

# Leveraging earth observations for estimating health risks associated with flooding precipitated by heavy rains

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November 26, 2022

## Abstract

**Purpose:**Flooding following heavy rains precipitated by hurricanes/tropical storms has previously been shown to increase fecal-oral diseases, vector-borne disease transmission and pregnancy complications during or following inundation. Remote sensing can be used to spatio-temporally resolve inundation extents for subsequent analysis of risks associated with flooding at a finer scale. Here we combined earth observations of the flooding caused by Hurricane Harvey in 2017 with Emergency Department (ED) visit data to evaluate health outcomes associated with flooding.**Methods:**Our study area included 1073 flooded and 1809 non-flooded census tracts in Texas which were categorized using the inundation maps from Dartmouth Flood Observatory. These maps were created using Sentinel and MODIS satellite imagery captured between 28th Aug - 4th Sep 2017 following the landfall of the hurricane. ED visits in the study area were obtained from Texas Department of State Health Services. A controlled interrupted time series design was employed using ED visits from non-flooded tracts as the control series and ED visits before a week of the landfall and through 2018 as control period. Poisson regression using generalized estimating equation with census tracts as the group variable was used to estimate the relative risk of the health outcomes associated with flooding during and following the flooded days, adjusting for the age, ethnicity, race, sex of the patient, day of week, month and year trends. **Results:**Flooding was associated with a 35% (95% CI: 22%-48%) increase in risk for insect stings and 24% (17%-31%) increase in risk of pregnancy complications during the flood period. Similarly, relative risks were also elevated ( $>1$ ) for drowning, hypothermia, and intestinal infectious diseases in the flooded tracts. Also, in the months following the flood period, the relative risk was still elevated ( $>1$ ) for pregnancy complications and insect stings while asthma and acute respiratory infections showed decreased risks. **Conclusion:** Earth observations have helped in understanding the health risks that are related to flooding. These earth observations can in turn be used to identify specific communities with increased health risks during and following flooding events.





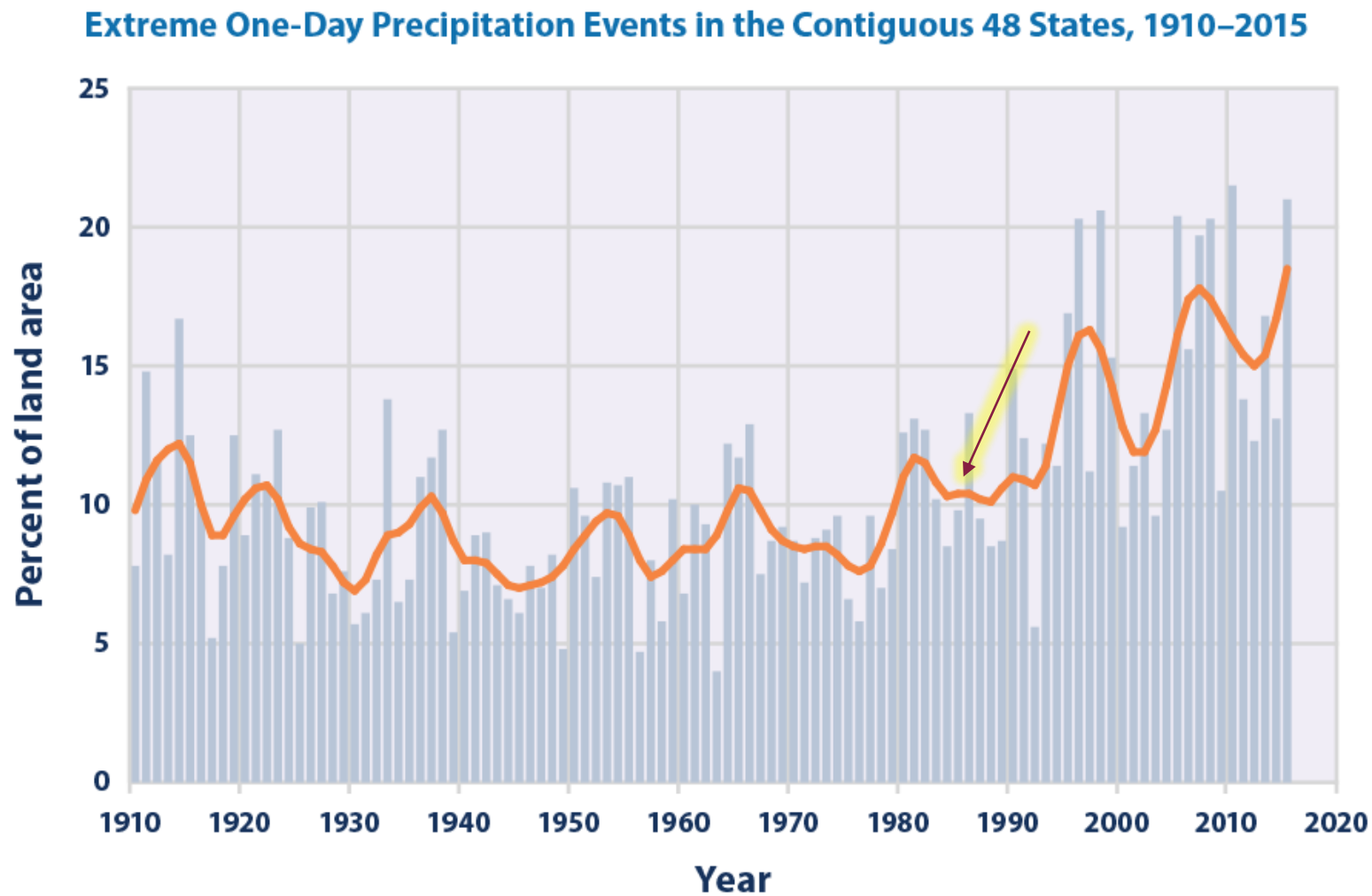
Sentinel-2 copernicus imagery of 08/30/2017

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The percent of land area that experienced extreme one day rainfall has increased over past three decades.

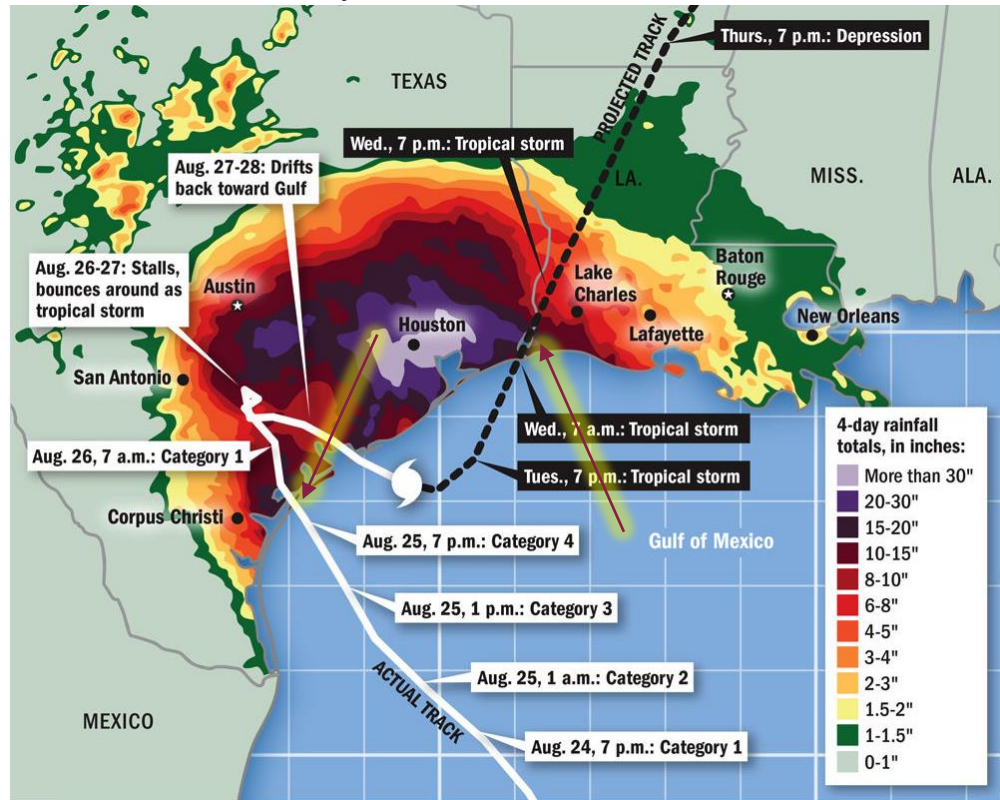


Data source: NOAA (National Oceanic and Atmospheric Administration). 2016. U.S. Climate Extremes Index. Accessed January 2016. [www.ncdc.noaa.gov/extremes/cei](http://www.ncdc.noaa.gov/extremes/cei).

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at [www.epa.gov/climate-indicators](http://www.epa.gov/climate-indicators).

# Hurricane Harvey, a category 4 hurricane, resulted in 40+ inches of rainfall in Texas

## Hurricane Harvey Track

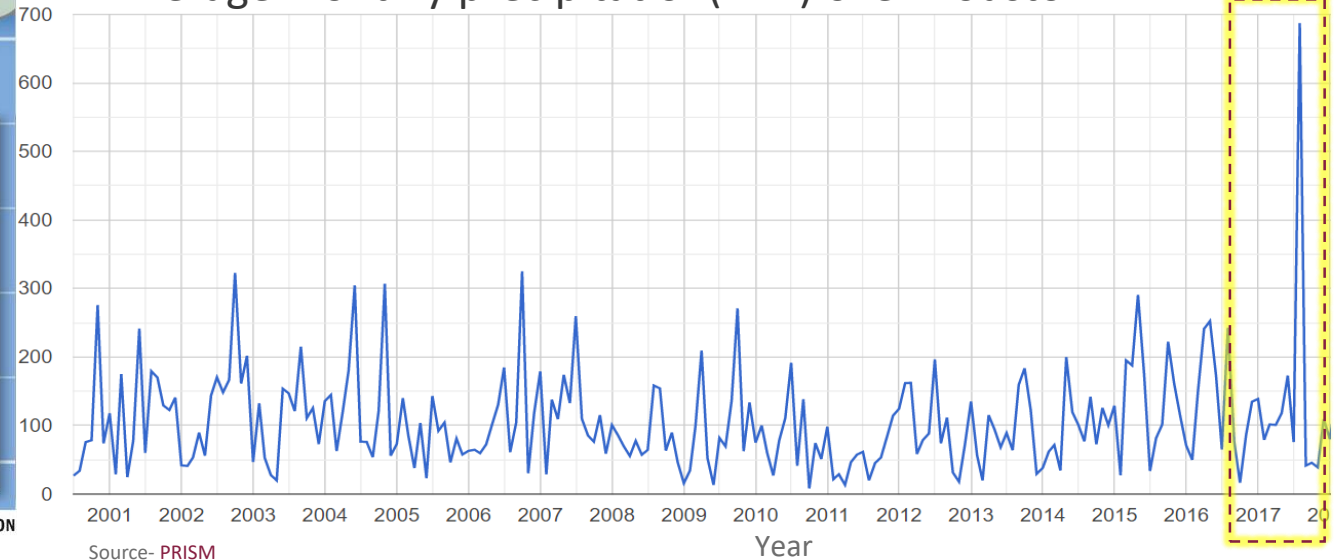


Source: National Weather Service

Advocate graphic by DAN SWENSON

Img source- <https://www.weather.gov/grb/Harvey>

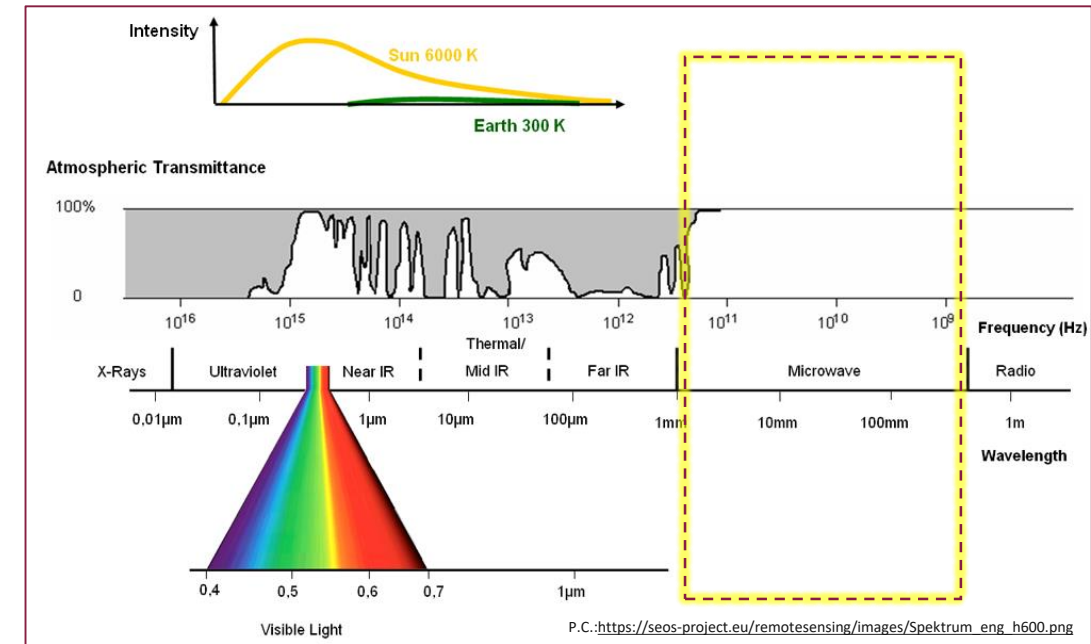
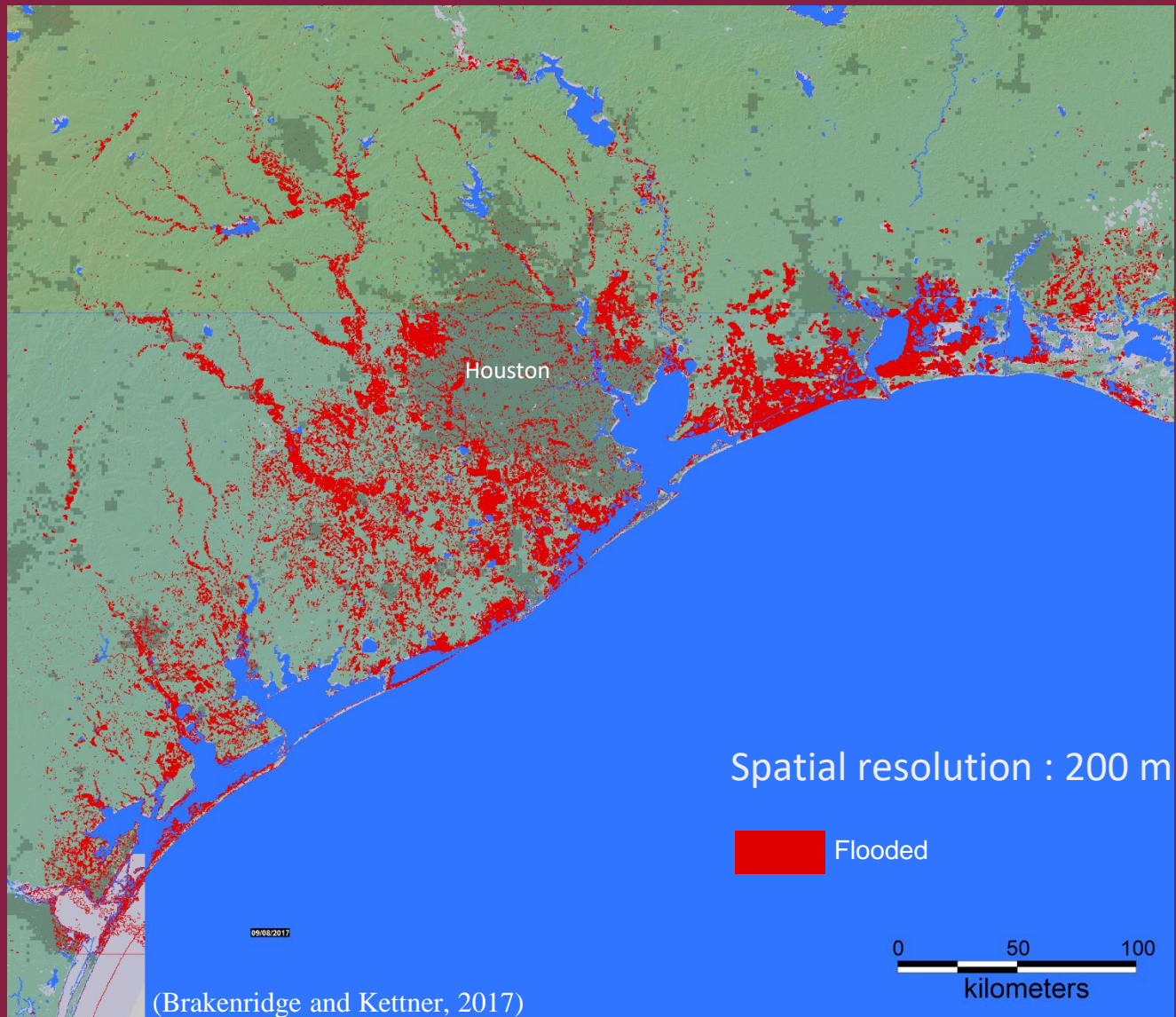
## Average monthly precipitation(mm) over Houston



Flooding observed using remote sensing is positively associated with cause-specific ED visits related to flooding

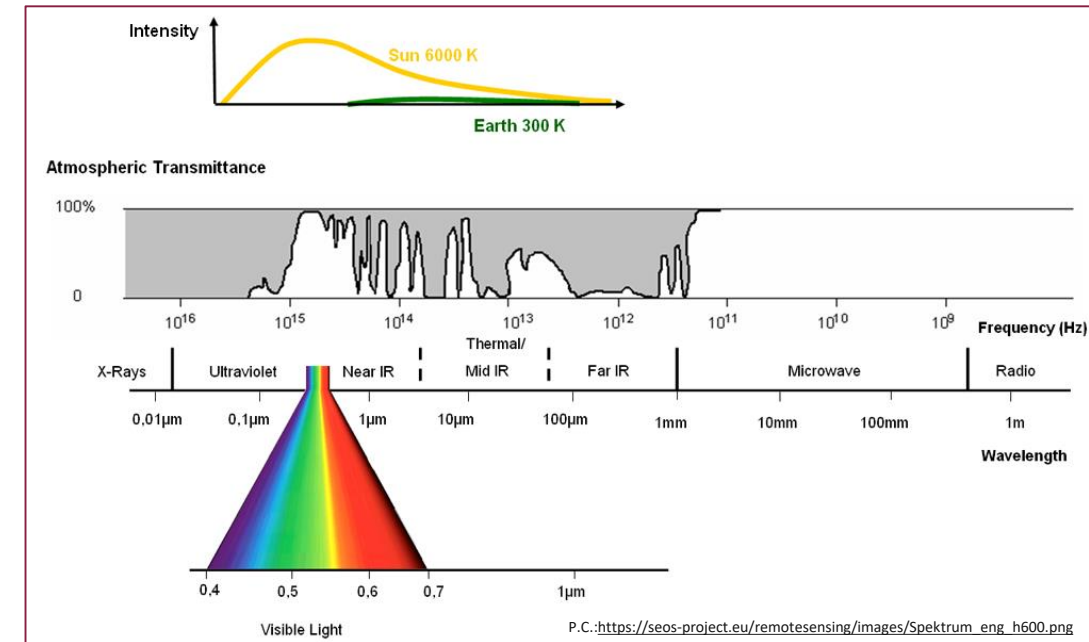
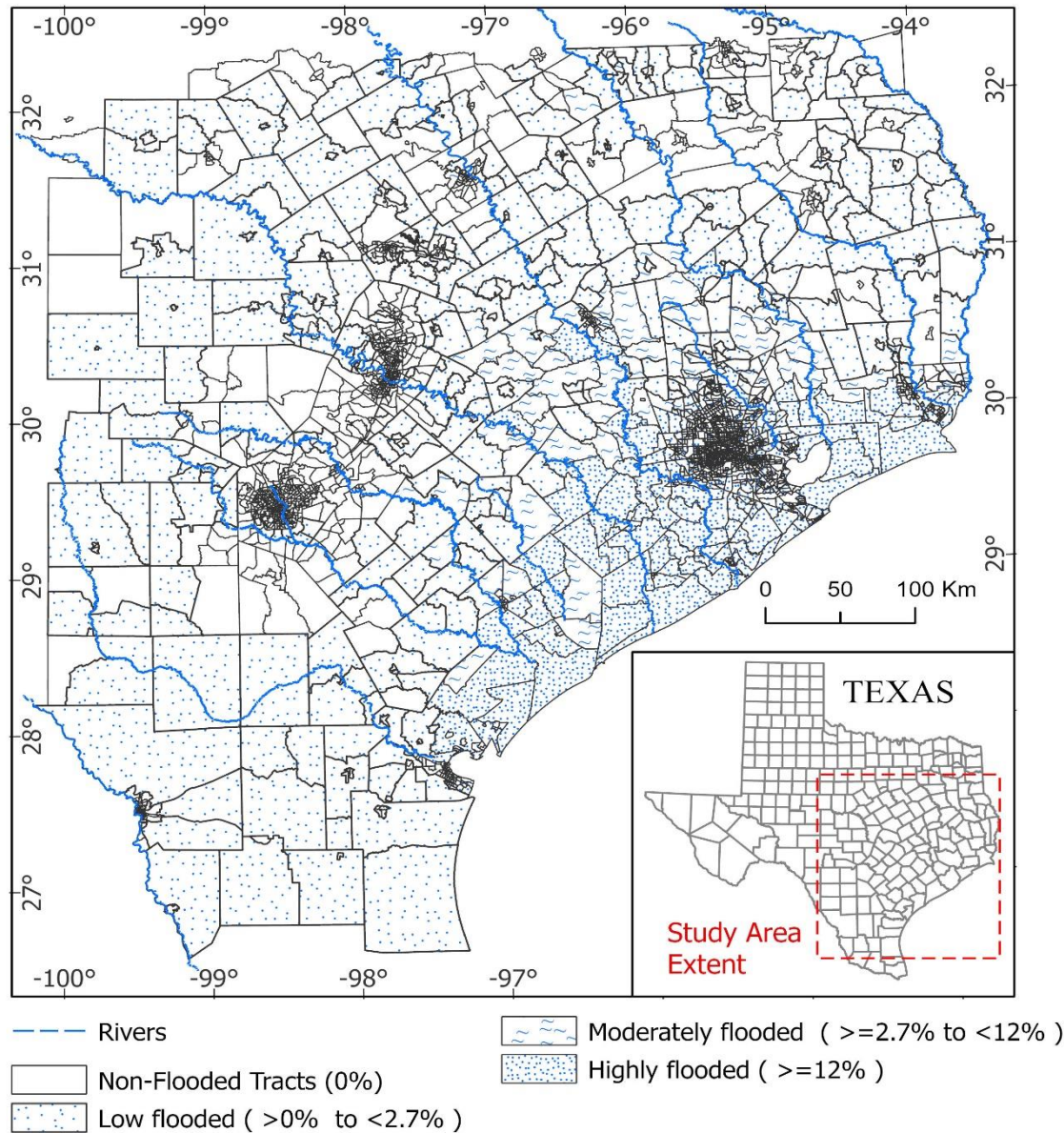


# Inundation as of 4<sup>th</sup> Sep, 2017 mapped using active remote sensing



> Exposure > Outcome > Analysis > Results

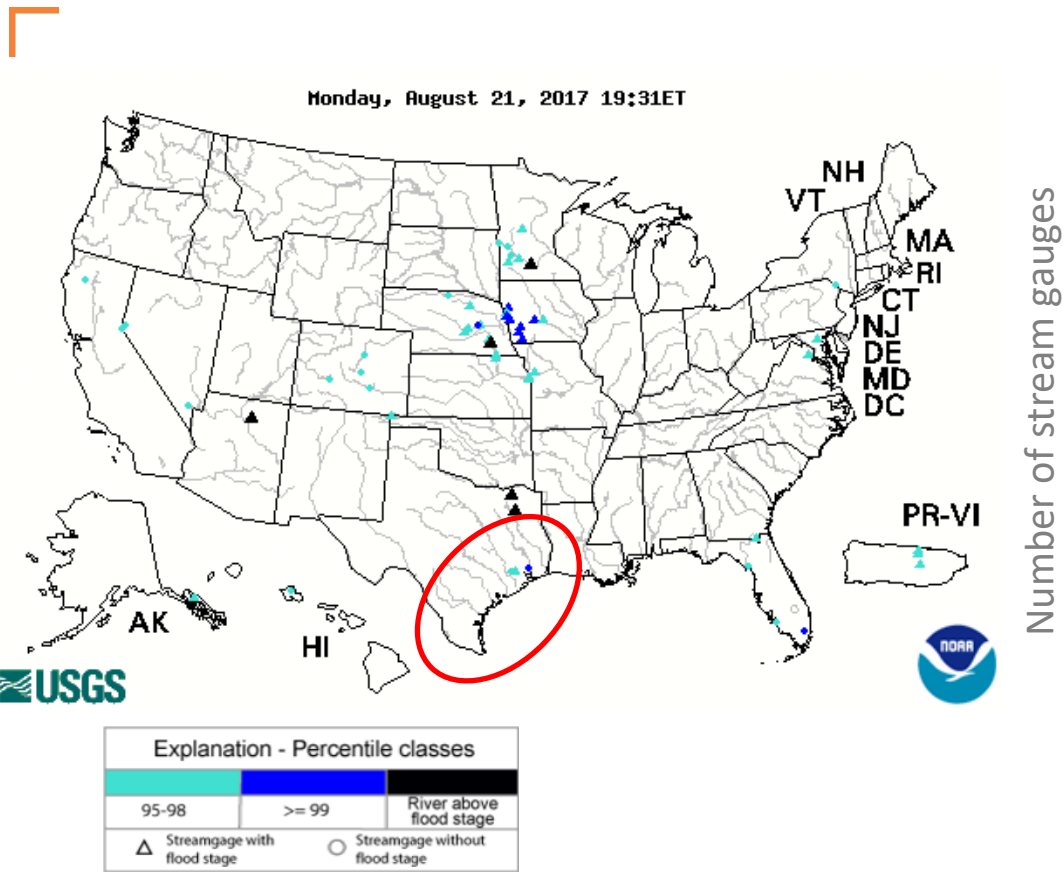
# Inundation as of 4<sup>th</sup> Sep, 2017 mapped using active remote sensing



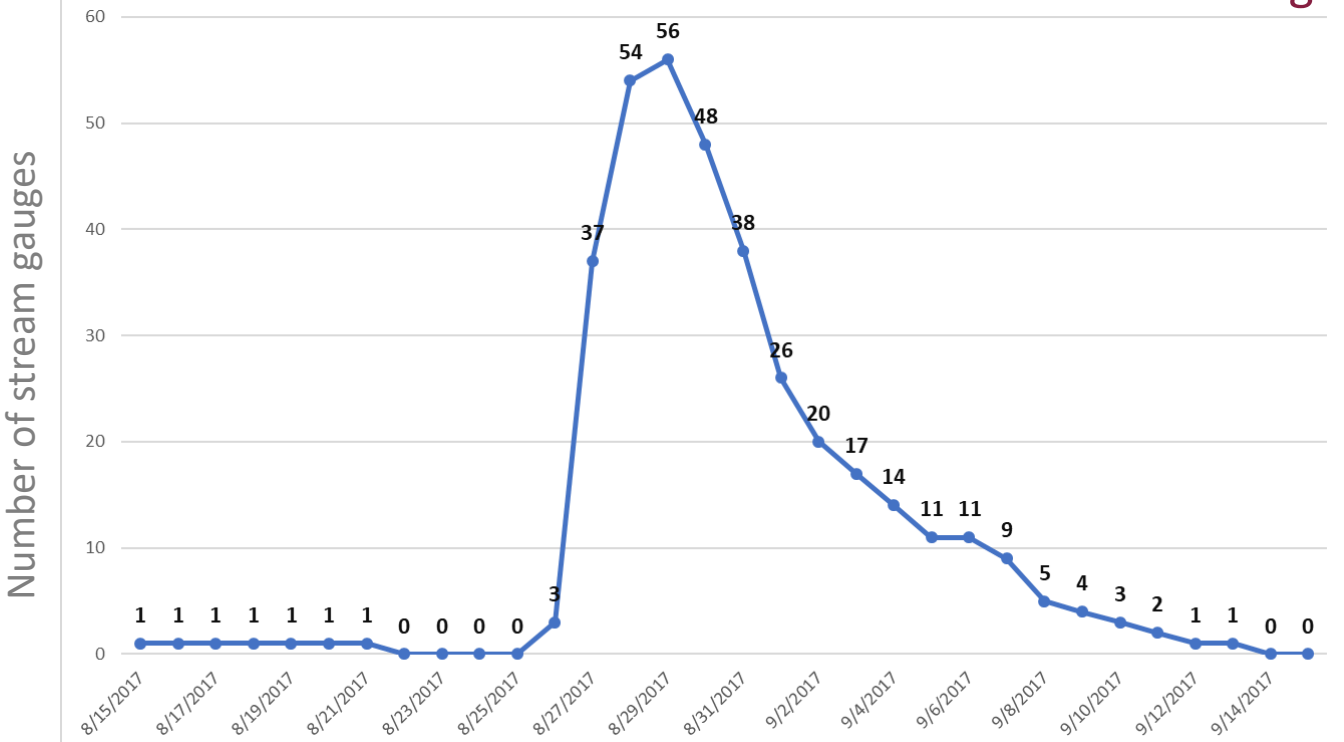
> Exposure > Outcome > Analysis > Results



# Period of flood - Defined using USGS stream gauges measurements in the study area



Number of stream gauges measured stage higher than National Weather Service- Flood Stage



Data Source: USGS Current Water Data for Texas  
URL: <https://waterdata.usgs.gov/tx/nwis/rt?>

Flood Period  
26<sup>th</sup> Aug – 13<sup>th</sup> September

> Exposure > Outcome > Analysis > Results



# Emergency Department (ED) Visit Spatial Temporal Data was used to evaluate the health risks

## VARIABLES

- Statement Start Date/ Admission Date - 2016, 2017, 2018
- Patient's Census Tract
- Patient's Age, Sex, Race, Ethnicity
- Hospital Name and Zip Code
- Diagnostic Codes
- Patient Address
- Patient Zip Code
- Patient Status During Discharge

*Texas Hospital Inpatient and Outpatient Discharge Research Data File, 2016,2017,2018. Texas Department of State Health Services, Center for Health Statistics, Austin, Texas(2020)*

> Exposure > Outcome > Analysis > Results

# 11 cause specific ED visits along with were filtered based on their observed association with flooding in previous studies

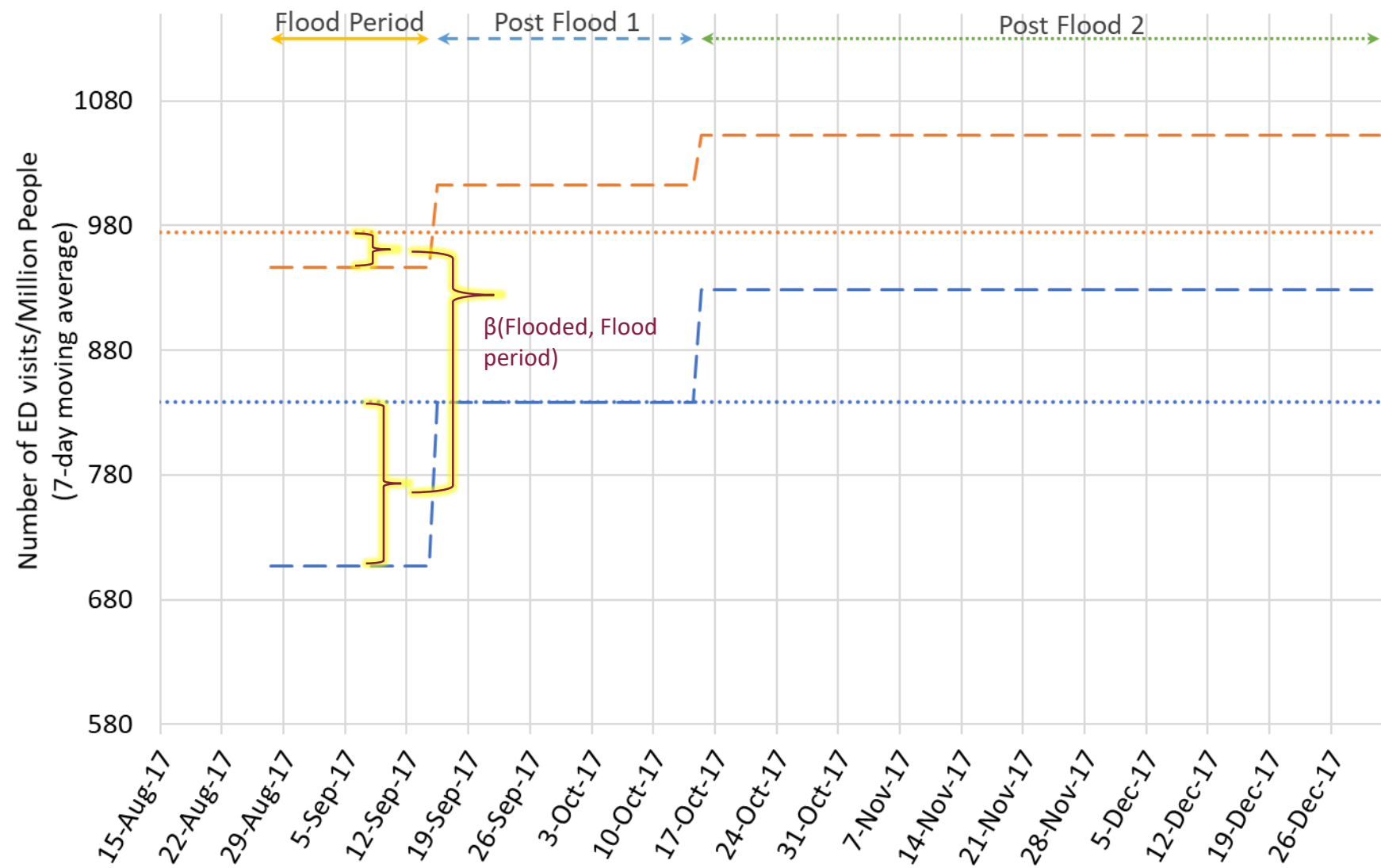
		Number of ED visits during flood and post flood periods		Literature	Potential reason
SL No	Outcomes	Flood Period	Post Flood		
1	Carbon monoxide(CO) poisoning	46	147	Chen et al., 2015; Noji, 2005; Van Sickle et al., 2007; Daley et al., 2001	Power outage & Use of portable generators without proper ventilation
2	Drowning	24	77	Daziano et al., 2015; Du et al., 2010	Direct outcome
3	Hypothermia	76	352	Diakakis et al., 2015; Du et al., 2010; CDC, 2000	Power Outage + Cold weather & Contact with cold flood water
4	Intestinal infectious Diseases	1631	11274	DAUDENS-VAYSSE et al., 2019;Waring et al., 2002; Zhang et al., 2019	Contamination of drinking water
5	Dehydration	5923	47121	Rosinger et al., 2018	Water insecurity
6	Insect Bite	1984	7737	CDC, 2000; Brewer et al., 1994; Faul et al., 2011; Bourque et al., 2006	Disturbance caused to insects habitat
7	Pregnancy complications	6821	42567	Grabich et al., 2069; Harville et al., 2009, 2015; Xiao et al., 2019	Mental stress; access to healthcare
8	Chest pain & Heart Palpitation	12831	82081	Hendrickson et al., 1997; Park et al., 2013; Reacher et al., 2004	Mental stress
9	Acute Respiratory Infections (ARI)	22442	254202	Saulnier et al., 2018; Milojevic et al., 2012	Molds and dampness in flooded buildings
10	Heat Related (Other than dehydration)	199	450	Dellinger et al.,1996	Clean up activities
11	Asthma	13060	85232	Hendrickson et al., 1997; Park et al., 2013; Reacher et al., 2004	Exacerbations due to the disaster impact and lack of access to medical resources

> Exposure > Outcome > Analysis > Results



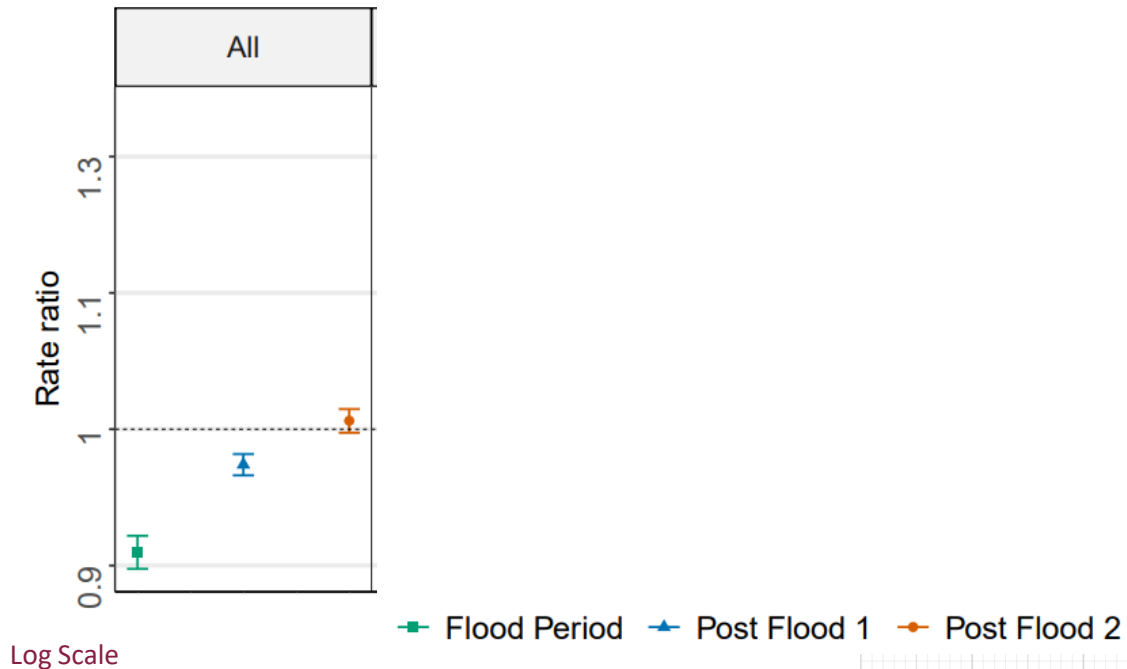
# Study Design: Controlled Before And After Analysis: Poisson regression

Outcome (% of ED visits) ~ Tract Flooded (binary) \* period + Patient Age + Sex + Race + Ethnicity + (year + month + day of week)



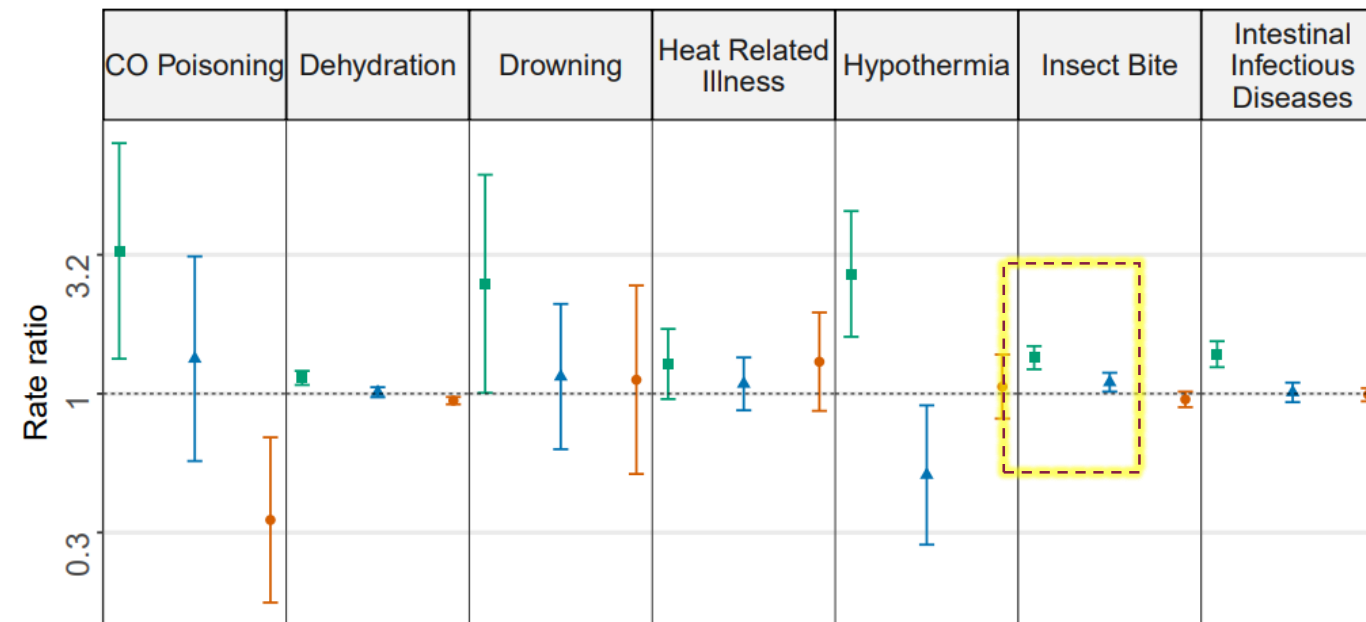
**Periods:**  
**Control Period/ Baseline:**  
1<sup>st</sup> Jul – 30<sup>th</sup> Dec 2016,  
1<sup>st</sup> Apr- 19<sup>th</sup> Aug 2017,  
1<sup>st</sup> Jul – 30<sup>th</sup> Dec 2018  
**Flood Period:** 26<sup>th</sup> Aug – 13<sup>th</sup> Sep 2017  
**Post flood 1:** 14<sup>th</sup> Sep – 13<sup>th</sup> Oct 2017  
**Post flood 2:** 14<sup>th</sup> Oct – 30<sup>th</sup> Dec 2017

The average rate of ED visits over the flood period was less in flooded tracts compared to non-flooded tracts.

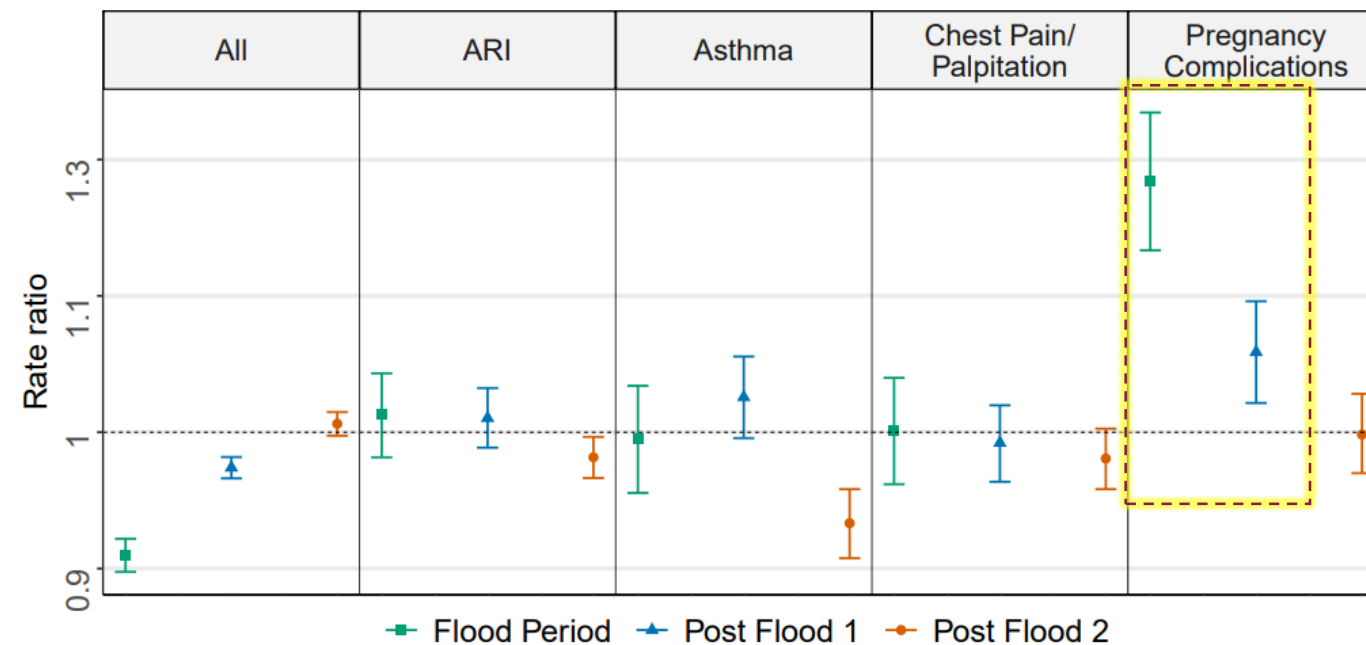


> Exposure > Outcome > Analysis > Results



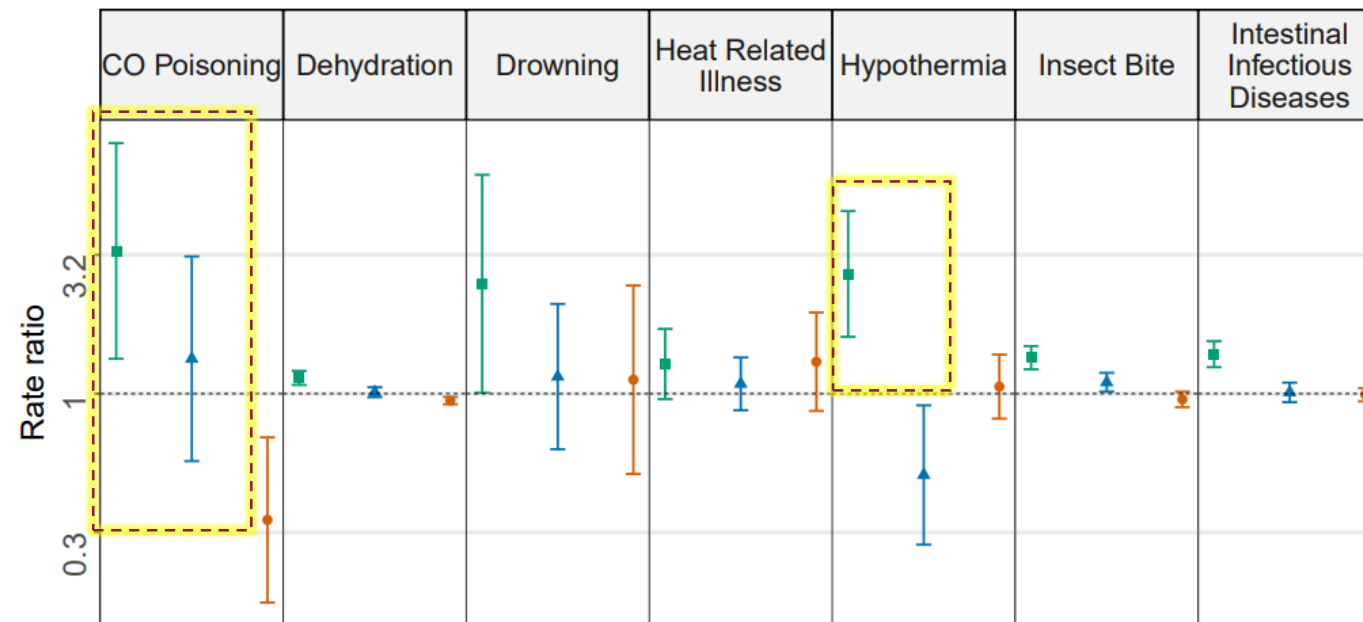


The ED visits related to insect bite and pregnancy complication were increased in flooded tracts compared to non-flooded tracts during both flood and post flood 1 periods.

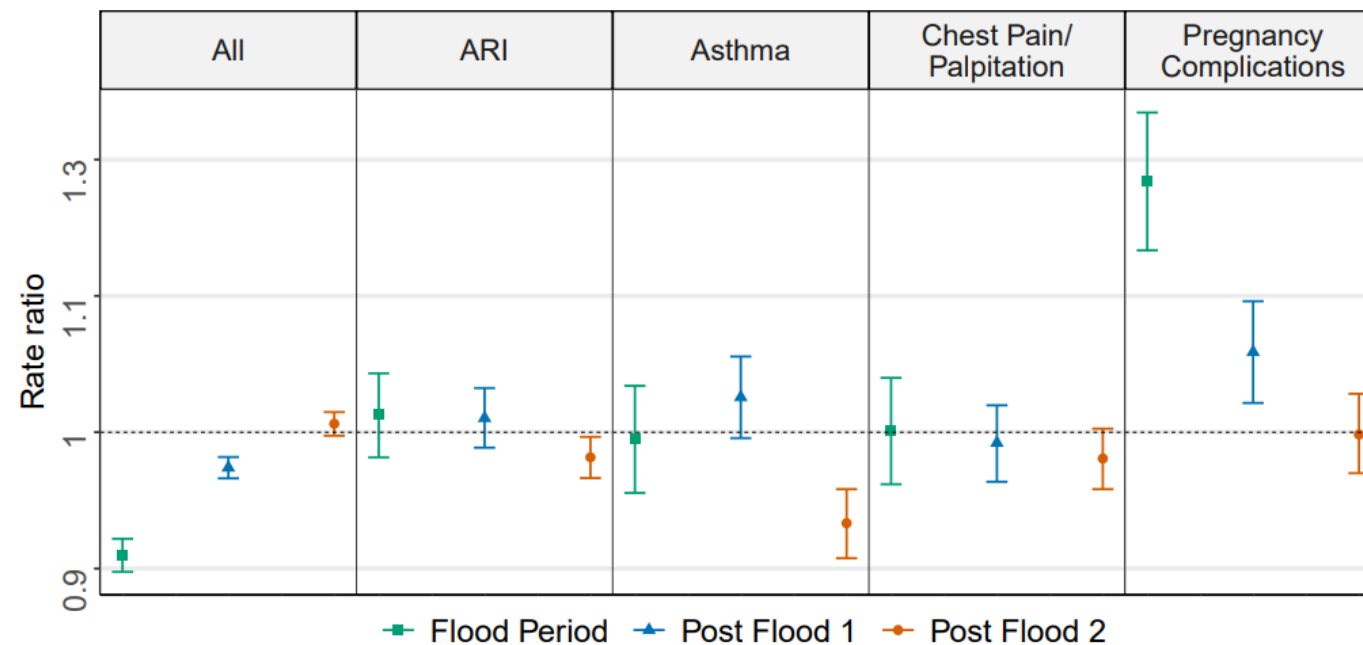


Log Scale

> Exposure > Outcome > Analysis > Results



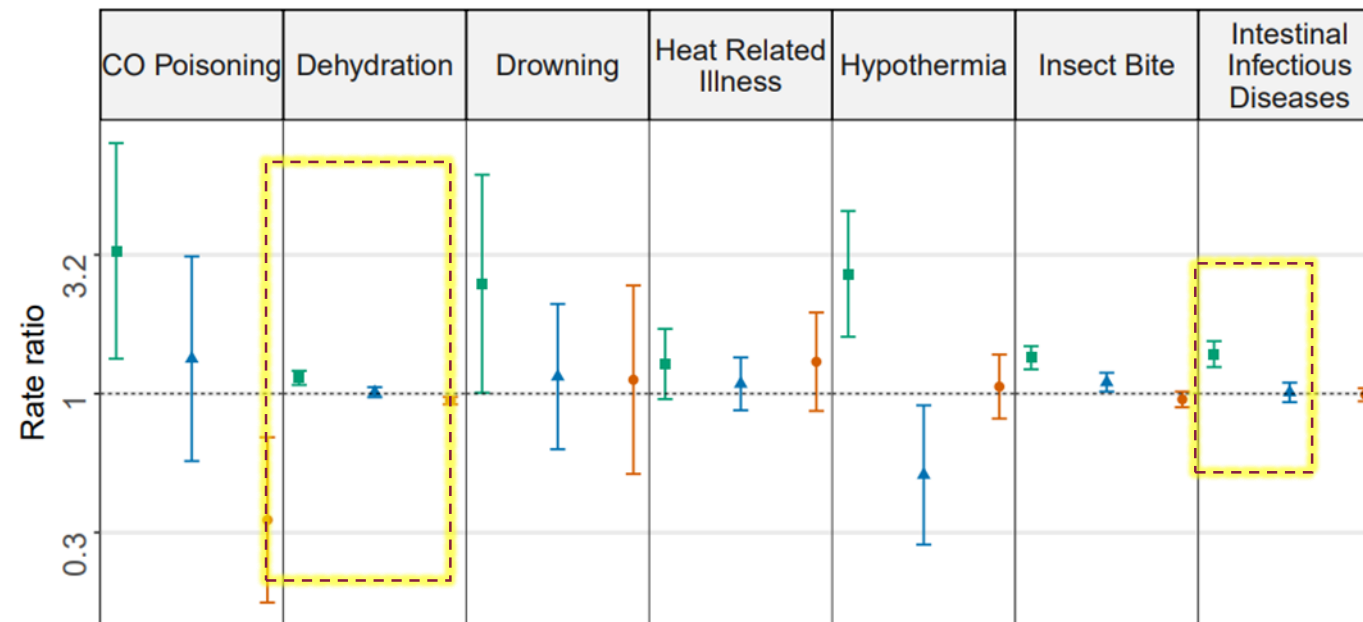
The average rate of ED visits related to CO poisoning and hypothermia increased by more than two times in the flooded tracts compared to non-flooded tracts.



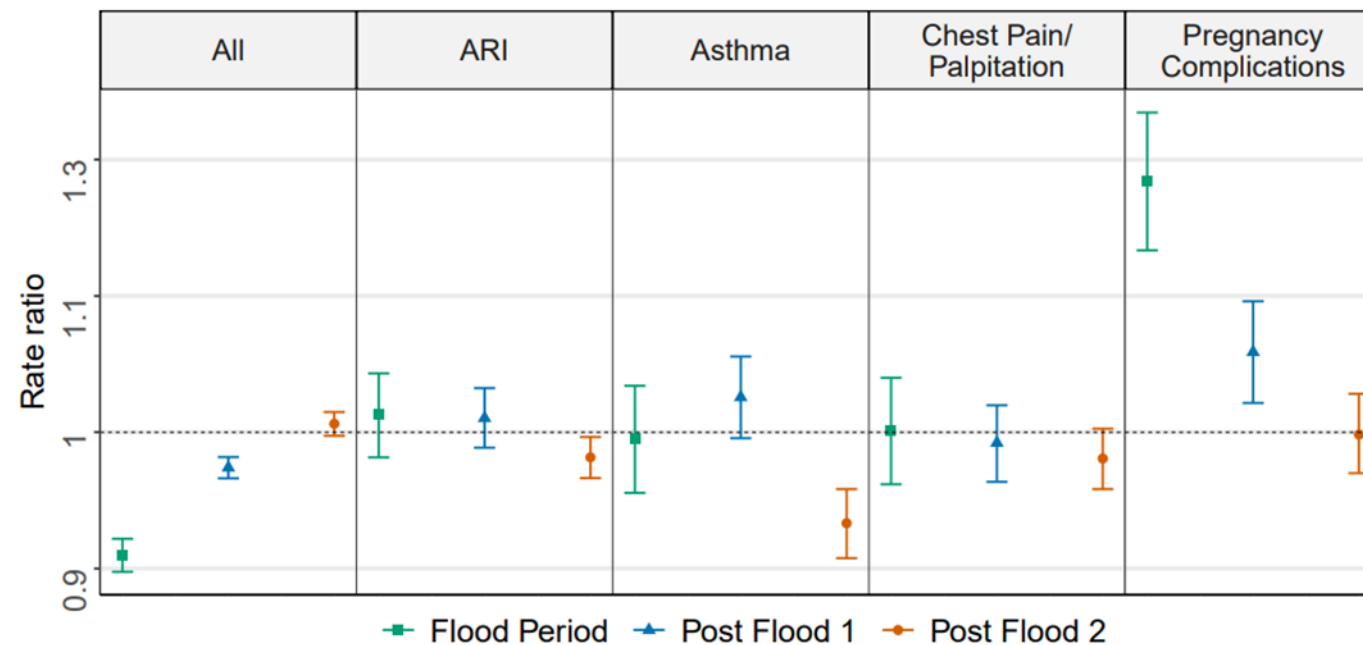
Log Scale

> Exposure > Outcome > Analysis > Results



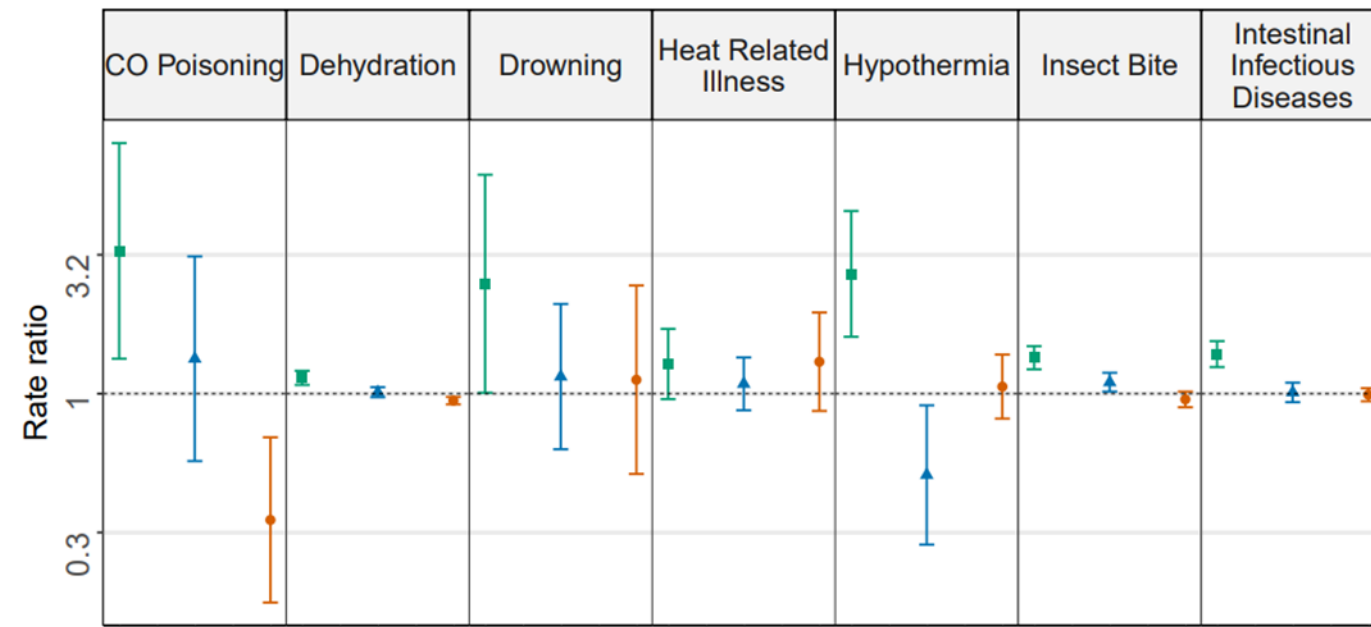


The ED visits related to Dehydration and Intestinal Infectious Diseases were increased in flooded tracts compared to non-flooded tracts during the flood period.

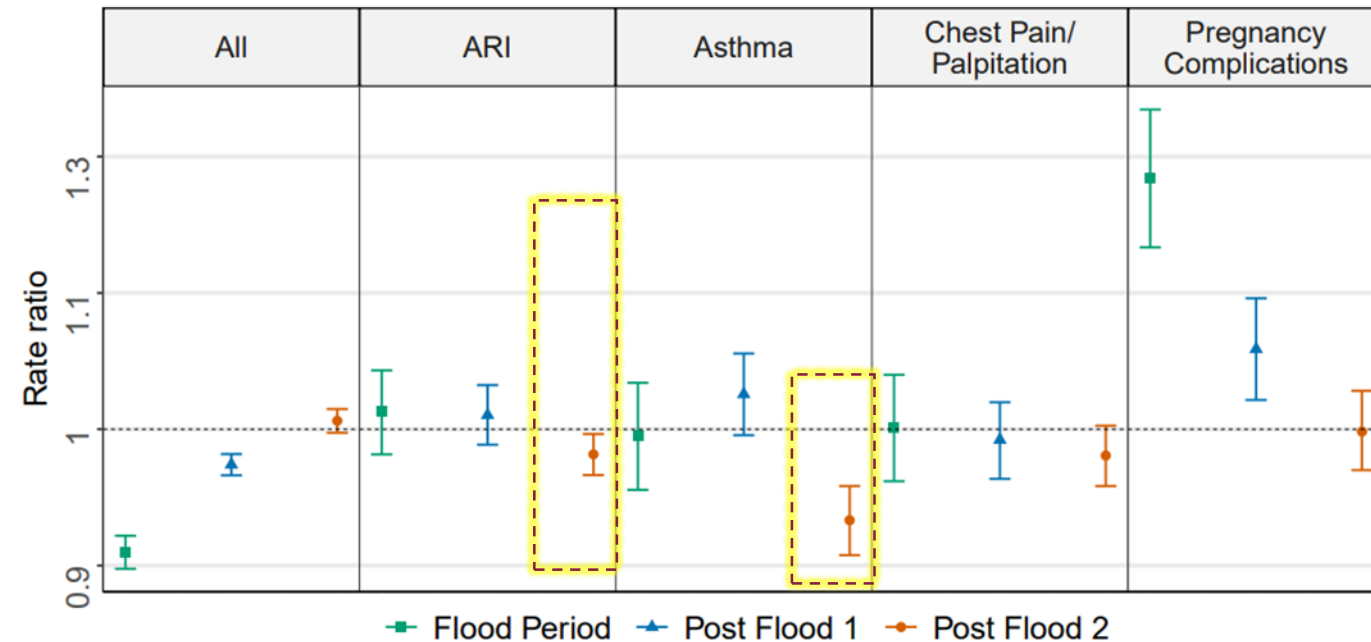


Log Scale

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The ED visits related to Acute Respiratory Infections (ARI) and Asthma were decreased in the flooded tracts compared to non-flooded tracts during the post flood 2



Log Scale

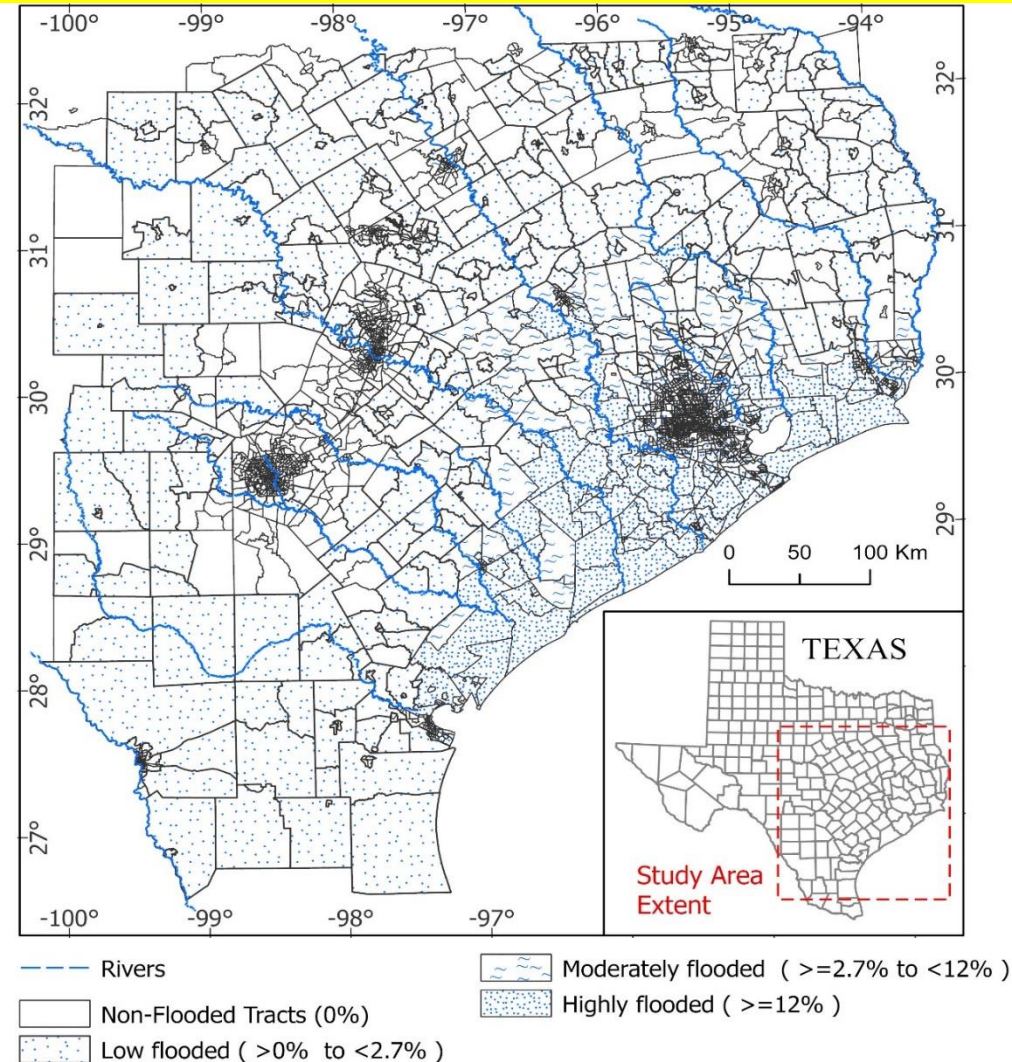
> Exposure > Outcome > Analysis > Results



# Rate Ratio of ED visits for the low flooded, moderately flooded and highly flooded census tracts with respect to the non flooded tracts after adjusting for the baseline.

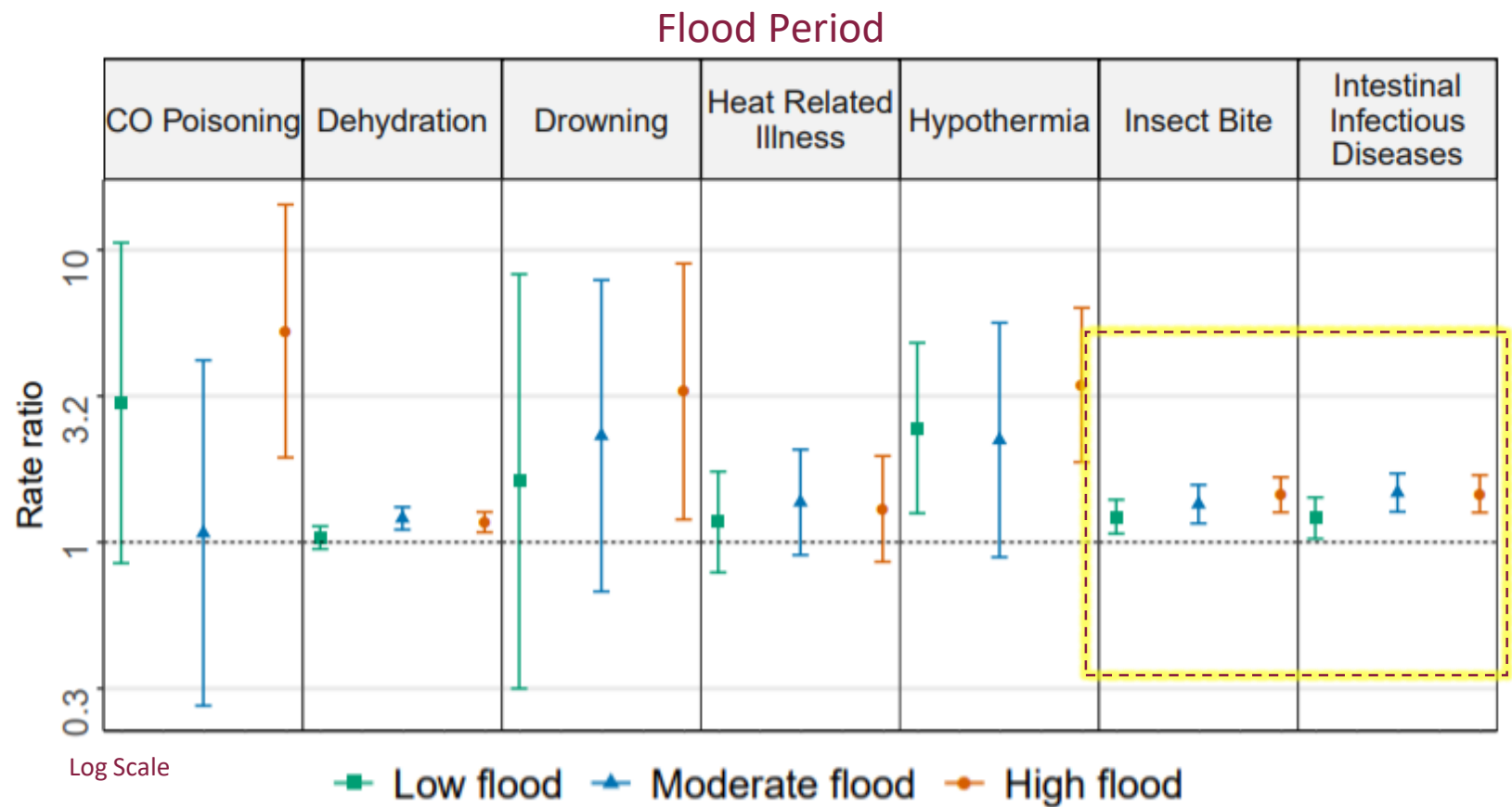
Outcome (% of ED visits)  $\sim$  Tract Flooded \* period + Patient Age + Sex + Race + Ethnicity + (year + month + day of week)

1. No flooding (reference)
2. Low flooded
3. Moderately flooded
4. High Flooded



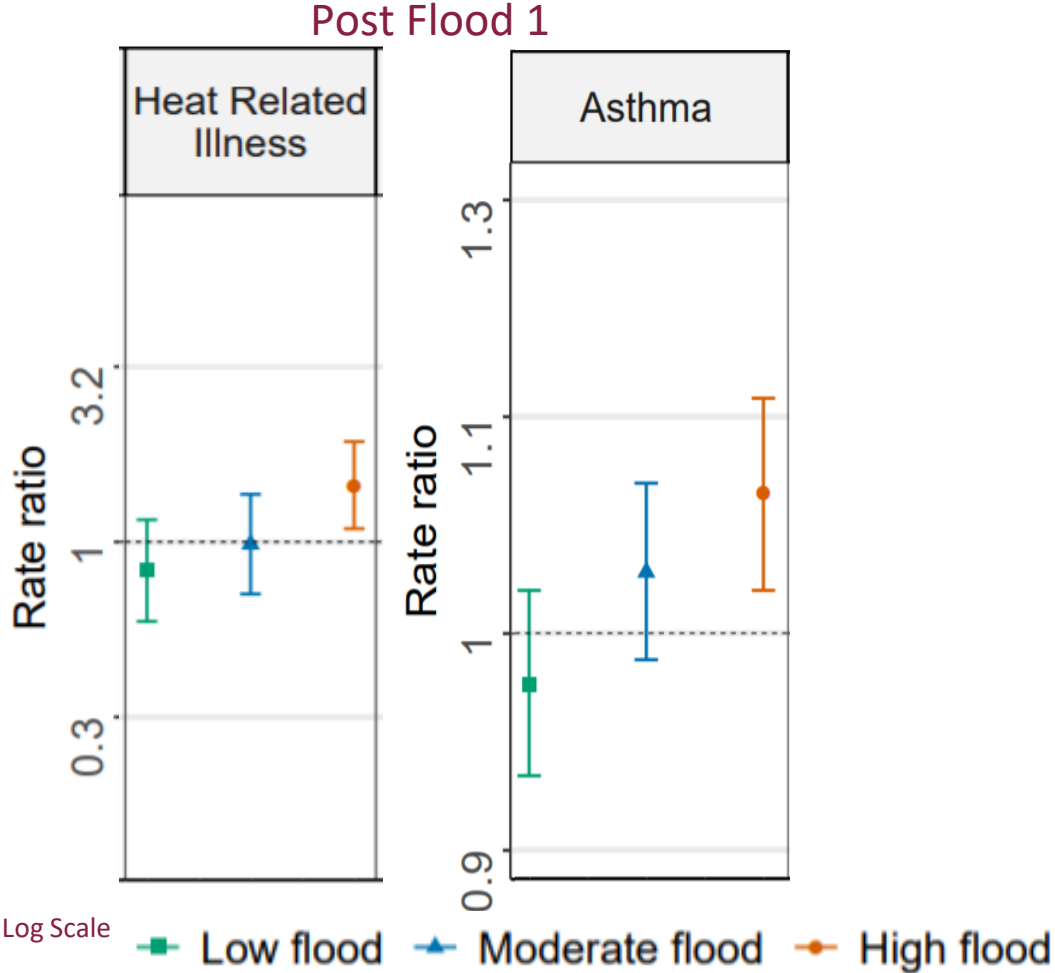
> Exposure > Outcome > Analysis > Results

The ED visits related to insect bite and intestinal infectious diseases were increased in all three flooded categories compared to non-flooded during the flood period.



> Exposure > Outcome > Analysis > Results

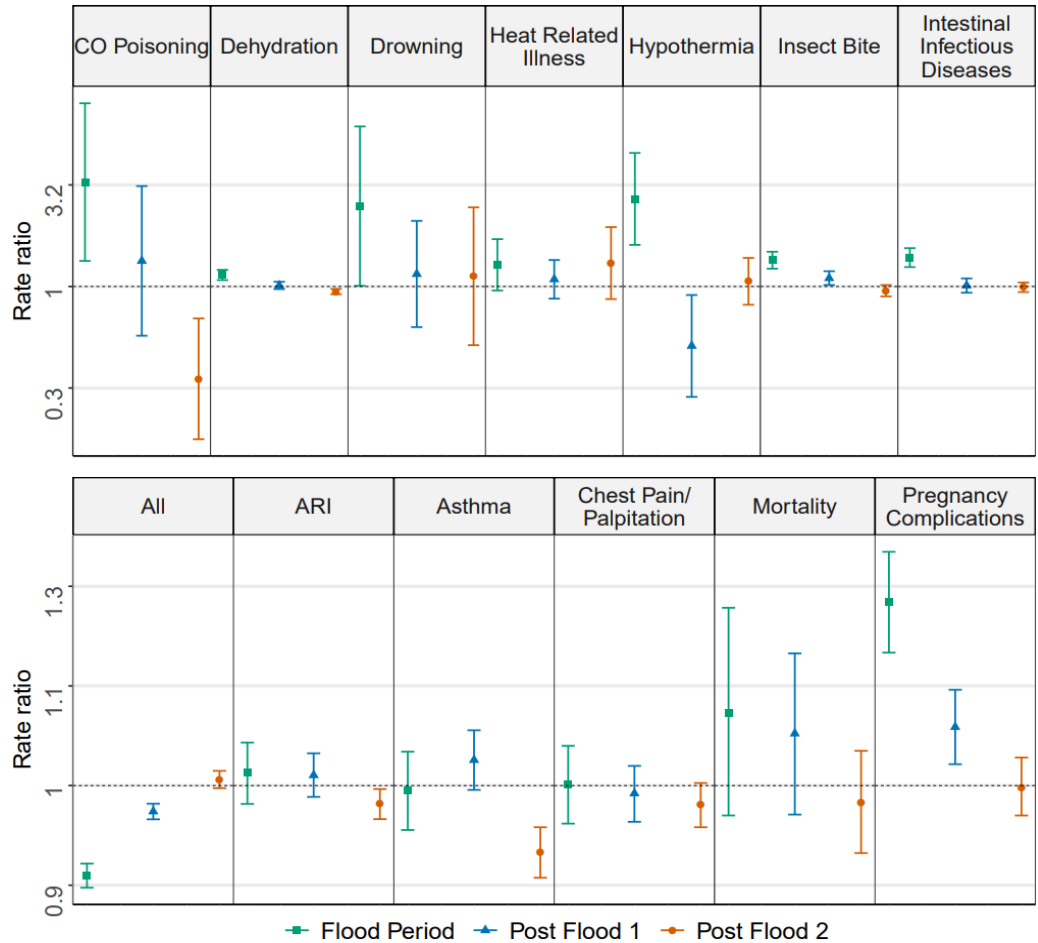
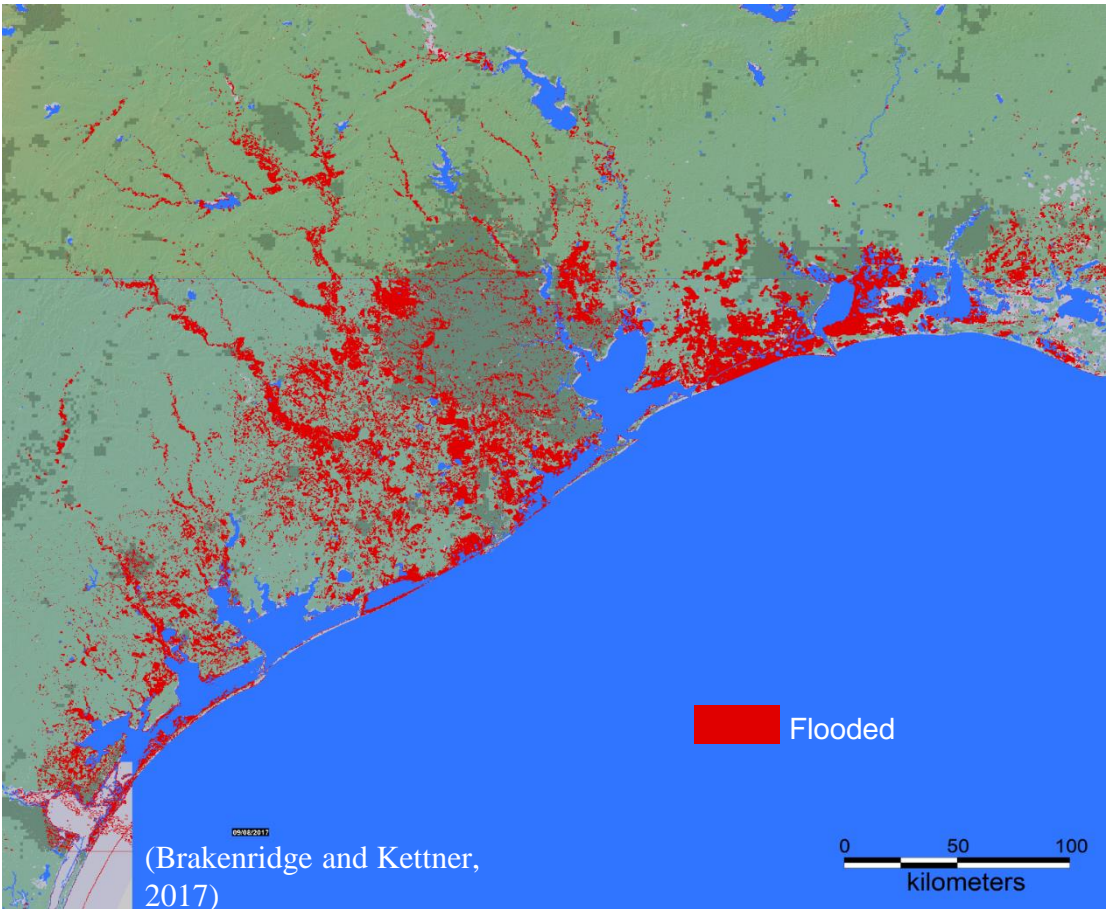
ED visits for asthma and heat-related illness were increased among the highly flooded tracts with respect to non-flooded, which was not reflected in dichotomous analysis.



> Exposure > Outcome > Analysis > Results



Exposure of census tracts to floods assessed using earth observation was useful in understanding the health outcomes that increased after the flooding



> Results Summary & Limitations<

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# Thank you

## Contacts

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# Questions?