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An economic investigation of the dengue incidence as a result of a tailings dam accident in Brazil

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Abstract: On November 2015, the Fundão Tailings Dam, located at Mariana municipality in Brazil, failed. Besides the deaths and injuries, economic losses, pollution and health problems associated to heavy metals in the water, Brazilian municipalities near the accident experienced an increase in the incidence of dengue. Since dengue fever is an insect-borne disease and the mosquito develops where there is stored water, there must be a relationship between the dam accident and the incidence of the disease. The purpose of this study is to test whether there is a causal relationship between the dam accident in Mariana and the number of dengue cases, number of hospitalizations due to dengue, and dengue outbreak in the municipalities affected by the accident. We find evidence that the accident had a positive and statistically significant impact on dengue indicators (for example, the probability of a dengue outbreak increased in 19%), what makes us call attention to another negative externality of tailings dam accidents.

Keywords: tailings dam accident, dengue outbreak, dengue incidence, Mariana, Brazil

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Keywords: dam accident, dengue outbreak, Mariana, Brazil

JEL Codes: I18, Q25, Q28, J28

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1. Introduction

The lack of a comprehensive database on tailings dams in Brazil has prevented analysis of the causes of their failures and, most importantly, of the severity and consequences of the major accidents.

The state of Minas Gerais is the center of mining in Brazil and the home of the worst environmental disaster caused by a tailings dam accident in Brazilian history.[i] In November 2015, Samarco's tailings facility burst (a dam known as Fundão), and completely destroyed the district of Bento Rodrigues located in the municipality of Mariana.[ii]

Two aspects made Bento Rodrigues/Mariana's accident (from now on Mariana) remarkable (Bowker Associates 2015). First, the volume of iron-mining tailings and toxic sludge released (50 to 60 million of m^3) was impressive, corresponding to almost the same amount released on the accidents in the Philippines in 1982 (28 million of m^3) and 1992 (32.2 million of m^3) together. Around the world, only 5 tailings dam accidents released a flood larger than 10 million m^3. The other aspect is that the waste reached around twice the distance reached on the second worst accident, the one which took place in Bolivia in 1996. The sludge traveled downstream the Doce River and its tributaries, till it reached the ocean.

Fortunately, although 80% of tailings were settled until the Hydroelectric Power Plant of Risoleta Neves (Candonga), more than 100 km away from Mariana, it did not collapse. The immediate impacts, however, were immense. The water supply to the residents of municipalities fed by the local rivers was discontinued, infrastructure was severely damaged, buildings were destroyed, several hectares of vegetation were affected, fish and other animals were killed, hundreds of people were displaced, 19 people died.

There is some literature that provides empirical evidence on the economic effects of natural disasters. Yang (2008) studies the impact of hurricane exposure on international flows to developing countries. Coffman and Nay (2012) estimate the effects on growth and population of a hurricane on the island of Kauai (Hawai). Cavallo et al. (2013) evaluate the causal impact of large natural disasters (earthquakes, storms, floods) on economic growth. Gallagher and Hartley (2017) measure the financial impact on families due to Hurricane Katrina.

The literature on the effects of non-natural disasters, for instance, the ones caused by the failure to built and maintain adequate infrastructure (and that therefore could be avoided) is, however, scarce. We aim to contribute to the incipient literature of avoidable disasters and look for empirical evidence on the adverse health consequences of tailings dam failures for those living near the dams.[iii]

More specifically, we evaluate whether the dam accident in Mariana had an impact on dengue cases, hospitalizations due to dengue, and on dengue outbreak using the difference in differences identification strategy. We then show that there is another potential element that should be accounted for the cost-benefit analysis of tailings dam construction.

Brazil is an important case in point to study causes of dengue, since dengue and other insect-borne diseases such as malaria and yellow fever are endemic in the subtropical large country, being a challenge to be overcome by the public health authorities (Bhatt et al. 2013).

The study is organized in 5 sections, including this introduction and excluding the references. The second section briefly describes the dengue fever and its transmission and helps us to formulate the identification strategy. The third section carefully discusses and presents the empirical strategy. The fourth section shows and discuss the main results, while the fifth section concludes.

2. Dengue fever

Dengue fever is a mosquito-borne (*Aedes aegypti* mosquito) disease characterized by its rapid transmission speed. It is endemic in tropical and subtropical areas.[iv] The mosquitoes thrive in urban areas and they lay their eggs in water-filled containers (Scholte et al. 2007). The eggs hatch when in contact with water and can survive for months.

The viruses are passed on to humans through the bites of an infected female mosquito. A female mosquito, usually, acquires the virus while feeding on the blood of an infected person, so infected humans are the source of the virus for uninfected mosquitoes and as such become the main multipliers of the disease.

The dengue virus comprises four different serotypes (DEN-1, DEN-2, DEN-3, and DEN-4). Recovery from infection by one dengue virus provides immunity only against that particular virus serotype.

Although dengue is an acute, infectious disease, that incapacitates temporarily the individuals, normally, it is not fatal. Severe dengue (previously known as dengue hemorrhagic fever - DHF), however, is a complication of the disease that usually occurs in the second contact with the virus being characterized by hemorrhaging blood vessels.

The early symptoms of the disease include fever, malaise, headache, joint pain, swollen lymph nodes, and skin rash. Success in treatment involves rapid diagnosis and immediate start of intravenous rehydration therapy.[v] It is not possible from the first symptoms to predict which patients will evolve to the severe form of the disease.

Since there is no dengue vaccine available for the population, the main alternative to prevent dengue spread is to control the mosquito (the vector). This control is made by environmental management, chemical and biological methods. The first two include "source reduction, 'cleanup' campaigns, regular container emptying and cleaning (targeting not only households, but also public spaces such as cemeteries, green areas, and schools), installation of water supply systems, solid waste management, and urban planning" (Guzman et al. 2010). The last method involves the application of larvicides, by biological control agents, to water stored for domestic use.

A key part of prevention policy involves educating the population and giving them the correct incentives to act preventively against dengue (Bouri et al. 2012). Public health authorities depend heavily on population's behavior to carry successful cleanup campaigns, which involves getting rid of standing water in flowerpots, non-used bottles, containers, discarded tires, and properly cleaning gutters and swimming pools.

This brief overview of the disease brings three important pieces of information used to design the identification strategy:

1) The mosquitoes lay their eggs in water-filled containers. Thus, the discontinuation of freshwater supply after the accident made the local

population store water in containers not exactly suited for it, increasing the number of mosquitoes breeding places (Schmidt et al. 2011). The number of pools of standing water (mud mixed with water) expanded after the dam accident as well.

2) The mosquitoes thrive in urban areas (Scholte et al. 2007).
3) As well summarized by WHO: "Dengue cannot be spread directly from person to person. However, a person infected and suffering from dengue fever can infect other mosquitoes. Humans are known to carry the infection from one country to another or from one area to another during the stage when the virus circulates and reproduces in the blood system".

3. Empirical strategy

Brazil has a high risk of dam accidents. Because of its huge size is pretty difficult to map and regulate all its dams, mainly due to the numerous small dams located in private proprieties. According to the 2016 report of the Brazilian regulatory agency, Agência Nacional de Águas (ANA)[vi], there were 22,920 identified dams in Brazil. The report calls attention to the fact that only 3,174 dams were classified according to their risk of accidents and just 12,590 of them (or 55% of total dams) have any type of authorization to operate.

A dam accident (any kind of dam)[vii] can result from natural causes or bad planning (ANA, 2016). Aguiar (2014) points, however, that age and the lack of maintenance are the main causes of accidents in the country.

The ideal exercise to calculate the impact of dam accidents would involve comparing the dengue indicators in municipalities where dam accidents and their consequences were observed to the same indicators in municipalities with no dam accidents. Given the lack of information to do so, we investigate the change in the status quo of dengue before and after the Mariana accident in what we call the area of influence of the disaster.

The disaster had a direct impact on 39 municipalities, 36 of them located in the state of Minas Gerais and the 3 remaining in the state of Espírito Santo, the neighbor state.[viii] These municipalities represent a good treatment group to study the impact of the accident on water pollution, agricultural damages, fish mortality. Concerning dengue, however, we must include in the treated group, municipalities where pools of standing water and precarious forms of water storage due to the discontinuation of freshwater supply were observed after the accident, furnishing the perfect breed environment for the mosquitoes. Yet, as humans carry the infection from one area to another area, we must also include in the treatment group municipalities close do Mariana where local inhabitants usually travel to.[ix]

As people living in Brazil countryside usually do not travel far from their home towns, initially, we consider as the area of influence any municipality located on a 100 km ray from Mariana. We believe that this is a safe cutoff since Belo Horizonte, the capital of the state, is 84 km far from Mariana. Some people could go to Belo Horizonte to do some shopping or attend a special doctors' appointment, for example. We then constructed a dummy variable (d100) which assumes a value equal to one if a municipality is located on a 100km ray from Mariana and zero otherwise to have a treatment group (131 municipalities) and a control group (1,537 municipalities), respectively. After, we widen the area of influence building a dummy variable (d200) which assumes a value equal to one if a municipality is located on a 200km ray from Mariana and zero otherwise to include municipalities with restrictions of freshwater due to the accident. The treatment group, in this case, includes 453 municipalities and the control group 1,215 municipalities. Finally, almost as a placebo exercise, we included in the treatment group municipalities located on a 500 km ray from Mariana. Since these municipalities are too far away from Mariana, we do not expect to find any impact of the dam accident in this case.

As the dam accident in Mariana took place in November 2015 we choose 2014 as the year before the accident and 2016 as the year after the accident. Regarding the control group, only municipalities on the Southeast region (the richer, most populous and with higher population density) of the country were included. Doing so we restrict the differences among the units of analysis (especially the unobserved ones), although we control for several observed variables in our estimations.

We use three different dependent variables: the number of dengue cases per inhabitant, the number of hospitalizations due to dengue per inhabitant, and a dummy variable of the dengue outbreak. According to WHO's definition, an outbreak corresponds to the occurrence of more than 300 cases of a particular disease per 100,000 inhabitants so a dummy variable assumes a value equal to 1 if the municipality has more than 300 dengue cases per 100,000 inhabitants, and is zero otherwise.[x]

We estimate difference-in-differences (DD) models by ordinary least squares (OLS) and by fixed effect (FE) to control for time-invariant unobserved characteristics:

$$y_{it} = \beta_0 + \beta_1 d200 + \beta_2 d2016 + \beta_3 d200 * d2016 + \delta controls + u_{it} \quad (1)$$

Where y_{it} is one of our three dengue indicators: the number of dengue cases per inhabitant, the number of hospitalizations due to dengue per inhabitant, or a dengue outbreak dummy. The vector $controls$ contains the control variables: rainfall in millimeters (Hii et al. 2012; Sirisena et al. 2017), population density (Schmidt et al. 2011; Sirisena et al. 2017; Wen et al. 2012; Wu et al. 2009), and the log of per capita gross domestic product (GDP), year dummies, state dummies and year and state crossed dummies aiming to control for regional and federal policy interventions.

The parameter of interest is β_3 and we expect it to have a positive sign since, as we argued before, a dam accident tends to increase all of our dengue indicators.

All variables are defined at the municipality level and are summarized along with their sources at Table A1.

4. Results

Table 1 shows the difference of means between dengue indicators, before and after the tailings dam accident, for the treatment and control groups (200 km ray). We can see that the area of influence had lower dengue indicators before the accident and higher dengue indicators after the accident. The opposite happened in the municipalities not affected by the accident. The differences are statistically significant.

Table 1 – Differences for dengue indicators according to accident and non-accident areas - 2014 and 2016 (200 km ray)

	2014				2016			
	Accident	Non-Accident	Difference	(p-value)	Accident	Non-Accident	Difference	(p-value)
Dengue cases per capita	0.00202	0.00542	-0.0034	0.0000	0.02071	0.01095	0.00976	0.0000
Dengue hospitalizations per capita	0.00159	0.00608	-0.00449	0.0000	0.02068	0.01316	0.00752	0.0000
Dengue Outbreak	0.01185	0.03451	-0.02266	0.01608	0.27014	0.08266	0.18748	0.0000

Results based on Test t

Table 2 summarizes the estimation results of equation (1) using ordinary least squares (OLS). The first and the second columns give the estimates when the dependent variables are dengue cases per capita and dengue hospitalizations per capita, respectively. The third column gives the results when the dependent variable is the occurrence of a dengue outbreak. As the dependent variable, in this case, is a dummy variable, and due to all the problems that result from using a linear model, we also estimate a non-linear probit model to check its robustness, which is summarized in Table A3 in the annex.

The results indicate that after the dam accident there was on average a higher incidence of dengue per capita, a higher number of hospitalizations per capita and a higher probability of a dengue outbreak. The impact of the accident, given by the coefficient of the interaction After*Treated has the expected positive signs. It calls attention to the effect of the accident on the probability of an outbreak (19%).

Table 2 – DD with controls and 200km ray – OLS

VARIABLES	Dengue cases per capita	Dengue hospitalizations per capita	Dengue Outbreak
After	0.0078***	0.0102***	0.0621***
	(0.001)	(0.001)	(0.014)
Treated	0.0006	0.0005	0.0080
	(0.000)	(0.001)	(0.008)
After*Treated	0.0106***	0.0090***	0.1900***
	(0.001)	(0.002)	(0.026)
Log of precipitation in millimeters	0.0476***	0.0460***	0.4853***
	(0.004)	(0.006)	(0.068)
Population density	-0.0001	0.0005	0.0005
	(0.000)	(0.000)	(0.003)
Log of income per capita	0.0046***	0.0069***	0.0515***
	(0.001)	(0.001)	(0.010)
Observations	3,329	3,329	3,329
R-squared	0.190	0.100	0.100

*** p<0.01. Robust standard errors in parentheses: Included year dummies, state dummies and crossed year and state dummies. Standard errors clustered by municipality.

The results are similar when we compute fixed effects estimates (Table 3), which controls by the unobservable fixed characteristics of municipalities. The variable of interest (After*Treated) always shows a positive and statistically significant coefficient, indicating that the accident increased incidence per capita, hospitalization per capita, and occurrences of outbreaks.

Table 3 – DD with controls and 200km ray – FE

VARIABLES	Dengue cases per capita	Dengue hospitalizations per capita	Dengue Outbreak
After	0.0064***	0.0095***	0.0509***
	(0.001)	(0.002)	(0.017)
After*Treated	0.0104***	0.0089***	0.1889***
	(0.001)	(0.002)	(0.026)
Log of precipitation in millimeters	0.0905***	0.0370	0.5413
	(0.030)	(0.048)	(0.575)
Population density	-0.0047	0.0478	0.0613
	(0.017)	(0.057)	(0.377)
Log of income per capita	-0.0048	-0.0007	-0.0501
	(0.005)	(0.008)	(0.068)
Observations	3,329	3,329	3,329
R-squared	0.265	0.136	0.131
Number of municipalities	1,666	1,666	1,666

*** p<0.01. Robust standard errors in parentheses: Included year dummies and their values crossed with state dummies. Clustered errors by municipality.

As shown in Tables 2 and 3, and as expected, precipitation is an extremely important explanatory variable. Its coefficients are larger than the one associated to the dam accident, although they are not significant when we control for the non-observable fixed effects of the municipalities, except when the dependent variable is dengue cases per capita. Evidence in this direction is provided by Santos et al. (2019) who use wavelet methods to show that rainfall and dengue incidence (with no controls) are closely correlated and in phase in the state of Paraíba (northeast of Brazil), except during some periods when lags are observed due to breeding times. We did not find effects of the population density on dengue indicators.

The results are also robust to the choice of municipalities that compose the treatment group. We obtain the same significant and positive impact coefficients when the municipalities affected by the accident are the ones 100km far from Mariana. As expected, we find no effects of the accident when the treatment group includes the municipalities in the 500km ray. The results are in Table A2 in the annex.

To test if our results are not a random effect, we likewise perform a placebo exercise by "pretending" that Mariana's accident happened in 2011. Thus, the years 2010 and 2012 are the years before and after the fake accident. The municipalities on a 200km ray from Mariana are the treatment group, to keep the baseline design model, although we have tested the other areas of influence as well. Since no other dam accident happened during this time in Minas Gerais, we do not expect to obtain significant results. As we guessed, we do not find any impact of the "fake dam accident" on any of our dengue indicators as shown in Table 4 (OLS estimates) and Table 5 (fixed effects estimates), which reinforces the main results as non-random.

Table 4 – Placebo DD with controls and 200 km ray – OLS

VARIABLES	Dengue cases per capita	Dengue hospitalizations per capita	Dengue Outbreak
After	-0.0056***	-0.0031***	-0.0565***
	(0.001)	(0.001)	(0.012)
Treated	0.0002	0.0019*	-0.0029
	(0.001)	(0.001)	(0.015)
After*Treated	0.0005	-0.0013	0.0131
	(0.001)	(0.001)	(0.016)
Observations	3,332	3,332	3,332
R-squared	0.124	0.046	0.031

*** p<0.01, * p<0.1. Robust standard errors in parentheses: Included logarithm of precipitation in millimeters, population density, logarithm of income per capita, year dummies, state dummies and crossed year and state dummies. Standard errors clustered by municipality.

Table 5 – Placebo DD with controls and 200 km ray – FE

VARIABLES	Dengue cases per capita	Dengue hospitalizations per capita	Dengue Outbreak
After	-0.0059***	-0.0029***	-0.0612***
	(0.001)	(0.001)	(0.012)
After*Treated	0.0005	-0.0015	0.0124
	(0.001)	(0.001)	(0.016)
Observations	3,332	3,332	3,332
R-squared	0.152	0.048	0.046
Number of municipalities	1,666	1,666	1,666

*** p<0.01. Robust standard errors in parentheses: Included logarithm of precipitation in millimeters, population density, logarithm of income per capita, year dummies, and crossed year and state dummies. Standard errors clustered by municipality.

According to Klinke and Renn (1999), when we evaluate the consequences of a tailings dam failure on the population and the environment, we must take into account the number of lost lives, the damaged surface and the persistence of the damages. Hatje et al. (2017)

point that the environmental impacts of Mariana's accident involve heavy rain and its consequences (enhanced erosion, remobilization and transport of contaminated particles), that will threaten the ecosystem for the years to come. We call attention to another negative externality of a tailings dam accident, the spread of diseases like dengue.[xi] Besides the immediate impacts, dengue spiked pressuring the few medical personnel and public health workers and draining the already scarce resources.

5. Conclusions

The paper verifies whether the dam accident in Mariana had an impact on the number of dengue cases, the number of hospitalizations due to dengue, and dengue outbreak in the municipalities affected by the accident. We find evidence that the dam failure had a negative impact, increasing all health indicators.

Our results and the perspective of new dam accidents in Brazil, given poor maintenance and regulation of tailings dams, add another source of concern to the Brazilian authorities. A new tragic tailings dam accident already took place in Brumadinho (another municipality in the state of Minas Gerais) in January 2019.

Dam’s accidents can have worse consequences in countries with diseases like dengue than in other countries. The increase in the disease indicators has a direct effect on health and all its associated costs, such as medical treatment and loss of workdays due to problems of morbidity. These costs represent direct negative externalities, but dengue also brings indirect effects. The disease increases both health and education costs. As children are particularly affected by the mosquitoes, they miss classes what harm their regular learning activities (Barron et al. 2015). Madsen (2015) points out that the prevalence of parasitic and infectious diseases affects the growth in labor productivity and inequality through the channel of cognitive ability.

As the main public policies for dengue prevention rests on the vector control, the results depend crucially on government actions. Our results add to these prevention policies, a need of stronger regulation to equalize the private cost of economic activities that involve dams in their facilities to its social cost.

7. References

Aguiar DPO (2014). Contribuição ao Estudo do Índice de Segurança de Barragens – ISB. Master dissertation - University of Campinas. Available at http://repositorio.unicamp.br/bitstream/REPOSIP/258108/1/Aguiar_DanielPrendadeOliveira_M.pdf.

ANA, Agência Nacional de Águas (2016) Encarte Especial sobre a Bacia do Rio Doce Rompimento da Barragem em Mariana/MG. https://www.ana.gov.br/sala-de-situacao/rio-doce/documentos-relacionados/encarte-qualidade-da-gua-do-rio-doce-dois-anos-apos-rompimento-de-barragem-de-fundao-1.pdf

Barron K, Gamboa L, and Rodriguez-Lesmes P. (2015). Short Term Health Shocks and School Attendance: The Case of a Dengue Fever Outbreak in Colombia, Documentos De Trabajo 012646. Universidad Del Rosario. https://ideas.repec.org/p/col/000092/012646.html

Bhatt S, Gething PW, Brady OJ, Messina JP, Farlow AW, Moyes CL, Drake JM, Brownstein JS, Hoen AG, Sankoh O, Myers MF, George DB, Jaenisch T, Wint JRW, Simmons CP, Scott TW, Farrar JJ, and Hay SI (2013). The global distribution and burden of dengue. Nature, v 496, 504–507. http://dx.doi.org/10.1038/nature12060

Bouri N, Sell TK, Franco C, Adalja A, Henderson DA, and Hynes NA (2012) Return of epidemic dengue in the United States: implications for the public health practitioner. Public Health Reports 127(3):259–266. https://doi.org/10.1177/003335491212700305

Bowker Associates (2015). Samarco Dam Failure Larges by Far in Recorded History, https://lindsaynewlandbowker.wordpress.com/2015/12/12/samarco-dam-failure-largestby-far-in-recorded-history/.

Cavallo E, Galiani S, Noy I, and Pantano JCA (2013) Catastrophic Natural Disasters and Economic Growth. The Review of Economics and Statistics, 1549-1561.

Coffman M and Noy I (2012) Hurricane Iniki: Measuring the Long-term Economic Impact of Natural Disaster Using Synthetic Control. Environment and Development Economics, v. 17, 04.

Gallagher J and Hartley D (2017) Household Finance After a Natural Disaster: The Case of Hurricane Katrina. American Economic Journal : Economic Policy, 09.

Gardner L, and Sarkar S (2013). A global airport-based risk model for the spread of dengue infection via the air transport network. PLoS One. 8(8):e72129. doi: 10.1371/journal.pone.0072129.

Gu W, Regens JL, Beier JC, and Novak RJ (2006). Source reduction of mosquito larval habitats has unexpected consequences on malaria transmission. Proceedings of the National Academy of Sciences of the United States of America, 103:17560–63. https://doi.org/10.1073/pnas.0608452103

Guzman MG, Halstead SB, Artsob H, Buchy P, Farrar J, Gubler DJ, Hunsperger E, Kroeger A, Margolis HS, Martínez E, Nathan MB, Pelegrino JL, Simmons C, Yoksan S, and Peeling RW (2010). Dengue: a continuing global threat. Nature Reviews Microbiology, 8:S7–S16. DOI: 10.1038/nrmicro2460

Hatje V, Pedreira RMA, Rezende CE, Schettini CAF, Souza GC, Marin DC, and Hackspacher PC (2017). The Environmental Impacts of One of the Largest Tailing Dam Failures Worldwide. Scientific Reports, 7(1):10706. DOI: 10.1038/s41598-017-11143x

Higa Y (2011). Dengue Vectors and their Spatial Distribution. Tropical Medicine and Health. 39(4 Suppl): 17–27. DOI: 10.2149/tmh.2011-S04.

Hii YL, Zhu H, Ng N, Ng LC, and Rocklöv J. (2012). Forecast of Dengue Incidence Using Temperature and Rainfall. PLoS Neglected Tropical Disease, 6(11):e1908. https://doi.org/10.1371/journal.pntd.0001908

Huber K, Loan LL, Hoang TH, Tien TK, Rodhain F, and Failloux AB (2002). Temporal genetic variation in Aedes aegypti populations in Ho Chi Minh City (Vietnam). Heredity 89: 7-14. https://doi.org/10.1038/sj.hdy.6800086

Klinke A and Renn O (1999). Prometheus Unbound. Challenges of Risk Evaluation, Risk Classification, and Risk Management. Report 153 (1999), Center of Technology Assessment. Stuttgart, Germany. DOI: 10.18419/opus-8558

Li Q, Cao W, Ren H, Ji Z, and Jiang H (2018). Spatiotemporal Responses of Dengue Fever Transmission to the Road Network in an Urban Area. Acta Tropica, v.183, p. 8-13. https://doi.org/10.1016/j.actatropica.2018.03.026

Madsen JB (2015) Barriers to Prosperity: Parasitic and Infectious Diseases, IQ, and Economic Development. World Development, v. 78: pp.172-187.

Nakata Y and Rost G (2015). Global Analysis for Spread of Infectious Diseases Via Transportation Networks. Journal of Mathematical Biology. 70, 1411–1456. https://doi.org/10.1007/s00285-014-0801-z

Sanna M and Hsieh YH (2017). Temporal Patterns of Dengue Epidemics: The Case of Recent Outbreaks in Kaohsiung. Asian Pacific Journal of Tropical Medicine, 10(3), 292-298. https://doi.org/10.1016/j.apjtm.2017.03.009t

Santos CAG, Guerra-Gomes IC, Gois BM, Peixoto RF, Keesen TSL, and da Silva RM (2019). Correlation of Dengue Incidence and Rainfall Occurrence Using Wavelet Transform for João Pessoa City. Science of Total Environment, 10(647), 794-805 10.1016/j.scitotenv.2018.08.019

Scholte EJ, Takken W, and Knols BGJ (2007). Infection of adult Aedes aegypti and Ae. albopictus mosquitoes with the entomopathogenic fungus Metarhizium anisopliae. Acta Tropica, 102(3), 151-158. https://doi.org/10.1016/j.actatropica.2007.04.011

Schmidt W-P, Suzuki M, Dinh Thiem V, White RG, Tsuzuki A, and Yoshida LM (2011). Population Density, Water Supply, and the Risk of Dengue Fever in Vietnam: Cohort Study and Spatial Analysis. PLoS Medicine, 8(8): e1001082. https://doi.org/10.1371/journal.pmed.1001082

Sirisena PDNN, Noordeen F, Kurukulasuriya H, Romesh TALAR, and Kumar FL (2017). Effect of Climatic Factors and Population Density on the Distribution of Dengue in Sri Lanka: A GIS Based Evaluation for Prediction of Outbreaks. PLoS One, 12(1): e0166806. https://doi.org/10.1371/journal.pone.0166806

Vormittag EMPA, Oliveira MA, and Gleriano JS (2018). Health Evaluation of the Barra Longa Population Affected by the Disaster in Mariana County. Ambiente & Sociedade, v. 21. http://www.scielo.br/pdf/asoc/v21/1809-4422-asoc-21-e01222.pdf.

Wen TH, Lin MH, and Fang CT (2012). Spatial Analysis and Modeling of Disease Population Movement and Vector-Borne Disease Transmission: Differentiating Spatial–Temporal Diffusion Patterns of Commuting and Noncommuting Dengue Cases. Annals of the Association of American Geographers, p.1026-1037. DOI 10.1080/00045608.2012.671130

Wu PC, Lay JG, Guo HR, Lin CY, Lung SC, and Su HJ (2009). Higher Temperature and Urbanization Affect the Spatial Patterns of Dengue Fever Transmission in Subtropical Taiwan. Science of the Total Environment, 407, p. 2224-2233. DOI 10.1016/j.scitotenv.2008.11.034

Yang D (2008) Coping with Disaster: The Impact of Hurricanes on International Financial Flows, 1970-2002, The B.E. Journal of Economic Policy & Analysis, 1-45.

Annex

Table A1 - Data and sources

Variable	Obs	Mean	Std. Dev.	Min	Max	Source
Dengue cases	16,729	422.3068	3500.52	0	193885	DATASUS
Dengue hospitalizations	16,729	493.6352	5293.203	0	351567	DATASUS
Dengue cases per capita	16,678	0.0070253	0.0141186	0	0.236635 8	DATASUS
Dengue hospitalizations per capita	16,678	0.0063705	0.0191417	0	0.369608 1	DATASUS
Outbreak	16,730	0.0638374	0.2444704	0	1	DATASUS
Log. of rainfall in millimeters	16,658	5.597777	0.0765334	5.261135	5.764564	INPE
Dam accident: 1 if municipality is 100km of the accident in year t and 0 c.c.; 1 if far 200k at year t+1 and 0 c.c.; and 1 if far 500km in year t+2 and 0 c.c.	16,690	0.1967046	0.397519	0	1	ANA
Population density	16,679	0.2010124	0.9396192	0	13.5935	IBGE
Log. GDP per capita	16,678	1.99901	0.5608811	0.897784	5.794363	IBGE

DATASUS = Department of Informatics of the Brazilian Ministry of Health (www.datasus.gov.br)
IBGE = Brazilian Institute for Geography and Statistics (www.ibge.gov.br)
TRE = Brazilian Regional Court of Elections (www.tre.gov.br)
ANA = Brazilian Agency of Water (www.ana.gov.br)
INPE = Brazilian Institute of Research (www.inpe.gov.br)

Table A2 - DD estimates for municipalities 100 km and 500 km far from Mariana's accident – check for robust identification of treated and non-treated groups

	Ray 100k			Ray 500 km		
VARIABLES	Dengue cases per capita	Dengue hospitalizations per capita	Dengue Outbreak	Dengue cases per capita	Dengue hospitalizations per capita	Dengue Outbreak
After	0.0114***	0.0128***	0.1380***	0.0119***	0.0152***	0.1387***
	(0.001)	(0.001)	(0.015)	(0.001)	(0.002)	(0.024)
Treated	-0.0017***	-0.0015***	-0.0203***	0.0024**	0.0031**	0.0319*
	(0.000)	(0.001)	(0.007)	(0.001)	(0.001)	(0.016)
After*Treated	0.0079***	0.0103**	0.0734*	0.0007	-0.0010	0.0105
	(0.002)	(0.005)	(0.039)	(0.001)	(0.002)	(0.022)
Observations	3329	3329	3329	3329	3329	3329
R-squared	0.158	0.093	0.064	0.155	0.09	0.065

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses: Included logarithm of precipitation in millimeters, population density, logarithm of income per capita, year dummies, state dummies and crossed year and state dummies. Standard errors clustered by municipality.

Table A3 – Probit estimates for dengue outbreak

	Coefficient	Marginal effect
VARIABLES	Dengue Outbreak	
After	0.6536***	
	(0.143)	
Treated	-0.0376	-0.0030
	(0.213)	(0.017)
After*Treated	0.9738***	0.1479***
	(0.236)	(0.054)
Observations	3329	3329

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses: Included logarithm of precipitation in millimeters, population density, logarithm of income per capita, year dummies, state dummies and crossed year and state dummies. Standard errors clustered by municipality.

[i] Other major tailings dam accident took place in Brumadinho, State of Minas Gerais, in January 2019. The worst consequence, in this case, was the number of lives lost.

[ii] Samarco is a Brazilian mining company controlled by a joint venture between Vale S.A.(Brazilian) and BHP Billiton (English-Australian).

[iii] The few evaluations are worried about the environmental consequences of the disaster (see, for example, Hatje et al. 2017). One exception is Vormitagg et al. 2018. They study the effects of Fundão dam accident on Barra Longa district of Mariana using 540 interviews with the local population. According to their results, 6.8% of the individuals perceived an increase in dengue cases and of other infectious diseases after the accident.

[iv] For more comprehensive information about Dengue see World Health Organization (WHO) Dengue/severe dengue frequently asked questions.

[v] Nowadays there is a vaccine (Dengvaxia) indicated for the prevention of dengue. It´s reliability, however, was questioned after several children died from various complications attributed to the vaccine.

[vi] https://www.ana.gov.br/todos-os-documentos-do-portal/documentos-aud/relatorio-de-gestao/relatorio-de-gestao-do-exercicio-2016.pdf/view

[vii] There are tailings dams, hydroelectric dams, irrigation dams, recreation dams, among others.

[viii] They are: Mariana , Governador Valadares, Barra Longa, Sem Peixe, Rio Doce, Santa Cruz do Escalvado, Rio Casca, São Domingos da Prata, São José do Goiabal, São Pedro dos Ferros, Dionísio, Raul Soares, Córrego Novo, Pingo D´Água, Marileia, Bom Jesus do Galho, Caratinga, Timóteo, Santana do Paraíso, Bugre, Iapu, Coronel Fabriciano, Ipaba, Ipatinga, Belo Oriente, Naque, Periquito, Sobrália, Fernandes Tourinho, Alpercata, Tumiritinga, Galileia, Conselheiro Pena, Resplendor, Itueta, Aimorés in the state of Minas Gerais, and Baixo Guandu, Colatina e Linhares in the state of Espírito Santo.

[ix] In regions with high population density the transmission of the dengue is faster (Wen at al., 2012; Wu et al., 2009). Given that the flight range of mosquitoes is limited (Gu et al. 2006; Higa, 2011), the widespread transmission tends to be related to human activity and travel (Gardner and Sarkar, 2013; Huber et al. 2002; Nakata and Rost, 2015; Li et al. 2018). The commuting activity also tends to increase the spread and transmission of outbreaks that are in their later stages (Sanna and Hsieh, 2017; Wen et al., 2012).

[x] Following this definition, around 10% and 8% of Brazilian municipalities experienced a dengue outbreak in 2015 and 2016 (own calculations using data from the Brazilian Health Ministry). Brazil is considered one of the countries with the highest risk of dengue infection and related public health burden problems (Bhatt et al. 2013).

[xi] In economics, an externality is a collateral effect. It is the cost (or benefit) that affects a party who did not choose to incur that cost (or benefit). An externality, therefore, can be negative or positive.