UNIVERSIDADE DE SÃO PAULO
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LIZ MATSUNAGA

Disasters and mental health: Evidence from the Fundao tailing dam breach in Mariana, Brazil

Desatres e saúde mental: Evidências do rompimento da barragem de Fundão em Mariana (MG)

SÃO PAULO
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Resumo

Esta dissertação investiga as consequências na saúde mental devido à ruptura da barragem de Fundao, em Mariana (MG), em novembro de 2015. Ao contrário de estudos anteriores, que consideram os municípios afetados como uma única região, investigamos cada região afetada separadamente, contabilizando efeitos heterogêneos devido ao vasto espectro do desastre. Utilizamos o método de diferença-em-diferenças para investigar as hospitalizações relacionadas à saúde mental e usamos a abordagem apresentada por Ferman e Pinto (2019) para corrigir nossas estimativas de erros padrão devido ao pequeno número de unidades tratadas em cada grupo afetado. Encontramos um efeito considerável nas internações por transtornos mentais no estado de Minas Gerais, especialmente em municípios localizados no alto rio Doce, próximos à barragem do Fundão. Nossas estimativas indicam que o desastre induziu pelo menos um aumento de duas vezes nas internações por transtornos mentais nessa região, com impactos consideráveis em um amplo conjunto de transtornos mentais. Também encontramos efeitos em municípios do estado de Minas Gerais localizados no médio rio Doce, à jusante do reservatório de Candonga - um aumento de quatro vezes nas hospitalizações devido a distúrbios com início na infância e adolescência - e nos municípios indiretamente afetados - um aumento de duas vezes nas hospitalizações relacionadas ao estresse. Finalmente, trazemos evidências dos efeitos tardios e persistentes do desastre na saúde mental, com um número crescente de hospitalizações persistindo (se não começando) anos após o colapso da barragem.

Palavras-chaves: economia ambiental, barragem de rejeitos, saúde mental, mineração, desastre, Samarco, Mariana.

Abstract

This paper investigates mental health consequences of Fundao dam rupture, in Mariana, Brazil, in 2015. Unlike previous studies that analyze the affected region as a unit, we investigate each affected region separately hence accounting for heterogeneous effects due to the vast spectrum of the disaster. We use a difference-in-differences framework to investigate mental disorders hospitalizations and use the approach of Ferman e Pinto (2019) to correct our standard errors estimations due to the few number of treated units in each affected group. We show a sizable effect in mental disorders hospitalizations in Minas Gerais state, especially at municipalities located near Fundao dam (upstream Candonga reservoir). Our estimations indicate that the disaster induced at least a two-fold increase in mental disorders hospitalizations in this region with considerable impacts in a broad set of mental disorders. We also find effects for municipalities in Minas Gerais state located downstream Candonga reservoir (a four-fold increase in hospitalizations due to disorders with onset on childhood and adolescence) and indirectly affected ones (a two-fold increase in stress-related hospitalizations). Finally, we bring evidences of the late and persisting effects of the disaster in mental health, with an increased number of hospitalizations persisting (if not starting) years after the dam collapsed.

Key-words: environmental economics, tailing dam, mental health, mining, disaster, Samarco, Mariana.

Contents

1 Introduction

Dams are very important, if not essential, to some economic activities such as certain types of mining operations, electricity generation, water supply, for agricultural and industrial consumption. They also provide services such as flood protection, buffer against climatic shocks and opportunities for recreation. For these reasons, 45,000 large dams have been built in the world and around half of the world rivers are obstructed by large dams (DUFLO; PANDE, 2007). Whereas dams generate large benefits, they also have important social costs, and these are often unevenly distributed among winners and losers from different projects. Duflo e Pande (2007), for example, estimate that dams in India tend to benefit downstream regions and either hurt or be indifferent for upstream and dam locations.

Other costs of dams are associated with environmental losses and the potentially devastating consequences of dam failures to downstream locations. A surprisingly large number of dam breaches are documented around the world. These date back to the Marib Dam failure in Sheba, Yemen in the year 575, causing the displacement of tens of thousands of people, and include major tragedies such as the Banqiao and Shimantan dam failures in China in 1975 (leaving over 150,000 deaths and one million people without their homes) and the Machchu-2 Dam breach in Morbi, India, in 1979 (killing an estimated of 5,000 people). Dam failures continue to happen nowadays. There were three breaches in 2019: Brumadinho, in Brazil (over 250 deaths), Spencer Dam, in the USA (1 presumed death), and Tiware Dam, in India (23 deaths). Nevertheless, studies on the social costs of dam failures are still scarce in the economic literature.

In this study, we focus on the aftermaths of the Fundao dam breach that took place in Mariana, in the state of Minas Gerais, Brazil, on November 5^{th}, 2015. The dam was used by the firm Samarco SA, owned by the Brazilian Vale and the Australian BHP Billiton mining companies, to deposit iron mining tailings. The dam failure killed 19 people and released 34 million m^3 of mining tailings in the environment, affecting 663.2 km (412 miles) of water bodies and devastating $1,469$ hectares of land, including permanent preservation areas (IBAMA, 2015). The mud directly affected thirty-five municipalities and approximately 1.1 million people. The dam collapse brought profound socioeconomic consequences, including the complete destruction of three districts, the ban of fishing in the Doce River's mouth and the interruption of Samarco's activities, a major source of jobs and tax revenues in the region. The magnitude of the collapse was such that it became the first Brazilian environmental crime classified as a violation of human rights by the Brazilian National Council of Human Rights.[1]

[1] In addition to pressuring justice, the resolution may base representations against Brazil in international

Disasters affect millions of people around the globe every year. There is, on average, at least one disaster every day worldwide, and the frequency and human impact of disasters have been increasing owing to climate change and growing population density. According to WHO (2014), people who experience humanitarian crises or emergency situations, such as wars, armed conflicts and natural or technological (man-made) disasters, are likely to be at risk of developing mental disorders. The term “disaster syndrome”, for instance, was coined by Tyhurst (1951) to describe the period right after a disaster when exposed persons are “dazed, stunned, unaware, frozen or wandering aimlessly” - these symptoms may affect up to 20/25% of exposed people and generally vanishes with time. Studies also show that disasters may cause anxieties and adverse mental health consequences not only to directly affected individuals, but also to indirectly affected ones (see Bromet, Havenaar e Guey (2011), Danzer e Danzer (2016) and Maeda e Oe (2017)). In addition, the disruption of the local economy due to the disaster, lingering negotiations to establish the terms for compensation and restoration of damages as well as uncertainties with respect to the implementation of the required actions are additional channels connecting disasters to mental health issues.

In turn mental, health issues may result in large losses in well-being and productivity as well as public and private health treatment spending.[2] According to Layard (2017), mentally ill individuals are less likely to be employed and, if employed, more likely to be out sick or working below par. If mentally ill individuals received treatment so that they were employment at the same rate as the rest of the population, total employment would be 4% higher.

By keeping so many people from working or from working productively, mental illness costs billions in welfare payments and lost tax revenues. The problem is compound over time if children suffer with mental health issues. Currie e Stabile (2006) estimate that mental health conditions are more important determinant of average human capital accumulation outcomes than physical health conditions.

Dealing with economic costs of disasters and catastrophes and their aftermath must involve looking at the consequences on mental health, as this factor is critical to recovery and renewal of individuals and communities, contributing in major ways to the costs of disasters (RAPHAEL; TAYLOR; MCANDREW, 2008). Despite the increasing numbers of disasters observed in the last decades,[3] the literature on the causal effects of disasters on mental health in Latin America, especially in Brazil, is still scarce.

Therefore, we expand on the literature by focusing our research on the consequences of Mariana’s disaster on mental health. For this we use hospitalization data from

courts, which may even result in diplomatic or economic sanctions.

[2] For more on this see WHO (2003).

[3] In 2005, approximately 162 million people were affected by disasters globally; in 2010, this estimate increased to more than 330 million (GOLDMANN; GALEA, 2014).

public hospitals. We use a difference-in-differences empirical strategy and address the issue of small number of treated units with a recent approach proposed by Ferman e Pinto (2019). In order to account for the heterogeneous impacts suffered by each affected region due to the disaster broad spectrum, we classify affected municipalities in categories and analyze each category individually.

We estimate a large and significant increase in the incidence of mental health issues in Minas Gerais state, especially when analyzing each affected region individually. For municipalities located near Fundao dam, we estimate that the disaster induced, at least, a two-fold increase in mental disorders hospitalizations, with a considerable impact in different groups of mental disorders: (i) stress-related disorders, (ii) psychoactive substance use, (iii) psychological development disorders, (iv) non-organic psychosis and (v) mental retardation. We also find effects for municipalities in Minas Gerais located downstream Candonga reservoir, where the physical impacts of the mud was less intense in comparison to municipalities located near Fundao dam, here we find a four-fold increase in hospitalizations due to mental disorders with onset on childhood and adolescence. And for indirectly affected municipalities, we find a two-fold increase in stress-related hospitalizations.

Our results are robust to the inclusion of control variables, time and unit fixed effects, different control groups, different pre and post-treatment time periods and time-specific trends. Finally, we analyze attendances in psycho-social care centers for a subset of affected municipalities and bring evidence of a late and persisting effects of the disaster on mental health. This complementary analyzes reinforces the results we've obtained using the hospitalization database.

This paper is divided into five sections in addition to this introduction. Section two briefly covers the literature on disasters and its relation with mental health. Section three provides a short background of mining activities in Brazil and briefly describe Mariana's tragedy and some of its major socioeconomic impacts in the region. Section four describes our empirical strategy and the databases used in our analyzes. Section five presents our main results. Section six presents our complementary results and a brief discussion on our findings. And section seven concludes.

2 Disasters and Mental Health

In this section we present an overall picture on the literature about mental health consequences of disasters.[1] This field has one of its main roots on studies about the consequences of war, particularly World War I and II and the Holocaust, beginning in the 1940s. In the 1960s and 1970s, there was a growing interest in how disaster could influence communities and result in large-scale effects, such as physical and mental consequences of different types of disaster. It was in this period that studies began to incorporate population-based epidemiologic methods. However it was only in the 1990s that the area experienced a rapid progress in research and practice due to the incentives of organizations such as the World Health Organization (WHO). At this time the field expanded to include terrorism, epidemics, and the role of stressors in vulnerability to psychopathology development after disasters. In the past decade, the field have been characterized by rigorous epidemiological methods and the development of evidence-based guidelines for early interventions (GOLDMANN; GALEA, 2014).

2.1 Major mental disorders

Exposure to disasters has been associated with a variety of mental disorders. Although the majority of individuals cope well in the face of a disaster, a substantial proportion experience some psychological impairment, and a smaller proportion will go on to develop mental disorders (NORRIS et al., 2002). Several empirical studies have documented the prevalence of various types of psychopathology following different types of disasters, from natural disasters such as Hurricane Katrina to technological or man-made disasters such as Chernobyl's Catastrophe or the World Trade Center attacks (Kessler et al. (2006), Bromet, Havenaar e Guey (2011) and Farfel et al. (2008)).

Bellow we describe the manifestations and burden of mental illness most covered in the disasters mental health literature - all descriptions and definitions were extracted from Goldmann e Galea (2014).

- ***Posttraumatic Stress Disorder***
  - Posttraumatic Stress Disorder is a mental illness that can follow exposure to a traumatic event and is characterized by reexperiencing of the event through nightmares and/or flashbacks; avoidance of stimuli reminiscent of the event and numbing of emotional responses; and symptoms of hyperarousal (e.g., being particularly watchful or on guard).

[1] For an extensive review on this topic, we recommend seeing Goldmann e Galea (2014).

- ***Major Depressive Disorder***
  - Major depressive disorder is one of the most common mental illnesses in the general population, characterized by sadness and loss of pleasure or interest in things once enjoyed, as well as a combination of other symptoms such as changes in sleep and weight, difficulty concentrating, and irritability.
  - In disaster research, depression is, after PTSD, the second most commonly studied post-disaster mental health condition.
- ***Substance Use Disorder***
  - Characterized by problematic alcohol or drug use that results in difficulty fulfilling obligations in work, home life, or school; legal issues; difficulties in social relationships; involvement in dangerous situations; increased tolerance; symptoms of withdrawal; and unsuccessful efforts to quit;
  - Some studies have observed increases in the use of alcohol, drugs, and cigarettes after a disaster, and some evidence shows that disaster victims use substances, particularly alcohol, as a coping strategy;
  - For example, 15% of Oklahoma City bombing survivors reported using alcohol to cope with their experience. Studies have also demonstrated increased use of alcohol, cigarettes, and marijuana in the period following the WTC attacks. See North et al. (1999) and Vlahov et al. (2002).

Other psychological symptoms that have been described in the literature are generalized anxiety disorder, death anxiety, panic disorder, and phobias, although in a lesser extent than those mentioned previously. Somatic symptoms also manifest in the aftermath of disasters; these may be associated with psychological distress. For example, exposed persons frequently report sleep disruption, due to feelings of grief over loss and anxiety about disaster reoccurrence and ongoing threats or due to symptoms of depression or posttraumatic stress disorder.[2]

Although these are the most common disorders studied in the literature, it doesn't mean that we should discard the occurrence of other types of mental illnesses in the aftermaths of disasters. According to Goldmann e Galea (2014), the field actually needs studies that evaluate a wider range of psychopathology than has currently been studied.

We evaluate all mental disorders listed in the fifth chapter (Mental and behavioural disorders) of the International Disorder Classification (ICD-10), see table 2.1. The disorders we've described above are also included in this table: posttraumatic stress disorders are classified under group "F40-F48 Neurotic, stress-related and somatoform disorders;

[2] For more, see Nolan (1995) and Ursano, Fullerton e Benedek (2009).

major depressive disorder is included in group “F30-F39 Mood [affective] disorders; and substance use disorders are included in group “F10-F19 Mental and behavioural disorders due to psychoactive substance use” (for a complete description of disorders categories in each group, see table A.1).

Table 2.1 – Classification of mental disorders according to ICD-10

ICD-10	***Disorder***
F00-F09	Organic, including symptomatic, mental disorders
F10-F19	Mental and behavioural disorders due to psychoactive substance use
F20-F29	Schizophrenia, schizotypal and delusional disorders
F30-F39	Mood [affective] disorders
F40-F48	Neurotic, stress-related and somatoform disorders
F50-F59	Behavioural syndromes associated with physiological disturbances and physical factors
F60-F69	Disorders of adult personality and behaviour
F70-F79	Mental retardation
F80-F89	Disorders of psychological development
F90-F98	Behavioural and emotional disorders with onset usually occurring in childhood and adolescence
F99-F99	Unspecified mental disorder

Source: Authors’ elaboration with ICD-10 data.

2.2 Trajectory of disorders and risk factors

Many may be the responses of an individual or, generally speaking, of a community in face of a disaster. At this point in the literature, interest in the course or trajectory of psychological symptoms following disasters is growing. Evidence from longitudinal studies suggests that post-disaster symptoms of mental health problems reach their peak in the year following the disaster and then improve, but in many studies symptoms persisted for months and even years for some participants (GOLDMANN; GALEA, 2014). According to Norris et al. (2002) there are four distinct symptom trajectories: (i) resistance, (ii) resilience, (iii) recovery, and (iv) chronic dysfunction.

Resistance is defined as experiencing no symptoms of mental illness or only mild symptoms after the disaster. **Resilience** is characterized by symptoms of mental disorder in the period immediately following the disaster that rapidly decline after a short while. **Recovery** differs from resilience such that symptoms that present after the disaster decrease gradually after a longer period of suffering. Finally, **chronic dysfunction** describes moderate or severe symptoms whose levels remain stable over time, and it is found only in a relatively small proportion of persons exposed to a traumatic event.

These definitions help us visualize possible mental health scenarios in the aftermath of traumatic events, thereby they may also be useful to support public policies formulators to develop appropriate strategies and measures in response to each case. Nevertheless, it is hard (or even impossible) to know beforehand which path an affected community will follow after a disaster. Each circumstance is very particular and depends on many factors. In the literature, there are studies dedicated to investigate such factors[3] that may influence communities vulnerabilities to disasters. They are mainly characteristics or experiences of individuals before, during, and after a disaster that may amplify the traumatic experience increasing the propensity to psychopathology. According to the period of time these risk factors are prevalent, we can divide them in three groups: pre-, peri- and post-disaster factors (GOLDMANN; GALEA, 2014).

Key pre-disaster risk factors that most show up in the literature are prior mental health problems, female gender, and younger age. As well as low socioeconomic status, minority ethnic status, and low social support or poor relationships (GOLDMANN; GALEA, 2014). Psychological outcomes such as PTSD and depression are generally worse for female disaster survivors, with the exception of alcohol and other substance use disorders, which are more prevalent among men after a disaster (NERIA; NANDI; GALEA, 2008). It's also worth mentioning that some of the pre-disaster risk factors described may be associated with greater risk of post-disaster psychopathology because they elevate risk or intensity of disaster exposure or because they leave an individual more vulnerable to the psychological consequences of the disaster experience. A combination of both increased exposure and vulnerability may amplify the role these factors play in shaping the risk of post-disaster psychological consequences (GOLDMANN; GALEA, 2014). In our work we consider pre-disaster risk factors as control variables.

Peri-disaster risk factors mainly revolves around how much exposure an individual experiences during the disaster occurrence. Indeed, this factor is so relevant that studies reveals it to be the most predictive factor of post-disaster mental illness. The measure of exposure to a disaster can be done in various ways and dimensions, such as the number and intensity of disaster-related events, the type of disaster, duration of exposure, death toll, and proximity to the epicenter of a disaster. Though, regardless of the measure, more intense exposure consistently and strongly predicts higher risk of mental health consequences (Norris et al. (2002), Neria, Nandi e Galea (2008), McFarlane e Williams (2012), Maguen et al. (2012)). Most measures of disaster exposure may be seen as proxies for the extent to which an individual experienced extremely stressful or traumatic events during the disaster, hence this is why it is important to consider this variable when evaluating impacts on mental health. We consider this issue by taking into account that municipalities were affected differently depending mainly on its location (proximity to Fundao dam), thereby dividing them into different categories. We discuss this classification in further sections.

Finally, regarding post-disaster risk factors we emphasize two in particular: post-disaster life stressors and social support. According to Goldmann e Galea (2014), these are

[3] These factors are commonly called "risk factors".

key factors to worsen mental disorders occurrence in the aftermath of a disaster. Examples of common life stressors in the post-disaster scenario that can increase vulnerability to mental illnesses are job loss, property damage, marital stress, physical heath conditions related to the disaster, and displacement. Exposure to these factors are also associated with long-term impairment in mental health, mainly with post-traumatic stress disorders and depression.[4] In Mariana's tragedy, an important post-disaster life stressor that play a major role in affected communities is dealing with the legal developments of the disaster, such as compensation actions. We discuss this issue in details in section 3.3.

As of social support, it may function as a buffer against negative psychological consequences of stressful events by helping individuals to cope with these experiences.[5] On the other hand, the lack of social support[6] are associated with psychological symptoms, as well as mental disorders such as posttraumatic stress disorder, depression and, less consistently, increased substance use.

These findings provide insight into the potential mechanisms through which disaster experience may influence various mental health outcomes and suggest areas where intervention may prevent or reduce the severity and course of disaster-related mental illness. In the next section we describe Mariana's Tragedy and its main developments in socioeconomic terms, highlighting possible risk factors that may have contributed to the emergency of psychological disorders in affected communities.

[4] Cerdá et al. (2013) conducted a study with Hurricane Ilke survivors and found that post-disaster stressors were associated with posttraumatic stress symptoms and functional impairment in interviews made over the subsequent 18 months from the disaster.

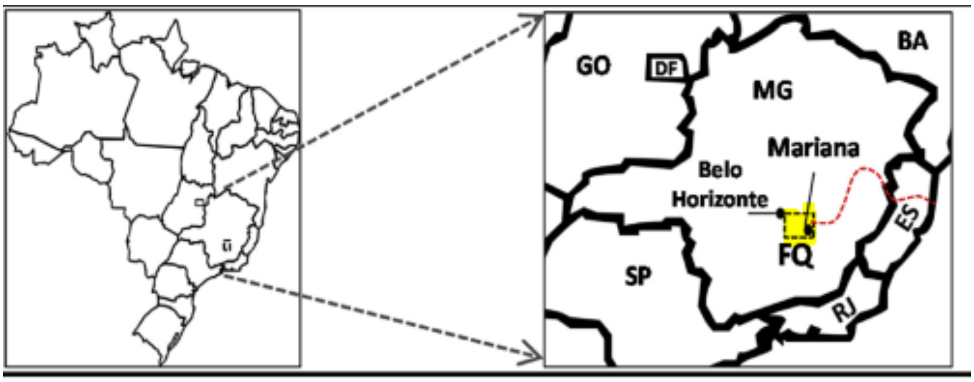
[5] For evidences see Guay, Billette e Marchand (2006) and Williams e Joseph (1999).

[6] This lack of social support are, in many cases, worsen in a post-disaster scenario due to displacement, death and disruption of communication.

3 Background: Mariana's Tragedy

Minas Gerais is a Brazilian state that has a historical relationship with mineral exploitation activities. Some of the state's cities are responsible for large part of mining activity in Brazil since the colonial period until present day: for instance the cities of Mariana, Ouro Preto, and Nova Lima located at the center-east of Minas Gerais at a region called "ferriferous quadrangle"(FQ) (BARRETO et al., 2001). The name of this region comes from its immense deposits of iron, manganese, gold, bauxite, topaz, emerald and other precious stones. It has approximately $7,000\ km^2$, extending from the city of Ouro Preto to Belo Horizonte (see figure 3.1) and its minerals have been exploited since the 17th century. The FQ represents almost 27% of all Minas Gerais'economic earns and iron production is estimated in more than 254 million tons per year (SEGURA et al., 2016).

Figure 3.1 – "Ferriferous Quadrangle" in Minas Gerais state



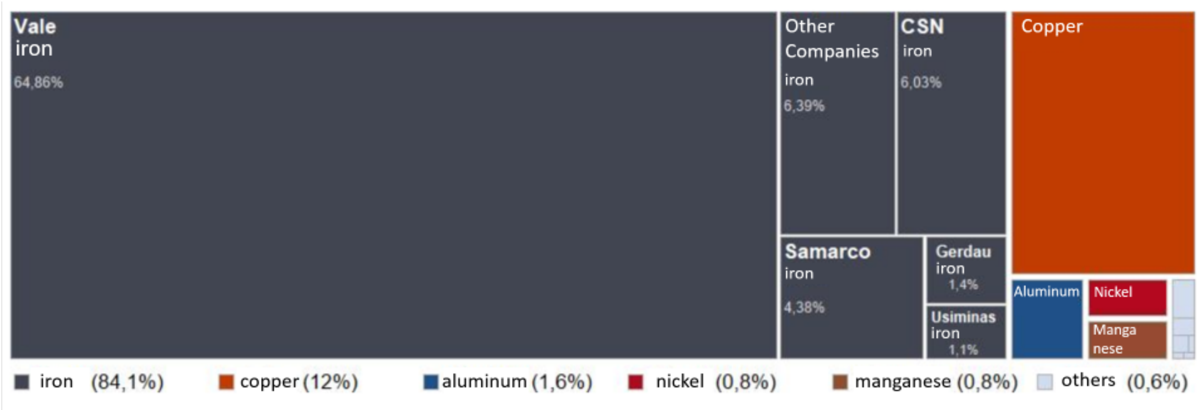
Source: Segura et al. (2016)

Nowadays, mineral extraction in Brazil is an essential activity concentrated in specific regions and controlled by few companies. In 2015, the year of Fundao dam rupture, the production of iron ore had prominent participation within the broad set of mineral commodities produced. Moreover, among the iron ore producing companies, Vale SA held 65% of the market share[1] (see figure 3.2) and, at a regional level, Minas Gerais state lead the domestic rank of iron ore production, accounting for 45.6% of total production in 2015 (see figure 3.3).

The concentration in the sector is such that, in 2015, Samarco company alone was responsible for 4.38% of all ore exports in Brazil, 24.9 million tons were produced by the company - 97% in pellets and 3% in iron ore fines -, with a revenue of R$ 6.5 billion, and generated around 6 thousand direct and indirect jobs.[2]

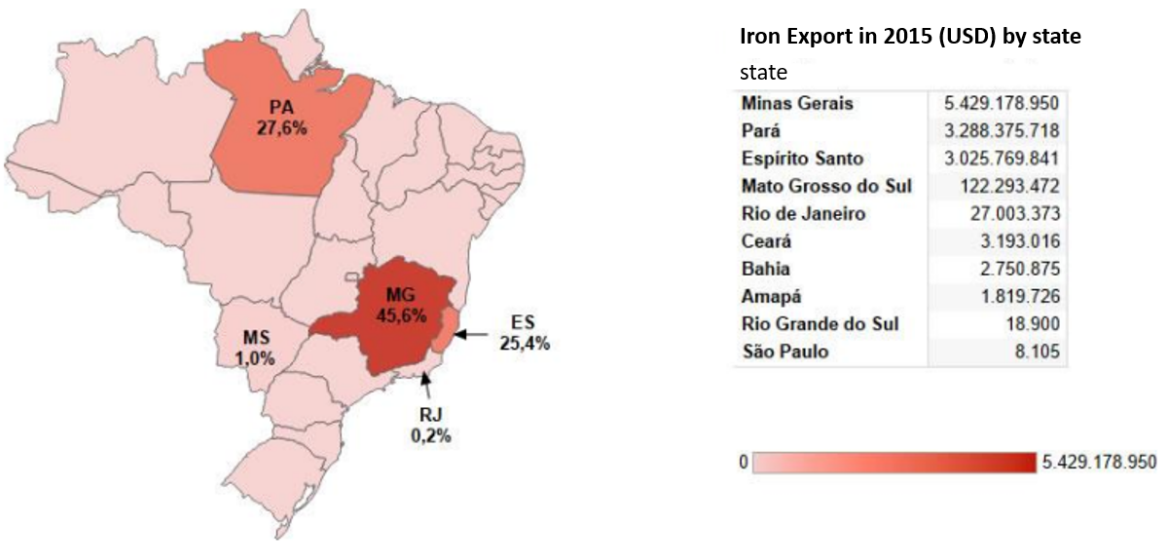
[1] Illustrating the great bargaining power that large mining companies have in Brazil.
[2] According to the company website: <https://www.samarco.com/en/a-samarco/>

Figure 3.2 – Ore exports by companies in Brazil from January to October 2015



Source: Simonato et al. (2018)

Figure 3.3 – Ore exports by companies in Brazil from January to October 2015

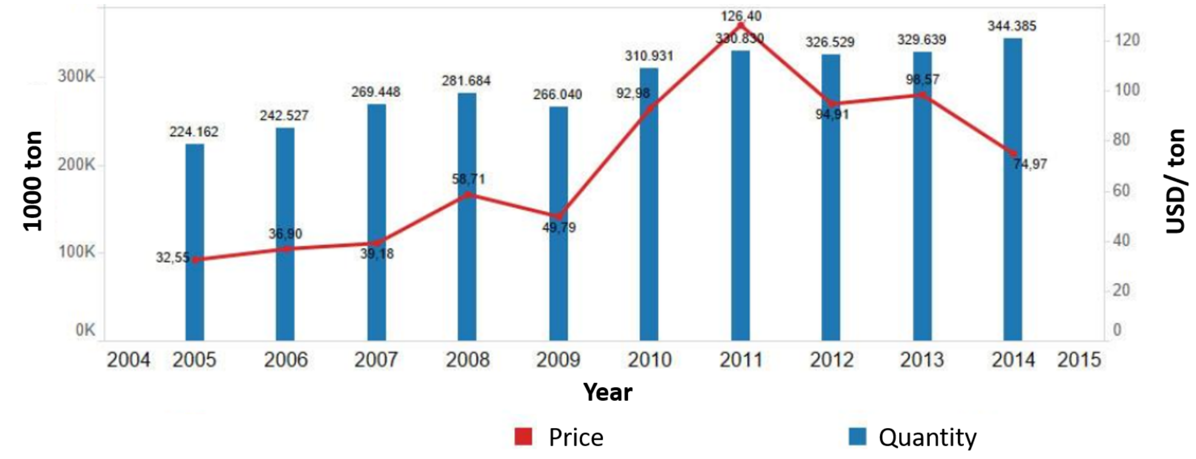


Source: Simonato et al. (2018)

Samarco is a privately held mining company owned by the Brazilian company Vale (50%) and the Anglo-Australian BHP Billiton (50%). It was founded in 1977 and its main product are iron ore pellets, which is sold to the steel industry in the Americas, the Middle East, Asia and Europe. The company has two operating units: Germano, in Mariana and Ouro Preto (MG), where iron ore extraction and beneficiation was carried out in three concentrators, and Ubu, in Anchieta (ES), where four pelletizing plants are located. The units are interconnected by three 400-kilometer-long pipelines, which run through 25 municipalities of both states.

Between 2005 and 2014 there was a period in Brazil known as the super cycle of commodities, mainly due to China's fast economic growth rates (SERRA, 2018). In this period there was a considerable variation in price and volume of iron ore exports, global imports of ore sixfold, also causing a steep increase in the price of iron ore, which ranged from 32 to 126 dollars between 2000 to 2011 (SIMONATO et al., 2018). This was a cycle in which Brazil ranked second in the world for mineral exports, with mining responsible for 5% of the national GDP and iron ore responsible for 92.6% of all the country's mineral exports (WANDERLEY et al., 2016). Samarco, in turn, took center stage in this process, becoming the second largest transoceanic iron ore exporter in the world and the 10th largest exporter of ores in the country (SALINAS, 2016).

Figure 3.4 – Iron Ore Export by Year in Brazil



Simonato et al. (2018)

Samarco also knew how to adapt to the post-boom of commodities, characterized by the fall in demand, and consequently in the price, of iron ore. This drop in prices, which were partly generated by an oversupply of ore in a post-crisis context of 2008,[3] intensified in 2014 by the expansion of low-cost iron ore production. In this context, the countries that have been successful in offering low-cost iron, such as Australia and Brazil, assumed a competitive advantage in this new cycle of the commodities market (BANK, 2014). However, it's worth emphasizing the pressure imposed to mining companies to reduce costs due to the falling prices - the broad outsourcing policy adopted by Samarco in these years is a reflect of such pressure (MILANEZ et al., 2015).

3.1 Fundao tailing dam

Although mining has an undeniable importance to the economy, it causes profound impacts to ecosystems and landscapes, being frequently associated with environmental degradation. Historically, it can be considered one of the main anthropogenic activities that most contribute to the pollution of watersheds around the world. It is also related

[3] Fundao dam operation started its operations in the middle of this period, in December 2008.

to a series of problems in human health and long-term damage to rivers and biodiversity (HATJE et al., 2017).

The impacts of mining on ecosystems and conservation are global and of major concern because of its synergy with other drivers of ecosystem changes. One major concern involves handling mining waste - common to almost all types of mining - and an issue that generally poses a great risk to the environment and public health when there is no environmentally sound management (e.g., Drury (2007), Murguía, Bringezu e Schaldach (2016)). The generation of mining waste is generally very high in mining exploitation activities, they frequently account for up to 90% of the ore exploited,[4] and thus its destination or reuse is complex and requires great investment and planning in its handling.

Mining waste can either be stored in dams (usually built using the upstream method, downstream method or center-line method), or can be disposed of in underground mines, in piles, by dry stacking (dry stacking method), among other methods. Tailing dams structures are the preferred method of mining companies, especially when the tailing is used as construction material for the dam itself. This preference is due to its lower cost relative to other methods (ESPÓSITO, 2000) - in Minas Gerais state alone, there are 220 tailing dams of this nature (SALINAS, 2016). Usually the tailing is transported by water and deposited using the hydraulic landfill technique, however, it poses a significant challenge to the geotechnical engineer, due to the fact that water is the primary instability agent.

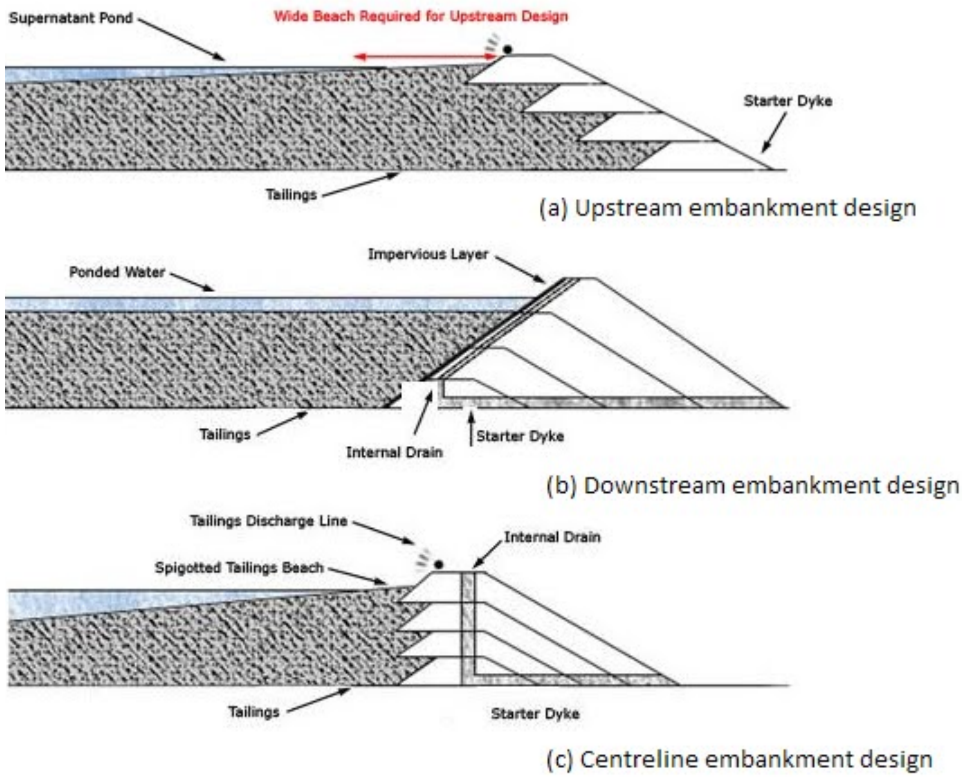
Among the most common methods of tailing disposal dams, the one with the greatest economic advantage is the upstream embankment - both Fundao dam and Córrego do Feijão dam[5] used this method (see figure 3.5). The main disadvantage of this technology is the instability, as later lifts are put on unstable tailing slime. Thereby this method requires a high level of monitoring during its operation. This is such a major restriction that, even though it is the cheaper method, it is not used in earthquake zones. Indeed, dams using the upstream embankment method are considered “unforgiving structures” and represent up to 66% of the worldwide reported mine tailings dams failures (CARMO et al., 2017).

Due to its potential risks and limitations, the quality of these structures needs to be ensured, beginning with site selection and continuing through the management of structures to their closure, following environmental norms, geotechnical and structural parameters, social, and safety and risk factors (KALSNES et al., 2017). However, since waste disposal and investment in its improvement do not seem to bring any direct financial return, entrepreneurs often build simpler, less-expensive, and thus less reliable, structures;

[4] E.g., 98.7% for copper, 97.9% for niobium, 96.6% for nickel, 98.6% for cobalt and almost 100% for gold.

[5] Vale’s dam located at Brumadinho city (MG) that collapsed in January, 2019.

Figure 3.5 – Conventional embankment design techniques for a tailings dam



Source: <www.tailings.info>

this has been a principal factor behind the majority of accidents reported in the literature.

Since the beginning of its operation, in 2008, Fundao dam had presented several anomalies related to drainage construction defects, mud and water management errors and saturation of sandy material. In some situations, emergency measures were implemented, one of them known as retreat of the dam axis begun in 2013[6] and it was considered by the company as a temporary solution, but continued until the collapse of the dam (CARMO et al., 2017).

Mining activities in Brazil represents an endemic crisis with deep roots in the country's history, not being restrained to a particular event.[7] Fundao dam burst in the municipality of Mariana figure out as a classical example on how lack of public enforcement aligned with careless maintenance and management of such an important structure due to a blind pursuit for profit can lead to environmental and socioeconomic disasters that may reverberate through time. Nevertheless, despite this subject's relevance, there is still a lack of economic research about Fundao's collapse effects on mental health, relevant information for designing recovery and compensation actions for affected communities.

[6] As described in the technical report: samarco2016.
[7] For a more detailed discussion on this topic see Salinas (2016)

Figure 3.6 – Minas Gerais' dam burst in the last 20 years

Year	City	Company	Main Impacts
2001	Nova Lima	Rio Verde Mining	Five people were killed.
2003	Cataguases	Cataguases de Papel	Animal deaths and shortage of energy for over 600.000 people
2007	Miraí	Rio Pomba/Cataguases	More then 4.000 were left unsheltered
2014	Itabirito	Dora Herculaneum	Three people were killed.
2019	Brumadinho	Vale	Over 200 people were killed and 93 were missing.

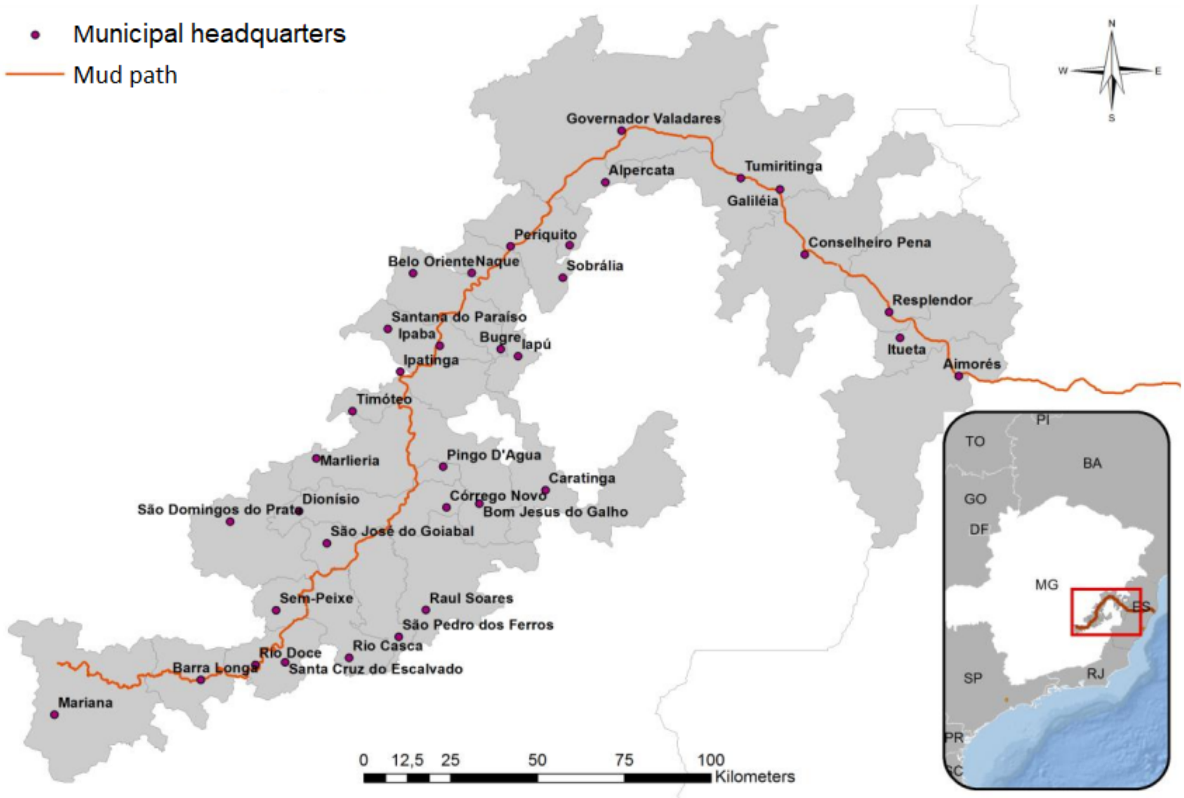
3.2 Socioeconomic impacts of the collapse

On November 5^{th}, 2015, Fundao dam collapsed in Mariana city, state of Minas Gerais, Brazil. About 34 million m^3 of tailings (80% of the total contained volume) were unleashed, killing 19 people, affecting 663.2 km of water bodies, and causing irreversible environmental damage to hundreds of watercourses in the the Doce River basin and associated ecosystems (IBGE, 2015). The disaster instantaneously caused the turbidity of the Doce river to reach a level 12,000 times higher than that allowed for consumption, and the oxygen level to suddenly drop below 1 mg/L (IGAM, 2015), causing the death of several tons of fish and many other living organisms. The harm done to biodiversity has yet to be precisely estimated. The mud reached the Atlantic Ocean on November 22^{nd} (16 days after the collapse), expanding the impacts to the fragile, yet diverse estuarine and coastal region in Espírito Santo state. The disaster directly affected forty-one municipalities in the states of Minas Gerais and Espírito Santo (see figure 3.7).

Doce River Basin is the 5^{th} largest basin of Brazil, it has a drainage area of 86,715 square kilometers, a territorial extension equivalent to Portugal, with 86% of its area in the state of Minas Gerais and 14% in the state of Espírito Santo. The basin has a population of about 3.5 million inhabitants, distributed in 202 municipalities in the state of Minas Gerais and 26 in Espírito Santo. The vast majority of municipalities (85%) with less than 20 thousand inhabitants has an expressive rural population. With great intra-regional diversity, both environmental, socioeconomic and cultural. These differences and local dynamics are also overlapped by the complex territorial systems created by large capital investments: mining, steel, cellulose and energy. The Doce River is 879 kilometers long and plays an important role in supplying water for domestic, agricultural and industrial use; and electricity generation. Not only the Doce river, but the set of rivers in the basin serves as channels for receiving and transporting waste and effluents (ESPINDOLA; GUERRA, 2017).

We can analyse the disaster consequences in two main dimension: (i) the geographic one and (ii) the temporal one. First, relative to the geographic dimension, Fundao dam collapse affected a wide geographical area, with the tailing mud crossing several municipalities. The disaster directly affected all municipalities bathed by the affected rivers,

Figure 3.7 – Directly affected municipalitis



Source: Simonato (2017)

although in different magnitudes and intensities depending on the municipality location, especially its distance from Fundao dam. Approximately two thirds[8] of the unleashed tailings were contained in Risoleta Neves hydroelectric reservoir, also known as Candonga reservoir, located at the municipality of Santa Cruz do Escalvado, in Minas Gerais state. Without the Candonga barrier, the impacts caused by the dam failure would have been much worse in terms of infrastructure and environmental damage. About 80% of the unleashed tailings stayed between the area downstream Fundao dam and Candonga reservoir, a distance of 113 km (see figure 4.8). Therefore, major physical impacts caused by the mud occurred mainly in these first hundred kilometers: regions closest to the dam were the most exposed and suffered the most physical damage, including the complete destruction of three districts - Bento Rodrigues and Paracatu de Baixo, located in the municipality of Mariana, and Gesteira, located in the municipality of Barra Longa. The remaining volume of the tailing mud followed along the course of the Doce River all the way to the sea, impacting municipalities in Minas Gerais and on the northern coast of Espírito Santo.

To better describe the impacts suffered by each region, we divide affected municipalities in groups according to its location from Fundao dam.

[8] Approximately 10.5 million m^3 of tailings were carried beyond the limits of Candonga reservoir according to Samarco's website - <https://www.samarco.com/en/rompimento-de-fundao/>

From Fundao dam to Candonga reservoir, in the upper part of Doce river, the disaster killed 19 people, destroyed or severely damaged 483 houses and displaced approximately 812 people (SERRA, 2018). It also devastated the aquatic ecosystems and the courses of the rivers, radically altered the landscape, destroyed localities and devastated properties, among other catastrophic situations. The losses to human communities were immeasurable and definitive. Even taking into account material aspects, mitigation measures cannot solve the symbolic and subjective issues: Bento Rodrigues village, for instance, ceased to exist (ESPINDOLA; NODARI; SANTOS, 2019).

After Candonga reservoir, in the middle and lower[9] parts of Doce river, the tailing sludge killed the ichthyofauna, drastically affected several species and alluvial ecosystems, particularly in the Rio Doce State Park, and harmed the riverside populations - especially those that depended on the river for supply, irrigation, fishing, tourism, sport or leisure. Among those affected, the resilience capacity is very unequal. At one extreme there are fishermen, sand collectors,[10] family farmers and the indigenous people the “Krenak”; on the other, there is a large company such as Celulose Nipo-Brasileira S.A. (Cenibra).

At the river’s mouth, as the mud advanced into the sea and spread, the effects were devastating and directly affected the ecosystems and ways of life of the populations, with effects still present for river and marine ecosystems and for fishermen, small traders and service providers (CDHM, 2016).

Finally, there are the indirectly affected municipalities, those that were not on the mud path, but that were deeply related to Samarco’s activities or were severely affected by the economic consequences of the disaster. As a result of the mud many people were forced to change professions, abandon the only job they had, therefore not always being able to fit in - more than 6.500 fisherman lost their revenue source, for example (SERRA, 2018). The impact is evident to farmers, fishermen, artisans, traders, tourist entrepreneurs, shellfish gatherers, crab scavengers and surfers who had their activities directly or indirectly related to water (CDHM, 2019). Although these municipalities are not considered directly affected, they also face severe consequences of the disaster and suffered abrupt changes in their standard of living.

As of the temporal dimension, besides the direct and short term consequences described above, it is important to investigate medium and long term impacts to affected communities. In this sense, some events that occurred after the disaster are also relevant to understand mental health consequences. Mainly how compensation actions are being handled by Samarco and the public powers. Hence, we dedicate an entire subsection to further discuss this issue. We analyze mainly the reports of the Brazilian Human Rights

[9] The lower part of Doce river basin begins just after the border between Minas Gerais and Espírito Santo.

[10] Sand collectors are the artisans that used Doce river’s sand to make their art.

Commission (CDHM)[11], that conducted a couple of expeditions to affected communities, one in 2016 and another in 2019, to investigate social consequences of the dam failure. And the reports released by the Brazilian Federal Public Ministry, conducted by Ramboll Foundation to analyze how compensation measures are being handled in the region.[12]

3.3 Compensation Actions

Here we discuss some of the main elements of compensation actions legally developed after Fudão dam collapse. This discussion is not intended to deeply cover all the issues,[13] our intention is to present an overview picture to illustrate some of the post-disaster challenges that affected population have been going through since the collapse in 2015. We consider this important when analyzing mental health consequences as many of these facts may collaborate to a situation of vulnerability that is considered a risk factor for the development of mental illnesses, as mentioned in section 2.

According to Losekann, Dias e Camargo (2019), the Brazilian legal frame to deal with environmental conflicts operates within a structure which largely originates from the country's democratization process in the 1980s, the implementation of consumer protection code in the 1990s, and the environmental legislative frame - expressed in the National Environment Policy[14]. Environmental laws in Brazil are mobilized to address a very wide range of disasters and the legal frame of damage is very vague and open, bringing additional difficulties to address the reparation process.

A common reaction of affected individuals and communities to disasters is to seek compensation actions through the justice system. In Mariana's tragedy, thousands of individual lawsuits and dozen of class actions seeking compensation for material and moral damages were filed at courts in the states of Minas Gerais and Espírito Santo. Morever, extra-judicial conflict resolution instruments - such as agreements at state and federal levels - were also put in use by Samarco, Vale/BHP and the public authorities.

Renova Foundation, created to manage recovery and compensation programs associated with Fundao dam collapse, is a result of an extra-judicial instrument: a Term of Conduction Adjustment[15]- the Transaction Term and Adjustment of Conduct (TTAC)

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[11] The Human Rights and Minorities Commission is one of the permanent commissions of the Brazilian Chamber of Deputies.

[12] In November, 2017, the Brazilian Federal Public Ministry set a long-term deal with consultancy company Ramboll Foundation, in which it settles that Ramboll Foundation will evaluate and monitor the work of the Renova Foundation to ensure that the remediation programs achieve the promised outcomes, and propose any additional measures necessary to fully restore the area within the shortest time frame possible. Source: <https://ramboll.com/-/media/files/rgr/documents/media/news/samarco-2017-uk.pdf?la=en>.

[13] For an extensive review of the legal framing and repercussions of Mariana's tragedy, we recommend seeing Losekann, Dias e Camargo (2019).

[14] Federal Law No. 6.938 of 1981.

[15] In general, a Term of Conduct Adjustment (TAC) is a device designed at promoting extrajudicial

was signed on March 2016, by Samarco, Vale and BHP Billiton together with the federal government and the state governments of Minas Gerais and Espirito Santos and other environmental institutions.[16] This Foundation is a private, non-profit foundation with its own governance structure, oversight and control. One of Renova's main goal defined in the TTAC is to execute the defined recovery programs with a strong focus on citizen participation in both the development and execution of the programs. However, in practice, the lack of participation is a returning issue (LOSEKANN; DIAS; CAMARGO, 2019). The recovery process after the disaster has been slow and full of frictions with affected groups.

Many studies have shown the precariousness of compensation measures and agreements, the neglect of the mining companies and the slowness to actually implement recovery actions after Fundao's disaster.[17] One of the most visible example regard the resettlement of displaced individuals, mainly from the districts of Bento Rodrigues, Paracatu de Baixo (both in Mariana) and Gesteira (in Barra Longa municipality). According to Ramboll (2019b), 512 families are covered by the Resettlement Program, but until November, 2019 (4 years after the failure), no family was resettled yet. Instead Renova Foundation had made available 414 temporary homes to affected families, 56% of which present some type of inadequacy (RAMBOLL, 2019b).

This issue is far from being the only one associated with the execution of compensation actions. In all affected areas, there are countless reports that mention damage resulting from actions taken in order to minimize the initial impact and its first damages (RAMBOLL, 2017). By examining the content of actions and lawsuits associated with Mariana's tragedy between 2015 and 2017, Losekann, Dias e Camargo (2019) conclude that the legal instruments in this process have serious problems, as they do not present themselves as effective ways of replacing litigation with a mediated resolution. On the contrary, the agreement themselves encourage new lawsuits and contribute to making reparation even more time-consuming.

By analyzing the claims, Losekann, Dias e Camargo (2019) observe the centrality of the issue of "water" as a recurrent aspect in all the actions and in all its dimensions: it appears in its consumption dimension, related to the drinking water supply, and it also appears as "river" and "sea" associated with the pollution caused along the basin. In the

alternatives to solve conflicts, which is set up by public agencies with a violator of a collective right. TACs must contain varied requirements to be fulfilled by the committed party, such as the repairing of damages to collective rights, the conduct adjustment to legal and normative obligations, and/or the compensation for damages that cannot be recovered. The benefits of such a device is usually justified by the urgent nature of ecological disasters, since the processing delays of the judicial system may result in aggravating the consequences of environmental damages, which makes repairing even more difficult (SANTOS; MILANEZ, 2017).

[16] Such as IBAMA, the Chico Mendes institute, Funai, the national Water Agency.

[17] See Losekann, Dias e Camargo (2019), Salinas (2016), CDHM (2016), CDHM (2019) and Haugsnes (2018).

social dimension, it appears as a fear of water contamination linked to human uses in multiple ways, revealing a distrust on technical-scientific reports of portability. According to the authors, this distrust can be credit to a general distrust in the political leaders and private companies, perceived by many as corrupt and negligent.

They also report several lawsuits that mention the inefficiency of the containment and management of dam tailings both along the river and in the ocean. There are complaints about how the tailings were removed in some cases and in other cases how the tailings were not removed yet. Concerns regarding their future are presented as well through the notion of risk. These insecurities and uncertainties about contamination are transformed into a claim for reparation in line with the projection of a possible future damage.

Moreover, there are claims that demand for the recognition of affected ecosystems, activities and traditional work, lifestyles and communities that are neglected by Samarco. Nevertheless, one of the most serious issue brought up by Losekann, Dias e Camargo (2019) is about the recognition of affected individuals themselves, which is also mentioned in CDHM (2016), CDHM (2019) and Ramboll (2019b). These claims mainly revolve around Renova Foundation's indemnity program and emergency financial assistance program.[18] In the former, the promise is that individuals that have lost their income due to the dam failure receive an amount close to the minimum wage (with an additional value for each family member), paid monthly to their families. And in the latter, the so-called indemnity for general damages, the goal is to compensate people and micro/small companies that suffered material or moral damages, as well as losses related to their economic activities as a direct consequence of Fundao dam rupture (CDHM, 2019).

Complaints are mainly about the registration processes through which individuals have to go through in order to be recognized as affected by the Foundation, and also about the implementation process and lack of transparency of Renova Foundation.[19] In both the indemnity and the financial assistance programs, to be eligible, people must first register and be recognized as affected in Renova's system, and, second, prove the damage they suffered. There are severe gaps in both of these two steps. First, the registration process is very slow and unclear, there is a lack of information about the criteria used for recognizing the "affected condition", in addition to excluding some segments such as artisans, people connected to the fishing productive chain, tourism, leisure and recreation (RAMBOLL, 2019a).

And, second, even after a person is registered, it is necessary to prove its damage and, again, this process is unclear and time-consuming. The average time an affected

[18] More information on Renova Foundation's recovery programs can be found in their website: <https://www.fundacaorenova.org/socioeconomicos/>.

[19] Other researchers have also discussed this issue, such as Espindola, Nodari e Santos (2019), Neves et al. (2018), Milanez et al. (2015).

family that is already registered in the system, have to wait in order to have all its documents analyzed and be granted the emergency financial aid is 45 months (or three and a half years) (RAMBOLL, 2019a). In November, 2019 - 4 years after the disaster - there were $29,672$ affected families registered in Renova's system, of which 18,183 (61.3%) had not received the financial aid yet - $6,448$ (35.4%) of the families hadn't received the aid, because their processes were still in analysis; $8,199$ (45.1%) hadn't received it because of the lack of specific policies for their situation; and 3.371 (18.5%) families were considered "only" indirectly affected, therefore were not eligible for the program (RAMBOLL, 2019a). The lack of transparency in the process is another recurrent issue, for instance, after denying the aid (both after registration and in cases of suspension), Renova Foundation does not justify the reasons for the refusal individually, nor does it give opportunity to review the decision or the information recorded in the register.

The perception of these numbers (the small proportion of indemnities and aids paid in relation to those requested) is strongly felt in the communities, as reported in CDHM (2016), CDHM (2019) and Haugsnes (2018). This format used to recognize affected individuals requires that they must prove their condition to the very companies that caused the damage, presupposing the principle of mistrust and contributing to a distributional injustice, through exclusion from Renova's compensation schemes.[20]

In conclusion, the proper existence of lawsuits, specially of Public Civil Actions, whose central concern is with remedial measures, makes clear the limitations and failures of compensation measures and, even more serious, it shows the apparent lack of interest of the companies in repairing the damage they are responsible for, which is substantiated in concrete facts.[21] The factors presented in this section act as amplifiers for the emergency of mental illnesses, since they generate even more uncertainties and anxieties in affected populations - all that added up with the disaster occurrence itself.

There are many reports that brings up qualitative evidences on the emergency of mental health disorders due to Fundao dam failure, mainly anecdotal reports (see CDHM (2016), CDHM (2019), Ramboll (2019b), DPES (2018)), however, there still is a lack of quantitative evidences. Neves et al. (2018) is the first to bring quantitative evidences based on a cross sectional set of self-reported interviews realised with affected individuals from Mariana that have lost their houses.[22] The authors find that these individuals

[20] CDHM (2016) report that there were hotel and inn owners who have received Renova's financial aid card, however, employees who had lost their jobs were not considered - even when there is no doubt that the termination of the employment contract was a consequence of the disaster. The CDHM also report the lack of financial assistance for various artisans and fishermen.

[21] An example presented in Losekann, Dias e Camargo (2019) is the delay in recognizing the damages suffered by the populations of northern Espírito Santo even after the determination from the Interfederative Committee. Another example is the limited definition used by the company to recognize affected individuals, which is deeply documented in Haugsnes (2018).

[22] The authors have applied several questionnaires and interviews with affected individuals from Mariana to measure mental health indicators.

present higher rates of mental health disorders when compared to the literature's baseline, although it is not possible to state a causal relation based solely on these interviews.

We intend to expand the study of mental health consequences due to Fundao dam failure by including all affected municipalities and using a difference-in-differences (DD) strategy to search for a causal relationship. Our main challenges and empirical framework are discussed in the next section.

4 Empirical Framework

According to Galea, Nandi e Vlahov (2005), the disaster context brings additional methodological challenges to mental health studies in four key areas: (i) defining the target population, (ii) obtaining a representative sample of affected people from this population, (iii) implementing an appropriate study design and (iv) measuring key constructs. With that in mind, we built an empirical framework to deal with these issues in the best way possible.

First, to define our target population, we determine which region will be considered in our analysis. Since we want to investigate mental health consequences in all affected region, we consider both directly and indirectly affected municipalities (see figure 4.1). The former is straight forwardly defined: directly affected municipalities are those that were located in the mud's path. Since the tailing sludge quickly reached the main river of the basin ("Doce" river) and the mud was contained mostly in the river channel, directly affected municipalities are mostly municipalities that are cut by the "Doce" river.

As for indirectly affected ones, classification is harder as the disaster consequences may be very broad. We understand that by choosing any classification, there will always be municipalities left out of the analysis due to the large spectrum of the disaster, therefore our choice of the affected population is supported by official classifications - municipalities that were indeed recognized as affected by Ramboll Foundation and Renova Foundation[1] - as they are more likely to have suffered more tangible impacts. These municipalities are basically those that were not in the mud path, but deeply relied on Samarco's activities or those that depended significantly on activities that were shut down after the disaster (such as fishing).

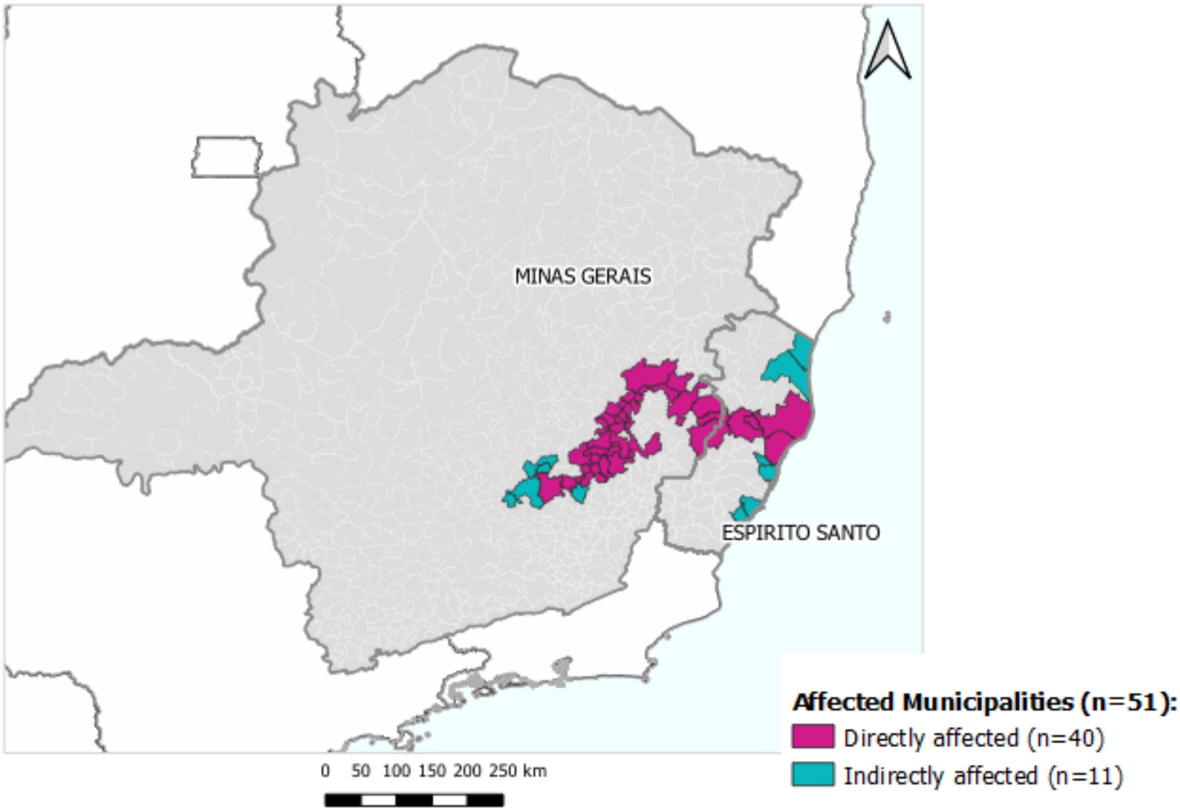
We end up with 51 affected municipalities (represented in figure 4.1): 40 in Minas Gerais state and 11 in Espírito Santo state.

Minas Gerais' state list of affected municipalities are: Rio Doce, Santa Cruz do Escalvado, Barra Longa, Mariana, Itueta, Resplendor, Aimores, Tumiritinga, Naque, Galileia, Periquito, Alpercata, Conselheiro Pena, Belo Oriente, Governador Valadares, Corrego Novo, Dionisio, Raul Soares, Sao Domingos do Prata, Timoteo, Sem-Peixe, Fernandes Tourinho, Marlieria, Bugre, Pingo-dAgua, Sao Jose do Goiabal, Sobralia, Sao Pedro dos Ferros, Iapu, Rio Casca, Bom Jesus do Galho, Ipaba, Santana do Paraiso, Caratinga, Ipatinga, Ponte Nova, Catas Altas, Santa Barbara, Congonhas, and Ouro Preto.

[1] As presented in section 3.3, Renova Foundation is the entity responsible for the reparation measures of the damages caused by the collapse of Fundao dam, and Ramboll Foundation is the company hired by the Brazilian Federal Public Ministry to evaluate and monitor the work of Renova Foundation.

And Espírito Santo's state list of affected municipalities are: Baixo Guandu, Colatina, Marilandia, Aracruz, Linhares, Conceicao da Barra, Fundao, Sao Mateus, Serra, Anchieta, and Guarapari.

Figure 4.1 – Map of affected municipalities



Source: Author's elaboration

The choice of the target population will likely influence our study results, as affected municipalities have been exposed to the disaster in rather different ways and intensities (as discussed in section 3.2). Selecting a larger area or population may result in the inclusion of people with different measures of exposure in the sample which, in turn, may lead to lower estimates of the burden of post-disaster mental disorders. Therefore, to deal with the heterogeneity of our affected group, we categorize affected municipalities to specifically estimate the impacts in each region. We further discuss this issue in section 4.3.

Secondly, to obtain a representative sample of affected people from the population, we use hospitalization data of the Brazilian Public Health System (SUS) that provides universal healthcare and covers all Brazilian population, approximately 201 million people. Even though approximately 51 million people (25% of the population) also have medical coverage from private health plans indicating a double coverage (public and private), we still have a significant proportion of the population for whom the public health system is the primary (or the only) one.[2] In our study, we only account for **public hospitalizations**, leaving aside private ones or attendances provided by Renova Foundation and also any type of medical attendances that do not classify as hospitalization.[3] Therefore our results are likely to be underestimated and must be interpreted as a lower bound of the disaster actual effect in mental health.

Regarding the third issue of implementing an appropriate study design, most studies use cross-sectional, post-disaster-only study designs to investigate mental health consequences (GOLDMANN; GALEA, 2014). Neves et al. (2018), which is one of the few studies regarding mental health consequences due to Fundao dam collapse, uses this framework for instance. These studies are limited by temporal ambiguity regarding the association between exposure and outcome, hence it is hard to establish a causal relation to whether the disaster exposure determined the mental health outcome. Therefore, we've decided to use the empirical method of difference-in-differences, a very common framework in the quasi-experimental literature, widely used in empirical studies of impact evaluation. Some recent works that used this framework in the environmental literature are McCoy e Zhao (2018) to analyze Hurricane Sandy impacts on investments in residential housing; Kiso (2019) and Stoever e Weche (2018) to investigate the impacts of environmental regulations on firm performances and decisions; Hsiang e Jina (2014) to identify the causal effect of environmental disasters on long-run growth; and Nishijima e Rocha (2020) to study the impacts of Fundao dam collapse in Dengue fever outbreaks in affected municipalities.

And finally, regarding the fourth issue of measuring key constraints, we've addressed it by using hospitalization data from public hospitals. We expect that only individuals that are actually suffering from severe mental health disorders would bother going to the hospital to get hospitalized. Therefore, by using this data set, we would be capturing a lower bound of the effect on mental health. Another benefit of using this measure is that it is not a self-reported one, therefore, it tends to be more reliable. As a complementary database we also use attendances in psycho-social care centers.

4.1 Data

DATASUS is a government agency within the Brazilian Ministry of Health responsible for the collection, processing and analysis of health information. Over the past 37 years, data of more than 200 million individuals have been stored in various systems under the custody of DATASUS (LIMA, 2016). In these databases we find information on hospitalizations, medical care, consults, highly complex procedures, immunization, deaths, births, health surveillance, among others.

[2] For an extensive review on SUS databases check Lima (2016).

[3] As an extension of our main results, we later analyze public medical attendances in primary healthcare units.

To investigate mental health consequences of Fundao dam collapse our main database is the Hospitalization Database from DATASUS which consists in a panel data set of hospitalizations in public hospitals. As a complementary data set we use outpatient records registered in psychiatric social centers.[4] Both data sets are publicly available and can be downloaded from DATASUS website. In this paper we leave aside private medical centers data, considering only data from the public healthcare system as aforementioned.

4.1.1 Hospitalizations Database (SIH)

By using this hospitalization data set to measure the effects of the disaster on mental health, we expect to capture a lower bound of the effect as one would expect that only the most severe cases of mental disorders would require hospitalization.

The Hospitalization Informational System (SIH) is the system that records the entire production of hospitalizations within the scope of Brazilian Public Health System (SUS) for the purpose of remunerating the services provided. Each admission generates an order that contains a code to identify the admission authorization, patient identification data (including municipality of residence), patient registration, medical procedures, diagnostic and diagnosed disease code according to the International Classification of Diseases (ICD-10). Although the main purpose of this database is to remunerate health service providers, it is the only data source that contains all health production carried out under the SUS and, therefore, it has been widely used in the literature for evaluating the Brazilian healthcare system (LIMA, 2016).

Table 4.1 – Hospitalizations by type of mental disorder, from 2013-2019

	Total	***Minas Gerais state***	***Espírito Santo state***
number of mental disorders hospitalizations	130,863	115,116	15,747
population in 2017	25,046,213	21,045,011	4,001,202
hospitalizations per 100,000 inhab. per month	6.22	6.51	4.69
Stress-related (%)	1.55%	1.46%	2.24%
Psychoactive substance use (%)	36.14%	36.14%	36.10%
Mood disorders (%)	15.45%	15.14%	17.69%
Personality and behaviour (%)	1.30%	1.41%	0.51%
Organic mental disorders (%)	7.92%	8.53%	3.48%
Disorders w/ onset on childhood/adolescence (%)	1.27%	1.39%	0.46%
Behavioural syndromes (%)	0.77%	0.21%	4.82%
Psychological development (%)	0.30%	0.33%	0.10%
Schizophrenia (%)	25.77%	25.92%	24.68%
Non-organic psychosis (%)	6.60%	6.39%	8.17%
Mental retardation (%)	2.62%	2.76%	1.64%
Other (%)	0.30%	0.33%	0.10%

Source: Author's elaboration using hospitalization data from DATASUS.

Table 4.1 shows that our sample has a total of 130,863 hospitalizations associated with mental health disorders - 115,116 (88%) in Minas Gerais state and 15,747 (12%)

4 This data set is a part of the Ambulatory Information System (SIA) from DATASUS.

in Espírito Santo state. This proportion is expected as Minas Gerais state's population is approximately five times the population of Espírito Santo. The percentage of hospitalizations by disorders are similar among both states, with more than 77% of mental hospitalizations being due to psychoactive substance use disorders, mood disorders an schizophrenia-related disorders. As for the number of hospitalizations per 100,000 inhabitants per month, in Minas Gerais state the average of hospitalizations is 1.4 times higher when compared to Espírito Santo state.

Table 4.2 – Hospitalizations by gender and type of mental disorder, 2013-2019

	Total	**Women**	**Men**
number of mental disorders hospitalizations	130,863	47,673	83,190
% of hospitalizations	100%	36%	64%
population in 2017	25,046,213	12,399,766	12,646,447
% of the population	100%	49.5%	50.5%
hospitalizations per 100,000 inhab. per month	6.22	4.58	7.83
Stress-related	0.10	0.11	0.08
Psychoactive substance use	2.25	0.99	3.49
Mood disorders	0.96	1.24	0.69
Personality and behaviour	0.08	0.09	0.07
Organic mental disorders	0.49	0.39	0.60
Disorders w/ onset on childhood/adolescence	0.08	0.08	0.08
Behavioural syndromes	0.05	0.03	0.06
Psychological development	0.02	0.01	0.02
Schizophrenia	1.60	1.16	2.04
Non-organic psychosis	0.41	0.35	0.47
Mental retardation	0.16	0.12	0.20
Other	0.02	0.02	0.02

Source: Author's elaboration using hospitalization data from DATASUS.

Regarding the differences in hospitalizations by gender, table 4.2 shows that, although women corresponds to 49.5% of the sample population, the number of women's hospitalizations is only 36% of the total number of hospitalizations in the period. The average proportion of hospitalizations per 100,000 inhabitants per month is 1.4 times higher for men as compared to women. Although for most disorders in our sample the proportion is higher for men than for women, especially hospitalizations due to psychoactive substance use, there are some disorders for which the proportion of hospitalizations is higher for women, such as stress-related disorders and mood disorders. These findings are in line with the literature on mental health as discussed on section 2.

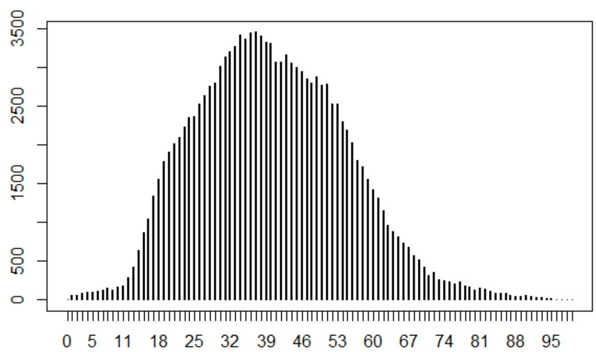
Finally, analyzing patient's age, table 4.3 shows that more than 80% of hospitalizations in our sample happen for people between 20 to 59 years old. These age groups ("20 to 39 years old" and "40 to 59 years old") also present the highest incidence of hospitalizations: respectively 8.1 and 10.3 hospitalizations per 100,000 inhabitants per month,

Table 4.3 – Summary statistics by age group and type of mental disorder, 2013-2019

	Total	Age groups				
		< 9	10 to 19	20 to 39	40 to 59	> 60
Panel A: Summary per age group						
number of mental disorders hospitalizations	130,863	941	8,296	56,579	52,262	12,785
% of hospitalizations	100%	0.7%	6.3%	43.2%	39.9%	9.8%
population in 2017	25,046,213	3,488,702	4,346,119	8,312,566	6,016,125	2,882,701
% of the population*	100%	13.9%	17.4%	33.2%	24.0%	11.5%
hospitalizations per 100,000 inhab. per month:	6.22	0.32	2.27	8.10	10.34	5.28
Panel B: Number of hospitalizations per disorder and percentage in each age group						
Mental disorders (total)	130,863	1%	6%	43%	40%	10%
Stress-related	2,029	2%	12%	40%	35%	10%
Psychoactive substance use	47,292	1%	5%	45%	43%	7%
Mood disorders	20,219	0%	7%	41%	41%	11%
Personality and behaviour	1,706	1%	11%	55%	28%	5%
Organic mental disorders	10,362	3%	8%	35%	32%	22%
Disorders w/ onset on childhood/adolescence	1,668	3%	18%	40%	31%	9%
Behavioural syndromes	1,005	1%	5%	43%	40%	10%
Psychological development	395	20%	29%	36%	11%	4%
Schizophrenia	33,723	0%	5%	42%	43%	10%
Non-organic psychosis	8,638	0%	7%	50%	36%	7%
Mental retardation	3,433	4%	18%	54%	18%	6%
Other	393	5%	13%	42%	27%	13%

(*) We use the proportion of people in each age group from the Brazilian census of 2010.
We remove the cities of Brumadinho and Itabirito from our sample.
Source: Author's elaboration using hospitalization data from DATASUS.

Figure 4.2 – Histogram of hospitalizations due to mental disorders by age - 2013 to 2019



Source: Author's elaboration

values that are above the general average of 6.22. Panel B of table 4.3 shows the percentage of hospitalizations in each age group by disorder. Even though for most disorders the number of cases are concentrated in age groups "20 to 39 years old" and "40 to 59 years old", for some types of disorders there is a different distribution. Psychological development disorders, for instance, present higher occurrence among younger people ("< 9", "10 to 19" and "20 to 39").

4.1.2 Psycho-Social Care Centers - Outpatient database

A breakthrough in Brazilian mental healthcare system happened in 2001 with the approval of Law no. 10216, which provides for the protection and rights of people with mental disorders and redirects its care model. This Law prohibits the admission of patients with mental disorders to institutions with asylum characteristics, instead it states that preferably patients should be redirected to psycho-social care centers that aims at patients' social reintegration and treatment (Brasil, 2001). Subsequently, in 2011, the Psychosocial Care Network (RAPS) was created,[5] with the objective of expanding the population's access to psychosocial care, promoting the link of people with mental disorders and/or with abuse of alcohol and other drugs and their families to the network's points of care and ensuring network articulation and integration, aiming at a continuous monitoring and attention to emergencies (SILVA et al., 2018).

According to the Brazilian mental health policy, centers for psycho-social care (CAPS) are the places of reference and treatment for people who suffer from mental disorders. These centers are local/regional health units that offer an intermediate care between the outpatient regime and hospitalization. According to the Brazilian Ministry of Health the main objective of this service is to receive patients with mental disorders, stimulate their social and family integration, and support them in their initiatives to seek autonomy. The implementation of the Psycho-social Care Network has been carried out nationwide in a non-linear and symmetrical way (PITTA, 2011). A survey carried out by the Brazilian Ministry of Health shows a significant expansion in the implementation of Psychosocial Care Centers in the last decades: in 1998 there was a total of 148 qualified CAPS and, in December 2014, this number increases to 2,209, revealing an expansion of care offerings in services (SILVA et al., 2018). In Minas Gerais state there is also an increase in installed CAPS in the years of our sample. Figure 4.3 shows that the number of municipalities with at least one psycho-social care center increased from 147 to 244, from 2013 to 2019. An average increase in coverage of 65% approximately.

However, despite the increasing number of psycho-social care centers in Brazil, their coverage is still limited - in 2015, the year of the disaster, only 23% of Minas Gerais' municipalities had a psycho-social care center and, more specifically, only 14 (of the 40) affected municipalities had them (table 6.1). Therefore, we use the database of attendances in psycho-social care centers to provide a complementary analysis of the impacts in mental health of Fundao dam rupture for some of the affected municipalities in Minas Gerais state.[6]

In our sample there is a total of 6,323,045 attendances in psycho-social care centers

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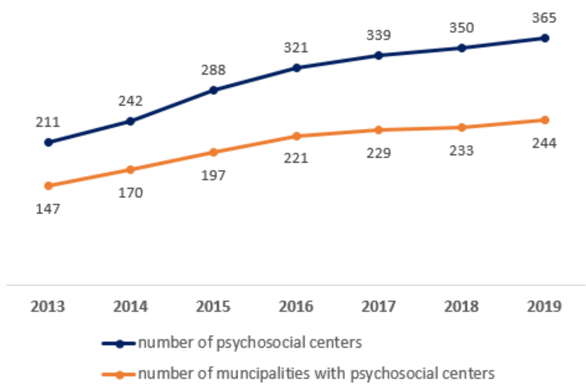
[5] By Decree no. 3088.

[6] The affected municipalities with a psycho-social care center in 2015 are: Mariana, Aimores, Belo Oriente, Caratinga, Conselheiro Pena, Governador Valadares, Ipaba, Ipatinga, Resplendor, Sao Domingos do Prata, Timoteo, Congonhas, Ouro Preto and Ponte Nova.

Figure 4.3 – Number of psycho-social care centers and municipalities with at least one center in Minas Gerais state - 2013 to 2019



Source: Author's elaboration with data from the Brazilian National Health Establishments database (CNES)

Table 4.4 – Psycho-social care centers' attendances[1] in Minas Gerais state, from 2013 to 2019

	Attendances in psycho-social care centers in Minas Gerais state	
	number of attendances	attendances per 100,000 inhab. per month
Total	6,323,045	497.20
Stress-related	5.72%	28.44
Psychoactive substance use	28.18%	140.13
Mood disorders	18.34%	91.21
Personality and behaviour	1.79%	8.89
Organic mental disorders	1.56%	7.76
Disorders w/ onset on childhood/adolescence	3.19%	15.87
Behavioural syndromes	0.15%	0.74
Psychological development	1.17%	5.82
Schizophrenia	28.02%	139.31
Non-organic psychosis	4.56%	22.66
Mental retardation	4.98%	24.75
Other	2.34%	11.63

[1]In our sample we only consider:
(i) attendances related to mental disorders specified in chapter V of the ICD-10, and
(ii) municipalities that had at least one psycho-social care center in 2015 (year of Fundão dam rupture).
Source: Author's elaboration with data from DATASUS.

associated with mental health disorders in Minas Gerais state from January, 2013 to December, 2019 (table 4.4). The majority of cases are related to psychoactive substance use (28%), schizophrenia (28%) and mood disorders (18%). As for the number of attendances per inhabitants, the average is of 498 attendances per 100,000 inhabitants per month, showing that the level of attendances at psycho-social care centers is much higher than the hospitalization's level (in Minas Gerais state the average of hospitalizations related to mental disorders was 6.51 per 100,000 inhabitants per month, as seem in table 4.1). Table 4.5 presents a comparison of the level of observations in each database. For Minas Gerais state, the number of mental disorders hospitalizations is approximately 2% of the number of attendances in psycho-social care centers, with this percentage varying depending on the disorder. This small proportion of hospitalizations versus psycho-social attendances is expected as only the most severe cases require hospitalization and these cases occur in a small portion of individuals that manifest mental health disorders.

Table 4.5 – Database comparison: number of observations by mental disorder, Minas Gerais state, 2013 to 2019.

	number of observations		
	psycho-social care center database	hospitalization database	**hospitalization per psycho-social center attendance**
All mental disorders	6,323,045	115,592	1.8%
Behavioural syndromes	9,394	249	2.7%
Disorders w/ onset on childhood/adolescence	201,829	1,596	0.8%
Organic mental disorders	98,629	9,849	10.0%
Psychological development	73,971	385	0.5%
Schizophrenia	1,771,593	29,932	1.7%
Mood disorders	1,159,896	17,501	1.5%
Other	147,877	380	0.3%
Personality and behaviour	113,047	1,633	1.4%
Non-organic psychosis	288,214	7,376	2.6%
Mental retardation	314,779	3,187	1.0%
Stress-related	361,711	1,681	0.5%
Psychoactive substance use	1,782,105	41,823	2.3%

Author's elaboration with the hospitalization database (SIH) and medical attendances database (SIA) from DATASUS.

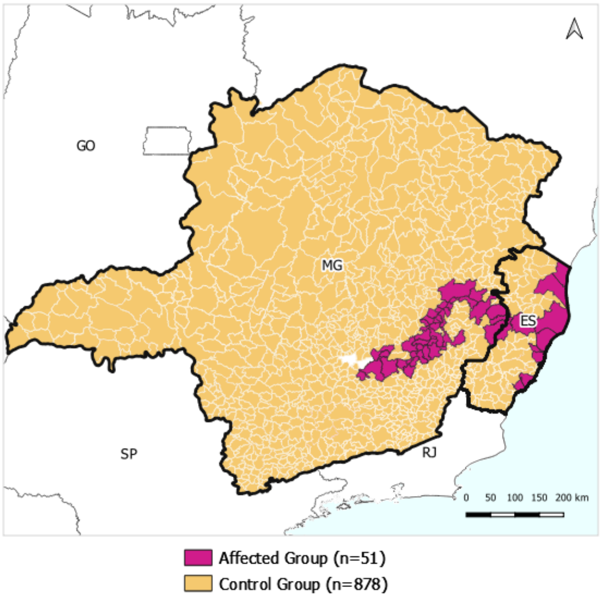
As for the database sets for our control variables, we use other Brazilian official databases, mainly from Brazilian Institute of Geography and Statisitcs (IBGE), National Mining Agency (ANM) and from State Finance Departments of Minas Gerais and Espírito Santo state (SEFAZ-MG and SEFAZ-ES).

4.2 Control Groups

We define four distinct sets of control groups, all of them composed of municipalities in Minas Gerais and Espírito Santo state. We've decided to pick only municipalities in these states as there might be non-observable time-varying intrastate variables, such as geographic, cultural, political and institutional characteristics, that might impact mental health hospitalizations. Hence, by delimiting our pool of candidates to be in the same state as our affected group, we are likely to be choosing a control group that is more similar to the treated group than otherwise. We also exclude from our pool the municipalities of Brumadinho and Itabirito as both of them also have had mining disasters in the period (see figure 3.6). In our estimation strategy framework we compare only municipalities in the same state - Minas Gerais affected group is compared to a control group that only contains Minas Gerais municipalities and the same for Espírito Santo state.

Our first control group is composed by all non-affected municipalities in both states (figure 4.4). This is our broadest group, with 878 municipalities: 811 in Minas Gerais state and 67 in Espírito Santo (see figure 4.4). However, considering all municipalities in both states, may result in a control group that does not fit so well as our counterfactual. That might be especially true for Minas Gerais state, as it is a wide and heterogeneous state with great diversity within its regions.

Figure 4.4 – Map of control group, first specification: all municipalities



Source: Author's elaboration

Therefore, for our second control group we pick municipalities in the same "intermediate geographical regions"[7] as affected ones (see table 4.6). Intermediate geographical regions are a group of regions that are articulated through the influence of one or more metropolises, regional capitals and/or representative urban centers. Therefore municipalities located in the same "intermediate regions" are likely to be more similar. We end up with 372 municipalities in this control group: 329 in Minas Gerais state (from 5 distinct intermediate regions) and 43 in Espírito Santo state (from 3 distinct intermediate regions), see figure 4.5.

Our third control group contains only municipality in the Doce river basin (figure 4.6). As all directly affected municipalities are in this region, we would expect that, by choosing a control group in this area, we would have municipalities that share similar characteristics due to the geographic proximity. Here, there are 161 municipalities in Minas Gerais state and 21 in Espírito Santo state.

Finally, we consider a possible spillover effect of the failure in neighboring municipalities.[8] We take this into account to define our last control group by excluding these frontier municipalities (figure 4.7). We consider as reference the second control group setting, that is municipalities located at the same intermediate geographic regions as affected

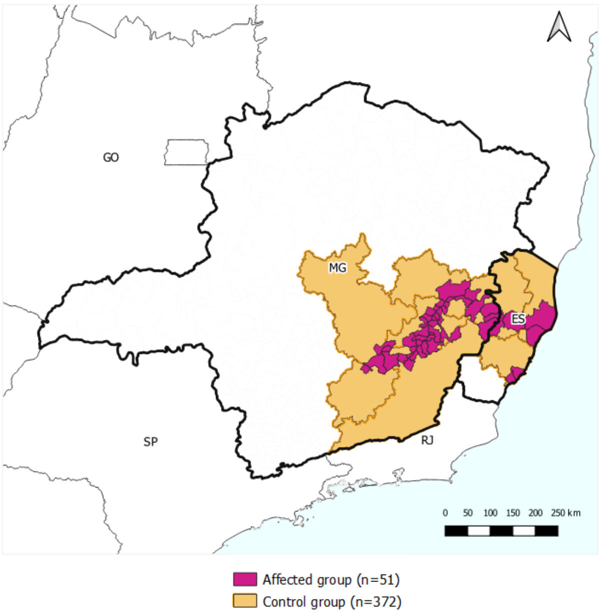
[7] This geographical classification was defined by the Brazilian Geographic and Statistics Institute (IBGE) in 2017.
[8] Municipalities that share a border with affected ones.

Table 4.6 – Intermediate geographic region description

State	Intermediate region	Affected group	Not affected group	Total
Minas Gerais	Belo Horizonte	4	68	72
Minas Gerais	Governador Valadares	10	48	58
Minas Gerais	Ipatinga	18	26	44
Minas Gerais	Juíz de Fora	7	139	146
Minas Gerais	Barbacena	1	48	49
Espírito Santo	Vitória	4	17	21
Espírito Santo	São Mateus	4	11	15
Espírito Santo	Colatina	3	15	18

Source: Author’s elaboration with data from IBGE.

Figure 4.5 – Map of control group, second specification: intermediate region

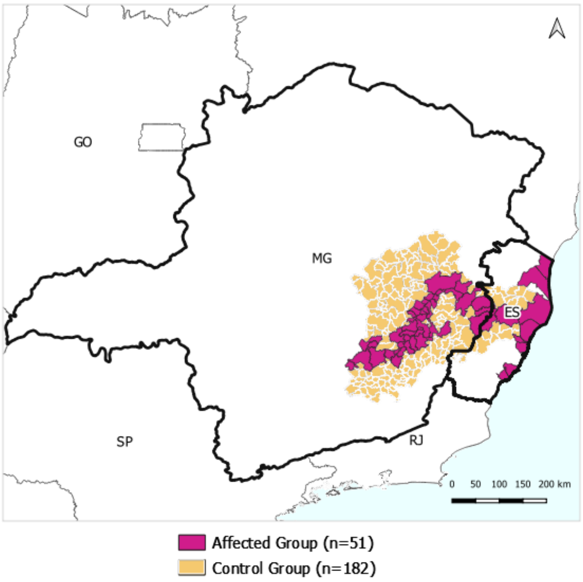


Source: Author’s elaboration

ones, and exclude from them frontier municipalities. Hence, in this forth group we end up with 287 municipalities, 264 in Minas Gerais state and 23 in Espírito Santo state.

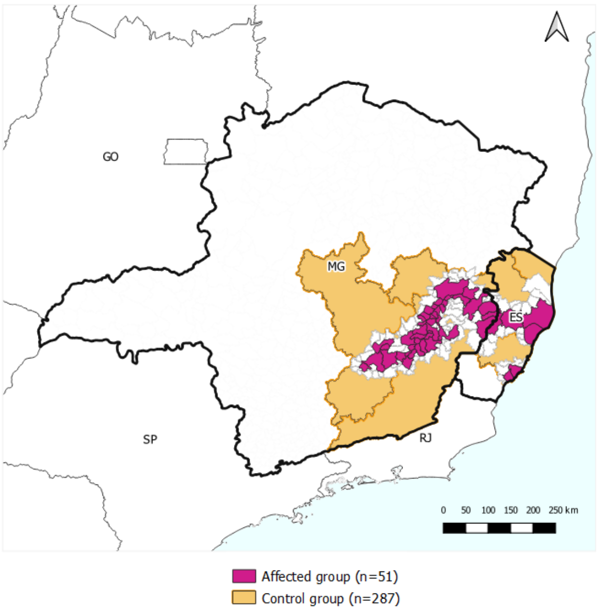
Table 4.7 presents a summary of the number of municipalities in each control group by state, as well as the numbers of municipalities in the affected group. Tables 4.8 and 4.9 compares distinct socioeconomic variables among treated and control groups in Minas Gerais and Espírito Santo state respectively.

Figure 4.6 – Map of control group, third specification: Doce river basin



Source: Author's elaboration

Figure 4.7 – Map of control group, fourth specification: intermediate region withou frontier municipalities



Source: Author's elaboration

4.3 Municipalities' Classification

As discussed in sections 3.2 and 3.3, Fundao dam failure affected municipalities in rather different ways and intensities, mainly according to the municipality's distance from Fundao dam. Analyzing the geographic dimension, the tailing mud traveled more than 650 km from Fundao's dam to Doce River mouth in the Atlantic Ocean. Approximately 80% of the tailings (ANA, 2016a) were stored in a hydroelectric power plant reservoir

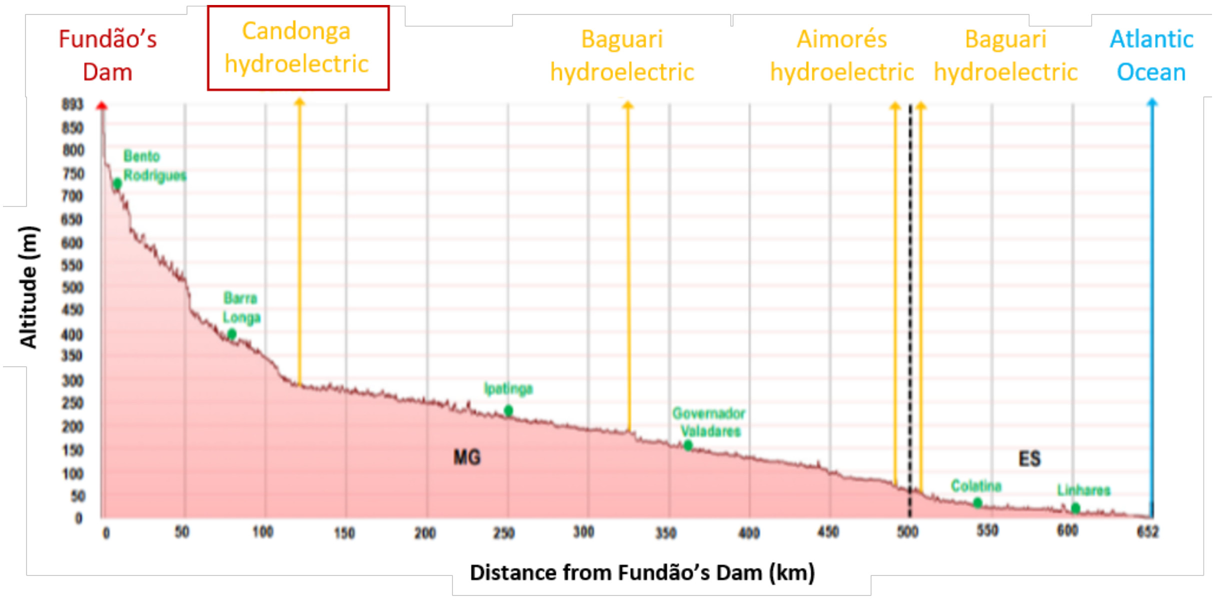
Table 4.7 – Control Group Municipalities' in each state

	Treated Group	Control Groups			
Number of municipalities in:	Affected municipalities	All municipalities	Intermediate Region	Doce river basin	Excluded frontier municipalities (spillover)
Minas Gerais state	40	811	329	161	264
Espírito Santo state	11	67	43	21	23
Total:	51	878	372	182	287

Source: Author's elaboration.

(Candonga reservoir), around 110 km from Fundao dam. From this point on the mud lost some of its destructive power and was confined to the river bed. There is also a great range of altitude variation in each of these segments. As illustrated in figure 4.8, there is a significant altitude variation, of around $500m$, in the first $100km$, from Fundao dam to Candonga reservoir. After that, in the next $600km$ from Candonga reservoir to the river mouth, there is a much smaller slope - altitude ranges $300m$ in this segment. The mud's destructive power is highly correlated with these slopes, reinforcing the reason why municipalities located before Candonga reservoir were the ones that suffered the most physical damage from the dam failure.

Figure 4.8 – Longitudinal profile of the watercourse affected by the Fundao's Dam collapse



Source: ANA (2016b)

To account for the heterogeneity in the affected group due to the geographic location and further investigate the effect in each region, we divide these municipalities in different categories. We derive our classification from the ones used by Ramboll and Renova Foundations (the complete list of municipalities in both Renova and Ramboll's classification are presented in table A.2). Both classifications are indeed very similar, creating a threshold in Candonga reservoir and dividing directly affected municipalities in

Table 4.8 – Socioeconomic characteristics by group, before the disaster 2010-2014

Panel A: Mean (*)	***Minas Gerais state***				
		Control Groups			
	Affected group	*All munic.*	*Intermediate Region*	*Doce river basin*	*Excluded frontier munic.*
Population	32,159	23,253	28,394	12,611	31,901
	(56,822)	(98,179)	(145,243)	(19,445)	(161,600)
Mining royalty	4,845,057	556,699	1,159,828	1,324,995	1,034,660
	(16,908,787)	(6,593,856)	(10,235,590)	(10,589,746)	(10,255,835)
Taxes	14,028,551	6,803,956	8,718,301	3,545,648	9,753,399
	(27,574,312)	(31,693,521)	(46,095,806)	(10,037,695)	(51,183,677)
GDP	759,475	417,690	570,390	174,607	658,326
	(1,575,639)	(2,587,002)	(3,834,727)	(504,728)	(4,270,009)
GDP per capita	15,159	11,841	10,851	9,631	10,220
	(18,456)	(13,724)	(15,888)	(19,467)	(9,301)
Added value:					
agriculture	10,967	24,681	11,084	10,993	11,385
	(10,403)	(43,308)	(14,172)	(12,385)	(14,595)
industry	362,543	109,079	158,367	63,674	177,139
	(874,247)	(606,486)	(874,472)	(297,118)	(964,876)
public sector	85,894	58,700	73,216	31,369	82,528
	(148,806)	(264,029)	(394,210)	(46,867)	(438,917)
services	260,971	184,170	263,670	60,734	310,182
	(561,190)	(1,421,481)	(2,143,658)	(168,001)	(2,389,402)

(*) Standard deviations are in parenthesis

Panel B: Median	***Minas Gerais state***				
		Control Groups			
	Affected group	*All munic.*	*Intermediate Region*	*Doce river basin*	*Excluded frontier munic.*
Population	9,590	8,073	6,795	6,622	6,636
Mining royalty	2,657	373	148	13	152
Taxes	1,898,762	1,844,101	1,575,909	1,474,707	1,549,838
GDP	77,070	66,870	50,483	44,759	50,613
GDP per capita	7,235	8,538	7,565	6,339	7,815
Added value:					
agriculture	6,545	10,671	6,890	6,782	7,162
industry	5,113	6,048	4,493	3,284	4,683
public sector	22,187	20,186	16,859	16,503	16,646
services	23,851	21,237	15,315	11,857	15,337

Source: Author's elaboration.

Table 4.9 – Socioeconomic characteristics by group, before the disaster 2010-2014 - Espírito Santo state

Panel A: Mean (*)	*Espírito Santo state*				
		Control Groups			
	Affected group	*All munic.*	*Intermediate Region*	*Doce river basin*	*Excluded frontier munic.*
Population	104,268	38,290	45,358	17,233	49,790
	(117,766)	(79,013)	(93,848)	(7,668)	(94,231)
Mining royalty	169,641	94,640	109,018	35,988	161,961
	(244,182)	(216,844)	(222,596)	(65,699)	(283,612)
Taxes	59,188,703	18,813,705	23,453,730	8,337,830	31,167,404
	(66,870,759)	(48,488,964)	(59,256,535)	(2,678,378)	(77,004,631)
GDP	2,846,259	939,854	1,015,731	178,751	1,344,696
	(3,505,859)	(2,757,376)	(3,250,012)	(81,294)	(4,115,509)
GDP per capita	34,084	22,786	13,252	10,688	13,799
	(43,393)	(66,185)	(7,817)	(2,702)	(9,922)
Added value:					
agriculture	47,207	32,435	37,762	30,475	45,853
	(43,113)	(32,954)	(38,801)	(14,937)	(49,153)
industry	1,158,178	302,110	199,411	23,607	259,626
	(1,377,474)	(918,467)	(689,426)	(17,993)	(890,585)
public sector	337,540	119,959	140,995	53,781	160,180
	(353,450)	(242,216)	(289,209)	(21,749)	(313,057)
services	928,026	346,024	425,482	62,306	563,003
	(1,246,605)	(1,151,944)	(1,407,144)	(36,535)	(1,754,440)

(*) Standard deviations are in parenthesis

Panel B: Median	*Espírito Santo state*				
		Control Groups			
	Affected group	*All munic.*	*Intermediate Region*	*Doce river basin*	*Excluded frontier munic.*
Population	88,117	15,149	16,387	14,330	22,014
Mining royalty	38,381	9,564	13,398	7,108	23,496
Taxes	35,491,043	7,511,981	8,671,300	7,377,907	10,976,886
GDP	1,386,981	204,333	208,556	152,225	231,778
GDP per capita	17,739	11,277	11,836	11,258	11,836
Added value:					
agriculture	29,592	28,182	31,156	26,349	33,643
industry	240,655	25,275	26,419	19,074	26,419
public sector	329,639	51,252	51,252	45,036	66,177
services	719,537	66,719	72,297	51,243	72,297

Source: Author's elaboration.

three categories: (i) municipalities located upstream Candonga reservoir, (ii) municipalities located downstream Candonga reservoir, and (iii) municipalities located at the coast. They both add another category for (iv) indirectly affected municipalities (see table 4.10).

For our analysis, we've decided to use Ramboll's classification (as presented in Ramboll (2017)) and include 4 more indirectly affected municipalities in Espírito Santo state, as they are considered as such in Renova's Classification. We also divide the affected groups by state. Since there are municipalities from both states located in the "downstream Candonga reservoir" category, we break this category in two: "downstream Candonga reservoir in Minas Gerais state" and "downstream Candonga reservoir in Espírito Santo state". The same is done for indirectly affected municipalities. This way we end up with groups that contains municipalities in one state only. We decided to do so to use a control group with only municipalities in the same state for each affected group. Hence, we end up with 51 affected municipalities divided into 6 distinct categories, as described bellow and presented in figure 4.9 (for a complete list of municipalities in each category, see Appendix table A.2).

Table 4.10 – Affected Municipalities' Classification

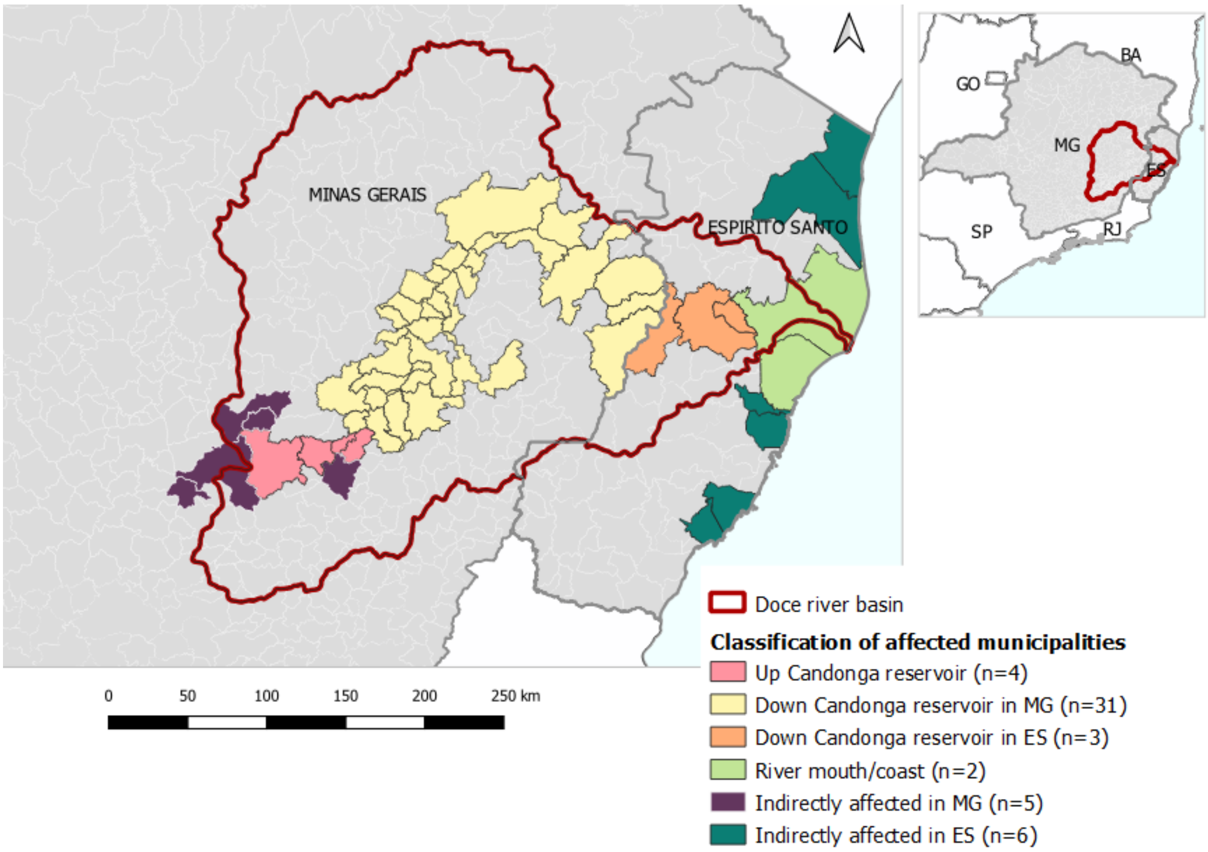
Number of Municipalities in:	***Minas Gerais state***	***Espírito Santo state***	***Total***
Upstream Candonga reservoir	4	-	4
Downstram Cadonga reservoir	31	3	34
Coast	-	2	2
Indirectly Affected	5	6	11
Total	**40**	**11**	**51**

Source: Author's elaboration.

1. **Upstream Candonga reservoir (n=4)**: Municipalities in this group suffered the most physical damage due to the failure. Particularly Mariana and Barra Longa, municipalities that had two villages devastated by the mud. Even though geographically close, Mariana is very distinct from the other 3 municipalities in this category. While it has around $60,000$ inhabitants, the other three have less than $6,000$ each. This is also true in economics terms, in 2015 Mariana's GDP per capita was 43 times greater than the sum of the other three, mostly due to the industrial sector (70% of Mariana's added value was connected to industrial activities, especially the mining sector). *Municipalities: Mariana, Barra Longa, Santa Cruz do Escalvado and Rio Doce.*

2. **Downstream Candonga reservoir in Minas Gerais state (n=31)**: This group contains 61% of all affected municipalities, it is also the most geographically vast,

Figure 4.9 – Map of affected municipalities by classification



Source: Author's elaboration

hence effects in this group were very diverse. In some municipalities water supply was interrupted for a while after the collapse. It also affected agriculture, cattle raising and fishing activities, as described in section 3.2. In economic terms, the most important cities in this category are Ipatinga, Governador Valadares and Timóteo. In Ipatinga this is explained by the presence of Usiminas' steel complex and in Governador Valadares by its central place as an important regional provider of services and goods. Timóteo's activities are based mainly on the industrial sector especially the stainless steel industry. *Municipalities: Aimores, Alpercata, Belo Oriente, Bom Jesus do Galho, Bugre, Caratinga, Conselheiro Pena, Corrego Novo, Dionisio, Fernandes Tourinho, Galileia, Governador Valadares, Iapu, Ipaba, Ipatinga, Itueta, Marlieria, Naque, Periquito, Pingo-d Agua, Raul Soares, Resplendor, Rio Casca, Santana do Paraiso, Sao Domingos do Prata, Sao Jose do Goiabal, Sao Pedro dos Ferros, Sem-Peixe, Sobralia, Timoteo and Tumiritinga.*

3. **Downstream Candonga reservoir in Espírito Santo state (n=3)**: These were the first municipalities affected in Espírito Santo state. These municipalities had their water supply interrupted for a short while after the disaster. In Baixo Guandu fishing is authorized and water harvesting is once again done in Doce river, however

fishermen are struggling to sell fish, as consumers are suspicious of the water quality. Many of them changed their profession. In Colatina a similar situation is reported, Colatina's traditional fisher market was demolished after 32 years of operation. *Municipalities: Baixo Guandu, Colatina and Marilandia.*

4. **Coast (n=2)**: Both municipalities in this category present similar added values and GDP. In Aracruz, the main economic sector is the industrial one, with emphasis on the cellulose industry. In Linhares, industrial sector is also the most important, but here with emphasis on furniture production. Fisheries communities in both municipalities were severely affected due to the ban of fishing in Doce River mouth, especially the village of Regencia, in Linhares. *Municipalities: Aracruz and Linhares.*

5. **Indirectly affected in Minas Gerais state (n=5)**: Municipalities located in this category were not located in the banks of affected rivers, but suffered severe economic damage due to Samarco's stoppage. Most of the municipalities in this category have strong connections to industrial activities, especially mining activities. Before the disaster, Ouro Preto, Congonhas and Santa Barbara received more than 10 million reais per year in mining royalties. Ouro Preto, in special, was deeply related with Samarco. The only exception in this category is Ponte Nova, its main source of added value before the disaster came from the public sector. *Municipalities: Ouro Preto, Catas Altas, Congonhas, Santa Barbara and Ponte Nova.*

6. **Indirectly affected in Espírito Santo state (n=6)**: Here we also have municipalities with close connections to Samarco, such as Anchieta, where all the iron extracted in Mariana were transformed in iron pellets in two industrial units before being exported by the municipality's harbour (Ubu Port). After the disaster, Samarco's units had it's activities suspended. In this category, we also have municipalities that did not depended directly on Samarco, but suffered severe economic impacts mainly due to the negative impacts on the marine ecosystem. The territory of São Mateus and Conceição da Barra for instance were not on mud path, but have had its main river contaminated when the tailings reached the coast of Espírito Santo. Communities that economically depended on crab fishing are struggling. Crab pickers report that they are no longer able to collect or sell enough animals to market, that their ecosystems are destroyed; and that people are afraid to buy crabs from the region for fear of contamination (CDHM, 2019). *Municipalities: Anchieta, Guarapari, Conceicao da Barra, Fundao, São Mateus and Serra.*

In table 4.11 we have a descriptive table of socioeconomic variables for each category. In panel A, we present the mean and standard deviation of the values and, in panel B, we present the median. Here, we see that there are significant differences between each affected region. In Minas Gerias state, for instance, there is a strong presence of the mining industry mostly in indirectly affected municipalities and in upstream Candonga reservoir, which can be seem at the value of minning royalties collected by these municipalities in the period. In contrast, municipalities located downstream Candonga reservoir are, in general, less connected to minning activities. Besides inter-group differences, there are also intra-group variations in socioeconomic variables. Again using mining royalties as a reference, for upstream Candonga reservoir there is a significant difference between the mean value ($R\$23,277,111$), presented in panel A, and the median value ($R\$250$), presented in panel B. This indicates a heterogeneity among municipalities in this category relative to their economic activities.

As we can see in the description of each category above and by analyzing table 4.11, affected municipalities' do not constitute an homogeneous region, neither in consumption logic (polarization of goods and services) nor in production logic. Due to the vast extension of the disaster, there are different economic structures with different dynamics among affected cities. Particularities of each region might influence communities resilience to deal with the disaster impacts as pre-disaster risk factors are important to determine mental health consequences.As discussed in section 2 Hence, in order to account for socioeconomic differences in affected municipalities, we (i) include municipalities fixed effects in our model to capture time-invariant characteristics that may impact mental health hospitalizations and (ii) include socioeconomic control variables to deal with time-variant characteristics.

4.4 Estimation Strategy

Simply put, our estimation strategy is a difference-in-differences framework in which we compare municipalities affected by Fundao dam collapse with non-affected ones[9] in the same region before and after the disaster occurrence. This a common strategy used in empirical studies of impact evaluation.

Our baseline specification is:

$$Y_{it} = \beta T_i d_t + ES_i d_t + X_{it}\gamma + \eta_t + \delta_i + u_{it} \tag{4.1}$$

where Y_{it} represents the number of mental disorders hospitalizations per $100,000$/inhabitants in municipality i in month/year t; T_i is a dummy variable equals to 1, if municipality i was affected by the disaster; and 0 otherwise; d_t is a temporal dummy assuming a value of 1 for the period after the dam collapse *(november/2015)* and 0 for previous periods; ES_i is a dummy equals to 1 if municipality i belongs to Espírito Santo state; X_{it} are the socioeconomic variables of municipality i extrapolated for period t, such as population size, GDP, among others; η_t is the time fixed-effect; δ_i is the municipality fixed-effect; u_{it} is the idiosyncratic and unobserved error term.

The coefficient of interest is β, which measures the change in mental disorder hospitalizations that is specific to affected municipalities due to Fundao dam collapse, conditional on socioeconomic time-varying variables X_{it}, municipality and time (month-year) fixed effects. We interpret β as a lower bound of the disaster impact on mental health, since we only consider hospitalizations in public hospitals. We also weight regressions by population size.[10]

[9] We use different sets of control groups. In one of the sets, we account for a possible spill over effect by excluding neighboring regions.

[10] See table A.5 for the list of population size of affected municipalities.

Table 4.11 – Control variables by category before Fundão failure, 2010-2014

	Minas Gerais state			Espírito Santo state		
Panel A: Mean (*)	**up candonga (n=4)**	**down candonga (n=31)**	**indirectly affected (n=5)**	**down candonga (n=3)**	**coast (n=2)**	**indirectly affected (n=6)**
Population	17,498	32,286	43,106	52,959	120,024	124,670
	(22,555)	(62,956)	(23,620)	(45,882)	(31,907)	(149,060)
Mining Royalties	23,227,111	14,459	20,089,124	307,802	254,163	72,386
	(40,230,206)	(27,364)	(18,576,865)	(364,702)	(57,324)	(142,580)
Taxes	22,848,690	8,839,320	39,145,671	19,680,038	77,629,927	72,795,961
	(36,990,146)	(21,566,191)	(35,276,635)	(14,125,076)	(797,887)	(83,780,417)
GDP	1,148,076	546,452	1,769,339	876,449	4,104,147	3,411,868
	(1,939,746)	(1,433,754)	(1,638,293)	(838,519)	(147,137)	(4,403,112)
GDP per capita	24,937	9,481	42,537	15,461	37,858	42,138
	(32,086)	(7,554)	(22,841)	(1,861)	(11,407)	(56,249)
Gross added value by:						
agriculture	7,507	11,408	11,002	33,036	95,585	38,167
	(4,062)	(11,275)	(7,324)	(7,638)	(59,348)	(35,244)
industry	824,718	186,526	1,084,111	215,164	2,177,186	1,290,015
	(1,424,882)	(593,894)	(1,191,554)	(184,691)	(531,663)	(1,599,753)
public sector	55,067	81,945	135,040	161,239	424,953	396,552
	(73,605)	(162,354)	(78,195)	(136,480)	(91,983)	(441,960)
services	268,713	220,907	503,169	381,862	1,069,868	1,153,828

(*) Standard deviations are in parenthesis

	Minas Gerais state			Espírito Santo state		
Panel B: Median	**up candonga (n=4)**	**down candonga (n=31)**	**indirectly affected (n=5)**	**down candonga (n=3)**	**coast (n=2)**	**indirectly affected (n=6)**
Population	5,478	8,591	50,671	30,219	120,024	70,957
Mining royalties	250	647	11,817,421	102,300	254,163	3,010
Taxes	1,621,624	1,809,274	13,757,731	12,295,493	77,629,927	26,059,822
GDP	33,290	52,862	898,713	395,792	4,104,147	1,375,634
GDP per capita	6,624	6,594	49,740	15,466	37,858	16,495
Added value by:						
agriculture	7,497	5,562	10,268	28,865	95,585	23,890
industry	2,505	4,967	242,725	140,723	2,177,186	219,145
public sector	14,325	20,060	149,580	94,662	424,953	244,187
services	8,723	21,971	476,399	117,794	1,069,868	655,564

Source: Author's elaboration.

By estimating equation 4.1 we obtain an average effect considering all affected municipalities as a single treated group. In our particular case, though, this might be masking different types of impacts since municipalities were affected in rather different ways and intensities.

Hence, to account for the heterogeneous impacts suffered by each region due to its geographic location we use the classification of affected municipalities presented in section 4.3 and estimate the following equation:

$$Y_{it} = \sum_{j=1}^{6} \beta_j C_{ij} d_t + ES_i d_t + X_{it}\gamma + \eta_t + \delta_i + u_{it} \tag{4.2}$$

where C_{ij} is a dummy equals to 1 if municipality i is classified in category j and 0 otherwise, where j corresponds to each category in our classification of affected municipalities. As we have six distinct categories; $j \in \{1, 2, 3, 4, 5, 6\}$.

An important challenge in estimating equation 4.2 is relative to the estimation of standard errors. Typically there are many clusters, and researchers rely on clustering in the group level, estimating cluster-robust standard-errors (BERTRAND; DUFLO; MULLAINATHAN, 2004). However, as we have only few treated units in each category, this would result in a biased estimation of the standard errors, leading to an over-rejection of the null hypothesis (MACKINNON; WEBB, 2018). For this reason, we rule out the possibility of making the correct inference based on cluster-robust standard errors. Therefore, we conduct inference by using the bootstrap procedure proposed by Ferman e Pinto (2019) to produce p-values.[11] This approach is designed to work well when there are very few treated units. It also accounts for heteroskedasticity in the errors generated by differences in group sizes.

Two main identification hypothesis of the difference-in-differences frameworks are: (i) the parallel trend hypothesis, which presupposes that in the absence of the disaster both treated and control groups would present similar trends in mental health hospitalizations; and (ii) there must be no other exogenous shock affecting only one of the two groups in the analyzed period. Although it is not possible to actually test to assure the parallel trends hypothesis, we present, in section 5.1, a set of evidences based on historical data in favour of the credibility of such hypothesis.

As for time-varying control variables X_{it}, Fundao dam failure caused a series of impacts on socioeconomic variables in affected municipalities, such as royalties generated by mining activities, taxes revenues, local activity level, GDP, among others. These variables, on the other hand, may also be correlated with occurrence of mental disorders. Therefore, in order to avoid endogeneity we do not use control variables real value in each period. To deal with this issue, we use a linear time trend for each control variable based on their pre-collapse values (before 11/2015). We extrapolate these values for the post-disaster period and include these extrapolated values in our regressions.[12]

[11] The technique does not produce a test statistic, but the bootstrapped distribution of pseudo-treatment effects provides a basis for determining an empirical P-value for the estimate of the treatment effect (see Ferman e Pinto (2019) for more details).

[12] See table A.4 for the list of control variables we use.

5 Estimation Results

5.1 Analysis of the Overall Trend (2013-2019)

To better understand the dynamics of mental hospitalizations in the whole period, we analyze the overall trend of treated vs control groups. By doing so, we aim (i) to confirm that in pre-disaster period (2013-2015) affected and non-affected municipalities have similar trends with respect to mental disorders hospitalizations, conditional on socioeconomic characteristics. And (ii) to visualize the dynamic of hospitalizations after the disaster to investigate the effects along time. Therefore, we estimate equation 5.1 based on an event study framework[1] and we graphically analyze the estimated coefficients to visualize the trend of mental disorders hospitalizations.

$$y_{it} = \alpha_t T_i d_t + X_{it}\gamma + \eta_t + \delta_i + u_{it} \tag{5.1}$$

Where y_{it} represents mental disorders per $100,000$ inhabitants in municipality i and time t, T_i is a treated dummy variable that is 1 if municipality i was affected by the disaster, d_t is a dummy variable that is 1 for time period t and 0 otherwise, X_{it} are control variables for municipality i and time t, η_t is time fixed effects and δ_i is municipality fixed effects.

The coefficients of primary interest are α_t's. We normalize $\alpha_{nov/2015}$ to zero, so α_t can be interpreted as the difference in mental disorders hospitalizations of affected municipalities versus non-affected ones in period t relative to the baseline difference of treated versus control groups in the month of the accident (nov/2015),[2] conditional on socioeconomic characteristics.

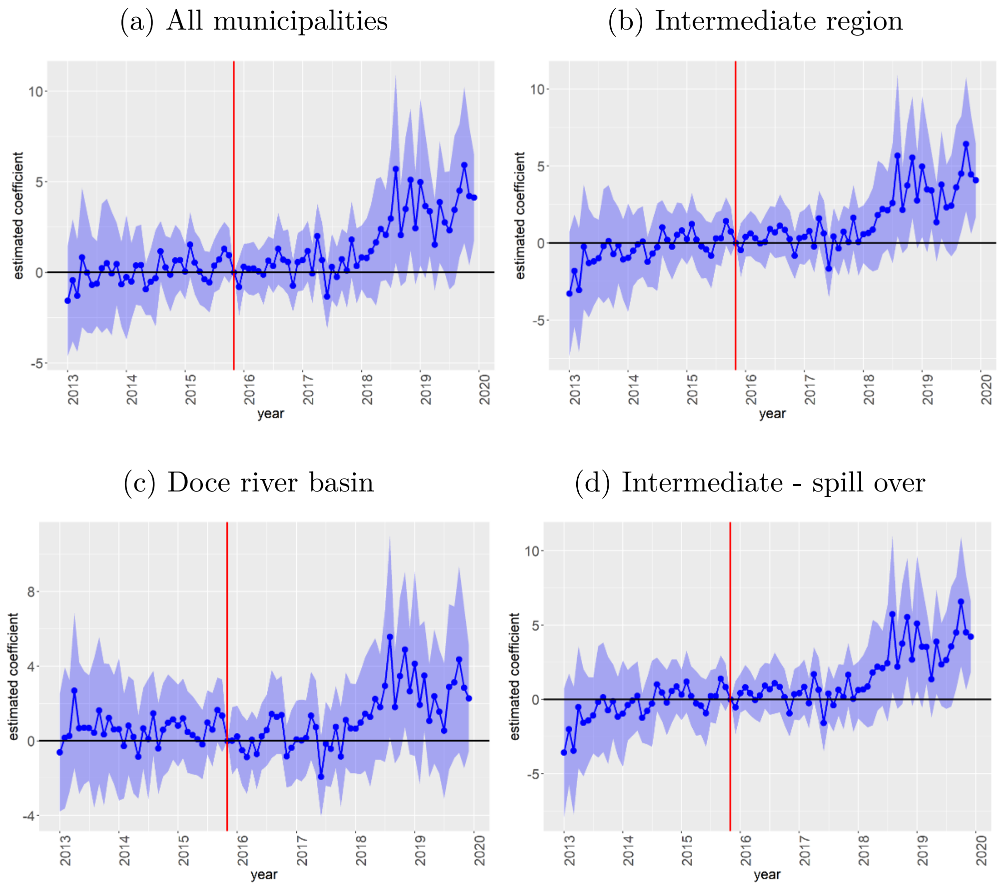
Based on the estimation of equation 5.1, we plot $\hat{\alpha}_t$ (the estimate of α_t) for the period of 2013-2019, with standard errors clustered at the municipality level and weight on population size. In figure 5.1, we have the graphics comparing the affected and control groups from Minas Gerais state. Here, we see that the overall trend is very similar among different sets of control groups. In all four graphics, we see that $\hat{\alpha}_t$ is stable and statistically zero until approximately early 2018 (approximately 2 years after the rupture), suggesting that treated and control groups have comparable pre-disaster trends relative to mental disorders hospitalizations, conditional on X_{it} and δ_i. The graphics also suggest a late effect of Fundao dam failure on mental health in affected municipalities in Minas Gerais state, with evidence that effects persist until the end of our sample in 12/2019.

As for municipalities in Espírito Santo state, we plot $\hat{\alpha}_t$ in figure 5.2. Here, results are considerably distinct depending on which control group we choose. If we observe results considering as control group only municipalities in the same intermediate region as affected ones (figures 5.2b and 5.2d), it appears that there is a downward trend in mental disorders hospitalizations after the disaster for affected municipalities. However, figures 5.2a and 5.2c do not present this same pattern. To further investigate pre-disaster trends we then follow the same strategy used by Kiso (2019).

To do so, we estimate an equation very similar to equation 5.1, but instead of including affected municipalities fixed effects for each period (i.e., $T_i \times d_t$), we only estimate it for the post-disaster period and replace the pre-disaster affected fixed effects dummies for the variable $T_i \times t \times \mathbb{1}_{t<nov15}$ (i.e., affected

[1] Our strategy here is similar to the one used by Kiso (2019) in his empirical work.
[2] Another way of interpreting this coefficient is as a time fixed effect for affected municipalities.

Figure 5.1 – Relative mental disorder's hospitalizations conditional on socioeconomic characteristics, by control group. ***Minas Gerais state.***



We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

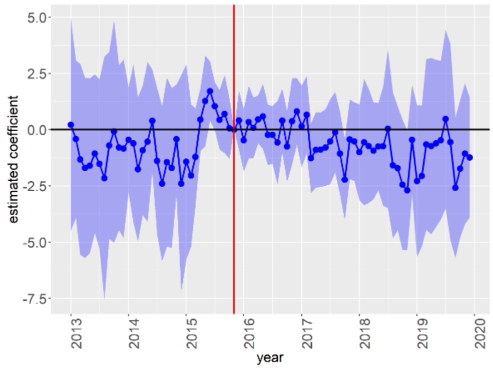
$\times$ t $\times$ $\mathbb{1}_{t<nov15}$ in tables 5.1 and 5.2). By doing so, we are parametrically measuring the time trend applicable only to the pre-disaster affected municipalities.

In table 5.1, we show the estimation results for Minas Gerais state. In each column we have the estimates considering a different control group. Here, we obtain a similar estimated coefficient for the variable $T_i \times t \times \mathbb{1}_{t<nov15}$ in all columns, ranging from 0.01 to 0.07. This economically and statistically insignificant coefficient estimate indicates that, conditional on X_{it} and δ_i, both affected and control groups exhibit very similar time trends in mental hospitalizations before the disaster (jan/2013 to nov/2015), which are captured by the time (month/year) fixed effects (η_t). Therefore, as visually represented in figure 5.1, affected municipalities show a similar behaviour relative to all four control groups in the pre-disaster period.

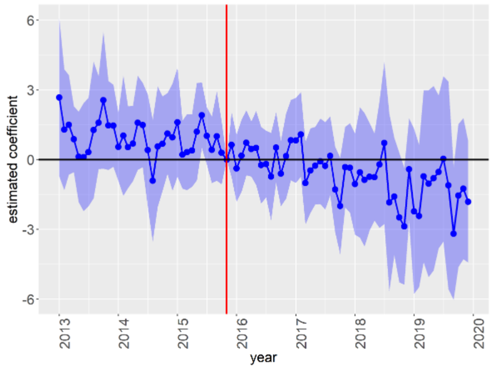
As for municipalities in Espírito Santo state, we present the estimation results in table 5.2. Here the estimated coefficient for the variable $T_i \times t \times \mathbb{1}_{t<nov15}$ varies from -0.01 to 0.08 depending on the control group. Furthermore, when considering as control group municipalities that belongs to Doce river basin, the estimated coefficient is statistically significant (column 3). This indicates that, in the pre-disaster period and for this control group, affected municipalities had a positive and different trend relative to control municipalities regarding mental disorders hospitalizations in general, which suggests that this might not be an appropriate control group. Differently from Minas Gerais state, where 39 municipalities

Figure 5.2 – Relative mental disorder's hospitalizations conditional on socioeconomic characteristics, by control group. ***Espírito Santo state.***

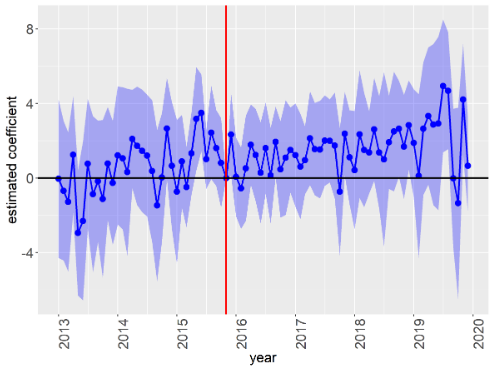
(a) All municipalities



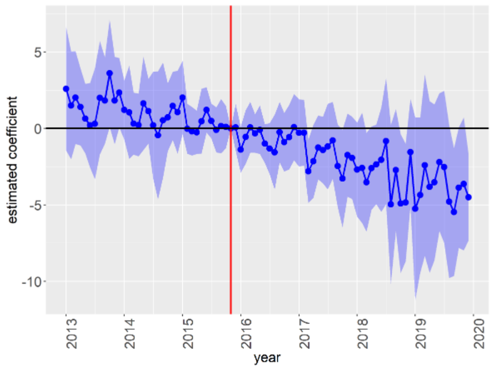
(b) Intermediate region



(c) Doce river basin



(d) Intermediate - spill over



We plot the estimate of α_t based on equation 5.1 for each period (month/year) wtih a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

(of the 40) in the treated group belongs to Doce river basin, only 4 municipalities in Espírito Santo state[3] (of 11 treated municipalities). Therefore, limiting our control group to municipalities in Doce river basin only might not be a good counterfactual for affected municipalities in Espírito Santo.

We also perform these estimations for each group of mental disorder separately to see what is the hospitalization pattern for each one of them individually.[4] For Minas Gerais state, for the vast majority of mental disorders hospitalizations, we obtain an estimated coefficient for the variable $T_i \times t \times \mathbb{1}_{t<nov15}$ that is statistically insignificant, suggesting that affected and control groups exhibit very similar time trends in hospitalizations before the disaster (jan/2013 to nov/2015). This, in turn, implies that for most mental disorders we do not reject our main hypothesis of pre-disaster parallel trend. There are, however, two exceptions: disorders with onset on childhood and schizophrenia-related disorders. We present the estimated values in table 5.3. Hence, we must be careful when interpreting the estimated coefficient of the disaster effects for these disorders. And, again, for both disorders the magnitude of the estimated coefficient is very similar for all four control groups, which suggests that the behaviour among municipalities in these groups are in fact very similar.

As for Espírito Santo state, by performing the estimations for each disorder group separately, we

[3] Municipalities in Espírito Santo state that belong to Doce river basin are: Baixo Guandu, Colatina, Marilândia and Linhares.

[4] See table 2.1 for the classification of mental disorders.

Table 5.1 – Pre-disaster trend, different control groups, Minas Gerais

	Dependent variable:			
	mental disorders hospitalizations per 100,000 inhab.			
	(1) all municipalities	(2) intermediate region	(3) Doce river basin	(4) intermediate - spillover
affected × t × $\mathbb{1}_{t<nov15}$	0.03	0.07	0.01	0.07
	(0.05)	(0.05)	(0.05)	(0.05)
Municipality fixed effects	x	x	x	x
Month fixed effects	x	x	x	x
Month-year fixed effects	x	x	x	x
Control variables	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	71,292	30,960	16,872	25,500
R^2	0.48	0.44	0.23	0.46
Adjusted R^2	0.47	0.44	0.22	0.45

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.
To see full table with all estimated coefficients, see table A.6 in the appendix.

Table 5.2 – Pre-disaster trend, different control groups, Espirito Santo state

	Dependent variable:			
	mental disorders hospitalizations per 100,000 inhab.			
	(1) all municipalities	(2) intermediate region	(3) Doce river basin	(4) intermediate - spillover
affected × t × $\mathbb{1}_{t<nov15}$	0.03	−0.01	0.08***	−0.04
	(0.05)	(0.02)	(0.03)	(0.03)
Municipality fixed effects	x	x	x	x
Month fixed effects	x	x	x	x
Month-year fixed effects	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Control variables	x	x	x	x
Observations	6,528	4,512	2,664	2,832
R^2	0.41	0.38	0.39	0.42
Adjusted R^2	0.39	0.35	0.35	0.38

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.
To see full table with all estimated coefficients, see table A.7 in the appendix.

obtain evidences that trends are not parallel in the pre-disaster period for stress-related disorders and for schizophrenia disorders (see table 5.4). Therefore, we must be careful when interpreting these disorder's estimated coefficients later on.

Table 5.3 – Pre-disaster trend for mental disorders, by control group. Minas Gerais state.

	Dependent variable:			
	hospitalizations per 100,000 inhab.			
	(1) all municipalities	(2) intermediate region	(3) Doce river basin	(4) intermediate - spillover
affected × t × $\mathbb{1}_{t<nov15}$: **disorders w/ onset on childhood**	0.004**	0.005**	0.002	0.005***
	(0.002)	(0.002)	(0.003)	(0.002)
affected × t × $\mathbb{1}_{t<nov15}$: **schizophrenia**	0.01	0.03**	0.01	0.03**
	(0.01)	(0.01)	(0.01)	(0.01)
Municipality fixed effects	x	x	x	x
Month fixed effects	x	x	x	x
Month-year fixed effects	x	x	x	x
Control variables	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Number of munic. in control group	811	329	161	264
Observations	71,292	30,960	16,872	25,500

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.

Table 5.4 – Pre-disaster trend for mental disorders, by control group. Espírito Santo state.

	Dependent variable:			
	hospitalizations per 100,000 inhab.			
	(1) all municipalities	(2) intermediate region	(3) Doce river basin	(4) intermediate - spillover
affected × t × $\mathbb{1}_{t<nov15}$: **stress disorders**	0.003*	0.004*	0.003	0.004**
	(0.002)	(0.002)	(0.002)	(0.002)
affected × t × $\mathbb{1}_{t<nov15}$: **schizophrenia**	0.03**	0.02**	0.06***	0.02*
	(0.01)	(0.01)	(0.02)	(0.01)
Municipality fixed effects	x	x	x	x
Month fixed effects	x	x	x	x
Month-year fixed effects	x	x	x	x
Control variables	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Number of munic. in control group	67	43	21	23
Observations	6,528	4,512	2,664	2,832

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.

5.2 Difference-in-differences estimates

In this section we present the estimates based on equation 4.1. The coefficient of interest is β, which measures the change in mental disorder hospitalizations that is specific to affected municipalities due to Fundao's collapse, conditional on socioeconomic time-varying variables X_{it}, municipality and time (month-year) fixed effects. As discussed in previous sections, β is interpreted as a lower bound of the disaster impact on mental health.

First, we investigate mental disorders as a whole. Table 5.5 presents different specifications of our regression model, using as a control group municipalities in the same intermediate region as affected ones, but excluding frontier municipalities.[5] Here, our intention is to show how the estimated coefficients

[5] For the complete table, see table A.19 in the appendix.

$\hat{\beta}_{MG}$ and $\hat{\beta}_{ES}$ (the estimate of β for Minas Gerais state and Espírito Santo state respectively) change depending on the specification. For further analyses, we use the specification in column (4) as our reference model. Also, we present in table A.3 the baseline values for mental disorders hospitalizations for affected municipalities, and we use it to compare the estimated effect of the disaster.

We estimate the coefficients considering the full specification for different control groups to test their robustness. Table 5.6 presents these results. The estimated coefficients for Minas Gerais state ($\hat{\beta}_{MG}$) are positive for all different control groups (although not statistically significant in columns (1) and (3)), ranging from 0.58-2.14. These are the first evidences of an increase in mental disorders hospitalizations for affected municipalities in Minas Gerais state. The average estimated increase in hospitalizations around 9.7% to 35.8%, as the baseline before the disaster[6] was 5.97 hospitalizations per 100,000 inhabitants per month. The estimated coefficient is the smallest in column (4), that is, when considering municipalities in Doce river basin as our control group. This may suggest that even municipalities in the basin that were not in the mud path may have been affected by the disaster (a possible spill over effect).

As for Espírito Santo state, we observe that the estimated coefficient ($\hat{\beta}_{ES}$) changes its direction depending on the control group. Which was also observed in section 5.1, when we analyzed the overall trend of treated versus control groups. Here it is not clear yet what was the impact on mental disorder's hospitalizations or if there was an effect at all.

Table 5.5 – Estimated lower bound of the effect of the disaster in mental heath, different specifications, 01/2013 to 12/2019. Control group: Excluded frontier municipalities

	Dependent variable:			
	mental hospitalizations per 100,000 inhab.			
	(1)	(2)	(3)	(4)
affected in MG × after (n=40)	0.40	0.24	2.11*	2.14*
	(1.38)	(1.01)	(1.13)	(1.10)
affected in ES × after (n=11)	−1.51**	−1.12	−1.12	−2.05**
	(0.66)	(0.97)	(0.97)	(1.00)
Municipality fixed effects		x	x	x
Month fixed effects			x	x
Month-year fixed effects			x	x
Control variables				x
Munic. in control group MG	264	264	264	264
Munic. in control group ES	23	23	23	23
Observations	28,392	28,392	28,392	28,332
R^2	0.03	0.43	0.45	0.46
Adjusted R^2	0.03	0.42	0.45	0.45

*p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by populationa size.
We include a fixed effect for each group of mental disorder.
Each treated group is compared to a control group made only by municipalities in its own state.

We do not expect that an stressful event as such affect different types of mental disorders in similar ways and intensities, some of these disorders are more likely to occur after stressful events than others, as discussed in section 2. There is a great variety of disorders classified as mental disorders, each of them with its own particularities and characteristics. Therefore, to further investigate Fundao dam

[6] See table A.3 for baseline reference values for affected municipalities.

Table 5.6 – Estimated lower bound of the effect of the disaster in mental health, different control groups, 01/2013 to 12/2019

	Dependent variable:			
	mental hospitalizations per 100,000 inhab.			
	(1) All munic.	(2) Intermediate region	(3) Doce river basin	(4) Excluded frontier munic.
affected in MG × after (n=40)	1.53	2.03^{*}	0.58	2.14^{*}
	(1.05)	(1.09)	(1.09)	(1.10)
affected in ES × after (n=11)	1.33	−1.31	1.86^{**}	-2.05^{**}
	(1.72)	(0.87)	(0.90)	(1.00)
Municipality fixed effects	x	x	x	x
Month fixed effects	x	x	x	x
Month-year fixed effects	x	x	x	x
Control variables	x	x	x	x
Munic. in control group MG	811	329	161	264
Munic. in control group ES	67	43	21	23
Observations	77,820	35,472	19,536	28,332
R^2	0.47	0.44	0.25	0.46
Adjusted R^2	0.46	0.43	0.23	0.45

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
We include a fixed effect for each group of mental disorder.
Each treated group is compared to a control group made only by municipalities in its own state.

collapse effects on mental health, we estimate the impacts for each group of mental illnesses separately according to the classification of mental disorders presented in table 2.1.

We do these estimations considering each of our four control groups.[7] The only estimated coefficient that is robust to all control groups are for mental disorders with onset on childhood for Minas Gerais state (table 5.7). We obtain an estimated coefficient that varies between 0.74 to 0.76, a considerable magnitude, as the baseline for this group of disorders before the disaster is of 0.154 hospitalizations per 100,000 inhabitants per month. That is, we estimate that, in average, hospitalization more than forth-folded after the disaster.

However, we must interpret this coefficient with some caution, as there is evidence that trends in the pre-disaster period were distinct for treated and control group regarding this particular disorder.[8] Table 5.3 report an estimated time-trend coefficient for the pre-disaster period that ranges from 0.002-0.005. Although these might suggest that trends were not parallel between treated and control group before the disaster, the magnitude of the coefficient is very low when compared to the estimated effect of the disaster on mental disorders that ranges between 0.74-0.76. We plot the estimated coefficients based on equation 5.1 in figure 5.3 to better visualize these magnitudes. These graphs show that the difference in trends between treated and control group before the disaster are almost insignificant when compared to the increase in level of the difference in hospitalizations between these two groups in post-disaster period.

This finding is consistent with the literature on mental health and disasters, which identifies children as a vulnerable group when exposed to extreme shocks. Among the disorders in this category, we have hyperkinetic disorders, mixed disorders of conduct and emotions, disorders of social functioning,

7 Results for all the estimations are presented in tables A.21, A.22, A.23 and A.24.
8 This is reported on table 5.3 in section 5.1.

Table 5.7 – Estimated lower bound of the effect of the disaster in ***disorders with onset on childhood***, different control groups, 01/2013 to 12/2019

	Dependent variable:			
	mental hospitalizations per 100,000 inhab.			
	(1) All munic.	(2) Intermediate region	(3) Doce river basin	(4) Excluded frontier munic.
affected in MG × after (n=40)	0.74*	0.76*	0.75*	0.76*
	(0.44)	(0.44)	(0.42)	(0.44)
affected in ES × after (n=11)	0.03	0.02	−0.04	0.05
	(0.04)	(0.04)	(0.07)	(0.05)
Municipality fixed effects	x	x	x	x
Month fixed effects	x	x	x	x
Month-year fixed effects	x	x	x	x
Control variables	x	x	x	x
Munic. in control group MG	811	329	161	264
Munic. in control group ES	67	43	21	23
Observations	77,820	35,472	19,536	28,332
R^2	0.18	0.22	0.26	0.23
Adjusted R^2	0.17	0.20	0.25	0.22
Note:	*p<0.1; **p<0.05; ***p<0.01 All regressions are clustered by municipality and weighted by population size. Each treated group is compared to a control group made only by municipalities in its own state.			

tic disorders, among others. All of them are likely to emerge in a stressful scenario.

These results are our first evidence that Fundao dam rupture affected mental disorders hospitalizations occurrence in Minas Gerais state, especially in mental disorders with onset on childhood and adolescence. There are, however, some limitations in analyzing all affected municipalities as a unique group,[9] as each region was affected in rather different ways and intensities. To continue our investigation, we break our treated group into categories, as defined in section 4.3, and estimate the impacts in mental health hospitalizations for each category.

5.2.1 Heterogeneous analysis: by municipality classification

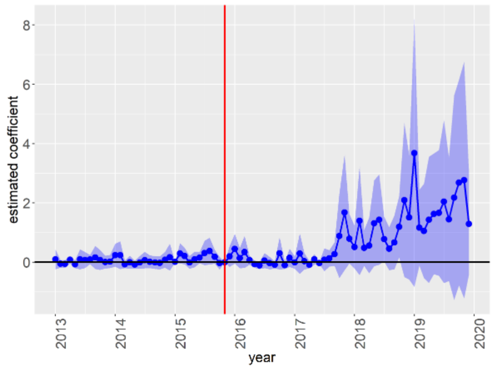
The estimated coefficients we present in this section come from the estimation of equation 4.2. And, as described in section 4.4, to deal with the issue of few treated municipalities in each group, we conduct inference by using the bootstrap procedure proposed by Ferman e Pinto (2019) to produce the p-values that are presented in brackets in our tables.

Table 5.8 present the estimates considering mental disorders hospitalizations for each category, therefore there are six estimated coefficients. Each column from (1) to (4) presents the estimations for a different control group and column (5) presents the baseline of hospitalizations before the disaster occurrence (from jan/2013 to oct/2015). This table shows that the group that is dragging the effect for Minas Gerais state are municipalities located upstream Candonga reservoir. The estimated coefficient ($\hat{\beta}$) for this group is the only one that is robust and statistically significant for all specifications. The estimates range from 3.86-4.66, indicating that Fundao failure had a sizable effect on mental disorders hospitalizations for this category, as the baseline before the disaster was of 4.63 hospitalizations per

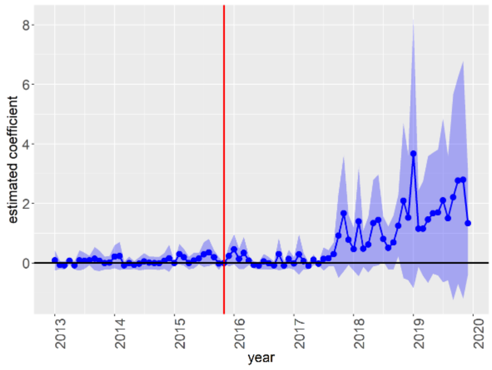
9 As extensively discussed in sections 3.2 and 4.3.

Figure 5.3 – Relative hospitalizations conditional on socioeconomic characteristics, by control groups. Minas Gerais state. ***Disorders with onset on childhood.***

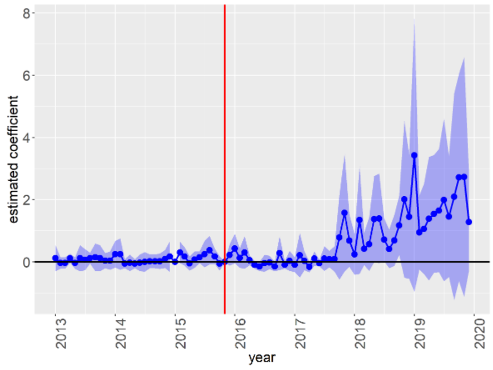
(a) All municipalities



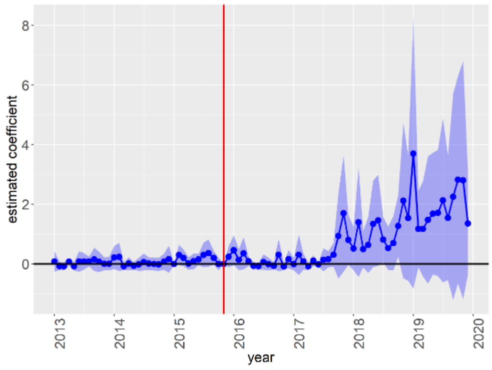
(b) Intermediate region



(c) Doce river basin



(d) Intermediate - spill over



We plot the estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

100,000 inhabitants per month, meaning that the disaster nearly doubled mental disorders hospitalizations for municipalities located upstream Candonga reservoir in average.

Also note that column (3) presents lower estimated coefficients than those presented in other columns for all categories in Minas Gerais state (up reservoir, down reservoir in MG and indirectly affected in MG), reinforcing the hypothesis of a possible spill over effect in Doce river basin.

Next, we estimate the effects considering each group of mental disorders separately.[10] Here, again, we estimate results considering all four control groups.[11] Table 5.9 present a visual representation summarizing our estimations' results for each disorder and category. In this table, we mark up which disorders and categories present an estimated coefficient ($\hat{\beta}$) statistically significant and robust to all four control groups. We use this preliminary analysis to identify where the impacts of the disaster are more prevalent, helping us spot which disorders were affected and for which category of affected municipalities. After this first and more superficial analysis, we focus our discussion in categories and disorders that present robust estimated coefficients by actually quantifying the impact and analyzing them individually.

Table 5.9 shows that municipalities located upstream Candonga reservoir are the ones where mental health impacts due to the disaster are more prevalent, a result that goes in the same direction

[10] See table 2.1 for the classification of mental disorders.

[11] See tables A.26, A.27, A.28 and A.29 for the estimates on each disorder and for each control group.

Table 5.8 – Estimated lower bounds of the disaster's effect on hospitalizations, by category and control groups, 2013-2019.

	mental disorders hospitalizations per 100,000 inhab. per month				
	(1) All municipalities	*(2)* Intermediate region	*(3)* Doce river basin	*(4)* Excluded frontier munic.	*(5)* Baseline before disaster
Panel A: Minas Gerais state					
up reservoir x after (n=4)	4.657*	4.35*	3.869**	4.389*	4.63
	[0.057]	[0.08]	[0.028]	[0.096]	
down reservoir MG x after (n=31)	1.278	1.639*	-0.201	1.667	6.19
	[0.123]	[0.086]	[0.542]	[0.107]	
indirectly affected MG x after (n=5)	1.676	1.895	0.96	1.976	5.38
	[0.166]	[0.165]	[0.24]	[0.165]	
Panel B: Espírito Santo state					
down reservoir ES x after (n=3)	3.141	0.163	2.485**	-0.375	2.08
	[0.118]	[0.514]	[0.047]	[0.562]	
coast x after (n=2)	-3.944	-4.41	-1.911	-4.902	6.37
	[0.863]	[0.948]	[0.928]	[0.957]	
indirectly affected ES x after (n=6)	-0.008	-0.997	0.783	-1.668	2.78
	[0.52]	[0.762]	[0.256]	[0.883]	
Municipality fixed effects	x	x	x	x	-
Time fixed effects	x	x	x	x	-
Control variables	x	x	x	x	-
Munic. in control group MG	811	329	161	264	-
Munic. in control group ES	67	43	21	23	-

*p<0.1; **p<0.05; ***p<0.01
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure described in Ferman e Pinto (2019).

Table 5.9 – Summary of the disaster's effect on hospitalizations, by disorder and by category, 2013-2019.

	Stress related	Psychoactive substance use	Mood	Personality and behaviour	Dementia related	Disorders with onset on childhood
up reservoir × after (n=4)	+*	+*	o	o	o	o
down reservoir MG × after (n=31)	o	o	o	o	o	+***
down reservoir ES × after (n=3)	o	o	o	o	o	o
coast × after (n=2)	o	o	o	o	o	o
indirectly affected MG × after (n=5)	o	o	o	o	o	o
indirectly affected ES × after (n=6)	o	o	o	o	o	o

	Behavioural syndromes	Psychological development	Schizophrenia	Non-organic psychosis	Mental retardation	Other
up reservoir × after (n=4)	o	+**	o	+*	+**	o
down reservoir MG × after (n=31)	o	o	o	o	o	o
down reservoir ES × after (n=3)	o	o	o	o	o	o
coast × after (n=2)	o	o	o	o	o	o
indirectly affected MG × after (n=5)	o	o	o	o	o	o
indirectly affected ES × after (n=6)	o	o	o	o	o	o

In this table, we present a summary of the coefficients for each category estimated based on equation 4.2.
P-values are obtained using the bootstrapping procedure described in Ferman e Pinto (2019).
Legend: "o" no statistically significant coefficient; "+" positive coefficient; "-" negative coefficient.
*p<0.1; **p<0.05; ***p<0.01

as the estimates we've obtained previously. This affected group present the most number of positive, statistically significant and robust estimated coefficients. More specifically, five groups of mental disorders hospitalizations increased after the disaster.

However, upstream Candonga reservoir municipalities are not the only group that suffered impacts on mental disorders hospitalizations in Minas Gerais state. We also obtain robust estimates for downstream Candonga reservoir and indirectly affected municipalities. Table 5.9 shows a significant effect on disorders with onset on childhood for municipalities located downstream Candonga reservoir and an increase in stress-related disorders for indirectly affected municipalities.

As for affected municipalities in Espírito Santo state, differently from the estimates we've obtained for Minas Gerais state municipalities, our results have been inconclusive so far with no clear indication of an increase (or decrease) in mental disorders hospitalizations due to the disaster occurrence.

Now that we've mapped which disorders were affected by the rupture in each category, to deepen our analysis, we investigate the effects for each category in Minas Gerais state.

5.2.2 Effects in Minas Gerais state by affected group category

There are three distinct categories of affected municipalities in Minas Gerais state:[12] upstream Candonga reservoir, downstream Candonga reservoir and indirectly affected municipalities. In this section, we present the disaster effect in each of them individually. Here we present the estimated coefficients considering all four distinct control groups, however, we only display graphics considering municipalities in Doce river basin as our control group, since the hospitalization's pattern among Minas Gerais state control groups are very similar (as discussed on section 5.1).[13]

As stated in the previous section, table 5.9 shows that the most affected category in terms of mental health hospitalizations was ***upstream Candonga reservoir***. This result does not come as a surprise, as these municipalities are the ones closer to Fundao dam location and, therefore, suffered the most physical damage. The disaster affected a broad set of mental disorders hospitalizations, more specifically: (i) stress-related disorders, (ii) psychoactive substance use, (iii) psychological development disorders, (iv) non-organic psychosis and (v) mental retardation. To better understand how the effect evolved in each of these disorders, we analyze them individually.

1. **Stress-related disorders** includes many different types of anxieties disorders and also post-traumatic stress disorders, which are very common in post-disaster contexts. Table 5.10 present the estimated coefficients for stress-related disorders. The estimated coefficient for upstream Candonga reservoir municipalities ranges from 0.165 to 0.242 and is statistically significant for all different control groups specifications. This result represents a sizable impact of the disaster in hospitalizations due to stress-related disorders as, before the rupture, there are no hospitalizations due to stress-related disorders for upstream Candonga municipality (see figure 5.4). These graphs also indicate that stress-related disorders hospitalizations increase right after the rupture, in a year period approximately; and then, again, later on - more then three years after the rupture in late 2018.

2. **Psychoactive substance abuse disorders** are another group of disorders that are very common on post-disaster onsets. This group mainly consists of mental and behavioural disorders due to alcohol or drugs consumption. Table 5.10 shows that the estimated coefficient for up reservoir

[12] Check section 4.3 for a review on affected municipalities' classification.
[13] To see the graphics of each disorder and each control group, you can check the appendix

Table 5.10 – Estimated lower bounds of the disaster's effect on hospitalizations by control groups, 2013-2019. ***Upstream reservoir municipalities.***

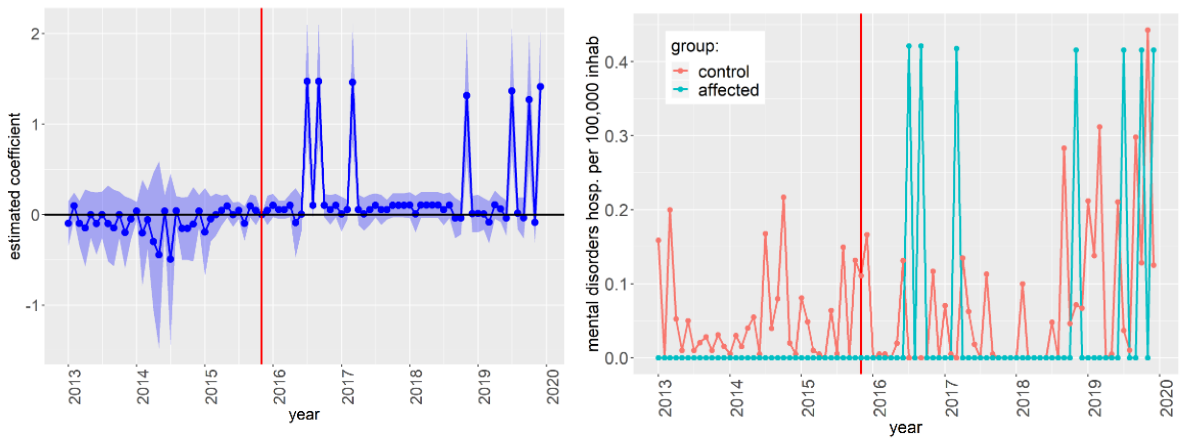
	mental disorders' hospitalizations per 100,000 inhab. per month				
	(1) All municipalities	*(2)* Intermediate region	*(3)* Doce river basin	*(4)* Excluded frontier munic.	*(5)* Baseline before disaster
Stress-related	0.181*	0.184*	0.242*	0.165*	0.00
	[0.055]	[0.058]	[0.059]	[0.07]	
Psychoactive substance use	2.694*	2.626*	2.226**	2.643*	0.94
	[0.054]	[0.072]	[0.046]	[0.08]	
Psychological development	0.139**	0.151**	0.229***	0.151**	0.00
	[0.032]	[0.033]	[0.004]	[0.036]	
Non-organic psychosis	0.671*	0.665**	0.673**	0.66**	0.20
	[0.051]	[0.016]	[0.018]	[0.023]	
Mental retardation	0.42**	0.475**	0.495**	0.466**	0.00
	[0.033]	[0.022]	[0.018]	[0.036]	
Municipality fixed effects	x	x	x	x	-
Time fixed effects	x	x	x	x	-
Control variables	x	x	x	x	-
Munic. in affected group	4	4	4	4	4
Munic. in control group	811	329	161	264	-

*p<0.1; **p<0.05; ***p<0.01
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure presented by Ferman e Pinto (2019).

Figure 5.4 – Stress-related disorder, ***upstream Candonga municipalities.***

(a) Relative hospitalizations[1]

(b) Hospitalizations trajectory[2]

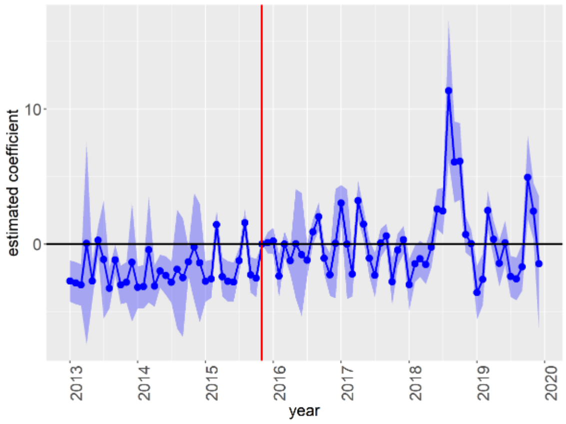


[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

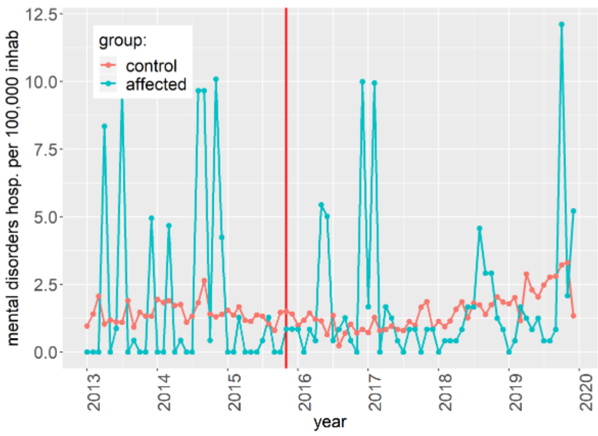
municipalities ranges from 2.22 – 2.69 hospitalizations per 100,000 inhabitants per month. Comparing this results to the baseline of 0.939 hospitalizations per 100,000 inhabitants per month before the disaster, we estimate at least a two-fold increase in hospitalizations. Figure 5.5 illustrates the dynamics of hospitalizations between treated and control groups. Here, the effect seems more prevalent a couple of years after the rupture, suggesting a late-effect.

Figure 5.5 – Psychoactive substance use disorders, ***upstream Candonga municipalities.***

(a) Relative hospitalizations[1]



(b) Hospitalizations trajectory[2]



[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

3. **Disorders of psychological development** comprise a group of psychiatric conditions originating in childhood that involve serious impairment in different areas. These disorders include developmental language disorder, learning disorders, motor disorders and autism spectrum disorders, among others. The scientific study of the causes of developmental disorders involves many different theories, one of them supports that stress is one of the main environmental causes for developmental disorders in early childhood. Hambrick, Brawner e Perry (2019) theorizes that developmental disorders can be caused by early childhood traumas, the authors compares developmental disorders in traumatized children to adults with post-traumatic stress disorder, linking extreme environmental stress to the cause of developmental difficulties.

   Table 5.10 presents the estimated coefficient for this group of disorders. For upstream Candonga reservoir municipalities, the estimated coefficient is positive and robust to all specifications and ranges between $0.14 - 0.23$. Here, the increase in hospitalizations induced by the disaster is also significant, as, before its occurrence, there are no observations of hospitalizations in affected municipalities in our sample period (see figure 5.6).

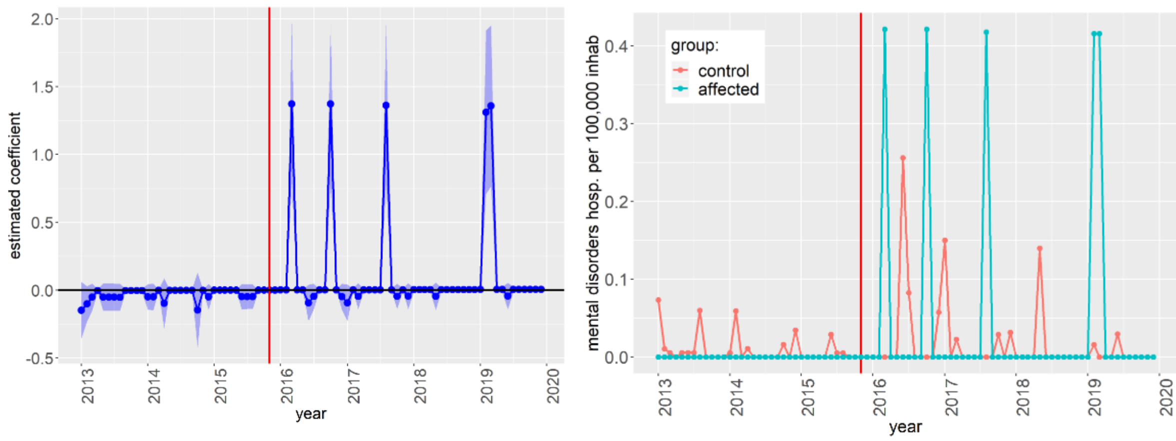
4. The term psychosis embraces a constellation of symptoms, such as hallucinations or delusions. Causes of psychotic disorders are multi factorial - prominent risk factors being: genetic risks, migration, growing up in urban environments, stressful life events, among others (SAMI et al., 2017). **Unspecified non-organic psychosis** are generally disorders with enduring or recurring symptoms that may indicate a longer-lasting condition (lasts more than one month), but that does not satisfy criteria for the other types of psychosis - such as schizophrenia, schizoaffective disorder, persistent Delusional Disorder.

   Table 5.10 reports that the estimated coefficient for municipalities located upstream Candonga reservoir ranges from $0.66 - 0.67$ and is robust to all specifications. When comparing to the baseline before the disaster of 0.205 hospitalizations per 100,000 inhabitants per month, this represents a three-fold impact. Figure 5.7 suggests that the effects regarding these disorders manifested mainly a few years after the collapse.

5. **Mental retardation group of disorders** (also know as intellectual impairment or disabilities)

Figure 5.6 – Disorders of psychological development, ***upstream Candonga municipalities.***

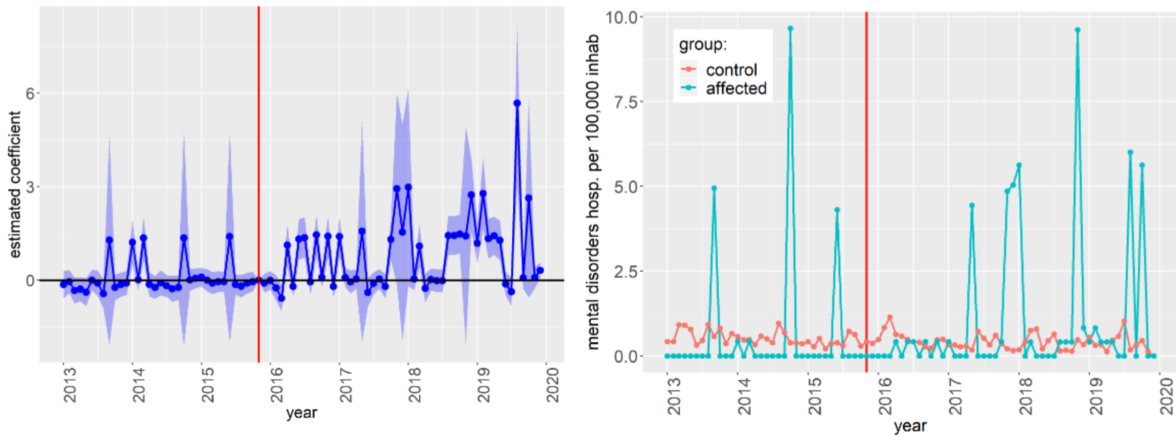
(a) Relative hospitalizations[1] (b) Hospitalizations trajectory[2]



[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

Figure 5.7 – Non-organic psychosis, ***upstream Candonga municipalities.***

(a) Relative hospitalizations[1] (b) Hospitalizations trajectory[2]



[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

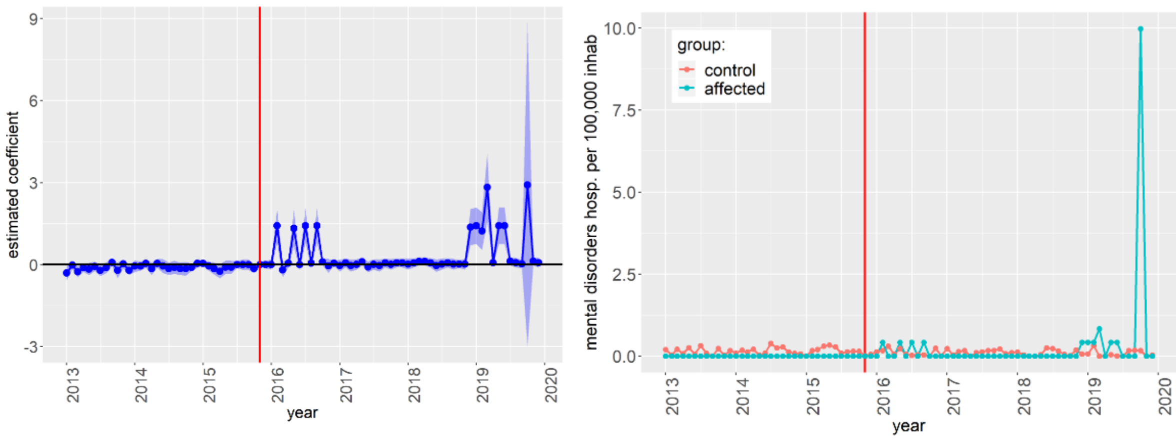
comprises from mild to profound mental. Hospitalizations that falls into this category are usually classified by (i) the degree of impairment of behaviour, which can be: non or minimal impairment of behaviour, significant impairment of behaviour requiring attention or treatment, other impairments of behaviour or without mention of impairment of behaviour. And by (ii) the type of the behaviour, which can be classified as: repetitive self injury, hyperkinesis, pica, wandering and absconding or hair pulling (ORGANIZATION et al., 1996).

Once, it was widely assumed that people with intellectual disability could not experience mental illness because they lacked the intellectual capacity. However, this was disproved in the literature on mental health disorders, as many studies reveals that persons with severe mental illness can experience posttraumatic stress disorder, depression, anxiety, and illness exacerbation after disaster

(NERIA; GALEA; NORRIS, 2009). In fact, individuals with intellectual disability may be at a greater risk for experiencing stress than their counterparts without a disability (HATTON; EMERSON, 2004) and likely to have fewer resources available to help them cope with that stress.[14] In our study we find that mental retardation disorders increased by $0.42 - 0.49$ hospitalizations per 100,000 inhabitants per month in municipalities located upstream Candonga reservoir as a consequence of the disaster (table 5.10). Which represents a four-fold in the number of hospitalizations when compared to the baseline value before the disaster of 0.096 hospitalizations per 100,000 inhabitants per month. Analyzing figure 5.8, we see that there is an increase in these hospitalizations right after the rupture, in a six months period approximately; and then again later on - more then three years after the rupture, in late 2018.

Figure 5.8 – Mental retardation, ***upstream Candonga municipalities.***

(a) Relative hospitalizations[1] (b) Hospitalizations trajectory[2]



[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

As for municipalities located ***downstream Candonga reservoir***, although not as much affected as upstream Candonga municipalities, we find evidence of an increased number of hospitalizations due to **disorders with onset on childhood and adolescence**. This group of disorders comprises: disturbance of activity and attention, hyperkinetic disorders, conduct disorders, mixed disorders of conduct and emotions, emotional disorders, disorders of social functioning, tic disorders and other behavioural and emotional disorders. As stated in the literature, children and adolescence exposed to trauma can suffer major adverse psychological effects including not only post-traumatic stress but also other psychological disorders. Bolton et al. (2000) find long-term effect on general psychopathology following trauma in adolescence due to a shipping disaster.[15]

In our study, we estimate that Fundao dam rupture increased by $0.85 - 0.98$ hospitalizations per 100,000 inhabitants per month on disorders with onset on childhood and adolescence (see table 5.11). This represents a four-fold in hospitalizations as compared to the baseline number of hospitalizations

[14] Scott e Havercamp (2014) conducted a large, nationally representative study in the United States and find that for adults with intellectual disabilities stress was significantly correlated with both mental illness and severity of behavior problems, with each additional stressor increasing the odds of poor mental health by 20%.

[15] The sinking of the "Jupiter" in Greek waters.

before the disaster, a very high impact for affected municipalities. We also see in figure 5.9 that the effects seems to appear mainly almost three years after the disaster, in late 2017.

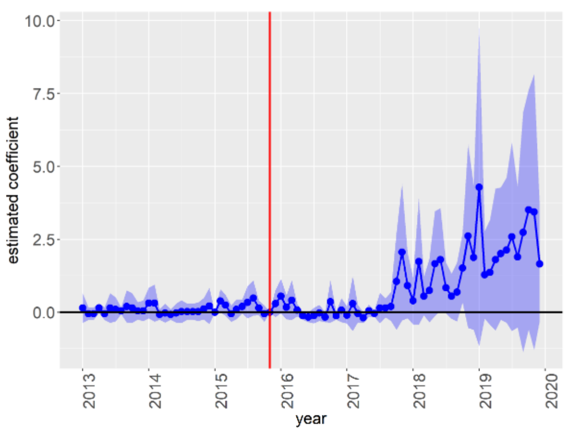
Table 5.11 – Estimated lower bounds of the disaster's effect on hospitalizations by control groups, 2013-2019. ***Downstream reservoir municipalities.***

	mental disorders' hospitalizations per 100,000 inhab. per month				
	(1) All municipalities	*(2)* Intermediate region	*(3)* Doce river basin	*(4)* Excluded frontier munic.	*(5)* Baseline before disaster
Disorders w/ onset on childhood/adolescence	0.968*** [0]	0.982*** [0]	0.853*** [0.001]	0.982*** [0]	0.19
Municipality fixed effects	x	x	x	x	-
Time fixed effects	x	x	x	x	-
Control variables	x	x	x	x	-
Munic. in affected group	31	31	31	31	31
Munic. in control group	811	329	161	264	-

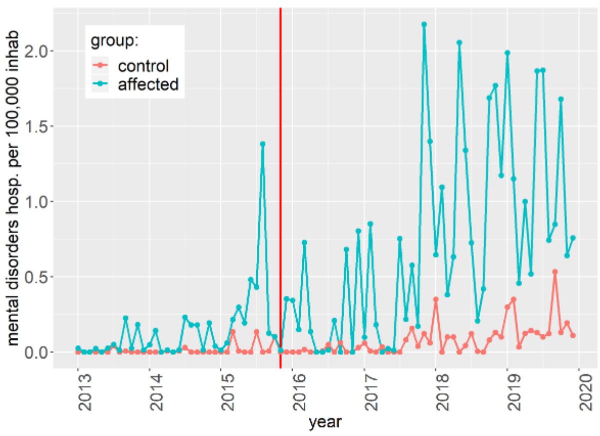
*p<0.1; **p<0.05; ***p<0.01
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure presented by Ferman e Pinto (2019).

Figure 5.9 – Disorders with onset on childhood and adolescence, ***downstream Candonga municipalities.***

(a) Relative hospitalizations[1]



(b) Hospitalizations trajectory[2]



[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

The last category in Minas Gerais state are the **indirectly affected**. For these municipalities we estimate an average increase of $0.06 - 0.19$ hospitalizations per 100,000 inhabitants per month due to stress-related disorders (see table 5.12). Implying that this type of disorder actually two-folded after the disaster, since the baseline before the failure was of $0,04$ hospitalizations per 100,000 inhabitants per month. Differently from what we see for upstream Candonga reservoir municipalities in figure 5.4a, for indirectly affected municipalities we do not observe an increase right after the disaster (figure 5.10). The effects start to appear mostly in early 2017, approximately two years after the dam failure, suggesting a late impact for this group of municipalities. This could be because this group did not suffered the immediate impacts of the tailing mud, as they were not located on the mud path. However, as they were closely related to Sarmarco's activities or to affected municipalities, this late effect might be due to the slowness of the recovery process, the difficulty for communities to return to their old standard of life[16] or negative economic externalities, for instance.

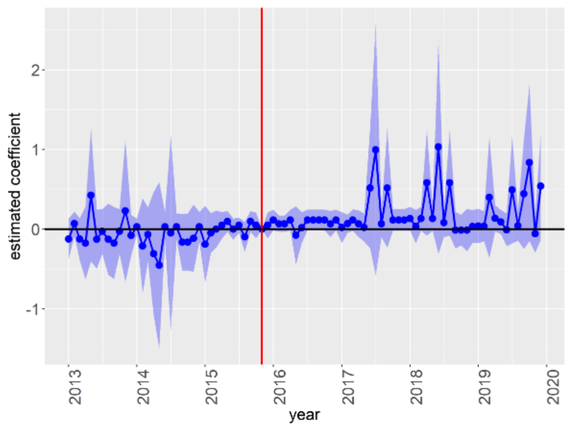
Table 5.12 – Estimated lower bounds of the disaster's effect on hospitalizations by control groups, 2013-2019. ***Indirectly affected municipalities.***

	mental disorders' hospitalizations per 100,000 inhab. per month				
	(1) All municipalities	*(2)* Intermediate region	*(3)* Doce river basin	*(4)* Excluded frontier munic.	*(5)* Baseline before disaster
Stress-related	0.093*	0.097	0.189*	0.066*	0.04
	[0.073]	[0.115]	[0.064]	[0.077]	
Psychoactive substance use	1.893*	1.893*	1.302	1.959*	1.77
	[0.065]	[0.068]	[0.105]	[0.099]	
Municipality fixed effects	x	x	x	x	-
Time fixed effects	x	x	x	x	-
Control variables	x	x	x	x	-
Munic. in affected group	5	5	5	5	5
Munic. in control group	811	329	161	264	-

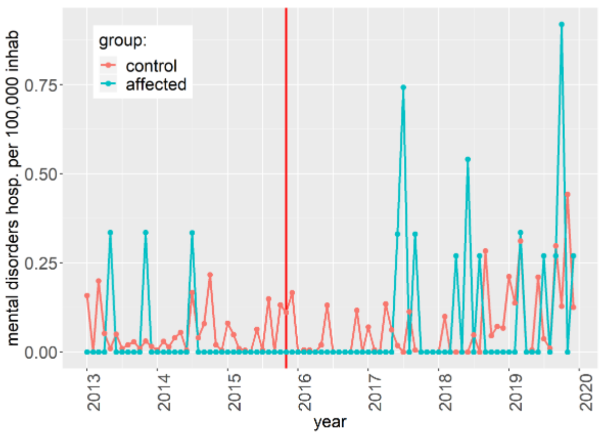
*p<0.1; **p<0.05; ***p<0.01
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure presented by Ferman e Pinto (2019).

Figure 5.10 – Stress-related disorder, ***indirectly affected municipalities.***

(a) Relative hospitalizations[1]



(b) Hospitalizations trajectory[2]



[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

5.3 Possible confounding variable: medical beds

A possible issue that may affect our identification strategy is if, as a consequence of the disaster, there was a relative expansion in the healthcare system of affected municipalities versus non-affected ones. This could be considered a confounding variable as a considerable expansion in the healthcare system could affect the number of hospitalizations we would capture in our databases. Hence, if affected municipalities had their healthcare infrastructure improved after the disaster, we would not be able to

[16] As described in sections 3.2 and 3.3.

distinguish the effect of the disaster itself from the effect of the healthcare expansion on the number of hospitalizations. To check if this could be a potential issue, we use the number of clinical medical beds as a proxy for healthcare system infrastructure.

Table 5.13 shows the number of clinical medical beds[17] before/after the disaster for each category of affected municipalities and for non affected municipalities both in Minas Gerais and Espírito Santo states. There is a level difference on the average number of medical beds between affected categories of Minas Gerais state, reinforcing the heterogeneity that exists between these groups. Also, there is a change in the number of clinical medical beds before and after the disaster for some categories. This change is slightly distinct depending on the category. In Minas Gerais state, there is an increase in the number of medical beds for up reservoir municipalities and a decrease for down reservoir, for instance.

To check if these differences are significant between affected/control groups, before/after the disaster, we estimate equation 4.2 considering medical beds per 100,000 inhabitants per month as our dependent variable, instead of considering hospitalizations. Table 5.14 presents the estimated coefficients and indicates that for most categories they are statistically insignificant. The only exception is the estimated coefficient for down reservoir municipalities in Minas Gerais state. However, it is negative, meaning that there was a decrease in clinical medical beds for these municipalities after the disaster. Therefore, we would not expect to have a confounding variable issue here, as we did not see an evident increase in healthcare capacity. On the contrary, we observe a decrease in clinical beds for municipalities down Candonga reservoir in Minas Gerais state, which could contribute to an underestimated effect.

Table 5.13 – Clinical medical beds per $100,000$ inhabitants, before and after the disaster

	Minas Gerais state				**Espírito Santo state**		
	before	*after*	*diff.*		*before*	*after*	*diff.*
not affected	58.61	50.48	-8.13	not affected	60.94	61.13	0.19
up reservoir	10.59	12.69	2.10	down reservoir	55.71	69.76	14.05
down reservoir	53.07	38.32	-14.75	coast	50.00	46.42	-3.59
indirectly affected	71.11	76.62	5.51	indirectly affected	39.25	44.85	5.60

Source: Author's elaboration.

[17] These data was collected from the Brazilian National Register of Health Institutions (CNES).

Table 5.14 – Diff-in-diff Medical Beds in Public Hospitals - 2010 to 2019

	Dependent variable:		
	medical beds per 100,000 inhabitants		
	(1) Surgical bed	(2) Clinical bed	(3) Complementary bed
up reservoir × after (n=4)	−2.04	3.96	−1.54
	(2.56)	(2.50)	(1.24)
down reservoir MG × after (n=31)	7.31	−12.25**	0.80
	(6.68)	(4.84)	(5.64)
down reservoir ES × after (n=3)	12.07	23.88	−0.56
	(15.16)	(34.76)	(6.00)
coast × after (n=6)	12.85	10.06	2.09
	(12.73)	(10.32)	(6.09)
indirectly affected MG × after (n=5)	−2.71	6.80	3.64
	(3.58)	(7.04)	(10.50)
indirectly affected ES × after (n=2)	−6.19	−17.78*	1.32
	(4.61)	(10.02)	(2.17)
ES state	−3.43	−4.46	1.66
	(5.04)	(7.65)	(1.94)
Observations	4,031	4,031	4,031
R^2	0.97	0.96	0.94
Adjusted R^2	0.96	0.95	0.94

Note: *p<0.1; **p<0.05; ***p<0.01
We consider only medical beds that are registered in Public Hospitals;
All regressions include year fixed effects, are clustered by municipality and weighted by population size;
There are 746 municipalities in Minas Gerais state and 46 municipalities in Espírito Santo state in the control group.

6 Complementary Results and Overall Discussion

6.1 Complementary results: psycho-social care centers

As discussed in section 4.1, psycho-social care centers are an important piece of the Brazilian Psychosocial Care Network, however it is not present in all municipalities. They are present in a small portion of municipalities, only 23% of municipalities in Minas Gerais state had at least one psycho-social care center in 2015, the year of Fundao dam rupture. Hence, here we analyze mental health consequences of the disaster in these specific municipalities, dropping from our sample all observations from municipalities without a psycho-social care center in 2015. We end up with a total of 14 affected municipalities in Minas Gerais state, classified into three categories (see table 6.1 for the number of municipalities in the control groups).

We present the estimated coefficient based on equation 4.2. And, to deal with the issue of few treated municipalities in each group, we conduct inference by using the bootstrap procedure proposed by Ferman e Pinto (2019) and present the obtained p-values in brackets bellow the estimated coefficients in our tables. This procedure is valid when errors are heteroskedastic and when there are only few treated units, or even just one.[1]

Table 6.1 – Municipalities in Minas Gerais state with psycho-social care centers in 2015.

	number of municipalities	**number of munic. with at least one CAPS in 2015**	**number of CAPS in 2015**	**average number of CAPS per municipality in 2015**
total Minas Gerais state[1]	851	197	288	1.46
upstream reservoir	4	1	1	1.00
downstream reservoir	31	10	13	1.30
indirectly affected	5	3	5	1.67
not affected	811	183	269	1.47

[1]We do not consider in our sample the municipalities of Brumadinho and Itabirito.

In this section, we present only results that are robust to estimations considering different sets of control groups. To see all the estimations for each disorder and each category, check appendix tables A.30, A.31 and A.32.

6.1.1 Upstream Candonga reservoir

The only municipality in this category that had a psycho-social care center installed in 2015 is Mariana city, the locus of the disaster. Here we estimate an increase in disorders related to psychological development and behavioural disorders after Fundao dam rupture and in comparison to distinct control groups. For both disorders, the mean value of attendances in the affected municipality before the collapse was zero (see column 5), which suggests that the disaster had an effect of great magnitude in both disorders, especially in disorders of "psychological development". The estimated coefficient ranges between 27.9 to 44.7. Moreover, for this particular group of disorders, we've also obtained robust evidences of an increase in hospitalizations, as presented in section 5.2.1.

[1] which is the case when we analyze the affected group located upstream Candonga reservoir.

Table 6.2 – Estimated lower bound of the disaster's effect on psychiatric centers' attendance, by control group. ***Upstream reservoir municipalities.***

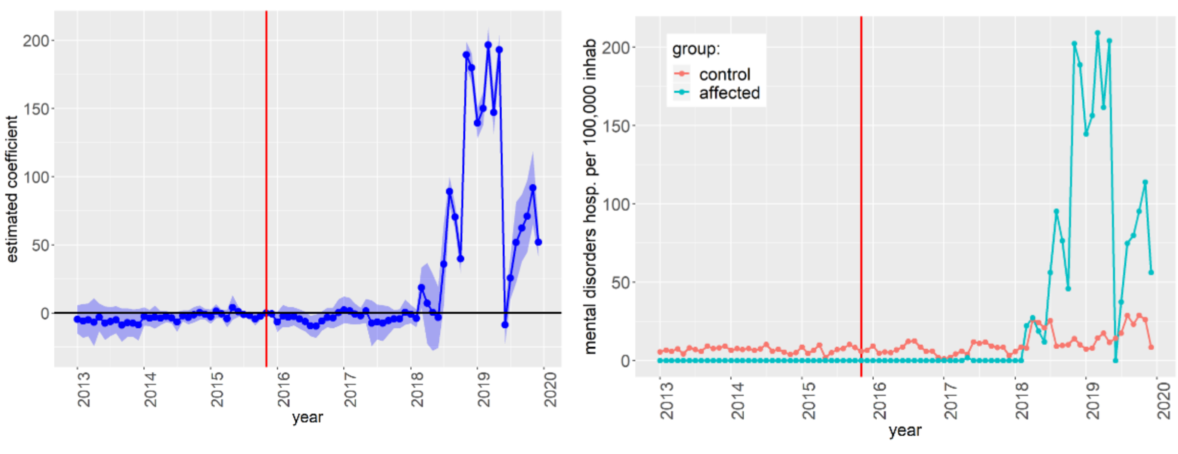
	Attendance in psycho-social care center per 100,000 inhab.				
	(1) All municipalities	*(2)* Intermediate region	*(3)* Doce river basin	*(4)* Excluded frontier munic.	*(5)* Baseline before disaster
Psychological development	36.572**	43.235*	27.906*	44.718*	0.00
	[0.035]	[0.064]	[0.09]	[0.073]	
Behavioural disorders	2.308**	2.394*	0.453	2.254*	0.00
	[0.033]	[0.066]	[0.391]	[0.068]	
Municipality fixed effects	x	x	x	x	-
Time fixed effects	x	x	x	x	-
Control variables	x	x	x	x	-
Munic. in affected group[1]	1	1	1	1	1
Munic. in control group	183	71	29	57	-

*p<0.1; **p<0.05; ***p<0.01
[1]The only affected municipality in this category is Mariana.
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure presented by Ferman e Pinto (2019).

Figure 6.1 and 6.2 show a late effect in these disorders, with an increased number of attendances in psycho-social care centers starting in early 2018 and persisting until the end of our sample in 2019.

Figure 6.1 – Psychological development disorders, ***upstream Candonga reservoir municipalities.***

(a) Relative attendances[1] (b) Attendances in psycho-social centers



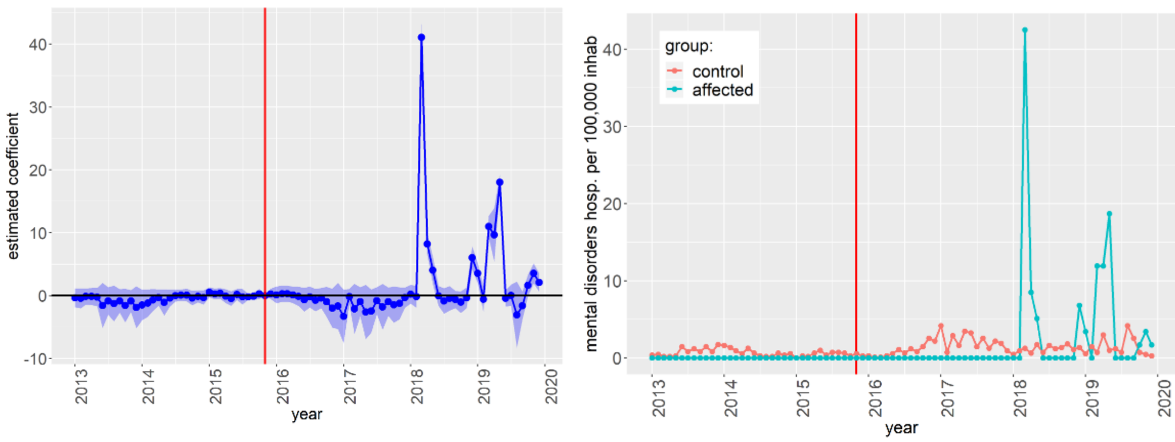
[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

6.1.2 Downstream Candonga reservoir

This is the category that comprises the most number of affected municipalities. Here we analyze 10 affected municipalities (of the 31 in this category) that had at least one psycho-social care center installed in 2015, year of Fundao dam rupture. Table 6.3 shows an estimated coefficient for mental

Figure 6.2 – Behavioural disorders, ***upstream Candonga reservoir municipalities.***

(a) Relative attendances[1] (b) Attendances in psycho-social centers



[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

disorders with onset on childhood and adolescence that is positive and statistically significant for all distinct control groups. The estimated coefficient ranges from 61.1 to 65.8 depending on the control group, which represent an increase of more than 35 times the baseline value for affected municipalities before the rupture (1.64 attendances in psycho-social care centers per 100,000 inhabitants per month). This result points in the same direction as the one we presented in section 5.2.1, where we analyzed hospitalizations due to disorders with onset on childhood and adolescence.

Figure 6.3 shows that the effects seems to start in early 2017, approximately a year after the rupture, with its peak in this same year.

Table 6.3 – Estimated lower bound of the disaster's effect on psychiatric centers' attendance, by control group. ***Downstream reservoir municipalities.***

	Attendance in psycho-social care center per 100,000 inhab.				
	(1) All municipalities	*(2)* Intermediate region	*(3)* Doce river basin	*(4)* Excluded frontier munic.	*(5)* Baseline before disaster
Disorders w/ onset on childhood & adolescence	61.143*** [0.005]	63.35** [0.029]	63.797** [0.047]	65.821** [0.01]	1.64
Municipality fixed effects	x	x	x	x	
Time fixed effects	x	x	x	x	-
Control variables	x	x	x	x	-
Munic. in affected group[1]	7	7	7	7	7
Munic. in control group	183	71	29	57	-

*p<0.1; **p<0.05; ***p<0.01
[1]There are ten affected municipalities in this category: Conselheiro Pena, Caratinga, Governador Valadares, Ipatinga, Resplendor, Aimores, Belo Oriente, Sao Domingos do Prata, Timoteo and Ipaba.
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure presented by Ferman e Pinto (2019).

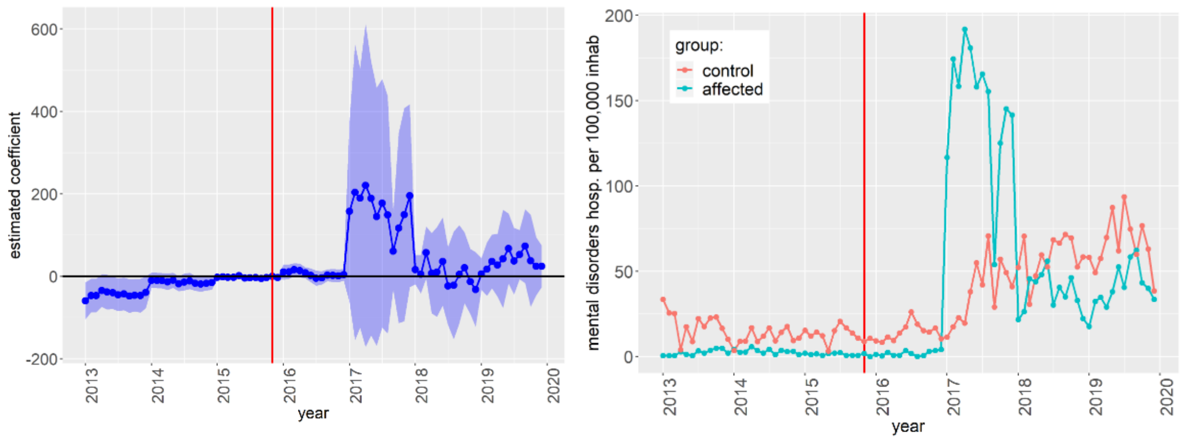
6.1.3 Indirectly affected municipalities

As for indirectly affected municipalities, we analyze three of the five municipalities in this category. Namely: Ouro Preto, Congonhas and Ponte Nova. Table 6.4 present the estimated coefficient for the

Figure 6.3 – Disorders with onset on childhood and adolescence, ***downstream Candonga reservoir municipalities.***

(a) Relative attendances[1]

(b) Attendances in psycho-social centers



[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

following mental disorders (i) psychoactive substance use, (ii) mood disorders and (iii) schizophrenia. The estimated effect for these disorders is a general two-fold increase compared to the baseline values before the disaster. Figures 6.4, 6.5 and 6.6 indicate that the impacts for these disorders started to manifest approximately a year after the rupture, in early 2017, and peaking in this same year.

Table 6.4 – Estimated lower bound of the disaster's effect on psychiatric centers' attendance, by control group. ***Indirectly affected municipalities.***

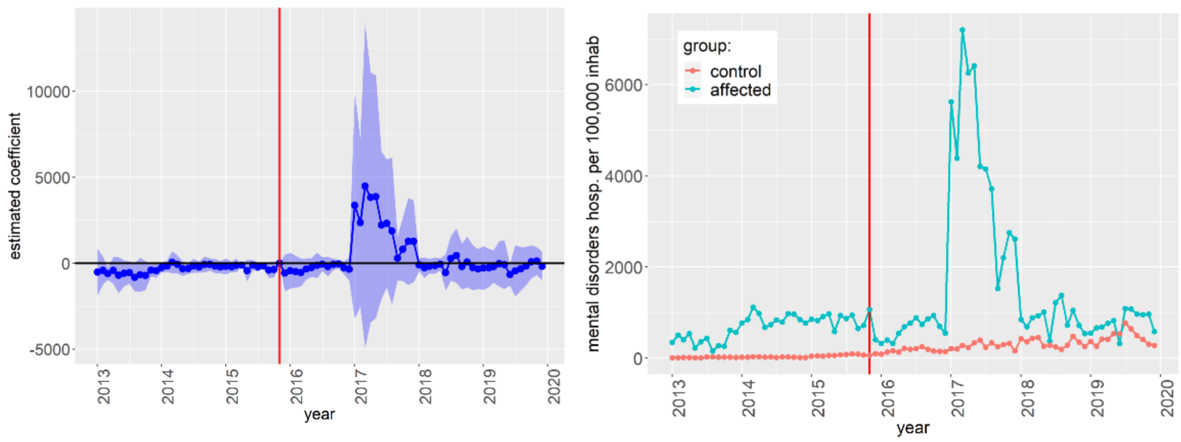
	Attendance in psycho-social care center per 100,000 inhab.				
	(1) All municipalities	*(2)* Intermediate region	*(3)* Doce river basin	*(4)* Excluded frontier munic.	*(5)* Baseline before disaster
Psychoactive substance use	745.418***	748.241***	718.906***	737.863***	641.57
	[0]	[0.001]	[0.007]	[0.002]	
Mood disorders	387.954***	393.033***	329.488**	399.459***	175.10
	[0.002]	[0.004]	[0.018]	[0.004]	
Schizophrenia	489.476**	481.662**	473.32	486.863**	471.48
	[0.012]	[0.049]	[0.114]	[0.016]	
Municipality fixed effects	x	x	x	x	-
Time fixed effects	x	x	x	x	-
Control variables	x	x	x	x	-
Munic. in affected group	2	2	2	2	2
Munic. in control group	183	71	29	57	-

*p<0.1; **p<0.05; ***p<0.01
[1]Affected municipalities are: Ouro Preto, Congonhas and Ponte Nova.
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure presented by Ferman e Pinto (2019).

Figure 6.4 – Psychoactive substance use disorders, ***indirectly affected municipalities.***

(a) Relative attendances[1]

(b) Attendances in psycho-social centers

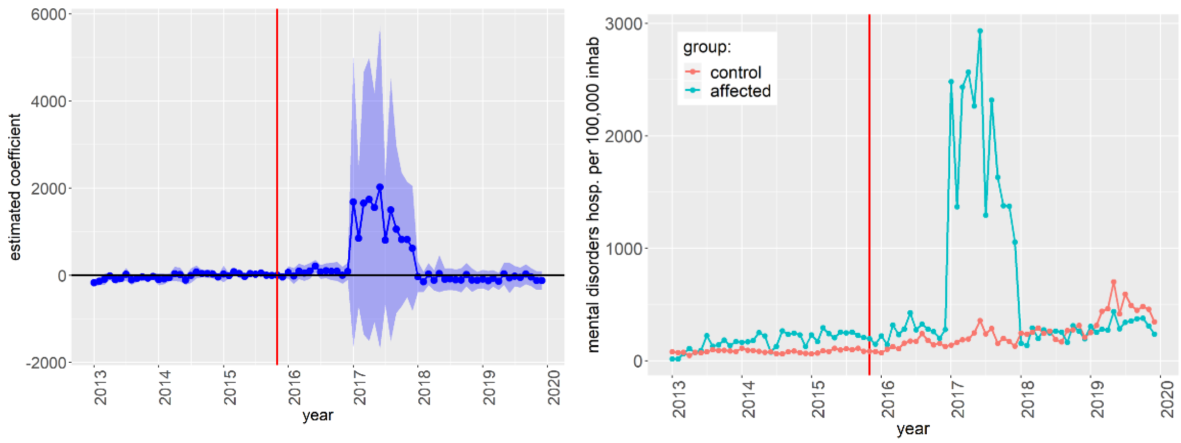


[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

Figure 6.5 – Mood disorders, ***indirectly affected municipalities.***

(a) Relative attendances[1]

(b) Attendances in psycho-social centers



[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

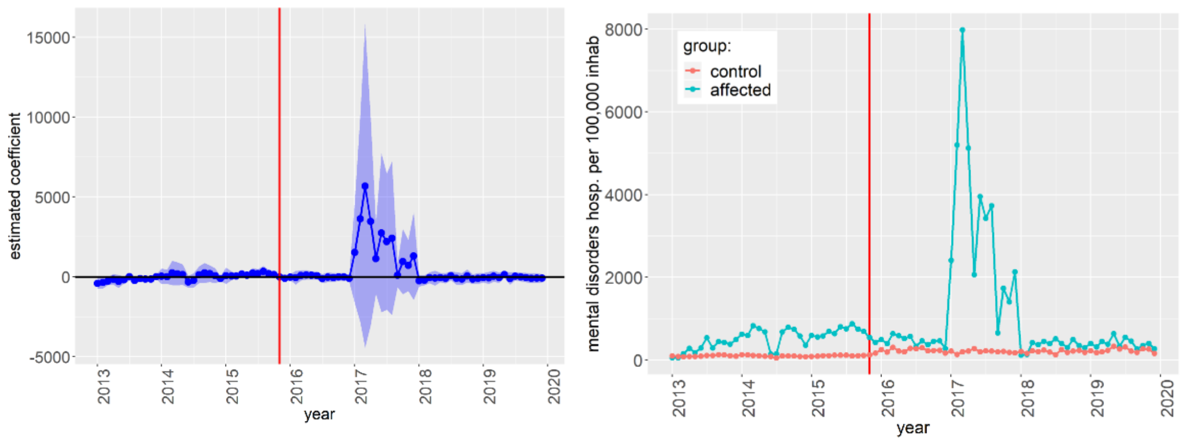
6.2 Possible confounding variable: psycho-social care centers

Analogous to the idea we've presented in section 5.3 for medical beds, a possible issue that may affect our identification strategy now is if, as a consequence of the disaster, there was a relative expansion in the number of psycho-social care centers only in affected municipalities versus non-affected ones. This could be considered a confounding variable as a considerable expansion in the number of psycho-social care centers could affect the number of attendances we would capture in our databases. Hence, if there were an increase in the number of psycho-social care centers only in affected municipalities, we would not be able to distinguish the effect of the disaster itself from the effect of the expansion of centers in the number of mental illnesses attendances.

Figure 6.6 – Schizophrenia disorders, ***indirectly affected municipalities.***

(a) Relative attendances[1]

(b) Attendances in psycho-social centers



[1]We plot the point estimate of α_t based on equation 5.1 for each period (month/year) with a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

Figure 6.7 shows the number of psycho-social care centers[2] by month for affected municipalities categories. Note that for all three categories, the number of psycho-social care centers seems reasonably stable in the whole period, especially for municipalities located up Candonga reservoir[3] and indirectly affected municipalities. Figure 6.8 shows the net number of psycho-social care centers openings in each period for each category. In panel B, we include the control group (considering all non affected municipalities in Minas Gerais state).

Qualitatively analyzing the trends presented in these graphs, we cannot state that the disaster induced a higher rate of psycho-social centers openings in affected municipalities comparing to the control group. Or, in other words, it doesn't seem to invalidate our empirical strategy. Also, in order to capture a possible effect of psycho-social care centers opening in the number of medical attendances, we've estimated our regressions in section 6.1 including the number of psycho-social care center as control variable.

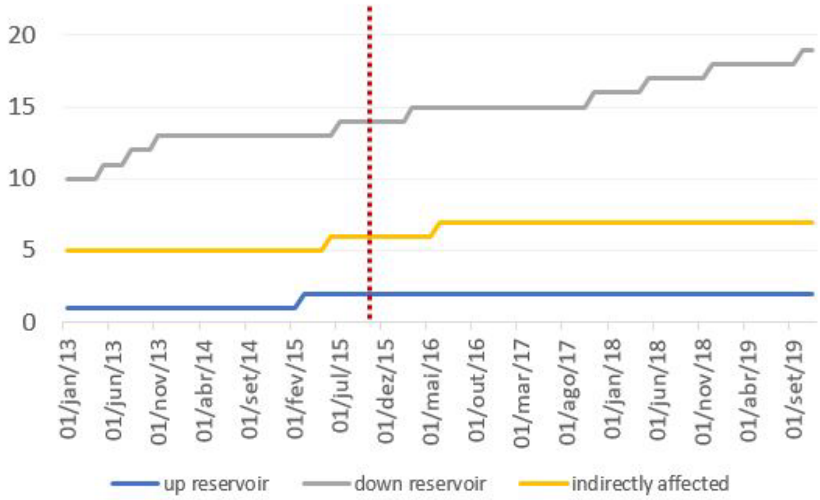
6.3 Discussion

Both databases (hospitalization database and psycho-social care center attendances) we use in our analysis point in the same direction, indicating, first, an increase in mental disorders in Minas Gerais state municipalities and, second, a heterogeneous regional effect.

Municipalities located near Fundao dam ("upstream Candonga reservoir") suffered the most severe mental health consequences of the disaster. This can be seem in the increased number of hospitalizations in multiple groups of mental disorders right after the rupture. Precisely, we find evidence of impacts on five groups of mental disorders: (i) stress-related disorders, (ii) psychoactive substance abuse, (iii) disorders of psychological development, (iv) unspecified non-organic psychosis and (v) mental retardation. For this category of affected municipalities, we also find evidence of an increased number of psycho-social care centers attendances related to psychological development disorders and behavioural disorders. However, here, the effect is not immediate, they seem to start to manifest approximately two

[2] These data was collected from the Brazilian National Register of Health Institutions (CNES).
[3] In this case, only Mariana city.

Figure 6.7 – Number of psychosocial care centers per month - affected groups, from jan/2013 to nov/2019



The red line represents nov/2015, the month of the collapse. This graph was elaborated with data from the Establishments database from DATASUS (CNES).

years after the collapse, in early 2018.

As municipalities in this category suffered severely due to the physical impact of the tailing mud and economically due to Samarco's activities interruption, it is not possible to distinguish which part of the effect comes from which channel (although it is probable that both of them influenced the outcome).

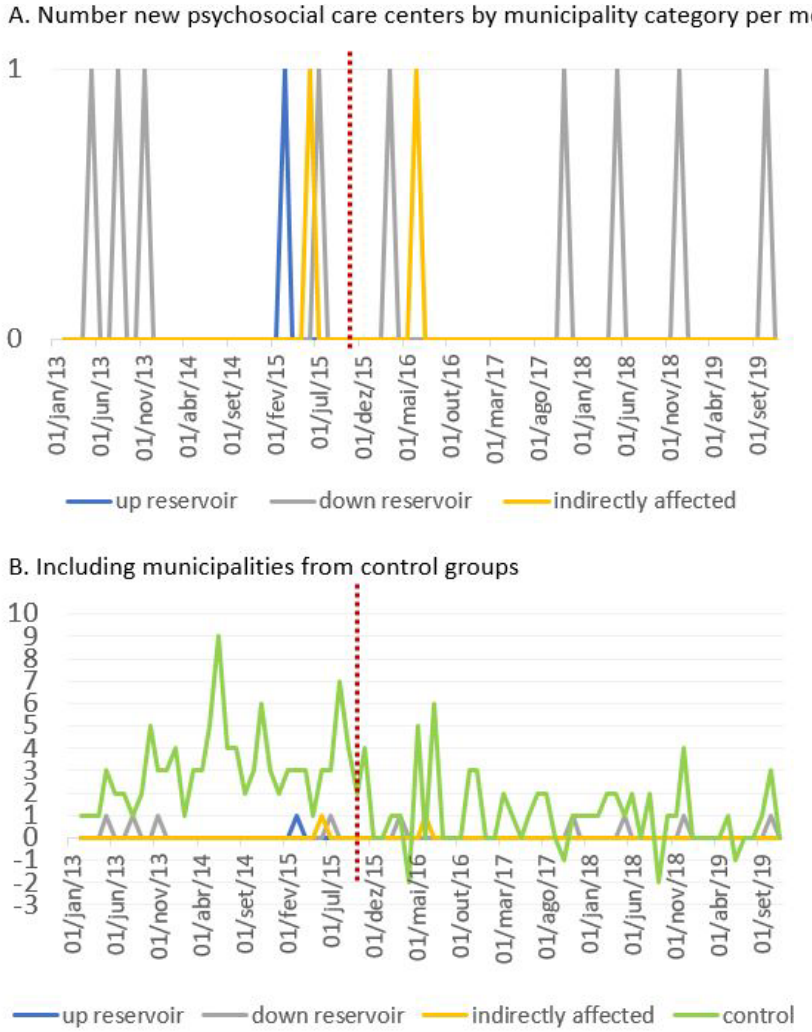
By analyzing affected municipalities in Minas Gerais state located downstream Candonga reservoir, we find a consistent effect in one specific type of mental disorder: those with onset on childhood and adolescence, notably a group of disorders that generally occurs in younger people. Although the physical impact in this region was smaller when compared to municipalities located near the dam ("upstream Candonga reservoir"), these municipalities were also located in the mud path and, therefore, directly exposed to the tailing mud and the stressful event itself.

Table 6.5 show the age percentile by mental disorder type and by database. Municipalities that were directly affected by the tailing mud ("upstream Candonga reservoir" and "downstream Candonga reservoir") present an increased number of hospitalizations due to disorders that manifest at a younger age, such as "disorders with onset on childhood" and "psychological development disorders". The 50% percentile for these disorders are 11 and 10 years old respectively.[4] This result goes in line with the literature on mental health consequences of disasters, as younger age is considered to be a risk factor for developing mental health issues after being exposed to a disaster.

As for indirectly affected municipalities, we find evidence of a late impact of the disaster on mental health, mainly starting a year after the collapse, in early 2017. For this category effects seems to be less "urgent" than those observed for directly affected municipalities. Here, our main findings come from the psycho-social care center attendances database, with evidences of an increased number of disorders due to (i) psychoactive substance use, (ii) mood disorders and (iii) schizophrenia-related disorders. This is the only region where we find an impact on mood disorders - a group that include disorders such as depression (depressive episode and recurrent depressive disorder), manic episodes, bipolar affective disorder, persistent mood disorders, among others. The most probable channel through which the collapse

[4] When considering the psycho-social center attendance database.

Figure 6.8 – Net number of psychosocial care centers openings per month - jan/2013 to nov/2019



The red line represents nov/2015, the month of the collapse. This graph was elaborated with data from the Establishments database from DATASUS (CNES).

affected mental health outcomes in this region is the economic one, as these municipalities did not suffer physical impacts of the tailing mud itself.

Each of the databases we've used in the analysis capture distinct outcomes of mental disorders. We identify what seems to be two types of reactions associated with the disaster that manifest on mental health outcomes. The first is related to the initial shock of the rupture itself and the destruction it caused on affected communities. This reaction seems to be more severe, as they manifest in an increased number of hospitalizations right after the disaster in municipalities located closer to the dam ("upstream Candonga reservoir"), where the destruction caused by the mud was more intense. As for the second type of reaction, they seem to appear in the medium-term, approximately one or two years after the rupture. Here, we see an increase in psycho-social care centers attendances for all affected regions. Although it is not clear what are the exact mechanisms, they are probably related to the negative economic effects the disaster brought to the region, as well as the slowness and inefficiency to implement compensation and recovery actions.

Table 6.5 – Age percentile by disorder and by database, Minas Gerais state municipalities, 2013 to 2019.

	psycho-social care center database				***hospitalization database***			
	number of	age percentile			number of	age percentile		
	observations	25%	50%	75%	observations	25%	50%	75%
All mental disorders	6,323,045	32	42	52	115,592	30	40	51
Behavioural syndromes	9,394	22	35	46	249	24	35	47
Disorders w/ onset on childhood/adolescence	201,829	8	11	14	1,596	22	35	48
Organic mental disorders	98,629	35	48	58	9,849	28	42	58
Psychological development	73,971	6	10	14	385	12	20	31
Schizophrenia	1,771,593	35	44	53	29,932	31	41	52
Mood disorders	1,159,896	35	46	55	17,501	30	40	51
Other	147,877	22	38	50	380	23	35	49
Personality and behaviour	113,047	29	38	48	1,633	25	33	43
Non-organic psychosis	288,214	31	43	54	7,376	27	37	48
Mental retardation	314,779	24	36	47	3,187	21	29	39
Stress-related	361,711	26	40	51	1,681	24	38	50
Psychoactive substance use	1,782,105	35	43	52	41,823	31	40	49

Source: Author's elaboration.

7 Conclusions

Given the increasing number of environmental disasters in the last decades, not only associated with mining activities and dams, but also in a context of global warming, understanding how disasters impact affected communities in its multiple dimensions is key to effectively designing recovery and compensations policies and programs. We have examined this issue on the context of mental health, an important determinant of communities recovery response to stressful events, by investigating one of the biggest environmental disasters in recent years - Fundao dam rupture in November, 2015, in Minas Gerais, Brazil. We have analyzed whether this disaster affected mental health by looking at mental disorders hospitalizations in public hospitals between 2013 and 2019, and comparing affected municipalities with distinct control groups. As a complementary result, we have also analyzed the outcomes on mental health using the psycho-social care centers attendances.

In the previous literature, most of mental health consequences of disasters have been typically measured in cross sectional studies, with many of them relying on self-reported measures, such questionnaires applications in the post-disaster period. This paper, on the other hand, estimates it by analyzing temporal changes in mental disorders that were actually measured on hospitalizations data sets. Furthermore, due to the vast spectrum of Fundao dam collapse, we investigate its heterogeneous impacts in each affected region individually, deepening the investigation according to the exposure suffered by each affected region.

The empirical strategy of the paper is to exploit the disaster occurrence as an exogenous event that only affected municipalities that were located on the tailing mud path or those indirectly affected - municipalities closely related to the affected waters or to Samarco's activities. Under these circumstances, we apply a difference-in-differences regression framework to mental disorders hospitalizations in public hospitals per 100,000 inhabitants per month, before and after the rupture, and compare affected municipalities with selected control groups from the same region. The comparison with the control groups "differences out" the factors that are common to both the affected and control groups, such as regional policies, for instance.

The regression analysis reveal sizeable increase in mental disorders hospitalizations in Minas Gerais state as a result of the disaster occurrence, especially when looking at each affected region individually. For municipalities located near the dam (upstream Candonga reservoir), our estimations indicate that the disaster induced, at least, a two-fold increase in mental disorders hospitalizations, with a considerable impact in different groups of mental disorders: (i) stress-related disorders, (ii) psychoactive substance use, (iii) psychological development disorders, (iv) non-organic psychosis and (v) mental retardation. For some of these disorders there were actually no hospitalization registrations in the pre-disaster period in our sample.

We also find effects for municipalities in Minas Gerais located downstream Candonga reservoir. Here, the lower bounds of the effects is a four-fold increase in hospitalizations per 100,000 inhabitants per month due to mental disorders with onset on childhood and adolescence. And for indirectly affected municipalities in Minas Gerais state, we estimate as a lower bound effect that stress-related hospitalizations two-folded after the dam failure.

Finally, we bring evidences of late and persisting effects of the disaster in mental health, with the increased number of hospitalizations persisting (if not starting) years after the dam collapsed, especially when analyzing attendances in psycho-social care centers. Many may be the reasons that explain this dynamic, among them, we emphasize the slowness of the recovery process of affected regions and problems faced by communities to guarantee their rights against Samarco company.

Our results are also supported by the literature of mental health and disasters, as our main findings involve disorders that are typically associated with disasters occurrence, such as stress-related disorders and disorders due to psychoactive substance use. Furthermore, we also detect a considerable effect in vulnerable groups, such as children/adolescents and people who suffer mental disabilities/impairments.

This was the first study to quantitatively measure impacts on mental health in each affected region individually due to Fundao dam rupture. Our findings serve to illustrate how effects might be very distinct among affected regions, as well as, the importance of handling recovery and compensation actions efficiently in the aftermaths of a disaster.

A Tables

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Table A.1 – Classification of mental disorders - Chapter V Mental and behavioural disorders according to ICD-10

ICD-10	***Group Description***	***Disorders***
F00-F09	Organic, including symptomatic, mental disorders	Dementia in Alzheimer's disease Vascular dementia Dementia in other diseases classified elsewhere Unspecified dementia Organic amnesic syndrome, not induced by alcohol and other psychoactive substances Delirium, not induced by alcohol and other psychoactive substances Other mental disorders due to brain damage and dysfunction and to physical disease Personality and behavioural disorders due to brain disease, damage and dysfunction Unspecified organic or symptomatic mental disorder
F10-F19	Mental and behavioural disorders due to psychoactive substance use	Mental and behavioural disorders due to use of alcohol Mental and behavioural disorders due to use of opioids Mental and behavioural disorders due to use of cannabinoids Mental and behavioural disorders due to use of sedatives or hypnotics Mental and behavioural disorders due to use of cocaine Mental and behavioural disorders due to use of other stimulants, including caffeine Mental and behavioural disorders due to use of hallucinogens Mental and behavioural disorders due to use of tobacco Mental and behavioural disorders due to use of volatile solvents Mental and behavioural disorders due to multiple drug use and use of other psychoactive substances
F20-F29	Schizophrenia, schizotypal and delusional disorders	Schizophrenia Schizotypal disorder Persistent delusional disorders Acute and transient psychotic disorders Induced delusional disorder Schizoaffective disorders Other nonorganic psychotic disorders Unspecified nonorganic psychosis
F30-F39	Mood [affective] disorders	Manic episode Bipolar affective disorder Depressive episode Recurrent depressive disorder Persistent mood [affective] disorders Other mood [affective] disorders Unspecified mood [affective] disorder
F40-F48	Neurotic, stress-related and somatoform disorders	Phobic anxiety disorders Other anxiety disorders Obsessive-compulsive disorder Reaction to severe stress, and adjustment disorders Dissociative [conversion] disorders Somatoform disorders Other neurotic disorders
F50-F59	Behavioural syndromes associated with physiological disturbances and physical factors	Eating disorders Nonorganic sleep disorders Sexual dysfunction, not caused by organic disorder or disease Mental and behavioural disorders associated with the puerperium, not elsewhere classified Psychological and behavioural factors associated with disorders or diseases classified elsewhere Abuse of non-dependence-producing substances Unspecified behavioural syndromes associated with physiological disturbances and physical factors
F60-F69	Disorders of adult personality and behaviour	Specific personality disorders Mixed and other personality disorders Enduring personality changes, not attributable to brain damage and disease Habit and impulse disorders Gender identity disorders Disorders of sexual preference Psychological and behavioural disorders associated with sexual development and orientation Other disorders of adult personality and behaviour Unspecified disorder of adult personality and behaviour
F70-F79	Mental retardation	Mild mental retardation Moderate mental retardation Severe mental retardation Profound mental retardation Other mental retardation Unspecified mental retardation
F80-F89	Disorders of psychological development	Specific developmental disorders of speech and language Specific developmental disorders of scholastic skills Specific developmental disorder of motor function Mixed specific developmental disorders Pervasive developmental disorders Other disorders of psychological development Unspecified disorder of psychological development
F90-F98	Behavioural and emotional disorders with onset usually occurring in childhood and adolescence	Hyperkinetic disorders Conduct disorders Mixed disorders of conduct and emotions Emotional disorders with onset specific to childhood Disorders of social functioning with onset specific to childhood and adolescence Tic disorders Other behavioural and emotional disorders with onset usually occurring in childhood and adolescence
F99-F99	Unspecified mental disorder	Mental disorder, not otherwise specified

Table A.2 – List of affected municipalities

State	*Municipality*	*Our Classification*	*Ramboll's Classification*	*Renova's Classification*
Minas Gerais	Rio Doce	up Candonga	up Candonga	up Candonga reservoir (high Doce river)
Minas Gerais	Santa Cruz do Escalvado	up Candonga	up Candonga	up Candonga reservoir (high Doce river)
Minas Gerais	Barra Longa	up Candonga	up Candonga	up Candonga reservoir (high Doce river)
Minas Gerais	Mariana	up Candonga	up Candonga	up Candonga reservoir (high Doce river)
Minas Gerais	Sem-Peixe	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Fernandes Tourinho	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Marlieria	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Bugre	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Pingo-dAgua	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Sao Jose do Goiabal	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Sobralia	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Sao Pedro dos Ferros	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Iapu	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Rio Casca	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Bom Jesus do Galho	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Ipaba	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Santana do Paraiso	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Caratinga	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Ipatinga	down Candonga in Minas Gerais	down Candonga	Doce river's trough
Minas Gerais	Corrego Novo	down Candonga in Minas Gerais	down Candonga without occupation near river banks	Doce river's trough
Minas Gerais	Dionisio	down Candonga in Minas Gerais	down Candonga without occupation near river banks	Doce river's trough
Minas Gerais	Raul Soares	down Candonga in Minas Gerais	down Candonga without occupation near river banks	Doce river's trough
Minas Gerais	Sao Domingos do Prata	down Candonga in Minas Gerais	down Candonga without occupation near river banks	Doce river's trough
Minas Gerais	Timoteo	down Candonga in Minas Gerais	down Candonga without occupation near river banks	Doce river's trough
Minas Gerais	Tumiritinga	down Candonga in Minas Gerais	down Candonga	medium Doce River
Minas Gerais	Naque	down Candonga in Minas Gerais	down Candonga	medium Doce River
Minas Gerais	Galileia	down Candonga in Minas Gerais	down Candonga	medium Doce River
Minas Gerais	Periquito	down Candonga in Minas Gerais	down Candonga	medium Doce River
Minas Gerais	Alpercata	down Candonga in Minas Gerais	down Candonga	medium Doce River
Minas Gerais	Conselheiro Pena	down Candonga in Minas Gerais	down Candonga	medium Doce River
Minas Gerais	Belo Oriente	down Candonga in Minas Gerais	down Candonga	medium Doce River
Minas Gerais	Governador Valadares	down Candonga in Minas Gerais	down Candonga	medium Doce River
Minas Gerais	Itueta	down Candonga in Minas Gerais	down Candonga	low Doce River
Minas Gerais	Resplendor	down Candonga in Minas Gerais	down Candonga	low Doce River
Minas Gerais	Aimores	down Candonga in Minas Gerais	down Candonga	low Doce River
Espírito Santo	Baixo Guandu	down Candonga in Espírito Santo	down Candonga	low Doce River
Espírito Santo	Colatina	down Candonga in Espírito Santo	down Candonga	low Doce River
Espírito Santo	Marilandia	down Candonga in Espírito Santo	down Candonga	low Doce River
Espírito Santo	Aracruz	coast	coast	Doce River's mouth/ coast
Espírito Santo	Linhares	coast	coast	Doce River's mouth/ coast
Minas Gerais	Ponte Nova	indirectly affected in Minas Gerais	pleading	up Candonga reservoir (high Doce river)
Minas Gerais	Catas Altas	indirectly affected in Minas Gerais	indirectly affected	not affected
Minas Gerais	Santa Barbara	indirectly affected in Minas Gerais	indirectly affected	not affected
Minas Gerais	Congonhas	indirectly affected in Minas Gerais	indirectly affected	not affected
Minas Gerais	Ouro Preto	indirectly affected in Minas Gerais	indirectly affected	not affected
Espírito Santo	Anchieta	indirectly affected in Espírito Santo	indirectly affected	not affected
Espírito Santo	Guarapari	indirectly affected in Espírito Santo	indirectly affected	not affected
Espírito Santo	Conceicao da Barra	indirectly affected in Espírito Santo	not affected	Doce River's mouth/ coast
Espírito Santo	Fundao	indirectly affected in Espírito Santo	not affected	Doce River's mouth/ coast
Espírito Santo	Sao Mateus	indirectly affected in Espírito Santo	not affected	Doce River's mouth/ coast
Espírito Santo	Serra	indirectly affected in Espírito Santo	not affected	Doce River's mouth/ coast

Table A.3 – Baseline[1] of mental disorders hospitalizations/100,000 inhab/month before the disaster: jan/2013-oct/2015

	Minas Gerais state			
	all affected	**up reservoir**	**down reservoir**	**indirectly affected**
All mental disorders	5.968	4.630	6.189	5.379
Stress-related	0.099	0.000	0.118	0.040
Psychoactive substance use	1.926	0.939	2.029	1.769
Mood disorders	0.856	0.450	0.899	0.785
Personality and behaviour	0.074	0.041	0.066	0.120
Dementia-related	0.257	0.041	0.313	0.066
Disorders w/ onset on childhood/adolescence	0.154	0.082	0.192	0.000
Behavioural syndromes	0.065	0.041	0.080	0.000
Psychological development	0.036	0.000	0.046	0.000
Schizophrenia	1.307	2.833	1.002	2.226
Non-organic psychosis	1.095	0.205	1.325	0.319
Mental retardation	0.096	0.000	0.115	0.040
Other	0.004	0.000	0.003	0.013

	Espírito Santo state			
	all affected	**down reservoir**	**coast**	**indirectly affected**
All mental disorders	3.440	2.085	6.375	2.779
Stress-related	0.139	0.179	0.104	0.141
Psychoactive substance use	1.067	0.500	2.814	0.624
Mood disorders	0.409	0.357	0.629	0.349
Personality and behaviour	0.012	0.035	0.012	0.007
Dementia-related	0.127	0.036	0.443	0.045
Disorders w/ onset on childhood/adolescence	0.030	0.000	0.012	0.041
Behavioural syndromes	0.356	0.284	0.127	0.444
Psychological development	0.002	0.000	0.000	0.004
Schizophrenia	1.157	0.624	2.189	0.936
Non-organic psychosis	0.046	0.018	0.011	0.063
Mental retardation	0.094	0.053	0.023	0.125
Other	0.002	0.000	0.012	0.000

[1]The means presented in this table are weigthed by population size.

Table A.4 – Control variables

control variable	***source***
population size	Brazilian Institute of Geography and Statistics
gdp per capita	Brazilian Institute of Geography and Statistics
gdp	Brazilian Institute of Geography and Statistics
taxes reveneus	Treasury Office from Minas Gerais and Espírito Santo states
public medical beds per 100,000 inhabitants	CNES - DATASUS
number of psychosocial care centers per 100,000 inhabitants	CNES - DATASUS

We consider public medical beds as a control variable only when using the hospitalization database; and
and we consider the number of psychosocial care centers as control variables only when
using the psychosocial care center database.

Table A.5 – Average population size of affected municipalities, from 2011 to 2018

state	***municipality***	***average pop. size***
Minas Gerais	Barra Longa	5,779
Minas Gerais	Mariana	58,021
Minas Gerais	Rio Doce	2,570
Minas Gerais	Santa Cruz do Escalvado	4,964
Minas Gerais	Aimores	25,443
Minas Gerais	Alpercata	7,399
Minas Gerais	Belo Oriente	25,263
Minas Gerais	Bom Jesus do Galho	15,409
Minas Gerais	Bugre	4,092
Minas Gerais	Caratinga	89,677
Minas Gerais	Conselheiro Pena	22,898
Minas Gerais	Corrego Novo	3,015
Minas Gerais	Dionisio	8,417
Minas Gerais	Fernandes Tourinho	3,259
Minas Gerais	Galileia	6,999
Minas Gerais	Governador Valadares	275,166
Minas Gerais	Iapu	10,746
Minas Gerais	Ipaba	17,831
Minas Gerais	Ipatinga	254,083
Minas Gerais	Itueta	6,022
Minas Gerais	Marlieria	4,087
Minas Gerais	Naque	6,737
Minas Gerais	Periquito	7,043
Minas Gerais	Pingo-d Agua	4,726
Minas Gerais	Raul Soares	24,165
Minas Gerais	Resplendor	17,497
Minas Gerais	Rio Casca	14,134
Minas Gerais	Santana do Paraiso	31,050
Minas Gerais	Sao Domingos do Prata	17,630
Minas Gerais	Sao Jose do Goiabal	5,627
Minas Gerais	Sao Pedro dos Ferros	8,225
Minas Gerais	Sem-Peixe	2,795
Minas Gerais	Sobralia	5,796
Minas Gerais	Timoteo	86,417
Minas Gerais	Tumiritinga	6,591
Minas Gerais	Catas Altas	5,163
Minas Gerais	Congonhas	52,112
Minas Gerais	Ouro Preto	73,196
Minas Gerais	Ponte Nova	59,356
Minas Gerais	Santa Barbara	29,773
Espírito Santo	Baixo Guandu	30,829
Espírito Santo	Colatina	120,023
Espírito Santo	Marilandia	12,117
Espírito Santo	Aracruz	92,746
Espírito Santo	Linhares	159,662
Espírito Santo	Anchieta	26,960
Espírito Santo	Conceicao da Barra	30,475
Espírito Santo	Fundao	19,488
Espírito Santo	Guarapari	117,026
Espírito Santo	Sao Mateus	121,710
Espírito Santo	Serra	471,506

Source: Author’s elaboration.

Table A.6 – Pre-disaster trend, different control groups, Minas Gerais

	Dependent variable:			
	mental disorders hospitalizations per 100,000 inhab.			
	(1) all municipalities	(2) intermediate region	(3) Doce river basin	(4) intermediate - spillover
affected × t × $\mathbb{1}_{t<nov15}$	0.03	0.07	0.01	0.07
	(0.05)	(0.05)	(0.05)	(0.05)
log(population)	−16.31	−16.18	−14.71	−15.05
	(12.42)	(17.24)	(19.36)	(19.16)
log(gdp per capita)	-9.88^{*}	-13.92^{**}	−6.28	-12.84^{*}
	(5.13)	(6.72)	(4.82)	(6.88)
log(gdp)	13.29^{**}	15.73^{*}	8.79	14.21
	(6.73)	(8.77)	(6.27)	(9.03)
log(taxes)	2.63	3.92	−0.83	3.56
	(2.66)	(3.38)	(5.76)	(3.74)
medical beds (*)	0.002	−0.01	0.01	−0.01
	(0.01)	(0.02)	(0.02)	(0.02)
Municipality fixed effects	x	x	x	x
Month fixed effects	x	x	x	x
Month-year fixed effects	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	71,292	30,960	16,872	25,500
R^2	0.48	0.44	0.23	0.46
Adjusted R^2	0.47	0.44	0.22	0.45
Note:	*p<0.1; **p<0.05; ***p<0.01			
	All regressions are clustered by municipality and weighted by population size.			
	(*) We consider medical beds per 100,000 inhab.			

Table A.7 – Pre-disaster trend, different control groups, Espirito Santo state

	Dependent variable:			
	mental disorders hospitalizations per 100,000 inhab.			
	(1) all municipalities	(2) intermediate region	(3) Doce river basin	(4) intermediate - spillover
affected × t × $\mathbb{1}_{t<nov15}$	0.03	−0.01	0.08^{***}	−0.04
	(0.05)	(0.02)	(0.03)	(0.03)
log(population)	82.58^{***}	34.33	13.65	27.89
	(29.45)	(21.97)	(20.51)	(25.51)
log(gdp per capita)	38.95^{**}	11.06	1.82	−6.33
	(16.33)	(14.86)	(10.60)	(17.88)
log(gdp)	-57.64^{**}	−15.36	−4.51	10.36
	(23.03)	(19.96)	(14.16)	(24.48)
log(taxes)	−0.10	−1.00	-3.29^{**}	−2.18
	(2.09)	(1.16)	(1.51)	(1.38)
medical beds (*)	0.01	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)
Municipality fixed effects	x	x	x	x
Month fixed effects	x	x	x	x
Month-year fixed effects	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	6,528	4,512	2,664	2,832
R^2	0.41	0.38	0.39	0.42
Adjusted R^2	0.39	0.35	0.35	0.38
Note:	*p<0.1; **p<0.05; ***p<0.01			
	All regressions are clustered by municipality and weighted by population size.			
	(*) We consider medical beds per 100,000 inhab.			

Table A.8 – Pre-disaster trend by disorder, Minas Gerais state. Control group: ***all municipalities.***

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected × t × $\mathbb{1}_{t<nov15}$	−0.003	0.01	0.01	0.003*	0.003	0.004**
	(0.003)	(0.02)	(0.01)	(0.001)	(0.01)	(0.002)
log(population)	−0.36	−13.62**	3.28	−0.46	−2.19	0.02
	(0.46)	(5.95)	(3.24)	(0.46)	(2.83)	(1.88)
log(gdp per capita)	0.19	−4.10*	−0.09	0.21	−1.96	0.33
	(0.16)	(2.46)	(0.79)	(0.21)	(1.33)	(0.69)
log(gdp)	−0.29	4.53	1.16	−0.26	2.95*	−0.64
	(0.22)	(3.11)	(1.12)	(0.28)	(1.71)	(0.99)
log(taxes)	0.03	0.94	0.82	0.12	−0.40	0.14
	(0.07)	(1.15)	(0.61)	(0.08)	(0.78)	(0.29)
medical beds (*)	0.0003	0.0001	0.002	0.001	−0.002	0.001
	(0.0003)	(0.004)	(0.001)	(0.0005)	(0.004)	(0.001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	71,292	71,292	71,292	71,292	71,292	71,292
R^2	0.12	0.36	0.23	0.09	0.32	0.22
Adjusted R^2	0.11	0.35	0.22	0.08	0.31	0.21

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected × t × $\mathbb{1}_{t<nov15}$	0.005	0.003	0.01	−0.01	0.002	−0.001**
	(0.005)	(0.002)	(0.01)	(0.02)	(0.003)	(0.0003)
log(population)	0.24	0.01	−1.36	−1.45	−0.62	0.19
	(0.18)	(0.17)	(4.38)	(1.55)	(0.75)	(0.20)
log(gdp per capita)	−0.01	−0.004	−3.40*	−1.01	−0.003	−0.02
	(0.04)	(0.08)	(1.78)	(0.69)	(0.33)	(0.05)
log(gdp)	0.02	−0.03	4.35*	1.45	−0.01	0.06
	(0.06)	(0.10)	(2.40)	(0.96)	(0.42)	(0.07)
log(taxes)	0.005	−0.03	0.50	0.44*	0.08	−0.005
	(0.03)	(0.04)	(0.79)	(0.27)	(0.11)	(0.02)
medical beds (*)	−0.0001	−0.0000	0.0005	−0.0002	0.0001	0.0001
	(0.0001)	(0.0001)	(0.005)	(0.0005)	(0.0005)	(0.0001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	71,292	71,292	71,292	71,292	71,292	71,292
R^2	0.05	0.02	0.32	0.20	0.13	0.06
Adjusted R^2	0.04	0.01	0.31	0.19	0.11	0.05

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.

Table A.9 – Pre-disaster trend by disorder, Minas Gerais state. Control group: ***intermediate region.***

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected × t × $\mathbb{1}_{t<nov15}$	−0.003	0.02	0.01	0.002	0.002	0.005**
	(0.003)	(0.02)	(0.01)	(0.002)	(0.01)	(0.002)
log(population)	−0.55	−12.09	5.23*	0.16	−4.69	2.59
	(0.89)	(8.77)	(2.74)	(0.73)	(4.75)	(3.43)
log(gdp per capita)	0.25	−7.83**	0.82	0.25	−1.80	0.76
	(0.27)	(3.40)	(0.99)	(0.38)	(1.79)	(1.44)
log(gdp)	−0.38	8.76*	−0.19	−0.27	2.22	−1.28
	(0.34)	(4.48)	(1.22)	(0.49)	(2.10)	(1.86)
log(taxes)	0.01	1.54	0.81	0.12	−0.41	−0.07
	(0.09)	(1.39)	(0.58)	(0.10)	(1.20)	(0.42)
medical beds (*)	0.001	−0.001	0.003	0.001	−0.01	0.0000
	(0.001)	(0.01)	(0.002)	(0.001)	(0.01)	(0.001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	30,960	30,960	30,960	30,960	30,960	30,960
R^2	0.07	0.39	0.13	0.10	0.25	0.28
Adjusted R^2	0.05	0.38	0.12	0.09	0.24	0.27

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected × t × $\mathbb{1}_{t<nov15}$	0.005	0.003	0.03**	−0.01	0.003	−0.0002
	(0.005)	(0.002)	(0.01)	(0.02)	(0.003)	(0.0002)
log(population)	0.55	0.15	−4.37	−3.11	−0.07	0.02
	(0.34)	(0.25)	(6.20)	(2.83)	(0.82)	(0.16)
log(gdp per capita)	0.04	−0.04	−4.44*	−1.84*	−0.15	0.06
	(0.09)	(0.10)	(2.32)	(1.07)	(0.37)	(0.06)
log(gdp)	−0.04	0.03	4.53	2.33	0.10	−0.06
	(0.11)	(0.13)	(3.01)	(1.48)	(0.49)	(0.07)
log(taxes)	−0.01	−0.08	1.39*	0.62	−0.01	0.01
	(0.05)	(0.07)	(0.71)	(0.39)	(0.16)	(0.03)
medical beds (*)	−0.0001	0.0001	−0.003	0.001	0.001	0.0000
	(0.0002)	(0.0001)	(0.01)	(0.001)	(0.001)	(0.0002)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	30,960	30,960	30,960	30,960	30,960	30,960
R^2	0.06	0.03	0.30	0.15	0.09	0.03
Adjusted R^2	0.05	0.01	0.28	0.14	0.08	0.02

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.

Table A.10 – Pre-disaster trend by disorder, Minas Gerais state. Control group: ***Doce river basin***

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected × t × $\mathbb{1}_{t<nov15}$	−0.0003	−0.01	0.01	−0.003	−0.0003	0.002
	(0.004)	(0.02)	(0.01)	(0.004)	(0.01)	(0.003)
log(population)	−3.11	−7.21	0.20	−0.63	−2.22	4.23
	(3.29)	(11.46)	(3.82)	(0.93)	(4.91)	(5.52)
log(gdp per capita)	0.27	−2.47	1.62	0.13	0.38	−2.62
	(0.53)	(2.87)	(1.44)	(0.33)	(0.99)	(3.05)
log(gdp)	−0.47	3.93	−0.92	−0.18	0.04	1.61
	(0.44)	(2.96)	(1.52)	(0.46)	(1.27)	(2.76)
log(taxes)	0.12	0.38	0.37	0.07	−1.92	−0.63
	(0.19)	(2.16)	(0.98)	(0.11)	(2.20)	(1.01)
medical beds (*)	0.001^{*}	0.003	0.003	−0.0004	0.001	0.0001
	(0.001)	(0.01)	(0.002)	(0.002)	(0.003)	(0.002)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	16,872	16,872	16,872	16,872	16,872	16,872
R^2	0.09	0.16	0.08	0.14	0.12	0.32
Adjusted R^2	0.07	0.15	0.06	0.12	0.10	0.31

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected × t × $\mathbb{1}_{t<nov15}$	0.005	0.004^{*}	0.01	−0.01	0.01	0.0001
	(0.005)	(0.002)	(0.01)	(0.01)	(0.003)	(0.0003)
log(population)	0.89	−0.34	0.25	−4.77	-1.88^{**}	−0.12
	(0.63)	(0.43)	(4.58)	(3.72)	(0.92)	(0.19)
log(gdp per capita)	−0.18	−0.03	−2.90	−0.45	−0.01	−0.02
	(0.19)	(0.09)	(2.09)	(0.96)	(0.28)	(0.04)
log(gdp)	0.16	0.04	3.41	1.22	−0.03	0.01
	(0.18)	(0.13)	(2.70)	(1.04)	(0.39)	(0.05)
log(taxes)	−0.08	−0.15	−0.19	1.03	0.18	−0.01
	(0.09)	(0.11)	(0.74)	(0.85)	(0.17)	(0.04)
medical beds (*)	0.0001	0.0001	−0.003	−0.0002	0.0002	0.0000
	(0.0003)	(0.0001)	(0.003)	(0.002)	(0.001)	(0.0001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	16,872	16,872	16,872	16,872	16,872	16,872
R^2	0.10	0.04	0.11	0.14	0.04	0.02
Adjusted R^2	0.08	0.02	0.09	0.13	0.02	0.004

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.

Table A.11 – Pre-disaster trend by disorder, Minas Gerais state. Control group: ***excluded frontier municipalities.***

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected × t × $\mathbb{1}_{t<nov15}$	−0.004	0.03	0.01	0.002	0.002	0.005***
	(0.003)	(0.02)	(0.01)	(0.002)	(0.01)	(0.002)
log(population)	0.16	−11.36	4.85	0.16	−5.20	4.13
	(0.70)	(9.83)	(3.04)	(0.84)	(5.24)	(4.00)
log(gdp per capita)	0.29	−6.82**	0.63	0.25	−1.88	1.15
	(0.36)	(3.41)	(1.03)	(0.41)	(1.85)	(1.58)
log(gdp)	−0.34	7.31	0.09	−0.29	2.29	−1.75
	(0.44)	(4.54)	(1.28)	(0.52)	(2.19)	(2.06)
log(taxes)	−0.01	1.59	0.79	0.12	−0.55	−0.24
	(0.10)	(1.55)	(0.65)	(0.11)	(1.34)	(0.49)
medical beds (*)	0.0005	−0.001	0.003	0.001	−0.01	0.0001
	(0.0004)	(0.01)	(0.002)	(0.001)	(0.01)	(0.001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	25,500	25,500	25,500	25,500	25,500	25,500
R^2	0.05	0.40	0.14	0.11	0.25	0.30
Adjusted R^2	0.03	0.39	0.13	0.09	0.24	0.29

	hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected × t × $\mathbb{1}_{t<nov15}$	0.005	0.003	0.03**	−0.01	0.003	−0.0003
	(0.005)	(0.002)	(0.01)	(0.02)	(0.003)	(0.0002)
log(population)	0.62	0.20	−4.03	−4.72	0.17	−0.04
	(0.40)	(0.27)	(6.93)	(3.27)	(0.94)	(0.18)
log(gdp per capita)	0.06	−0.04	−4.31*	−2.14*	−0.08	0.05
	(0.10)	(0.10)	(2.41)	(1.19)	(0.37)	(0.06)
log(gdp)	−0.07	0.03	4.29	2.70*	0.01	−0.05
	(0.12)	(0.14)	(3.13)	(1.63)	(0.50)	(0.07)
log(taxes)	−0.01	−0.08	1.23	0.66	0.03	0.03
	(0.05)	(0.08)	(0.76)	(0.45)	(0.18)	(0.03)
medical beds (*)	−0.0001	0.0001	−0.002	0.001	0.001	0.0001
	(0.0002)	(0.0001)	(0.01)	(0.001)	(0.001)	(0.0002)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	25,500	25,500	25,500	25,500	25,500	25,500
R^2	0.07	0.03	0.31	0.17	0.10	0.03
Adjusted R^2	0.05	0.01	0.30	0.15	0.09	0.02

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.

Table A.12 – Pre-disaster trend by disorder, Espírito Santo state. Control group: ***all municipalities.***

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected × t × $\mathbb{1}_{t<nov15}$	0.003*	0.002	0.003	0.001	−0.005	0.0004
	(0.002)	(0.03)	(0.01)	(0.001)	(0.004)	(0.002)
log(population)	−1.26	51.98***	6.35	0.49	2.37	−1.09*
	(1.14)	(17.47)	(4.86)	(0.38)	(2.70)	(0.62)
log(gdp per capita)	−1.50*	26.76***	2.65	0.09	1.38	−0.55
	(0.86)	(9.86)	(3.37)	(0.22)	(1.15)	(0.49)
log(gdp)	2.15*	−38.93***	−3.77	−0.15	−2.25	0.87
	(1.14)	(13.86)	(4.49)	(0.27)	(1.55)	(0.68)
log(taxes)	−0.0002	0.48	−0.27	0.01	−0.09	0.004
	(0.03)	(0.86)	(0.32)	(0.01)	(0.14)	(0.02)
medical beds (*)	0.0003	0.01	0.001	0.0000	0.001	0.0000
	(0.0004)	(0.01)	(0.001)	(0.0001)	(0.001)	(0.0002)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	6,528	6,528	6,528	6,528	6,528	6,528
R^2	0.13	0.23	0.31	0.06	0.12	0.15
Adjusted R^2	0.10	0.20	0.29	0.03	0.08	0.12

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected × t × $\mathbb{1}_{t<nov15}$	−0.001	−0.0000	0.03**	−0.01*	0.002	−0.0002
	(0.004)	(0.0003)	(0.01)	(0.003)	(0.002)	(0.0002)
log(population)	−1.13	0.02	16.58**	8.39	−0.29	0.17
	(1.92)	(0.16)	(7.43)	(6.62)	(0.63)	(0.16)
log(gdp per capita)	−0.40	0.07	10.76**	−0.19	−0.23	0.12
	(1.24)	(0.10)	(4.27)	(5.40)	(0.48)	(0.11)
log(gdp)	1.09	−0.03	−15.77***	−0.87	0.18	−0.16
	(1.50)	(0.12)	(5.88)	(6.75)	(0.62)	(0.14)
log(taxes)	−0.003	−0.03***	−0.22	−0.04	0.04***	0.01
	(0.12)	(0.01)	(0.42)	(0.58)	(0.01)	(0.01)
medical beds (*)	0.0000	−0.0001**	0.01***	−0.0005	−0.0002	−0.0001
	(0.001)	(0.0000)	(0.002)	(0.002)	(0.0004)	(0.0003)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	6,528	6,528	6,528	6,528	6,528	6,528
R^2	0.29	0.03	0.34	0.44	0.06	0.03
Adjusted R^2	0.27	−0.001	0.32	0.42	0.03	−0.0001

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.

Table A.13 – Pre-disaster trend by disorder, Espírito Santo state. Control group: ***intermediate region.***

	Dependent variable: hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected × t × $\mathbb{1}_{t<nov15}$	0.004*	−0.02	−0.005	0.001	−0.003	0.001
	(0.002)	(0.02)	(0.004)	(0.001)	(0.003)	(0.002)
log(population)	−1.22	15.48	5.90	0.03	−0.37	−1.54*
	(1.44)	(10.60)	(4.92)	(0.33)	(3.09)	(0.78)
log(gdp per capita)	−1.61*	5.76	2.13	−0.10	0.05	−0.87
	(0.95)	(7.49)	(3.33)	(0.21)	(1.22)	(0.59)
log(gdp)	2.31*	−8.06	−2.70	0.13	−0.21	1.32
	(1.28)	(10.42)	(4.44)	(0.27)	(1.69)	(0.81)
log(taxes)	−0.001	−0.11	−0.29	−0.01	−0.12	0.01
	(0.03)	(0.40)	(0.24)	(0.01)	(0.11)	(0.02)
medical beds (*)	0.0004	0.005	0.001	0.0000	0.001	−0.0001
	(0.0004)	(0.004)	(0.001)	(0.0001)	(0.001)	(0.0002)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	4,512	4,512	4,512	4,512	4,512	4,512
R^2	0.17	0.26	0.21	0.07	0.08	0.20
Adjusted R^2	0.14	0.23	0.17	0.03	0.04	0.17

	Dependent variable: hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected × t × $\mathbb{1}_{t<nov15}$	−0.004	−0.0001	0.02**	−0.01*	0.003	−0.0001
	(0.004)	(0.0003)	(0.01)	(0.003)	(0.002)	(0.0001)
log(population)	0.08	0.12	9.31	6.53	−0.16	0.19
	(2.00)	(0.20)	(6.35)	(6.20)	(0.80)	(0.21)
log(gdp per capita)	−0.22	0.12	6.10	−0.19	−0.19	0.09
	(1.14)	(0.10)	(4.04)	(5.08)	(0.60)	(0.10)
log(gdp)	0.71	−0.11	−8.48	−0.29	0.13	−0.11
	(1.42)	(0.13)	(5.34)	(6.33)	(0.78)	(0.13)
log(taxes)	0.03	−0.02***	−0.45**	−0.06	0.04**	0.01
	(0.11)	(0.01)	(0.22)	(0.50)	(0.02)	(0.01)
medical beds (*)	−0.0000	−0.0001**	0.004**	−0.0002	−0.0003	−0.0002
	(0.001)	(0.0000)	(0.002)	(0.002)	(0.0005)	(0.0003)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	4,512	4,512	4,512	4,512	4,512	4,512
R^2	0.35	0.05	0.23	0.49	0.09	0.04
Adjusted R^2	0.33	0.004	0.20	0.46	0.05	−0.0000

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.

Table A.14 – Pre-disaster trend by disorder, Espírito Santo state. Control group: ***Doce river basin.***

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected × t × $\mathbb{1}_{t<nov15}$	0.003	0.01	−0.004	0.001	0.01	−0.0004
	(0.002)	(0.02)	(0.01)	(0.001)	(0.01)	(0.002)
log(population)	−0.44	3.29	3.16	0.11	−2.00	−1.60*
	(1.37)	(8.69)	(5.35)	(0.30)	(4.11)	(0.85)
log(gdp per capita)	−0.10	1.30	−0.27	0.002	−0.57	−0.61
	(1.07)	(4.01)	(4.01)	(0.23)	(1.58)	(0.47)
log(gdp)	0.17	−3.39	0.65	0.01	0.51	0.97
	(1.57)	(6.08)	(5.37)	(0.33)	(2.39)	(0.68)
log(taxes)	0.04	−1.28	−0.57**	−0.04***	−0.37*	0.03
	(0.06)	(0.77)	(0.21)	(0.01)	(0.22)	(0.03)
medical beds (*)	0.0004	0.01	0.001	−0.0001	0.002	−0.001*
	(0.001)	(0.005)	(0.002)	(0.0002)	(0.001)	(0.0003)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	2,664	2,664	2,664	2,664	2,664	2,664
R^2	0.11	0.23	0.17	0.07	0.11	0.15
Adjusted R^2	0.05	0.18	0.12	0.01	0.05	0.10

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected × t × $\mathbb{1}_{t<nov15}$	0.002	−0.0003	0.06***	−0.004	0.002	0.0001
	(0.01)	(0.0005)	(0.02)	(0.003)	(0.004)	(0.0003)
log(population)	1.90	0.11	2.03	7.11	−0.44	0.39
	(2.38)	(0.25)	(6.28)	(5.40)	(1.12)	(0.28)
log(gdp per capita)	1.67	0.02	1.29	−0.72	−0.40	0.19
	(1.32)	(0.13)	(3.31)	(4.85)	(0.98)	(0.16)
log(gdp)	−2.17	0.06	−2.04	0.56	0.40	−0.25
	(1.89)	(0.18)	(4.51)	(6.22)	(1.33)	(0.21)
log(taxes)	0.22*	−0.04***	−0.63*	−0.66*	0.01	−0.01
	(0.12)	(0.01)	(0.35)	(0.33)	(0.03)	(0.01)
medical beds (*)	0.001	−0.0002**	0.01**	−0.003	0.0005	−0.0005
	(0.001)	(0.0001)	(0.002)	(0.002)	(0.0004)	(0.0005)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	2,664	2,664	2,664	2,664	2,664	2,664
R^2	0.22	0.06	0.25	0.41	0.10	0.06
Adjusted R^2	0.17	−0.01	0.20	0.37	0.03	−0.002

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.

Table A.15 – Pre-disaster trend by disorder, Espírito Santo state. Control group: ***excluded frontier municipalities.***

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected × t × $\mathbb{1}_{t<nov15}$	0.004**	−0.04*	−0.01*	0.001	−0.005	0.001
	(0.002)	(0.02)	(0.01)	(0.001)	(0.004)	(0.003)
log(population)	−1.53	17.16	7.54	−0.21	−2.49	−2.25**
	(1.78)	(14.08)	(5.23)	(0.29)	(3.66)	(1.01)
log(gdp per capita)	−1.86	−1.92	1.20	−0.27	−1.87	−1.24*
	(1.23)	(10.00)	(3.43)	(0.17)	(1.48)	(0.69)
log(gdp)	2.67	3.85	−1.06	0.38	2.63	1.85*
	(1.66)	(14.01)	(4.55)	(0.23)	(2.09)	(0.92)
log(taxes)	0.03	−1.10*	−0.39	−0.03**	−0.33**	0.03
	(0.07)	(0.63)	(0.26)	(0.01)	(0.15)	(0.02)
medical beds (*)	0.0001	0.003	0.0003	−0.0000	0.001	−0.0002
	(0.0004)	(0.01)	(0.001)	(0.0001)	(0.001)	(0.0002)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	2,832	2,832	2,832	2,832	2,832	2,832
R^2	0.20	0.31	0.24	0.15	0.13	0.24
Adjusted R^2	0.14	0.27	0.19	0.09	0.07	0.19

	Dependent variable:					
	hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected × t × $\mathbb{1}_{t<nov15}$	−0.004	−0.0002	0.02*	−0.01	0.003	−0.0001
	(0.005)	(0.0003)	(0.01)	(0.01)	(0.002)	(0.0001)
log(population)	−1.65	0.02	3.16	8.70	−0.87	0.30
	(2.10)	(0.22)	(5.74)	(8.63)	(0.75)	(0.28)
log(gdp per capita)	−0.86	0.06	1.26	−0.27	−0.66	0.10
	(1.07)	(0.10)	(4.03)	(6.72)	(0.58)	(0.14)
log(gdp)	1.47	−0.004	−1.80	−0.31	0.78	−0.11
	(1.41)	(0.14)	(5.32)	(8.32)	(0.75)	(0.18)
log(taxes)	0.04	−0.04***	−0.63**	0.22	0.02	−0.0004
	(0.15)	(0.01)	(0.27)	(0.60)	(0.02)	(0.01)
medical beds (*)	0.0002	−0.0001*	0.004**	−0.001	−0.0004	−0.0002
	(0.001)	(0.0001)	(0.002)	(0.002)	(0.0005)	(0.0003)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Month-year fixed effects × affected	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19	nov15-dic19
Observations	2,832	2,832	2,832	2,832	2,832	2,832
R^2	0.39	0.05	0.28	0.53	0.15	0.05
Adjusted R^2	0.35	−0.01	0.23	0.50	0.10	−0.01

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
(*) We consider medical beds per 100,000 inhab.

Table A.16 – Estimated lower bound of the effect of the disaster in mental heath, different specifications, 01/2013 to 12/2019. Control group: All municipalities in Minas Gerais and Espírito Santo state.

	Dependent variable:			
	mental hospitalizations per 100,000 inhab.			
	(1)	(2)	(3)	(4)
affected in MG × after (n=40)	0.11	0.24	1.53	1.53
	(1.22)	(1.01)	(1.07)	(1.05)
affected in ES × after (n=11)	−1.46***	1.56	1.56	1.33
	(0.56)	(1.76)	(1.76)	(1.72)
ES state × after	0.39	−1.75	−0.46	−1.44
	(1.12)	(1.53)	(1.57)	(1.46)
ES state	−1.78			
	(1.30)			
after	−1.19***			
	(0.35)			
constant	7.29***			
	(0.58)			
log(population)				−3.75
				(11.34)
log(gdp per capita)				−8.46
				(5.17)
log(gdp)				10.93
				(6.89)
log(taxes)				−1.55
				(1.16)
medical beds per 100,000 inhab				−0.0004
				(0.01)
Municipality fixed effects		x	x	x
Month fixed effects			x	x
Month-year fixed effects			x	x
Control variables				x
Munic. in control group MG	811	811	811	811
Munic. in control group ES	67	67	67	67
Observations	78,036	78,036	78,036	77,820
R^2	0.01	0.45	0.47	0.47
Adjusted R^2	0.01	0.45	0.46	0.46

*p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
We include a fixed effect for each group of mental disorder.
Each treated group is compared to a control group made only by municipalities in its own state.

Table A.17 – Estimated lower bound of the effect of the disaster in mental heath, different specifications, 01/2013 to 12/2019. Control group: Intermediate region.

	Dependent variable:			
	mental hospitalizations per 100,000 inhab.			
	(1)	(2)	(3)	(4)
affected in MG × after (n=40)	0.63	0.24	2.03*	2.03*
	(1.32)	(1.01)	(1.12)	(1.09)
affected in ES × after (n=11)	−1.14*	−0.79	−0.79	−1.31
	(0.59)	(0.96)	(0.96)	(0.87)
ES state × after	2.36***	0.61	2.40***	1.01
	(0.63)	(0.41)	(0.63)	(0.72)
ES state	−3.54***			
	(0.98)			
after	−1.62***			
	(0.44)			
constant	7.20***			
	(0.91)			
log(population)				8.19
				(14.03)
log(gdp per capita)				−7.42
				(6.45)
log(gdp)				9.24
				(8.44)
log(taxes)				−1.43*
				(0.82)
medical beds per 100,000 inhab				−0.005
				(0.02)
Municipality fixed effects		x	x	x
Month fixed effects			x	x
Month-year fixed effects			x	x
Control variables				x
Munic. in control group MG	329	329	329	329
Munic. in control group ES	43	43	43	43
Observations	35,532	35,532	35,532	35,472
R^2	0.03	0.41	0.44	0.44
Adjusted R^2	0.03	0.40	0.43	0.43

*p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
We include a fixed effect for each group of mental disorder.
Each treated group is compared to a control group made only by municipalities in its own state.

Table A.18 – Estimated lower bound of the effect of the disaster in mental heath, different specifications, 01/2013 to 12/2019. Control group: Doce river basin

	Dependent variable:			
	mental hospitalizations per 100,000 inhab.			
	(1)	(2)	(3)	(4)
affected in MG × after (n=40)	1.91	0.24	0.61	0.58
	(1.18)	(1.01)	(1.10)	(1.09)
affected in ES × after (n=11)	0.99*	1.86*	1.86*	1.86**
	(0.56)	(1.05)	(1.05)	(0.90)
ES state × after	−0.50	−2.04***	−1.67**	−2.47***
	(0.95)	(0.58)	(0.73)	(0.93)
ES state	−1.53*			
	(0.85)			
after	−0.87			
	(0.69)			
constant	5.18***			
	(0.58)			
log(population)				−14.19
				(17.59)
log(gdp per capita)				−9.14
				(5.90)
log(gdp)				11.47
				(7.35)
log(taxes)				−1.78
				(1.80)
medical beds per 100,000 inhab				0.01
				(0.01)
Municipality fixed effects		x	x	x
Month fixed effects			x	x
Month-year fixed effects			x	x
Control variables				x
Munic. in control group MG	161	161	161	161
Munic. in control group ES	21	21	21	21
Observations	19,572	19,572	19,572	19,536
R^2	0.03	0.22	0.24	0.25
Adjusted R^2	0.03	0.21	0.23	0.23

*p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
We include a fixed effect for each group of mental disorder.
Each treated group is compared to a control group made only by municipalities in its own state.

Table A.19 – Estimated lower bound of the effect of the disaster in mental heath, different specifications, 01/2013 to 12/2019. Control group: Excluded frontier municipalities

	Dependent variable:			
	mental hospitalizations per 100,000 inhab.			
	(1)	(2)	(3)	(4)
affected in MG × after (n=40)	0.40	0.24	2.11^{*}	2.14^{*}
	(1.38)	(1.01)	(1.13)	(1.10)
affected in ES × after (n=11)	-1.51^{**}	−1.12	−1.12	-2.05^{**}
	(0.66)	(0.97)	(0.97)	(1.00)
ES state × after	2.78^{***}	0.94^{**}	2.81^{***}	1.73^{**}
	(0.75)	(0.45)	(0.68)	(0.77)
ES state	-3.83^{***}			
	(1.10)			
after	-1.64^{***}			
	(0.48)			
constant	7.46^{***}			
	(1.01)			
log(population)				10.46
				(16.18)
log(gdp per capita)				−7.04
				(6.81)
log(gdp)				8.85
				(8.91)
log(taxes)				−1.40
				(1.10)
medical beds per 100,000 inhab				−0.004
				(0.02)
Municipality fixed effects		x	x	x
Month fixed effects			x	x
Month-year fixed effects			x	x
Control variables				x
Munic. in control group MG	264	264	264	264
Munic. in control group ES	23	23	23	23
Observations	28,392	28,392	28,392	28,332
R^2	0.03	0.43	0.45	0.46
Adjusted R^2	0.03	0.42	0.45	0.45

*p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by populationa size.
We include a fixed effect for each group of mental disorder.
Each treated group is compared to a control group made only by municipalities in its own state.

Table A.20 – Estimated lower bound of the effect of the disaster in mental health, different control groups, 01/2013 to 12/2019

	Dependent variable:			
	mental hospitalizations per 100,000 inhab.			
	(1) All munic.	(2) Intermediate region	(3) Doce river basin	(4) Excluded frontier munic.
affected in MG × after (n=40)	1.53	2.03*	0.58	2.14*
	(1.05)	(1.09)	(1.09)	(1.10)
affected in ES × after (n=11)	1.33	−1.31	1.86**	−2.05**
	(1.72)	(0.87)	(0.90)	(1.00)
ES state × after	−1.44	1.01	−2.47***	1.73**
	(1.46)	(0.72)	(0.93)	(0.77)
log(population)	−3.75	8.19	−14.19	10.46
	(11.34)	(14.03)	(17.59)	(16.18)
log(gdp per capita)	−8.46	−7.42	−9.14	−7.04
	(5.17)	(6.45)	(5.90)	(6.81)
log(gdp)	10.93	9.24	11.47	8.85
	(6.89)	(8.44)	(7.35)	(8.91)
log(taxes)	−1.55	−1.43*	−1.78	−1.40
	(1.16)	(0.82)	(1.80)	(1.10)
medical beds per 100,000 inhab	−0.0004	−0.005	0.01	−0.004
	(0.01)	(0.02)	(0.01)	(0.02)
Municipality fixed effects	x	x	x	x
Month fixed effects	x	x	x	x
Month-year fixed effects	x	x	x	x
Munic. in control group MG	811	329	161	264
Munic. in control group ES	67	43	21	23
Observations	77,820	35,472	19,536	28,332
R^2	0.47	0.44	0.25	0.46
Adjusted R^2	0.46	0.43	0.23	0.45

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
We include a fixed effect for each group of mental disorder.
Each treated group is compared to a control group made only by municipalities in its own state.

Table A.21 – Estimated lower bound of the effect of the disaster in mental health by disorder, using all municipalities as control group, 01/2013 to 12/2019

	Dependent variable:					
	mental hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected in MG ×s after (n=40)	0.06	0.58	0.12	0.03	0.27	0.74*
	(0.04)	(0.68)	(0.17)	(0.02)	(0.20)	(0.44)
affected in ES ×s after (n=11)	0.02	0.74	−0.02	0.01	0.12	0.03
	(0.03)	(1.00)	(0.20)	(0.02)	(0.14)	(0.04)
log(population)	−0.33	−5.53	3.02	−0.17	−2.58	−0.34
	(0.34)	(5.38)	(2.35)	(0.32)	(2.22)	(1.37)
log(gdp per capita)	0.05	−2.58	−0.41	0.17	−2.01*	0.40
	(0.20)	(2.33)	(0.85)	(0.20)	(1.18)	(0.79)
log(gdp)	−0.08	2.36	1.41	−0.21	2.86*	−0.70
	(0.28)	(3.07)	(1.17)	(0.27)	(1.58)	(1.16)
log(taxes)	0.04	−0.46	−0.20	0.02	−0.26	0.14*
	(0.03)	(0.51)	(0.21)	(0.02)	(0.17)	(0.08)
medical beds per 100,000 inhab	0.0003	−0.001	0.001	0.0004	−0.002	0.0004
	(0.0002)	(0.004)	(0.001)	(0.0004)	(0.003)	(0.0005)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Munic. in control group MG	811	811	811	811	811	811
Munic. in control group ES	67	67	67	67	67	67
Observations	77,820	77,820	77,820	77,820	77,820	77,820
R^2	0.11	0.35	0.24	0.09	0.32	0.18
Adjusted R^2	0.10	0.34	0.23	0.08	0.31	0.17

	Dependent variable:					
	mental hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected in MG ×s after (n=40)	−0.05	−0.01	0.17	−0.41	0.04	0.001
	(0.05)	(0.02)	(0.26)	(0.36)	(0.04)	(0.01)
affected in ES ×s after (n=11)	0.04	0.01	0.50	−0.13	0.02	−0.005
	(0.10)	(0.01)	(0.40)	(0.20)	(0.02)	(0.005)
log(population)	0.65	0.02	−1.16	2.80	−0.21	0.09
	(0.46)	(0.14)	(3.54)	(2.13)	(0.50)	(0.13)
log(gdp per capita)	0.22	0.02	−2.87*	−1.44	0.01	−0.03
	(0.22)	(0.07)	(1.70)	(1.05)	(0.30)	(0.05)
log(gdp)	−0.18	−0.05	3.44	2.04	−0.03	0.06
	(0.23)	(0.09)	(2.31)	(1.37)	(0.40)	(0.07)
log(taxes)	0.04	−0.02	−0.20	−0.65**	−0.003	0.004
	(0.05)	(0.01)	(0.27)	(0.27)	(0.03)	(0.01)
medical beds per 100,000 inhab	0.0002	−0.0000	0.001	−0.001*	0.0000	0.0001
	(0.0002)	(0.0001)	(0.004)	(0.0005)	(0.0004)	(0.0001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Munic. in control group MG	811	811	811	811	811	811
Munic. in control group ES	67	67	67	67	67	67
Observations	77,820	77,820	77,820	77,820	77,820	77,820
R^2	0.15	0.02	0.32	0.21	0.13	0.06
Adjusted R^2	0.14	0.01	0.31	0.20	0.11	0.05

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
Each treated group is compared to a control group made only by municipalities in its own state.
As a control group we consider municipalities in the same region as affected and exclude frontier municipalities.

Table A.22 – Estimated lower bound of the effect of the disaster in mental health by disorder, using municipalities in the same intermediate region as control group, 01/2013 to 12/2019

	Dependent variable:					
	mental hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected in MG × after (n=40)	0.06	0.73	0.14	−0.01	0.23	0.76*
	(0.05)	(0.69)	(0.17)	(0.03)	(0.22)	(0.44)
affected in ES × after (n=11)	0.03	−0.93*	−0.28**	−0.005	0.05	0.02
	(0.03)	(0.50)	(0.13)	(0.02)	(0.14)	(0.04)
log(population)	−0.35	−0.84	4.66*	0.12	−3.35	0.89
	(0.53)	(6.58)	(2.56)	(0.48)	(3.19)	(2.18)
log(gdp per capita)	0.10	−4.16	0.45	0.15	−1.58	0.95
	(0.33)	(2.82)	(1.15)	(0.34)	(1.41)	(1.56)
log(gdp)	−0.13	4.86	0.20	−0.15	2.04	−1.48
	(0.44)	(3.75)	(1.42)	(0.44)	(1.81)	(2.15)
log(taxes)	0.04	−0.23	−0.26	0.02	−0.27	0.18
	(0.03)	(0.33)	(0.18)	(0.02)	(0.21)	(0.12)
medical beds per 100,000 inhab	0.001	−0.0002	0.001	0.0004	−0.01	−0.0002
	(0.0004)	(0.01)	(0.001)	(0.001)	(0.01)	(0.001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Munic. in control group MG	329	329	329	329	329	329
Munic. in control group ES	43	43	43	43	43	43
Observations	35,472	35,472	35,472	35,472	35,472	35,472
R^2	0.06	0.38	0.14	0.10	0.25	0.22
Adjusted R^2	0.05	0.37	0.13	0.09	0.24	0.20

	Dependent variable:					
	mental hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected in MG × after (n=40)	−0.05	−0.02	0.52*	−0.38	0.06	−0.005
	(0.04)	(0.02)	(0.27)	(0.36)	(0.05)	(0.01)
affected in ES × after (n=11)	0.12	0.01	0.02	−0.34	−0.004	0.001
	(0.09)	(0.01)	(0.22)	(0.25)	(0.02)	(0.004)
log(population)	1.31*	0.03	1.12	4.39	0.20	0.01
	(0.68)	(0.20)	(4.25)	(3.41)	(0.52)	(0.10)
log(gdp per capita)	0.43	0.002	−2.15	−1.60	−0.06	0.04
	(0.35)	(0.10)	(1.97)	(1.73)	(0.34)	(0.05)
log(gdp)	−0.44	−0.02	2.13	2.32	−0.03	−0.04
	(0.38)	(0.13)	(2.61)	(2.21)	(0.45)	(0.06)
log(taxes)	0.06	−0.02	−0.25	−0.71**	0.01	0.005
	(0.05)	(0.02)	(0.18)	(0.29)	(0.04)	(0.01)
medical beds per 100,000 inhab	0.0002	0.0001	−0.002	−0.001	0.0004	−0.0000
	(0.0003)	(0.0001)	(0.01)	(0.001)	(0.001)	(0.0001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Munic. in control group MG	329	329	329	329	329	329
Munic. in control group ES	43	43	43	43	43	43
Observations	35,472	35,472	35,472	35,472	35,472	35,472
R^2	0.19	0.03	0.29	0.17	0.09	0.03
Adjusted R^2	0.18	0.01	0.28	0.16	0.08	0.02

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
Each treated group is compared to a control group made only by municipalities in its own state.
As a control group we consider municipalities in the same region as affected and exclude frontier municipalities.

Table A.23 – Estimated lower bound of the effect of the disaster in mental health by disorder, using Doce river basin as control group, 01/2013 to 12/2019

	Dependent variable:					
	mental hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected in MG × after (n=40)	0.17	−0.08	0.15	−0.08	−0.02	0.75*
	(0.12)	(0.68)	(0.19)	(0.07)	(0.22)	(0.42)
affected in ES × after (n=11)	0.02	0.51	0.44**	0.02	0.39**	−0.04
	(0.06)	(0.51)	(0.18)	(0.02)	(0.18)	(0.07)
log(population)	−1.55	−10.14	0.58	−0.27	−5.26	0.10
	(1.47)	(8.76)	(2.98)	(0.51)	(5.17)	(2.72)
log(gdp per capita)	0.26	−4.27	−0.29	−0.06	−0.72	0.38
	(0.30)	(2.90)	(1.07)	(0.34)	(0.78)	(1.97)
log(gdp)	−0.45	5.56	1.06	0.04	1.07	−1.51
	(0.32)	(3.58)	(1.28)	(0.49)	(1.04)	(2.74)
log(taxes)	0.03	−0.24	−0.24	−0.05	−0.21	0.32
	(0.08)	(0.78)	(0.34)	(0.04)	(0.60)	(0.27)
medical beds per 100,000 inhab	0.001**	0.005	0.003	−0.0002	0.001	0.001
	(0.0004)	(0.01)	(0.002)	(0.001)	(0.002)	(0.001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Munic. in control group MG	161	161	161	161	161	161
Munic. in control group ES	21	21	21	21	21	21
Observations	19,536	19,536	19,536	19,536	19,536	19,536
R^2	0.08	0.16	0.09	0.13	0.11	0.26
Adjusted R^2	0.06	0.15	0.07	0.12	0.10	0.25

	Dependent variable:					
	mental hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected in MG × after (n=40)	−0.06	0.01	0.09	−0.41	0.08	−0.01
	(0.05)	(0.03)	(0.26)	(0.36)	(0.05)	(0.01)
affected in ES × after (n=11)	−0.15	0.02	0.62**	−0.01	0.05	0.004
	(0.12)	(0.01)	(0.27)	(0.14)	(0.04)	(0.004)
log(population)	1.20*	−0.26	−1.38	3.34	−0.58	0.03
	(0.21)	(0.35)	(3.50)	(2.69)	(0.64)	(0.13)
log(gdp per capita)	0.36	0.04	−1.87	−2.87	−0.11	0.01
	(0.38)	(0.10)	(1.96)	(1.79)	(0.32)	(0.04)
log(gdp)	−0.43	−0.04	2.26	3.87	0.06	−0.02
	(0.39)	(0.14)	(2.57)	(2.44)	(0.44)	(0.05)
log(taxes)	0.11*	−0.06	−0.27	−0.71**	0.004	−0.01
	(0.07)	(0.04)	(0.29)	(0.34)	(0.07)	(0.01)
medical beds per 100,000 inhab	0.001	−0.0001	0.001	−0.001	0.0004	−0.0002
	(0.001)	(0.0001)	(0.002)	(0.001)	(0.0005)	(0.0002)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Munic. in control group MG	161	161	161	161	161	161
Munic. in control group ES	21	21	21	21	21	21
Observations	19,536	19,536	19,536	19,536	19,536	19,536
R^2	0.13	0.03	0.12	0.15	0.03	0.02
Adjusted R^2	0.12	0.01	0.10	0.13	0.02	0.002

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
Each treated group is compared to a control group made only by municipalities in its own state.
As a control group we consider municipalities in the same region as affected and exclude frontier municipalities.

Table A.24 – Estimated lower bound of the effect of the disaster in mental health by disorder using municipalities in the same region and excluding spill overs, 01/2013 to 12/2019

	Dependent variable:					
	mental hospitalizations per 100,000 inhab.					
	(1) Stress related	(2) Psychoactive substance use	(3) Mood	(4) Personality and behaviour	(5) Dementia related	(6) Disorders with onset on childhood
affected in MG × after (n=40)	0.03	0.79	0.13	−0.005	0.24	0.76*
	(0.04)	(0.70)	(0.17)	(0.03)	(0.23)	(0.44)
affected in ES × after (n=11)	0.05	−1.27**	−0.44***	−0.002	−0.02	0.05
	(0.04)	(0.61)	(0.16)	(0.02)	(0.18)	(0.05)
log(population)	−0.06	0.86	5.22*	0.14	−3.88	1.56
	(0.56)	(7.77)	(2.79)	(0.56)	(3.74)	(2.53)
log(gdp per capita)	0.08	−3.36	0.47	0.17	−1.70	1.26
	(0.40)	(2.99)	(1.19)	(0.37)	(1.55)	(1.77)
log(gdp)	−0.05	3.89	0.30	−0.19	2.22	−1.89
	(0.51)	(3.95)	(1.48)	(0.48)	(1.98)	(2.42)
log(taxes)	0.09**	−0.33	−0.22	0.01	−0.40	0.21
	(0.03)	(0.45)	(0.26)	(0.03)	(0.34)	(0.15)
medical beds per 100,000 inhab	0.0004	−0.0003	0.001	0.0004	−0.01	−0.0002
	(0.0003)	(0.01)	(0.002)	(0.001)	(0.01)	(0.001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Munic. in control group MG	264	264	264	264	264	264
Munic. in control group ES	23	23	23	23	23	23
Observations	28,332	28,332	28,332	28,332	28,332	28,332
R^2	0.05	0.40	0.15	0.11	0.25	0.23
Adjusted R^2	0.03	0.39	0.14	0.09	0.24	0.22

	Dependent variable:					
	mental hospitalizations per 100,000 inhab.					
	(7) Behavioural syndromes	(8) Psychological development	(9) Schizophrenia	(10) Non-organic psychosis	(11) Mental retardation	(12) Other
affected in MG × after (n=40)	−0.05	−0.02	0.58**	−0.38	0.06	−0.01
	(0.04)	(0.02)	(0.27)	(0.36)	(0.05)	(0.01)
affected in ES × after (n=11)	0.15	0.01	−0.05	−0.51	−0.01	−0.0000
	(0.11)	(0.01)	(0.24)	(0.31)	(0.03)	(0.01)
log(population)	0.95	0.03	1.10	4.13	0.39	0.02
	(0.69)	(0.22)	(4.85)	(4.14)	(0.61)	(0.12)
log(gdp per capita)	0.30	−0.01	−2.34	−1.96	−0.01	0.04
	(0.33)	(0.11)	(2.09)	(1.92)	(0.35)	(0.05)
log(gdp)	−0.31	−0.01	2.28	2.74	−0.09	−0.04
	(0.37)	(0.14)	(2.77)	(2.45)	(0.47)	(0.06)
log(taxes)	0.07	−0.02	−0.20	−0.61*	−0.003	0.01
	(0.06)	(0.02)	(0.23)	(0.35)	(0.05)	(0.01)
medical beds per 100,000 inhab	0.0003	0.0001	−0.001	−0.0004	0.0005	−0.0000
	(0.0003)	(0.0001)	(0.01)	(0.001)	(0.001)	(0.0001)
Municipality fixed effects	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x
Munic. in control group MG	264	264	264	264	264	264
Munic. in control group ES	23	23	23	23	23	23
Observations	28,332	28,332	28,332	28,332	28,332	28,332
R^2	0.19	0.03	0.31	0.18	0.10	0.03
Adjusted R^2	0.17	0.01	0.30	0.16	0.09	0.02

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
Each treated group is compared to a control group made only by municipalities in its own state.
As a control group we consider municipalities in the same region as affected and exclude frontier municipalities.

Table A.25 – Estimated lower bound of the disaster's effect on mental hospitalizations by gender, different control groups, 01/2013 to 12/2019

	Dependent variable:							
	mental hospitalizations per 100,000 inhab.							
	Men				*Women*			
	(1) All munic.	(2) Intermediate region	(3) Doce river basin	(4) Excluded frontier munic.	(5) All munic.	(6) Intermediate region	(7) Doce river basin	(8) Excluded frontier munic.
affected in MG × after (n=40)	1.68	2.70*	0.11	2.91*	1.39**	1.43**	1.02	1.43**
	(1.51)	(1.59)	(1.49)	(1.61)	(0.67)	(0.70)	(0.80)	(0.70)
affected in ES × after (n=11)	2.00	−1.87	2.18*	−2.77*	0.66	−0.76	1.51**	−1.31*
	(2.52)	(1.21)	(1.25)	(1.44)	(0.99)	(0.61)	(0.67)	(0.67)
ES state × after	−1.98	1.98*	−3.07***	3.07**	−0.88	0.13	−1.83**	0.49
	(2.17)	(1.16)	(1.17)	(1.28)	(0.82)	(0.40)	(0.80)	(0.41)
log(population)	−8.50	3.21	−27.59	6.46	0.96	13.26	−1.12	14.60
	(15.67)	(19.85)	(22.57)	(23.08)	(8.27)	(9.80)	(14.02)	(11.21)
log(gdp per capita)	−11.62	−14.20	−17.66**	−13.81	−5.54	−0.91	−0.72	−0.53
	(7.43)	(9.25)	(8.31)	(9.89)	(3.86)	(4.45)	(4.39)	(4.67)
log(gdp)	13.91	16.97	21.93**	16.27	8.23	1.80	1.17	1.67
	(9.69)	(12.11)	(10.20)	(12.90)	(5.30)	(5.77)	(5.38)	(6.10)
log(taxes)	−1.82	−1.72	−2.05	−1.41	−1.26*	−1.15*	−1.53	−1.36
	(1.65)	(1.10)	(2.20)	(1.40)	(0.76)	(0.61)	(1.49)	(0.88)
medical beds per 100,000 inhab	−0.005	−0.01	0.01	−0.01	0.003	−0.003	0.01	−0.002
	(0.02)	(0.03)	(0.02)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)
Municipality fixed effects	x	x	x	x	x	x	x	x
Month fixed effects	x	x	x	x	x	x	x	x
Month-year fixed effects	x	x	x	x	x	x	x	x
Control variables	x	x	x	x	x	x	x	x
Munic. in control group MG	811	329	161	264	811	329	161	264
Munic. in control group ES	67	43	21	23	67	43	21	23
Observations	77,400	35,388	19,536	28,248	77,400	35,388	19,536	28,248
R^2	0.40	0.41	0.20	0.43	0.33	0.26	0.16	0.27
Adjusted R^2	0.40	0.41	0.18	0.42	0.32	0.25	0.14	0.26

Note: *p<0.1; **p<0.05; ***p<0.01
All regressions are clustered by municipality and weighted by population size.
Each treated group is compared to a control group made only by municipalities in its own state.

Table A.26 – Estimated lower bounds of the disaster's effect on hospitalizations, by category and disorders, 2013-2019. ***Control group 1:*** *all municipalities in Minas Gerais and Espírito Santo state.*

	Stress related	Psychoactive substance use	Mood	Personality and behaviour	Dementia related	Disorders with onset on childhood
up reservoir × after (n=4)	0.181*	2.694*	0.271	0.02	0.658	-0.162
	[0.055]	[0.054]	[0.278]	[0.277]	[0.105]	[0.948]
down reservoir MG × after (n=31)	0.036	0.145	0.092	0.036	0.228	0.968***
	[0.173]	[0.38]	[0.326]	[0.226]	[0.144]	[0]
down reservoir ES × after (n=3)	-0.076	1.803	0.128	-0.008	0.44**	0.04
	[0.768]	[0.143]	[0.441]	[0.66]	[0.031]	[0.133]
coast × after (n=2)	0.059	-2.589	-0.354	-0.045	-0.41	0.04
	[0.316]	[0.884]	[0.835]	[0.908]	[0.93]	[0.14]
indirectly affected MG × after (n=5)	0.093*	1.893*	0.28	-0.012	0.192	-0.045
	[0.073]	[0.065]	[0.239]	[0.425]	[0.283]	[0.43]
indirectly affected ES × after (n=6)	-0.001	-0.07	-0.005	-0.011	0.008	-0.003
	[0.51]	[0.54]	[0.571]	[0.745]	[0.497]	[0.563]

	Behavioural syndromes	Psychological development	Schizophrenia	Non-organic psychosis	Mental retardation	Other
up reservoir × after (n=4)	-0.008	0.139**	-0.274	0.671*	0.42**	0.046*
	[0.526]	[0.032]	[0.647]	[0.051]	[0.033]	[0.099]
down reservoir MG × after (n=31)	-0.079	-0.032	0.488	-0.59	-0.016	0.003
	[0.986]	[0.974]	[0.203]	[1]	[0.598]	[0.431]
down reservoir ES × after (n=3)	0.003	0.013	1.049*	-0.278	0.022	0.003
	[0.511]	[0.149]	[0.069]	[0.895]	[0.442]	[0.217]
coast × after (n=2)	0.357***	0.017*	-0.605	-0.437	0.021	0.003
	[0.003]	[0.065]	[0.843]	[0.996]	[0.434]	[0.252]
indirectly affected MG × after (n=5)	0.019	0.022	-1.081	0.166	0.172	-0.025
	[0.148]	[0.118]	[0.803]	[0.169]	[0.147]	[0.896]
indirectly affected ES × after (n=6)	0.015	0.005	0.265	-0.212	0.003	-0.004
	[0.427]	[0.414]	[0.252]	[0.949]	[0.503]	[0.63]

*p<0.1; **p<0.05; ***p<0.01
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure described in Ferman e Pinto (2019).
There are 611 municipalities in the control group for Minas Gerais state and 67 in the control group Espírito Santo state.

Table A.27 – Estimated lower bounds of the disaster's effect on hospitalizations, by category and disorders, 2013-2019. ***Control group 2:*** *intermediate region.*

	Stress related	Psychoactive substance use	Mood	Personality and behaviour	Dementia related	Disorders with onset on childhood
up reservoir × after (n=4)	0.184*	2.626*	0.218	-0.018	0.494	-0.128
	[0.058]	[0.072]	[0.317]	[0.336]	[0.18]	[0.905]
down reservoir MG × after (n=31)	0.037	0.254	0.089	0.005	0.129	0.982***
	[0.249]	[0.301]	[0.331]	[0.39]	[0.306]	[0]
down reservoir ES × after (n=3)	-0.077	-0.127	-0.084	-0.029	0.259**	0.044
	[0.742]	[0.508]	[0.659]	[0.933]	[0.046]	[0.112]
coast × after (n=2)	0.061	-2.807	-0.518	-0.028	-0.458	0.033
	[0.301]	[0.932]	[0.914]	[0.94]	[0.996]	[0.151]
indirectly affected MG × after (n=5)	0.097	1.893*	0.281	-0.054	0.161	-0.014
	[0.115]	[0.068]	[0.27]	[0.485]	[0.336]	[0.389]
indirectly affected ES × after (n=6)	0.004	-0.677	-0.173	-0.005	-0.062	-0.004
	[0.462]	[0.768]	[0.786]	[0.624]	[0.786]	[0.607]

	Behavioural syndromes	Psychological development	Schizophrenia	Non-organic psychosis	Mental retardation	Other
up reservoir × after (n=4)	-0.009	0.151**	-0.342	0.665**	0.475**	0.034
	[0.607]	[0.033]	[0.663]	[0.016]	[0.022]	[0.171]
down reservoir MG × after (n=31)	-0.079	-0.042	0.842	-0.571	-0.004	-0.003
	[0.95]	[0.985]	[0.172]	[1]	[0.585]	[0.475]
down reservoir ES × after (n=3)	0.114	0.013	0.545	-0.527	0.024	0.007
	[0.287]	[0.125]	[0.216]	[0.997]	[0.433]	[0.168]
coast × after (n=2)	0.356***	0.012	-0.781	-0.285	0.008	-0.002
	[0]	[0.107]	[0.93]	[0.993]	[0.565]	[0.466]
indirectly affected MG × after (n=5)	0.022	0.026	-0.889	0.184	0.219	-0.031
	[0.141]	[0.16]	[0.773]	[0.221]	[0.148]	[0.938]
indirectly affected ES × after (n=6)	0.049	0.002	0.016	-0.13	-0.009	-0.008
	[0.219]	[0.432]	[0.562]	[0.887]	[0.615]	[0.85]

*p<0.1; **p<0.05; ***p<0.01
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure described in Ferman e Pinto (2019).
There are 329 municipalities in the control group for Minas Gerais state and 43 in the control group Espírito Santo state.

Table A.28 – Estimated lower bounds of the disaster's effect on hospitalizations, by category and disorders, 2013-2019. ***Control group 3:*** *Doce river basin.*

	Stress related	Psychoactive substance use	Mood	Personality and behaviour	Dementia related	Disorders with onset on childhood
up reservoir × after (n=4)	0.242*	2.226**	0.332	-0.068	0.341	-0.09
	[0.059]	[0.046]	[0.237]	[0.394]	[0.173]	[0.839]
down reservoir MG × after (n=31)	0.154***	-0.683	0.063	-0.08	-0.277	0.853***
	[0.005]	[0.899]	[0.371]	[0.735]	[0.915]	[0.001]
down reservoir ES × after (n=3)	-0.165	0.708	0.498	-0.021	0.516**	0.045
	[0.868]	[0.169]	[0.1]	[0.848]	[0.033]	[0.106]
coast × after (n=2)	0.018	-1.412	0.083	-0.017	-0.179	-0.005
	[0.453]	[0.981]	[0.252]	[0.777]	[0.794]	[0.544]
indirectly affected MG × after (n=5)	0.189*	1.302	0.368	-0.11	-0.077	0.016
	[0.064]	[0.105]	[0.137]	[0.843]	[0.529]	[0.297]
indirectly affected ES × after (n=6)	-0.002	0.284	0.24	0.001	0.191*	-0.013
	[0.482]	[0.285]	[0.224]	[0.45]	[0.083]	[0.736]

	Behavioural syndromes	Psychological development	Schizophrenia	Non-organic psychosis	Mental retardation	Other
up reservoir × after (n=4)	-0.015	0.229***	-0.525	0.673**	0.495**	0.028
	[0.822]	[0.004]	[0.789]	[0.018]	[0.018]	[0.209]
down reservoir MG × after (n=31)	-0.105	-0.03	0.376	-0.479	0.018	-0.011
	[0.958]	[0.939]	[0.13]	[0.999]	[0.443]	[0.67]
down reservoir ES × after (n=3)	-0.185	0.006	1.166**	-0.088	-0.013	0.017**
	[0.826]	[0.315]	[0.022]	[0.702]	[0.603]	[0.048]
coast × after (n=2)	-0.063	0.005	-0.471	0.106	0.049	-0.025
	[0.688]	[0.301]	[0.803]	[0.222]	[0.388]	[0.976]
indirectly affected MG × after (n=5)	0.026	0.082**	-1.252	0.217	0.235*	-0.034
	[0.1]	[0.022]	[0.939]	[0.154]	[0.076]	[0.839]
indirectly affected ES × after (n=6)	-0.286	-0.007	0.39	-0.02	0.032	-0.026
	[0.956]	[0.664]	[0.235]	[0.563]	[0.337]	[0.997]

*p<0.1; **p<0.05; ***p<0.01
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure described in Ferman e Pinto (2019).
There are 161 municipalities in the control group for Minas Gerais state and 21 in the control group Espírito Santo state.

Table A.29 – Estimated lower bounds of the disaster's effect on hospitalizations, by category and disorders, 2013-2019. ***Control group 4:*** *intermediate region without frontier municipalities.*

	Stress related	Psychoactive substance use	Mood	Personality and behaviour	Dementia related	Disorders with onset on childhood
up reservoir x after (n=4)	0.165*	2.643*	0.201	-0.017	0.503	-0.086
	[0.07]	[0.08]	[0.349]	[0.323]	[0.19]	[0.744]
down reservoir MG x after (n=31)	0.011	0.285	0.072	0.006	0.129	0.982***
	[0.368]	[0.349]	[0.369]	[0.392]	[0.316]	[0.001]
down reservoir ES x after (n=3)	-0.061	-1.069	-0.038	-0.036	0.059	0.04
	[0.693]	[0.817]	[0.543]	[1]	[0.298]	[0.178]
coast x after (n=2)	0.017	-3.365	-0.612	-0.007	-0.459	0.012*
	[0.406]	[0.954]	[0.984]	[0.679]	[0.997]	[0.086]
indirectly affected MG x after (n=5)	0.066*	1.959	0.256	-0.052	0.179	0.015
	[0.077]	[0.1]	[0.291]	[0.45]	[0.342]	[0.31]
indirectly affected ES x after (n=6)	0.013	-1.133	-0.315	0.003	-0.123	0.001
	[0.406]	[0.861]	[0.973]	[0.324]	[0.974]	[0.434]

	Behavioural syndromes	Psychological development	Schizophrenia	Non-organic psychosis	Mental retardation	Other
up reservoir x after (n=4)	-0.012	0.151**	-0.312	0.66**	0.466**	0.027
	[0.71]	[0.036]	[0.637]	[0.023]	[0.036]	[0.221]
down reservoir MG x after (n=31)	-0.079	-0.043	0.89	-0.581	-0.003	-0.002
	[0.934]	[0.982]	[0.185]	[1]	[0.574]	[0.473]
down reservoir ES x after (n=3)	-0.068	0.001	0.469	0.301	0.023	0.004
	[0.604]	[0.375]	[0.219]	[0.163]	[0.401]	[0.348]
coast x after (n=2)	0.334***	0.018	-0.801	-0.083	0.052	-0.009
	[0.002]	[0.132]	[0.915]	[0.715]	[0.156]	[0.71]
indirectly affected MG x after (n=5)	0.02	0.025	-0.847	0.178	0.213	-0.036
	[0.16]	[0.15]	[0.77]	[0.236]	[0.234]	[0.933]
indirectly affected ES x after (n=6)	0.067	-0.004	-0.029	-0.157	0.022	-0.013
	[0.112]	[0.566]	[0.602]	[0.872]	[0.367]	[0.884]

*p<0.1; **p<0.05; ***p<0.01
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure described in Ferman e Pinto (2019).
There are 264 municipalities in the control group for Minas Gerais state and 23 in the control group Espírito Santo state.

Table A.30 – Estimated lower bound of the disaster's effect on psychiatric centers' attendance, by control group. ***Upstream reservoir municipalities.***

	Attendance in psycho-social care center per 100,000 inhab.				
	(1) All municipalities	*(2)* Intermediate region	*(3)* Doce river basin	*(4)* Excluded frontier munic.	*(5)* Baseline before disaster
Stress-related	-32.824	-21.965	-47.131	-21.463	2.82
	[0.553]	[0.629]	[0.524]	[0.586]	
Psychoactive substance use	-368.073	-416.528	-627.843	-451.809	305.12
	[0.999]	[0.996]	[0.994]	[0.994]	
Mood disorders	3.49	-14.089	-101.988	-17.415	230.07
	[0.112]	[0.502]	[0.647]	[0.422]	
Personality and behaviour	-4.487	-8.975	-11.714	-10.445	0.00
	[0.399]	[0.586]	[0.513]	[0.526]	
Organic mental disorders	-5.264	-9.853	-16.798	-10.434	4.20
	[0.548]	[0.709]	[0.734]	[0.659]	
Disorders w/ onset on childhood/adolescence	5.386	-0.59	-70.308	2.052	0.00
	[0.188]	[0.319]	[0.863]	[0.234]	
Behavioural syndromes	2.308**	2.394*	0.453	2.254*	0.00
	[0.033]	[0.066]	[0.391]	[0.068]	
Psychological development	36.572**	43.235*	27.906*	44.718*	0.00
	[0.035]	[0.064]	[0.09]	[0.073]	
Schizophrenia	-35.805	-94.575	-288.244	-72.994	491.23
	[0.429]	[0.713]	[0.909]	[0.609]	
Non-organic psychosis	-6.498	-22.578	-55.9	-16.093	66.67
	[0.533]	[0.772]	[0.912]	[0.528]	
Mental retardation	-18.155	-35.31	-28.894	-44.395	31.90
	[0.409]	[0.687]	[0.692]	[0.585]	
Other	27.008**	-7.788	-22.199	-7.244	0.00
	[0.031]	[0.501]	[0.99]	[0.901]	
Municipality fixed effects	x	x	x	x	-
Time fixed effects	x	x	x	x	-
Control variables	x	x	x	x	-
Munic. in affected group	1	1	1	1	1
Munic. in control group	183	71	29	57	-

*p<0.1; **p<0.05; ***p<0.01
[1]The only affected municipality in this category is Mariana.
The coefficients are estimated based on equation 4.2.
P-values are reported in brackets and are obtained using the bootstrapping procedure presented by Ferman e Pinto (2019).

Table A.31 – Estimated lower bound of the disaster's effect on psychiatric centers' attendance, by control group. ***Downstream reservoir municipalities.***

	Attendance in psycho-social care center per 100,000 inhab.				
	(1) All municipalities	*(2)* Intermediate region	*(3)* Doce river basin	*(4)* Excluded frontier munic.	*(5)* Baseline before disaster
Stress-related	35.487	42.414	30.226	41.931	17.03
	[0.223]	[0.29]	[0.371]	[0.297]	
Psychoactive substance use	-84.726	-71.609	-174.885	-71.145	142.22
	[0.672]	[0.606]	[0.754]	[0.567]	
Mood disorders	71.106	87.52	111.765	89.162	56.25
	[0.203]	[0.226]	[0.288]	[0.234]	
Personality and behaviour	4.704	8.103	10.397	7.945	3.93
	[0.283]	[0.271]	[0.305]	[0.271]	
Organic mental disorders	0.408	1.281	0.254	1.379	3.89
	[0.325]	[0.349]	[0.442]	[0.423]	
Disorders w/ onset on childhood/adolescence	61.143***	63.35**	63.797**	65.821**	1.64
	[0.005]	[0.029]	[0.047]	[0.01]	
Behavioural syndromes	2.868*	2.891	3.329	2.922	0.56
	[0.07]	[0.101]	[0.156]	[0.135]	
Psychological development	5.52	6.605	11.925	6.609	0.50
	[0.209]	[0.216]	[0.147]	[0.263]	
Schizophrenia	57.647	71.808	112.582	73.677	66.48
	[0.258]	[0.214]	[0.202]	[0.277]	
Non-organic psychosis	2.363	1.501	-2.876	1.55	14.50
	[0.356]	[0.396]	[0.439]	[0.4]	
Mental retardation	25.026	26.894	22.73	26.276	11.54
	[0.209]	[0.275]	[0.324]	[0.298]	
Other	-6.1	2.413	5.525	3.34	0.33
	[0.455]	[0.364]	[0.303]	[0.34]	
Municipality fixed effects	x	x	x	x	-
Time fixed effects	x	x	x	x	-
Control variables	x	x	x	x	-
Munic. in affected group	1	1	1	1	1
Munic. in control group	183	71	29	57	-

*p<0.1; **p<0.05; ***p<0.01

[1]There are ten affected municipalities in this category: Conselheiro Pena, Caratinga, Governador Valadares, Ipatinga, Resplendor, Aimores, Belo Oriente, Sao Domingos do Prata, Timoteo and Ipaba.

The coefficients are estimated based on equation 4.2.

P-values are reported in brackets and are obtained using the bootstrapping procedure presented by Ferman e Pinto (2019).

Table A.32 – Estimated lower bound of the disaster's effect on psychiatric centers' attendance, by control group. ***Indirectly affected municipalities.***

	Attendance in psycho-social care center per 100,000 inhab.				
	(1) All municipalities	*(2)* Intermediate region	*(3)* Doce river basin	*(4)* Excluded frontier munic.	*(5)* Baseline before disaster
Stress-related	36.21**	45.023	23.626	47.897	40.85
	[0.049]	[0.307]	[0.291]	[0.318]	
Psychoactive substance use	745.418***	748.241***	718.906***	737.863***	641.57
	[0]	[0.001]	[0.007]	[0.002]	
Mood disorders	387.954***	393.033***	329.488**	399.459***	175.10
	[0.002]	[0.004]	[0.018]	[0.004]	
Personality and behaviour	-3.636	-3.385	-2.643	-3.798	8.63
	[0.353]	[0.405]	[0.29]	[0.356]	
Organic mental disorders	-2.553	-2.952	-2.707	-3.476	7.75
	[0.344]	[0.473]	[0.396]	[0.461]	
Disorders w/ onset on childhood/adolescence	26.979*	23.071	-41.448	28.591	0.64
	[0.095]	[0.181]	[0.845]	[0.106]	
Behavioural syndromes	-1.745	-1.564	-2.521	-1.506	1.72
	[0.987]	[0.961]	[0.977]	[0.84]	
Psychological development	12.381	17.098*	7.557	18.498	0.21
	[0.106]	[0.092]	[0.222]	[0.115]	
Schizophrenia	489.476**	481.662**	473.32	486.863**	471.48
	[0.012]	[0.049]	[0.114]	[0.016]	
Non-organic psychosis	36.746***	30.333*	24.694	30.941	28.97
	[0.005]	[0.09]	[0.156]	[0.131]	
Mental retardation	0.951	1.109	7.826	-0.712	27.70
	[0.166]	[0.411]	[0.372]	[0.378]	
Other	15.164*	0.76	-5.298	0.727	0.00
	[0.097]	[0.405]	[0.721]	[0.553]	
Municipality fixed effects	x	x	x	x	-
Time fixed effects	x	x	x	x	-
Control variables	x	x	x	x	-
Munic. in affected group	1	1	1	1	1
Munic. in control group	183	71	29	57	-

*p<0.1; **p<0.05; ***p<0.01

[1]Affected municipalities are: Ouro Preto, Congonhas and Ponte Nova.

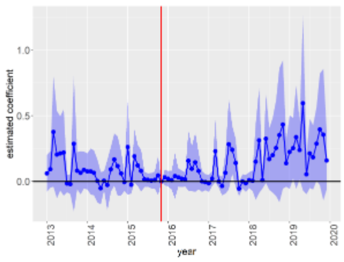
The coefficients are estimated based on equation 4.2.

P-values are reported in brackets and are obtained using the bootstrapping procedure presented by Ferman e Pinto (2019).

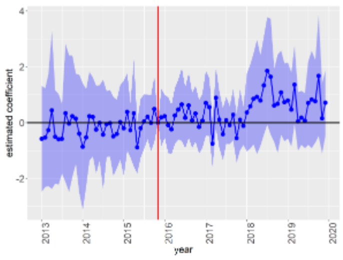
B Figures

Figure B.1 – Relative hospitalizations conditional on socioeconomic characteristics, Minas Gerais state. Control group: ***All municipalities.***

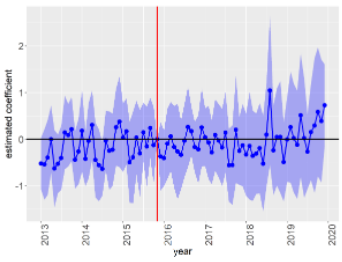
(a) Stress-related disorders



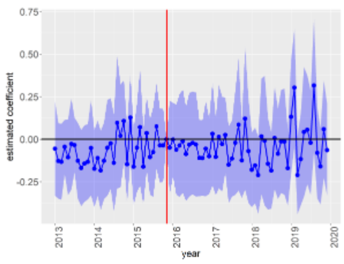
(b) Psychoactive substance



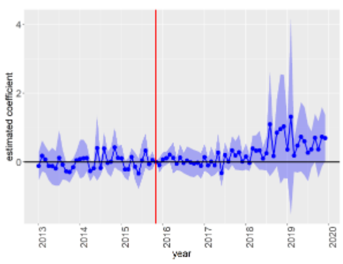
(c) Mood disorders



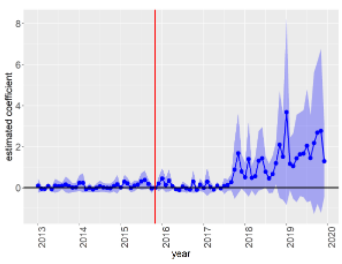
(d) Personality and behaviour



(e) Dementia-related disorders



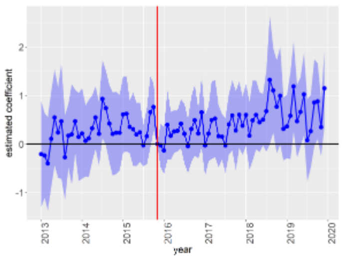
(f) Disorders with onset on childhood



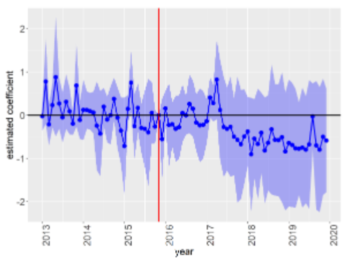
(g) Behavioural syndromes

(h) Psychological develop.

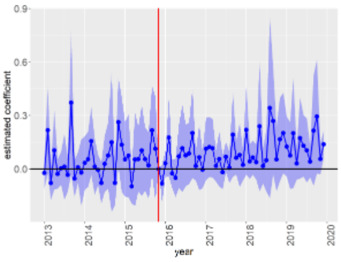
(i) Schizophrenia related



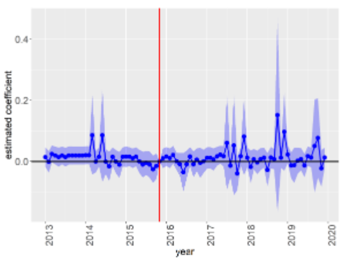
(j) Non-organic psychosis



(k) Mental retardation

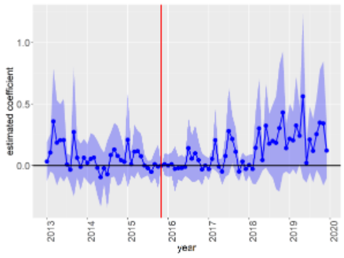


(l) Other mental disorders

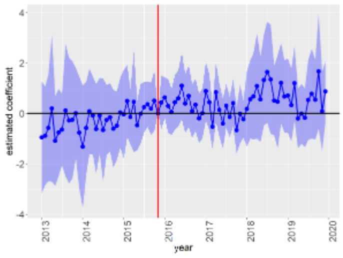


We plot the estimate of α_t based on equation 5.1 for each period (month/year) wtih a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

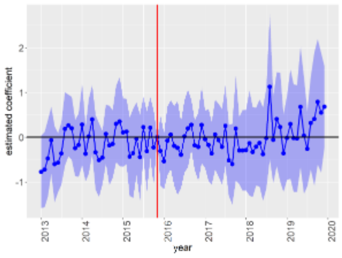
Figure B.2 – Relative hospitalizations conditional on socioeconomic characteristics, Minas Gerais state. Control Group: ***Intermediate region.***



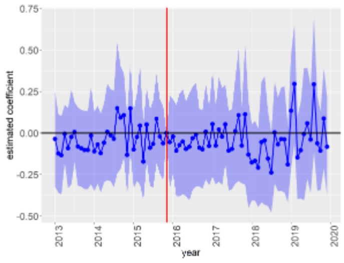
(a) Stress-related disorders



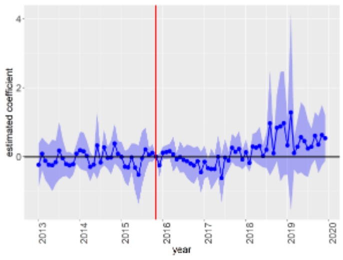
(b) Psychoactive substance



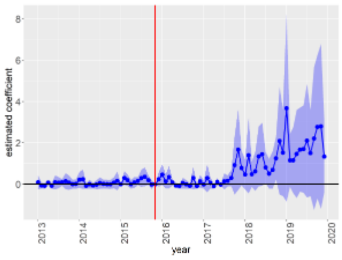
(c) Mood disorders



(d) Personality and behaviour

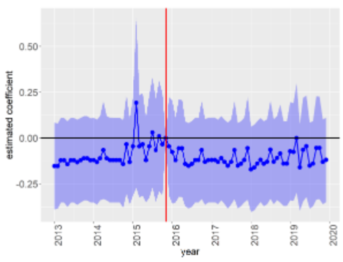


(e) Dementia-related disorders

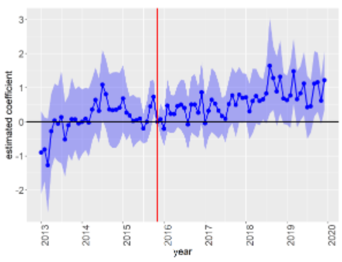


(f) Disorders with onset on childhood

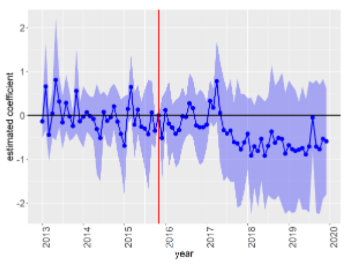
(g) Behavioural syndromes



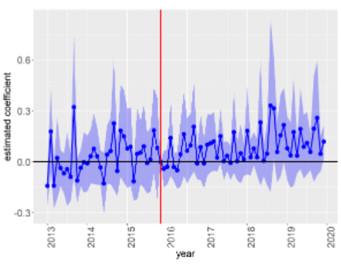
(h) Psychological develop.



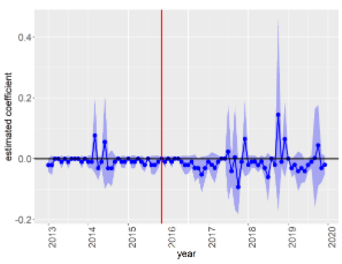
(i) Schizophrenia related



(j) Non-organic psychosis



(k) Mental retardation

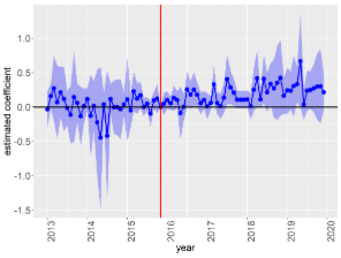


(l) Other mental disorders

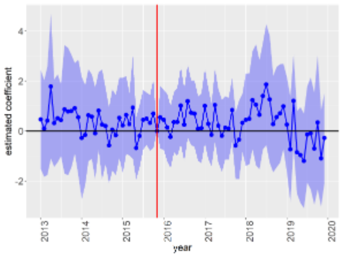
We plot the estimate of α_t based on equation 5.1 for each period (month/year) wtih a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

Figure B.3 – Relative hospitalizations conditional on socioeconomic characteristics, Minas Gerais state. Control group: ***Doce river basin.***

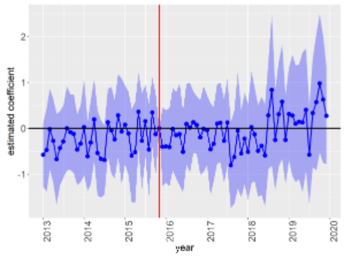
(a) Stress-related disorders



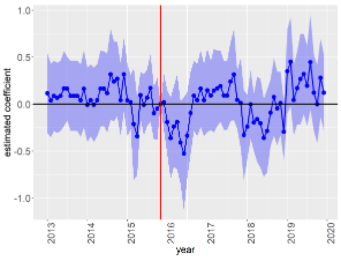
(b) Psychoactive substance



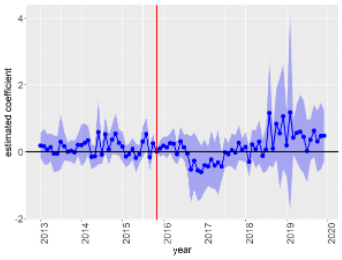
(c) Mood disorders



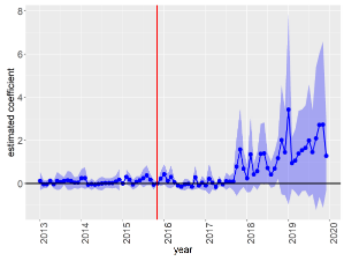
(d) Personality and behaviour



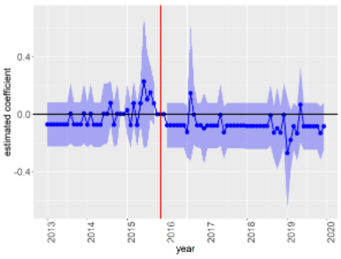
(e) Dementia-related disorders



(f) Disorders with onset on childhood

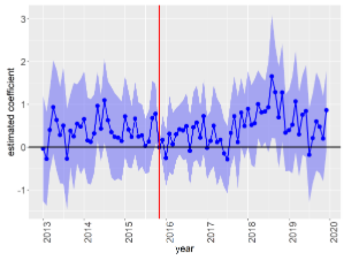


(g) Behavioural syndromes

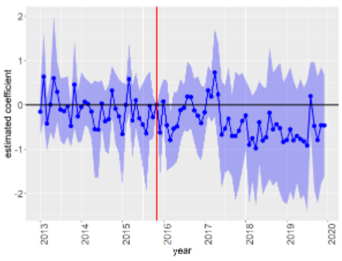


(h) Psychological develop.

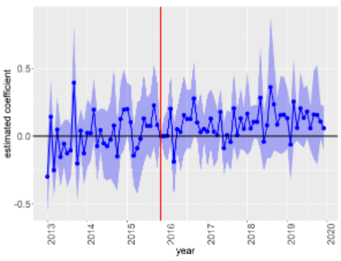
(i) Schizophrenia related



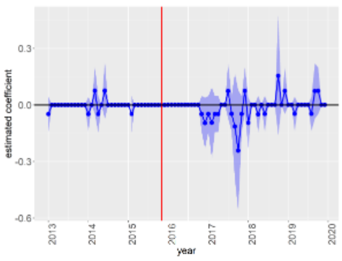
(j) Non-organic psychosis



(k) Mental retardation



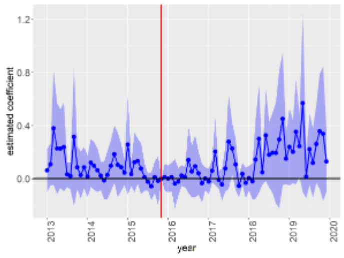
(l) Other mental disorders



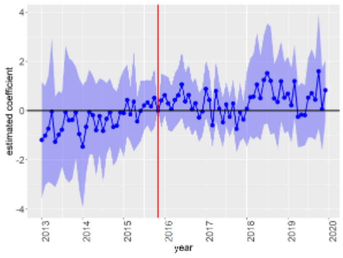
We plot the estimate of α_t based on equation 5.1 for each period (month/year) wtih a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

Figure B.4 – Relative hospitalizations conditional on socioeconomic characteristics, Minas Gerais state. Control group:***Excluded frontier municipalities.***

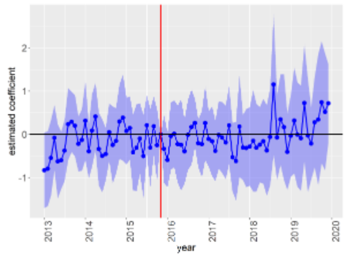
(a) Stress-related disorders



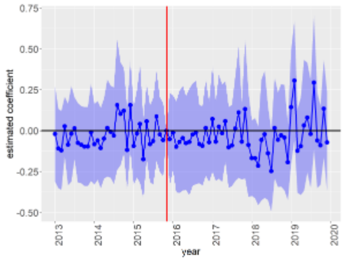
(b) Psychoactive substance



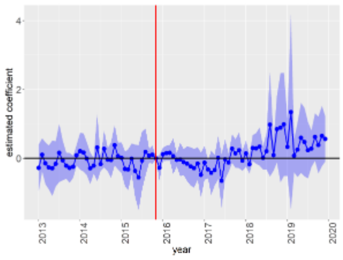
(c) Mood disorders



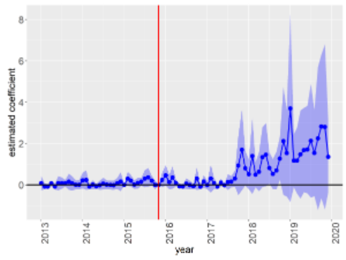
(d) Personality and behaviour



(e) Dementia-related disorders

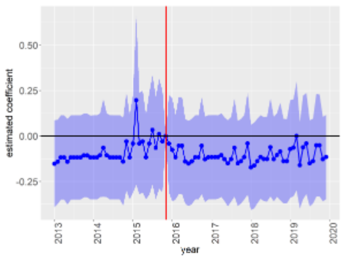


(f) Disorders with onset on childhood

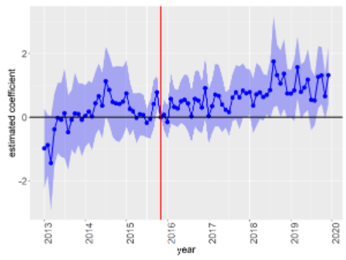


(g) Behavioural syndromes

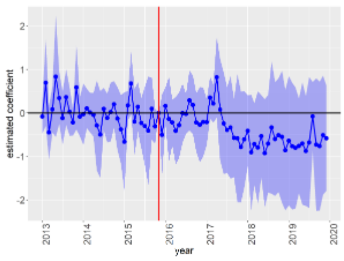
(h) Psychological develop.



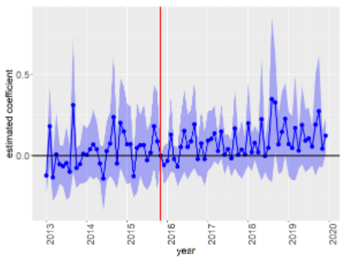
(i) Schizophrenia related



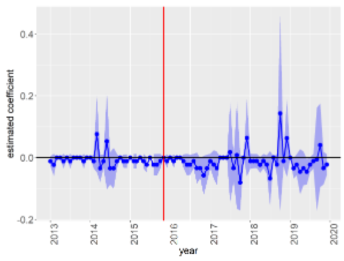
(j) Non-organic psychosis



(k) Mental retardation



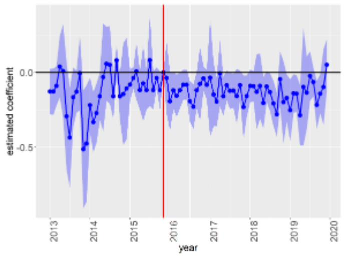
(l) Other mental disorders



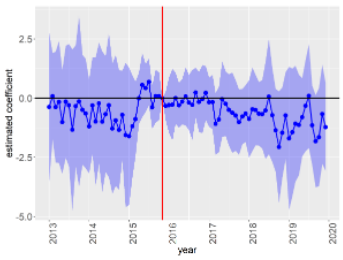
We plot the estimate of α_t based on equation 5.1 for each period (month/year) wtih a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

Figure B.5 – Relative hospitalizations conditional on socioeconomic characteristics, Espirito Santo state. Control group: ***all municipalities.***

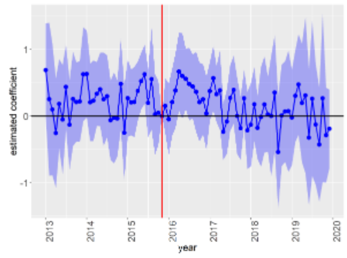
(a) Stress-related disorders



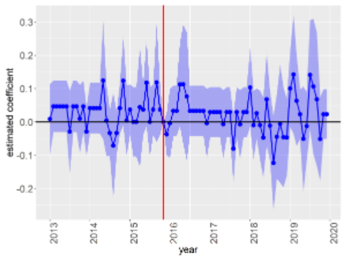
(b) Psychoactive substance



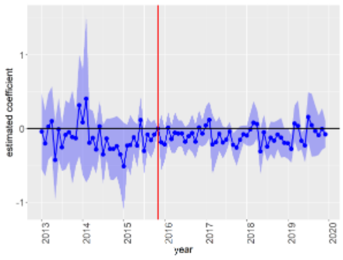
(c) Mood disorders



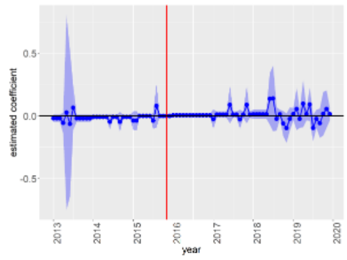
(d) Personality and behaviour



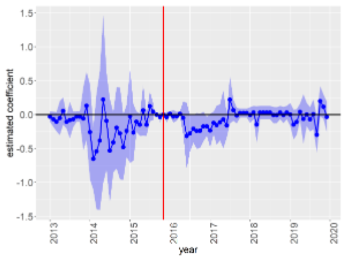
(e) Dementia-related disorders



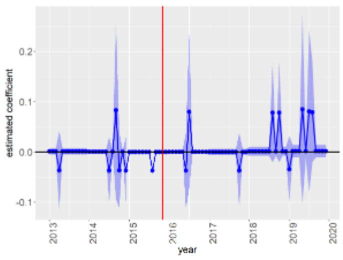
(f) Disorders with onset on childhood



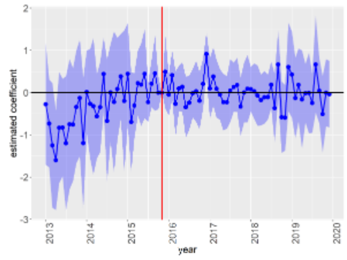
(g) Behavioural syndromes



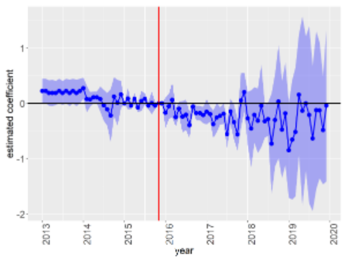
(h) Psychological develop.



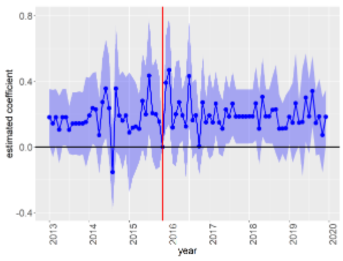
(i) Schizophrenia related



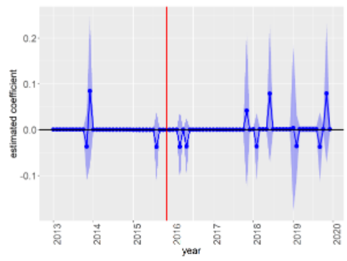
(j) Non-organic psychosis



(k) Mental retardation



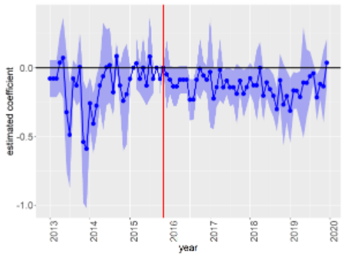
(l) Other mental disorders



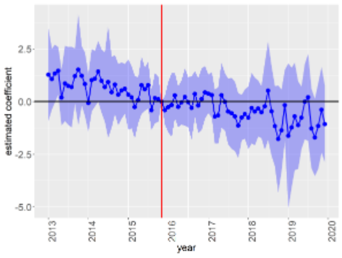
We plot the estimate of α_t based on equation 5.1 for each period (month/year) wtih a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

Figure B.6 – Relative hospitalizations conditional on socioeconomic characteristics, Espirito Santo state. Control group: ***Intermediate region.***

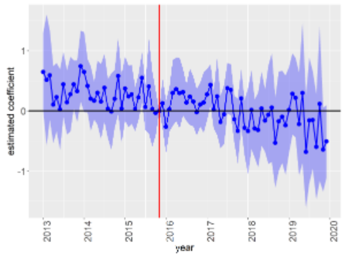
(a) Stress-related disorders



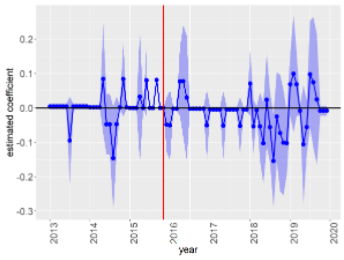
(b) Psychoactive substance



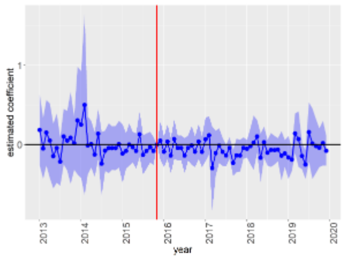
(c) Mood disorders



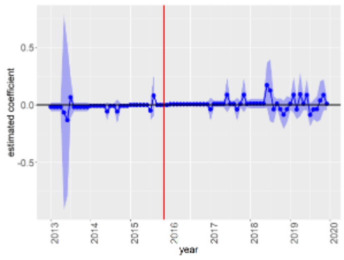
(d) Personality and behaviour



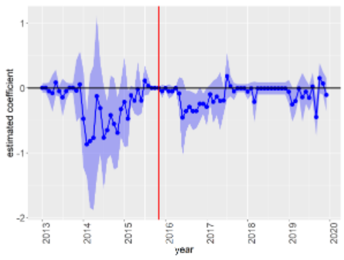
(e) Dementia-related disorders



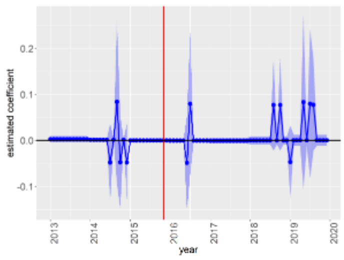
(f) Disorders with onset on childhood



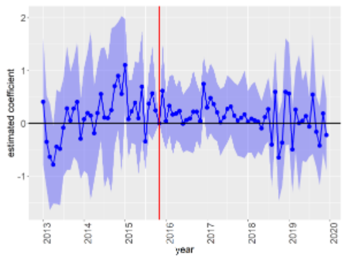
(g) Behavioural syndromes



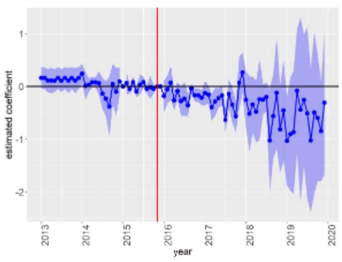
(h) Psychological develop.



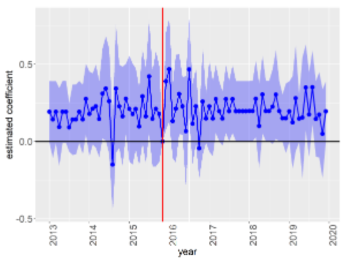
(i) Schizophrenia related



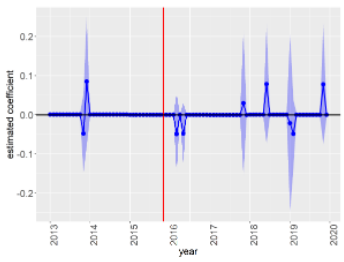
(j) Non-organic psychosis



(k) Mental retardation



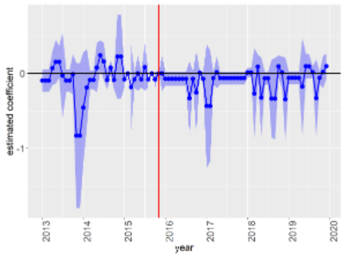
(l) Other mental disorders



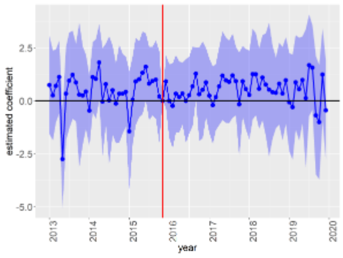
We plot the estimate of α_t based on equation 5.1 for each period (month/year) wtih a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

Figure B.7 – Relative hospitalizations conditional on socioeconomic characteristics, Espirito Santo state. Control group:***Doce river basin.***

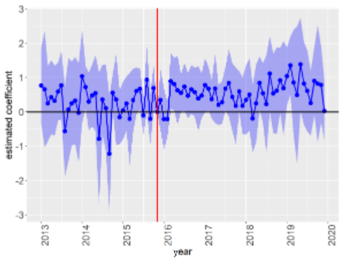
(a) Stress-related disorders



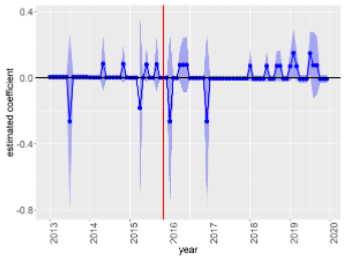
(b) Psychoactive substance



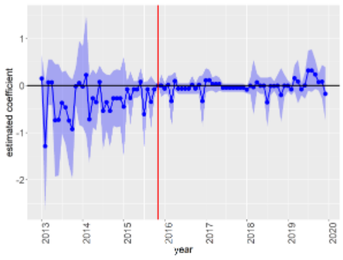
(c) Mood disorders



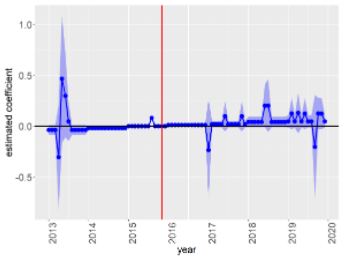
(d) Personality and behaviour



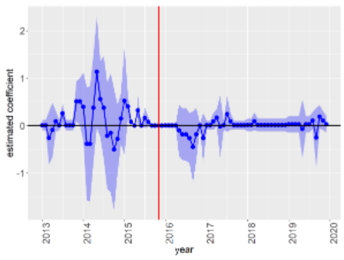
(e) Dementia-related disorders



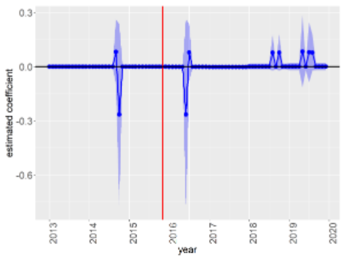
(f) Disorders with onset on childhood



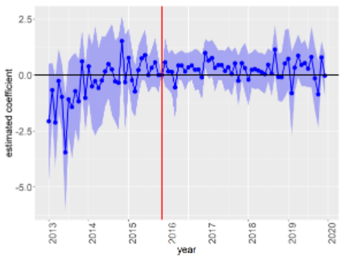
(g) Behavioural syndromes



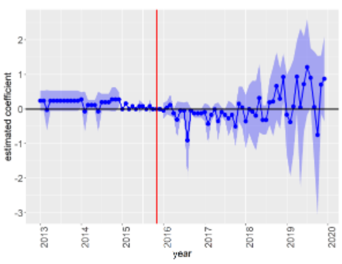
(h) Psychological develop.



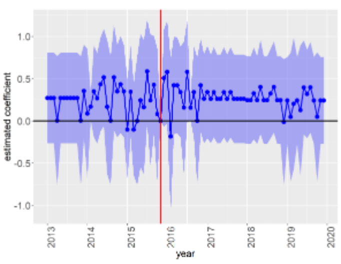
(i) Schizophrenia related



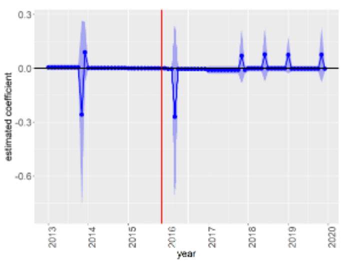
(j) Non-organic psychosis



(k) Mental retardation



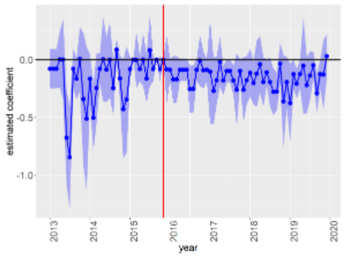
(l) Other mental disorders



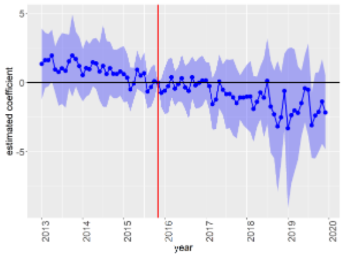
We plot the estimate of α_t based on equation 5.1 for each period (month/year) wtih a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

Figure B.8 – Relative hospitalizations conditional on socioeconomic characteristics, Espirito Santo state. Control group: ***excluded frontier municipalities.***

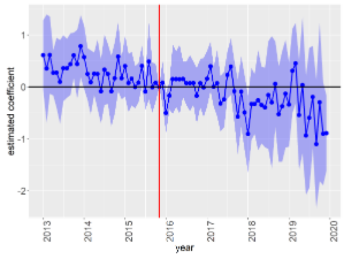
(a) Stress-related disorders



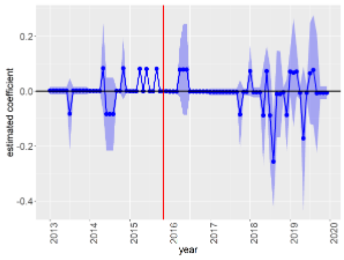
(b) Psychoactive substance



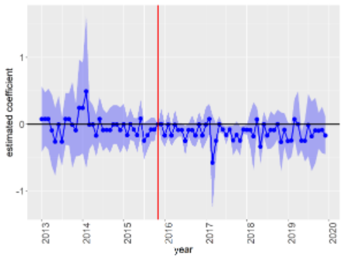
(c) Mood disorders



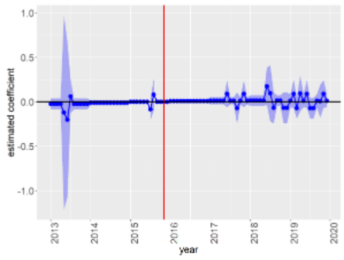
(d) Personality and behaviour



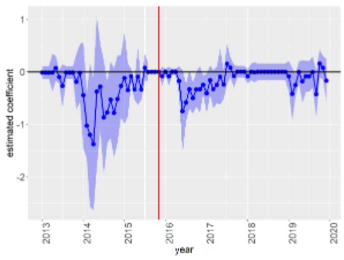
(e) Dementia-related disorders



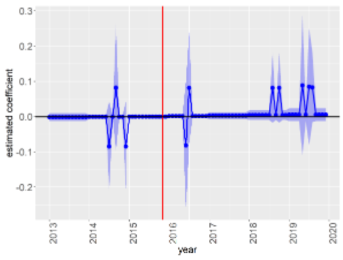
(f) Disorders with onset on childhood



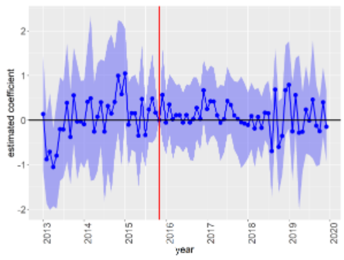
(g) Behavioural syndromes



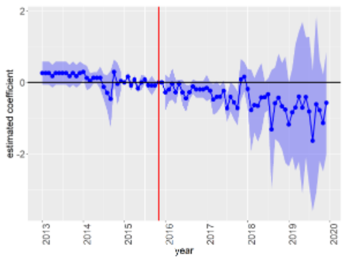
(h) Psychological develop.



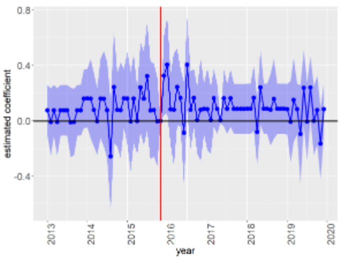
(i) Schizophrenia related



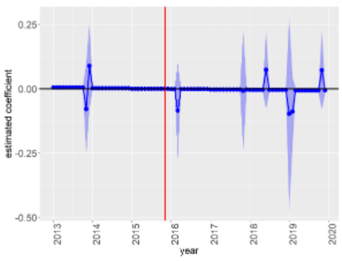
(j) Non-organic psychosis



(k) Mental retardation



(l) Other mental disorders



We plot the estimate of α_t based on equation 5.1 for each period (month/year) wtih a 95% confidence interval. We normalize α_{nov15} to zero. The red vertical line represents nov/2015 - the month of Fundao's collapse.

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