The Impact of Infrastructure Investment on Resilience to Environmental Shocks: Evidence from Ecuador

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Abstract

Increasing climate variability has direct impacts on health–particularly through vector-borne diseases. Sanitation infrastructure may have a mitigating impact on these effects. We investigate the impact of infrastructure investments on health following major weather events using a novel dataset that links information from a broad range of sources over several years in Ecuador. We find that particularly high levels of precipitation increase hospitalizations from vector-borne diseases and improvements in sanitation infrastructure decrease hospitalizations. The decrease in hospitalizations from sanitation infrastructure is particularly pronounced in months in which cantons have particularly high precipitation. These effects are largest in population-dense cantons and after 2008, when public policy surrounding sanitation was devolved to the local level. The findings suggest that improving sanitation infrastructure is a key element of building resilience to climate change and it should receive particular attention in population-dense areas.

1 Introduction

Infrastructure has been hypothesized to have positive impacts on development, but it has been difficult to pinpoint the mechanism (Calderon and Servén, 2014). While much of the literature points to energy, transport, and communications sectors ((Lipscomb, Mobarak, and Barham, 2013); (Foster, Gorgulu, Straub, and Vagliasindi, 2023); (Jedwab and Storeygard, 2020)), an additional mechanism is that sanitation infrastructure may help to improve health and resilience to negative shocks. This is particularly important as climate change worsens; climate change increases both average temperatures and variability in climate over time. High variation in precipitation can cause flooding, particularly in areas where infrastructure is weak and has not been optimized to deal with tail events (Few, Ahern, Matthies, and Kovats, 2004). The health impacts of flooding are often then substantial (Haines and Patz, 2004).

Climate change has increased migration to cities in developing countries, putting enormous pressure on the periphery of developing cities where infrastructure is minimal (Henderson, Storeygard, and Deichmann, 2017). At the same time, variability in climate worsens flooding and has direct impacts on health–these impacts are particularly strong in population-dense areas, so the impacts of increasing migration may be particularly strong. Diseases which depend on parasites are exacerbated by extreme precipitation (Patz, Graczyk, Geller, and Vittor, 2000). In countries with weak infrastructure, climate variation can directly impact local health as neighborhoods struggle to keep up with new issues related to erosion, flooding, and high temperatures. These issues are particularly pronounced in cities that receive substantial in-migration for economic opportunity and grow more quickly than they can respond through infrastructure investments as well as in response to disasters caused by climate change (Alirol, Getaz, Stoll, Chappuis, and Loutan, 2011). We study the extent to which health issues respond to climate pressures and the impact of government investment in infrastructure on improving adaptation and lessening the health impacts of these pressures.

We use a novel dataset of infrastructure and spending information at the municipal/canton level from 2001 to 2019 in Ecuador to investigate the mitigating effects of infrastructure investments on health and welfare following major weather events. We combine the municipal infrastructure data with data on local precipitation, municipal finances, and health. Our specifications include a broad range of controls including year, month, and canton fixed effects. Identification is based on deviations from vector-borne disease related hospitalizations that *would have* occurred in the canton in that month and year in the absence of a change in the level of infrastructure holding constant a range of controls.

Ecuador is a particularly good environment for this study as it underwent substantial improvements in its water and sanitation conditions during the last two decades. According to the Joint Monitoring Programme of the WHO and the World Bank (WHO, 2023), households with safely managed drinking water increased from 58% in 2010 to 67% in 2020 but this proportion still lags behind the average in Latin America (75.3% in 2020). In addition, the coverage of basic services in sanitation expanded from 39% to 50% during the 2000-2020 period, still below the 55% average of the region in 2020.

Climate variability and extreme weather events are associated with a higher incidence of illness. A review of the epidemiology literature on health and mortality impacts of flooding finds some direct impacts on mortality from extreme events, but larger impacts from fecal-oral and vector-borne disease transmission (Ahern, Kovats, Wilkinson, Few, and Matthies, 2005). We find that very high levels of precipitation (often leading to flooding) are associated with increased levels of illnesses such as bacterial intestinal infections, protozoan infections, and symptoms affecting the digestive system like diarrhea. Canton-months with at least one daily mean precipitation level above the 95th percentile (12 mm) over the period of reference have on average 1.11 more hospitalizations from vector-borne diseases per month than they would otherwise have on average.

Improved sanitation infrastructure does reduce vector-borne diseases. We find that cantons with basic infrastructure have 1.03 fewer monthly hospitalizations than those with no sanitation infrastructure. Going from no infrastructure to primary sanitation treatment only has a minimal and not statistically significant impact on health, but secondary treatment facilities reduce hospitalizations by 1.94 per month.

In periods of extreme weather, sanitation infrastructure substantially reduces the impact of high precipitation. An additional treatment facility reduces the expected number of hospitalizations from an extreme weather event in a canton-month by 1.57, fully offsetting the impact of the average increase in hospitalizations of 1.11 from extreme weather events. These impacts are particularly large when a canton goes from no infrastructure to primary or secondary treatment: primary treatment reduces the expected impact of precipitation by 2.91 and secondary treatment reduces the impact by 3.21 hospitalizations.

Governments must determine how best to target money for sanitation infrastructure to get the largest possible impact per dollar–one might think that the Federal government is best at determining the optimal placement of sanitation infrastructure, particularly in view of their better access to information and highly trained sanitation professionals as well as the potential spillovers that could occur between jurisdictions (Lipscomb and Mobarak, 2016). On the other hand, cantons may be best placed know how to expand sanitation services to improve their health outcomes. Ecuador is an excellent environment for evaluating the effect of Federal level versus local level management of sanitation infrastructure: in 2008 Ecuador had a major constitutional reform in which cantons became responsible for local sanitation infrastructure spending. We compare the effect of infrastructure built prior to 2008 to infrastructure built post-2008 and find that the mitigation impacts of the post-2008 infrastructure are larger, suggesting that at least within-canton, decentralization of investment decision-making led to an improvement in the allocation of infrastructure.

We find that increases in sewerage spending and loans does decrease hospitalizations. Targeting regions in which sanitation infrastructure will be particularly helpful is also important. Population-dense cantons (ie those over 71 people per square km, the 60th percentile population density for Ecuador) have larger externality problems, but they also may have higher baseline levels of infrastructure provision. Perfect optimization would suggest that the benefits of an additional dollar of sanitation spending would be the same across all jurisdictions once population has been controlled for. We show that the health benefits from increased infrastructure provision are higher in population-dense cantons.

This paper contributes to a small but growing literature on resilience to climate change and infrastructure investment (Balboni, 2019). Road infrastructure can improve resilience by providing access to markets and allowing for migration (Burgess and Donaldson, 2010), but there is little evidence on the role of sanitation. This paper also contributes to our understanding of the impacts of climate shocks to health. Baez and Santos (2007) found large negative shocks to children's health and nutrition following Hurricane Mitch in Nicaragua. Using a large sample of over 100 years of data on disasters in Latin America, Caruso (2017) finds that climate disasters have differentially larger impacts on children.

In section 2, we discuss the progression of infrastructure in Ecuador, 3 discusses the unique canton-level dataset that we have on infrastructure and infrastructure level spending from the Development Bank of Ecuador. Section 4 discusses our empirical specification and identification, and section 5 discusses our results. Finally, 6 concludes and discusses potential policy implications.

2 Background

The Expansion of Infrastructure in Ecuador Ecuador underwent a vast expansion in its physical infrastructure from 2005-2020. Gross fixed capital[1] increased substantially over this period. Figure 1 shows that the gross fixed capital investment remained below 20% of GDP until 2005 and increased consistently to 25% on average during the following 10 years, reaching a 28% maximum in 2013 (World Bank, 2020).

The Development Bank of Ecuador (BDE) is the largest institution that offers financing options to the lo-

[1] Gross fixed capital corresponds to the physical assets within countries and includes land improvements, plant, machinery, and equipment purchases, and the construction of physical infrastructure, such as roads, railways, schools, and hospitals.

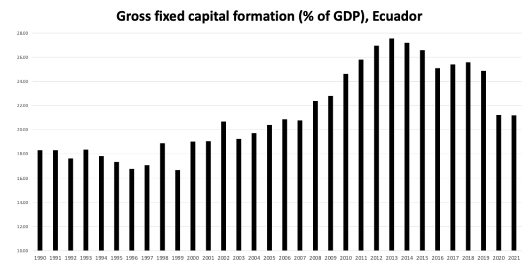

Figure 1: Infrastructure investment in Ecuador, 1990-2021. Source: World Bank

cal governments in Ecuador to complete projects in sanitation, roads, irrigation, flooding control, energy, and transportation. BDE is the primary financing institution for local governments at the provincial and municipal level (de Desarrollo del Ecuador, 2023). The BDE offers loans for cantons to construct sewer networks, wastewater treatment plants, stormwater sewage systems, and other physical infrastructure that helps increase communities' resilience to climate change-related events. After an administrative and financial assessment, the BDE disburses funds for projects with a payment schedule over time. The number of loans and the dollar amounts given by the BDE have increased during our period, particularly over the 2010-2017 period.

Improvements in infrastructure varied widely by sector and region across Ecuador. The Development Bank financed infrastructure projects averaging $427 per capita from 2007 to 2017 across Ecuador, but there was substantial variation in the level of financing. For example, Canton Santa Clara, comprising 3,983 inhabitants, received $4,743.2 per person during this period, while Guayaquil, the most populous canton with 2,617,349 inhabitants, received a comparatively modest $104 per person. The Bank allocated funds totaling $9,300 million for projects between 2007 and 2017 of which sanitation projects received $3,750 million (40%). Spending on sanitation varied from $2,515 per personin El Pangui, located in the Amazon, to $6.7 per person in Jipijapa in the coastal region.

In addition to the overall variation in sanitation spending in Ecuador, government expenditures on health increased more than five times from 2000 to 2016, as presented in figure 3; over the period Ecuador went from substantially below average in spending on health as a percentage of GDP to exceeding the average spending in Latin America.

The increased investment in water and sanitation shown at the canton level is matched by increased access to infrastructure services at the household level. According to the National Institute of Statistics of Ecuador, 69% of households had access to municipal water in 2006. After 2010, this proportion increased systematically until 2016, when 84% of households had water access from the municipality, as shown in Figure 4 (Senplades, 2017). In 2016, INEC began to evaluate the water quality in dwellings using the quarterly sur-

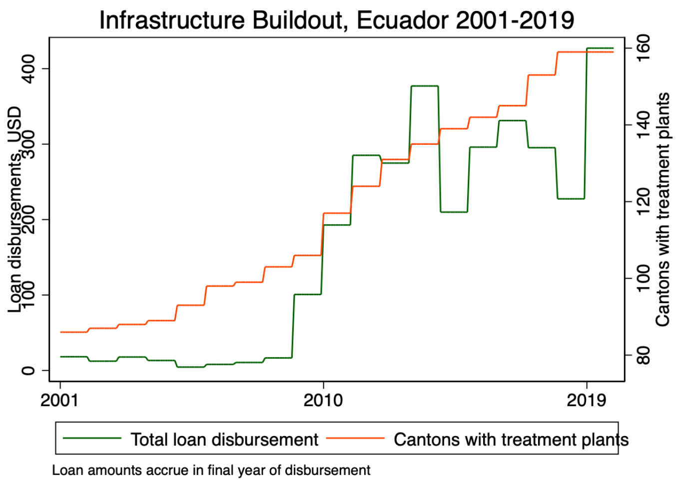

Figure 2: Infrastructure development

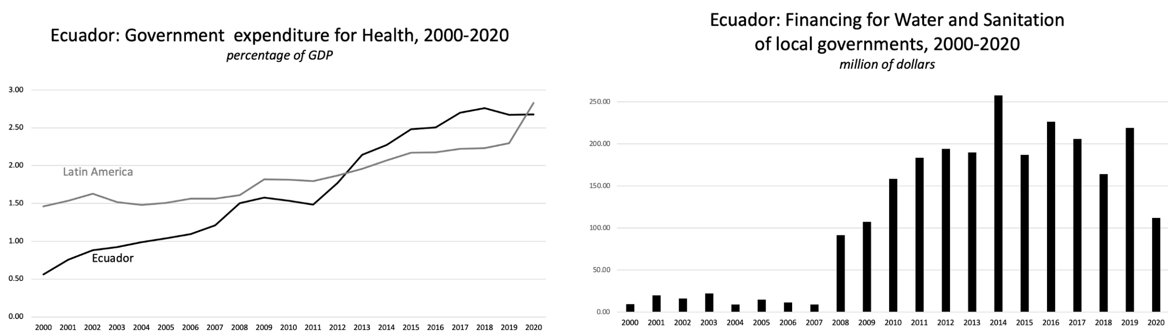

Figure 3: Government expenditures on Health, and Water and sanitation investment in Ecuador, 1990-2020. Source: ECLAC-UN and Bank of Development.

vey at the household level. Nationally, 70% of households accessed safely managed water services in 2016, with a dramatic difference between urban (79.1%) and rural (51.4%) sectors (Moreno, Pozo, Vancraeynest, Bain, Palacios, and Jácome, 2020). The lack of quality drinkable water remains a public health challenge.

In 2016 the government initiated Prosaneamiento, a program to improve household access to potable water, sewage, and solid waste management. This program set a 95% coverage goal in five years, with a planned $ 4.7 billion budget from BDE (BDE, 2014). The program had two components: financing that depended on the debt management capacity of the municipality and a non-repayable component that was determined by the needs of every canton. The non-repayable amount per municipality was defined using five indicators: malnutrition, poverty, potable water, sewage, and solid waste service coverage. Table **??** shows the total funds for water and sanitation for municipalities under Prosaneamiento program with almost $3.0 billion in subsidies that would benefit more than 7.7 million people (BDE, 2014). Figure 5 shows the progressivity of the subsidy with respect to the gap in sanitation service for every municipality in 2013.

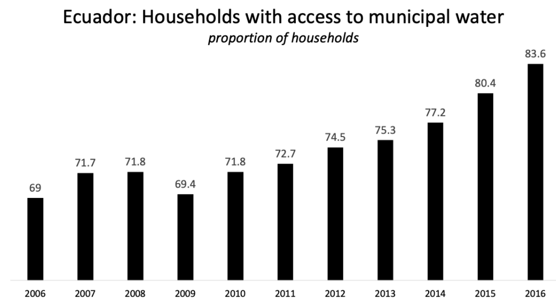

Figure 4: Proportion of households with safely managed water in Ecuador, 2006-2016. Source: World Health Organization and Unicef Joint Monitoring Programme (WHO, 2023)

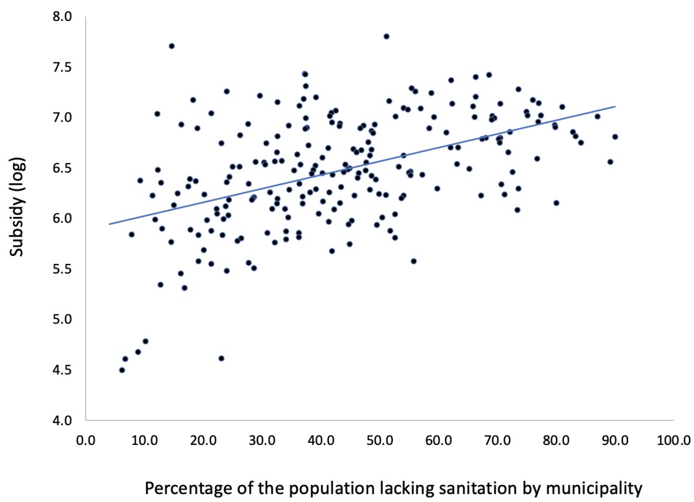

Figure 5: Percentage of the population lacking sanitation services and subsidy (log) for municipalities, 2013. Source: Bank of Development.

Decentralization through Constitutional Change in Ecuador A referendum in 2008 generated a constitutional change aimed at strengthening the provision of water and sanitation in Ecuador. Before 2008, the constitution declared the state uniquely responsible for providing water, sanitation, and related services. This scheme generated a lack of sustainable funding for municipal projects, translating into a decline in the quality of sanitation services. The new constitution approved in 2008 assigned differentiated responsibilities to local governments. For example, Article 264 explicitly states that Municipal governments are responsible for "drinking water, sewerage, wastewater treatment, solid waste management, environmental remediation, and other services as established by law." This constitutional change sought to improve services and planning over longer horizons. Municipalities were incentivized to increase the effort in collecting municipal taxes to sustain sanitation projects. The new constitution also opened opportunities to create collaboration among municipalities to benefit economies of scale in operations to improve the management of water and sanitation.

The decentralization of decision-making led by this 2008 constitutional reform promoted an increase in borrowing and decision-making at the canton level. Resources to finance canton-level local water and sanitation projects from the Development Bank of Ecuador increased sharply after 2008.

The Impact of Weather on Health in Ecuador Weather has a substantial impact on health–particularly in areas where flooding may create sanitation problems, extreme precipitation can exacerbate the prevalence of vector-borne diseases (Few et al., 2004). We see this in figure 6, which compares precipitation events to the prevalence of hospitalization for vector-borne diseases. There we see that both precipitation and vector-borne diseases exhibit substantial cyclicality.

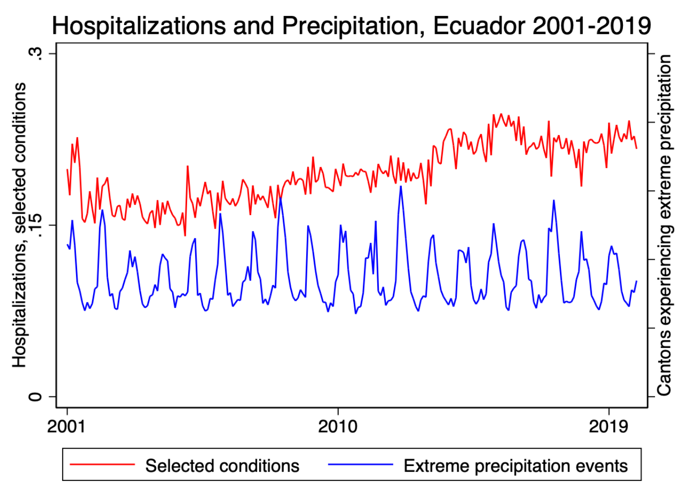

Figure 6: Precipitation and hospitalizations

3 Data

Our analysis draws on administrative data from Ecuador's health system, infrastructure data on water treatment by canton, administrative data on canton spending and borrowing, and climate data. Instituto Nacional de Estadística y Censos (INEC) is the national statistical agency of Ecuador, and its institutional mission includes collecting and housing numerous datasets covering diverse topics of public interest in the country. The analysis in this paper leverages the wealth of information from a handful of data sources obtained through INEC, including administrative hospital discharge records and a census of sanitation and water infrastructure through the National Municipal Information System. Climate data is collected from global 1x1km gridded monthly precipitation data from the GPCC, a division under the German National Meteorological Service that produces research-quality climatology datasets. We use monthly observations at the canton level from across Ecuador from 2001-2019.

Hospital Data Our data set of patient discharges contains de-identified administrative records of every patient treated at Ecuador's health establishments (hospitals, health centers, and clinics) from 2000 to 2019 collected from Ecuador's Instituto Nacional de Estadística y Censos (INEC). The data includes information about patient location, intake time, and diagnosis[2]. Using the diagnosis (ICD) codes, we identify patients with conditions related to poor water and sanitation conditions: salmonella infections, shigellosis, bacterial food-borne illnesses, infectious gastroenteritis, colitis, etc. We tally the incidence of the associated conditions and total hospitalizations by month in every canton. Summary statistics are shown in Table 1. On average, a canton has 380 hospitalizations per month. Before 2008, there were an average of 309 monthly hospitalizations while after 2008 there were 430 monthly hospitalizations. This mirrors the extensive expansion of the healthcare sector in Ecuador since the early 2000s. Hospitalizations are significantly higher in population-dense cantons than in sparsely populated cantons reflecting the higher population in these cantons–in all of our specifications we control for population.

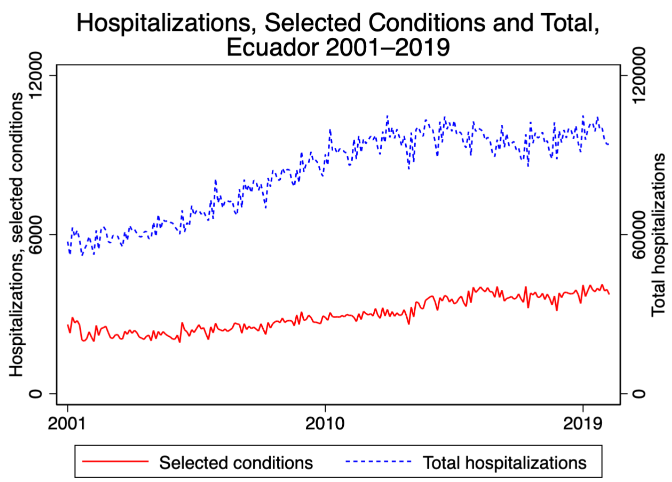

Figure 7: Hospitalizations

We are primarily interested in hospitalizations for vector-borne diseases that would be related to flooding. On average, cantons have 13.6 monthly hospitalizations for these diseases (or approximately 3.6 percent of all hospitalizations). Hospitalizations for vector-borne diseases have increased since 2008, from 10.73 on average to 15.44: this again reflects the substantial increase in healthcare access in Ecuador since the early 2000s. As we may expect based on both higher population and the externalities related to contagion from vector-borne diseases, hospitalizations for vector-borne diseases are much higher in population-dense cantons than in sparsely populated cantons–on average sparsely populated cantons have 4.6 hospitalizations per month while population-dense cantons have 26.6 hospitalizations per month.

[2]Diagnoses are represented by International Classification of Diseases (ICD) codes, a standard developed and maintained by the World Health Organization.

Table 1: Summary Statistics

	Full Sample mean/sd	Pre-2008 mean/sd	Post-2008 mean/sd	Not dense mean/sd	Dense mean/sd
Total Monthly hospitalizations	380	309	430	114	775
	(1,502)	(1,286)	(1,637)	(148)	(2,308)
Hospitalizations for selected conditions	13.57	10.73	15.44	4.59	26.60
(Monthly)	(51.29)	(39.20)	(58.07)	(6.01)	(78.27)
Any Water Treatment	0.53	0.41	0.62	0.53	0.53
	(0.50)	(0.49)	(0.49)	(0.50)	(0.50)
Primary Treatment	0.11	0.09	0.12	0.12	0.10
	(0.31)	(0.29)	(0.33)	(0.32)	(0.29)
Secondary Treatment	0.08	0.07	0.09	0.04	0.13
	(0.27)	(0.25)	(0.28)	(0.21)	(0.34)
Total annual municipal income	14.55	6.88	19.99	6.47	26.56
	(60.61)	(25.70)	(75.76)	(7.05)	(93.96)
Recieved any loan	0.94	0.86	1.00	0.93	0.95
	(0.24)	(0.35)	(0.00)	(0.25)	(0.21)
Total annual municipal spending	12.24	5.74	16.84	5.46	22.31
	(51.40)	(22.03)	(64.19)	(5.92)	(79.71)
Annual muni. spending on health	0.32	0.14	0.45	0.19	0.51
	(1.56)	(0.85)	(1.90)	(0.35)	(2.42)
Annual spending on sanitation	0.60	0.04	0.99	0.45	0.81
	(2.96)	(0.23)	(3.81)	(1.85)	(4.07)
Annual Spending on Sewerage	0.20	0.01	0.33	0.16	0.26
	(1.29)	(0.16)	(1.66)	(1.05)	(1.57)
Annual spending on potable water	0.26	0.02	0.42	0.18	0.36
	(2.23)	(0.10)	(2.90)	(1.05)	(3.27)
No. of outlying precip. months	0.97	0.98	0.95	0.94	1.00
	(1.65)	(1.61)	(1.68)	(1.71)	(1.57)
Annual cantonal population	68,324	62,658	72,342	25,298	132,360
	(233,057)	(213,258)	(246,096)	(26,402)	(356,798)
Population Density	113.95	103.54	121.33	25.57	245.48
	(304.06)	(270.70)	(325.50)	(16.21)	(448.10)
Observations	4153	1723	2430	2484	1669

Infrastructure Data The census of sanitation infrastructure, also curated by INEC, contains detailed information about the state of water and sanitation infrastructure in each canton throughout the country. It is based on direct reports by municipal administrators. The report includes the age and length of service of various types of infrastructure within each canton, which we use to impute the roll-out of sewage treatment facilities throughout the country. It also contains specific information about the different processes the facilities employ to treat wastewater, allowing us to differentiate facilities based on their wastewater treatment strategies. We categorize a canton as having a treatment center continuously from the first year they report a treatment center being open. To the extent that some treatment centers may have gone out of operation prior to the census or some treatment centers may have closed temporarily during our sample, there may be some measurement error in our treatment center variables causing estimates to be biased toward 0.

Table 1 shows that 53% of cantons have wastewater treatment of some sort on average over the period 2001-2019. Prior to 2008, this was 41% of cantons, and this grew to an average of 62% post 2008. Surprisingly, rural and urban cantons are equally likely to have wastewater treatment. This may reflect the greater density of cantons in urban areas and the likelihood that several cantons may share one treatment plant in urban areas while distance makes that impossible in rural areas. To the extent that this happens, this will mean that our estimates are biased downward as there is measurement error in our treatment variables.

Primary treatment is more common than secondary treatment, and both primary and secondary treatment grow over time. Primary treatment which separates solids from liquid sewage waste but does not treat the liquid is more common in sparsely populated areas while secondary treatment which also treats the liquid sewage waste is more common in population-dense areas.

Municipal Finances Municipal finance data, provided by the Banco de Desarrollo de Ecuador (BDE), contains each canton's annual ledgers of income and expenditures in Ecuador from 2000-2020. These figures are disaggregated into spending on health, education, roads, sanitation, and other. This provides a full accounting of fiscal activity as well as the relative investment status of particular sectors. These categories show the annual dollar value (in millions of USD) of the income received through taxes, user fees, and other income-generating activities for each year, and outlays on capital investment, personnel, and other expenditures for each broad public interest category.

Loan data from the BDE includes detailed information about all loans made by BDE. Nearly every canton has received a loan from BDE, especially after 2008. We use the amount that has been loaned to the canton from 2001 up to that date, with all loan spending considered to have been made in the final year of the loan. We focus on loans earmarked for the sanitation sector and its constituent activities, especially sewerage and household sanitation. We include only loans made to local governments and loans earmarked for capital investment (i.e. excluding loans to fund non-infrastructure such as studies). We also tally the total and category-specific annual investment in each canton.

Climate Data This analysis also incorporates verified total monthly precipitation data from the Global Precipitation Climatology Center (GPCC). This data is constructed and verified using a combination of surface and satellite measurements and algorithmic interpolation. We use the data gridded at 1x1 km and average it over the area of each municipality in Ecuador for each month in the period. With this information, we identify canton-months that experience outlying precipitation events, which we define as monthly total rainfall at the 95th or greater percentile over the period.

The data is linked at the canton-month level which provides us with precision in capturing hospitalizations directly following major weather events and allows us to estimate the mitigating effect of various types of infrastructure investment.

4 Empirical Specification

We test the extent to which infrastructure development improves health and reduces hospitalization for vector-borne illnesses. We use a simple difference in differences specification, as follows:

$$Y_{it} = \beta_i + \beta_1 Infrastructure_{it} + \beta_2 PrecipitationEvent_{it} + \beta_3 Infrastructure_{it} * PrecipitationEvent_{it} + \gamma_{it} + \phi_t + \epsilon_{it} \tag{1}$$

Our outcome variable is hospitalizations for vector-borne diseases, a direct welfare measure of sanitation-related investments. i indexes cantons and t indexes month-year; observations are at the canton-month level in order to allow for the matching of weather events to the corresponding hospitalizations that follow. We are interested in two key parameters–the impact of infrastructure β_1, and the differential impact of infrastructure directly following major weather events β_3. β_1 provides us with an estimate of the extent to which monthly hospitalizations in a canton decrease on average following the construction of improved infrastructure, or in the spending specifications they provide us with an estimate of the impact of an additional 1 million US dollars of spending of each type on monthly hospitalizations in the canton. We expect β_2 to be positive as climate events lead to more hospitalizations as a result of increased flooding and sanitation issues. β_3 provides an estimate of the impact of infrastructure investments and spending on resilience following major climate events–more negative values of β_3 show the extent to which sanitation infrastructure can reduce the health impacts of major climate events.

In all specifications we have a vector of controls γ_{it}, canton fixed effects β_i, and time fixed effects ϕ_t. The vector of controls includes population and population density, municipal spending and municipal tax receipts, total hospitalizations, an indicator for whether the municipality received any loan, and spending on health in the canton in a given year. We control for hospitalizations for all other causes in order to hold hospital access constant as health care access did increase in general over the period. Canton fixed effects control for anything time-invariant about the canton, year fixed effects control for year over year changes in things like health care provision across Ecuador, and month fixed effects control for seasonal changes. Standard errors are clustered at the canton-year level.

We show the results for the full sample, the sample pre- and post-2008, and for population-dense and low-population density cantons. This allows us to observe the extent to which infrastructure can improve resilience in general across all cantons in Ecuador. Separating the results by pre-2008 and post-2008 allows us to observe the impact of infrastructure when sanitation investment decisions are made by the central government versus the local government. To the extent that local governments may be able to make choices that better fit the local needs, we may expect to see a larger effect in the post-2008 sample. However, to the extent that there may be spillovers between jurisdictions when localities can determine their infrastructure investments, we may expect to see larger effects in the pre-2008 data.

The population density of the canton has a substantial impact on the level of externalities that are expected from sanitation investment: in remote areas, improving sewerage is expected to have little impact on health, while highly population-dense cantons may have substantial impacts from the same level of spending. We define "dense" cantons as those that have higher population density than the 60th percentile, or 71 people per square km. We test the extent to which the effects of infrastructure on hospitalization are magnified in population-dense areas.

5 Results

We find that, consistent with the hypothesis that improved sanitation infrastructure reduces disease, particularly during severe climate events, there is a large and statistically significant impact of improved sanitation on health. In this section, we test these effects on all wastewater treatment and separately for primary

Table 2: Impacts of Infrastructure on Hospitalizations

	Full Sample	Pre-2008	Post-2008	Not dense	Dense
WW plantx Outl. precip	-1.57***	-0.96**	-0.96***	-0.51***	-2.30***
	(0.30)	(0.48)	(0.31)	(0.20)	(0.62)
WW plant	-1.03***	-1.40**	-0.10	-0.53***	-1.61***
	(0.23)	(0.60)	(0.27)	(0.14)	(0.56)
Outlying precip.	1.11***	1.08***	0.64***	0.42***	1.84***
	(0.20)	(0.29)	(0.22)	(0.14)	(0.43)
Prim. treat. x Outl. precip.	-2.91***	-1.68	-2.52**	-0.40	-7.29**
	(0.93)	(1.46)	(1.04)	(0.29)	(3.66)
Prim. treat.	-0.44	0.11	0.31	0.11	-0.79
	(0.52)	(1.36)	(0.62)	(0.29)	(0.96)
Outlying precip.	0.60***	1.18***	0.04	0.24**	0.92***
	(0.14)	(0.24)	(0.15)	(0.11)	(0.27)
Second. treat. x Outl. precip.	-3.21*	-0.21	-4.27**	-0.39	-4.23*
	(1.86)	(2.88)	(2.16)	(0.60)	(2.47)
Second. treat.	-1.94**	0.42	-1.39**	-1.37	-0.74
	(0.81)	(1.53)	(0.60)	(0.99)	(1.00)
Outlying precip.	0.49***	1.06***	-0.00	0.20*	0.88***
	(0.14)	(0.22)	(0.14)	(0.11)	(0.28)
Observations	49836	20676	29160	20028	29808

Each group of coefficients represents the outputs of a model that regresses hospitalizations for specific vector-borne illnesses in a canton on the measure of infrastructure, an indicator for outlying monthly precipitation events (defined as 95th percentile or higher compared to the sample as a whole), and their interaction. Observations are from 2001-2019. These regressions also include year, month and canton fixed effects, and a suite of controls that include annual canton population, total monthly hospitalizations for all conditions, municipal income, municipal expenditure, municipal expenditures on health, and an indicator for whether a canton received a development loan that accrued in that year. Columns represent different subsamples, displaying the full sample of all cantons in all months, trends in all cantons before and after 2008, and in all years between high and low-density cantons, dense is defined as cantons with more than 71 people per square km (the 60th percentile). Financial variables are in millions of dollars. (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$)

and secondary treatment. We also test the effects of municipal spending and loans on disease and resilience following major climate events.

Results for wastewater treatment plants are shown in table 5. Panel A shows that wastewater treatment plants reduce hospitalizations by one per month on average (statistically significant at the 1% level). An outlying precipitation event increases hospitalizations from vector-borne diseases by 1.11 (statistically significant at the 1% level). However, cantons with a wastewater plant have a significantly lower impact of an outlying precipitation event–the interaction effect (-1.57, statistically significant at 1% level) more than fully compensates for the increase in hospitalizations following an outlying precipitation event. While major weather events do increase hospitalizations due to vector-borne diseases, these effects are overwhelmingly in cantons that do not have improved sanitation.

Our data allows us to separate the effect of primary treatment from secondary treatment. We find that both primary (Panel B) and secondary (Panel C) treatments reduce hospitalizations, but only the secondary treatment is statistically significant. Secondary treatment reduces hospitalizations by 1.94 (statistically significant at 5% level) per month. Both primary and secondary treatment have a large effect on resilience–primary treatment reduces the hospitalizations during outlying precipitation events by 2.91 (statistically significant at the 1% level) while secondary treatment reduces hospitalizations during outlying precipitation events by 3.21 (statistically significant at the 10% level).

We test whether this effect of sanitation infrastructure access is larger or smaller following the decentralization of municipal works in 2008 in Ecuador. We may expect the effect to be either larger or smaller–the central government may be better able to design and manage major sanitation investments as they have more sector experts which would suggest that the coefficient would be larger in earlier years prior to decentralization. On the other hand, the local government may have a better idea of specific needs in a canton and may be better able to target resources to where they are needed. We find evidence that overall, wastewater treatment plants had more of an impact pre-2008 when resources were centralized. However, secondary treatment appears to have more of an impact post-2008. The overall impact on resilience following outlying weather events is approximately the same (-0.96 and statistically significant at the 5% and 1% level for pre-2008 and post-2008 respectively), the effect on resilience seems to be larger post-2008 for both primary and secondary treatment, with the effect substantially larger for secondary treatment.

As one would expect from the externalities related to poor treatment of sanitation, major precipitation events have a much larger impact in population-dense cantons than in sparsely populated cantons. The effect of a major weather event in a densely populated area is approximately 1.84 hospitalizations per month (significant at 1% level) while in a sparsely populated area it is 0.42 hospitalizations per month significant at 1% level). Densely populated cantons have approximately 4 times the effect on the health of the sparsely populated cantons. In all specifications, we have controlled for population of the canton and monthly hospitalizations in the canton, so this is not a direct impact of more people being located in densely populated cantons or better health care access in densely populated cantons. Similarly, the impact of infrastructure in the densely populated cantons is even larger following extreme weather events- a reduction of 2.3 hospitalizations (significant at the 1% level) from outlying weather events avoided by access to wastewater plants in densely populated cantons while the impact is only 0.51 (significant at the 1% level) in sparsely populated cantons. Primary treatment is particularly important in densely populated cantons, with an effect of the interaction of primary treatment and an outlying weather event as a decrease of 7.29 hospitalizations per month (significant at the 5% level) during outlying weather events in the densely populated cantons but only 0.40 (not statistically significant) in the sparsely populated cantons. Secondary treatment has a similarly large, though smaller effect–4.23 hospitalizations (significant at the 10% level) are avoided in the

Table 3: Impacts of the Marginal Dollar of Sanitation Spending on Hospitalizations

		Full Sample	Pre-2008	Post-2008	Not dense	Dense
Panel A						
	Sew. spend x Outl. precip.	-0.08**	-0.05	-0.03	-0.00	-0.09*
		(0.04)	(0.13)	(0.03)	(0.01)	(0.05)
	Sew. spend	-0.06	-1.28***	-0.09*	0.07***	-0.04
		(0.05)	(0.35)	(0.05)	(0.02)	(0.07)
	Outlying precip.	0.70***	0.77***	0.32	0.16	1.29***
		(0.19)	(0.24)	(0.20)	(0.11)	(0.37)
Panel B						
	Sewerage, loan x Outl. precip.	-0.02	-0.82*	0.05	0.01	0.01
		(0.04)	(0.44)	(0.03)	(0.02)	(0.06)
	Sewerage, loan	-0.15***	0.13	-0.11**	0.06***	-0.13**
		(0.04)	(0.17)	(0.05)	(0.02)	(0.07)
	Outlying precip.	0.36**	0.72***	-0.03	0.15	0.68*
		(0.16)	(0.23)	(0.19)	(0.11)	(0.35)
Panel C						
	Sani. loan x Outl. precip.	-0.04	0.34	0.01	-0.01	-0.03
		(0.03)	(0.28)	(0.02)	(0.02)	(0.04)
	Sani. loan	-0.04	-0.67*	-0.06	0.09***	-0.01
		(0.04)	(0.37)	(0.04)	(0.02)	(0.04)
	Outlying precip.	0.51***	0.57**	0.03	0.18	0.87**
		(0.18)	(0.23)	(0.22)	(0.11)	(0.37)
	N	49836	20676	29160	20028	29808

Each group of coefficients represents the outputs of a model that regresses hospitalizations for specific vector-borne illnesses in a canton on the measure of infrastructure finance, an indicator for outlying monthly precipitation events (defined as 95th percentile or higher compared to the sample as a whole), and their interaction. Observations are from 2001-2019. These regressions also include year, month and canton fixed effects, and a suite of controls that include annual canton population, total monthly hospitalizations for all conditions, municipal income, municipal expenditure, municipal expenditures on health, and an indicator for whether a canton received a development loan that accrued in that year. Columns represent different subsamples, displaying the full sample of all cantons in all months, trends in all cantons before and after 2008, and in all years between high and low-density cantons, dense is defined as cantons with more than 71 people per square km (the 60th percentile). Financial variables are in millions of dollars. (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$)

month following a major precipitation event in cantons with secondary treatment.

These large effects suggest that particularly as major weather events become more common in response to climate change, infrastructure investment is important in helping communities to build resilience. These benefits should be considered when analyzing the overall costs and benefits of major infrastructure investments.

Using data from the Development Bank of Ecuador (BDE), we are able to observe both municipal spending and borrowing for sanitation and potable water. Spending using sanitation loans and municipal finances is somewhat more difficult to interpret as large amounts of spending may be more common in cantons that started with particularly low initial levels of sanitation. In addition, costs may be higher in more remote areas than in Quito, the capital of Ecuador. However, these regressions provide us with an estimate of the

Table 4: Impacts of the Marginal Dollar of Potable Water Spending

		Full Sample	Pre-2008	Post-2008	Not dense	Dense
Panel A						
	Pot. water spend x Outl. precip.	-0.11**	-0.54***	-0.01	-0.05*	-0.09
		(0.05)	(0.18)	(0.05)	(0.03)	(0.07)
	Pot. water spend	-0.00	-0.52*	-0.07	0.06*	0.05
		(0.05)	(0.27)	(0.05)	(0.04)	(0.06)
	Outlying precip.	0.70***	1.13***	0.14	0.32**	1.10***
		(0.22)	(0.28)	(0.25)	(0.13)	(0.38)
Panel B						
	Pot. water, loan x Outl. precip.	-0.08	0.41	-0.01	-0.04	-0.04
		(0.07)	(0.42)	(0.06)	(0.05)	(0.08)
	Pot. water, loan	-0.01	-1.07	-0.08	0.11***	0.01
		(0.05)	(0.79)	(0.06)	(0.03)	(0.06)
	Outlying precip.	0.45***	0.63***	0.10	0.22**	0.79**
		(0.17)	(0.22)	(0.20)	(0.11)	(0.34)
	N	49836	20676	29160	20028	29808

Each group of coefficients represents the outputs of a model that regresses hospitalizations for specific vector-borne illnesses in a canton on the measure of infrastructure finance, an indicator for outlying monthly precipitation events (defined as 95th percentile or higher compared to the sample as a whole), and their interaction. Observations are from 2001-2019. These regressions also include year, month and canton fixed effects, and a suite of controls that include annual canton population, total monthly hospitalizations for all conditions, municipal income, municipal expenditure, municipal expenditures on health, and an indicator for whether a canton received a development loan that accrued in that year. Columns represent different subsamples, displaying the full sample of all cantons in all months, trends in all cantons before and after 2008, and in all years between high and low-density cantons, dense is defined as cantons with more than 71 people per square km (the 60th percentile). Financial variables are in millions of dollars. (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$)

extent to which an additional dollar of spending will have an impact on current levels of infrastructure.

Results for sanitation and sewerage spending are shown in table 5. An additional $1 million in sewerage spending (Panel A) is associated with a reduction of 0.06 hospitalizations. However, this effect is much larger pre-2008 when much of the sewerage network was being developed: at that time an additional $1 million was associated with 1.28 fewer hospitalizations (significant at the 1% level) while post 2008 the effect was -0.09 (significant at the 1% level). This higher level of impact could be related either to a more basic level of infrastructure prior to 2008 or to better planning under Federal government management prior to decentralization. Sewerage spending does have a resilience benefit as well: an additional $1 million in spending leads to 0.08 fewer hospitalizations following outlying precipitation events. This impact comes primarily from population-dense cantons for which the interaction term is -0.09 (significant at the 10% level).

Sewerage loans, shown in table 5 Panel B do also result in a reduction in hospitalizations of 0.15 for every $1 million that has been dispersed (statistically significant at the 1% level). The impact of an additional dollar in loans is substantially larger post-2008, suggesting that management at the canton level may be effective at spending the money in ways that improve health.

Sewerage loans are particularly effective in population-dense cantons: there is a positive and statistically significant estimate in population sparse cantons which may be related to sparse cantons being those with the lowest levels of sanitation. Sewerage loans reduce hospitalizations following outlying precipitation events prior to 2008, but there is no statistically significant impact of loans on resilience otherwise.

Loan spending on sanitation (Panel C) has very similar impacts to sewerage loans. Sanitation loans of $1 million have a point estimate of a 0.04 reduction in hospitalizations (not statistically significant). This effect appears to come primarily from observations prior to 2008. Again, this large impact prior to 2008 could be either because the cantons had lower baseline levels of hygiene and could make more of an impact, or it could be because the Federal government is better at spending than the canton governments. There is little observed resilience impact from sewerage or sanitation loan spending–this may be because sewer loans are unable to be redirected toward the areas that need the money most once the loan has already been granted, therefore it is difficult for this type of funding to flexibly respond to major weather events.

While sanitation spending is important in terms of contamination, we may expect to see more direct impacts from access to potable water. We observe the effects of potable water loans and spending in table 5. Overall, we see little impact of potable water loans or spending, but we do see differentially larger impacts of both loans and spending pre-2008 when decisions over infrastructure spending were centralized. Potable water spending does appear to have similar or potentially even larger impacts than sanitation following major climate events–potable water loans decrease hospitalizations following major weather events by 0.8 (not statistically significant) and spending decreases hospitalizations by 0.11 (significant at the 5% level). The values for sewerage are 0.02 (not significant) for loans and 0.08 (significant at the 1% level) for spending.

6 Conclusion

We use a period of vast expansion in sanitation spending and investment in Ecuador in order to evaluate the impact of sanitation infrastructure investment on health. We find that sanitation infrastructure and spending is important not only for improving health overall but also for improving resilience following major weather events. Our results show, consistent with the literature, that extreme precipitation and flooding have negative effects on health (Ahern et al., 2005). However, we find that these effects are mitigated by improved sanitation infrastructure. Resilience from negative flooding and rain shocks depends in large part on the built infrastructure around sanitation. This suggests that a cost-benefit analysis of major sanitation infrastructure programs should take into account the worsening potential for extreme weather and the possibility that sanitation infrastructure can have mitigating impacts on the health consequences of flooding.

Finding the best possible use of the marginal dollar of government spending for resilience to climate change is important. This paper adds to a growing literature testing the extent to which different programs reduce the health and welfare impacts of climate change, for example, social welfare programs (Macours, Schady, and Vakis (2012); Garg, McCord, and Montfort (2020); Banerjee and Maharaj (2020)) and index funds (del Valle, 2023).

Improving resilience to climate change is important. Migration is an increasingly common response (Cai, Feng, Oppenheimer, and Pytlikova, 2016), but adaptation is necessary everywhere. Flooding is likely to become more and more problematic in the coming years, and will cause increased disease (Few et al., 2004). Population density will increase as well, as peri-urban areas receive an increasing number of climate change related migration (Jessoe, Manning, and Taylor, 2018). This paper shows that resilience to major weather shocks can be improved through better sanitation networks.

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