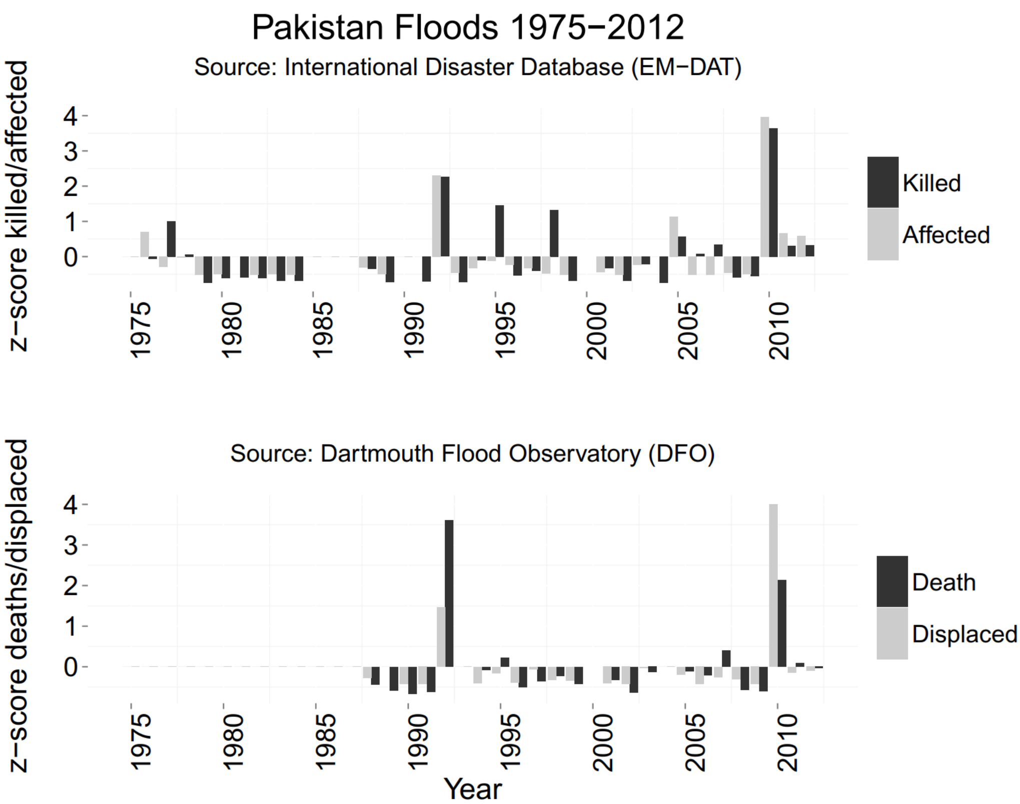


Figure 2: Loss of Human Capital (Standardized Values)



8 Tables

Table 1: Impact of Flood on Health Outcomes

	(1) Child Development	(2) Functional Development	(3) Cognitive Development
		Panel A	
Flood	-0.038	-0.014	-0.024
	(0.010)	(0.0052)	(0.0067)
	[0.000]	[0.006]	[0.000]
		Panel B	
Flood Intensity	-0.019	-0.0062	-0.013
	(0.0067)	(0.0031)	(0.0044)
	[0.004]	[0.043]	[0.003]
Controls	YES	YES	YES
Area Fixed Effects	YES	YES	YES
Time Fixed Effects	YES	YES	YES
No. of Districts	133	133	133
No. of Clusters	11864	11864	11864
N	19091	19091	19091

In panel A, the variable 'Flood' binary treatment indicator, taking the value of 1 if a child was exposed to flood during the time period in-utero, and 0 otherwise. Similarly, in panel B, the variable 'Flood Extent' represents a continuous index reflecting the severity of flooding experienced by a child during in utero. Both 'Flood' and 'Flood Intensity' are the interaction terms of flood and dummy for in-utero time period. Columns (1–3) present indices of child development characteristics: column 1 indicates overall child development, column 2 covers functional development (including hearing, seeing, and walking), and column 3 assesses cognitive development (embracing memory, understanding, and self-care). The regression model controls for all key covariates including age, gender, area type (rural or urban), level of education, distance to school, mobility, displacement, and past flood risk to the district. The area fixed effect includes the province and time fixed effects includes the month and year of birth of children. Standard errors, presented in parentheses, are clustered at the household level, and p-values testing a zero treatment effect are presented in brackets.

Table 2: Impact of Flood on Educational Outcomes – Enrollment

	(1) Children Enrollment	(2) Delay in Enrollment	(3) Enrolled in Grade 5
	Panel A		
Flood	-0.040	0.15	-0.0079
	(0.0041)	(0.011)	(0.0022)
	[0.000]	[0.000]	[0.000]
	Panel B		
Flood Intensity	-0.032	0.10	-0.0072
	(0.0025)	(0.0068)	(0.0012)
	[0.000]	[0.000]	[0.000]
Controls	YES	YES	YES
Area Fixed Effects	YES	YES	YES
Time Fixed Effects	YES	YES	YES
No. of Districts	133	133	133
No. of Clusters	13474	11871	11871
N	128519	97422	97422

In panel A, the variable 'Flood' binary treatment indicator, taking the value of 1 if a children was exposed to flood during the time period in-utero, and 0 otherwise. Similarly, in panel B, the variable 'Flood Extent' represents a continuous index reflecting the severity of flooding experienced by a child during in utero. Both 'Flood' and 'Flood Intensity' are the interaction terms of flood and dummy for in-utero time period. Columns (1–3) present educational outcomes for the children: column 1 is a dummy variable indicates the ratio of enrollment, column 2 covers the number of years delay in early childhood enrollment, and column 3 represents the current grade of children. The regression controls for all key covariates including age, gender, area type (rural or urban), distance to school, mobility, displacement, and past flood risk to the district. The area fixed effect includes the province and time fixed effects includes the month and year of birth of children. Standard errors, presented in parentheses, are clustered at the household level, and p-values testing a zero treatment effect are presented in brackets.

Table 3: Impact of Flood on Educational Outcomes – Learning Outcomes

	(1) Enrollment	(2) Language	(3) Math	(4) English
		Panel A		
Flood	-0.015	-0.10	-0.11	-0.072
	(0.0070)	(0.023)	(0.037)	(0.024)
	[0.029]	[0.000]	[0.003]	[0.003]
		Panel B		
Flood Intensity	-0.013	-0.11	-0.11	-0.078
	(0.0046)	(0.015)	(0.024)	(0.016)
	[0.004]	[0.000]	[0.000]	[0.000]
Controls	YES	YES	YES	YES
Area Fixed Effects	YES	YES	YES	YES
Time Fixed Effects	YES	YES	YES	YES
No. of Districts	152	152	152	152
No. of Villages	4406	4404	4404	4404
No. of Clusters	79334	76059	75889	75919
N	227707	194550	192371	191549

In panel A, the variable 'Flood' binary treatment indicator, taking the value of 1 if a children was exposed to flood during the time period in-utero, and 0 otherwise. Similarly, in panel B, the variable 'Flood Extent' represents a continuous index reflecting the severity of flooding experienced by a child during in utero. Both 'Flood' and 'Flood Intensity' are the interaction terms of flood and dummy for in-utero time period. Columns (1–4) present educational outcomes for the children: column 1 is a ratio of enrollment, column (2–4) represents the learning levels of children. The regression model controls for all key covariates including household characteristics income, age, gender, area type (rural or urban), father's & mother's education. The area fixed effect includes the province, district and village and time fixed effects includes the year of birth of children. Standard errors, presented in parentheses, are clustered at the household level, and p-values testing a zero treatment effect are presented in brackets.

Table 4: Impact of Flood on Economic and Housing Outcomes

	(1) Financial Capacity	(2) Housing Condition	(3) Monthly Income
	Panel A		
Flood	-0.074	-0.13	-1009.1
	(0.014)	(0.0038)	(412.3)
	[0.000]	[0.000]	[0.014]
	Panel B		
Flood Intensity	-0.067	-0.080	-473.2
	(0.0083)	(0.0023)	(247.8)
	[0.000]	[0.000]	[0.056]
Controls	YES	YES	YES
Area Fixed Effects	YES	YES	YES
Time Fixed Effects	YES	YES	YES
No. of Districts	133	133	133
No. of Clusters	141286	141286	141286
N	770738	770738	770738

In panel A, the variable 'Flood' binary treatment indicator, taking the value of 1 if a household who was exposed to flood during the year 2010, and 0 otherwise. Similarly, in panel B, the variable 'Flood Extent' represents a continuous index reflecting the severity of flooding experienced by a household. Both 'Flood' and 'Flood Intensity' are the interaction terms of flood and dummy for in-utero time period. Columns (1–4) present food insecurity outcomes for the households: column 1 is a overll food insecurity experience scale, column 2 represents the dummy for financial concern and worry about food for a household, column 3 covers the lack of availability of nutrious food, and column 4 represents the extreme food shortage and hunger. The regression controls for all key covariates including income, age, gender, area type (rural or urban), education, mobility, displacement, and past flood risk to the district. The area fixed effect includes the province and time fixed effects includes the month and year of birth of children. Standard errors, presented in parentheses, are clustered at the household level, and p-values testing a zero treatment effect are presented in brackets.

Table 5: Impact of Flood on Experienced Food Insecurity

	(1) Food Insecurity	(2) Food Concerns due to Financial Constraints	(3) Limited Access to Nutritious Food	(4) Limited Variety in Food Consumption	(5) Meal Skipping Instances
			Panel A		
Flood	0.10	0.037	0.032	0.031	0.0026
	(0.014)	(0.0044)	(0.0049)	(0.0049)	(0.0031)
	[0.000]	[0.000]	[0.000]	[0.000]	[0.408]
			Panel B		
Flood Intensity	0.047	0.023	0.0094	0.0070	0.0079
	(0.0085)	(0.0026)	(0.0029)	(0.0029)	(0.0019)
	[0.000]	[0.000]	[0.001]	[0.016]	[0.000]
Controls	YES	YES	YES	YES	YES
Area Fixed Effects	YES	YES	YES	YES	YES
Time Fixed Effects	YES	YES	YES	YES	YES
No. of Districts	133	133	133	133	133
No. of Clusters	141286	141286	141286	141286	141286
N	770738	770738	770738	770738	770738

In panel A, the variable 'Flood' binary treatment indicator, taking the value of 1 if a household who was exposed to flood during the year 2010, and 0 otherwise. Similarly, in panel B, the variable 'Flood Extent' represents a continuous index reflecting the severity of flooding experienced by a household. Columns (1–3) present economic outcomes for the households: column 1 is a financial capacity of a household taking overall house ownership and number of rooms as proxy, column 2 covers the housing condition including material of house and household assets, and column 3 represents the income of household in terms of Pakistani rupees. The regression controls for all key covariates including age, gender, area type (rural or urban), education, mobility, displacement, and past flood risk to the district. The area fixed effect includes the province and time fixed effects includes the month and year of birth of children. Standard errors, presented in parentheses, are clustered at the household level, and p-values testing a zero treatment effect are presented in brackets.

Table 6: Summary Statistics

	Mean	SD	N
Child Development Index	18.9019	0.7471	25,016
Child Functional Development Index	9.9601	0.3180	25,016
Child Cognitive Development Index	9.9418	0.5078	25,016
Enrollment ASER	0.7203	0.4489	248916
English Learning Level	3.0812	1.5988	208605
Math Learning Level	4.0379	2.4052	209518
Language Learning Level	3.1041	1.5581	211890
Financial Capacity Index	2.5853	1.4482	871559
Housing Condition Index	0.3210	0.4669	881157
total_income	2.7e+04	4.2e+04	881157
Food Insecurity Index	0.9935	1.3531	881157
Financial Concern for Availability of Food	0.2175	0.4126	871559
Limited Access to Nutritious Food	0.3521	0.4776	871559
Limited in Diversity of Food	0.3460	0.4757	871559
Skipping Meals	0.0888	0.2844	871559
Enrollment	0.2636	0.4406	814006
Delay in Enrollment	4.8866	1.0704	214890
Enrolled in 5th Grade	0.0810	0.2728	214890

The table provides an overview of PSLM dataset in Pakistan for 2019-20. For each variable, the table presents mean values (Mean), standard deviations (SD), and the number of observations (N).

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