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Dolores de la Mata
Mauricio G. Valencia-Amaya

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Inter-American Development Bank
Department of Research and Chief Economist

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Mauricio G. Valencia-Amaya

Universidad del Rosario

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Abstract[*]

This paper studies the link between severe weather shocks in Colombia and municipality-level incidence of dengue and malaria. The unexpectedly high variability of the 2010 rainfalls relative to previous periods and their regional heterogeneity are exploited as an identification strategy. A differences-in-differences (DD) strategy is thereby implemented where the period 2007-2009 is defined as the pre-treatment period and 2010-2011 as the post-treatment period. The treatment group is all municipalities that experienced higher intra-year rain variability in 2010 than in 2007-2009. The results from the different specifications confirm that the relationship between climate events and vector-borne diseases is intricate. The 2010 weather shocks are associated with not only an increase in the number of dengue cases, in the case of high variability (but not extreme) yearly rain, but also a decrease in its incidence, in particular in the presence of extreme rain events. Floods seem to have decreased the number of dengue cases.

JEL classifications: I10, Q54

Keywords: Climate variability, Weather shocks, Vector-borne diseases, Dengue

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1. Introduction

Over the last hundred years the world has experienced a significant warming as a result of the increase in the emission of greenhouse gases. This phenomenon has had regional and global consequences, such as reduced soil moisture, precipitation, droughts, sea level rise, high-temperature events, and floods, among others. Model-based projections conclude that the average annual global temperature for the period between 2007-2027 will rise about 0.2°C per decade, the average sea level will increase by 0.1 to 0.2 meters by 2090-2099 (relative to 1980-1999), and the frequency of climate shocks, such as heavy precipitation, heat extremes, and heat events, are very likely to increase in the next 100 years (IPCC, 2007). Moreover, the wide range of those projections generates uncertainty in terms of the regional and local socio-economic impacts of climate change (Yohe and Schlesinger, 2002).

Even though climate shocks are part of the history of mankind, the increasing rate of occurrence of such events and its devastating effects on the lives of millions of people around the world have recently attracted attention to this issue (UNDP, 2007). What is more, risks and vulnerabilities related to climate change are increasingly faced by poor people (UNDP, 2007; World Bank, 2010). Indeed, during the period 2000-2004, 1 out of 19 of the people affected by a climate shock was living in a developing country, compared with only 1 out of 1,500 for OECD countries (UNDP, 2007: 76). In developing countries, a high percentage of the population still depends on agriculture as its primary source of income, and many of the people living in the surroundings of the urban areas (slum dwellers) live in deplorable conditions. For these people, even small changes in climate can have an enormous impact. Climate shocks might not only destroy crops and affect people's assets and savings, but also affect their accumulation of human capital through a deterioration of health, nutrition, and education. This implies a higher uncertainty, vulnerability, and fewer opportunities to overcome their current living conditions, creating cumulative vicious cycles of disadvantages that are transmitted from generation to generation (UNDP, 2007).

In this context, understanding the links between natural shocks and human capital—health in particular—becomes important, especially when designing policies aimed at reducing vulnerability and enhancing the inherent resilience of regions and communities. In this paper we exploit the unexpectedly severe weather shocks of 2010 in Colombia to study the link between these shocks and the incidence of dengue and malaria under extreme weather events. We exploit as our identification strategy the intensity of the 2010 rainfalls relatively to previous periods as well as regional heterogeneity. This allows us to implement a differences-in-differences (DD) strategy where the period 2007-2009 is defined as the pre-treatment period and 2010-2011 the post treatment period. We define as the treatment group all municipalities that during 2010 experienced intra-year rainfall variability higher than the 2007-2009 average variability.[1] Despite not using all the variation of the rainfall data, the DD strategy defined here has the advantage of restricting the effect of severe weather shocks, which are plausibly assumed to be unexpected for the treated municipalities.

We extend the analysis in four ways. First, we analyze heterogeneous effects by municipality characteristics (climate, altitude, poverty) as well as on different age and gender groups. Second, to analyze nonlinearities between the rainfall variability and incidence of diseases, we estimate a model with two treatments. Third, we run placebo regressions where the outcome variables are the occurrence of diseases that should not be affected by severe weather shocks. Finally, we define two alternative specifications that consider different definitions of weather shocks. One considers the incidence of floods on dengue and malaria. The other exploits all the variability in monthly rainfall by correlating monthly rain shocks (taking into account the monthly rain level relative to historic mean) with monthly number of disease cases reported at the municipality level.

The results indicate that the relationship between weather variability and vector-borne diseases is intricate. On the one hand, results for dengue using the Diff-in-Diff specification indicate that the severe weather shocks of 2010 had an important and strong effect on the average monthly cases of dengue. In particular, during the post-treatment period (2010-2011), dengue increased by four more cases per month, representing almost 70 percent of the mean value. The effect is stronger for the year 2010, when the average number of dengue cases per month increased by six more cases. Densely populated areas of rural and urban settings, as well as large cities with more than 500,000 inhabitants, absorb most of the effect, supporting the idea that dengue is mainly an urban disease. In terms of poverty levels, municipalities with the lowest levels of the multidimensional poverty index were the most affected. The effect does not differ by gender; however, it is stronger in teenagers and young adults, particularly in the year 2010.

[1] Municipalities are decentralized subdivisions of the Country. Colombia has 33 departments and 1,123 municipalities.

Favorable conditions, in terms of temperature and altitude, magnify the effect of the weather shocks on the number of dengue cases. Results for malaria using the Diff-in-Diff specification show no significant causal relationship between the weather shocks of 2010 and average monthly cases of malaria, except when considering only municipalities with populations between 10,000 and 15,000 inhabitants, in which case the effect is significant and positive. In terms of poverty, populations with the lowest multidimensional poverty indices experienced a greater impact of the shocks on the disease average monthly cases.

On the other hand, results from a Diff-in-Diff specification with two treatments, as well as from two additional specifications, one using floods as an alternative measure of a weather shock, and the other accounting for the rainfall deviation from historical averages, show that there seems to be a non-linear relationship between the weather variability and the incidence of vector-borne diseases. Milder shocks (low intensity) are associated with significant increases, whereas stronger shocks (high intensity) have negative effects, although non-significant. This result goes in line with the findings when analyzing the effects of floods. Floods can be considered a form of extreme weather event associated with high precipitation levels (stronger shocks). Results from this specification point out that these events are related to lower incidence of both dengue and malaria cases. These findings coincide with the results of our last specification, which exploits all the variability in monthly rainfall by correlating monthly rain shocks (taking into account the monthly rain level relative to historic mean) with monthly number of disease cases reported at the municipality level. Results from this specification indicate that negative shocks (rains below more than one standard deviation relative to the historical mean) are positively correlated with the incidence of dengue, while positive shocks (above average monthly rains) are negatively correlated with the occurrence of the disease.

The data come from several sources. Rainfall and temperature data are collected at the municipality level by the Institute of Hydrology, Meteorology, and Environmental Studies of Colombia and available at a monthly level. Data on dengue and malaria incidence are collected by the Colombian National Public Health Surveillance System (SIVIGILA). SIVIGILA generates an event-based database—i.e., every time a dengue or malaria event occurs, health care providers are obliged to report those cases to the national health care authorities following a specific protocol—from which we construct the monthly number of cases registered at the municipality level.

The study of the relation between climate shocks and diseases is of high relevance for Colombia. First, the country is a natural disaster hotspot (de la Fuente, 2012) and there have been an increase in the number of cases of infectious diseases such as dengue and malaria in recent years. Second, in terms of the severity of climate shocks and the spread of vector-borne diseases, the year 2010 stands alone: that year's severe weather shocks were the worst experienced by Colombia in its recent history, affecting more than 90 percent of all Colombian municipalities. Additionally, according to the National Health Institute of Colombia (Instituto Nacional de Salud), in 2010 the country experienced its worst dengue epidemic in a decade; cases per 100,000 inhabitants increased to nearly 19.5 from an average of 6.9 for the previous three years. Therefore, the particularity of the year 2010 provides a unique opportunity to exploit a natural experiment in order to assess the causal impact of the severe change in the intensity of climate events on the incidence of vector-borne diseases in the Colombia.

The paper is structured as follows. Section 2 presents a literature review; Section 3 describes the data and the different data sources on weather-related events, health outcomes, and municipality socioeconomic characteristics; Section 4 describes the weather shocks occurred in Colombia during 2010; Section 5 illustrates the incidence of dengue and malaria in Colombia between 1995-2012, and Section 6 a characterization of the population infected during the period 2007-2009; Section 7 introduces the identification strategy; Section 8 presents the results from the differences in differences specification; Section 9 has several extensions; Section 10 presents alternative measures of weather shocks; and Section 11 concludes.

2. Literature Review

2.1 Climate Change and Vector-Borne Diseases

Baylis and Risley (2013) and Hunter (2011) present a complete literature review on the relationship between climate change and vector-borne diseases. This section summarizes some of their main findings.

Climate change may affect not only the occurrence, timing, and geographical distribution of different infectious diseases, but also the intensity of outbreaks. According to Baylis and Risley (2013), in terms of spatial relationships, climate variables such as temperature and altitude affect, for example, the distribution of mosquito vectors. Temporal relationships can be either seasonal or inter-annual. In the case of seasonal relationships, in temperate regions, changes in temperature and humidity have a direct influence on the survival of viruses, and an indirect effect on human health by affecting the immune system (which increases the likelihood of colds and flu, for instance) and by changing some human behaviors, such as time spent indoors, human migration, housing patterns, and demography. In the case of inter-annual relationships, El Niño-Southern Oscillation (ENSO) events, such as El Niño and La Niña, are associated with outbreaks of dengue and malaria in many regions of the world (Baylis and Risley, 2013).

Climate change may also have effects on hosts and vectors by altering their survival and growth rates and therefore the timing and spread of disease. In the case of hosts, climate change may spread certain diseases that exhibit endemic stability, such as malaria, to areas and regions not previously exposed, and therefore, since individuals in these regions may have not developed immunity to such diseases, outbreaks are likely to spur. In the case of vectors, climate change might alter temperature and moisture and this in turn might affect the probability of vector insects carrying pathogens (the maturation time of pathogens is also affected by climate change); climate change may also limit vector insects' survival rates, and hence their abundance and geographical distribution vectors. As Baylis and Risley (2013: 5366) state:

> "Changes to temperature and moisture will also lead to increases or decreases in the abundance of many disease vectors. This may also result from a change in the frequency of extreme weather events such as ENSO. Outbreaks of several biting midge and mosquito-borne diseases, for example, have been linked to the occurrence of ENSO [18, 22, 59–62] and mediated, at least in part, by increase in the vector population size in response to heavy rainfall, or rainfall succeeding drought, that ENSO sometimes brings [18, 22]. Greater intra- or interannual variation in rainfall, linked or unlinked to ENSO, may lead to an increase in the frequency or scale of outbreaks of such diseases."

As noted above, climate variability and changing weather patterns, especially in humidity, temperature, and precipitation, may alter the timing of vector-borne diseases. However, in the case of some diseases, such as malaria, there is still debate regarding the causality of climate change in the changing transmission patterns of the disease (particularly the geographical distribution of the disease). However, there is agreement that the presence of water is important for egg-laying and larval survival and that both temperature and humidity influence mosquitoes' lifespan and hence the chances for humans to be infected. In consequence, by changing rainfall levels (and therefore mosquitoes' survival rates), climate change might affect the timing and exposure time to the disease, although not necessarily where it appears (Blanco and Hernández, 2009).

The importance of climate change in the epidemiology of vector-borne diseases is to some extent clear: it affects not only the ecology of vectors and hosts, but also modifies human behaviors. However, infectious diseases are recognized to be multifactorial, and so the relative importance of climate change for the spread of specific diseases spreads remains unclear in comparison to other factors that might simultaneously affect them, such as changing human behaviors, in terms of agricultural practices, migration or international trade, and changing insect behaviors because of, for example, adaptation and genetic evolution. Changes in human behavior will lead to climate change affecting vector-borne diseases in a differential way, depending on the idiosyncratic determinants of every disease (Hunter, 2011). Hunter additionally notes:

> "Heavier rainfall during warmer months could lead to increased vegetation growth and consequently increases in animal host populations. In several tropical countries, the monsoon season is strongly associated with both dengue fever and malaria. However, it can also be the case that heavy rainfall events reduce mosquito population size by washing away developing larvae out of their stagnant pools" (Hunter, 2011: 641).

According to IPCC (2007), one of the consequences of climate changes is the increase in the frequency and intensity of climate disasters. Severe weather shocks, such as floods, are known to affect the epidemiology of some vector-borne diseases, especially in the aftermath of events by, for instance, modifying the number of mosquitoes. In this sense, there is evidence of malaria and/or dengue epidemics outbreaks following floods (Hunter, 2011). Water that remains may become a site for mosquito breeding; habitat destruction may force mobility of both humans and animals, altering their exposure to vectors and hosts; and destruction of houses and public facilities (e.g., health centers, for example) may increase human vulnerability by reducing in-house protection and hindering early diagnosis and treatment of disease. Once again, however, preexisting factors may play an important role and, depending on the intensity of the weather shock, vectors or hosts populations might increase or decrease, in turn possibly affecting disease transmission. Moreover, although some studies have demonstrated a relationship between higher than normal precipitation or temperature levels and a subsequently higher incidence of malaria, many other studies relating the impact of ENSO events and malaria cases are known to suffer from endogeneity. Hunter (2011: 642)

> "The evidence for a long-term trend association is conflicting. These types of analyses are known as ecological analyses and are prone to the ecological fallacy, a form of bias from an association observed between variables not necessarily implying at a population or an individual level. Long-term trend analyses are also very difficult to control for potential confounding whereby associations are due to other unknown predictor variables."

In general, Hunter (2011) concludes that there is good evidence of the relationship between climate shocks or ENSO events and higher risk of dengue and malaria incidence, but the existence of different covariates makes it difficult to make causal attributions.

2.2. Climate Change and Vector-Borne Diseases in Colombia

To the best of our knowledge few papers have studied the relationship between climate change and disease outcomes in Colombia, particularly dengue and malaria. Moreover, these papers have studied this relationship from a non-economic perspective. For example, Mantilla, Oliveros and Barnston (2009) analyzed the effects of the ENSO state, namely sea surface temperature in the Pacific Ocean, on the annual number of malaria cases at the regional level for the period 1960-2006. Their results indicate a positive effect of a rise in the sea surface temperature (the warm phase of ENSO) on the number of malaria cases in Colombia. This finding is coherent with previous results for Colombia, such as Bouma et al. (1997) and Poveda et al. (2000), for dengue and malaria cases. El Niño events are characterized by an increase in air temperature and a decrease in precipitation. However, other studies, such as Blanco et al. (2009), have found a positive impact of the annual level of precipitation on malaria cases, but not on dengue cases (this disease was found to be more affected by temperature changes). The same study found no evidence that climate change is raising the cases of malaria and dengue in Colombia. Yet, Cárdenas et al. (2006) reports a positive incidence of El Niño events on leishmaniasis cases in Northeastern Colombia, but the incidence is negative for La Niña events; their conclusions support the existence of a relationship between climate change and the incidence of this disease. Finally, Rodríguez and de la Hoz (2005) report a broadening in the geographical scope of dengue to higher altitudes. Therefore, the literature is clear-cut neither on the existence of an impact of climate change on infectious diseases nor on the kind of relationship between extreme weather events and the prevalence of these diseases. In this sense, this research will contribute to the existing literature providing new evidence of the impact of climate change, in particular of extreme weather shocks, not previously studied in the literature, on health outcomes from an economic point of view.

2.3 Impacts of Rainfall Variability on Socioeconomic Outcomes

Several papers have analyzed the effects of rainfall on health outcomes during childhood. Rocha and Soares (2012) analyze the impact of rainfall fluctuations during the gestational period on health at birth. They concentrate on the semiarid region of Northeastern Brazil to highlight the role of water scarcity as a determinant of early life health. This helps to minimize the nonlinear effects that rainfall can have on health, and they are able to interpret a negative rainfall shock (water scarcity) as a negative effect on health. They find that negative rainfall shocks are robustly correlated with higher infant mortality, lower birth weight, and shorter gestation periods. Mortality effects are concentrated on intestinal infections and malnutrition, and they are greatly minimized when the local public health infrastructure is sufficiently developed (municipality coverage of piped water and sanitation). The effects are stronger during the fetal period (second trimester of gestation), for children born during the dry season, and for mortality in the first six months of life. Their findings seem to be driven by water scarcity per se, and not by reduced agricultural production. Their results suggest that expansions in public health infrastructure would be a cost-effective way of reducing the response of infant mortality to rainfall shocks in the Brazilian semiarid.

Kudamatsu, Persson and Strömberg et al. (2010) estimate how random weather fluctuations affected infant mortality across 28 African countries in the past, combining high-resolution data from retrospective fertility surveys (DHS) and climate-model reanalysis (ERA-40). Infants were much more likely to die when exposed in utero to much longer malaria spells than normal in epidemic malaria regions, and to droughts in arid areas, especially when born in the dry season. Kim (2010) uses the variation in rainfall within and across years at a detailed geographic level in West Africa to estimate how rainfall shocks impact early child health. One of the possible channels identified by the author is the fact that rainfall affects the opportunity cost of parenting time and may thus have a negative impact on child welfare. On the other hand, rainfall also generates variation in income through its effect on agricultural output, and more income usually reduces child mortality. The author finds that rainfall shocks have an adverse effect on the survival of young children born in the rainy season. This may be partly attributable to a reduction in mothers' time dedicated to breastfeeding their children as a result of the rainfall shocks, which is likely due to a trade-off with work time.

However, climate shocks can also have positive consequences through a sudden increase in the income of households. For instance, for the case of Indonesian adults, Maccini and Yang (2009) studied the impact of early-life shocks (higher rainfall) on economic development variables, including health, education, and household's assets. Their results point out that higher early-life rainfall has a positive effect on women's variables (resulting in higher socioeconomic status), but not on men's, stressing gender discrimination issues in Indonesian society. The channel through which higher rainfall influences the future socioeconomic status of women is through its impact on agricultural production, which in turn increases household income and later in life improves women's health status and schooling attainment.

3. Data

3.1 Weather-Related Events and Damages

The municipality rainfall and temperature database is provided by the Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia (Institute of Hydrology, Meteorology, and Environmental Studies of Colombia, IDEAM). The database contains the monthly rainfall levels (millimeters) for 809 Colombian municipalities between 1999 and 2011, which represents almost 72 percent of all municipalities and 90 percent of the total population. For a subset of municipalities (548) we have rainfall information for a longer period (1991-2011). We additionally have monthly temperature for 137 municipalities.

The municipality historic temperature and altitude database is provided by Departamento Administrativo Nacional de Estadística (National Administrative Department of Statistics, DANE). Altitude is measured in meters above sea level (m.a.s.l.) of the seat of the municipal government. Temperature is measured in degrees Celsius (°C) and is calculated as the annual average.[2]

The source for weather related damages is the SNPAD national disasters database, developed by the governmental institution "Sistema Nacional para la Prevención y Atención de Desastres" (National System for the Prevention and Attention of Disasters). This is an open-access database which contains the records of the different natural events that have affected Colombia since 1998 at a municipality level. The main sources of information for SNPAD database are CREPAD (Comité Regional para la Prevención y Atención de Desastres, Regional Committee for the Prevention and Attention of Disasters) and CLOPAD (Comité Local para la Prevención y Atención de Desastres, Local Committee for the Prevention and Attention of Disasters). Both institutions are in charge of addressing and reporting emergencies and disasters at the regional and municipality level, and protocols of action are defined by SNPAD for different administrative levels. Territorial authorities, such as municipalities' mayors and departmental governors, have general responsibility. Every municipality has an emergency coordinator as well as a number of coordinators in charge of areas such as health, rescue, shelter, social community, infrastructure and services, and sectoral institutions.

In terms of the definitions used in this dataset, according to SNPAD, a disaster is defined as "damage or serious disturbance of normal living conditions in a given geographical area, caused by natural phenomena and/or by the catastrophic effects of accidentally human actions" (Article 18, Decree 919, 1989). It is also defined as "the result of the manifestation of one or various natural or unintended anthropogenic events, which find favorable vulnerabilities (in people, infrastructure, livelihoods, provision of services, and/or environmental resources), causing casualties, damages, and material, economic or environmental losses, which generates an intense, severe, and widespread disturbance in the normal functioning of society, requiring the State and the national system to execute response actions to the emergency, rehabilitation, and reconstruction."

Some of the variables included in the database are the following: date of the event; municipality code; type of event (avalanche, landslides, collapse, erosion, hailstorm, structural fire, floods, rain, rough water, drought, earthquake, electric storm, tornado, strong wind, tropical

[2] Note that the historic temperature is an historic mean, and a unique value is available for each municipality. This variable does not distinguish by season.

depression, epidemic, eruption, wildfire, others); number of casualties; number of people affected (defined as the total number of people who were not physically injured but lost material goods, affecting their normal functioning in a society), number of people wounded, or missing; number of houses destroyed (houses with structural damages), number of houses affected (houses with no structural damages); and number of different public and/or private infrastructure affected (roads, pedestrian bridges, vehicular bridges, water conduits, sewage systems, schools, health centers, and community centers).

Since the SNPAD database contains both the date of every single event reported by these institutions and the municipality code, we were able to group different disasters by month and year at the municipality, departmental, and national level.

3.2 Health Outcomes

The source for the country-wide health-related events is provided by the Sistema Nacional de Vigilancia en Salud Pública (National Public Health Surveillance System, SIVIGILA) part of the "Instituto Nacional de Salud" (National Health Institute).

Since 1998 SIVIGILA has been in charge of monitoring the dynamics of health-related events from a specific list of priority diseases for public health surveillance. At the end of 2006 SIVIGILA implemented specific protocols to collect individual-level information on priority diseases, and from this information SIVIGILA generates an event database. Each time a health provider receives a case, it is required to report the event to the health authorities following well-defined guidelines for compilation and notification that are specific to each of the priority diseases. The information in the SIVIGILA database includes, among other data, the disease code, disease name, notification date, notification week, medical consultation date, hospital name, patient's age, gender, occupation, type of health insurance, ethnic group, municipality and department of residence, municipality and department of origin, and area. This allows us to construct at the municipality level the number of occurrences of a disease on a monthly basis.

Out of all the diseases included in the SIVIGILA database, the following were chosen based on their strong relation to climate variability: dengue, severe dengue, malaria (mixed types), dengue mortality, malaria falciparum, malaria vivax, severe malaria, malaria mortality. These diseases were then grouped into two categories: dengue and malaria. We dropped from the database the reported cases of foreigners who did not list Colombia as their country of residence.

Wrong dates and typographical errors were also dropped; these cases represented less than one 1 percent of the information. Once the database was cleaned, the above-mentioned disease cases categories were grouped by month using the notification date and the patient's municipality of residence.

3.3. Municipality Socioeconomic Characteristics

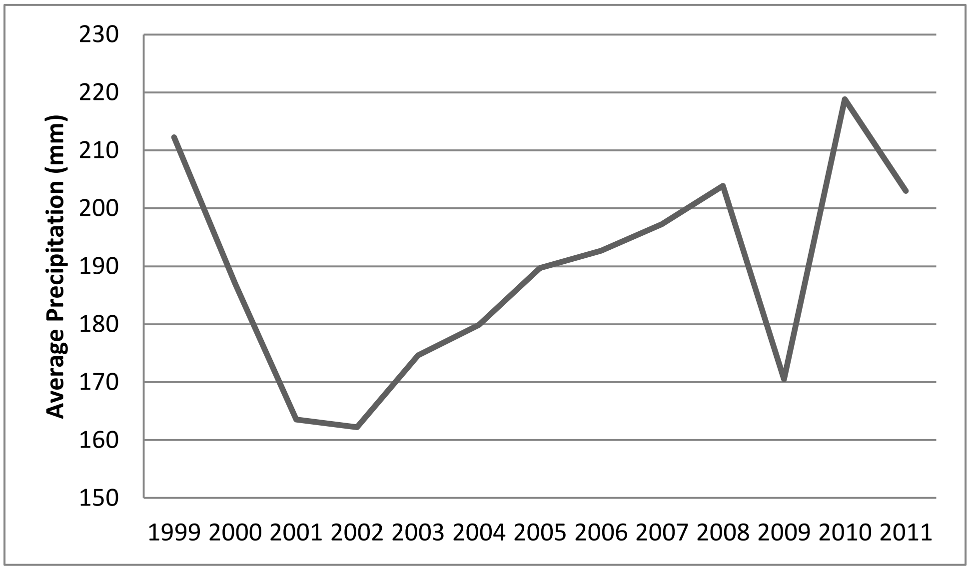
Municipalities' characteristics, such as Unsatisfied Basic Needs and population covered by the contributory and subsidized health regime are provided by DANE. Information on the Multidimensional Poverty Index is provided by the Departamento Nacional de Planeación (DNP). This index was constructed for every Colombian municipality based on the 2005 population census.

4. Weather Shocks in Colombia in 2010

From 1998 to 2011, the average annual increase in the number of climate-related events was 23 percent. During this period, floods, landslides, and strong winds accounted for almost 85 percent of all climate-related events in the country (floods, 51 percent; landslides, 21 percent; strong winds, 13 percent). The relative importance of these events has remained stable over the years. Changes in precipitation levels are one of the most important determinants of the occurrence of climate-related events in Colombia. In fact, there is a strong link between ocean-atmosphere phenomena and the occurrence of climate shocks in the country. For example, the La Niña event peak in strength between late 2010 and early 2011 was considered one of the strongest observed on record. The effects of La Niña vary geographically, causing droughts in the Western Pacific but floods and heavy rains in northern South America, where Colombia is located. According to DANE (2011), the periodically flooded areas in Colombia (having as baseline the year 2001) are 1,212,965 hectares, but the floods of 2010-2011 reached 1,642,108 hectares, or 35 percent more than traditionally flooded areas.

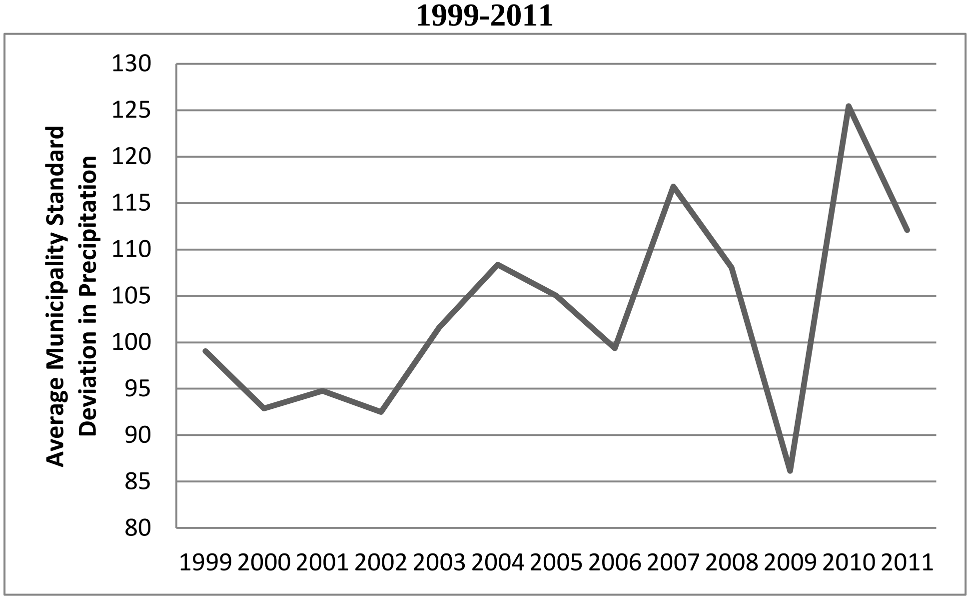
In this scenario, the La Niña event was the most important cause of precipitation variability in 2010, which were 18 percent above the annual average between 1999 and 2009 (see Figures 1 and 2). This increase in precipitation level played in turn an important role in the severe weather shocks of 2010, the worst experienced by Colombia in its recent history. At the municipality level, almost 90 percent of all Colombian municipalities (1,020 out of 1,123) suffered from climate-related events in 2010, an increase of almost 125 percent compared with the average number of municipalities affected by these events between 1998 and 2009.

Figure 1. Average Precipitation Level in Colombia, 1999-2011



Source: Authors' calculations based on IDEAM.

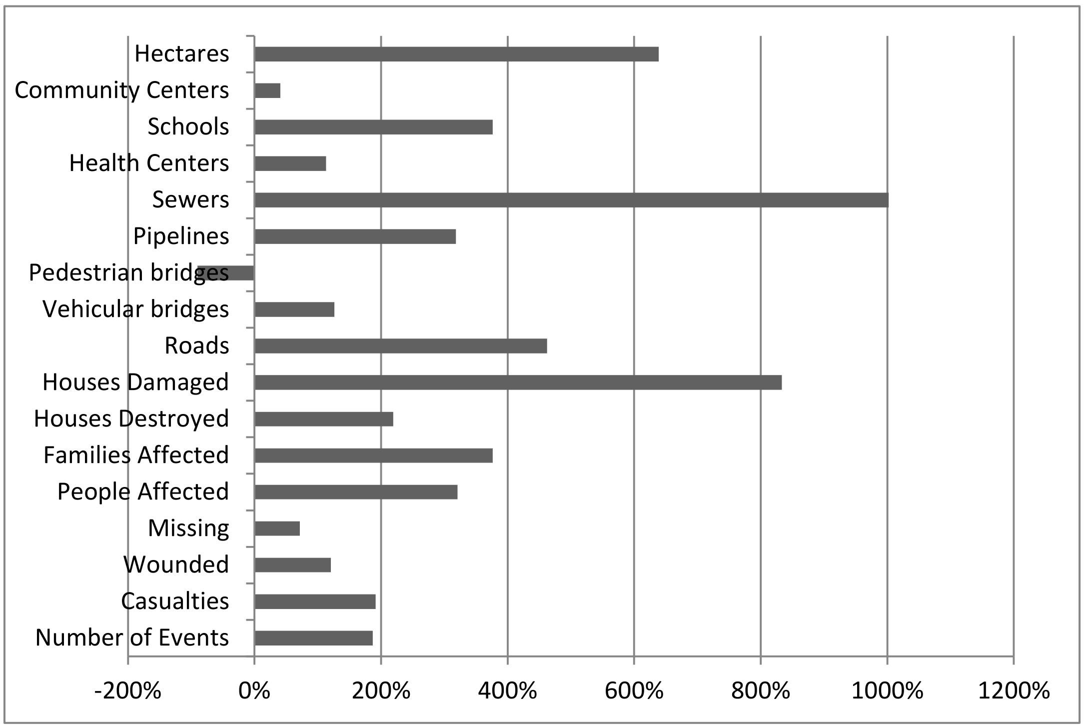
Figure 2. Intra-Year Standard Deviation of Precipitation Levels in Colombia, 1999-2011



Source: Authors' calculations based on IDEAM.

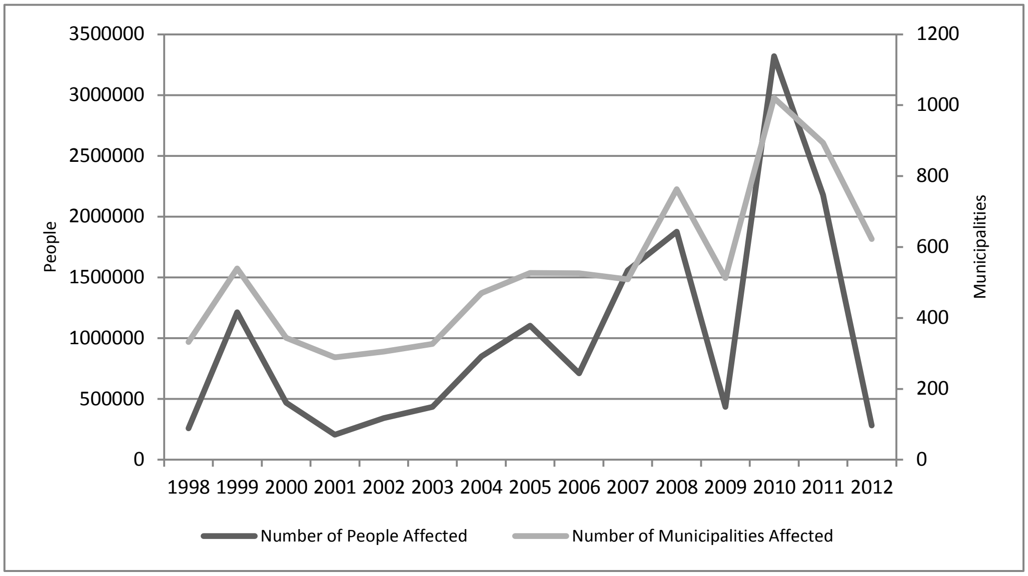
The 2010 weather shocks were not only broader in scope but also stronger in terms of the magnitude of disasters. Figure 3 shows the percentage change in the magnitude of the events of 2010 in different categories compared with the averages between 1998 and 2009. Figure 4 shows the number of people (per 100,000 inhabitants) and the number of municipalities that were affected by climate-related events during the period 1998-2012. The year 2010 stands alone as the most intense year in terms of the severity of climate shocks.

Figure 3. Average Change in the Magnitude of the Weather Events of 2010 Compared with the Average between 1998 and 2009



Source: Authors' calculations based on SNPAD.

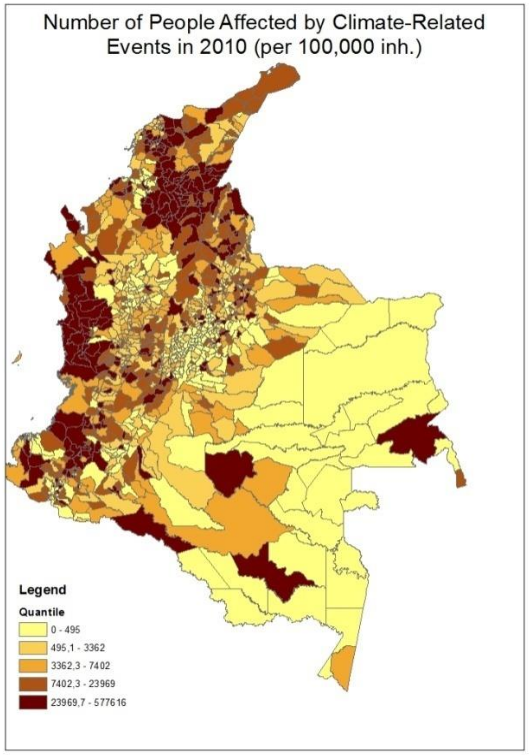
Figure 4. Intensity of Climate Shocks in Colombia, 1998-2012 (number of municipalities and number of people affected by climate-related disasters)



Source: Authors' calculations based on SNPAD.

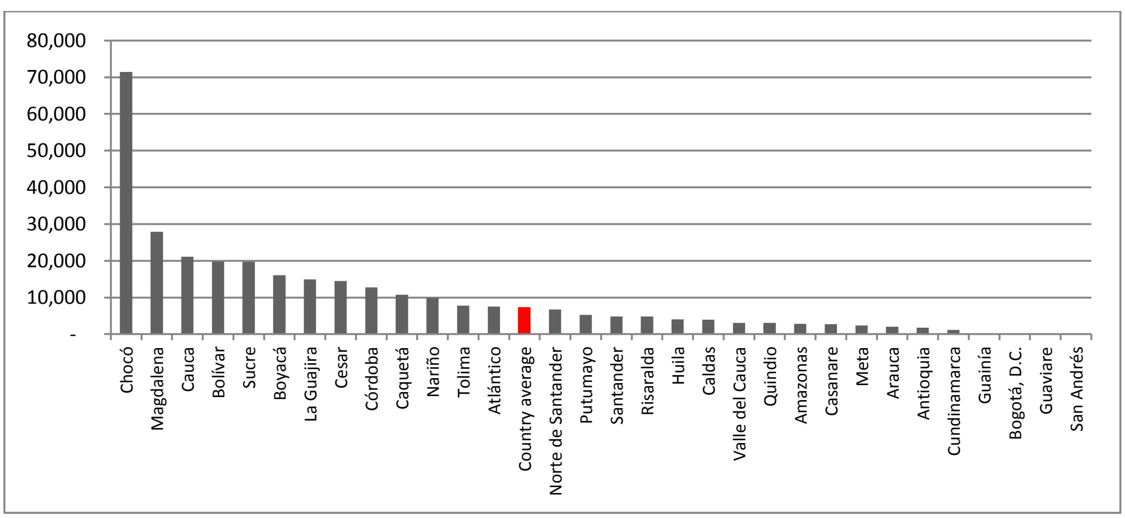
Even though the climate shocks of 2010 hit almost the entire country, some regions suffered more than others. This fact is shown in Map 1. The map shows the number of people affected by the weather shocks of 2010 per 100,000 inhabitants. The darker zones represent the most affected areas. These areas are spread all over the country, but they are particularly concentrate in the Caribbean and Pacific regions. In fact, out of the 13 departments that had more severe shocks in 2010 than the national average, 10 belong to these regions (see Figure 5). The most affected Departments were Chocó, Magdalena, Cauca, Bolívar, and Sucre. The Department of Chocó, which belongs to the Pacific region, has been by far the most affected territory in terms of climate-related events; it is also one of the rainiest regions in the world. With barely 1 percent of Colombia's population, Chocó accounted, on average, for 13 percent of the people affected by natural disasters during the period 1998-2012.

Map 1. People Affected by Climate-Related Events in Colombia, 2010 (per 100,000 inhabitants)



Source: Authors' calculations based on SNPAD.

Figure 5. People Affected by Climate-Related Events in Colombia, 2010 (per 100,000 inhabitants) by Department



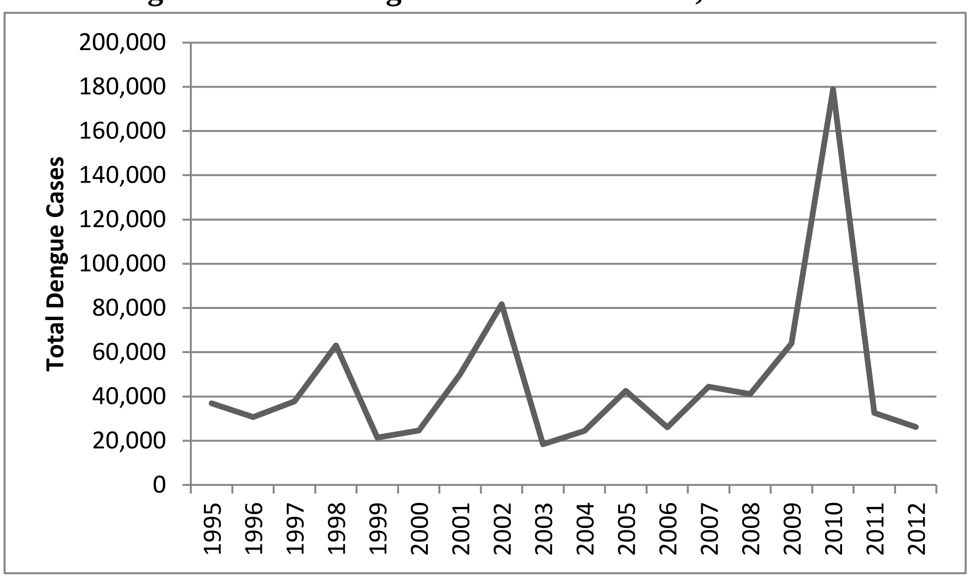
Source: Authors' calculations based on SNPAD.

In order to deal with the climate shocks of 2010, on November 18 of that year the Colombian government declared a public calamity in 28 out of the 32 departments (Resolution 572); it also created a fund called *Colombia Humanitaria*, institution responsible for channeling resources from private and international organizations; on December 7 the government declared a social, economic, and environmental emergency (Decree 4580). Throughout December 2010, the government issued 25 decrees as a national strategy to alleviate the impact of the disasters.

5. Dengue and Malaria in Colombia

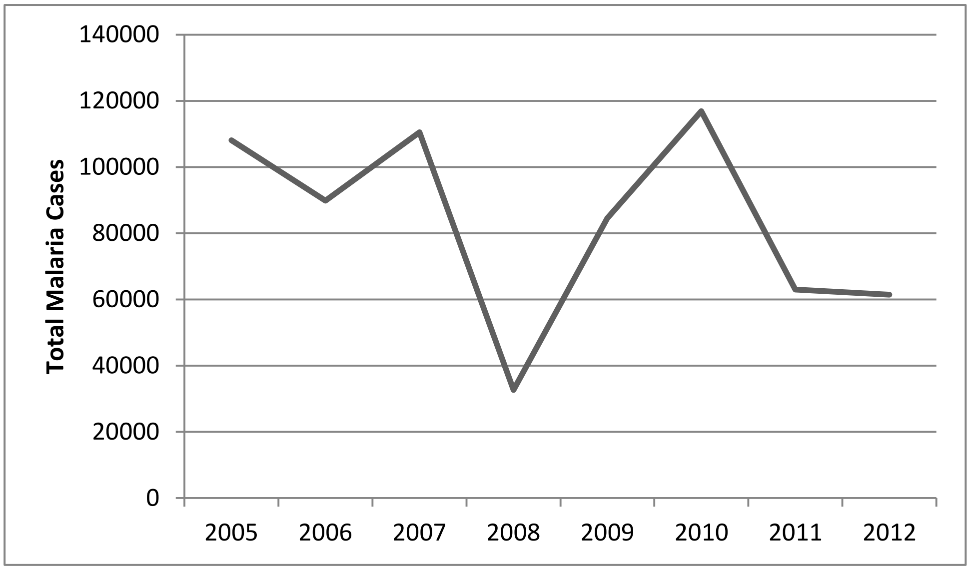
Dengue and malaria were prevalent in many regions of Colombia before the 2010 climate shocks. However, according to the National Health Institute (INS), in 2010 the worst dengue epidemic in the previous 10 years hit Colombia, affecting 178,815 people (180 percent more than the previous year); see Figure 6. Likewise, 116,914 people suffered from malaria the same year (38 percent more than in 2009), as shown in Figure 7.

Figure 6. Total Dengue Cases in Colombia, 1995-2012



Source: Sivigila.

Figure 7. Total Malaria Cases in Colombia, 2005-2012



Source: *Sivigila.*

6. Characteristics of the Population Affected by Dengue and Malaria: Sivigila Microdata Files (2007-2009)

To analyze the characteristics of the population affected by dengue and malaria, in this subsection we use Sivigila microdata from the pre-treatment period.

6.1 Dengue

During the period 2007-2009, Colombia presented an average of 44,483 dengue cases per year.[3] Only 33 percent of the people infected reside in rural areas (rural centers and disperse areas). The disease affects equally males and females, and the average age of the population affected is 25 years old, which means that mostly younger people are infected. In fact, approximately 25 percent of cases are among children under the age of 12. A very small share of the affected population (0.5 percent) is reported as displaced or migrant, and 12 percent belongs to an ethnic minority group (Afro-descendant or other). In terms of health insurance status, most affected people have some type of insurance coverage: 47 percent was covered by the contributory regime, 33 percent by the subsidized regime, and 5 percent by other regimes. Still, 15 percent of the ill population was not covered by any type of insurance. Although the disease had a low

[3] This number is calculated considering only those cases in which the dengue event reported to Sivigila indicates that it is probable or confirmed (doubtful cases are dropped).

mortality rate (0.1 percent of cases), many of the cases are reported as severe dengue (14 percent of dengue hemorrhagic fever), as shown in Table 1.

6.2 Malaria

On average, 78,887 people were affected by malaria between 2007 and 2009. Contrary to dengue, malaria cases are mostly concentrated in rural areas (65 percent of cases). The disease affects more males than females, and the average age of affected people is 25 years old. A small share of the affected population (1.6 percent) is reported as displaced or migrant, while 35 percent belong to a minority ethnic group (Afro-descendant or other). Only 5 percent belong to the contributory regime, 41 percent belong to the subsidized regime, and 5 percent are covered by other regimes. However, 48 percent of the people affected are not covered by any kind of health insurance, as shown in Table 2.

7. Identification Strategy

7.1. Difference-in-Differences Estimation

In order to identify the causal effect of interest we will implement as the main identification strategy a difference-in-differences approach exploiting the unexpectedly severe weather shocks of 2010 (the time dimension) and their variation across municipalities (the regional dimension). The pre-treatment period goes from 2007 and 2009 and the post treatment period from 2010 to 2011. Our baseline specification is the following:

$$outcome_{mty} \alpha + \beta Treat_m + \gamma Post_t + \delta Treat_m * Post_t + \lambda_Y + \lambda_T + \lambda_M + \Gamma' X_{m,t} + \varepsilon_{it} \quad (1)$$

where *outcome* is the variable of interest (incidence of dengue or malaria) in municipality *m* in month *t* and year *y*; *Treat* is a dummy variable that equals 1 if municipality *m* experienced a severe weather shock in 2010; *Post* is a dummy variable that takes the value 1 for post-treatment period (2010 and after); $\lambda_{Y,}$ λ_T and λ_M are year, month and municipality fixed effects; and ***X*** are other time-varying municipality level characteristics.[4] Although 2011 was not a year of severe

[4] Note that exogenous time-varying municipality characteristics are harder to obtain. Most of the municipality-level information regarding socioeconomic characteristics is gathered through censuses. Other municipality level information might be available through administrative data which is harder to have access to, and, in many cases, this information is not harmonized. Hence, in most of our specifications we only control for annual municipality population.

weather shocks, we consider it as a post-treatment period in order to analyze potential lagged effects of the shocks in the treated municipalities (i.e., those that suffered the worst shocks).

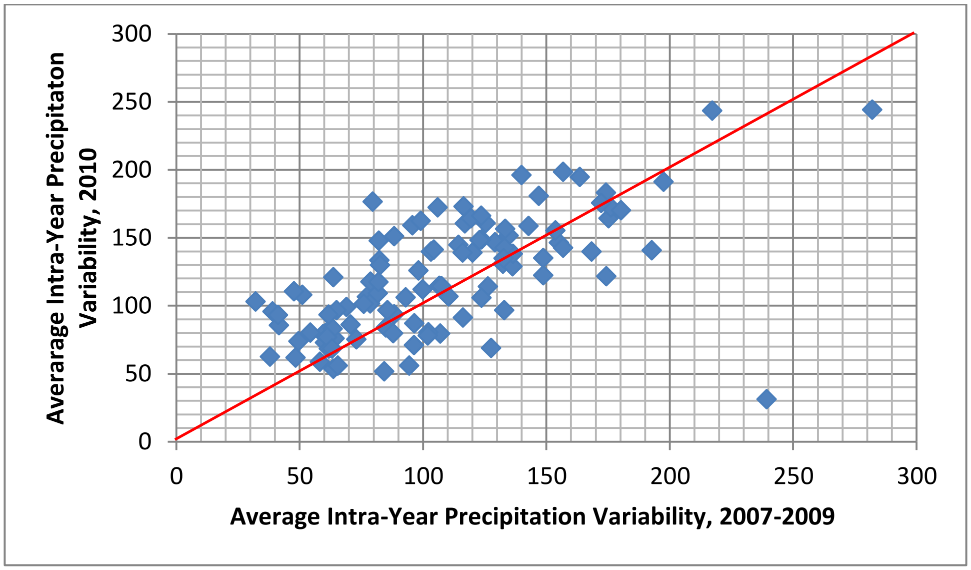
7.2. Definition of Weather Shock and of Control and Treatment Municipalities

In order to construct treated and control municipalities we need to define a criterion for what constitutes a "shock." For this purpose, we use the variability in rainfall data since the weather-related events occurred in Colombia during 2010 were mainly related with rain. We proceed as follows. We calculate the intra-year precipitation variability for each municipality and for every year between 2007 and 2010. Then, we compare the intra-year variability in 2010 with the average intra-year variability in the pre-treatment period (2007-2009). A municipality is considered treated if the 2010 intra-year variability is higher than that of the pre-treatment average.[5]

The total number of municipalities considered under this treatment definition is 798, which is the total number of municipalities for which precipitation records are available. These municipalities represent 72 percent of total Colombian municipalities. So, according to the above definition, there are 620 municipalities in the treatment group and 168 municipalities in the control group.[6] Figure 8 presents graphically our treatment and control definition. The 45-degree line separates municipalities with above-average variability (above the line) from those with below-average variability (below the line).

[5] $Treat = 1$ if $SD(rainfall_t)_{2010} > \frac{1}{3}\sum_{y=2007}^{2009} SD(rainfall_t)_y$ where *SD* stands for intra year standard deviation.
[6] The number of treated and control groups for municipalities with less than 500,000 inhabitants are 611 and 166, respectively.

Figure 8. Definition of Control and Treatment Municipalities



Source: Authors' calculations.

Our definition of weather shock is a relative measure: we only consider that a municipality suffered a severe shock in 2010 if the annual rain variability was sufficiently high relative to the pre-treatment period. We could have considered an alternative definition of "treated" municipalities choosing a different reference period, i.e., comparing 2010 rainfall variability with some measure of historical variability average over a longer period of time. However, given that the pre-treatment years (with the exception of 2009) were also quite unstable years in terms of high rainfall variability, we want to avoid considering as treated a municipality that presented high variability in both pre and post-treatment periods. This way of defining a weather shock is slightly different from previous literature which focuses mainly on monthly rainfall deviation from some historical average. Given that in previous literature finds that both above and below average rainfall can increase the incidence of diseases we decided to consider just the increase in the variability as a proxy for the changing weather conditions.

Importantly, our definition allows us to consider as treated only municipalities that suffered unexpectedly high rainfall variability during 2010. This definition makes more plausible the presumption that the shock was "unexpected," which is a key identifying assumption in interpreting the DD estimates as *causal* effects.

We argue that the municipalities suffering the shock are those which could not anticipate the weather shock. A potential problem of this assumption is that, on the one hand, if the municipalities in the treatment group are those that usually have higher rainfall variability, then these municipalities may be better prepared to buffer problems related to high rainfall variability. This would be a problem only if this group of municipalities actually anticipated the 2010 shocks by implementing in advance, for instance, public programs to prevent diseases related to climate shocks, downward biasing our estimates. On the other hand, municipalities suffering more variability during 2010 could always be more likely to suffer this type of shocks. Hence, if weather characteristics are correlated with municipality socioeconomic characteristics, then there could be a spurious correlation between the 2010 shock and the incidence of diseases.

In order to discard these potential problems we analyze the pre-treatment trends in the outcome variables in treatment and control municipalities.

7.3 Pre-Treatment Characteristics of Treatment and Control Groups

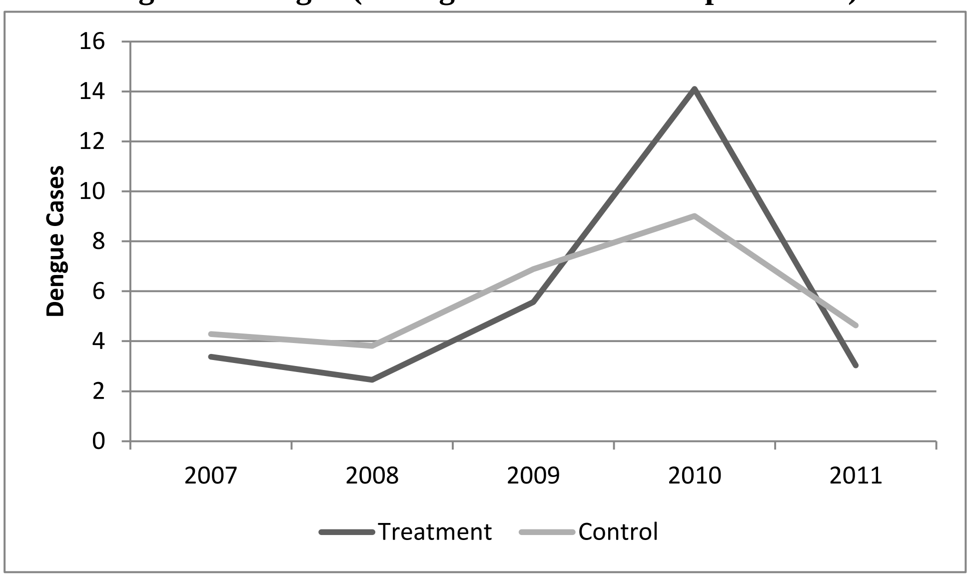
Tables 3 and 4 present descriptive statistics for the treatment and control group in the pre-treatment period (Table 3 includes all municipalities, whereas Table 4 includes only municipalities with less than 500,000 inhabitants). Although some of the differences are statistically significant, differences in magnitudes are not very important in most of the variables. One issue of special concern is the higher incidence of malaria cases in the control group, which could mean that the treatment and control groups might be different in certain unobservable characteristics that simultaneously affect the incidence of malaria (but not dengue, since both treatment and control groups are quite similar). In terms of the diff-in-diff strategy, this issue could affect the interpretation of a causality relationship as long as these unobserved differences generate different time trends in the outcomes of interest. In the next subsection we provide evidence that this does not seem to be the case.

7.4 Common Trends in the Pre-Treatment Period

The key assumption for our identification strategy is that in the absence of the 2010 climate shocks, the evolution of the outcome of interest (incidence of dengue and malaria) would have followed the same trend as the control group (common trend assumption). To check the validity of this assumption Figures 9 and 10 present the evolution of dengue and malaria. Despite the incidence of both diseases is higher in the control group, the pre-treatment trends are similar, indicating the common trend assumption is plausible. Figures 11 and 12 also show that in the pre-treatment period there are not different trends between groups in other characteristics as well, such as average rain levels or the incidence of weather-related events, measured by houses destroyed due to climate-related events.

To directly test the validity of the common trend assumption through regression analysis, we run placebo regressions defining the period from July 2008 to December 2009 as the placebo post-treatment period. The results indicate that neither dengue nor malaria has a differential trend in the pre-treatment period.[7] We do the same exercise but using as dependent variable other outcomes as monthly rains levels, houses destroyed due to natural disasters (monthly number of cases), people affected by water-related events (monthly number of cases) and total number of weather-related events (monthly number of cases) and in none of these cases are there significant trend differences in the pre-treatment period.[8]

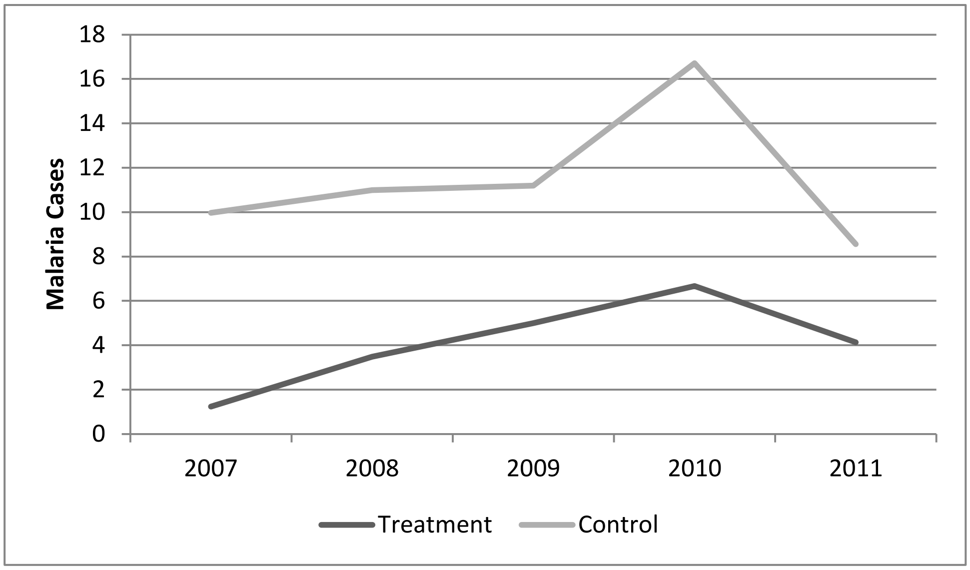
Figure 9. Dengue (average number of cases per month)



Source: Authors' calculations based on Sivigila data.

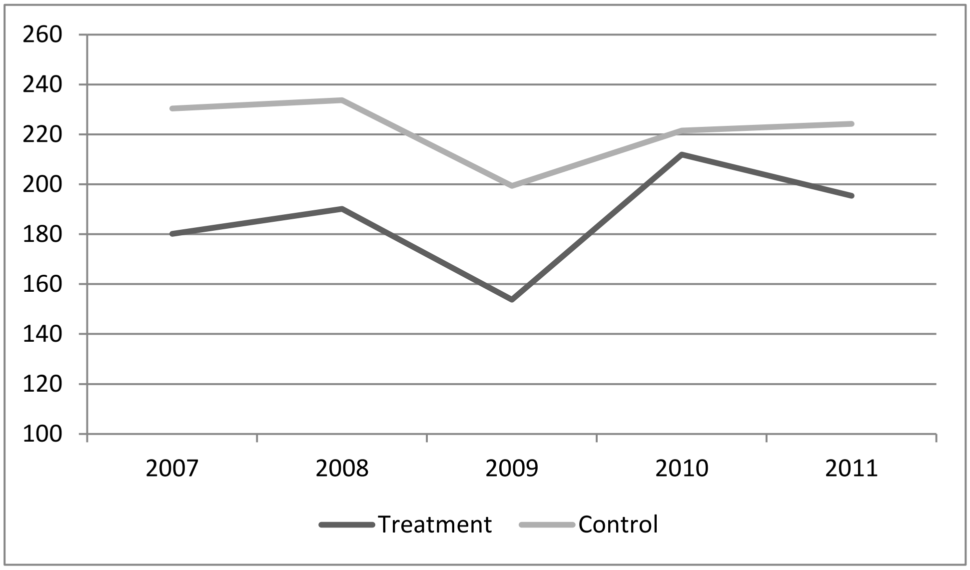
[7] Results are reported in Table B2 of the Appendix.
[8] Results are reported in table B3 of the Appendix.

Figure 10. Malaria (average number of cases per month)



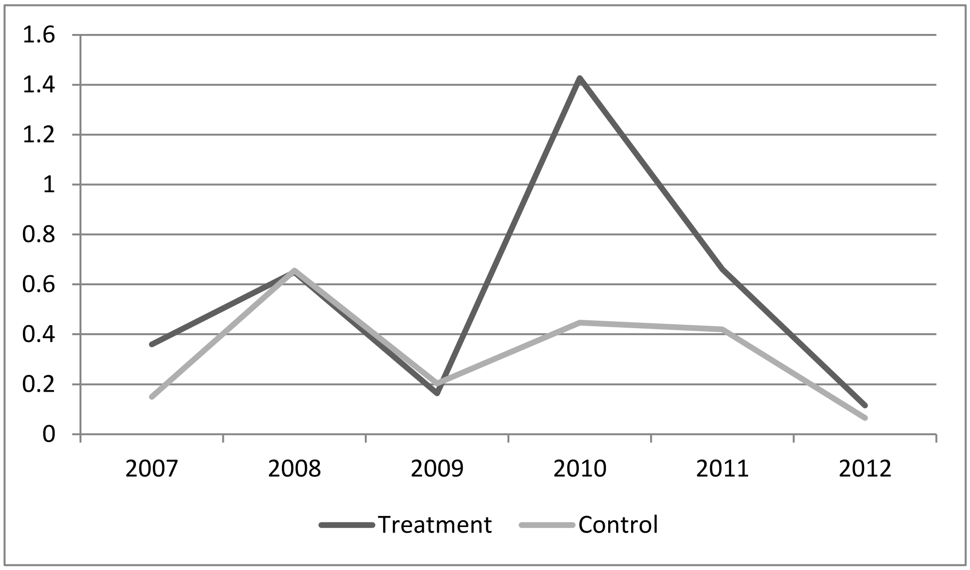
Source: Authors' calculations based on Sivigila data.

Figure 11. Precipitation Levels, 2007-2011



Source: Authors' calculations based on IDEAM data.

Figure 12. Number of Houses Destroyed by Climate-Related Events, 2007-2012



Source: Authors' calculations based on SNPAD data.

8. Results

8.1 Diff-in-Diff Baseline Specification

Table 5 presents the results of the baseline differences-in-differences specification using panel fixed effects. Panel A shows the results for dengue, whereas panel B shows the results for malaria. The coefficient of *Treat*Post* is the estimated δ parameter of equation (1), while the coefficients of *Treat*2010* and *Treat*2011* are the estimated parameters for the each of the post-treatment years. In panel A, the outcome is the total number of dengue cases by municipality; in panel B, the outcome is the total number of malaria cases by municipality. According to the estimations (columns 1 and 2), 2010 weather shocks has a positive and significant effect on the average monthly cases of dengue, especially in that same year, 2010. Specifically, the incidence of dengue increased by four cases per month during the post-treatment period 2010-2011 (almost 70 percent of the mean value).

Dengue is usually concentrated in cities with large populations. Therefore, by excluding cases occurred in cities with less than 500,000 inhabitants the results are no longer significant, although the signs are still positive, but the coefficients are smaller (see columns 3 and 4 of Table 5), indicating that large cities drive most of the effect. Panel B of Table 5 shows the effect of the 2010 weather shocks on the number of malaria cases. Weather shocks effects have a negative sign, but none of the coefficients is significant in any of the specifications. The magnitude of the coefficients does not change much when restricting the sample to municipalities with less than 500,000 inhabitants.[9]

8.2 Heterogeneous Effects

8.2.1 Age and Gender

The effects of the weather shock on the incidence of dengue do not differ by gender but they do have heterogeneous effects by age groups.[10,11] Table 6 shows the baseline specification results using as outcome the number of monthly cases by age groups. Panel A presents the results for all municipalities and Panel B for municipalities with less than 500,000 inhabitants. According to the results, the severe weather shock of 2010 has a positive and significant impact on the number of dengue cases in teenagers and young adults (ages 13-18, 19-25, and 25-35) in the year 2010. The magnitude of the effect was close to 68 percent of the mean for ages 13-18, about 87 percent for ages 19-25; and 124 percent for ages 25-35. The effects are not significant in the year 2011.

Considering only municipalities with less than 500,000 inhabitants (Panel B of Table 6), the results are similar for the age groups 13-18 and 19-25 (though the impact is weaker than in Panel A). However, the coefficient is no longer significant for the 25-35 age group, and, in contrast to the results of Panel A, it is significant for the 6-12 age group. In terms of magnitude, the effect remains strong, as it represents almost 81 percent of the mean of the 6-12 age group, 60 percent of the 13-18 age group, and 90 percent of the 25-25 age group. Again, the effects are not significant in the year 2011.

8.2.2 Rural-Urban

Dengue is primarily an urban disease. This fact is supported by the results of Table 7, which shows the impact of the weather shocks on the incidence of dengue distinguishing whether they occurred in urban or rural area within a municipality. "Urban centers" refers to the geographic

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[9] The baseline specification results for different ranges of population size are shown in Table A1 of the Appendix. In line with the previous results, the effect of the 2010 severe weather shocks on dengue cases is significant only for municipalities with more than 100,000 inhabitants. In these cities, the weather shock caused 85 more dengue cases per month in 2010, a result that is almost 149 percent of the mean. In the case of malaria, the shock effect is significant only for municipalities with populations between 10,000 and 15,000 inhabitants. The magnitude of the shock effect is important, since it represents more than 100 percent of the mean cases for these municipalities. The result is also coherent with the fact that malaria is a disease that affects mainly small rural populations.

[10] Due to data availability, results for age and gender are only reported for dengue.

[11] Results by gender are reported in Table A2 of the Appendix.

area whose boundaries are established by Municipal Council agreements, of the Municipal Council, and it is where the seat of the Municipality is located. “Rural centers” refers to villages, police posts, and districts belonging to the municipality rural area and comprising at least 20 contiguous houses; and, finally, “disperse rural area” refers to populations belonging to the area outside the county seat and characterized by the disperse arrangement of existing houses. The estimated effects are significant and positive only in densely populated settlements, both urban and rural, but not for disperse rural areas. The magnitude of the effects on both urban centers are rural centers is large, representing more than 105 percent of the urban area mean, and 150 percent of the rural centers mean. When considering only municipalities with less than 500,000 inhabitants (columns 4, 5, 6 of Table 7), the impact persists solely for rural centers.

8.2.3 Multidimensional Poverty

Next, we analyze the effects of the shocks by poverty level. We use the multidimensional poverty index, which is expressed as a value between 0 (richest municipality) and 1 (poorest municipality). The municipalities are divided quartiles according to distribution of the poverty index in 2005.[12] Results are reported in Table 8. Richer municipalities (first quartile) were the most affected in terms of increase in the number of dengue cases. For these municipalities, the weather shock increased the number of dengue cases by 21 in 2010, almost 116 percent of the mean value. The result is not significant, although it remains positive, for municipalities with less than 500,000 inhabitants.

The impact of the weather shock on malaria was also strong on richer municipalities. The impact is almost 123 percent of the mean value and remains positive and significant when considering only municipalities with less than 500,000 inhabitants, but the magnitude of the effect is somewhat smaller, 97 percent of the mean value.

8.2.4 Climate and Geography

Altitude and average temperatures are important factors determining dengue and malaria transmission. According to the National Institute of Health, dengue and malaria are more likely to appear in areas below 1,800 meters and with temperatures between 15°C and 40°C for dengue and between 25°C and 30°C for malaria. Results of the estimations considering only populations

[12] Q1 is composed of municipalities in which the poverty index takes values between 0 and 0.61; Q2 values are between 0.61 and 0.708; Q3 values are between 0.708 and 0.81; and Q4 are values above 0.81.

with the appropriate altitude and temperature conditions are shown in Table 9. The estimations are similar to those shown in Table 5, but the magnitude of the coefficients is larger, indicating a greater effect of the 2010 weather shock on incidence of dengue, even for municipalities with less than 500,000 inhabitants. Results for malaria are still not significant under this specification.[13]

8.3. Mechanisms

In order to shed some light on possible channels that might foster the dissemination of diseases when severe weather-related events occur, we estimate equation (1) using as outcome variables the following variables: municipality rainfall monthly levels, number of houses destroyed (number of monthly cases) due to climate related-events, number of people affected by weather-related events, number of total climate-related events, number of school affected and the number of casualties reported. Results reported in Table 10 indicate that rainfall levels and the number of climate-related events where significantly higher in treatment municipalities.[14] A consequence of that seems to be an increase of houses destroyed due to climate-related events. Although the coefficients are positive, there are not statistically significant differences between the treated and control groups in the number of people affected by weather-related events, schools affected or the number of casualties due to weather events.

[13] We performed a number of exercises to analyze heterogeneous effects by municipality altitude, temperature, and average precipitation levels (but not combining these characteristics). The results are shown in Tables A3 to A8 of the Appendix. Although altitude does not seem to be the main factor determining the incidence of dengue, the shock has a strong and significant impact on municipalities with average temperatures between 20°C and 25°C. These municipalities experienced on average 19 more dengue cases compared with municipalities with similar temperatures but without weather shocks in 2010. This represents a 130 percent increase in the number of cases of dengue relative to the mean, for municipalities between these temperature ranges. For malaria there are not statistically significant effects. Additionally, the impact of the weather shocks of 2010 on the number of dengue cases is greater in municipalities for which the average precipitation level during the pre-treatment period 2007-2009 was below or equal to two chosen thresholds 200 mm or 230 mm). A possible interpretation of this result is that the unexpected shock of 2010 had a greater impact in places that were neither used to nor prepared for unexpectedly high rain variability. However, the impact of the shock on the number of malaria cases is significant only for places that had higher average precipitations levels (above 230 mm.) during 2007-2009.

[14] Note that higher variability of rains which define treatment status is also associated with an increase of average rainfall levels in the post treatment period.

9. Extensions

9.1 Diff-in-Diff Specification with Two Treatments

In order to get a further insight into the effects of the intensity of the 2010 climate shocks, we estimate the following specification:

$$outcome_{mty} = \alpha + \beta Treat_m + \gamma Post_t + \delta Treat_m * Post_t + \beta_2 Treat\_H_m + \delta_2 Treat\_H_m * Post_t + \lambda_Y + \lambda_T + \lambda_M + \Gamma'^{X_{mt}} + \varepsilon \quad (2)$$

where *outcome* is the variable of interest (incidence of dengue or incidence of malaria) in municipality *m* in month *t* and year *y*; *Treat* is a dummy variable that equals 1 if municipality *m* experienced severe weather shock in 2010, and *Treat_H* that takes the value of 1 if the shock was severe (2010 variability is 50 percent higher than the 2007-2009 variability average); *Post* is a dummy variable that takes the value 1 for post-treatment period (2010 and after); $\lambda_{Y,}$ λ_T and λ_M are year, month and municipality fixed effects; and *X* are other time-varying municipality-level characteristics.

Results are shown in Table 11. According to the results, in the case of dengue (panel A), there seems to be a nonlinear relation between the intensity of the shock and the effect on the total number of dengue cases. The coefficients associated with milder shocks (low intensity) remain positive and significant when considering all the municipalities. However, the coefficients associated with stronger shocks (high intensity) are negative, but not significant. Specifications that include only municipalities with less than 500,000 inhabitants are not significant.

In the case of malaria (panel B), the coefficients of both *Treat* and *Treat_H* (low and high rain intensity, respectively) are negative, but only the coefficients of *Treat_H* (high intensity) are statistically significant.

9.2 Placebo Diff-in-Diff Regressions

In order to check the robustness of our DD results we estimate equation (1) using other diseases available in the Sivigila database as outcome variables. A priori, we expect no effect of the 2010 weather shocks on trauma and diseases such as ophidism (poisoning by venomous snakebite), diarrhea, pesticide poisoning, AIDS, tuberculosis, and varicella. Regressions are shown in Table B1 of the Appendix. Except for ophidism and tuberculosis; all relevant coefficients are not significant. In the case of ophidism, although the coefficients are statistically significant, their sign is negative and close to zero; in the case of tuberculosis, the coefficient is significant only in 2011 and at a 10 percent confidence level.

10. Alternative Measures of Weather Shocks

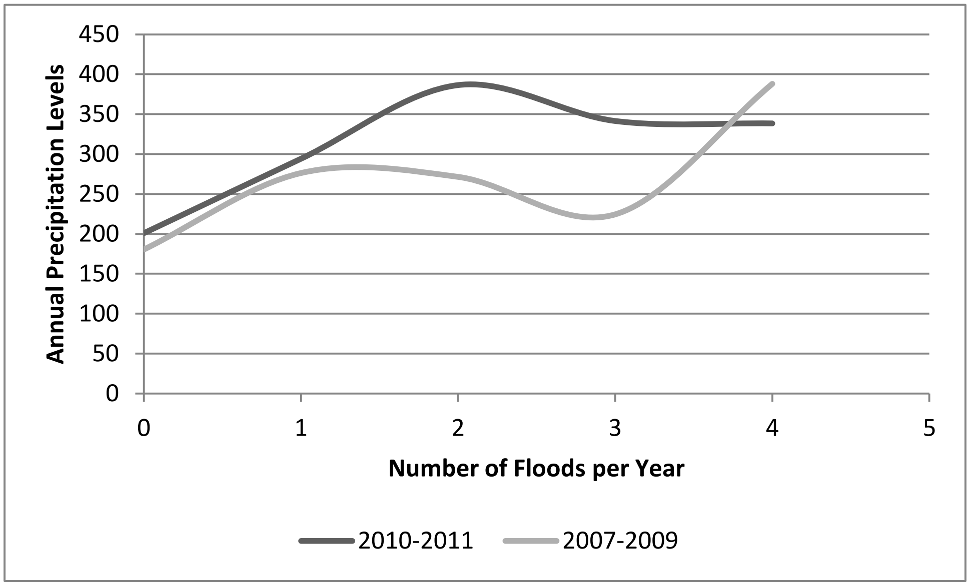
10.1 Floods

Floods are generally associated with high precipitation levels (see Figure 13). As was shown in Section 9.1, there seems to be nonlinearities in the relationship between rain variability and the total number of dengue and malaria cases. Using the information available in the SNPAD about natural disasters in the country, this section examines the relationship between the number of floods and the incidence of dengue and malaria during the period 2007-2011. We estimate the following equation:

$$outcome_{mty} = \alpha + \beta_1 Flood_{my} + \beta_2 Flood_{my}^2 + \beta_3 Flood_{my} * \sum_{t=2007}^{2011} year_t + \beta_4 Flood_{my}^2 * \sum_{t=2007}^{2011} year_t + \lambda_Y + \lambda_T + \lambda_M + \varepsilon, \qquad (3)$$

where *outcome* is the variable of interest (incidence of dengue or malaria) in municipality *m* in month *t* and year *y*; *Flood* denotes the number of floods experienced by municipality *m* in year *y*; *year* is a dummy variable that takes the value 1 for year *t*; $\lambda_{Y,}$ λ_T and λ_M are year, month and municipality fixed effects.

Figure 13. Number of Floods and Precipitation Levels, 2007-2009 and 2010-2011



Source: Authors' calculations based on SNPAD data.

Results are presented in Table 12. The marginal effect of an increase in the number of floods on the number of dengue or malaria cases is evaluated at different values of the variable *Flood* when it takes the values of 0 (no floods during the year), 1, or 2 floods during the year.

If we consider floods as a form of extreme weather event associated with extreme precipitation levels, the results are generally in line with the findings of the DD specification where we consider moderate and severe weather shocks (Section 9.1). Floods are therefore related to a lower incidence of both dengue and malaria cases. When analyzing all municipalities, one additional flood when the number of floods is equal to 0 is associated with a significant and important decrease in the number of dengue cases in the years 2007, 2008, and 2011. The magnitudes of the effects with respect to their mean values are 279 percent in 2007, 393 percent in 2008, and 385 percent in 2011. The coefficients for the years 2009 and 2010 are not significant. The marginal effect of one additional flood when the number of floods is 1 has a significant and important effect in the years 2008 and 2011 (604 percent and 642 percent of their mean values), but not in the years 2007, 2008, and 2011. Finally, the marginal effect of one additional flood when the number of floods is equal to 2 is associated with a significant increase in the number of dengue cases in 2007 (507 percent of the mean), but not in the other years.

Dropping municipalities with less than 500,000 inhabitants generates a slightly different picture. The marginal effect of one additional flood on the total number of dengue cases when the number of floods is equal to 0 is negative and significant in 2011 (223 percent of the mean), but not in the other years; the marginal effect of one additional flood when the number of floods is 1 is positive and significant in 2009 (354 percent of the mean) and negative and significant in 2011 (263 percent of the mean). When there are two floods one additional flood has no significant effect in these municipalities.

The results are not significant for malaria (see Table 13). The only exception is the year 2009. In that year, one additional flood when the number of floods is 1 shows a significant effect on the increase of malaria cases, especially for municipalities with less than 500,000 inhabitants.

10.2 Rainfall Deviation from Historical Monthly Average

The weather events of 2010 were particularly severe, providing giving the possibility to exploit them as an exogenous severe climate variation in a Difference in Difference setup. However, by using a DD we are not fully exploiting all the variability of the weather data. In line with previous literature (Kudamatsu, Persson and Strömberg, 2010; Maccini and Yang, 2009; and Rocha and Soares, 2012) we propose a specification where we analyze the correlation between monthly rain and monthly number of dengue or malaria cases at the municipality level.

We propose the following alternatives to define a weather shock. First, we define the weather shock imputed to month *t* in municipality *m* as a log-deviation of rainfall *r* in month *t* relative to a historical average $\bar{r}$ in that same municipality-month, $S_{mty} = \ln(r_{mty}) - \ln(\overline{r_t})$, or a lagged version of this variable, $S_{mty} = \ln(r_{mt-1y}) - \ln(\overline{r_{t-1}})$ (models 1 and 2). As in Rocha and Soares (2012) this variable can be approximately interpreted as the percentage deviation from the historical monthly average. Second, we construct dummies to capture extreme rainfall events (Kudamatsu, Persson and Strömberg, 2010; Maccini and Yang, 2009, and Rocha and Soares, 2012). Given that previous literature has shown that both positive and negative rainfall shocks may have either positive or negative effects on health, we construct extreme events (positive or negative) dummies in the following way: 1) positive shock: $D_{mty} = 1$ if $r_{mty} > sd_{mty} + \overline{r_t}$ (or even more extreme $D'_{mty} = 1$ if $r_{mty} > 2sd_{mty} + \overline{r_t}$); 2) negative shock: $D_{mty} = 1$ if $r_{mty} < \overline{r_t} - sd_{mty}$ (or even more extreme $D'_{mty} = 1$ if $r_{mty} < \overline{r_t} - 2sd_{mty}$) (models 3 and 4) . The historical average $\overline{r}$ for each municipality-month is calculated over the period 1999-2007.[15]

We estimate the following specification:

$$outcome_{mty} = \alpha + \beta Shock_{mty} + \lambda_Y + \lambda_T + \lambda_M + \Gamma'^{X_{m,t}} + \varepsilon_{it} \quad (4)$$

where *outcome* is the health variable of interest in municipality *m* in month *t* and year *y; shock* is the shock variable (log deviation of monthly rainfall or dummies indicating extreme weather shocks); $\lambda_{Y,}$ λ_T and λ_M are year, month and municipality fixed effects; and *X* are other time-varying municipality-level characteristics.[16]

In this specification we are assuming that there is no other shock, other than the monthly weather shock, that simultaneously affects the occurrence of diseases. This assumption would be violated if, for instance, the municipality can anticipate a severe weather event by increasing public resources devoted to campaigns preventing vector-borne diseases, which would downward bias the effects of severe weather shocks. Another potential concern with this specification is that there could be confounding omitted variables correlated both with rainfall and occurrence of vector-borne diseases. For instance, municipalities more likely to experience rainfall shocks may tend to have worse socioeconomic conditions, which are also correlated with worse health outcomes. However, by including municipality fixed effects we control for any time-invariant effect associated with both climatic and socioeconomic conditions of a given municipality. By including month fixed effects we control for any recurrent level effect, common to all municipalities, in a given month of the year typically associated, for instance, with dry or rainy seasons. Year fixed effects control for aggregate shocks that impact the whole country.

10.3 Baseline Specification

Results are presented Table 14. In the first and second models, the rain shock is the percentage deviation of rainfall in month *t* relative to the month historical mean (model 1) or its lag (model 2). Results for dengue are reported in columns 1 (all municipalities) and 2 (municipalities with less than 500,000 inhabitants). The results indicate that, on average, for the period 2007 to 2011, above-average rains are negatively associated with the number of cases of dengue at the

[15] Our rain data is available for the period 1991-2011. We performed the analysis using this subset of municipalities and constructing the historical means in the period 1991-2007. The results are qualitatively similar.
[16] In some specifications we control for monthly temperature. We have this information only for 171 municipalities.

municipality level. Particularly, a 1 percent increase in rainfall above average is associated with a reduction of 0.44 in the number of monthly cases of dengue. Results are almost the same if monthly lagged rains are used. When analyzing only municipalities with less than 500,000 inhabitants, the correlation is still negative and statistically significant only when using the lags, but the magnitude is smaller (0.25-0.28 less cases of dengue). For malaria, all the estimated coefficients are negative but smaller in magnitude, and none of them statistically significant when using the contemporaneous rainfall deviation. However, when using the lags as control variables the effect of a 1 percent increase in rainfall above average is associated with a statistically significant reduction of 0.22-0.23 in the number of monthly cases of malaria.

Models 3 and 4 present the correlation between extreme weather shocks (positive or negative) and disease. Model 3 estimates indicate that the occurrence of a negative shock in a given month (i.e., rains below more than one standard deviation relative to the historical mean) are positively associated with the number of monthly cases in the municipality, although the effects are not statistically significant, while positive shocks (above normal monthly rainfalls) are negatively correlated with the occurrence of dengue, although the effect are not statistically significant. Model 4 incorporates a differential effect for those events that are even more extreme (when monthly rainfall is two standard deviations above or below the historical mean) but none of these effects are statistically significant, except for a negative impact of extreme positive (excess rain) shock. For malaria, none of the estimated effects are statistically significant. Even after controlling for the average monthly temperature, results are still robust (Table C1 of the Appendix).[17] The magnitude of the effects is even larger for dengue but not statistically significant for malaria.

The results are in line with results discussed in Section 9.1. (diff-in-diff specification with two treatments) and Section 9.3 (floods), where excessive positive rains or floods are generally negatively correlated with the occurrence of the diseases.

We additionally analyze heterogeneous effects by some municipality characteristics (altitude, average temperatures, precipitation levels and the multidimensional poverty index).[18]

[17] The sample of municipalities is smaller due to data availability of monthly temperatures.

[18] Results are reported in tables C2 to C10 of the appendix. Table C2 of the Appendix shows the heterogeneous effects of rain shocks on dengue by municipality altitude. For municipalities at or above 1,000 meters there is a significant negative correlation between deviations from the historical mean and dengue. Table C3 shows a negative correlation with malaria as well, although the magnitude of the coefficients is one tenth the magnitude relative to dengue.

The results dividing municipalities by multidimensional poverty are noteworthy. We find that the negative correlation between rain shocks and dengue decreases and eventually turns positive as the poverty level increases. Although the results are less robust, the same pattern is observed for malaria.

11. Conclusions

In this paper we exploited the unexpectedly severe weather shocks that hit Colombia in 2010 to study the link between climate shocks and the incidence of dengue and malaria. Using as identification strategy the variability of the 2010 rainfalls relatively to previous periods, as well as the regional heterogeneity, we implemented a difference in differences strategy where the period 2007-2009 was defined as the pre-treatment period and 2010-2011 as the post treatment period. We defined as the treatment group all municipalities that during 2010 experienced intra-year rainfall variability higher than the 2007-2009 average variability. We extended the diff-in-diff analysis to explore the relationship between floods and vector-borne diseases and also proposed an alternative specification that exploits all the variability in monthly rainfall by correlating monthly rain shocks (constructed taking into account the monthly rain level relative to historic mean) with monthly number of diseases at the municipality level.

The different results indicate that the relationship between weather variability and the incidence of vector-borne diseases is intricate. On the one hand, the diff-in-diff results show that the severe weather events of 2010 affected the number of monthly cases of dengue mainly in large municipalities (in terms of population) in both urban and rural areas (but not in disperse rural areas). The effect is magnified for municipalities located at altitudes lower than 1,800 meters above the sea level and with annual average temperatures between 15°C and 40°C. The impact is also stronger and significant in teenagers (13-18 years old) and young adults (19-35 years old). Additionally, the less multidimensionally poor are the most affected. Broadly, results of the diff-in-diff estimations for malaria are not significant, except for municipalities with

Classifying municipalities by their historical temperature levels (Tables C4 and C5), we find a negative correlation between deviations from the historical rainfall mean and dengue in municipalities with average annual temperature between 20°C-25°C. There are also significant effects of rainfall shocks on malaria cases going in the same direction as in the case of dengue. However, the sign of the coefficient is positive for municipalities with average temperature above 25°C. Finally, we divide municipalities by their average monthly rains (below 200 mm per month and above 200 mm per month). The results in Tables C6 and C7 of the Appendix indicate that the negative correlation between rainfall shocks and dengue is only present in municipalities that have lower levels of rain.

populations between 10,000 and 15,000 and for municipalities that experienced extreme precipitation levels during the pre-treatment period (2007-2009). As in the case of dengue, the weather shocks of 2010 have a greater and significant incidence in the less multidimensionally poor municipalities. On the other hand, results from alternative specifications show that the weather shocks of 2010 are associated with not only an increase in the number of dengue cases, in the case of high but not extreme rain events, but also a decrease in its incidence, in particular in the presence of extreme rain events. Floods, which are linked to heavy rains, seem to have decreased the number of dengue cases, a result that is in line with the negative correlation found between monthly positive rainfall shocks and dengue cases.

One of the consequences of climate change is the increase in the number of extreme weather events. In Colombia, the number of these events as well as the number of people affected has increased during the last decade. Since the future is expected to include even more climate events, acknowledging the relationship between climate variability and outbreaks of vector-borne diseases is important for policymakers. Although this relationship is complex, it is possible for governments to identify risk-factors associated with climate variability in order to mitigate the impact of climate change on the spread of these diseases and reduce the vulnerability of communities that could be potentially affected.

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Tables

Table 1. Dengue Characterization, 2007-2009

	2007	2008	2009	2007-2009
Dengue hemorrhagic fever	0.15	0.11	0.14	0.14
Dead	0.002	0.001	0.001	0.001
Urban Area (%)	61.10	66.77	66.88	68.31
Rural Area (%)	16.84	10.95	9.77	11.13
Disperse Rural Area (%)	22.04	22.26	23.33	20.55
Male	0.52	0.56	0.53	0.53
Age	21.93	21.28	30.30	25.64
Age 5 and younger	0.17	0.20	0.13	0.16
Age 6 to 12	0.22	0.23	0.19	0.21
Age above 55	0.07	0.07	0.19	0.13
Ethnic group	0.15	0.13	0.10	0.12
Contributory Regime	0.46	0.45	0.48	0.47
Subsidized Regime	0.31	0.32	0.34	0.33
Special + Exemption Regime	0.06	0.05	0.05	0.05
No affiliation	0.18	0.18	0.12	0.15
Displaced or migrant	0.006	0.005	0.004	0.005

Source: Authors' calculations based on Sivigila data.

Table 2. Malaria Characterization, 2007-2009

	2007	2008	2009	2007-2009
Dead	0.0004	0.0004	0.0002	0.0003
Urban Area (%)	22.79	17.97	14.72	17.51
Rural Area (%)	11.99	17.41	19.03	17.02
Disperse Rural Area (%)	65.20	64.62	66.25	65.47
Male	0.63	0.64	0.65	0.64
Age	22.9	23.7	28.3	25.6
Age 5 and younger	0.11	0.11	0.07	0.09
Age 6 to 12	0.16	0.15	0.17	0.16
Age above 55	0.04	0.05	0.12	0.08
Ethnic group	0.34	0.40	0.31	0.35
Contributory Regime	0.05	0.05	0.04	0.05
Subsidized Regime	0.31	0.40	0.47	0.41
Special + Exemption Regime	0.04	0.05	0.05	0.05
No affiliation	0.60	0.50	0.42	0.48
Displaced or migrant	0.015	0.018	0.015	0.016

Source: Authors' calculations based on Sivigila data.

Table 3. Characteristics of the Treatment and Control Groups in Pre-treatment Period

Variable	Treatment group (mean)	Control group (mean)	t-test (p-value)
Average Temperature	22.12 °C	23.47 °C	21.33 (0.00)
Altitude (mts)	1,193.22	910.10	-25.65 (0.00)
Average rainfall	185.63	221.66	17.86 (0.00)
Average rainfall variability	105.66	125.91	30.58 (0.00)
Municipalities under 1800 mts (%)	71.45	79.17	-1.76 (0.0778)
Municipalities with temperatures between 20°C-30°C (%)	55.8	60.11	-0.77 (0.4417)
Unsatisfied Basic Needs (% of population, 2005)	43.69	46.97	13.81 (0.00)
Multidimensional Poverty Index	0.69	0.72	18.06 (0.00)
Contributive Health Regime (% population covered, 2008)	23.62	21.89	-2.6 (0.0093)
Subsidized Health Regime (% population covered, 2008)	41.82	42.46	0.87 (0.3825)
Population (average, 2005)	55,963	33,239	-6.22 (0.00)
Dengue, monthly cases	5.98	5.88	-0.16 (0.8703)
Malaria, monthly cases	4.09	11.78	15.73 (0.00)
% Municipalities with Dengue in Urban Areas	74.19	72.62	0.38 (0.7021)
% Municipalities with Dengue in Rural Areas	59.68	59.52	0.033 (0.9739)
% Municipalities with Dengue in Disperse Rural Areas	64.19	69.05	-1.03 (0.3016)
% Municipalities free of dengue (2007-2009)	18.22	17.85	0.047 (0.9627)
% Municipalities free of malaria (2007-2009)	31.08	25.31	0.59 (0.5557)
Dengue, monthly cases, municipalities with less than 100,000 inh.	1.16	2.43	15.22 (0.00)
Dengue, monthly cases, municipalities with populations between 10,000 and 15,000 inh.	0.50	1.10	9.58 (0.00)
Dengue, monthly cases, municipalities with populations between 15,000 and 30,000 inh.	1.05	2.18	11.04 (0.00)
Dengue, monthly cases, municipalities with populations between 30,000 and 60,000 inh.	3.13	6.40	7.29 (0.00)
Dengue, monthly cases, municipalities with populations between 60,000 and 100,000 inh.	4.79	10.39	5.13 (0.00)
Dengue, monthly cases, municipalities with more than 100,000 inh.	38.15	41.11	-1.97 (0.0485)
Dengue, monthly cases, municipalities with populations between 100,000 and 500,000 inh.	31.79	55.47	4.84 (0.00)
Malaria, monthly cases, municipalities with less than 100,000 inh.	2.94	10.22	14.23 (0.00)
Malaria, monthly cases, municipalities with populations between 10,000 and 15,000 inh.	1.42	3.24	2.96 (0.0031)
Malaria, monthly cases, municipalities with populations between 15,000 and 30,000 inh.	3.56	8.11	4.76 (0.00)
Malaria, monthly cases, municipalities with populations between 30,000 and 60,000 inh.	9.35	32.53	7.70 (0.00)

Table 3., continued

Variable	Treatment group (mean)	Control group (mean)	t-test (p-value)
Malaria, monthly cases, municipalities with populations between 60,000 and 100,000 inh.	3.44	43.68	13.01 (0.00)
Malaria, monthly cases, municipalities with more than 100,000 inh.	7.03	17.67	7.25 (0.00)
Malaria, monthly cases, municipalities with populations between 100,000 and 500,000 inh.	11.24	32.07	7.18 (0.00)
Dengue, monthly cases, years 0-5	0.47	0.55	1.97 (0.0491)
Dengue, monthly cases, years 6-12	0.63	0.77	2.47 (0.0135)
Dengue, monthly cases, years 13-18	0.53	0.57	1.01 (0.3112)
Dengue, monthly cases, years 19-25	0 .53	0.59	1.51 (0.1305)
Dengue, monthly cases, years 25-35	0 .89	0.89	0.0645 (0.9486)
Dengue, monthly cases, years 35-45	0 .86	0.80	-0.58 (0.5630)
Dengue, monthly cases, years 45-55	0.7	0.63	-0.74 (0.4583)
Dengue, monthly cases, years 55 and more	1.64	1.27	-1.65 (0.098)
Dengue, monthly cases, urban areas	5.19	4.9	-0.54 (0.5916)
Dengue, monthly cases, rural center	0.37	0.50	7.44 (0.00)
Dengue, monthly cases, disperse rural areas	0.44	0.44	0.09 (0.9272)

Source: Authors' calculations based on DANE and CEDE data.
Note: The gap in the population size between treatment and control groups are explained to a large extend by the inclusion of Bogotá D.C. in the treatment group. Without Bogotá D.C., the treatment group average population decreases to 43,038.

Table 4. Characteristics of the Treatment and Control Groups in Pre-treatment Period (Municipalities with Less Than 500,000 inh.)

Variable	Treatment group (mean)	Control group (mean)	t-test (p-value)
Average Temperature	22.11°C	23.47°C	21.50 (0.00)
Altitude (mts)	1195.89	910.11	-25.84 (0.00)
Average rainfall	185.87	220.8	17.17 (0.00)
Average rainfall variability	96.88	128.37	28.42 (0.00)
Municipalities under 1800 mts (%)	71	80	-2.05 (0.0404)
Municipalities with temperatures between 20-30° (%)	56	61	-0.89 (0.3726)
Unsatisfied Basic Needs (% of population, 2005)	43.96	47.06	13.07 (0.00)
Multidimensional Poverty Index	0.69	0.72	16.96 (0.00)
Contributive Health Regime (% population covered, 2008)	22	22	-1.17 (0.2417)
Subsidized Health Regime (% population covered, 2008)	42	42	0.112 (0.9108)
Population (average, 2005)	30,473	33,239	3.99 (0.0001)
Dengue, monthly cases	3.41	5.91	8.15 (0.00)
Malaria, monthly cases	4.11	11.93	15.77 (0.00)
% Municipalities free of dengue (2007-2009)	0.19	0.17	-3.10 (0.0020)
% Municipalities free of malaria (2007-2009)	31	25	0.57 (0.5703)
% Municipalities with Dengue in Urban Areas	74.14	72.89	1.5 (0.1336)
% Municipalities with Dengue in Rural Areas	59.41	60.24	0.32 (0.7451)
% Municipalities with Dengue in Disperse Rural Areas	63.83	69.27	-0.19 (0.8468)
Dengue, monthly cases, years 0-5	53.19	57.83	12.26 (0.00)
Dengue, monthly cases, years 6-12	60.39	60.84	12.35 (0.00)
Dengue, monthly cases, years 13-18	59.25	61.44	10.98 (0.00)
Dengue, monthly cases, years 19-25	58.10	63.85	11.36 (0.00)
Dengue, monthly cases, years 25-35	60.88	63.25	8.05 (0.00)
Dengue, monthly cases, years 35-45	54.82	56.02	6.45 (0.00)
Dengue, monthly cases, years 45-55	49.75	54.81	5.75 (0.00)
Dengue, monthly cases, years 55 and more	54.00	57.22	3.28 (0.0010)
Dengue, monthly cases, urban areas	1.78	4.27	8.05 (0.00)
Dengue, monthly cases, rural center	0.20	0.40	2.83 (0.0046)
Dengue, monthly cases, disperse rural areas	0.24	0.38	9.44 (0.00)

Source: Authors' calculations based on DANE and CEDE data.

Table 5. DD Specification: Effects of the 2010 Weather Shocks on Dengue and Malaria

A. Dengue				
Outcome: Dengue Cases	**Baseline (1)**	**Baseline by year (2)**	**Baseline, municipalities with less than 500,000 inh. (3)**	**Baseline by year, municipalities with less than 500,000 inh. (4)**
Treat*Post	4.129**		1.926	
	(1.761)		(1.201)	
Treat*2010		6.007**		1.697
		(2.906)		(1.764)
Treat*2011		0.309		2.393
		(1.808)		(1.634)
Observations	41,735	41,735	41,300	41,300
R-squared	0.021	0.021	0.021	0.021
Number of municipalities	788	788	777	777
B. Malaria				
Outcome: Malaria Cases	**Baseline Post (1)**	**Baseline Post by year (2)**	**Baseline Post, municipalities with less than 500,000 inh. (3)**	**Baseline Post by year, municipalities with less than 500,000 inh. (4)**
Treat*Post	-1.451		-1.122	
	(2.983)		(2.787)	
Treat*2010		-2.513		-2.292
		(3.708)		(3.552)
Treat*2011		0.71		1.265
		(2.003)		(1.865)
Observations	41,735	41,735	41,300	41,300
R-squared	0.006	0.007	0.009	0.009
Number of municipalities	788	788	777	777
Number of Treated municipalities	620	620	611	611
Number of control municipalities	168	168	166	166

Note: The coefficient Treat*Post is the estimated parameter δ of equation (1), which is the DD estimation (using panel data with fixed effects) of the effect of the 2010 weather shocks on the respective outcome. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed types), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. The coefficients Treat*2010 and Treat*2011 are the DD estimation of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively on the respective outcomes. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post treatment period. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. (1) Baseline specification with one treatment, (2) baseline specification with heterogeneous effects by year, (3) baseline specification for municipalities with less than 500,000 inhabitants, (4) baseline specification with heterogeneous effects by year for municipalities with less than 500,000inhabitants.

Table 6. DD Specification: Effects of the 2010 Weather Shocks Dengue by Age Groups

A. Dengue: All population								
Outcome: Dengue Cases by age group	Younger than 5 yrs. (1)	Between 6 and 12 yrs. (2)	Between 13 and 18 yrs. (3)	Between 19 and 25 yrs. (4)	Between 25 and 35 yrs. (5)	Between 35 and 45 yrs. (6)	Between 45 and 55 yrs. (7)	Older than 55 yrs. (8)
Treat*2010	0.184	0.207	0.359***	0.465***	1.090**	0.969	0.736	2.255
	(0.242)	(0.221)	(0.106)	(0.143)	(0.447)	(0.618)	(0.547)	(1.411)
Treat*2011	0.291	0.262	0.154	0.0358	0.0641	-0.032	-0.0288	-0.442
	(0.396)	(0.339)	(0.226)	(0.191)	(0.213)	(0.205)	(0.170)	(0.389)
Observations	41,735	41,735	41,735	41,735	41,735	41,735	41,735	41,735
R-squared	0.013	0.011	0.008	0.014	0.025	0.025	0.025	0.027
Number of municipalities	788	788	788	788	788	788	788	788
Number of Treated municipalities	620	620	620	620	620	620	620	620
Number of control municipalities	168	168	168	168	168	168	168	168

B. Dengue: Less than 500,000 inhabitants								
Outcome: Dengue Cases by age group	Younger than 5 yrs. (1)	Between 6 and 12 yrs. (2)	Between 13 and 18 yrs. (3)	Between 19 and 25 yrs. (4)	Between 25 and 35 yrs. (5)	Between 35 and 45 yrs. (6)	Between 45 and 55 yrs. (7)	Older than 55 yrs. (8)
Treat*2010	0.301	0.366**	0.218***	0.334***	0.383	0.0377	-0.0457	0.188
	(0.203)	(0.178)	(0.076)	(0.115)	(0.270)	(0.381)	(0.338)	(0.884)
Treat*2011	0.468	0.436	0.315*	0.163	0.288	0.295	0.252	0.253
	(0.322)	(0.277)	(0.187)	(0.175)	(0.207)	(0.201)	(0.164)	(0.339)
Observations	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300
R-squared	0.05	0.036	0.012	0.011	0.026	0.034	0.035	0.034
Number of municipalities	777	777	777	777	777	777	777	777
Number of Treated municipalities	611	611	611	611	611	611	611	611
Number of control municipalities	166	166	166	166	166	166	166	166

Note: The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively, on the respective outcome. The coefficients are the DD estimation of the effect of the 2010 weather shocks on the respective outcome in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed types), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. (1) younger than 5 years old, (2) between 6 and 12 years old, (3) between 13 and 18 years old, (4) between 19 and 25 years old, (5) between 25 and 35 years old, (6) between 35 and 45 years old, (7) between 45 and 55 years old, (8) older than 55 years old.

Table 7. DD specification: Effects of the 2010 Weather Shocks Dengue by Living Area

	All municipalities			Less than 500,000 inh.		
Outcome: Dengue Cases by living area	**Urban Area (1)**	**Rural Center (2)**	**Disperse Rural Area (3)**	**Urban Area (4)**	**Rural Center (5)**	**Disperse Rural Area (6)**
Treat*2010	5.350**	0.652**	0.00478	1.311	0.415*	-0.0288
	(2.675)	(0.282)	(0.115)	(1.591)	(0.239)	(0.112)
Treat*2011	0.279	0.0666	-0.0349	2.251	0.156*	-0.0131
	(1.708)	(0.096)	(0.0738)	(1.537)	(0.085)	(0.0725)
Observations	41,735	41,735	41,735	41,300	41,300	41,300
R-squared	0.02	0.012	0.037	0.018	0.01	0.037
Number of municipalities	788	788	788	777	777	777
Number of Treated municipalities	620	620	620	611	611	611
Number of control municipalities	168	168	168	166	166	166

The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively, on the respective outcome. The coefficients are the DD estimation of the effect of the 2010 weather shocks on the respective outcome in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed types), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. (1) Urban area refers to the geographic area whose boundaries are established by Municipal Council agreements and it is where the seat of the Municipality is located; (2) rural area refers to villages, police posts, and districts belonging to the municipality rural area and comprising at least 20 contiguous houses (3) disperse rural area refers to populations belonging to the area outside the county seat and characterized by the disperse arrangement of existing houses.

Table 8. DD specification: Effects of the 2010 Weather Shocks on Dengue by Multidimensional Poverty Levels

	All municipalities				Municpalites with less than 500,000 inh.			
Outcome: Dengue Cases	**MPI: Quartile 1 (1)**	**MPI: Quartile 2 (2)**	**MPI: Quartile 3 (3)**	**MPI: Quartile 4 (4)**	**MPI: Quartile 1 (5)**	**MPI: Quartile 2 (6)**	**MPI: Quartile 3 (7)**	**MPI: Quartile 4 (8)**
				A. Dengue				
Treat*2010	21.61**	-2.579	0.375	0.173	6.075	-2.579	0.375	0.173
	(10.700)	(2.591)	(0.591)	(0.369)	(6.607)	(2.591)	(0.591)	(0.369)
Treat*2011	6.093	0.000194	0.424	0.013	12.09	0.001	0.424	0.013
	(7.338)	(0.896)	(0.508)	(0.326)	(7.345)	(0.896)	(0.508)	(0.326)
Observations	10,551	10,312	10,450	10,422	10,116	10,312	10,450	10,422
R-squared	0.041	0.053	0.033	0.017	0.042	0.053	0.033	0.017
Number of municipalities	195	194	193	206	188	192	193	204
				B. Malaria				
Treat*2010	0.930***	-3.794	0.0385	-1.738	0.729**	-3.794	0.0385	-1.738
	(0.334)	(6.483)	(5.710)	(8.153)	(0.290)	(6.483)	(5.710)	(8.153)
Treat*2011	0.901*	2.997	-0.948	6.959	0.867**	2.997	-0.948	6.959
	(0.463)	(3.707)	(4.262)	(4.687)	(0.426)	(3.707)	(4.262)	(4.687)
Observations	10,551	10,312	10,290	10,422	10,116	10,312	10,290	10,422
R-squared	0.019	0.055	0.041	0.011	0.015	0.055	0.041	0.011
Number of municipalities	195	194	193	206	188	192	193	204
Number of Treated municipalities	167	141	153	159	160	141	153	157
Number of control municipalities	28	53	40	47	28	51	40	47

The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively, on the respective outcome. The coefficients are the DD estimation of the effect of the 21010 weather shocks on the respective outcome in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed types), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.The multidimensional poverty index is provided by Departamento Nacional de Planeación (DNP). The index is based on the 2005 census and is expressed as a value between 0 and 1, the higher the number the more multidimensional poor. (1) and (5) Multidimensional poverty index between 0 and 0.61 (quartile 1), (2) and (6) multidimensional poverty index between 0.61-0.708 (quartile 2), (3) and (7) multidimensional poverty index between 0.708 and 0.81 (quartile 3), (4) and (8) multidimensional poverty index above 0.81 (quartile 4).

Table 9. DD specification: Effects of the 2010 Weather Shocks on Dengue and Malaria by Altitude and Temperature Ranges Linked to Their Incidence

Outcome: Dengue Cases/Malaria Cases	**Baseline Post**	**Baseline Post by year**	**Baseline Post, municipalities with less than 500,000 inh.**	**Baseline Post by year, municipalities with less than 500,000 inh.**
A. Dengue (Altitude < 1,800 masl and Temperatures Between 15 C and 40 C)				
Treat*2010		8.991**		2.995
		(3.604)		(2.352)
Treat*2011		-0.101		2.796
		(3.802)		(2.086)
Treat*post	6.047***		2.931*	
	(2.204)		(1.605)	
Constant	-177.7***	-177.7***	-37.24***	-37.22***
	(48.090)	(48.200)	(12.240)	(12.160)
Observations	30,479	30,479	30,103	30,103
R-squared	0.07	0.071	0.027	0.027
Number of municipalities	576	576	570	570
B. Malaria (Altitude < 1,800 masl and Temperatures Between 25 C and 30 C)				
Treat*2010		-3.657		-2.855
		(8.104)		(7.781)
Treat*2011		3.061		4.704
		(4.901)		(4.810)
Treat*post	-1.776		-0.764	
	(6.669)		(6.280)	
Constant	-28.81	-29.06	-46.26	-47.09
	(33.710)	(33.920)	(44.440)	(44.900)
Observations	13,931	13,931	13,774	13,774
R-squared	0.015	0.015	0.016	0.017
Number of municipality	269	269	267	267

The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the 2010 weather shocks on the respective outcome in the years 2010 and 2011, respectively, on the respective outcome. The coefficients are the DD estimation of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed types), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 10. DD specification: Effects of the 2010 Weather Shocks on Dengue and Malaria with Two Treatments

A. Dengue				
Outcome: Dengue Cases	**Baseline Post (1)**	**Baseline Post by year (2)**	**Baseline Post, municipalities with less than 500,000 inh. (3)**	**Baseline Post by year, municipalities with less than 500,000 inh. (4)**
Treat*Post	4.932**		1.543	
	(2.389)		(1.285)	
Treat_H*Post	-3.016		1.433	
	(3.465)		(2.119)	
Treat*2010		6.868*		1.023
		(3.820)		(1.887)
Treat*2011		1.006		2.603
		(1.769)		(1.639)
Treat_H*2010		-3.207		2.514
		(5.082)		(3.289)
Treat_H*2011		-2.651		-0.842
		(1.660)		(0.948)
Observations	41,735	41,735	41,300	41,300
R-squared	0.021	0.021	0.022	0.021
Number of municipality	788	788	777	777
Number of Treated municipalities	524	524	518	518
Number of Treated_H municipalities	96	96	93	93
Number of control municipalities	168	168	166	166

B. Malaria				
Outcome: Malaria Cases	**Baseline Post (1)**	**Baseline Post by year (2)**	**Baseline Post, municipalities with less than 500,000 inh. (3)**	**Baseline Post by year, municipalities with less than 500,000 inh. (4)**
Treat*Post	-0.747		-0.375	
	(3.044)		(2.838)	
Treat_H*Post	-2.643**		-2.794**	
	(1.078)		(1.146)	
Treat*2010		-1.522		-1.262
		(3.801)		(3.632)
Treat*2011		0.828		1.428
		(2.056)		(1.930)
Treat_H*2010		-3.686***		-3.838***
		(1.354)		(1.407)
Treat_H*2011		-0.435		-0.571
		(1.094)		(1.190)
Observations	41,735	41,735	41,300	41,300
R-squared	0.007	0.007	0.009	0.01
Number of municipalities	784	784	777	777
Number of Treated municipalities	524	524	518	518
Number of Treated_H municipalities	96	96	93	93
Number of control municipalities	168	168	166	166

Note: The coefficient Treat*Post is the estimated parameter δ of equation (1), which is the DD estimation (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 on the respective outcome. The coefficients Treat*2010 and Treat*2011 are the DD estimation of the effect of the 2010 weather shocks on the respective outcome in the years 2010 and 2011, respectively on the respective outcomes. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed types), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month, year and department fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. (1) Baseline specification with one treatment, (2) baseline specification with heterogeneous effects by year, (3) baseline specification for municipalities with less than 500,000 inhabitants, (4) baseline specification with heterogeneous effects by year for municipalities with less than 500,000 inhabitants.

Table 11. DD Specification: Effects of the 2010 Weather Shocks on Other Outcomes

	A. Rain	B. Houses destroyed (Per 100,000 inhabitants)	C. People affected by water related events (Per 100,000 inhabitants)
	(1)	(2)	(3)
Treat*Post	29.88***	4.877**	2.911
	(3.268)	(1.854)	(121.6)
Observations	41,735	41,735	41,735
Number of municipalities	784	784	784
	D. Total Events	**E. Schools affected**	**F. Casualties** (Per 100,000 inhabitants)
	(4)	(5)	(6)
Treat*Post	0.045***	0.017	0.0546
	(0.013)	(0.011)	(0.053)
Observations	41,735	41,735	41,735
Number of municipalities	784	784	784

Note: The coefficient on Treat*Post is the estimated parameter δ of equation (1), which is the DD estimation (panel fixed effects) of the effect of the 2010 weather shocks on the respective outcome. Period 2007-2009 is the pre-treatment period, 2010-2011 is the post-treatment period (for the case of rain data, panel A) and period 2010-2012 the post treatment period for the other outcomes (panels B to F). All regressions include month and year and department fixed effects; robust standard errors clustered at municipality level in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 12. Effects of the Number of Floods on the Number of Dengue Cases by Year

Marginal effect: from zero (0) to one (1) flood						
	All municipalities			**Municipalities with less than 500,000 inh.**		
Year	**Marginal Effect**	**F**	**Prob > F**	**Marginal Effect**	**F**	**Prob > F**
2007	-9.85*	3.61	0.058	-5.04	1.87	0.172
2008	-10.66**	4.18	0.041	-5.84	2.47	0.116
2009	-8.27	2.64	0.105	-4.34	1.38	0.240
2010	-2.22	0.25	0.614	-0.94	0.07	0.798
2011	-12.84**	4.76	0.029	-7.44**	3.97	0.047
Marginal effect: from one (1) to two (2) floods						
	All municipalities			**Municipalities with less than 500,000 inh.**		
Year	**Marginal Effect**	**F**	**Prob > F**	**Marginal Effect**	**F**	**Prob > F**
2007	4.01	1.44	0.230	4.74	1.54	0.215
2008	-16.39**	4.03	0.045	-3.83	0.51	0.475
2009	-16.95	1.24	0.265	20.47*	2.82	0.094
2010	-8.53	1.26	0.262	-5.72	1.27	0.260
2011	-21.38**	4.17	0.042	-8.78**	6.22	0.013
Marginal effect: from two (2) to three (3) floods						
	All municipalities			**Municipalities with less than 500,000 inh.**		
Year	**Marginal Effect**	**F**	**Prob > F**	**Marginal Effect**	**F**	**Prob > F**
2007	17.87*	2.9	0.089	14.51	1.74	0.188
2008	-22.13	2.46	0.117	-1.82	2.6	0.108
2009	-25.63	1.19	0.277	45.28	2.63	0.106
2010	-14.84	0.53	0.466	-10.51	0.11	0.741
2011	-29.92	2.33	0.128	-10.12	2.51	0.114

Note: This table shows the regressions results of equation (3). All regressions include month, year and department fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Dengue cases include the total number of dengue, severe dengue, and dengue mortality.

Table 13. Effects of the Number of Floods on the Number of Malaria Cases by Year

Marginal effect: from zero (0) to one (1) flood						
All municipalities				Municipalities with less than 500,000 inh.		
Year	**Marginal Effect**	**F**	**Prob > F**	**Marginal Effect**	**F**	**Prob > F**
2007	-3.869	1.00	0.316	-3.317	0.72	0.395
2008	-2.089	0.41	0.521	-1.788	0.29	0.593
2009	-0.806	0.07	0.795	-0.763	0.05	0.816
2010	1.452	0.18	0.668	1.182	0.11	0.742
2011	-2.539	0.60	0.438	-3.198	0.77	0.380
Marginal effect: from one (1) to two (2) floods						
All municipalities				**Municipalities with less than 500,000 inh.**		
Year	**Marginal Effect**	**F**	**Prob > F**	**Marginal Effect**	**F**	**Prob > F**
2007	-2.213	1.15	0.284	-1.403	0.31	0.575
2008	-2.916	0.09	0.761	-3.069	0.01	0.927
2009	0.499	2.68	0.102	3.450*	2.83	0.093
2010	0.477	0.17	0.679	-3.228	1.51	0.219
2011	-2.567	0.03	0.869	-2.739	0.15	0.699
Marginal effect: from two (2) to three (3) floods						
All municipalities				**Municipalities with less than 500,000 inh.**		
Year	**Marginal Effect**	**F**	**Prob > F**	**Marginal Effect**	**F**	**Prob > F**
2007	-0.558	0.03	0.870	0.512	0.01	0.917
2008	-3.743	0.17	0.676	-4.351	0.04	0.837
2009	1.805	1.17	0.279	7.663	0.78	0.379
2010	-0.499	0.16	0.689	-7.638	2.65	0.104
2011	-2.595	0.02	0.897	-2.281	0.00	0.989

Note: This table shows the regressions results of equation (3). All regressions include month, year and department fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Malaria cases include the total number of malaria (mixed types), malaria falciparum, malaria vivax, severe malaria, and malaria mortality.

Table14. Panel Data Fixed Effects: The Effects of Monthly Weather Shocks on Dengue and Malaria

Model	VARIABLES	DENGUE All Municipalities	DENGUE Municipalities with less than 500,000 inh.	MALARIA All Municipalities	MALARIA Municipalities with less than 500,000 inh.
1	$\log(rain_t) - \log(\overline{rain})$	-0.444*	-0.249	-0.0433	-0.0366
		(0.249)	(0.157)	(0.171)	(0.175)
	Obs.	40,063	39,597	40,063	39,597
	Nr. of municipalities	784	776	784	776
2	$\log(rain_{t-1}) - \log(\overline{rain})$	-0.428**	-0.282*	-0.222*	-0.227*
		(0.204)	(0.144)	(0.125)	(0.130)
	Obs.	40,063	39,597	40,063	39,597
	Nr. of municipalities	784	776	784	776
3	Positive shock	-0.631	-0.532	-0.395	-0.403
		(0.532)	(0.429)	(0.319)	(0.321)
	Negative shock	0.0382	0.0764	-0.357	-0.405
		(0.401)	(0.271)	(0.400)	(0.400)
	Obs.	40,063	39,597	40,063	39,597
	Nr. of municipalities	784	776	784	776
4	Positive shock	-0.445	-0.277	-0.290	-0.281
		(0.536)	(0.502)	(0.344)	(0.350)
	Negative shock	-0.200	-0.0319	-0.207	-0.256
		(0.417)	(0.279)	(0.405)	(0.403)
	Extreme positive shock	-0.413	-0.568*	-0.235	-0.272
		(0.606)	(0.309)	(0.435)	(0.457)
	Extreme negative shock	1.638	0.747	-1.022	-1.019
		(0.995)	(0.513)	(0.830)	(0.822)
	Obs.	40,063	39,597	40,063	39,597
	Nr. of municipalities	784	776	784	776

All regressions include month and year fixed effects and control for population. Robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Positive shock takes the value one if $rain_{mty} > sd_{mty} + \overline{rain_t}$ (and extreme positive shock takes the value one if $rain_{mty} > 2sd_{mty} + \overline{rain_t}$). Negative shock takes the value one if $rain_{mty} < \overline{rain_t} - sd_{mty}$ (and extreme negative shock takes the value one if $rain_{mty} < \overline{rain_t} - 2sd_{mty}$). Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed types), malaria falciparum, malaria vivax, severe malaria, and malaria mortality.

Appendix A. Baseline Results

Table A1. DD Specification: Effects of 2010 Weather Shocks on Dengue and Malaria by Municipality Population Size

A. Dengue						
Outcome: Dengue Cases	**Less than 100,000 inh. (1)**	**Between 10,000 and 15,000 inh. (3)**	**Between 15,000 and 30,000 inh. (4)**	**Between 30,000 and 60,000 inh. (5)**	**Between 60,000 and 100,000 inh. (6)**	**More than 100,000 inh. (2)**
Treat*2010	-0.027	-0.728	0.843	1.154	2.56	85.28**
	(0.569)	(0.841)	(0.641)	(2.043)	(6.936)	(40.340)
Treat*2011	0.796	0.00573	0.763	1.313	10.18	4.212
	(0.640)	(0.971)	(0.731)	(1.551)	(8.518)	(18.090)
Observations	38,907	7,469	10,446	6,083	1,527	2,828
R-squared	0.038	0.034	0.053	0.273	0.111	0.109
Number of municipalities	733	152	207	124	32	56
B. Malaria						
Outcome: Malaria Cases	**Less than 100,000 inh. (1)**	**Between 10,000 and 15,000 inh. (3)**	**Between 15,000 and 30,000 inh. (4)**	**Between 30,000 and 60,000 inh. (5)**	**Between 60,000 and 100,000 inh. (6)**	**More than 100,000 inh. (2)**
Treat*2010	-0.509	1.932**	4.589	4.384	-64.23	-32.77
	(2.781)	(0.971)	(3.988)	(10.180)	(40.390)	(43.770)
Treat*2011	1.731	0.718	1.489	21.87	-39.6	-7.292
	(1.773)	(0.782)	(2.898)	(13.360)	(24.210)	(16.800)
Observations	38,907	7,469	10,446	6,083	1,527	2,828
R-squared	0.008	0.01	0.012	0.154	0.115	0.049
Number of municipalities	733	152	207	124	32	56
Number of Treated municipalities	576	119	168	97	22	45
Number of control municipalities	157	33	39	27	10	11

Note: The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 on the respective outcome. The coefficients are the DD estimation of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. (1) less than 100,000 inhabitants, (2) more than 100,000 inhabitants, (3) between 10,000 and 15,000 inhabitants, (4) between 15,000 and 30,000 inhabitants, (5) between 30,000 and 60,000 inhabitants, (6) between 60,000 and 100,000 inhabitants.

Table A2. DD Specification: Effects of 2010 Weather Shocks on Dengue by Gender

	A. All municipalities		B. Municipalities with less than 500,000 inhabitants	
	Male (1)	**Female (2)**	**Male (3)**	**Female (4)**
Treat*2010	2.921**	3.086**	0.8	0.9
	(1.428)	(1.483)	(0.864)	(0.908)
Treat*2011	0.186	0.122	1.209	1.183
	(0.924)	(0.892)	(0.854)	(0.785)
Observations	41,735	41,735	41,300	41,300
R-squared	0.023	0.02	0.024	0.018
Number of municipalities	784	784	777	777

Notes: The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively, on the respective outcome. The coefficients are the DD estimation of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05,* p<0.1.

Table A3. DD Specification: Effects of 2010 Weather Shocks on Dengue by Altitude

				A. Dengue: All Municipalities			
Outcome: Dengue Cases	**Above 1,800 mts. (1)**	**At or below 1,800 mts. (2)**	**At or below 1,500 mts. (3)**	**At or below 1,000 mts. (4)**	**Between 1,000 and 1,500 mts. (5)**	**Below 800 mts. (6)**	**Below 500 mts. (7)**
Treat*2010	0.149	8.931**	10.49**	5.845*	18.64	0.118	0.0418
	(0.164)	(3.588)	(4.219)	(2.989)	(15.960)	(1.743)	(1.869)
Treat*2011	0.0646	0.0252	-0.319	0.61	-11.54	3.037	3.675
	(0.056)	(3.776)	(4.710)	(4.338)	(10.290)	(3.177)	(3.567)
Observations	11,087	30,648	25,698	20,382	5,095	17,318	15,424
R-squared	0.045	0.071	0.073	0.061	0.114	0.031	0.028
Number of municipalities	205	579	488	389	95	333	298
Number of Treated municipalities	172	446	374	290	81	240	214
Number of control municipalities	33	133	114	99	14	93	84
				B. Dengue: Municipalities with less than 500,000 inhabitants			
Outcome: Dengue Cases	**Above 1,800 mts. (1)**	**At or below 1,800 mts. (2)**	**At or below 1,500 mts. (3)**	**At or below 1,000 mts. (4)**	**Between 1,000 and 1,500 mts. (5)**	**Below 800 mts. (6)**	**Below 500 mts. (7)**
Treat*2010	0.0746	2.953	3.49	1.657	3.934	-0.4	-0.542
	(0.152)	(2.342)	(2.754)	(1.696)	(11.700)	(1.568)	(1.654)
Treat*2011	-0.0147	2.833	3.479	3.92	-2.067	4.664	5.653*
	(0.036)	(2.085)	(2.560)	(2.851)	(4.423)	(3.072)	(3.419)
Observations	11,028	30,272	25,322	20,114	4,987	17,161	15,267
R-squared	0.054	0.027	0.028	0.037	0.047	0.036	0.035
Number of municipalities	204	573	482	385	93	331	296
Number of Treated municipalities	171	440	368	286	79	238	212
Number of control municipalities	33	133	114	99	14	93	84

Notes: The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively, on the respective outcome. The coefficients are the DD estimation of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. (1) municipalities above 1,800 meters, (2) municipalities at or below 1,800 meters, (3) municipalities at or below 1,500 meters, (4) municipalities at or below 1,000 meters, (5) municipalities between 1,000 and 1,500 meters, (6) municipalities below 800 meters, (7) municipalities below 500 meters.

Table A4. DD Specification: Effects of 2010 Weather Shocks on Malaria by Altitude

A. Malaria: All Municipalities							
Outcome: Malaria Cases	**Above 1,800 mts. (1)**	**At or below 1,800 mts. (2)**	**At or below 1,500 mts. (3)**	**At or below 1,000 mts. (4)**	**Between 1,000 and 1,500 mts. (5)**	**Below 800 mts. (6)**	**Below 500 mts. (7)**
Treat*2010	-0.0125	-2.631	-3.293	-3.036	-0.134	-2.454	-2.972
	(0.022)	(4.605)	(5.392)	(6.189)	(1.179)	(6.615)	(7.210)
Treat*2011	0.00901	0.931	1.363	1.903	-0.399	2.16	1.739
	(0.023)	(2.530)	(3.091)	(3.682)	(0.539)	(4.140)	(4.424)
Observations	11,087	30,648	25,698	20,382	5,095	17,318	15,424
R-squared	0.005	0.01	0.011	0.013	0.021	0.015	0.015
Number of municipalities	205	579	488	389	95	333	298
Number of Treated municipalities	172	446	374	290	81	240	214
Number of control municipalities	33	133	114	99	14	93	84
B. Malaria: Municipalities with Less than 500,000 inhabitants							
Outcome: Malaria Cases	**Above 1,800 mts. (1)**	**At or below 1,800 mts. (2)**	**At or below 1,500 mts. (3)**	**At or below 1,000 mts. (4)**	**Between 1,000 and 1,500 mts. (5)**	**Below 800 mts. (6)**	**Below 500 mts. (7)**
Treat*2010	-0.0101	-2.213	-2.821	-2.512	-0.129	-1.927	-2.342
	(0.022)	(4.375)	(5.133)	(5.909)	(1.185)	(6.405)	(6.956)
Treat*2011	0.013	1.842	2.439	3.16	-0.376	3.195	2.956
	(0.022)	(2.357)	(2.891)	(3.501)	(0.542)	(4.042)	(4.304)
Observations	11,028	30,272	25,322	20,114	4,987	17,161	15,267
R-squared	0.006	0.012	0.013	0.015	0.021	0.016	0.016
Number of municipalities	204	573	482	385	93	331	296
Number of Treated municipalities	171	440	368	286	79	238	212
Number of control municipalities	33	133	114	99	14	93	84

Notes: The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively, on the respective outcome. The coefficients are the DD estimation of the effect of the 2010 weather shocks in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. (1) municipalities above 1,800 meters, (2) municipalities at or below 1,800 meters, (3) municipalities at or below 1,500 meters, (4) municipalities at or below 1,000 meters, (5) municipalities between 1,000 and 1,500 meters, (6) municipalities below 800 meters, (7) municipalities below 500 meters.

Table A5. DD Specification: Effects of 2010 Weather Shocks on Dengue by Temperature

	A. Dengue: All municipalities		
Outcome: Dengue Cases	**Below 20°C (1)**	**Between 20°C and 25°C (5)**	**Above 25°C (3)**
Treat*2010	-0.575	19.53**	-0.242
	(0.795)	(9.230)	(1.736)
Treat*2011	-0.17	-10.01	3.718
	(0.292)	(6.826)	(3.341)
Observations	13,640	9,704	17,206
R-squared	0.034	0.119	0.028
Number of municipalities	252	178	336
Number of Treated municipalities	205	151	244
Number of control municipalities	47	27	92
	B. Dengue: Municipalities with less than 500,000 inhabitants		
Outcome: Dengue Cases	**Below 20°C (1)**	**Between 20°C and 25°C (2**	**Above 25°C (3)**
Treat*2010	-0.673	5.728	-0.763
	(0.778)	(6.102)	(1.550)
Treat*2011	-0.3	-0.505	5.359
	(0.298)	(2.152)	(3.260)
Observations	13,581	9,485	17,049
R-squared	0.037	0.046	0.035
Number of municipalities	251	174	330
Number of Treated municipalities	204	147	240
Number of control municipalities	47	27	90

Notes: The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively, on the respective outcome. The coefficients are the DD estimation of the effect of the 2010 weather shocks in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. (1) Municipalities with temperatures below 20°C, (2) municipalities with temperatures between 20°C and 25°C, (3) municipalities with temperatures below 25°C.

Table A6. DD Specification: Effects of 2010 Weather Shocks on Malaria by Temperature

A. Malaria: All municipalities			
Outcome: Malaria Cases	**Below 20°C (1)**	**Between 20°C and 25°C (2)**	**Above 25°C (3)**
Treat*2010	0.12	-1.609	-3.976
	(0.126)	(3.543)	(6.764)
Treat*2011	-0.181	-0.887	1.139
	(0.146)	(2.622)	(4.121)
Observations	13,640	9,704	17,206
R-squared	0.005	0.019	0.014
Number of municipalities	252	178	332
Number of Treated municipalities	205	151	244
Number of control municipalities	47	27	92
B. Malaria: Municipalities with less than 500,000 inhabitants			
Outcome: Malaria Cases	**Below 20°C (1)**	**Between 20°C and 25°C (2)**	**Above 25°C (3)**
Treat*2010	0.122	-1.687	-3.416
	(0.126)	(3.553)	(6.531)
Treat*2011	-0.182	-0.741	2.303
	(0.147)	(2.629)	(4.019)
Observations	13,581	9,485	17,049
R-squared	0.005	0.015	0.016
Number of municipalities	251	174	330
Number of Treated municipalities	204	147	240
Number of control municipalities	47	27	90

Notes: The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively, on the respective outcome. The coefficients are the DD estimation of the effect of the severe 2010 shocks in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. (1) Municipalities with temperatures below 20°C, (2) municipalities with temperatures between 20°C and 25°C,(3) municipalities with temperatures below 25°C.

Table A7. DD Specification: Effects of 2010 Weather Shocks on Dengue and Malaria by Precipitation Intensity, 2007-2009

A. Dengue

	All municipalities				Municipalities with less than 500,000 inhabitants			
Outcome: Dengue Cases	**Precipitation 2007-2009 below or equal to 200 mm. (1)**	**Precipitation 2007-2009 above 200 mm. (2)**	**Precipitation 2007-2009 below or equal to 230 mm. (3)**	**Precipitation 2007-2009 above 230 mm. (4)**	**Precipitation 2007-2009 below or equal to 200 mm. (1)**	**Precipitation 2007-2009 above 200 mm. (2)**	**Precipitation 2007-2009 below or equal to 230 mm. (3)**	**Precipitation 2007-2009 above 230 mm. (4)**
Treat*2010	5.349*	10.42	8.271**	-1.477	1.657	2.633	2.705	-1.477
	(2.829)	(6.844)	(3.607)	(1.785)	(2.029)	(4.252)	(2.201)	(1.785)
Treat*2011	1.259	4.318	0.663	1.671	3.115	3.028*	3.206	1.671
	(3.124)	(4.712)	(2.893)	(1.293)	(2.952)	(1.743)	(2.606)	(1.293)
Observations	27,831	13,904	31,291	10,444	27,453	13,847	30,856	10,444
R-squared	0.02	0.085	0.022	0.062	0.024	0.022	0.02	0.062
Number of municipalities	526	262	592	196	520	257	584	193
Number of Treated municipalities	440	180	486	134	434	177	479	132
Number of control municipalities	86	82	106	62	86	80	105	61

B. Malaria

	All municipalities				Municipalities with less than 500,000 inhabitants			
Outcome: Malaria Cases	**Precipitation 2007-2009 below or equal to 200 mm. (1)**	**Precipitation 2007-2009 above 200 mm. (2)**	**Precipitation 2007-2009 below or equal to 230 mm. (3)**	**Precipitation 2007-2009 above 230 mm. (4)**	**Precipitation 2007-2009 below or equal to 200 mm. (1)**	**Precipitation 2007-2009 above 200 mm. (2)**	**Precipitation 2007-2009 below or equal to 230 mm. (3)**	**Precipitation 2007-2009 above 230 mm. (4)**
Treat*2010	-5.322	5.156	-5.863	11.52*	-5.405	6.989	-5.918	11.52*
	(4.185)	(6.482)	(3.864)	(6.857)	(4.191)	(5.613)	(3.851)	(6.857)
Treat*2011	-2.342	4.678	-0.178	7.493*	-2.336	8.127**	-0.133	7.493*
	(2.197)	(3.527)	(2.229)	(4.021)	(2.192)	(3.508)	(2.211)	(4.021)
Observations	27,831	13,904	31,291	10,444	27,453	13,847	30,856	10,444
R-squared	0.007	0.017	0.003	0.049	0.007	0.024	0.003	0.049
Number of municipalities	526	262	592	196	520	257	584	193
Number of Treated municipalities	440	180	486	134	434	177	479	132
Number of control municipalities	86	82	106	62	86	80	105	61

Notes: The coefficients on Treat*2010 and Treat*2011 are the estimated parameters δ of equation (1), which are the DD estimations (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively, on the respective outcome. The coefficients are the DD estimation of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post-treatment period. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. 200 mm. represents a value close to the pre-treatment mean and 230 mm. represents the percentile 75 of the average rainfall between 2007 and 2009. (1) Municipalities with average precipitation levels between 2007 and 2009 below or equal to 200 mm., (2) Municipalities with average precipitation levels between 2007 and 2009 above 200 mm., (3) Municipalities with average precipitation levels between 2007 and 2009 below or equal to 230 mm., (4) Municipalities with average precipitation levels between 2007 and 2009 greater than 230 mm.

Appendix B. Difference in Differences, Placebos

Table B1. Placebo DD specification: Effects of 2010 Weather Shocks on Other Diseases

						A. All municipalities						
Outcome: Number of Cases	**Ophidism**		**Diarrhea**		**Pesticide Poisoning**		**AIDS**		**Tuberculosis**		**Varicella**	
Treat*Post	-0.0918**		-0.0694		0.0292		0.0602		0.0928		-0.162	
	(0.037)		(0.070)		(0.073)		(0.080)		(0.121)		(0.793)	
Treat*2010		-0.0825**		-0.00169		0.0379		0.0654		0.00682		-0.53
		(0.034)		(0.002)		(0.061)		(0.093)		(0.118)		(0.526)
Treat*2011		-0.111**		-0.207		0.0114		0.0496		0.268*		0.586
		(0.055)		(0.207)		(0.114)		(0.086)		(0.160)		(1.578)
Observations	41,735	41,735	41,735	41,735	41,735	41,735	41,735	41,735	41,735	41,735	41,735	41,735
R-squared	0.056	0.056	0.004	0.009	0.037	0.037	0.055	0.055	0.047	0.047	0.069	0.069
Number of municipalities	788	788	788	788	788	788	788	788	788	788	788	788
Number of Treated municipalities	**620**	**620**	**620**	**620**	**620**	**620**	**620**	**620**	**620**	**620**	**620**	**620**
Number of control municipalities	**168**	**168**	**168**	**168**	**168**	**168**	**168**	**168**	**168**	**168**	**168**	**168**
						B. Municipalities with less than 500,000 inh.						
Outcome: Number of Cases	**Ophidism**		**Diarrhea**		**Pesticide Poisoning**		**AIDS**		**Tuberculosis**		**Varicella**	
Treat*Post		-0.0773**	-0.0663		0.00345		-0.00579		-0.0259		-0.283	
		(0.032)	(0.066)		(0.050)		(0.038)		(0.075)		(0.570)	
Treat*2010		-0.0728**		5.02E-05		0.0179		-0.0165		-0.0864		-0.228
		(0.030)		(0.002)		(0.046)		(0.041)		(0.087)		(0.430)
Treat*2011	-0.0864			-0.202		-0.026		0.0161		0.0974		-0.397
	(0.053)			(0.201)		(0.081)		(0.063)		(0.091)		(0.985)
Observations	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300
R-squared	0.07	0.07	0.006	0.011	0.037	0.037	0.152	0.152	0.039	0.039	0.211	0.211
Number of municipalities	777	777	777	777	777	777	777	777	777	777	777	777
Number of Treated municipalities	611	611	611	611	611	611	611	611	611	611	611	611
Number of control municipalities	166	166	166	166	166	166	166	166	166	166	166	166

Notes: The coefficient Treat*Post is the estimated parameter δ of equation (1), which is the DD estimation (using panel data with fixed effects) of the effect of the severe weather shocks of 2010 on the respective outcome. The coefficients Treat*2010 and Treat*2011 are the DD estimation of the effect of the severe weather shocks of 2010 in the years 2010 and 2011, respectively on the respective outcomes. Period 2007-2009 is the pre-treatment period; 2010-2011 is the post treatment period. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B2. DD Specification: Placebos Using 2007-1-2008-6 and 2008-7-2009-12 as Pre-Treatment and Post-Treatment, Respectively: Effects on Dengue and Malaria

Outcome: Dengue Cases/Malaria Cases	Baseline (1)	Baseline, municipalities with less than 500,000 inh. (2)	Baseline, municipalities with populations between 100,000 and 500,000 (3)	Municipalities with Less than 100,000 inh. (4)	Municipalities with populations between 10,000 and 15,000 inh. (5)	Municipalities with populations between 15,000 and 30,000 inh. (6)	Municipalities with populations between 30,000 and 60,000 inh. (7)	Municipalities with populations between 60,000 and 100,000 inh. (8)	Municipalities with more than 100,000 inh. (9)
A. Dengue									
Treat*Post	**-0.134**	**-0.705**	**-15.64**	0.0437	0.174	-0.019	1.675	-5.327	-5.162
	(0.915)	(0.771)	(11.630)	(0.368)	(0.200)	(0.887)	(1.373)	(4.099)	(13.600)
Constant	-26.21	-18.68*	121.5	-2.488	2.705	-0.155	0.93	-14.65	-145.6
	(33.760)	(10.230)	(115.800)	(2.752)	(3.747)	(9.994)	(32.100)	(36.260)	(300.600)
Observations	27,815	27,539	1,542	25,997	4,988	7,088	4,052	995	1,818
R-squared	0.025	0.019	0.108	0.016	0.016	0.015	0.04	0.108	0.107
Number of municipalities	784	777	44	733	148	204	116	29	51
B. Malaria									
Treat*Post	**2.739**	**2.946**	**-11.59**	**3.792**	**1.778**	**0.879**	**35.26**	**-57.37**	**-12.55**
	(4.284)	(4.246)	(9.562)	(4.440)	(1.237)	(2.902)	(23.730)	(48.520)	(10.080)
Constant	-1.819	-34.54*	-106.4	-35.87	2.881	-7.698	-437.6	-748.9	11.19
	(5.045)	(17.600)	(132.300)	(33.640)	(41.160)	(122.800)	(472.300)	(558.800)	(13.680)
Observations	27,815	27,539	1,542	25,997	4,988	7,088	4,052	995	1,818
R-squared	0.004	0.006	0.055	0.006	0.011	0.01	0.025	0.149	0.049
Number of municipalities	784	777	44	733	148	204	116	29	51

Notes: The coefficient on Treat*Post is the estimated parameter δ of equation (1), which is the DD estimation (using panel data with fixed effects) of the effect of the severe weather shocks of 2010. Period 2007-1 (January 2007)-2008-6 (June 2008) is the pre-treatment period; 2008-7 (July 2008)-2009-12 (December 2009) is the post-treatment period. All regressions include month and year fixed effects; robust standard errors clustered at municipality level in parentheses. Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality. *** p<0.01, ** p<0.05, * p<0.1. (1) less than 100,000 inhabitants, (2) more than 100,000 inhabitants, (3) between 10,000 and 15,000 inhabitants, (4) between 15,000 and 30,000 inhabitants, (5) between 30,000 and 60,000 inhabitants, (6) between 60,000 and 100,000 inhabitants.

Table B3. DD Specification: Placebos Using 2007-1-2008-6 and 2008-7-2009-12 as Pre-Treatment and Post-Treatment, Respectively: Effects on Rain Levels, Houses Destroyed by Climate Events, People Affected by Water-Related Events, and Total Events (all types of weather events)

	Rain	Houses destroyed (per 100,000 inh.)	People affected by water related events (per 100,000 inh.)	Total events
Treat*Post	5.153	2.018	-74.35	0.013
	(3.943)	(2.118)	(102.500)	(0.008)
Constant	76.27***	3.230584	-135.6	-0.174***
	(4.064)	(2.824)	(130.000)	(0.043)
Observations	27,815	27,815	27,815	27,815
R-squared	0.277	0.0055	0.021	0.05
Number of municipalities	784	784	784	784

Notes: The coefficient on Treat*Post is the estimated parameter δ of equation (1), which is the DD estimation (panel fixed effects) of the effect of the severe weather shocks of 2010 on the respective outcome. 2007-1 (January 2007)-2008-6 (June 2008) is the pre-treatment period; 2008-7 (July 2008)-2009-12 (December 2009) is the post-treatment period. All regressions include month and year and department fixed effects; robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Appendix C. Alternative Measures of Weather Shocks: Rainfall Deviation from Historical Monthly Average, Heterogeneous Effects

Table C1. Panel Data Fixed Effects: Effects of Monthly Weather Shocks on Dengue and Malaria, Controlling for Temperature

Model	VARIABLES	DENGUE		MALARIA	
		All Municipalities	Municipalities with less than 500,000 inh.	All Municipalities	Municipalities with less than 500,000 inh.
1	$\log(rain_t) - \log(\overline{rain})$	-2.125*	-1.516**	-0.297	-0.321
		(1.164)	(0.752)	(0.266)	(0.276)
	Obs.	8,686	8,467	8,686	8,467
	Nr. of municipalities	169	165	169	165
2	$\log(rain_{t-1}) - \log(\overline{rain})$	-1.914*	-1.237	0.0634	0.0664
		(1.065)	(0.792)	(0.283)	(0.295)
	Obs.	8,686	8,467	8,686	8,467
	Nr. of municipalities	169	165	169	165
3	Positive shock	-3.372	-2.403	-0.787	-0.870
		(2.365)	(1.877)	(0.842)	(0.866)
	Negative shock	1.751	1.322	-0.550	-0.538
		(1.302)	(0.956)	(0.578)	(0.578)
	Obs.	8,686	8,467	8,686	8,467
	Nr. of municipalities	169	165	169	165
4	Positive shock	-2.665	-2.003	-1.442	-1.621
		(2.224)	(2.206)	(0.970)	(1.050)
	Negative shock	1.361	1.212	-0.526	-0.484
		(1.402)	(0.986)	(0.648)	(0.622)
	Extreme positive shock	-1.593	-0.902	1.484	1.696
		(2.524)	(1.108)	(1.185)	(1.376)
	Extreme negative shock	2.529	0.709	-0.166	-0.360
		(2.359)	(1.694)	(1.341)	(1.236)
	Obs.	8,686	8,467	8,686	8,467
	Nr. of municipalities	169	165	169	165

Notes: All regressions include month and year fixed effects and control for population. Robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Positive shock takes the value one if $rain_{mty} > sd_{mty} + \overline{rain_t}$ (and extreme positive shock takes the value one if $rain_{mty} > 2sd_{mty} + \overline{rain_t}$). Negative shock takes the value one if $rain_{mty} < \overline{rain_t} - sd_{mty}$ (and extreme negative shock takes the value one if $rain_{mty} < \overline{rain_t} - 2sd_{mty}$). Dengue cases include the total number of dengue, severe dengue, and dengue mortality; malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality.

Table C2. Panel Data Fixed Effects: Effects of Monthly Weather Shocks on Dengue by Level of Altitude

		All Municipalities			Municipalities with less than 500,000 inhabitants		
Model	VARIABLES	LESS THAN 1000 mts	BETWEEN 1000mts & 1800mts	MORE THAN 1800 mts	LESS THAN 1000 mts	BETWEEN 1000mts & 1800mts	MORE THAN 1800 mts
1	$\log(rain_t) - \log(\overline{rain})$	-0.356	-1.215	-0.0194	0.0376	-1.512**	-0.0193
		(0.351)	(0.802)	(0.0134)	(0.135)	(0.593)	(0.0133)
	Obs.	19,145	10,037	10,881	18,846	9,929	10,822
	Nr. of municipalities	386	191	207	381	189	206
2	$\log(rain_{t-1}) - \log(\overline{rain})$	-0.251	-1.800**	-0.0193	0.00358	-1.741**	-0.0191
		(0.244)	(0.827)	(0.0139)	(0.107)	(0.784)	(0.0139)
	Obs.	19,145	10,037	10,881	18,846	9,929	10,822
	Nr. of municipalities	386	191	207	381	189	206
3	Positive shock	-0.476	-1.834	-0.0275	-0.155	-1.965	-0.0273
		(0.718)	(1.593)	(0.0247)	(0.336)	(1.502)	(0.0247)
	Negative shock	0.689	0.338	0.0537	-0.0330	0.671	0.0539
		(0.679)	(0.844)	(0.0458)	(0.379)	(0.794)	(0.0460)
	Obs.	19,145	10,037	10,881	18,846	9,929	10,822
	Nr. of municipalities	386	191	207	381	189	206
4	Positive shock	-0.221	-1.457	-0.0229	0.187	-1.625	-0.0232
		(0.572)	(1.746)	(0.0264)	(0.435)	(1.814)	(0.0266)
	Negative shock	0.329	0.0880	0.0373	-0.128	0.506	0.0375
		(0.672)	(0.868)	(0.0293)	(0.410)	(0.801)	(0.0294)
	Extreme positive shock	-0.557	-0.856	-0.0107	-0.746	-0.773	-0.00967
		(0.805)	(2.131)	(0.0265)	(0.489)	(0.950)	(0.0266)
	Extreme negative shock	2.280	1.639	0.143	0.607	1.081	0.143
		(1.853)	(1.059)	(0.202)	(0.873)	(0.828)	(0.202)
	Obs.	19,145	10,037	10,881	18,846	9,929	10,822
	Nr. of municipalities	386	191	207	381	189	206

Notes: All regressions include month and year fixed effects and control for population. Robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Positive shock takes the value one if $rain_{mty} > sd_{mty} + \overline{rain_t}$ (and extreme positive shock takes the value one if $rain_{mty} > 2sd_{mty} + \overline{rain_t}$). Negative shock takes the value one if $rain_{mty} < \overline{rain_t} - sd_{mty}$ (and extreme negative shock takes the value one if $rain_{mty} < \overline{rain_t} - 2sd_{mty}$). Dengue cases include the total number of dengue, severe dengue, and dengue mortality.

Table C3. Panel Data Fixed Effects: Effects of Monthly Weather Shocks on Malaria by Level of Altitude

		All Municipalities			Municipalities with less than 500,000 inhabitants		
Model	VARIABLES	LESS THAN 1000 mts	BETWEEN 1000mts & 1800mts	MORE THAN 1800 mts	LESS THAN 1000 mts	BETWEEN 1000mts & 1800mts	MORE THAN 1800 mts
1	$\log(rain_t) - \log(\overline{rain})$	-0.164	-0.114*	-0.00808***	-0.130	-0.114*	-0.00821***
		(0.282)	(0.0626)	(0.00304)	(0.287)	(0.0631)	(0.00306)
	Obs.	19,145	10,037	10,881	18,846	9,929	10,822
	Nr. of municipalities	386	191	207	381	189	206
2	$\log(rain_{t-1}) - \log(\overline{rain})$	-0.244	-0.165*	-0.000436	-0.236	-0.164*	-0.000551
		(0.203)	(0.0979)	(0.00269)	(0.211)	(0.0986)	(0.00267)
	Obs.	19,145	10,037	10,881	18,846	9,929	10,822
	Nr. of municipalities	386	191	207	381	189	206
3	Positive shock	-0.959	-0.00669	-0.00393	-0.945	-0.00448	-0.00417
		(0.680)	(0.107)	(0.00469)	(0.688)	(0.108)	(0.00471)
	Negative shock	-0.877	0.277*	0.0184**	-0.950	0.278*	0.0183**
		(0.789)	(0.163)	(0.00826)	(0.793)	(0.164)	(0.00829)
	Obs.	19,145	10,037	10,881	18,846	9,929	10,822
	Nr. of municipalities	386	191	207	381	189	206
4	Positive shock	-0.608	-0.112	-0.00152	-0.561	-0.106	-0.00150
		(0.736)	(0.138)	(0.00649)	(0.745)	(0.140)	(0.00654)
	Negative shock	-0.557	0.206*	0.0168**	-0.640	0.207*	0.0168**
		(0.815)	(0.115)	(0.00813)	(0.811)	(0.117)	(0.00816)
	Extreme positive shock	-0.759	0.243	-0.00554	-0.834	0.235	-0.00615
		(0.948)	(0.256)	(0.00898)	(0.966)	(0.258)	(0.00899)
	Extreme negative shock	-2.015	0.454	0.0139	-1.947	0.447	0.0138
		(1.572)	(0.490)	(0.0194)	(1.540)	(0.494)	(0.0194)
	Obs.	19,145	10,037	10,881	18,846	9,929	10,822
	Nr. of municipalities	386	191	207	381	189	206

Notes: All regressions include month and year fixed effects and control for population. Robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Positive shock takes the value one if $rain_{mty} > sd_{mty} + \overline{rain_t}$ (and extreme positive shock takes the value one if $rain_{mty} > 2sd_{mty} + \overline{rain_t}$). Negative shock takes the value one if $rain_{mty} < \overline{rain_t} - sd_{mty}$ (and extreme negative shock takes the value one if $rain_{mty} < \overline{rain_t} - 2sd_{mty}$). Malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality.

Table C4. Panel Data Fixed Effects: Effects of Monthly Weather Shocks on Dengue by Level of Temperature)

		All Municipalities			Municipalities with less than 500,000 inhabitants		
Model	VARIABLES	LESS THAN 20˚C	BETWEEN 20˚C & 25˚C	MORE THAN 25˚C	LESS THAN 20˚C	BETWEEN 20˚C & 25˚C	MORE THAN 25˚C
1	$\log(rain_t) - \log(\overline{rain})$	-0.0501	-2.485*	0.279*	-0.0523	-1.518**	0.216
		(0.0364)	(1.339)	(0.162)	(0.0376)	(0.652)	(0.133)
	Obs.	13,184	8,249	16,128	13,125	8,030	15,940
	Nr. of municipalities	251	153	332	250	149	329
2	$\log(rain_{t-1}) - \log(\overline{rain})$	-0.0524	-2.917***	0.123	-0.0549	-1.642***	0.138
		(0.0461)	(1.076)	(0.150)	(0.0473)	(0.526)	(0.101)
	Obs.	13,184	8,249	16,128	13,125	8,030	15,940
	Nr. of municipalities	251	153	332	250	149	329
3	Positive shock	-0.00504	-3.597	0.327	-0.0132	-2.576	-0.00866
		(0.0558)	(2.394)	(0.423)	(0.0571)	(1.978)	(0.357)
	Negative shock	0.129	1.308	-0.0254	0.125	0.761	-0.302
		(0.0807)	(1.170)	(0.600)	(0.0782)	(0.936)	(0.426)
	Obs.	13,184	8,249	16,128	13,125	8,030	15,940
	Nr. of municipalities	251	153	332	250	149	329
4	Positive shock	0.0272	-2.586	0.0840	0.0246	-1.979	0.0442
		(0.0921)	(2.362)	(0.424)	(0.0944)	(2.394)	(0.415)
	Negative shock	0.119	0.170	-0.00531	0.116	0.398	-0.319
		(0.0800)	(1.166)	(0.671)	(0.0772)	(0.928)	(0.482)
	Extreme positive shock	-0.0748	-2.301	0.521	-0.0880	-1.360	-0.114
		(0.106)	(2.920)	(0.520)	(0.103)	(1.285)	(0.311)
	Extreme negative shock	0.0792	6.793*	-0.135	0.0737	2.166	0.112
		(0.310)	(3.637)	(0.788)	(0.311)	(1.616)	(0.705)
	Obs.	13,184	8,249	16,128	13,125	8,030	15,940
	Nr. of municipalities	251	153	332	250	149	329

Notes: All regressions include month and year fixed effects and control for population. Robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Positive shock takes the value one if $rain_{mty} > sd_{mty} + \overline{rain_t}$ (and extreme positive shock takes the value one if $rain_{mty} > 2sd_{mty} + \overline{rain_t}$). Negative shock takes the value one if $rain_{mty} < \overline{rain_t} - sd_{mty}$ (and extreme negative shock takes the value one if $rain_{mty} < \overline{rain_t} - 2sd_{mty}$). Dengue cases include the total number of dengue, severe dengue, and dengue mortality.

Table C5. Panel Data Fixed Effects: Effects of Monthly Weather Shocks on Malaria by Level of Temperature

		All Municipalities			Municipalities with less than 500,000 inhabitants		
Model	VARIABLES	LESS THAN 20˚C	BETWEEN 20˚C & 25˚C	MORE THAN 25˚C	LESS THAN 20˚C	BETWEEN 20˚C & 25˚C	MORE THAN 25˚C
1	$\log(rain_t) - \log(\overline{rain})$	0.00269	-0.202*	-0.141	0.00260	-0.199*	-0.126
		(0.0142)	(0.108)	(0.311)	(0.0142)	(0.109)	(0.322)
	Obs.	13,184	8,249	16,128	13,125	8,030	15,940
	Nr. of municipalities	251	153	332	250	149	329
2	$\log(rain_{t-1}) - \log(\overline{rain})$	0.00338	-0.480	-0.111	0.00332	-0.479	-0.109
		(0.00458)	(0.357)	(0.201)	(0.00459)	(0.362)	(0.212)
	Obs.	13,184	8,249	16,128	13,125	8,030	15,940
	Nr. of municipalities	251	153	332	250	149	329
3	Positive shock	0.0475	-0.128	-1.050	0.0474	-0.121	-1.059
		(0.0837)	(0.0861)	(0.797)	(0.0841)	(0.0812)	(0.805)
	Negative shock	0.0478	0.230	-0.934	0.0478	0.193	-1.024
		(0.0399)	(0.215)	(0.984)	(0.0400)	(0.217)	(0.983)
	Obs.	13,184	8,249	16,128	13,125	8,030	15,940
	Nr. of municipalities	251	153	332	250	149	329
4	Positive shock	0.0506	-0.0303	-0.662	0.0506	-0.00362	-0.658
		(0.0646)	(0.125)	(0.862)	(0.0648)	(0.141)	(0.872)
	Negative shock	0.0547	0.205	-0.624	0.0548	0.165	-0.704
		(0.0472)	(0.139)	(1.012)	(0.0474)	(0.136)	(1.004)
	Extreme positive shock	-0.00728	-0.224	-0.828	-0.00751	-0.267	-0.860
		(0.0530)	(0.262)	(1.084)	(0.0534)	(0.301)	(1.102)
	Extreme negative shock	-0.0551	0.152	-2.067	-0.0557	0.169	-2.128
		(0.0690)	(0.598)	(1.968)	(0.0693)	(0.619)	(1.942)
	Obs.	13,184	8,249	16,128	13,125	8,030	15,940
	Nr. of municipalities	251	153	332	250	149	329

Notes: All regressions include month and year fixed effects and control for population. Robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Positive shock takes the value one if $rain_{mty} > sd_{mty} + \overline{rain_t}$ (and extreme positive shock takes the value one if $rain_{mty} > 2sd_{mty} + \overline{rain_t}$). Negative shock takes the value one if $rain_{mty} < \overline{rain_t} - sd_{mty}$ (and extreme negative shock takes the value one if $rain_{mty} < \overline{rain_t} - 2sd_{mty}$). Malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality.

Table C6. Panel Data Fixed Effects: Effects of Monthly Weather Shocks on Dengue by Level of Precipitation

		All Municipalities		Municipalities with less than 500,000 inh.	
Model	VARIABLES	MORE THAN 200mm	LESS THAN 200mm	MORE THAN 200mm	LESS THAN 200mm
1	$\log(rain_t) - \log(\overline{rain})$	0.680	-0.708**	0.277	-0.399**
		(0.443)	(0.309)	-0.181	(0.198)
	Obs.	13,025	27,038	12,968	26,629
	Nr. of municipalities	246	538	245	531
2	$\log(rain_{t-1}) - \log(\overline{rain})$	0.134	-0.520**	-0.108	-0.319*
		(0.271)	(0.248)	(0.115)	(0.180)
	Obs.	13,025	27,038	12,968	26,629
	Nr. of municipalities	246	538	245	531
3	Positive shock	0.533	-1.131	0.0235	-0.815
		(0.538)	(0.761)	(0.174)	(0.635)
	Negative shock	-0.531	0.508	-0.285	0.270
		(0.386)	(0.492)	(0.295)	(0.389)
	Obs.	13,025	27,038	12,968	26,629
	Nr. of municipalities	246	538	245	531
4	Positive shock	0.254	-0.783	0.254	-0.537
		(0.247)	(0.797)	(0.233)	(0.746)
	Negative shock	-0.695	0.178	-0.392	0.140
		(0.452)	(0.513)	(0.335)	(0.391)
	Extreme positive shock	0.687	-0.749	-0.564**	-0.597
		(1.282)	(0.722)	(0.246)	(0.446)
	Extreme negative shock	0.927	2.594	0.596	1.024
		(0.598)	(1.686)	(0.470)	(0.825)
	Obs.	13,025	27,038	12,968	26,629
	Nr. of municipalities	246	538	245	531

Notes: All regressions include month and year fixed effects and control for population. Robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Positive shock takes the value one if $rain_{mty} > sd_{mty} + \overline{rain_t}$ (and extreme positive shock takes the value one if $rain_{mty} > 2sd_{mty} + \overline{rain_t}$). Negative shock takes the value one if $rain_{mty} < \overline{rain_t} - sd_{mty}$ (and extreme negative shock takes the value one if $rain_{mty} < \overline{rain_t} - 2sd_{mty}$). Dengue cases include the total number of dengue, severe dengue, and dengue mortality.

Table C7. Panel Data Fixed Effects: Effects of Monthly Weather Shocks on Malaria by Level of Precipitation

		All Municipalities		Municipalities with less than 500,000 inh.	
Model	VARIABLES	MORE THAN 200mm	LESS THAN 200mm	MORE THAN 200mm	LESS THAN 200mm
1	$\log(rain_t) - \log(\overline{rain})$	0.744	-0.180	0.747	-0.188
		(0.670)	(0.125)	(0.666)	(0.130)
	Obs.	13,025	27,038	12,968	26,629
	Nr. of municipalities	246	538	245	531
2	$\log(rain_{t-1}) - \log(\overline{rain})$	-0.571	-0.115	-0.569	-0.125
		(0.426)	(0.105)	(0.419)	(0.114)
	Obs.	13,025	27,038	12,968	26,629
	Nr. of municipalities	246	538	245	531
3	Positive shock	-0.724	-0.0757	-0.721	-0.0858
		(0.916)	(0.167)	(0.910)	(0.163)
	Negative shock	-1.858**	0.385	-1.871**	0.375
		(0.848)	(0.417)	(0.852)	(0.414)
	Obs.	13,025	27,038	12,968	26,629
	Nr. of municipalities	246	538	245	531
4	Positive shock	-0.476	-0.0869	-0.473	-0.0731
		(0.807)	(0.270)	(0.802)	(0.274)
	Negative shock	-1.642**	0.499	-1.656**	0.482
		(0.747)	(0.474)	(0.747)	(0.469)
	Extreme positive shock	-0.610	0.0248	-0.609	-0.0263
		(1.302)	(0.243)	(1.336)	(0.256)
	Extreme negative shock	-1.221	-0.892*	-1.213	-0.838
		(1.803)	(0.525)	(1.796)	(0.516)
	Obs.	13,025	27,038	12,968	26,629
	Nr. of municipalities	246	538	245	531

Notes: All regressions include month and year fixed effects and control for population. Robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Positive shock takes the value one if $rain_{mty} > sd_{mty} + \overline{rain_t}$ (and extreme positive shock takes the value one if $rain_{mty} > 2sd_{mty} + \overline{rain_t}$). Negative shock takes the value one if $rain_{mty} < \overline{rain_t} - sd_{mty}$ (and extreme negative shock takes the value one if $rain_{mty} < \overline{rain_t} - 2sd_{mty}$). Malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality.

Table C8. Panel Data Fixed Effects: Effects of Monthly Weather Shocks on Dengue by Level of Poverty

		All Municipalities				Municipalities with less than 500,000 inh.			
Model	VARIABLES	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1	$\log(rain_t) - \log(\overline{rain})$	-1.731	-0.235***	-0.0208	0.0228	-0.721	-0.235***	-0.0208	0.0228
		(1.061)	(0.0861)	(0.0565)	(0.0316)	(0.671)	(0.0861)	(0.0565)	(0.0316)
	Obs.	10,044	9,958	10,076	9,985	9,578	9,958	10,076	9,985
	Nr. of municipalities	190	189	199	206	182	189	199	206
2	$\log(rain_{t-1}) - \log(\overline{rain})$	-2.038**	-0.172*	-0.0398	0.0601*	-1.325*	-0.172*	-0.0398	0.0601*
		(0.943)	(0.0897)	(0.0467)	(0.0353)	(0.705)	(0.0897)	(0.0467)	(0.0353)
	Obs.	10,044	9,958	10,076	9,985	9,578	9,958	10,076	9,985
	Nr. of municipalities	190	189	199	206	182	189	199	206
3	Positive shock	-2.243	-0.460	-0.0974	-0.0386	-1.613	-0.460	-0.0974	-0.0386
		(2.010)	(0.293)	(0.103)	(0.0577)	(1.702)	(0.293)	(0.103)	(0.0577)
	Negative shock	-0.0151	0.314	0.0581	0.0480	-0.206	0.314	0.0581	0.0480
		(1.498)	(0.196)	(0.109)	(0.110)	(1.087)	(0.196)	(0.109)	(0.110)
	Obs.	10,044	9,958	10,076	9,985	9,578	9,958	10,076	9,985
	Nr. of municipalities	190	189	199	206	182	189	199	206
4	Positive shock	-1.759	-0.309	-0.0109	-0.0279	-0.915	-0.309	-0.0109	-0.0279
		(2.000)	(0.318)	(0.116)	(0.0753)	(1.964)	(0.318)	(0.116)	(0.0753)
	Negative shock	-0.823	0.224	-0.0214	0.0471	-0.492	0.224	-0.0214	0.0471
		(1.563)	(0.196)	(0.0964)	(0.113)	(1.132)	(0.196)	(0.0964)	(0.113)
	Extreme positive shock	-1.081	-0.338	-0.195	-0.0235	-1.591	-0.338	-0.195	-0.0235
		(2.204)	(0.233)	(0.161)	(0.101)	(1.161)	(0.233)	(0.161)	(0.101)
	Extreme negative shock	5.570	0.689	0.487	0.00652	1.962	0.689	0.487	0.00652
		(3.916)	(0.608)	(0.399)	(0.146)	(1.940)	(0.608)	(0.399)	(0.146)
	Obs.	10,044	9,958	10,076	9,985	9,578	9,958	10,076	9,985
	Nr. of municipalities	190	189	199	206	182	189	199	206

Notes: All regressions include month and year fixed effects and control for population. Robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Positive shock takes the value one if $rain_{mty} > sd_{mty} + \overline{rain_t}$ (and extreme positive shock takes the value one if $rain_{mty} > 2sd_{mty} + \overline{rain_t}$). Negative shock takes the value one if $rain_{mty} < \overline{rain_t} - sd_{mty}$ (and extreme negative shock takes the value one if $rain_{mty} < \overline{rain_t} - 2sd_{mty}$). Dengue cases include the total number of dengue, severe dengue, and dengue mortality.

Table C9. Panel Data Fixed Effects: Effects of Monthly Weather Shocks on Malaria by Level of Poverty)

		All Municipalities				Municipalities with less than 500,000 inh.			
Model	VARIABLES	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1	$\log(rain_t) - \log(\overline{rain})$	-0.0346	-0.201	-0.0709	0.182	-0.0275	-0.201	-0.0709	0.182
		(0.0277)	(0.172)	(0.181)	(0.510)	(0.0270)	(0.172)	(0.181)	(0.510)
	Obs.	10,044	9,958	10,076	9,985	9,578	9,958	10,076	9,985
	Nr. of municipalities	190	189	199	206	182	189	199	206
2	$\log(rain_{t-1}) - \log(\overline{rain})$	-0.0995**	0.0128	-0.208	-0.303	-0.0928**	0.0128	-0.208	-0.303
		(0.0391)	(0.337)	(0.213)	(0.286)	(0.0429)	(0.337)	(0.213)	(0.286)
	Obs.	10,044	9,958	10,076	9,985	9,578	9,958	10,076	9,985
	Nr. of municipalities	190	189	199	206	182	189	199	206
3	Positive shock	-0.0531	0.0882	-0.442	-0.573	-0.0408	0.0882	-0.442	-0.573
		(0.0672)	(0.480)	(0.767)	(0.887)	(0.0766)	(0.480)	(0.767)	(0.887)
	Negative shock	0.0412	-0.470*	-1.010	-0.0599	0.00584	-0.470*	-1.010	-0.0599
		(0.0485)	(0.260)	(0.635)	(1.547)	(0.0353)	(0.260)	(0.635)	(1.547)
	Obs.	10,044	9,958	10,076	9,985	9,578	9,958	10,076	9,985
	Nr. of municipalities	190	189	199	206	182	189	199	206
4	Positive shock	-0.0594	-0.315	-0.442	0.551	-0.0337	-0.315	-0.442	0.551
		(0.0805)	(0.256)	(0.661)	(1.003)	(0.0848)	(0.256)	(0.661)	(1.003)
	Negative shock	0.0724	-0.305	-0.983*	0.510	0.0303	-0.305	-0.983*	0.510
		(0.0641)	(0.252)	(0.574)	(1.556)	(0.0548)	(0.252)	(0.574)	(1.556)
	Extreme positive shock	0.0136	0.899	-0.000743	-2.463*	-0.0168	0.899	-0.000743	-2.463*
		(0.0704)	(0.940)	(0.469)	(1.400)	(0.0666)	(0.940)	(0.469)	(1.400)
	Extreme negative shock	-0.215	-1.275	-0.166	-3.957	-0.166	-1.275	-0.166	-3.957
		(0.225)	(0.941)	(1.059)	(3.189)	(0.236)	(0.941)	(1.059)	(3.189)
	Obs.	10,044	9,958	10,076	9,985	9,578	9,958	10,076	9,985
	Nr. of municipalities	190	189	199	206	182	189	199	206

Notes: All regressions include month and year fixed effects and control for population. Robust standard errors clustered at municipality level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Positive shock takes the value one if $rain_{mty} > sd_{mty} + \overline{rain_t}$ (and extreme positive shock takes the value one if $rain_{mty} > 2sd_{mty} + \overline{rain_t}$). Negative shock takes the value one if $rain_{mty} < \overline{rain_t} - sd_{mty}$ (and extreme negative shock takes the value one if $rain_{mty} < \overline{rain_t} - 2sd_{mty}$). Malaria cases include the total number of malaria (mixed shapes), malaria falciparum, malaria vivax, severe malaria, and malaria mortality.