Impacts of pesticide exposure on birth outcomes and child health in Brazil

Stela Januzzi* Leonardo Cardoso† Loredany Rodrigues‡

Abstract

We examine the effects of pesticide exposure on four child health outcomes in Brazil: low birth weight, preterm birth, infant mortality, and childhood cancer. Using a panel dataset covering 5,510 municipalities from 2019 to 2022, we construct a novel municipal-level exposure index based on a shift-share approach. Our results indicate that each additional kilogram of pesticide applied per hectare increases the incidence of low birth weight by 1.2 cases per 1,000 live births. We find no no effects on preterm birth, infant mortality, or childhood cancer.

Keywords: Child Health Outcomes, Pesticide Exposure, Panel Data.
JEL Classification: I18, Q53, Q58.

Resumo

Este trabalho investiga como agrotóxicos impactam quatro indicadores de saúde infantil no Brasil: baixo peso ao nascer, parto prematuro, mortalidade infantil e incidência de câncer infantil. Utilizando um painel com dados de 5510 municípios brasileiros entre 2019 e 2022, foi criada uma proxy para exposição do município ao uso de perticidas. Os resultados indicam que cada quilograma adicional de agrotóxico aplicado por hectare aumenta a incidência de baixo peso ao nascer em 1,2 casos por 1000 nascidos vivos. Não foram encontrados efeitos sobre parto prematuro, mortalidade infantil ou câncer infantil.
Palavras-chave: Saúde Infantil, Exposição a Agrotóxicos, Dados em Painel.
Classificação JEL: I18, Q53, Q58.

1 Introduction

Brazil is a leading global supplier of agricultural commodities such as grains and animal protein (Gaboardi et al., 2023). Agricultural sector plays a central role in the national economy, driving growth through exports that sustain the trade balance and generate vital foreign exchange. In 2023, agricultural exports grew by 3.9%, while imports declined by 4.5% compared to the previous year. The sector accounted for 48.6% of total Brazilian exports. The soybean complex was the top contributor, with exports totaling USD 41.04 billion in the first half of 2023, an 8.6% increase over the same period in 2022 (Ferreira and de C. Souza Jr, 2024).

Beyond Brazil's natural advantages in agriculture – such as abundant arable land, favorable climate, fertile soils, and water availability – the country also has a highly capitalized and competitive agricultural sector, characterized by a high capital-to-labor ratio and intensive use of advanced machinery, equipment, and chemical inputs (Lobão and Staduto, 2020). Among these inputs are pesticides, toxic substances deliberately

*Department of Rural Economics (DER), Postgraduate Program in Applied Economics (PPGEA), Federal University of Viçosa (UFV). Corresponding author at stela.januzzi@ufv.br.
†PPGEA, UFV, leonardocardoso@ufv.br.
‡PPGEA, UFV, loredany.rodrigues@ufv.br.

applied to control pests, weeds, fungi, and other threats to crops (Mahmood et al., 2016). This paper investigates the health impacts on individuals living near pesticide-treated areas, who may be exposed through contaminated water or by inhaling pesticide-laden air and dust.

Over the years, Brazil has emerged as one of the world's largest importers and consumers of pesticides. Soybean, corn, and sugarcane alone account for nearly 70% of all agrochemical use nationwide (Valadares et al., 2020). There are several factors that explain the high consumption and use of pesticides in Brazil. As a tropical country, Brazil does not experience frost or extremely cold periods that could help disrupt pest cycles. Additionally, the expansion of monoculture farming creates ecological imbalances and affects biodiversity, fostering agricultural pests and diseases. Moreover, the overall increase in agricultural production itself contributes to the rising use of pesticides (Vasconselos, 2018).

However, evidence suggests that increasing amounts of pesticides per hectare are required to sustain crop yields. This trend indicates a growing dependence on agrochemicals in Brazilian agriculture (Valadares et al., 2020). According to Moraes (2019), between 1991 and 2015, the number of pesticides applied per hectare of cultivated land in Brazil nearly quadrupled. Recent data from FAOSTAT (2024) further highlight this pattern, showing that Brazil applied, in 2022, an average of 12.6 kg of pesticides per hectare of farmland compared to an average of 5,8 kg/ha in 2010.

Compared to other large agricultural producers like China and the United States, Brazil displays notably high levels of pesticide use (see Figure 1) (FAOSTAT, 2024). However, its intensity is less exceptional when contrasted with countries such as Costa Rica, Colombia, and Japan, which have consistently reported higher pesticide application rates per hectare.

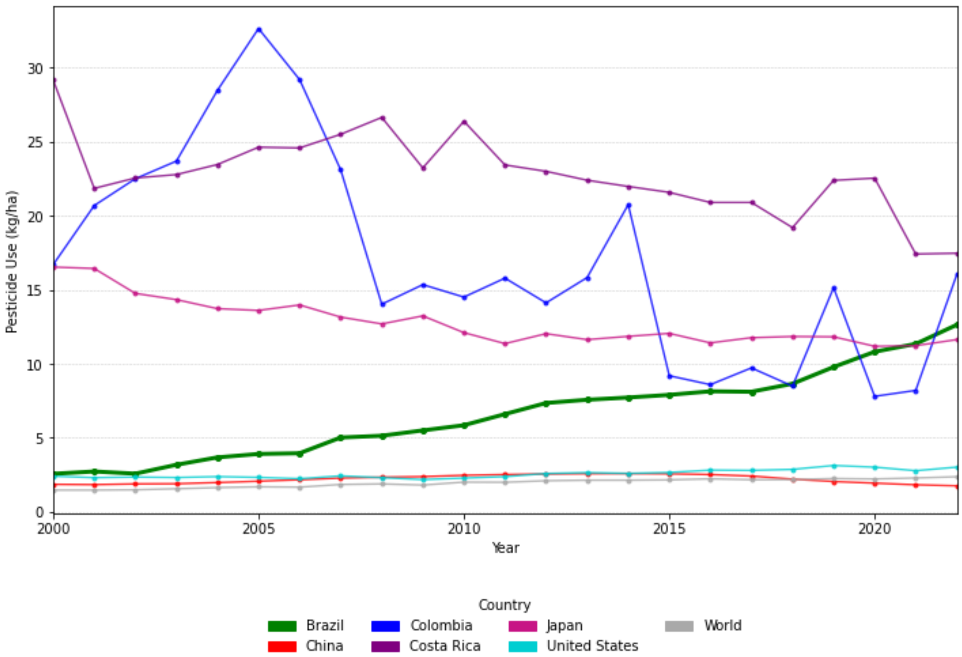

Figure 1: Pesticide Use per Hectare of Cropland (2000–2022)

Own elaboration based on FAOSTAT(2024) extracted in Our World in Data.

Despite the advantages of its use, such as higher crop yields, reduced pest pressures, and lower production costs in the short term (Goeb et al., 2020; Moraes, 2019), pesticides are recognized as toxic not only to the environment but also to human health, creating negative externalities that are often challenging to detect and quantify (Devi et al., 2022; Mahmood et al., 2016; Moraes, 2019). The methods used to apply pesticides, such as aerial spraying, tractor-mounted equipment, or manual application by agricultural workers, lead to the dispersion of these chemicals into the surrounding environment (FAO, 2023; Pignati et al., 2014). As a result, humans may absorb these toxic substances through inhalation, accidental ingestion, or skin penetration, which can lead to adverse health effects (Calzada et al., 2023).

Pesticide exposure can occur through two different pathway. The first exposure pathway, the acute and direct exposure, is often related to occupation – agricultural workers being much more exposed. Additionally, there are also intentional poisoning (Valadares et al., 2020). From 2006 to 2018, direct pesticide exposure among agricultural workers in 141 countries led to an estimated 385 million cases of poisoning and 11,000 deaths annually (Boedeker et al., 2020). In Brazil alone, 2,548 cases of agricultural pesticide poisoning were recorded in 2017, with 61 resulting in fatalities (SINITOX, 2017). The second pathway, the indirect and chronic pesticide exposure, may occur through the ingestion of contaminated food, drinking of contaminated water (from rivers or groundwater near sprayed areas), inhalation of contaminated air and dust, or long-term work with pesticides (Devi et al., 2022). The population affected by chronic exposure is likely much larger than that directly affected by acute pesticide poisoning (Landrigan, 2018). This indirect exposure is more challenging to quantify as its health effects often manifest over the long term.

In this context, the literature highlights strong correlations between chronic pesticide exposure and adverse health outcomes, particularly affecting infants and babies up to one year old living near treated agricultural areas. These populations are especially vulnerable to the harmful effects of pesticides and highly responsive to environmental conditions. Additionally, observed health abnormalities can be more directly attributed to pesticide exposure rather than other potential factors (Dias et al., 2023).

Larsen et al. (2017) found that residential pesticide exposure increased the incidence of preterm births by 5% and congenital disabilities by 9%, but only among mothers exposed to high pesticide levels – defined as an average of 4,000 kg during pregnancy. Jones (2020) showed that rising insecticide and fungicide use in the US (2008-2018) was associated with higher rates of preterm birth and low birth weight. Similarly, Camacho and Mejia (2017) reported that glyphosate spraying on coca plantations in Colombia increased the likelihood of respiratory and dermatological illnesses, as well as miscarriages. In Ecuador, Calzada et al. (2023) found that living near plantations during pregnancy – especially when the first trimester coincided with intensive fumigation – raised the probability of low birth weight and low Apgar score by 0.35 and 0.33 percentage points, respectively (2015-2017).

In Brazil, Dias et al. (2023) examined the impact of glyphosate use in soybean plantations on infant mortality, primarily in Brazil's Center-West and South regions, concluding that cities receiving water from rivers contaminated by these pesticides had higher infant mortality rates and low birth weight. Panis et al. (2024) found that women exposed to glyphosate, atrazine, and 2,4-D had higher rates of breast cancer compared to non-exposed women, in a case-control study conducted in a region of Paraná state from 2016 to 2019. Furthermore, Skidmore et al. (2023) concluded that the higher exposure to pesticides through soy expansion between 2008 and 2019 contributed to the rise in childhood blood-borne cancer. Moreover, Paumgartten (2020) conducted a literature review and noted that, in addition to the scarcity of studies on this topic in developing countries, most works in Brazil suffer from limitations, such as non-random sample selection, small sample sizes, imprecise exposure assessments, and multiple comparative challenges. Additionally, longitudinal studies are either absent at the national level or restricted to specific regions. Furthermore, to the best of current knowledge, no study in Brazil has successfully inferred a causal relationship between pesticide exposure and adverse health outcomes.

In this context, we address this gap by investigating whether residential exposure to agricultural pesticides contributes to adverse health outcomes among children living in highly exposed areas. The central hypothesis of this paper is that infants and children living in municipalities characterized by intensive pesticide-dependent agriculture are more likely to experience adverse health outcomes. These include negative birth outcomes, such as low birth weight and preterm birth, as well as increased risks of infant mortality and childhood cancer. The primary mechanism proposed for these effects is maternal and early-life exposure to environmental contamination, particularly through pesticide-laden air and polluted water sources during pregnancy and early childhood.

We use a two-way fixed effects panel covering the period from 2019 to 2022 across Brazilian municipalities. It allows for causal inference between residential agricultural pesticide exposure and health issues among infants and children, while also assessing the magnitude of these effects nationwide.

The findings are expected to provide empirical evidence on the potential harms of indirect pesticide exposure to public health. In doing so, this study seeks to contribute to discussions, policy proposals, and legislation regarding pesticide regulation and its effects on vulnerable populations. In the field of economics, shedding light on this debate is essential due to the potential loss of human capital and the high costs associated with curative healthcare that may be caused by indirectly pesticide exposure.

To achieve its objective, this study is divided into five sections: the present introduction, the section on theoretical and empirical aspects about pesticides and human health, the methods section, the results, and finally, the conclusion.

2 Pesticides and human health

Residents who live closer to pesticide-treated agricultural land tend to show higher levels of pesticide residues in household dust and/or pesticide metabolites in biological samples, as well as increased oxidative stress markers, greater DNA damage and decreased cholinesterase activity compared to those who live further away, according to the study review by Dereumeaux et al. (2020). In addition, other studies have already linked pesticide exposure among rural populations, including farmers, agricultural workers, and pesticide applicators, with conditions such as non-Hodgkin lymphoma (NHL), multiple myeloma, leukemia, and bladder, prostate, and colon cancers (Andreotti et al., 2018).

Several studies have explored the relationship between pesticide exposure and the health of pregnant women, newborns, and children. The review studies of Paumgartten (2020), focused on brazilian studies, and Shirangi et al. (2011), discuss that studies analyzing residential exposure often consists in case studies or case-control designs, typically with small sample sizes and focus on specific regions or agricultural communities. These studies frequently report high concentrations of pesticides in blood, urine, or household dust among individuals living near treated areas.

Despite numerous studies reporting associations between residential pesticide exposure and adverse health outcomes, particularly related to birth and reproduction, there is no clear consensus that these effects are consistent or independent of contextual factors. The review by Shirangi et al. (2011), which examined 25 studies from 1979 to 2007, found mixed evidence, with generally weak correlations for outcomes such as congenital malformations, stillbirth, and miscarriages. These inconsistencies often stem from limitations in exposure assessment and confounding variables. Even in studies that do find associations, the effects typically depend on factors such as proximity to application sites, timing and duration of exposure during pregnancy, and the intensity of pesticide use (Larsen et al., 2017; Shirangi et al., 2011).

Although many smaller studies focus on specific regions and involve a limited number of participants, international research has employed statistical and econometric methodologies to analyze larger samples, producing more precise results, as discussed below. Moreover, these studies generally reach the consensus that chronic pesticide exposure is harmful to certain health outcomes.

Schreinemachers (2003) compared birth data from 43,634 newborns in high and low-wheat-producing counties between 1995 and 1997, across 262 agricultural counties in the Midwestern United States. At the time, more than 85% of the acreage was treated with chlorophenoxy herbicides such as 2,4-D and MCPA. Using a logistic regression model with generalized estimating equations (GEE), the study found higher rates of circulatory, respiratory, and musculoskeletal anomalies in infants born in the high wheat-producing counties.

Along the same lines, Larsen et al. (2017), analyzing 500,000 birth observations from 1997 to 2011 in the agriculturally dominant San Joaquin Valley, California, concluded that being exposed to very high levels of agricultural pesticides increased prematurity by 5%, birth abnormalities by 9% and preterm birth by 8%. This study highlights that proximity to agricultural fields (up to 1,000 meters) amplifies the likelihood of adverse birth outcomes, although the exact distance between these areas and each individual's residence was not specifically measured.

Furthermore, studies analysing pesticide exposure and infant health may be subject to endogeneity, as pesticide use could be correlated with other variables, and there may be omitted variable bias. To address this issue, Jones (2020) employed the detection of the *Spotted Wing Drosophila* (SWD) as an instrumental variable to predict pesticide use aimed at controlling the pest. These predicted pesticide usage levels were then used to estimate their impact on infant health through an instrumental variables model using the two-stage least squares (2SLS) method. The author analyzed data from infected and non-infected counties in US. The results indicate that a 10% increase in insecticide and fungicide usage was associated with a 0.18 and 0.15 percentage point increase in infant prematurity, as well as a 0.08 and 0.08 percentage point increase in instances of low birth weight, respectively. These findings remained robust across alternative model specifications and falsification tests.

Calzada et al. (2023) examinated the impact of aerial fumigation of banana plantations in Ecuador on the health of newborns born near these plantations. Using a difference-in-differences (DID) approach, they found that pesticide exposure increases the likelihood of low birth weight and a low Apgar score at the first minute by approximately 0.35 and 0.33 percentage point, respectively. The authors emphasize that pesticides significantly impact newborn health when the first and second trimesters of pregnancy coincide with the season of intense fumigations. Newborns exposed to heavy fumigation during this gestational period have an average birth weight lower than those who were not exposed in between 38 and 89 grams. Furthermore, most of the effect of pesticides occurs within the first 100-150 meters around the plantation, diminishing quickly at further distances.

While there is a considerable amount of literature inferring a correlation, few papers are able to infer causality between pesticide exposure and health, which is much more difficult and is also the distinguishing feature of the work by Camacho and Mejia (2017). In this study, the authors aimed to analyze the effects of exposure to glyphosate—the most widely used herbicide globally—on the health of the Colombian population subjected to government-led aerial spraying campaigns for coca crop eradication. They gathered medical consultation data from 2003 to 2007 alongside records of the square kilometers of herbicide sprayed in each municipality. Using an individual fixed-effects regression model, which tracked the same 687,735 individuals over time, the results indicated a significant increase in the proportion of medical consultations for dermatological (0.85% increase) and respiratory issues (0.87% increase) among residents in glyphosate-exposed areas. To ensure the robustness of their findings, the authors conducted various analyses, including placebo tests and subgroup verifications, which reinforced that the observed effects were indeed linked to glyphosate exposure rather than other confounding factors.

In the case of Brazil, Skidmore et al. (2023) estimate the impact of soybean production on pediatric deaths from acute lymphoblastic leukemia (ALL) in upstream soybean cultivation areas within the same watershed in the Amazon and Cerrado regions, from 2008 to 2019. The study concluded that soybean expansion in these areas contributes to rising childhood cancer rates, primarily due to exposure to contaminated water, based on the premise that soybean expansion is linked to increased pesticide use in these regions. The findings indicate that a 10-percentage-point increase in the proportion of municipal land used for soybean cultivation is associated with an additional 0.40 deaths from ALL among children under five per 10,000 people and 0.21 additional deaths among children under ten per 10,000 people. In total, the intensification of soybean farming was correlated with 123 additional childhood leukemia deaths.

Similarly, Dias et al. (2023) examined the relationship between glyphosate (the most widely used herbicide in both the world and Brazil) exposure and birth outcomes of populations living in soybean areas. Specifically, the study focused on how glyphosate use in upstream municipalities could impact exposure in downstream municipalities within the same watershed. Glyphosate exposure was defined based on soybean cultivation intensity, and the analysis covered 1,119 municipalities, primarily in Brazil's Center-West and South regions, the country's main soybean-producing areas. The authors employed an instrumental variable approach, leveraging the natural suitability of certain areas for genetically modified seeds and the regulatory change that allowed their introduction. The findings showed that living in areas receiving water from rivers near glyphosate spraying zones increases infant mortality rates by 0.93 per 1,000 inhabitants, with most deaths attributed to perinatal conditions and respiratory issues. The study references multiple works suggesting that glyphosate can affect fetal development by impairing placental cells and harming unborn children in utero.

As this discussion draws to a close, it becomes evident that significant challenges and barriers persist in the investigation of the effects of pesticides on human health. There are various approaches to assessing pesticide exposure, yet accurately measuring the distance between residences and treated areas remains a challenge. Moreover, studies employ diverse methodologies to analyze the correlation between chronic residential pesticide exposure and adverse health outcomes. Notably, most research focuses on identifying correlations, while only a few studies, such as Camacho and Mejia (2017), successfully establish causal relationships.

Research on this topic remains scarce in Brazil, with the international literature, particularly for developed countries, being far more extensive than for developing nations (Dias et al., 2023). This gap, among other factors, is largely attributed to the limited availability of data on pesticide use in the country's agricultural sector. Notably, there is no publicly available data on pesticide application at the municipal level, nor are there records specifying usage by crop type. Additionally, according to Paumgartten (2020), no longitudinal retrospective or prospective cohort study has investigated the chronic health effects of pesticides in Brazil. Most existing research consists of ecological, cross-sectional, and case-control studies with inaccurate exposure assessments, which hinder causal inference. As a result, the morbidity and mortality attributed to pesticide exposure remain uncertain in the country, highlighting the need for large-scale prospective cohort studies.

Thus, based on previous studies and existing gaps in the literature, we capture the nationwide impact of residential pesticide exposure on the health of the most vulnerable population: infants and children. Covering the period from 2019 to 2022, this research employs a longitudinal design with a panel data model, using Shift-Share approach. This approach allows for causal inference between pesticide exposure and health outcomes, which, to the best of our knowledge, has not been previously conducted. To achieve this, the study draws upon the methodology of Pignati et al. (2014) to develop an expanded pesticide exposure estimator for the entire country, using pesticide consumption data from INDEA, one of the few data sources providing pesticide usage by crop in Brazil.

3 Methods

3.1 Strategic Approach and Calculation of the Pesticide Exposure Index

The primary sources of residential exposure considered are contamination through air and water, supporting the hypothesis that proximity to agricultural areas contributes to negative health indicators. Therefore, chronic exposure through the ingestion of pesticide-contaminated food is not included in this study, based on the assumption that this type of exposure is widespread throughout the population, regardless of their place of residence. Given the lack of comprehensive data on pesticide consumption and use at the local level, as previously discussed, this study is based on the methodology proposed by Pignati et al. (2014) and Dias et al. (2023) to develop the estimator of indirect pesticide exposure.

The Pignati et al. (2014) approach estimates pesticide consumption for all Brazilian municipalities by utilizing pesticide trade data from the state of Mato Grosso, obtained from the Relatório Consolidado de Comércio Agrotóxicos no Estado do Mato Grosso, published by the Mato Grosso Agricultural Defense Institute (INDEA). This database compiles information from agronomic prescriptions detailing pesticide usage across all municipalities in Mato Grosso. Specifically, it provides data on the volume (in kilograms or liters) of pesticide active ingredients intended for users within the state. This information can be filtered by municipality, region, chemical group, active ingredients, and usage across major crops.

The approach employed in this study involves using data on the total volume of all pesticide active ingredients applied to seven selected crops with the highest pesticide usage to estimate pesticide consumption for these crops. This estimate is then extrapolated to all municipalities in Brazil and serves as a proxy for pesticide exposure in each city. Thus, in this study, pesticide consumption in these crops will be considered a proxy for exposure. For Brazilian municipalities where these selected crops are cultivated and sprayed with pesticides, we assume that, on average, the resident population is more exposed to pesticides the greater the pesticide usage per crop and the larger the cultivated area in each city.

The seven crops selected for analysis in this study are: soybeans, cotton, corn, sugarcane, coffee, rice, and beans. The selection criteria were based on the high pesticide usage associated with each crop, their relevance to Brazil's agricultural sector, and the availability of data for Mato Grosso, according to the Consolidated Report from which pesticide data will be extracted. Additionally, we ensured that the selected crops are widely cultivated across the country, excluding those that are specific to the Mato Grosso region as well as those prevalent in other states but not commonly grown in Mato Grosso. Data on the planted areas of these crops per municipality will be obtained from PAM – Municipal Agricultural Production, via the System of Automatic Recovery (SIDRA) from the Brazilian Institute of Geography and Statistics (IBGE).

The chosen analysis period spans from 2019 to 2022, offering a comprehensive period for pesticide exposure analysis, according to the data available from INDEA. Moreover, this period coincides with the intensification of pesticide use and liberalization in the country, particularly the record liberalization of pesticides between 2019 and 2022, during the presidency of Jair Bolsonaro (MAPA, 2024). Therefore, it is a crucial period for analyzing the effects of pesticide exposure on birth outcomes.

Accordingly, the formula for constructing the Pesticide Exposure Index is presented below, along with detailed explanations of its calculation:

$$\text{ExpPesticides}_{mt} = \frac{\sum_c \left(\text{AvgMTPesticeIntensity}_c \cdot S_{c,mt}\right)}{A_m} \tag{1}$$

Where m represents each municipality in Brazil, t denotes years, and c corresponds to each of the seven crops with the highest pesticide usage: soybeans, cotton, corn, sugarcane, coffee, rice, and beans; $AvgMTPesticideIntensity$ denotes the annual mean intensity of pesticide use for crop c in the state of Mato Grosso, computed over the 2019–2022 period ; S represents the cultivated area of crop c in the mucipality m and year t. A represents the total land area of each municipality m.

To construct the municipal-level pesticide exposure index, the following steps were undertaken:

1. First, the pesticide use intensity for the state of Mato Grosso was calculated for each selected crop ($AvgMTPesticideIntensity$). Data on the total quantity (in kilograms) of all active pesticide ingredients used in each of the seven crops (c), from 2019 to 2022 (t), in the state, were obtained from INDEA. This total was then divided by the total cultivated area (in hectares) of each crop in each year of Mato Grosso, with area data sourced from IBGE-SIDRA.

   Next, the average pesticide use intensity for the entire study period was computed by summing the annual pesticide intensity values (kg per hectare) for each crop across the four years and dividing by the total number of years.

   This period-average was chosen to minimize measurement errors caused by possible outliers or atypical values in any single year. Temporal variations in pesticide exposure across years are reflected through the changes in the share of cultivated area allocated to each crop (c) at the municipal level.

2. After calculating the average annual pesticide use intensity for each crop, this value is multiplied by the cultivated area of each crop in all Brazilian municipalities (Sc, mt) for each year of analysis. This procedure results in an estimated pesticide use for each crop (c) in each municipality (m) for each year.

3. Subsequently, the estimated pesticide use values for all crops are summed to generate an estimate of the total pesticide exposure for each municipality in the country.

4. Finally, this estimate of total municipal exposure is divided by the total agricultural area of each municipality (Am), to produce a normalized exposure indicator. This normalization is important because it adjusts for differences in the scale of agricultural production, providing a more accurate measure of pesticide use intensity at the municipal level. By relating total pesticide use to the size of the cultivated area, the indicator better reflects relative intensity rather than absolute volume, preventing the results from being disproportionately influenced by larger agricultural municipalities. Additionally, normalized variables tend to have lower variance across observations, improving model stability and interpretability.

Using this estimator, we obtain a pesticide exposure variable for each Brazilian municipality, based on the pesticides applied to the selected crops. This will serve as the study's primary explanatory variable. Similar calculations have been employed in previous literature, such as the study by Dias et al. (2023), which estimated residential and indirect exposure to glyphosate. Due to the lack of local-level pesticide usage data, as is also the case in this study, the authors imputed pesticide use by distributing the total glyphosate usage in Brazil, obtained at an aggregate level from IBAMA, proportionally to the soybean-planted area in each municipality and normalizing it by the municipality's total area.

It is important to acknowledge that the chosen approach has limitations, as do other methodologies previously applied in this field. First, extrapolating pesticide consumption data from Mato Grosso to the entire country may not yield highly precise estimates, given that pesticide use in crops can vary across different Brazilian states. However, no clear evidence was found indicating significant regional differences in pesticide application for the same crop type, meaning that our approach remains valid.

Furthermore, we assume that pesticide consumption for a given crop is equivalent to pesticide exposure. Given the lack of data on pesticide use across agricultural crops in the country and the immense complexity of precisely measuring the distance between each household and cultivated areas in all Brazilian municipalities, we consider this approach to be the best possible, given the circumstances. A similar methodology was previously employed by Dias et al. (2023), as discussed above, and it is reasonable to assume that, on average, municipalities with higher production of pesticide-intensive crops indeed experience greater exposure to these chemicals.

There is also the possibility of underreporting in pesticide consumption and use, which may lead to an underestimation of the exposure levels captured in our data, for two main reasons. First, due to data limitations, our pesticide information—sourced from INDEA—is available only for the main crops produced in the state of Mato Grosso. Consequently, our municipal-level exposure index is based on just seven crops with the highest levels of pesticide use. However, actual pesticide exposure is likely to be considerably higher, given the wider variety of crops cultivated across municipalities. Second, since the pesticide consumption data relies on self-reported records by end-users, there is a strong likelihood that some pesticide applications go unreported. This includes both unregistered uses and the continued application of pesticides that have been officially banned in the country. Unfortunately, there is no way for us to fully address this limitation, and we must acknowledge the high probability that pesticide consumption is underestimated in the available data.

Despite these probable limitations, this approach will allow for estimating pesticide exposure for each selected crop and, consequently, for all Brazilian municipalities with at least one of these crops, which has never been done, to the best of our knowledge. This estimate is highly relevant as it allows for a better understanding of pesticide exposure at the municipal level in Brazil, in addition to providing clearer evidence of the broader effects to which the entire population is subjected due to the excessive use of agrochemicals on the country's soil. Given the continuous rise in the number of new chemicals approved each year in the country, this analysis is extremely relevant and of significant public interest. Moreover, the chosen shift-share approach will enable the inference of causality between this exposure and birth-related issues, as discussed below.

3.2 Description of the Econometric Model

Beyond the limitations associated with estimating pesticide exposure, there is also a recurring challenge in studies examining the relationship between pesticides and health: potential endogeneity. This issue may arise for several reasons, such as measurement errors in the calculation of pesticide exposure and omitted variable bias. In the first case, if measurement error in the explanatory variable is correlated with other factors affecting birth outcomes, the estimates may be biased. Regarding omitted variables, there may be unobserved characteristics influencing health outcomes that are not captured by the variables included in the model. If these omitted variables are correlated with both pesticide use and health outcomes, this could also lead to biased estimates.

As observed in the literature, some authors employ an instrumental variable approach to address endogeneity, as seen in Dias et al. (2023) and Jones (2020). This study adopts a shift-share approach for constructing the index that serves as our main explanatory variable. By design, this method helps address potential endogeneity issues, contributing to a more reliable estimation of the causal relationship between pesticide exposure and the dependent variables.

Thus, as outlined in Borusyak et al. (2025), the shift-share relies on two components: shifts, which are exogenous factors that affect different units at the same time, in a heterogeneous way, and shares, which reflect a unit's exposure to these shifts. The shares are used to weight the variation in shifts for each unit. In this way, the treatment $\mathbf{X}_i$ is constructed by multiplying shifts by shares, which reflect the exposure of units to these changes. This combination allows the model to capture variations in circumstances faced by different units. For the causal relationship between the treatment variable and the dependent variable to be valid, the instrument (the treatment variable derived from the shift-share) must be correlated with $\mathbf{X}_i$ and uncorrelated with the error term e_i, ensuring that the variation in $\mathbf{X}_i$ is exogenous.

In this analysis, the shares correspond to the proportion of total cultivated area allocated to each of the seven selected crops within each municipality (reflecting structural exposure levels). The shifts are represented by the time-varying pesticide use intensity per hectare for each crop, measured based on state-level variations in Mato Grosso. The treatment variable is constructed as the weighted sum of these two components: for each municipality and year, the pesticide exposure index is calculated by multiplying the crop-specific pesticide intensity (shifts) by the municipality-specific crop area share (shares), and summing across all crops.

This approach ensures that the treatment is plausibly exogenous to the health outcomes of interest, as it captures exposure driven by external agricultural trends rather than municipality-level health or demographic factors.

Furthermore, the models will be estimated using a two-way fixed effects panel specification, which offers additional advantages by controlling for both unobserved time-invariant characteristics at the municipal level and year-specific shocks that could affect all municipalities simultaneously. The dependent variable is modeled as a function of the treatment and other control variables.

The model structure is expressed by the following equation:

$$y_{i,t} = \alpha + \beta \cdot \mathbf{X}_{i,t} + e_i \tag{2}$$

Where y_{it} represents the health outcome variables, presented in Table 1 below; $\mathbf{X}_i$ is the vector of all control variables, as specified in Table 2; $beta$ is the parameter of interest, capturing the magnitude impact of the control variables on the health outcomes; e_i is the error term; i denotes Brazilian municipalities and t denotes years.

Discussing the study variables, we established that the majority of the variables would be expressed in rate format to ensure comparable magnitudes across all variables in the study, thereby facilitating the interpretation of the results. Consequently, variables related to birth outcomes are represented as rates per 1,000 live births, while children health variables, as well as infrastructure-related variables, are represented as rates per 100,000 inhabitants. Exceptions include the main exposure variable (pesticide exposure) and the per capita GDP variable, which were not expressed as rates. Detailed descriptions of each variable are presented in Tables 1 and 2 below.

Specifically, Table 1 presents the dependent variables, which include three distinct birth outcomes and one children health outcome. The selection of these outcomes is based on existing literature, which has provided evidence that chronic and residential pesticide exposure is associated with pregnancy complications and adverse children health outcomes (Calzada et al., 2023; Dias et al., 2023; Jones, 2020; Larsen et al., 2017; Schreinemachers, 2003; Shirangi et al., 2011; Skidmore et al., 2023). In this regard, the model will be estimated four different times, once for each dependent variable.

Table 1: Description of the dependent variables

Variables	Definition	Base Literature
infant_mort_rate	Number of deaths of children under one year of age per 1,000 live births, per year, by municipality	Dias et al., 2023
preterm_birth_rate	Number of preterm births (before 37 completed weeks of gestation) per 1,000 live births, per year, by municipality	Dias et al., 2023; Jones, 2020; Larsen et al., 2017
low_birth_weight	Number of newborns weighing less than 2,500 grams per 1,000 live births, per year, by municipality	Dias et al., 2023; Jones, 2020; Larsen et al., 2017; Calzada et al., 2023
childhood_cancer_rate	Number of children (aged 0 to 19) diagnosed with malignant neoplasm (cancer) per 100,000 children per year, by municipality	Skidmore et al., 2023; Andreotti et al., 2018

Source: Own Elaboration.

Table 2, presented below, lists the explanatory variables of the study, along with their description, data source, and expected sign of association. The primary explanatory variable is the pesticide exposure proxy, measured annually and at the municipal level. In addition, a set of control variables was included to account for socioeconomic, structural, and individual-level conditions that may influence children's health outcomes independently of pesticide exposure.

Beyond maternal characteristics and birth outcome-related variables, the model also incorporates municipal-level per capita GDP and the number of Primary Health Care Units (PHCUs) and Health Centers in each municipality. It is important to note that data on municipal per capita GDP were available only up to 2021; therefore, the 2021 values were imputed for 2022. Additionally, data on PHCUs refer specifically to the month of December for each year analyzed.

Regarding data sources, the health-related data used to construct both the dependent variables and the control variables will be obtained from various official databases available through DATASUS, the national health information system managed by the Brazilian Ministry of Health. Specifically, variables related to birth outcomes and maternal characteristics will be sourced from the Live Birth Information System (Sistema de Informações sobre Nascidos Vivos – SINASC). Variables on infant and child mortality will be extracted from the Mortality Information System (Sistema de Informações sobre Mortalidade – SIM), while data on childhood cancer cases will be retrieved from the Brazil Oncology Panel (Painel-Oncologia Brasil).

Population data, necessary for calculating population-based rates, will be obtained from the population estimates provided by the Brazilian Institute of Geography and Statistics (IBGE), with the exception of census years, in which case official census figures will be used. Municipal GDP per capita figures will also be sourced from IBGE. Finally, information on the number of Primary Health Care Units and Health Centers in each municipality will be extracted from the National Registry of Health Establishments (Cadastro Nacional de Estabelecimentos de Saúde – CNES).

The analysis aims to capture the causal impact of pesticide exposure on birth outcomes and child health. According to the literature, indirect pesticide exposure in municipalities is expected to negatively affect infant and child health (Calzada et al., 2023; Dias et al., 2023; Jones, 2020; Larsen et al., 2017; Schreinemachers, 2003; Shirangi et al., 2011; Skidmore et al., 2023). Thus, this exposure is expected to be positively related to the infant mortality rate, preterm birth rate, low birth weight and children aged 0 to 19 diagnosed with cancer.

Regarding the control variables, it is expected that advanced maternal age, low maternal education (defined as less than three years of schooling), multiple pregnancy (when a woman is pregnant with more than one child), and municipal-level rates of infant mortality, low birth weight, and preterm births will be positively associated with adverse children health outcomes (Azimi and Lotfi, 2013; Calzada et al., 2023; Dias et al., 2023; Larsen et al., 2017).

Table 2: Description of the explanatory variables

Variables	Definition	Data Source	Expected Signal
exp_pesticides (proxy)	Annual total municipal exposure to pesticides, considering the seven selected crops, normalized by the total agricultural land area in the municipality (primary explanatory variable)	INDEA-MT; PAM (IBGE)	+
mun_GPD	Annual Municipal Gross Domestic Product per capita (in thousand BRL)	SIDRA (IBGE)	-
PHCU_rate	Annual rate number of Primary Care Units and Health Centers per 100,000 inhabitants per year, by municipality	CNES (DATASUS)	
mother_prenatal	Annual rate number of mothers with seven or more prenatal care visits during pregnancy per 1,000 live births, by municipality	SINASC (DATASUS)	-
infant_mort	Annual rate number of deaths of children under one year of age per 1,000 live births, by municipality		+
low_weight	Annual rate number of newborns weighting less than 2,500 grams per 1,000 live births, by municipality		+
mother_adv_age	Annual rate number of mothers aged over 35 years at the time of childbirth per 1,000 live births, by municipality		+
mother_white	Annual rate number of mothers self-identifying as white per 1,000 inhabitants, by municipality		-
hospital_births	Annual rate number of births occurring in hospitals per 1,000 live births, by municipality		-
mother_educ_ _3years	Annual rate number of mothers with three or fewer years of education, per 1,000 live births, by municipality		+
mult_births	Annual rate of multiple births per 1,000 live births, by municipality		+

Source: Own Elaboration.

The literature consistently highlights that advanced maternal age, typically defined as 35 years or older, is associated with an increased risk of pregnancy complications and negative birth outcomes (Correa-de Araujo and Yoon, 2021; Frederiksen et al., 2018). In addition, mothers with lower educational attainment generally face more barriers in accessing prenatal care, health information, and other essential services, which in turn heightens the risk of complications during pregnancy, delivery, and child health in general. Similarly, multiple pregnancies are also associated with a higher probability of both obstetric complications and adverse neonatal outcomes (Falcone et al., 2024; Larsen et al., 2017; Shahraki et al., 2016).

Furthermore, municipalities with relatively high rates of infant mortality, preterm births, and low birth weight newborns may reflect broader structural deficiencies in maternal and child healthcare services. These systemic shortcomings can translate into a greater underlying vulnerability for children's health overall, potentially influencing more severe outcomes such as childhood cancer incidence (Force et al., 2019; Macinko and Mendonça, 2018; Reidpath and Allotey, 2003; Velame and Antunes, 2024).

The control variables remained — such as municipal GDP per capita, maternal race (white), the number of prenatal care visits (seven or more), birth occurring in a hospital setting, and the rate of Primary Health Care Units and Health Centers per 100,000 inhabitants —are expected to be negatively associated with adverse health outcomes in infants and children. These variables serve as important proxies for socioeconomic status, access to healthcare services, and the overall quality of maternal and child health care within each municipality. Higher levels of these indicators typically reflect better living conditions, greater availability of health services, and improved maternal care during pregnancy and childbirth, all of which are known to reduce risks of negative birth and child health outcomes. (Dias et al., 2023; Force et al., 2019; Larsen et al., 2017; Macinko and Mendonça, 2018; Reidpath and Allotey, 2003; Trevilato et al., 2022).

Higher municipal GDP per capita, a greater availability of Primary Health Care Units, and adequate prenatal care coverage serve as important proxies for the overall socioeconomic development and healthcare infrastructure of each municipality. These variables capture not only the economic capacity of the locality but also its ability to provide essential health services and preventive care to the population, including pregnant women and children (Dias et al., 2023; Guimarães et al., 2018; Larsen et al., 2017; Macinko and Mendonça, 2018).

Births occurring in hospital settings, as opposed to home deliveries or other non-institutional locations, may reflect better access to professional medical care during labor and delivery. This generally ensures that births are monitored by trained healthcare professionals and that any obstetric complications can be managed with appropriate medical infrastructure and emergency support, reducing risks to both mothers and newborns (Vedam et al., 2014).

Furthermore, being born to white mothers is frequently associated with more favorable socioeconomic conditions and better access to healthcare services in Brazil, given the country's well-documented racial and social inequalities. Including this variable aims to control for potential disparities in health outcomes that may arise from unequal access to healthcare and living conditions linked to race (Larsen et al., 2017).

The next section presents the results along with their discussion.

4 Results and Discussion

4.1 Descriptive Results

The residential pesticide exposure index developed in this study made it possible to assess the intensity of pesticide use across each analyzed crop. As shown in Figure 4 below, cotton stands out as the crop with the highest pesticide use per hectare, with a mean intensity that is substantially higher than that observed for other crops.

Through the normalization applied in the calculation of the exposure indicator, it was possible to distinguish the municipalities that are indeed more exposed to pesticides used in the seven analyzed crops, as they present higher application intensity per cultivated area. The underlying assumption is that the greater the amount of pesticides used in a smaller area, the higher the exposure risk for the population residing in that municipality.

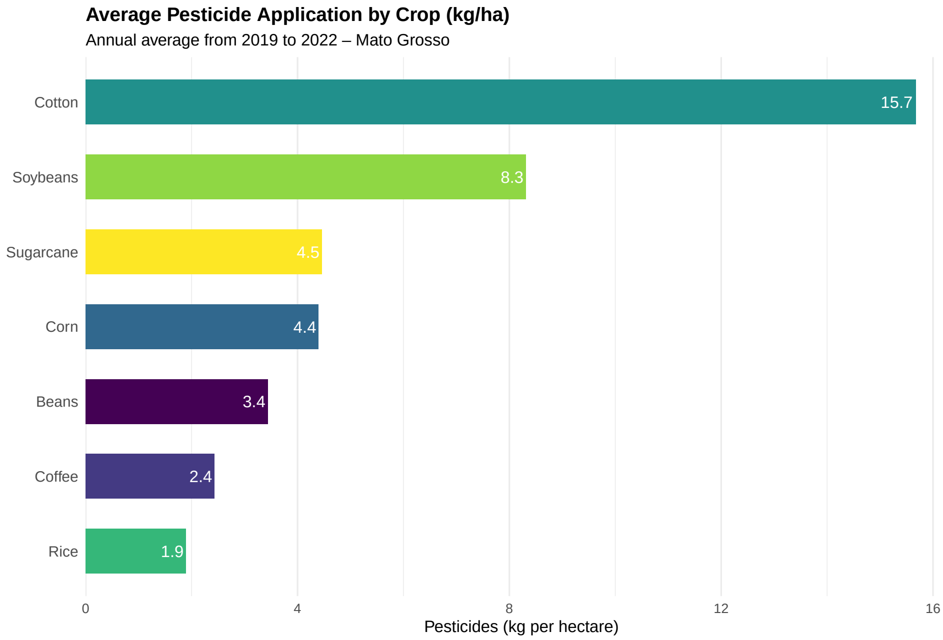

Figure 2: Average pesticide use intensity for the state of Mato Grosso, by crop (2019–2022)

Own elaboration based on INDEA-MT and PAM-IBGE.

Furthermore, Table 3 below presents the descriptive statistics for the study variables.

Most of the variables included data for 5,563 municipalities, totaling 22,252 observations throughout the study period. However, when incorporating the variable for the rate of Primary Health Care Units (PHCU), which controls for municipal health service access, the final analytical sample consisted of 21,703 observations from 5,510 Brazilian municipalities. This reduction occurred because the PHCU variable had missing data for 53 municipalities, leading the R software (used for the present study) to automatically exclude these cases from the analysis. Given that the number of excluded municipalities was relatively small, the decision was made to maintain this control variable in the model.

Regarding the pesticide exposure indicator, the average amount of pesticides applied per hectare of agricultural land in Brazilian municipalities over the four years of analysis was 3.66 kg/ha. The standard deviation, approximately 1.98 kg/ha, which is more than half the mean, highlights the considerable variability in pesticide exposure levels across municipalities in Brazil. The municipality with the highest exposure level, as previously mentioned, was Landri Sales, with an average of 11.74 kg/ha. Additionally, there were 648 observations with a pesticide exposure value of zero, indicating municipalities with no cultivation of any of the seven crops included in the analysis during the study period.

The municipal per capita GDP also reveals significant socioeconomic disparities among Brazilian municipalities between 2019 and 2022. The average per capita GDP was 29.94 Brazilian reais (in thousands), but the standard deviation exceeded the mean value, suggesting a high degree of inequality. The highest per capita GDP was 920.83 thousand reais, observed in the municipality of Catas Altas, Minas Gerais, while the lowest, at 4.47 thousand reais, was recorded in Matões do Norte, Maranhão.

The average number of Primary Health Care Units (PHCUs) per 100,000 inhabitants was approximately 37, with the standard deviation also showing a relatively high value, indicating variability in health infrastructure across municipalities.

Table 3: Descriptive Statistics

Variables	Mean	Std	Max	Min	N
exp_pestice	3.66	1.98	11.74	0	22,252
infant_mort_rate	12.31	12.53	181.82	0	22,252
preterm_birth_rate	114.2	43.92	629.50	0	22,252
low_birth_weight	78.90	34.36	444.44	0	22,252
childhood_cancer_rate	19.85	48.14	2573.53	0	22,252
mun_GPD	29.94	35.36	920.83	4.47	22,252
PHCU_rate	37.07	19.68	229.49	0.84	21,703
mother_prenatal	764.45	134.78	1000	30.22	22,252
mother_adv_age	146.80	55.96	571.40	0	22,252
mother_white	363.47	310.07	1000	0	22,252
hospital_births	990.30	26.09	1000	458,50	22,252
mother_educ_3years	22.74	32.34	643.06	0	22,252
mult_births	20.57	22.16	333.33	0	22,252

Source: Own Elaboration using data from SINASC, INDEA, PAM, CNES, SIDRA-IBGE, SIM and Painel-Oncologia Brasil.

The national average infant mortality rate was 12.31 deaths per 1,000 live births, reflecting a concerningly high level of infant deaths. Regarding childhood cancer, the mean number of children aged 0 to 19 years diagnosed with a malignant neoplasm was 19.85 cases per 100,000 children in the same age group. The standard deviation for this variable was 48.14, highlighting substantial disparities in incidence rates across municipalities. The municipality with the highest number of childhood cancer cases per 100,000 children was Montauri, located in the state of Rio Grande do Sul.

Finally, the average number of mothers who attended seven or more prenatal care consultations was notably high, reaching 764.45 mothers per 1,000 live births. This indicates a positive aspect of prenatal healthcare coverage in the country. Furthermore, the vast majority of births occurred in hospital settings, with an average of 990.3 hospital deliveries per 1,000 live births. The number of mothers with up to three years of schooling—representing the lowest education level after no formal education—was relatively low, with an average of 22.74 mothers per 1,000 live births.

4.2 Econometric Results

Table 5 presents the estimated effects of residential pesticide exposure on two key birth outcomes: the rate of low birth weight and the rate of preterm births. The results are shown for two model specifications for each outcome: one controlling for both municipality and year fixed effects and another controlling only for municipality fixed effects.

Focusing on the main explanatory variable, the pesticide exposure proxy *(exp_pesticide)*, the results reveal a statistically significant and positive association with the rate of low birth weight in the second specification, which includes only municipality fixed effects. Specifically, the coefficient of approximately 1.20 suggests that, for each additional kilogram of pesticide applied per hectare, there is an estimated increase of about 1.20 cases of low birth weight per 1,000 live births ($p < 0.10$). This finding indicates that, after controlling for unobserved municipal characteristics, higher pesticide exposure levels are modestly associated with worse birth outcomes regarding low birth weight.

This result aligns with expectations, as shown in Dias et al. (2023), Jones (2020) e Larsen et al. (2017), which reveal that residential exposure to pesticides, whether through contaminated air or water ingestion, has the potential to negatively affect the health of individuals living in the area. In this case, the higher the exposure of pregnant women to these pesticides, the greater the likelihood of giving birth to a low birth weight child.

For the other outcome, preterm birth, pesticide exposure did not show statistically significant effects in any of the specifications, even after the inclusion of year fixed effects, which goes against expectations, according to the specialized literature.

Table 4: Pesticide Exposure Impact on Birth Outcomes

	low_weight	*low_weight*	*preterm_birth*	*preterm_birth*
exp_pesticide	0.738 (0.699)	**1.197 .** **(0.705)**	0.790 (0.938)	1.242 (0.937)
Control variables				
mun_GPD	-0.010 (0.016)	0.059* (0.024)	-0.028 (0.026)	0.039 (0.025)
PHCU_rate	0.036 (0.044)	0.172*** (0.044)	0.063 (0.055)	0.189*** (0.056)
mother_prenatal	-0.044*** (0.005)	-0.027*** (0.005)	-0.079*** (0.006)	-0.066*** (0.006)
mother_adv_age	0.020* (0.009)	0.030** (0.009)	0.035** (0.011)	0.045*** (0.011)
mother_white	-0.012 . (0.007)	-0.018** (0.007)	-0.014 (0.009)	-0.020* (0.009)
hospital_births	-0.022 (0.029)	-0.040 (0.029)	-0.029 (0.035)	-0.049 (0.035)
mother_educ_3years	-0.007 (0.016)	-0.044** (0.016)	-0.065*** (0.019)	-0.103*** (0.019)
mult_births	0.550*** (0.019)	0.553*** (0.019)	0.528*** (0.022)	0.531*** (0.022)
Observations	21,703	21,703	21,703	21,703
FE: municipality	✓	✓	✓	✓
FE: year	✓		✓	
Std.Errors by municipality	✓	✓	✓	✓

Source: Own Elaboration. Robust standard errors, adjusted for clustering by municipality, are presented in parentheses. The symbols . , *, **, and *** indicate rejection of the null hypothesis at significance levels of 10%, 5%, 1% and 01.%, respectively.

Looking at the control variables, several presented expected and statistically significant relationships with the birth outcomes. Municipal GDP *(mun_GPD)* showed a marginally positive effect on low birth weight in the specification without year fixed effects. The availability of primary health care units *(PHCU_rate)* was also positively associated with both low birth weight and preterm birth in the specification with only municipality fixed effects, suggesting that areas with better health infrastructure may also identify and report more adverse outcomes.

Maternal and individual-level factors played an important role. A higher number of prenatal care visits *(mother_prenatal)* was consistently associated with lower rates of both adverse outcomes, reinforcing its protective role (Dias et al., 2023; Macinko and Mendonça, 2018). Advanced maternal age *(mother_adv_age)* and multiple births *(mult_births)* were both positively and significantly associated with higher rates of low birth weight and preterm birth, aligning with established evidence in the literature (Correa-de Araujo and Yoon, 2021; Falcone et al., 2024; Larsen et al., 2017). For white mothers *(mother_white)*, the results were more significant in the fixed effects models controlling only for municipalities, and they are aligned with the existing literature suggesting that white mothers generally have better socioeconomic conditions and better acess to healthcare service, leading to lower rates of adverse birth outcomes (Larsen et al., 2017).

For the variable related to hospital births *(hospital_births)*, no significant results were found in any specification. Furthermore, for mothers with low education levels, the coefficient sign was contrary to expectations, suggesting that lower maternal education was associated with lower chances of having children with low birth weight or preterm birth.

In summary, while most models did not show a strong association between pesticide exposure and the studied outcomes, the significant positive effect observed for low birth weight in the model with municipality fixed effects highlights the need for further investigation into potential health risks linked to pesticide exposure.

Table 6 presents the effects of pesticide exposure on infant mortality rates and childhood cancer rates, also considering the two specifications of controlling for both municipality and year fixed effects, and other controlling only for municipality fixed effects.

Table 5: Pesticide Exposure Impact on Infant Mortality and Childhood Cancer

	inf_mort	*inf_mort*	*child_cancer*	*child_cancer*
exp_pesticide	-0.077 (0.257)	-0.045 (0.260)	-0.151 (1.112)	-0.021 (1.114)
Control variables				
mun_GPD	-0.009 . (0.004)	-0.008 . (0.004)	-0.020 (0.029)	0.009 (0.027)
PHCU_rate	0.014 (0.017)	0.024 (0.017)	-0.017 (0.051)	0.022 (0.049)
low_birth_weight	0.009 . (0.005)	0.011* (0.005)	-0.039 (0.027)	-0.036 (0.027)
preterm_birth	0.034*** (0.004)	0.034*** (0.004)	0.033 (0.025)	0.033 (0.025)
Observations	21,703	21,703	21,703	21,703
FE: municipality	✓	✓	✓	✓
FE: year	✓		✓	
Std.Errors by municipality	✓	✓	✓	✓

Source: Own Elaboration. Robust standard errors, adjusted for clustering by municipality, are presented in parentheses. The symbols . , *, **, and *** indicate rejection of the null hypothesis at significance levels of 10%, 5%, 1% and 01.%, respectively.

The main explanatory variable of interest, pesticide exposure, did not show statistically significant effects on either infant mortality or childhood cancer rates in any of the model specifications. Across all columns, the estimated coefficients for pesticide exposure were negative but not statistically significant at any conventional level (including the 10% level).

These findings suggest that, within the scope of this dataset and model specification, there is no robust evidence of a direct association between increased pesticide exposure and higher rates of infant mortality or childhood cancer in Brazilian municipalities during the study period.

Regarding the childhood cancer model, it is clear that none of the variables reached statistical significance, indicating that the model under analysis was not able to fit the data well for this outcome.

In the case of the infant mortality model, the fit appears to be better, as several control variables were statistically significant and presented coefficients with directions consistent with what is expected in the literature, except for the *PHCU_rate*, which was not significant. A higher municipal per capita GDP *(mun_GDP)* reduces the probability of infant mortality, while higher rates of low birth weight *(low_birth_weight)* and preterm births *(preterm_birth)* increase this probability, although the magnitude of the coefficients suggests that these effects are relatively small.

Hence, the results presented in Table 6 indicate that while preterm birth is a strong predictor of infant mortality, pesticide exposure does not show a significant effect on infant mortality or childhood cancer rates within this analytical framework.

Robustness checks were conducted for all models. The Hausman test indicated that fixed effects models were preferable to random effects, ensuring better control for unobserved heterogeneity across municipalities. Moreover, robust standard errors clustered at the municipal level were applied to account for potential heteroskedasticity and within-cluster correlation, thereby reducing the risk of artificially inflated significance levels. Additionally, multicollinearity diagnostics were performed to ensure that high correlations among explanatory variables did not bias the estimated coefficients.

After analyzing the results for all child health indicators, it is noticeable that a statistically significant association was found only for low birth weight.

5 Final Remarks

This study aimed to analyze the impact of residential exposure to pesticides on four child health outcomes: low birth weight, preterm birth, infant mortality, and the incidence of cancer in children aged 0 to 19 years across 5,510 Brazilian municipalities. A panel data analysis was conducted covering the period from 2019 to 2022, a time marked by an intense liberalization of pesticide regulations in Brazil.

Due to the lack of comprehensive nationwide data on pesticide use and exposure at municipal level, a pesticide exposure index was developed following a shift-share approach. This allowed for a causal assessment of the relationship between pesticide exposure and child health outcomes. The exposure estimates were based on pesticide consumption data from the state of Mato Grosso, considering the seven crops with the highest pesticide use: cotton, soybeans, sugarcane, corn, rice, beans, and coffee.

The results indicate that for each additional kilogram of pesticide applied per hectare, there is an estimated increase of approximately 1.20 cases of low birth weight per 1,000 live births ($p < 0.10$), aligning with expectations based on the existing literature. However, no statistically significant associations were found for the other three outcomes.

Research on this topic in Brazil faces a fundamental challenge due to the scarcity and fragmentation of data, which makes such analyses complex and likely underestimates the true effects of pesticide exposure on human health. The limited significance and strength of the overall findings may be directly related to methodological constraints, including the short four-year analysis period, the extrapolation of data from a single state (Mato Grosso) to the entire country, and the focus on only seven crop types to estimate exposure levels, all of which are closely tied to the broader issue of data scarcity.

Despite these limitations, this study makes an important contribution by providing one of the first national-level analyses using a municipal panel design to investigate the relationship between pesticide exposure and child health outcomes in Brazil. The creation of a tailored exposure indicator and the use of robust econometric techniques help fill a critical gap in the literature. Future research would benefit greatly from more detailed and disaggregated data on pesticide application, as well as from longer observation periods, to allow for more precise and comprehensive analyses.

Finally, the results highlight the urgent need for stronger public policies aimed at regulating pesticide use, improving environmental monitoring, and increasing the transparency and accessibility of pesticide-related data. Advancing research in this area and strengthening evidence-based policymaking are essential steps toward safeguarding public health, especially for vulnerable populations such as children.

References

Andreotti, G., Koutros, S., Hofmann, J. N., Sandler, D. P., Lubin, J. H., Lynch, C. F., Lerro, C. C., De Roos, A. J., Parks, C. G., Alavanja, M. C., et al. (2018). Glyphosate use and cancer incidence in the agricultural health study. *JNCI: Journal of the National Cancer Institute*, 110(5):509–516.

Azimi, C. and Lotfi, M. (2013). Association of smoking habits of mother during pregnancy with pregnancy outcome. *Iranian journal of public health*, 42(7):748.
Boedeker, W., Watts, M., Clausing, P., and Marquez, E. (2020). The global distribution of acute unintentional pesticide poisoning: estimations based on a systematic review. *BMC public health*, 20:1–19.
Borusyak, K., Hull, P., and Jaravel, X. (2025). A practical guide to shift-share instruments. *Journal of Economic Perspectives*, 39(1):181–204.
Calzada, J., Gisbert, M., and Moscoso, B. (2023). The hidden cost of bananas: the effects of pesticides on newborns' health. *Journal of the Association of Environmental and Resource Economists*, 10(6):1623–1663.
Camacho, A. and Mejia, D. (2017). The health consequences of aerial spraying illicit crops: The case of colombia. *Journal of health economics*, 54:147–160.
Correa-de Araujo, R. and Yoon, S. S. (2021). Clinical outcomes in high-risk pregnancies due to advanced maternal age. *Journal of women's health*, 30(2):160–167.
Dereumeaux, C., Fillol, C., Quenel, P., and Denys, S. (2020). Pesticide exposures for residents living close to agricultural lands: A review. *Environment international*, 134:105210.
Devi, P. I., Manjula, M., and Bhavani, R. (2022). Agrochemicals, environment, and human health. *Annual Review of Environment and Resources*, 47(1):399–421.
Dias, M., Rocha, R., and Soares, R. R. (2023). Down the river: glyphosate use in agriculture and birth outcomes of surrounding populations. *Review of Economic Studies*, 90(6):2943–2981.
Falcone, V., Nisticò, F., De Luca, A., Arniani, S., Messina, G., Nante, N., and D'Urso, A. (2024). Determinants of health and pregnancy and birth outcomes: an overview. *European Journal of Public Health*, 34(Supplement_3):ckae144–2074.
FAO (2023). Pesticides use and trade, 1990–2021. Technical Report 70, Food and Agriculture Organization of the United Nations, Rome.
FAOSTAT (2024). Total pesticide use per area of cropland – fao. `https://ourworldindata.org/grapher/pesticide-use-per-hectare-of-cropland`. With major processing by Our World in Data.
Ferreira, D. and de C. Souza Jr, J. R. (2024). Comércio exterior do agronegócio em 2023. Carta de Conjuntura, Nota de Conjuntura 6, 1° Trimestre.
Force, L. M., Abdollahpour, I., Advani, S. M., Agius, D., Ahmadian, E., Alahdab, F., Alam, T., Alebel, A., Alipour, V., Allen, C. A., et al. (2019). The global burden of childhood and adolescent cancer in 2017: an analysis of the global burden of disease study 2017. *The Lancet Oncology*, 20(9):1211–1225.
Frederiksen, L. E., Ernst, A., Brix, N., Lauridsen, L. L. B., Roos, L., Ramlau-Hansen, C. H., and Ekelund, C. K. (2018). Risk of adverse pregnancy outcomes at advanced maternal age. *Obstetrics & Gynecology*, 131(3):457–463.
Gaboardi, S. C., Candiotto, L. Z. P., and Panis, C. (2023). Agribusiness in brazil and its dependence on the use of pesticides. *Hygiene and Environmental Health Advances*, 8:100080.
Goeb, J., Dillon, A., Lupi, F., and Tschirley, D. (2020). Pesticides: What you don't know can hurt you. *Journal of the Association of Environmental and Resource Economists*, 7(5):801–836.
Guimarães, W. S. G., Parente, R. C. P., Guimarães, T. L. F., and Garnelo, L. (2018). Acesso e qualidade da atenção pré-natal na estratégia saúde da família: infraestrutura, cuidado e gestão. *Cadernos de saude publica*, 34(5):e00110417.
Jones, B. A. (2020). Invasive species control, agricultural pesticide use, and infant health outcomes. *Land Economics*, 96(2):149–170.
Landrigan, P. J. (2018). Pesticides and human reproduction. *JAMA internal medicine*, 178(1):26–27.
Larsen, A. E., Gaines, S. D., and Deschênes, O. (2017). Agricultural pesticide use and adverse birth outcomes in the san joaquin valley of california. *Nature communications*,

8(1):302.
Lobão, M. S. P. and Staduto, J. A. R. (2020). Modernização agrícola na amazônia brasileira. *Revista de Economia e Sociologia Rural*, 58:e188276.
Macinko, J. and Mendonça, C. S. (2018). Estratégia saúde da família, um forte modelo de atenção primária à saúde que traz resultados. *Saúde em Debate*, 42:18–37.
Mahmood, I., Imadi, S. R., Shazadi, K., Gul, A., and Hakeem, K. R. (2016). Effects of pesticides on environment. *Plant, soil and microbes: volume 1: implications in crop science*, pages 253–269.
MAPA (2024). Registros concedidos de agrotóxicos. Atualizado até 2024.
Moraes, R. F. (2019). Agrotóxicos no brasil: padrões de uso, política da regulação e prevenção da captura regulatória. Texto para discussão n. 2506, Instituto de Pesquisa Econômica Aplicada (IPEA).
Panis, C., Candiotto, L. Z. P., Gaboardi, S. C., Teixeira, G. T., Alves, F. M., da Silva, J. C., Scandolara, T. B., Rech, D., Gurzenda, S., Ponmattam, J., et al. (2024). Exposure to pesticides and breast cancer in an agricultural region in brazil. *Environmental Science & Technology*.
Paumgartten, F. J. (2020). Pesticides and public health in brazil. *Current opinion in toxicology*, 22:7–11.
Pignati, W., Oliveira, N. P., and Silva, A. M. C. d. (2014). Vigilância aos agrotóxicos: quantificação do uso e previsão de impactos na saúde-trabalho-ambiente para os municípios brasileiros. *Ciência & Saúde Coletiva*, 19:4669–4678.
Reidpath, D. D. and Allotey, P. (2003). Infant mortality rate as an indicator of population health. *Journal of Epidemiology & Community Health*, 57(5):344–346.
Schreinemachers, D. M. (2003). Birth malformations and other adverse perinatal outcomes in four us wheat-producing states. *Environmental Health Perspectives*, 111(9):1259–1264.
Shahraki, M., Agheli, L., Arani, A. A., and Sadeghi, H. (2016). The effect of mothers' education and employment on children's health. *Jentashapir Journal of Health Research*, 7(4):e30977.
Shirangi, A., Nieuwenhuijsen, M., Vienneau, D., and Holman, C. J. (2011). Living near agricultural pesticide applications and the risk of adverse reproductive outcomes: a review of the literature. *Paediatric and perinatal epidemiology*, 25(2):172–191.
SINITOX (2017). Dados nacionais de intoxicação por agrotóxicos de uso agrícola em 2017. `https://sinitox.icict.fiocruz.br/dados-nacionais`. Acessado em: 07 de outubro de 2024.
Skidmore, M. E., Sims, K. M., and Gibbs, H. K. (2023). Agricultural intensification and childhood cancer in brazil. *Proceedings of the National Academy of Sciences*, 120(45):e2306003120.
Trevilato, G. C., Riquinho, D. L., Mesquita, M. O., Rosset, I., Augusto, L. G. d. S., and Nunes, L. N. (2022). Anomalias congênitas na perspectiva dos determinantes sociais da saúde. *Cadernos de Saúde Pública*, 38:e00037021.
Valadares, A. A., Alves, F., and Galiza, M. (2020). O crescimento do uso de agrotóxicos: uma análise descritiva dos resultados de censo agropecuário 2017. *Instituto de Pesquisa Econômica Aplicada (IPEA)*, 65:1–42.
Vasconselos, Y. (2018). Agrotóxicos na berlinda. *Revista Pesquisa FAPESP*, (271). Accessed: 12 Feb. 2025.
Vedam, S., Leeman, L., Cheyney, M., Fisher, T. J., Myers, S., Low, L. K., and Ruhl, C. (2014). Transfer from planned home birth to hospital: improving interprofessional collaboration. *Journal of midwifery & women's health*, 59(6):624–634.
Velame, K. T. and Antunes, J. L. F. (2024). Mortalidade por câncer na infância e adolescência: análises de tendência e distribuição espacial nas 133 regiões intermediárias brasileiras agrupadas por macrorregiões. *Revista Brasileira de Epidemiologia*, 27:e240003.