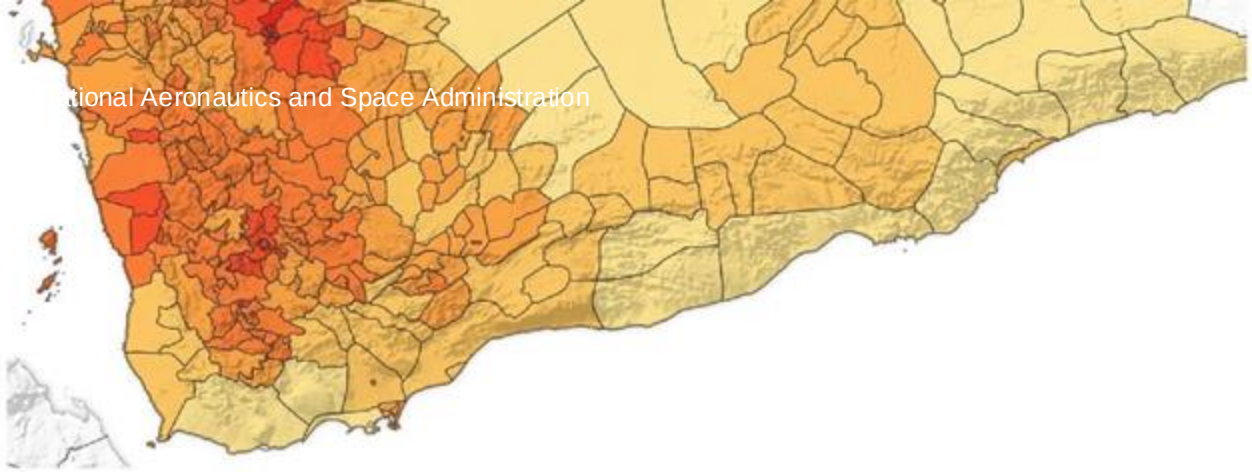


The Application of Earth Observations for Assessing Waterborne Disease Risk

Part 2: Using Remote Sensing-Based Vibrios Predictive Intelligence for Intervention and Mitigation

Dr. Antar Jutla (University of Florida), Bailey Magers (University of Florida)

March 27, 2025

Training Outline

Part 1

Overview of Monitoring Water-borne Diseases using Remote Sensing Observations

March 25, 2025

Part 2

Using Remote Sensing-based Vibrio Predictive Intelligence for Intervention and Mitigation

March 27, 2025

Homework

Opens Month 3/27/2025 – Due 4/10/2025 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

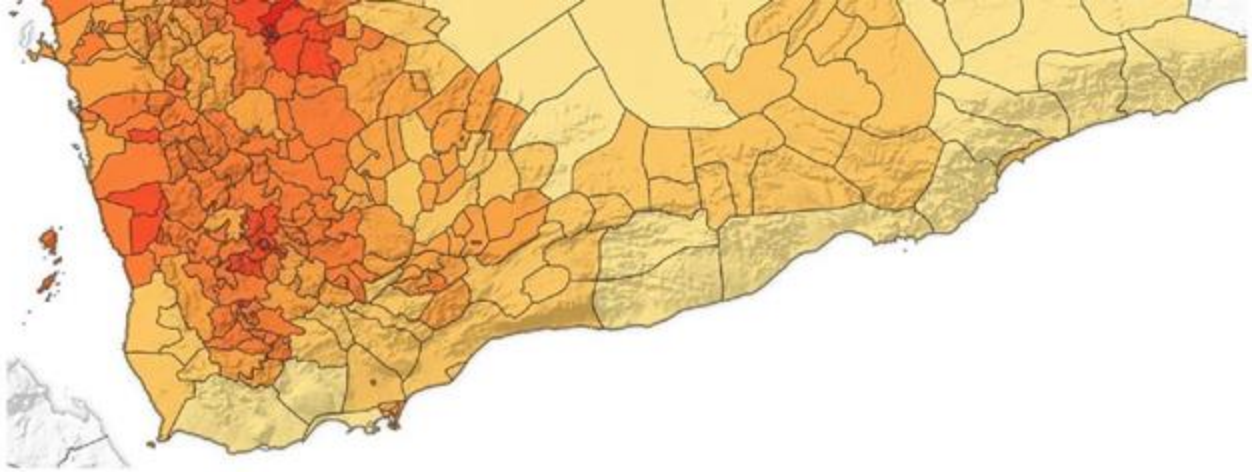
Part 2 – Trainers

Dr. Antarpreet Jutla

Associate Professor, Department of Environmental Engineering Sciences
Co-Director, USGS Florida Water Resources Center, University of Florida

Bailey Magers

PhD Candidate, Engineering School of Sustainable Infrastructure and Environment, University of Florida



The Application of Earth Observations for Assessing Waterborne Disease Risk

Part 2: Using Remote Sensing-Based Vibrios Predictive Intelligence for Intervention and Mitigation

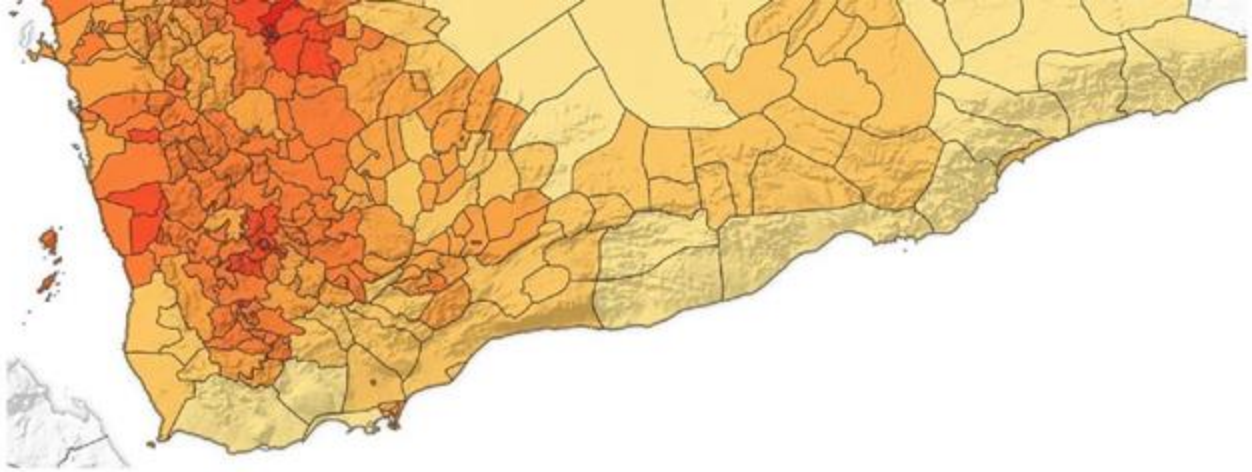
Part 2 Objectives

1. Recognize how satellite observations are used for prediction of waterborne diseases.

2. Recognize how satellite observations with in situ water quality data are integrated to develop waterborne diseases using cholera as an example.

Outline

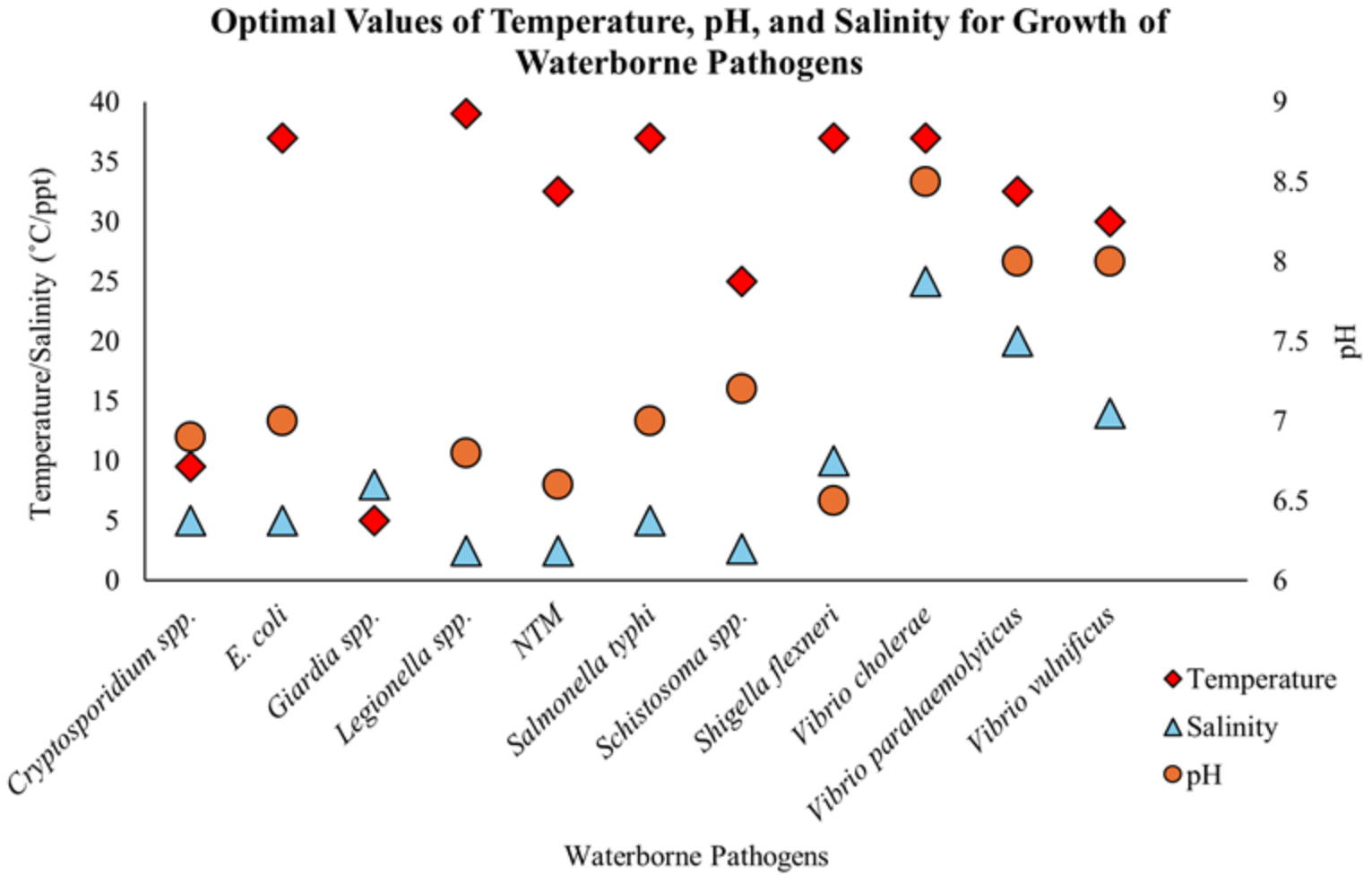
- Waterborne Diseases: The Impending Threat of Vibrios
- *Vibrio cholerae*: Lessons Learned From a Model Pathogen
- Art of Prediction
- The Cholera Risk Model incorporating NASA Remote Sensing Data
- Interpreting and Understanding Cholera Risk
- Lessons Learned and Future Applications in Florida



Waterborne Diseases: The Impending Threat of Vibrios

Impacts of Environmental Variability on Waterborne Pathogens

- Ocean Warming
- Increased Salinity Variability
- Ocean Acidification
- Ocean Deoxygenation
- Increased Precipitation Extremes
- Increased Nutrient Runoff



Hurricane Ian Impacts

Sep 2022

WINK

Spike in vibrio cases after Hurricane Ian

The Guardian

Florida issues warning over flesh-eating bacteria in wake of Hurricane Ian

The New York Times

Hurricane Ian Is Blamed for Deadly Bacterial Infections in Florida

CNN

Dangerous flesh-eating bacterial infections increased in Florida after Hurricane Ian

TIME

Flesh-Eating Bacteria Cases Are Rising in Florida After Hurricane Ian

Hurricane Milton Impacts

And when we thought we had enough… Hurricane Milton happened.

NATION

Vibrio vulnificus

Add Topic +

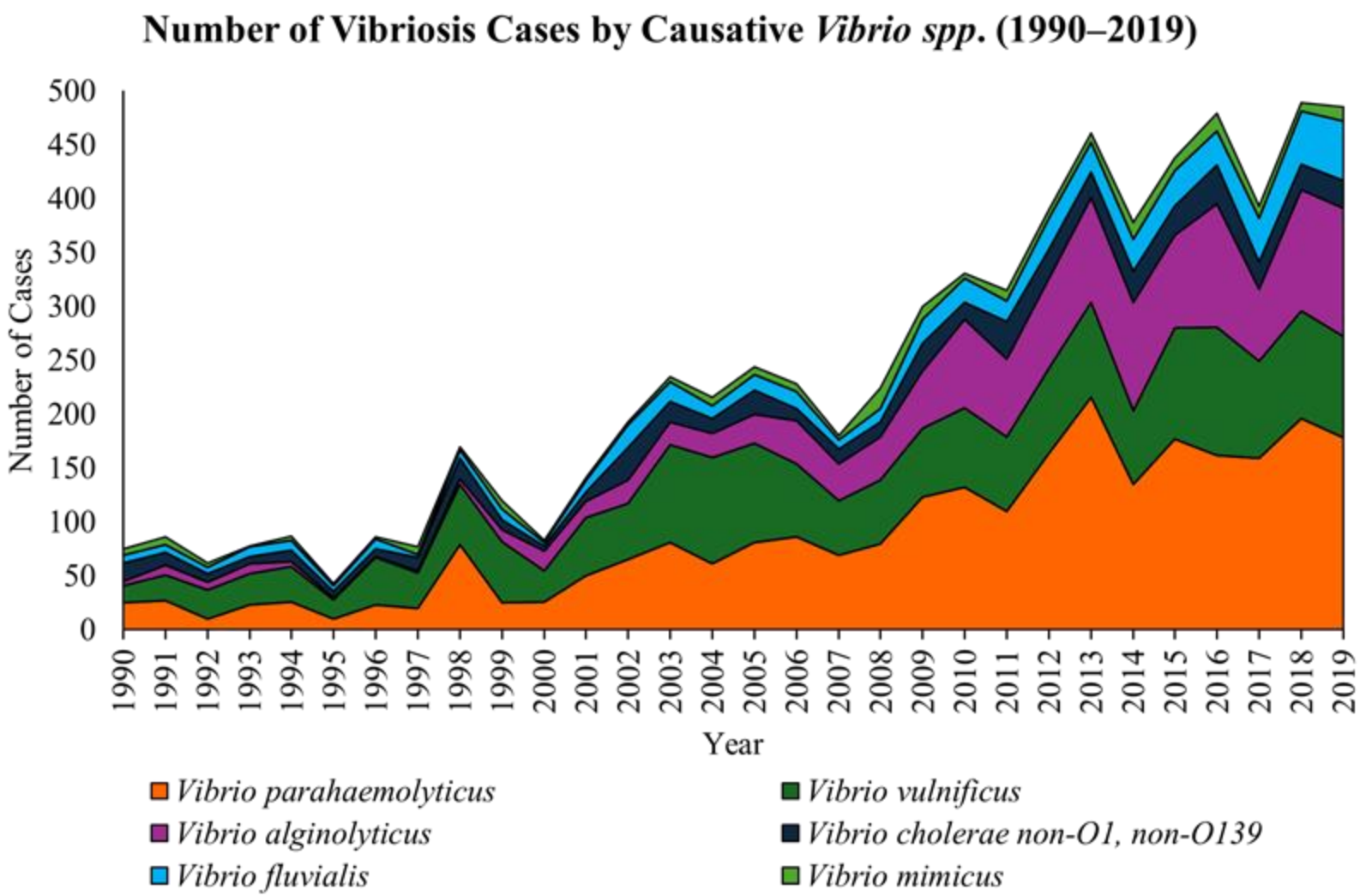
Flesh-eating bacteria cases rise to record level after hurricanes in Florida

The bacteria can infect a person with an open wound, such as a cut, and can cause the skin and soft tissue around the wound to quickly break down.

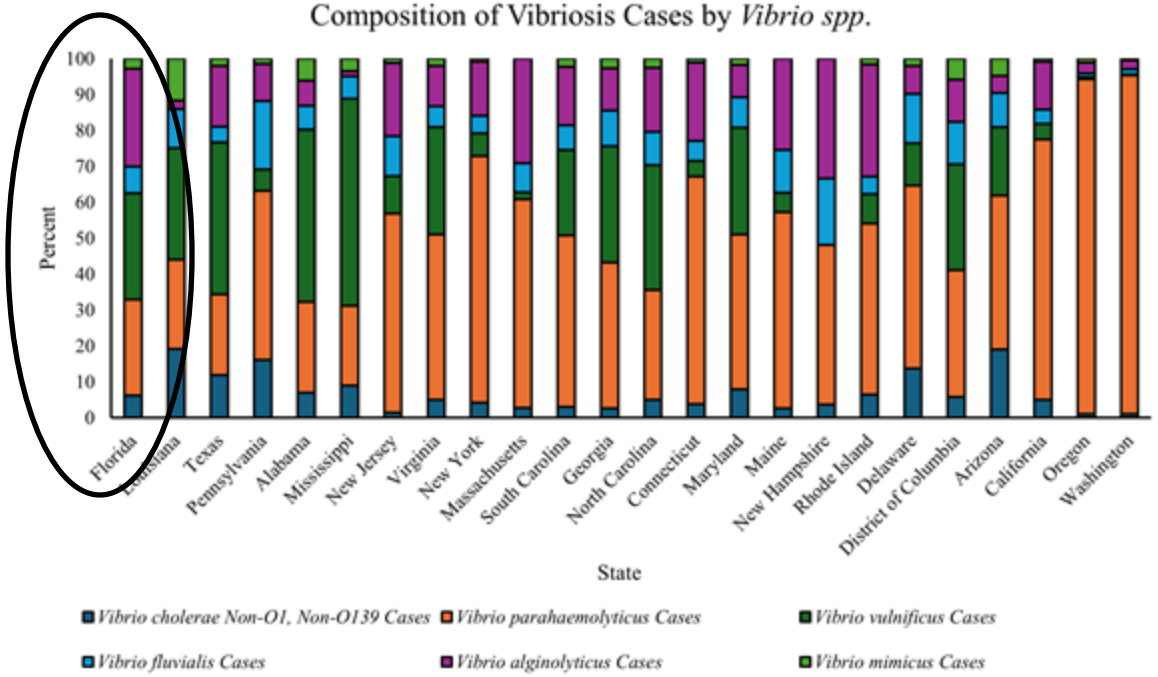
Liz Freeman, C. A. Bridges and Thao Nguyen USA TODAY NETWORK

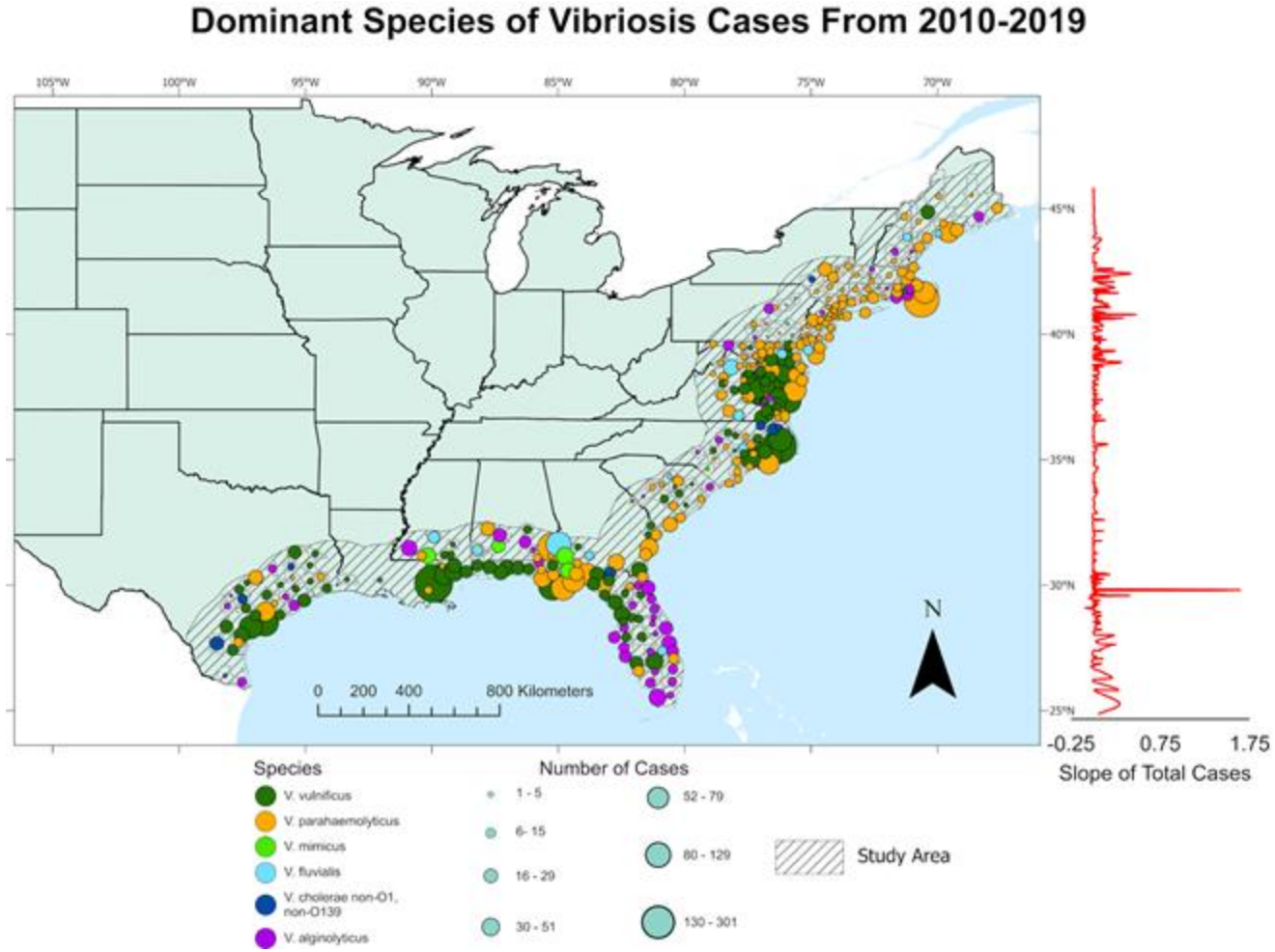
Published 2:32 a.m. ET Oct. 22, 2024 | **Updated 9:53 p.m. ET Oct. 22, 2024**

Increased Presence of WBD and Vibriosis

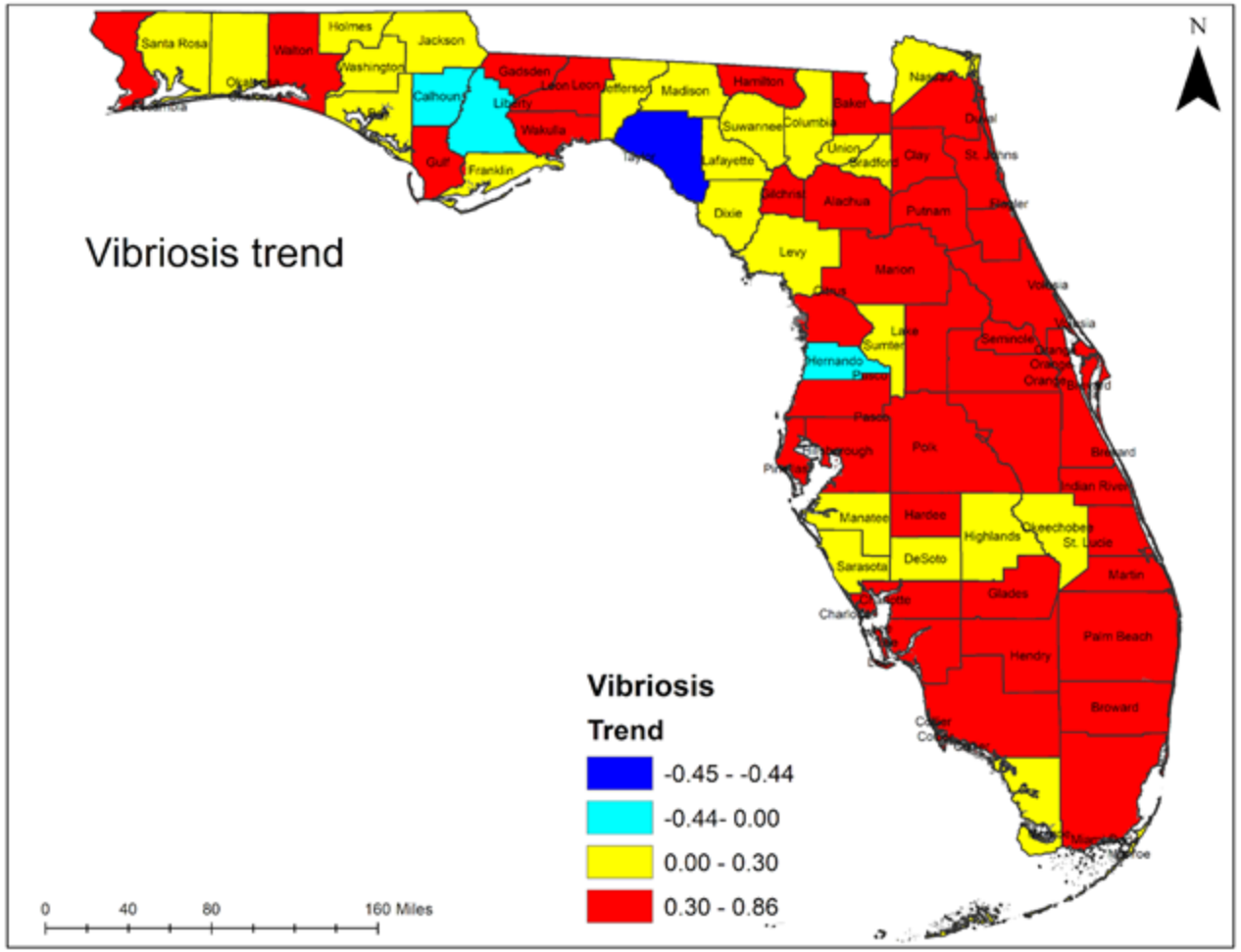


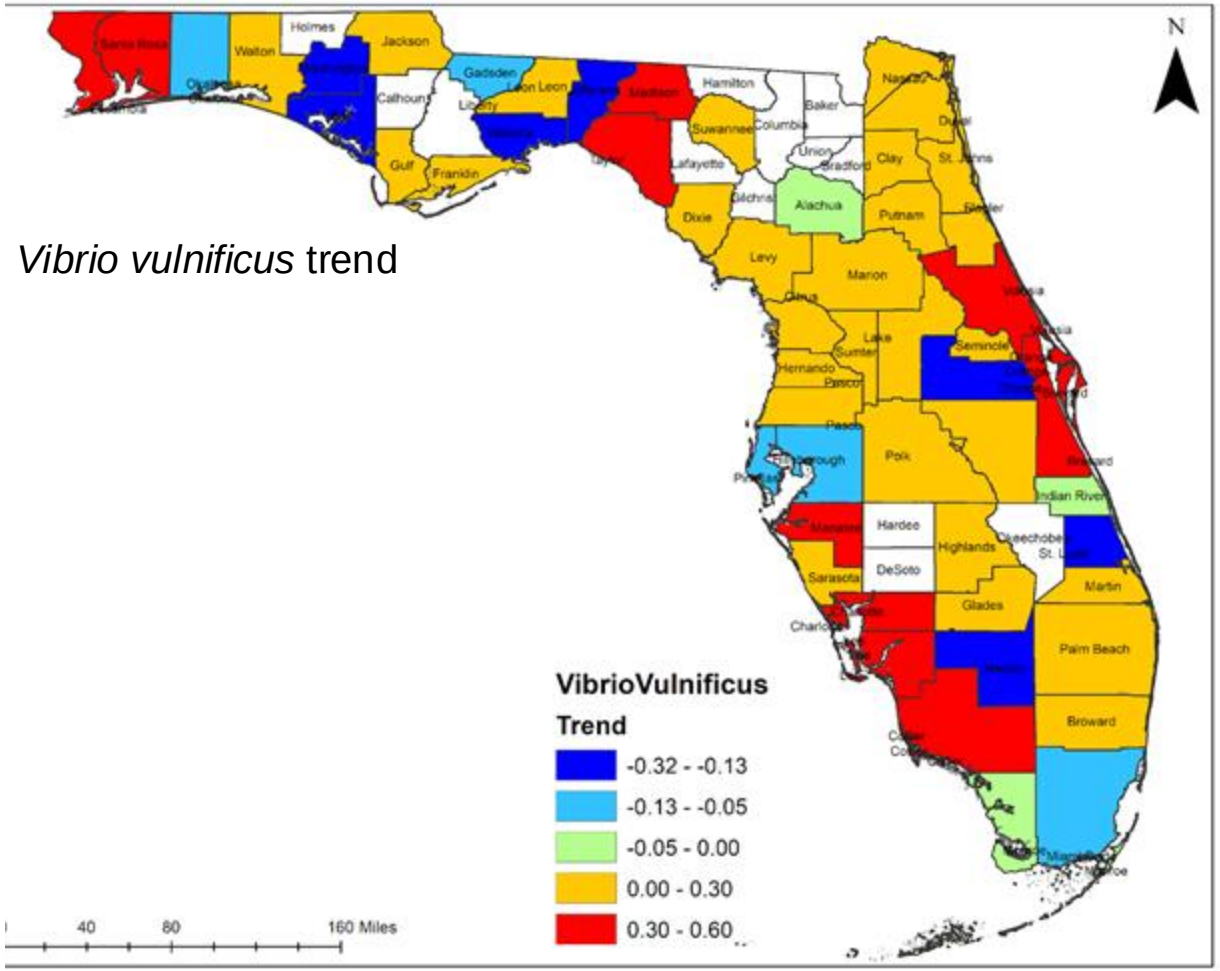
What Pathogenic *Vibrio spp.* are in the USA?





Temporal Trends in Florida: 2001-2022





Environmental Factors Influencing *Vibrio spp.*

- Sea Surface Temperature
- Precipitation
- Flooding
- Coastal Salinity
- Dissolved Organic Matter
- Chlorophyll – Proxy for Phytoplankton and Zooplankton

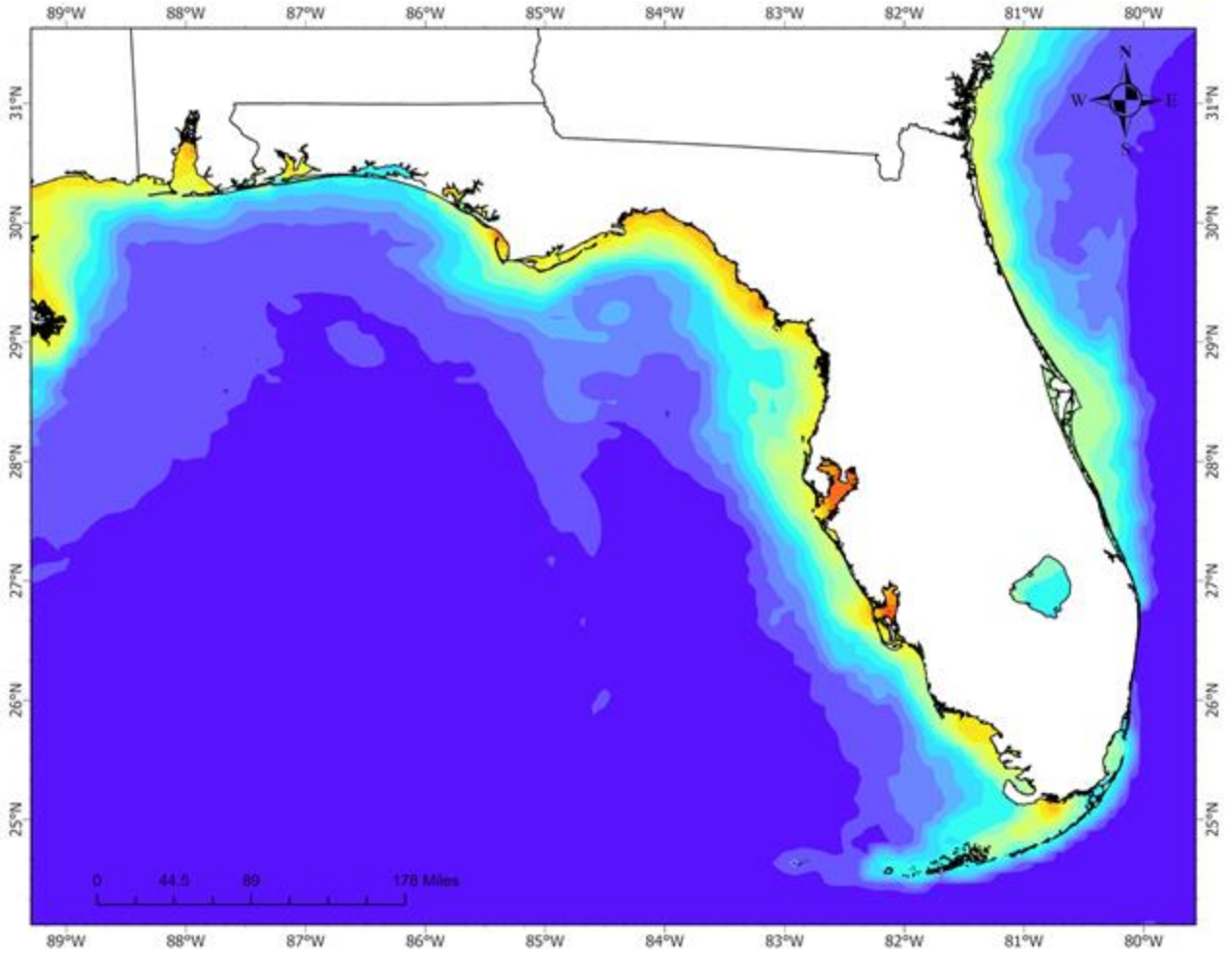
These environmental data are available from NASA Earth observations.

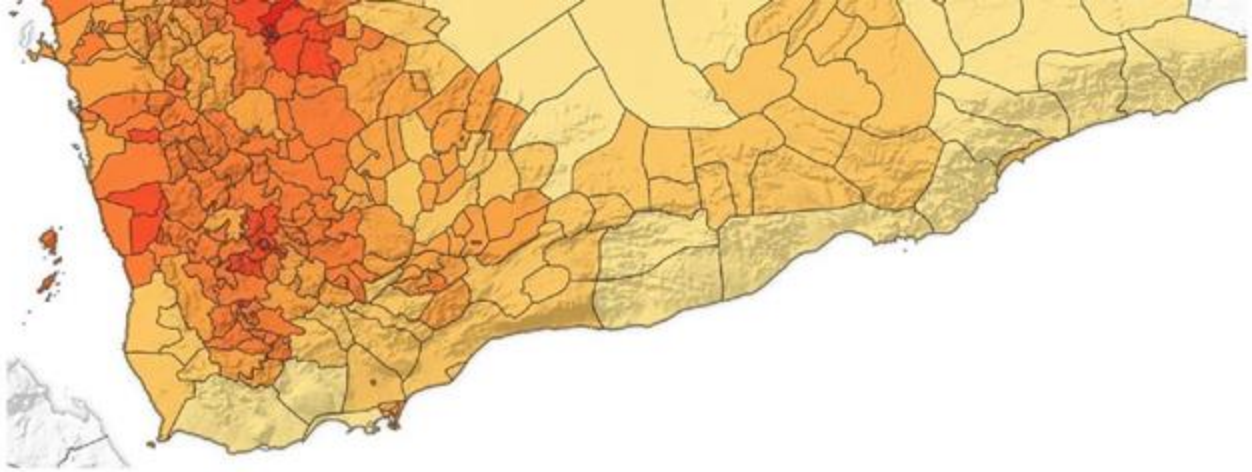
Prediction of *Vibrio spp*. For Florida

Genomic sequencing and microbiological sampling has provided insights to the presence and abundance of other pathogenic *Vibrio spp.*, particularly in the United States.

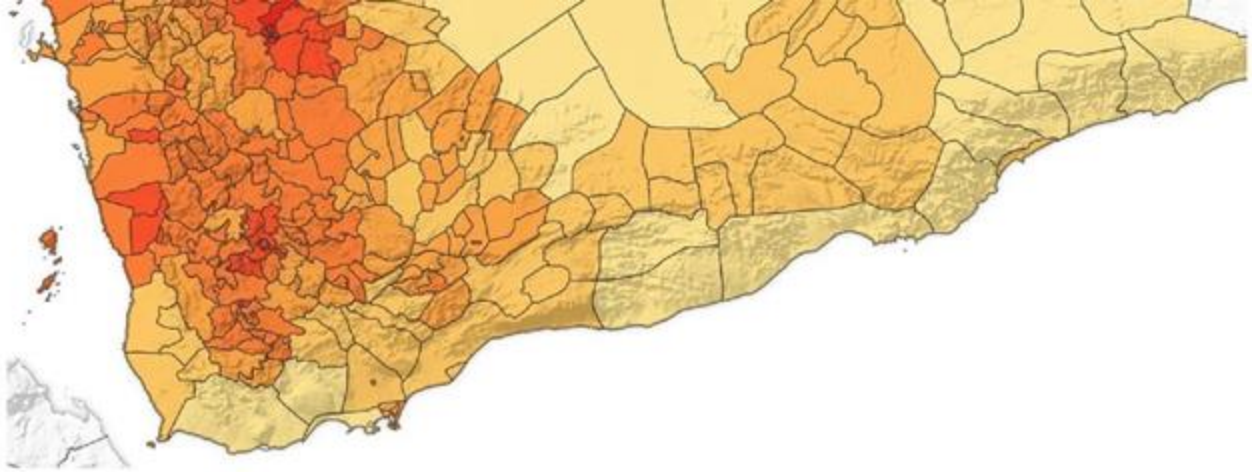
Advances in remote sensing of sea surface temperatures, salinity, chlorophyll, and phytoplankton make monitoring coastlines and brackish waters more feasible, helping to predict risk of vibriosis.

Chlorophyll-a From PACE OCI





Vibrios are autochthonous to brackish water!



Vibrio cholerae: Lessons Learned From a Model Pathogen

Cholera

50 Countries
Impacted by Cholera in 2023

700,000 Cases
Of Cholera in 2023

4,300 Deaths
Of Cholera in 2023

Hours
The Length of Time Cholera can be Fatal if Untreated

Vibrio cholerae

Cholera is a diarrheal disease caused by consumption of contaminated drinking water containing *Vibrio cholerae,* a bacterium.

V. cholerae is found in riverine, estuarine, and coastal environments and also freshwater ecosystems globally.

V. cholerae is an ecologically significant bacterium, and it will never be eradicated.

Cholera is caused by consuming a large enough dose of *V. cholerae* to cause an infection.

Timeline of *Vibrio cholerae* Studies

1960s

Microbiological Theory

- Temperature, Precipitation, Salinity (*Vibrio spp.*)
- Dose response established

1970s 1980s

Microbiological Theory

- Viable But Non Culturable (VBNC) Bacteria

1990s

Field Data Campaigns

- Temperature, Precipitation, Salinity and Aquatic ecology
- Characterization of Serotypes (0139)

2000s

Prevention and Earth Observations

- Exploration of data from satellites for linking with cholera outbreaks
- Sari Filtration

2010s

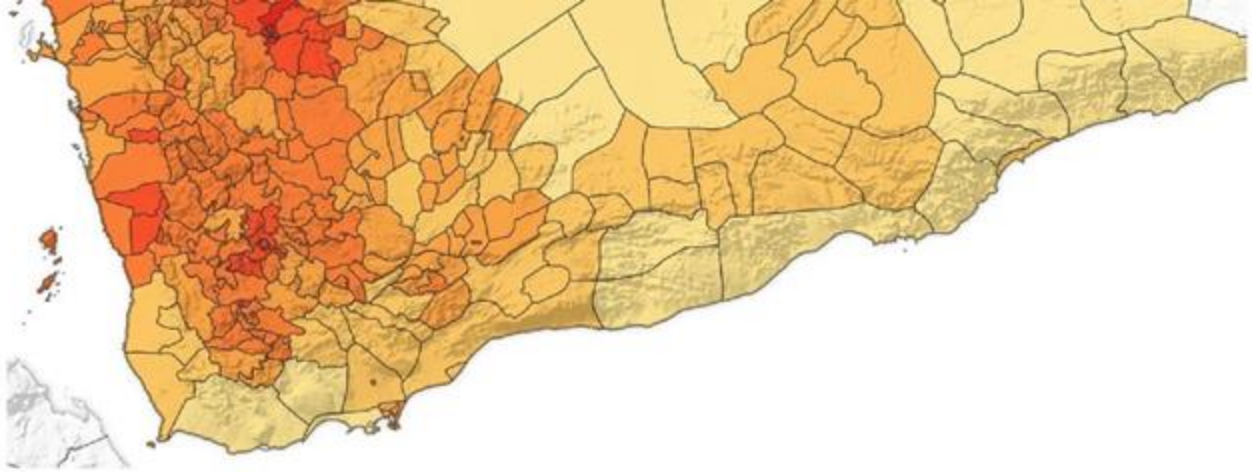
Integration of Microbiological, Field data, Earth Observations

- Epidemic/ Endemic Cholera
- Four-week Predictive Prototyping

2020s

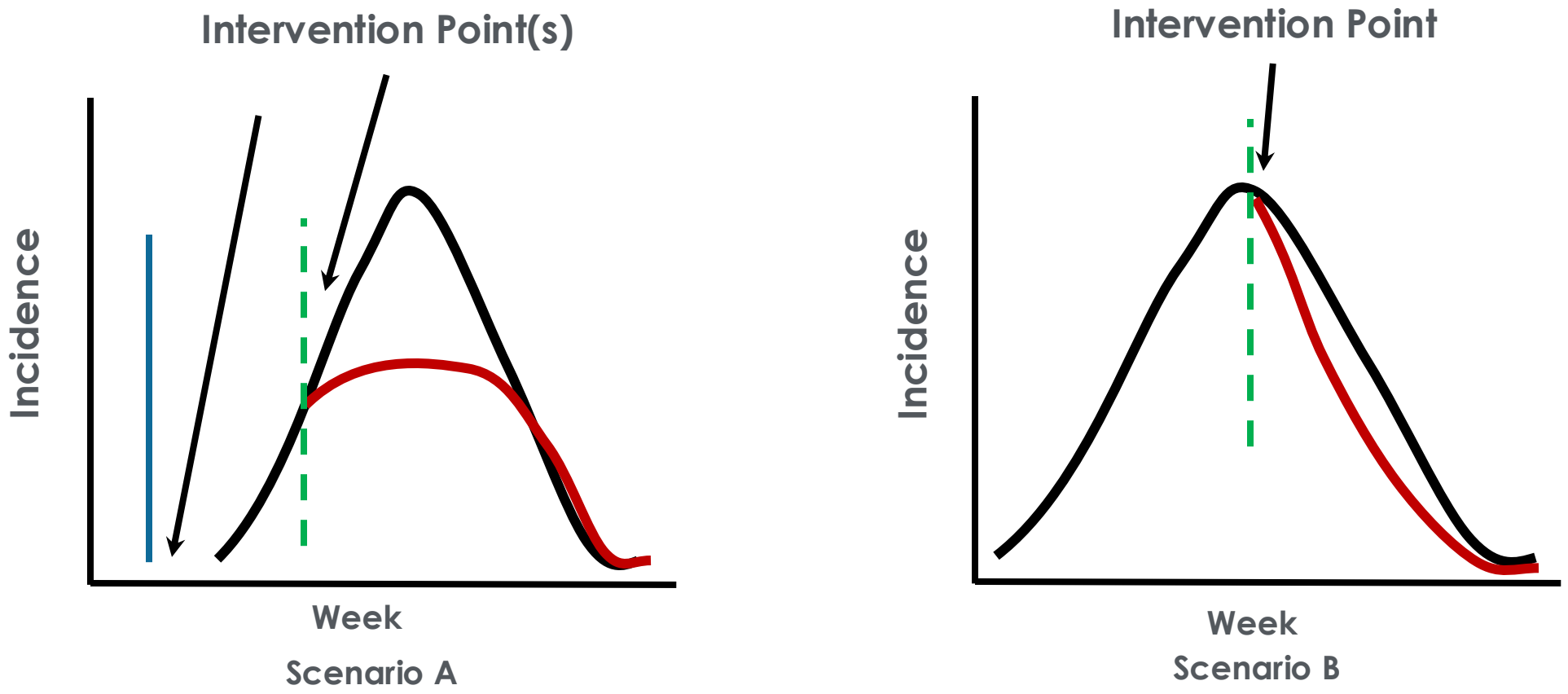
Integration of Microbiological, Field data, Earth Observations

- Real time cholera prediction



The Art of Prediction

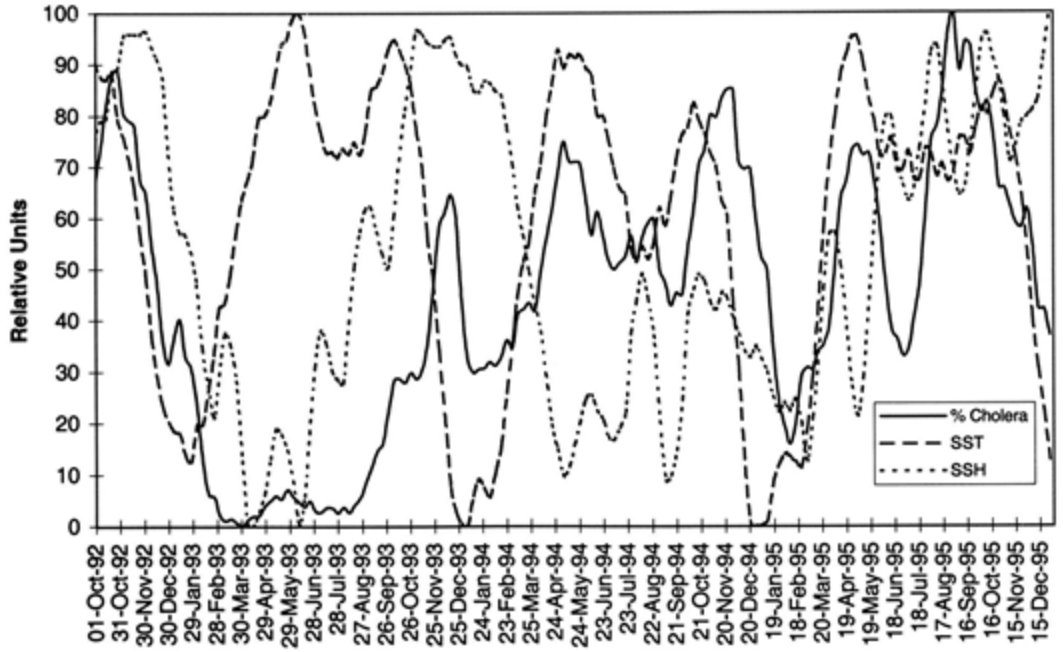
Prediction and Predictability

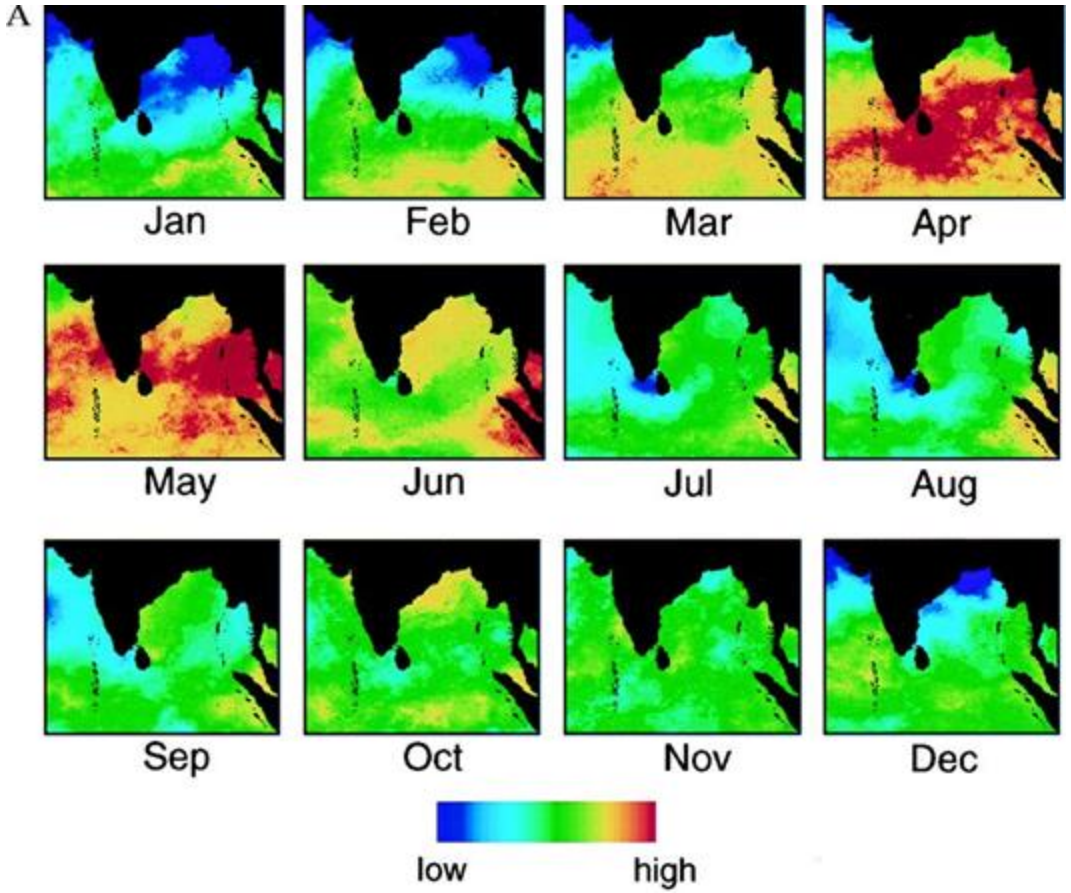


Schematic representation of the disease control measures implemented at the beginning (Scenario A) and after the peak (Scenario B) of an outbreak, and potential cases averted.

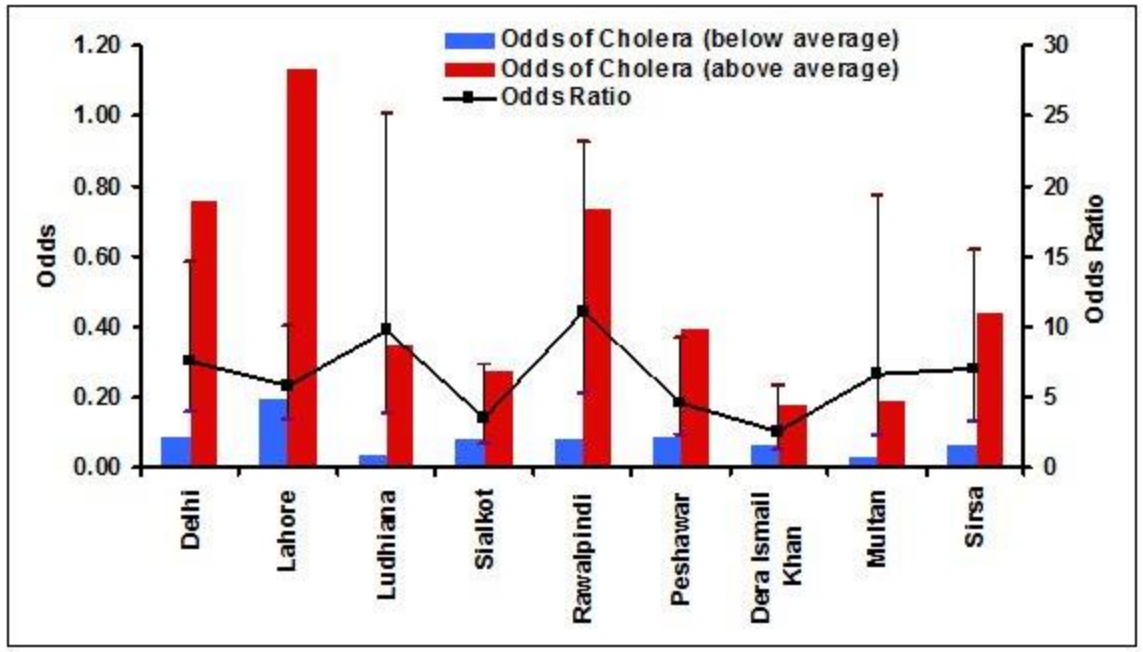
Using Remote Sensing for Cholera

- Lobitz, Brad, et al. "Climate and infectious disease: Use of remote sensing for detection of *Vibrio cholerae* by indirect measurement." *Proceedings of the National Academy of Sciences*, vol. 97, no. 4, 15 Feb. 2000, pp. 1438–1443, https://doi.org/10.1073/pnas.97.4.1438

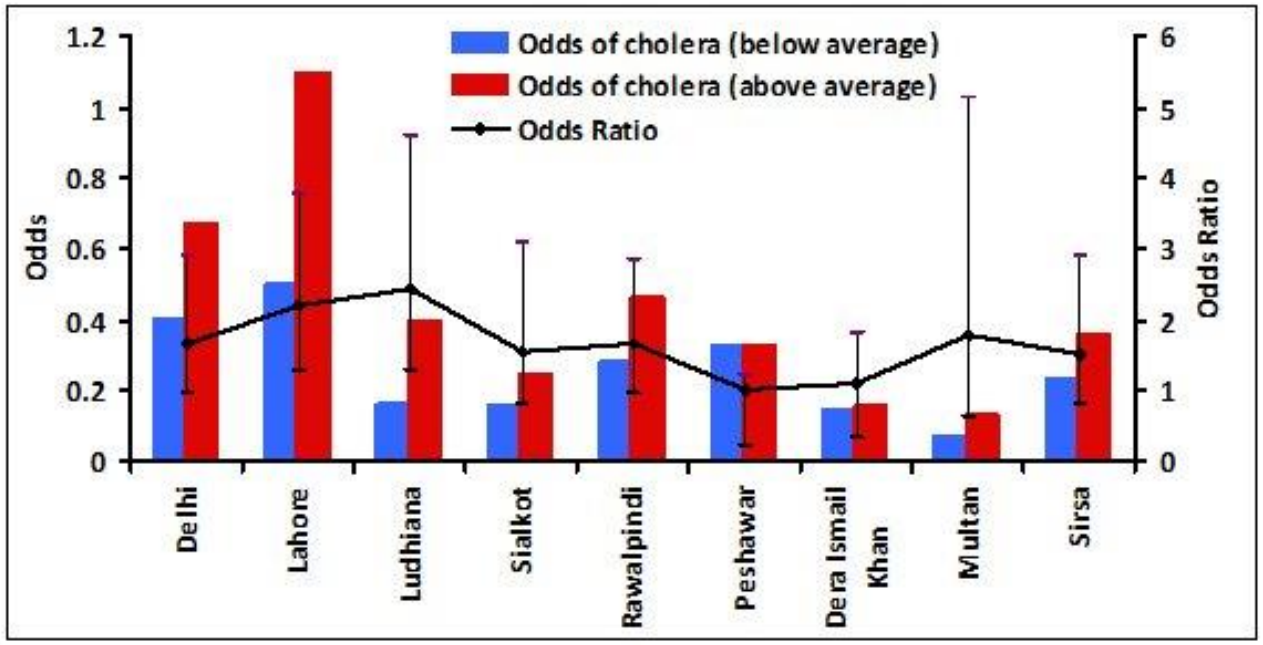




Cholera in the Indus River Basin



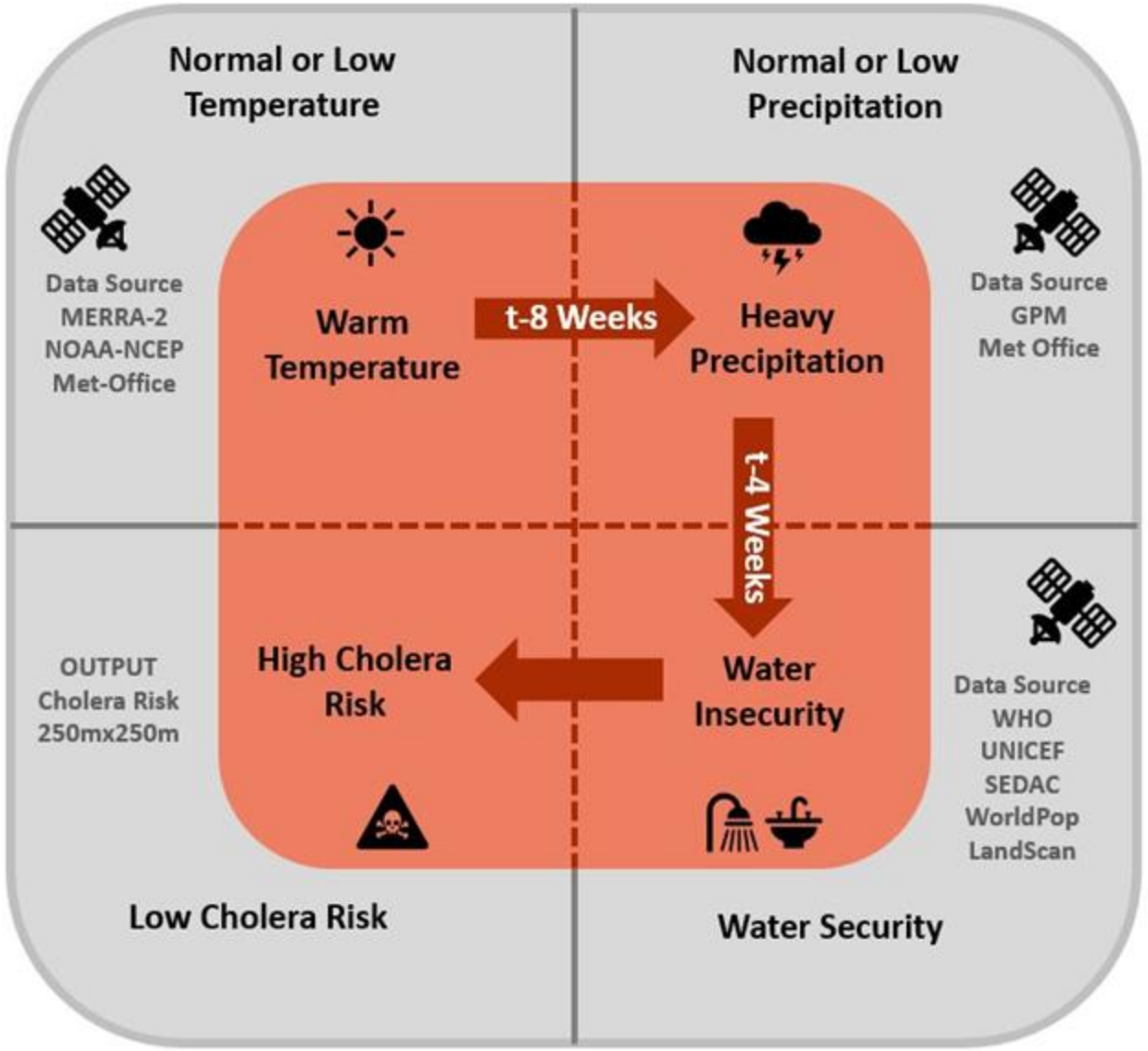
Odds of cholera outbreaks during above average and below average temperature and corresponding odds ratio.



Odds of cholera outbreaks during above average and below average rainfall and corresponding odds ratio.

Jutla, A.S., Whitcombe, E, Hasan, H., Haley, B., Akanda, A., Huq, A., Alam, M., Sack, B., Colwell, R. 2013. Environmental factors influencing epidemic cholera. American Journal of Tropical Medicine and Hygiene, 89(3):597-607.

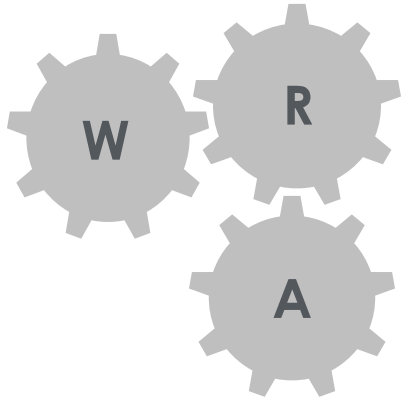
Environment Sensitive Cholera Hypothesis



Pathogen Module
Growth Curves

Population Module
Density
Displacement
Income*
Age*

UF Weighted Raster Algorithm (UFWRA)

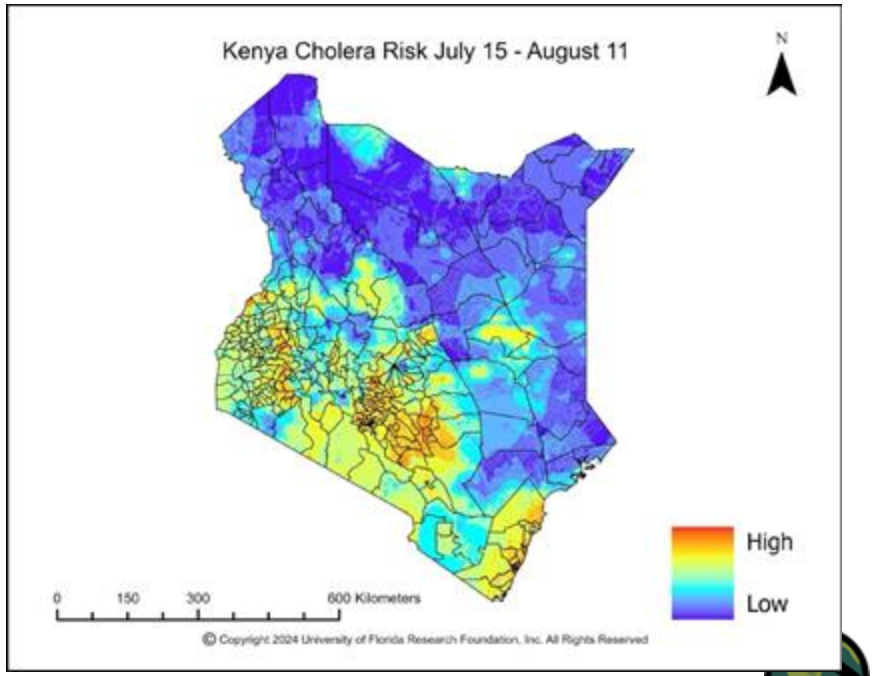


Environmental Module
Air Temperature
Precipitation

Interaction Module
Natural Disasters
Anthropogenic Disasters
Civil Status

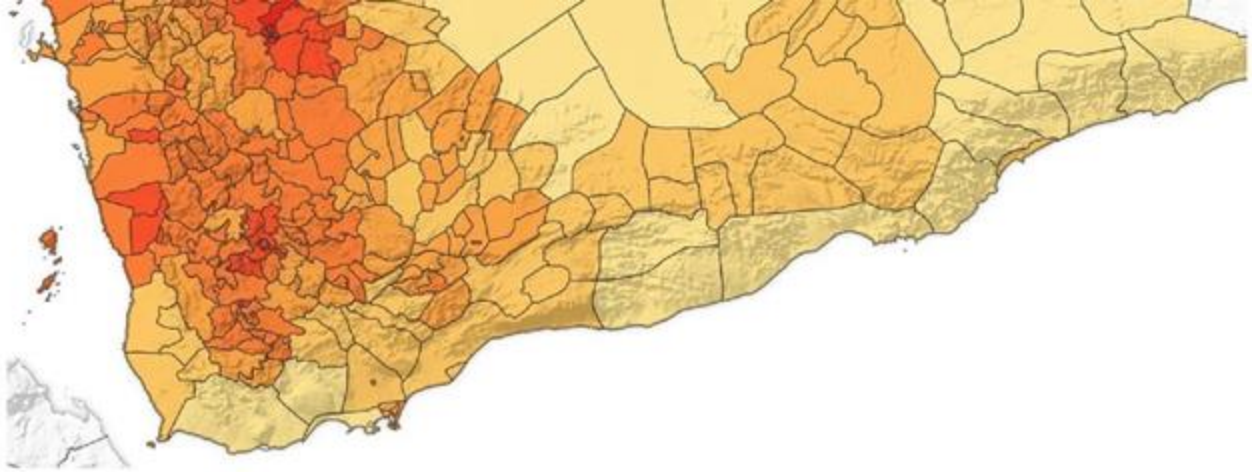
WASH Module
Drinking Water
Sanitation

Cholera Risk Map



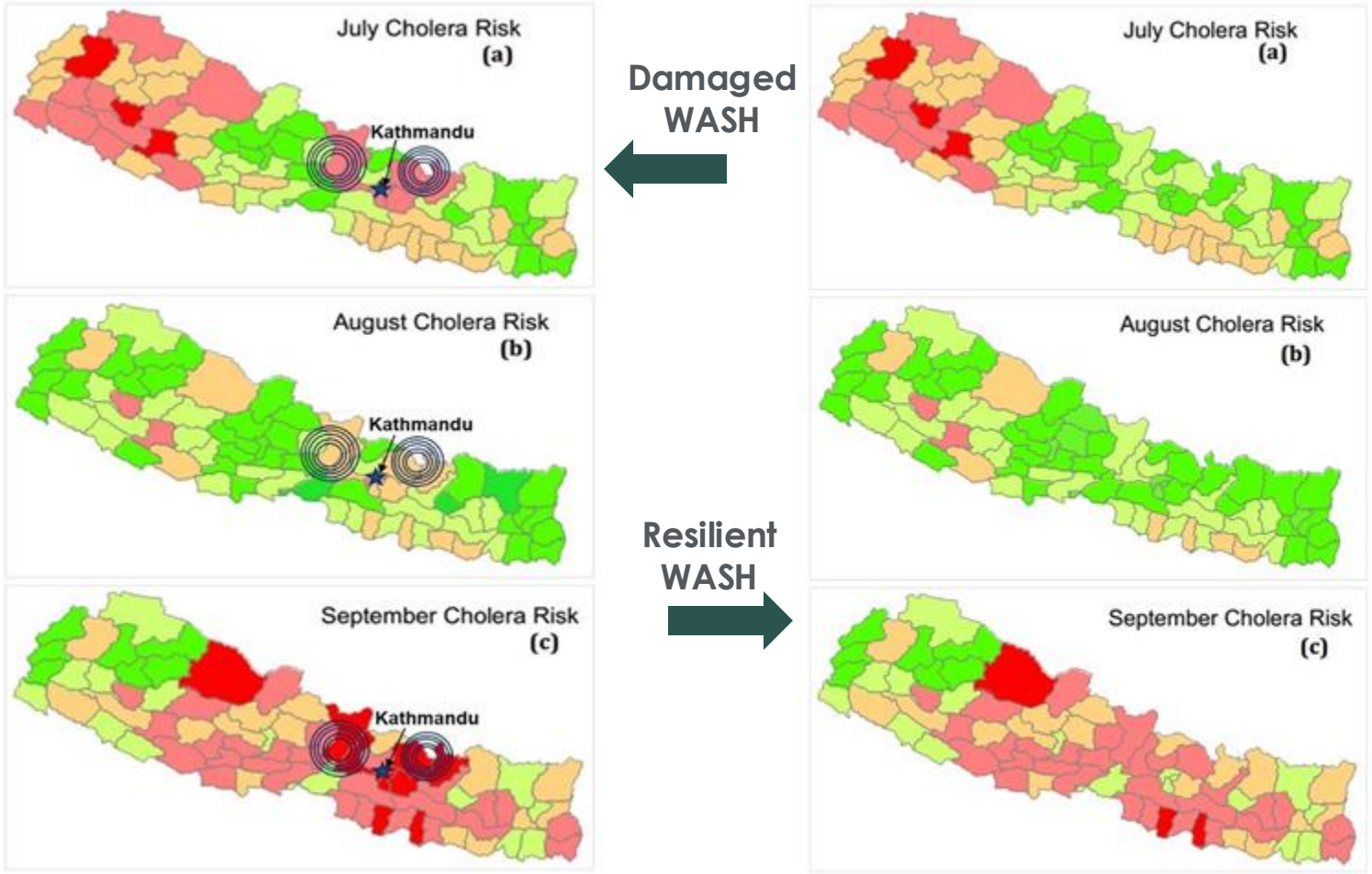
Remote Sensing Data Used in *Vibrio cholerae* Model

Variable	Data Product	Spatial Resolution	Temporal Resolution	Availability
Historic Precipitation Data	TRMM	0.25 deg X 0.25 deg	Daily	https://disc.gsfc.nasa.gov/datasets/TRMM_3B42_Daily_7/summary
Recent Precipitation Data	GPM IMERG	0.1 deg X 0.1 deg	Daily	https://disc.gsfc.nasa.gov/datasets/GPM_3IMERGDL_07/summary
Historic and Recent Temperature Data	MERRA-2	0.5 deg X 0.625 deg	Daily	https://disc.gsfc.nasa.gov/datasets/M2SDNXSLV_5.12.4/summary
SPEI Data	ERA5	30 km X 30 km	Monthly	https://www.drought.gov/data-download
Population Data	ORNL LandScan	~1 km X ~1 km	N/A	https://landscan.ornl.gov/



The Cholera Risk Model

Impact of Resilient WASH

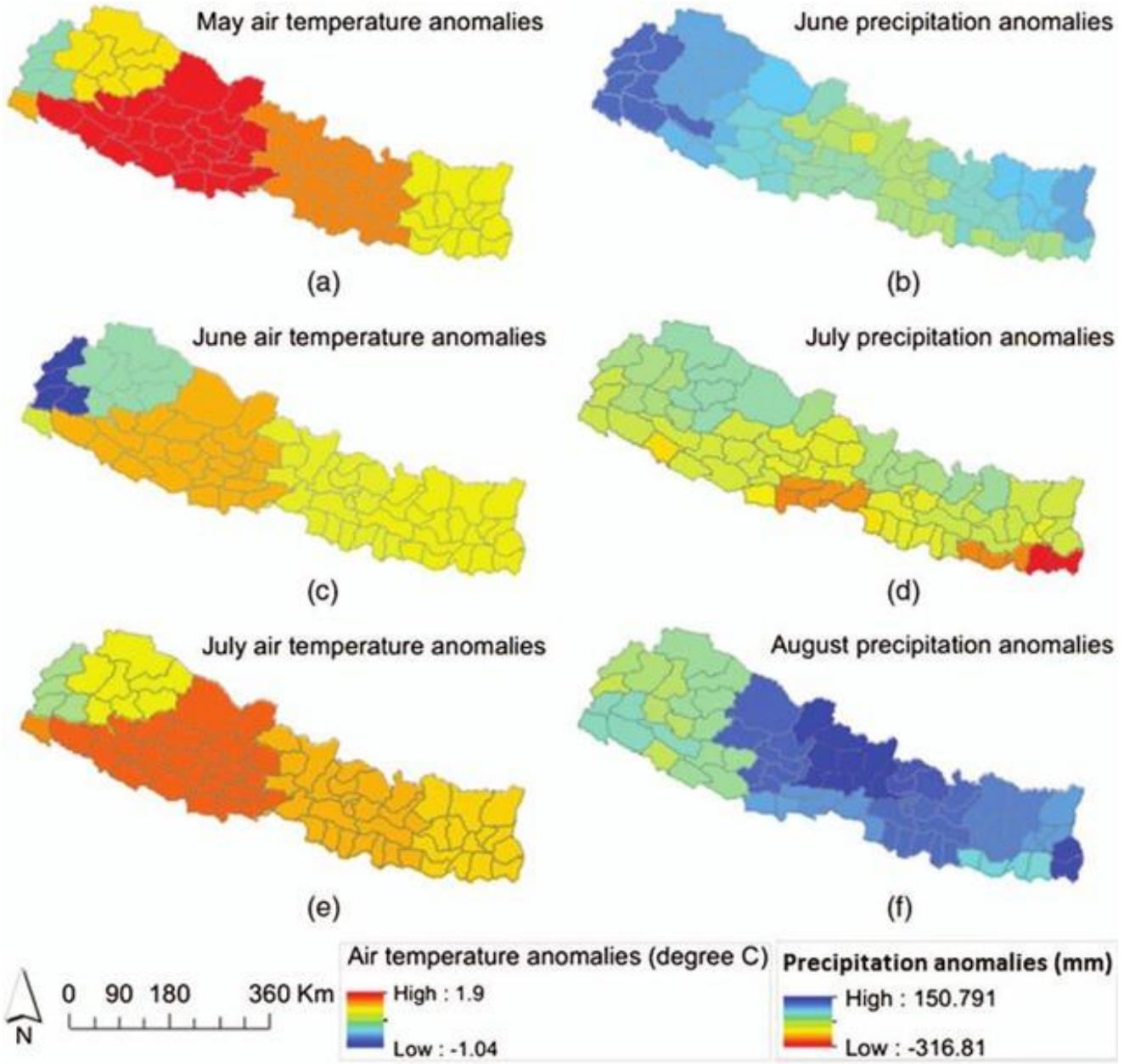


Pathogen analysis results by UIUC confirm that proactive response by the local communities shortly after the earthquake allow the microbial community to return to the pre-earthquake condition.

Uprety et al, 2017 *Earthquake Spectra*; Uprety et al, 2017 *Frontiers in Microbiology; Khan et al, ASCE JWRPM, 2018*

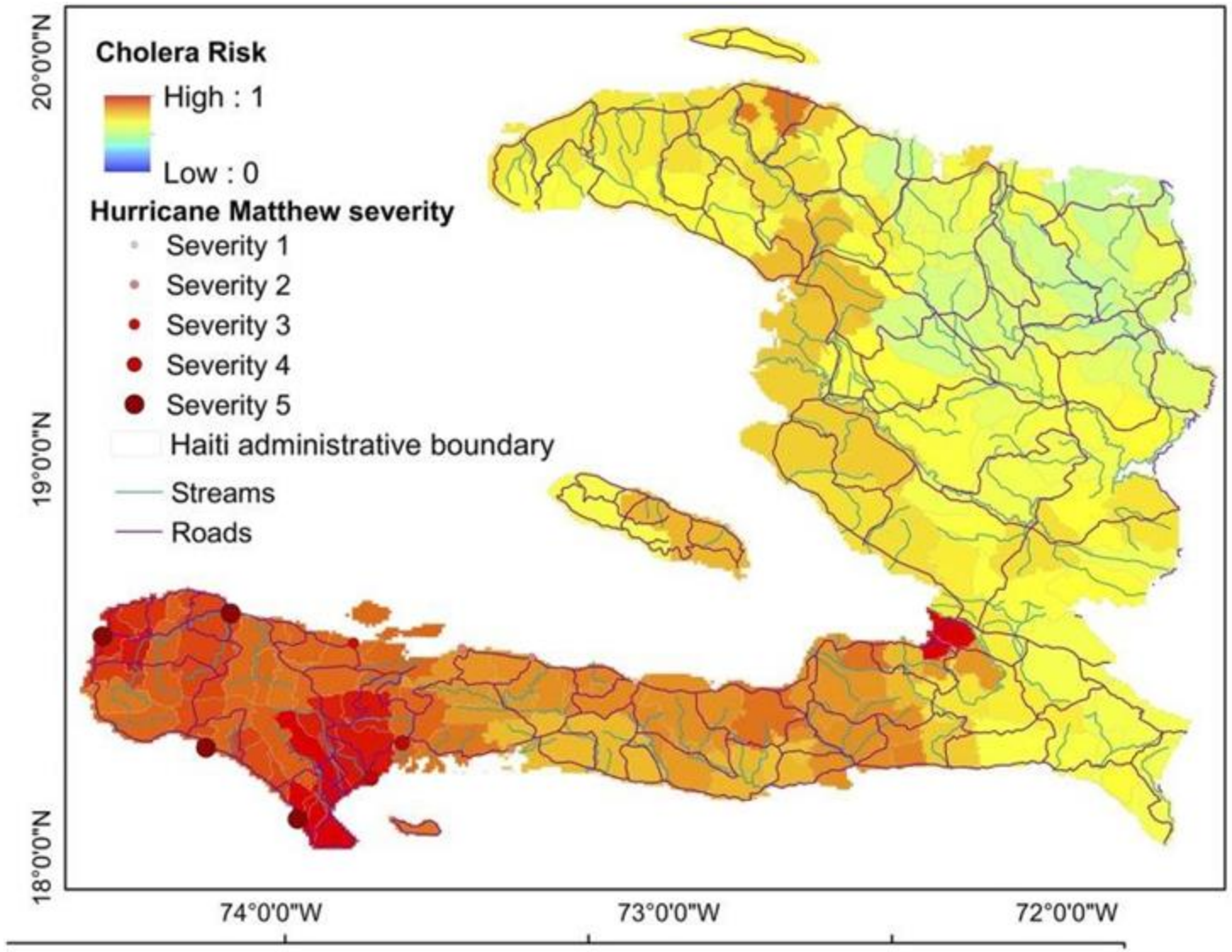
Nepal

- Khan, Rakibul, et al. "Evaluation of risk of cholera after a natural disaster: Lessons learned from the 2015 Nepal earthquake." Journal of Water Resources Planning and Management, vol. 144, no. 8, 31 Aug. 2018, https://doi.org/10.1061/(asce)wr.1943-5452.0000929.



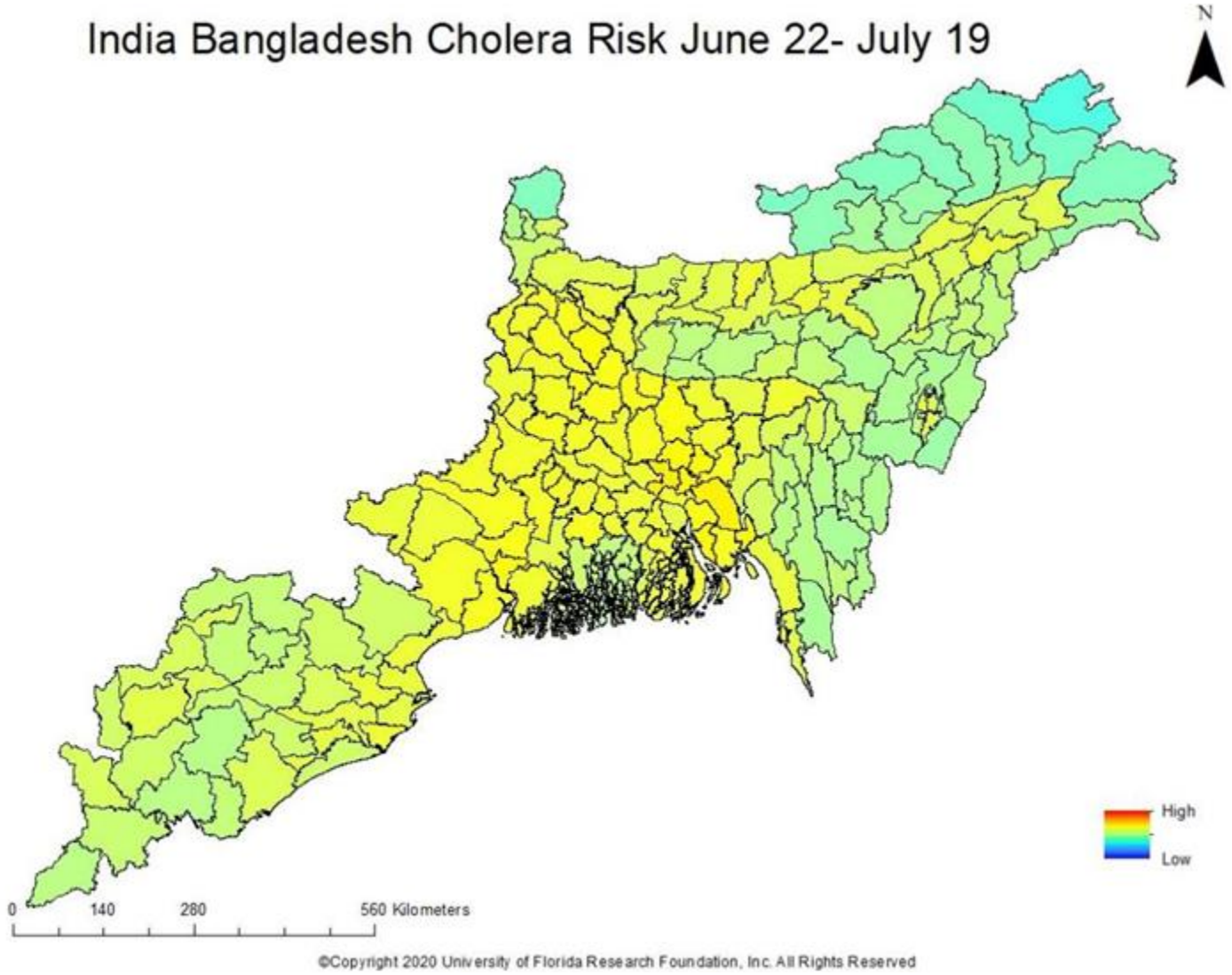
Haiti

- Khan, Rakib, Anwar Huq, et al. "Assessment of risk of cholera in Haiti following Hurricane Matthew." The American Journal of Tropical Medicine and Hygiene, vol. 97, no. 3, 7 Sept. 2017, pp. 896–903, https://doi.org/10.4269/ajtmh.17-0048.



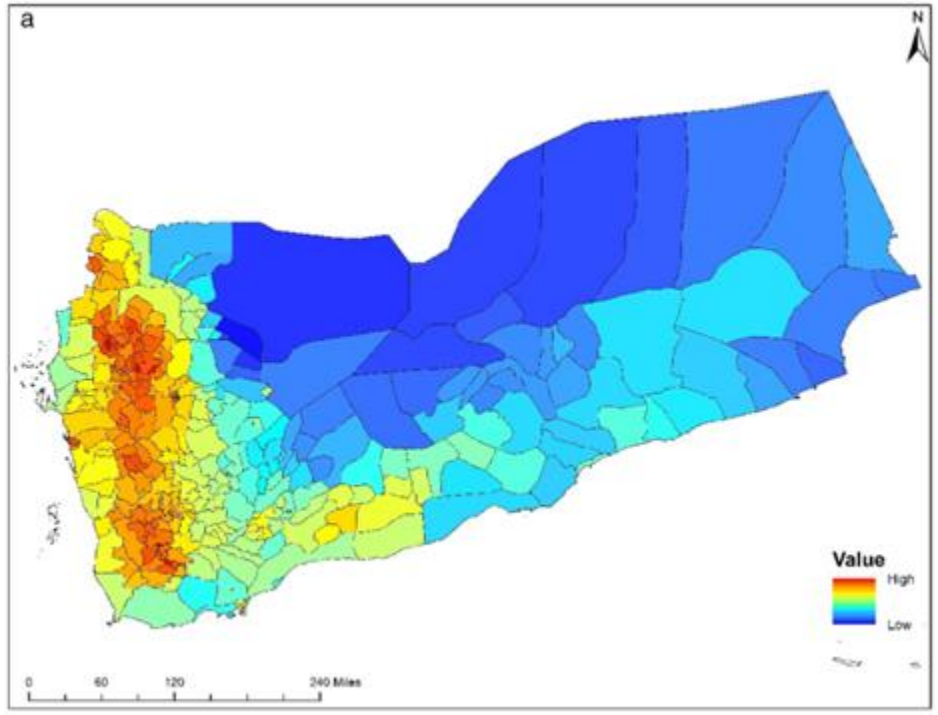
More Rain ≠ More Cholera

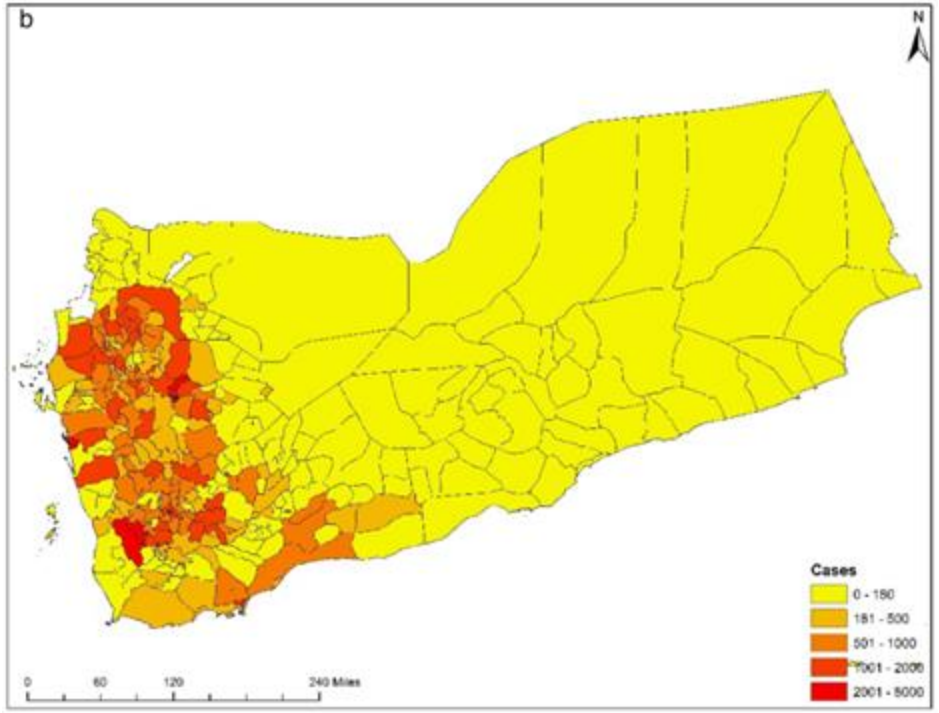
- Week 1: May 25-June 21 **Low**
- Week 2: June 1- June 28 **Low**
- Week 3: June 8- July 5 **Low**
- Week 4: June 15- July 12 **Low**
- Week 5: June 22- July 19 **Low**



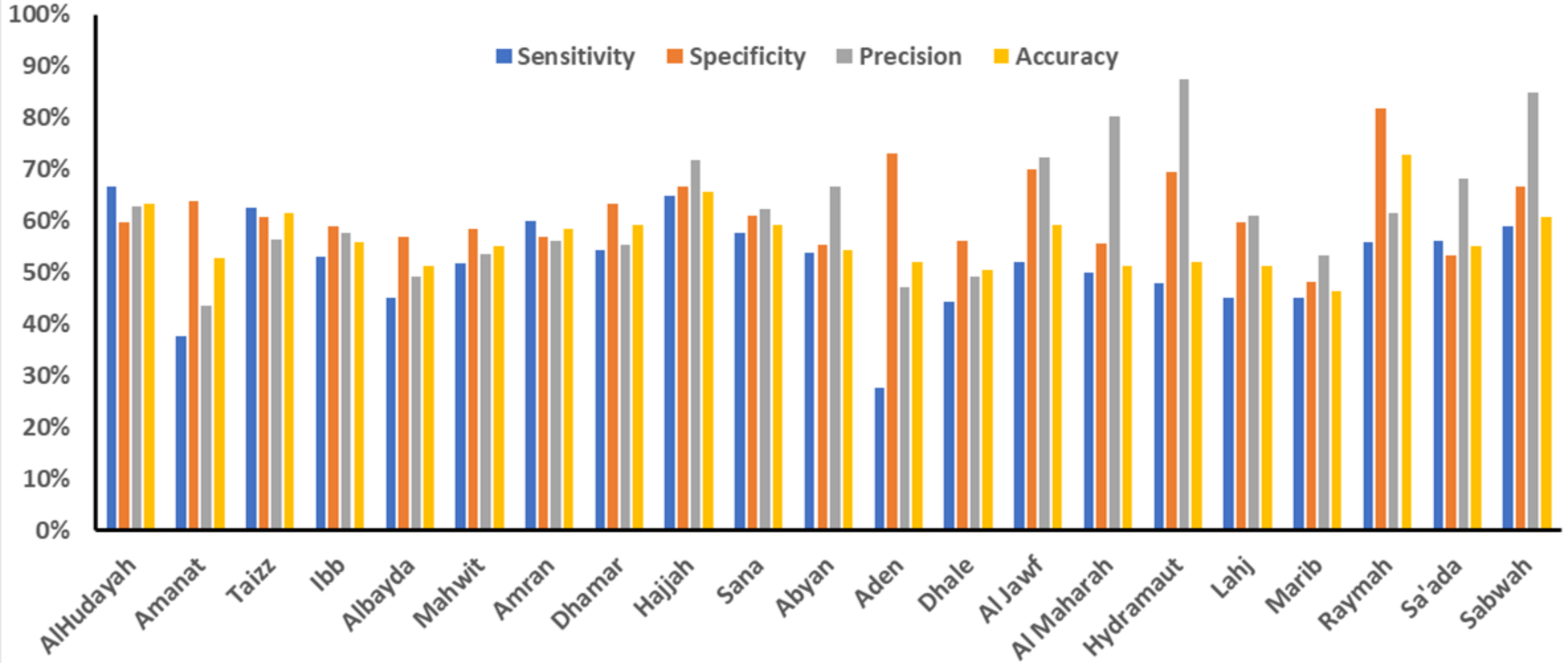
Yemen

- Usmani, Moiz, et al. "Combating Cholera by Building Predictive Capabilities for Pathogenic Vibrio Cholerae in Yemen." Scientific Reports, vol. 13, no. 1, 8 Feb. 2023, https://doi.org/10.1038/s41598-022-22946-y.





Model Validation



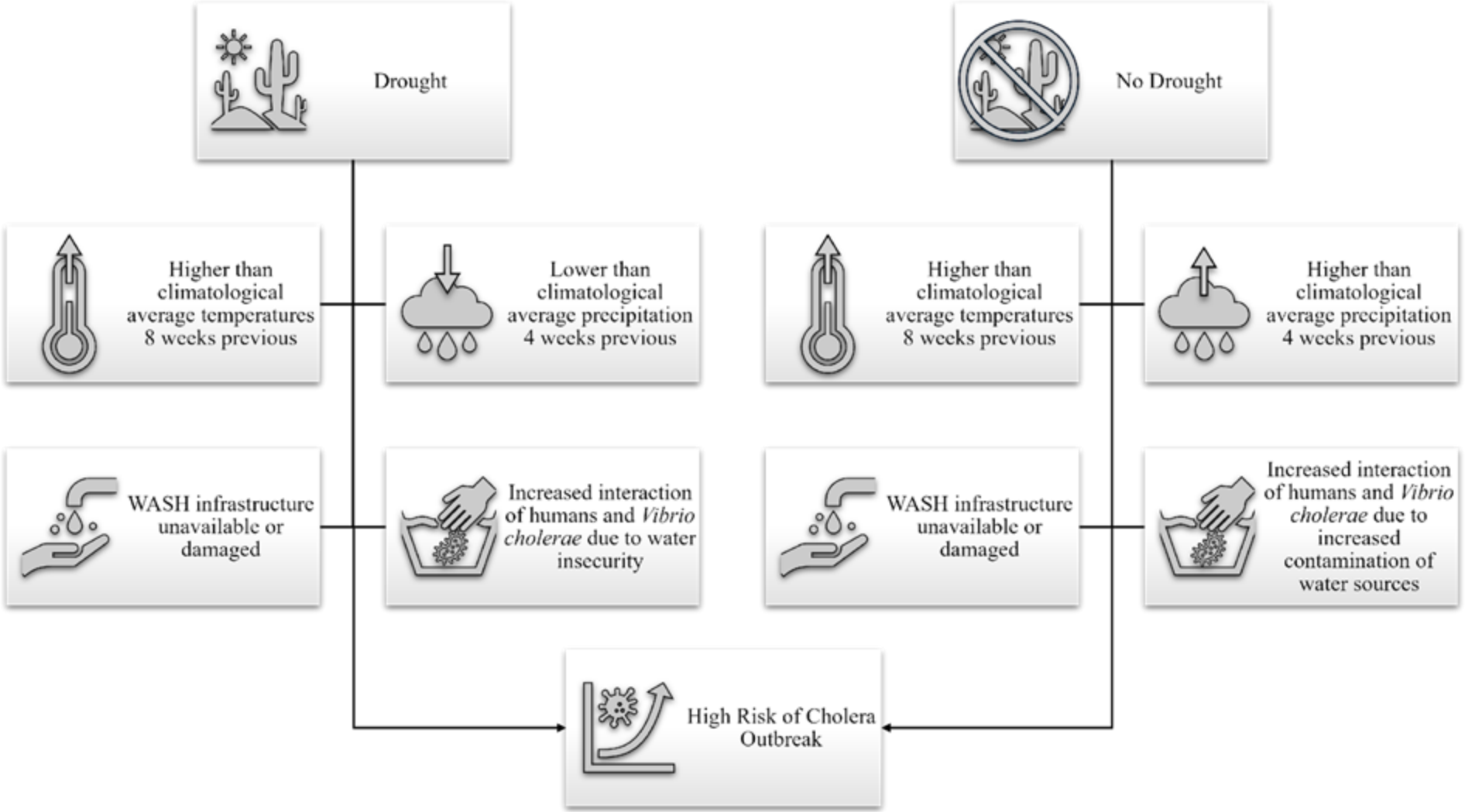
Drought Impacting Vibrio

We observed a few regional anomalies with our hypothesis.

In 2022, an outbreak occurred in Ethiopia that did not fall under the conditions of our previous hypothesis or model.

Upon investigation, the region was experiencing a drought at the time of outbreak.

Modified Hypothesis for Extreme Events

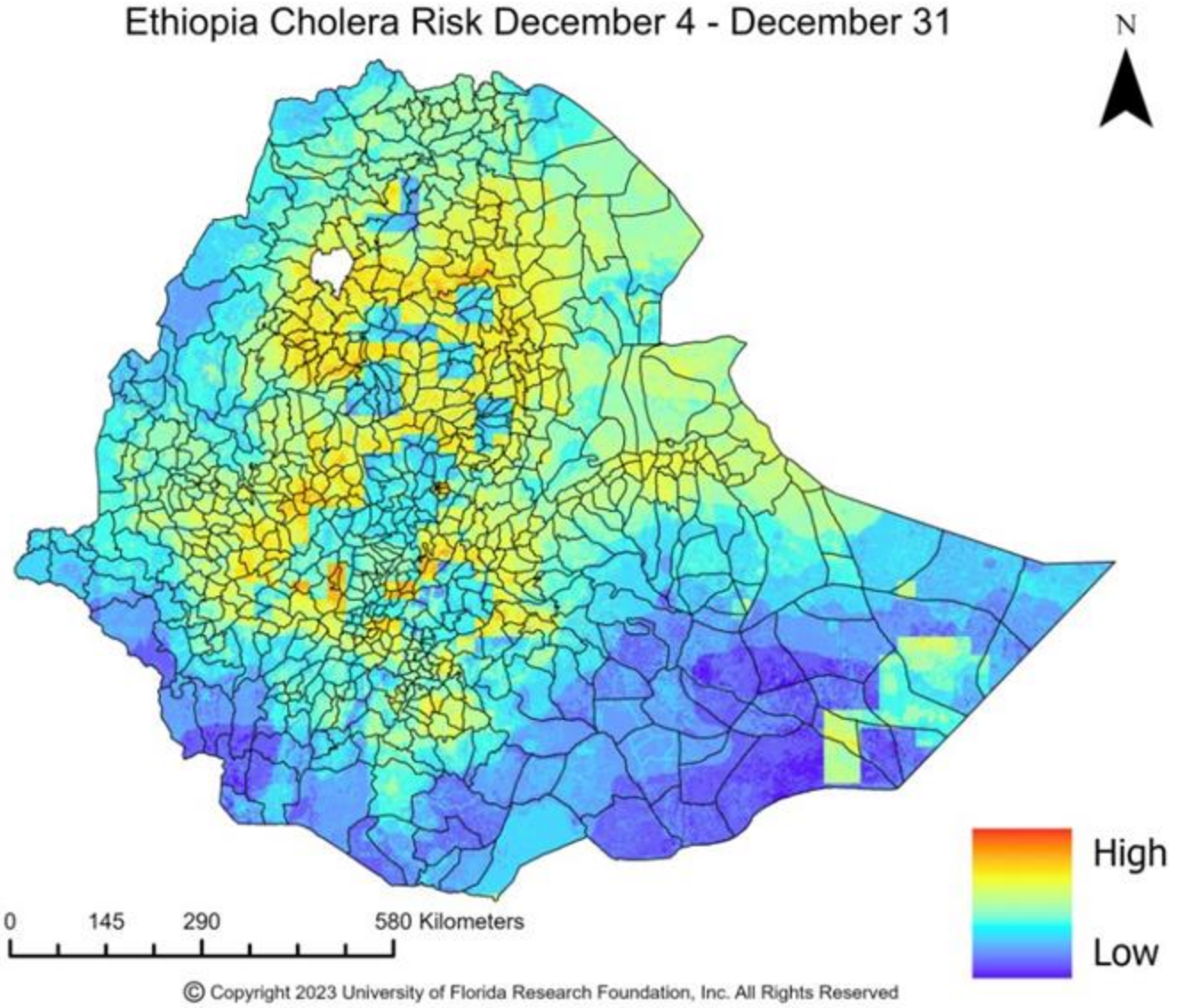


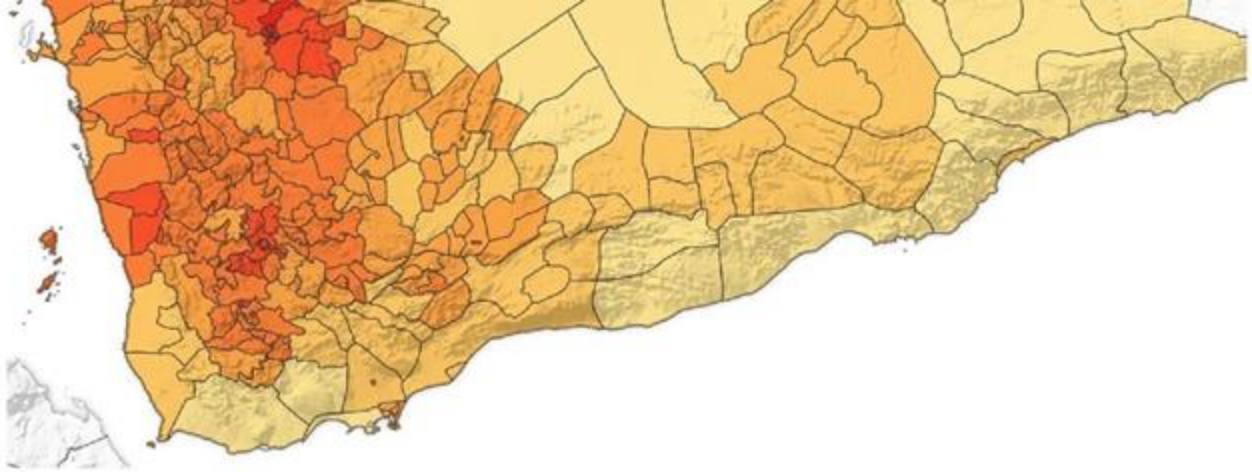
Odds of Cholera Increase During a Drought

- Cholera Outbreaks are **3 times** more likely during a drought.
- When combined with our previous hypothesis, we found that the odds of a cholera outbreak are **3.5 times** more likely during extreme climate events.

Updated Cholera Model

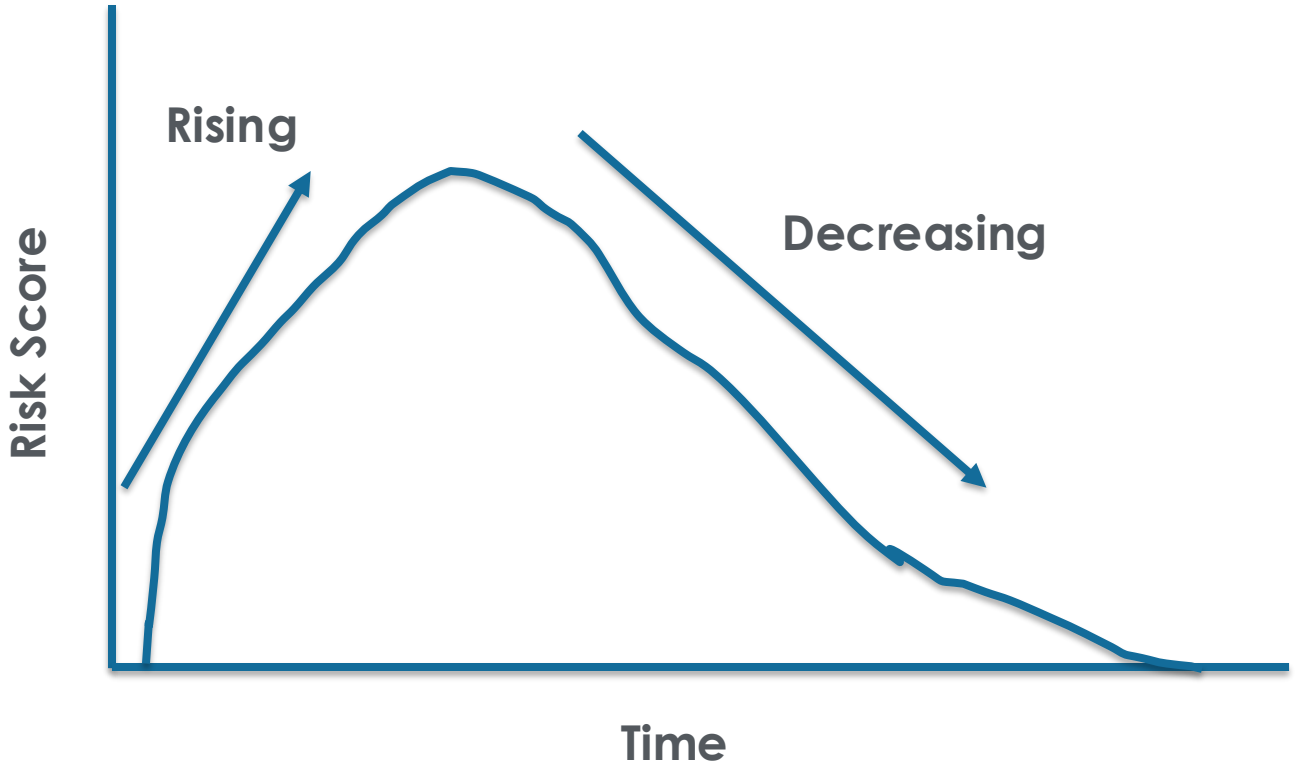
Two Scenarios: Drought or Excess Rainfall





Interpreting and Understanding Cholera Risk

Threat Level = Risk Score + Rising/Decreasing Value



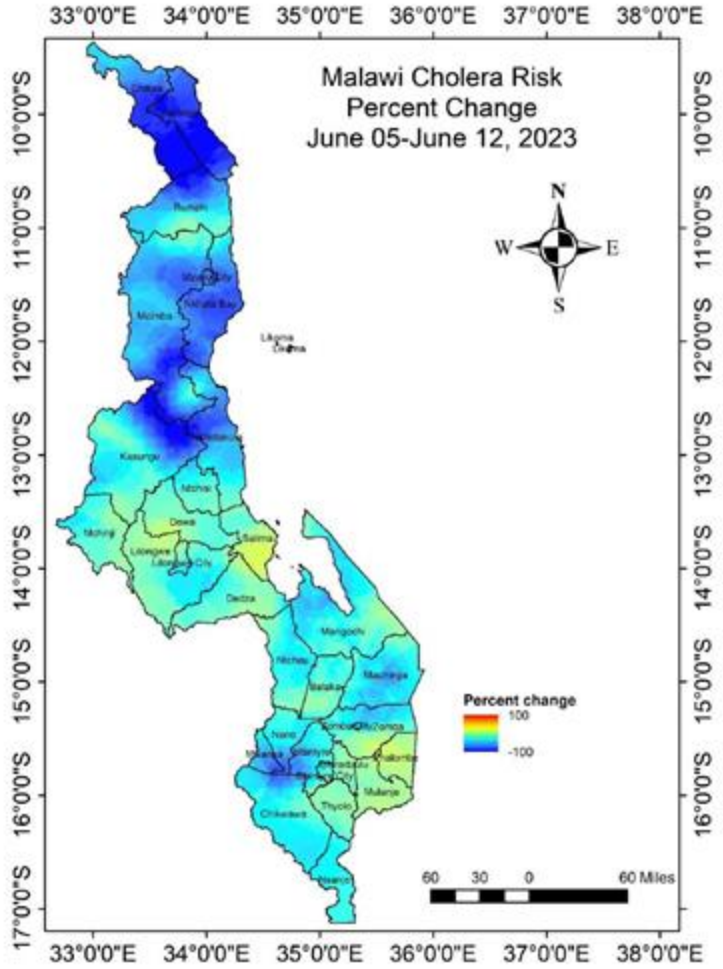


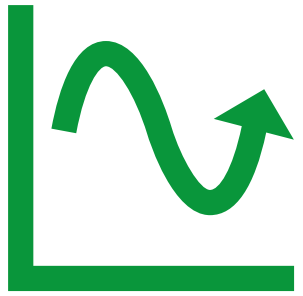
Figure 3: Changes in the risk scores from previous week (in percentage)

What is Risk?

Values are on a Scale of 0 to 1	0.3 > Risk = **Low** 0.5 > Risk > 0.3 = **Medium** Risk > 0.5 = **High**
High Risk	High chance of populations with insufficient or damaged WASH infrastructure interacting with water contaminated with *V. cholerae* Region will have cases of cholera greater than the spatial average of all cases
Medium Risk	Chance of populations with insufficient or damaged WASH infrastructure interacting with water contaminated with *V. cholerae*, but not likely Will need to monitor the region for the next 4 weeks It implies that the region is one standard deviation below the spatial average of cholera cases
Low Risk	No or very low risk of cases of cholera

Interpretation Disclaimers

Risk cannot be converted to number of cholera cases.



Model results are generally valid for the next 4 weeks, but week-to-week variation should be taken with caution.

Cholera Situation Awareness Reports

- Generated for a Particular Region – On request currently
  - New Regions: 10 days turnaround time
  - Existing Regions: 3-5 days turnaround time
- Report produced every Monday/Tuesday

- Users can send comments, feedback, or requests using email: **cholerapredict ion_users@lists.ufl.edu**

SITUATION AWARENESS REPORT

Disease: Cholera

Country: Malawi

FORECAST VALIDITY PERIOD: June 12 – July 09, 2023
LEVEL OF THREAT: Low decreasing*
WHAT TO DO: Activity 2*
*Please see Appendix D for details

The Cholera Prediction System Consortia

at

GEOHEALTH & HYDROLOGY LABORATORY
GeoHLab @ University of Florida

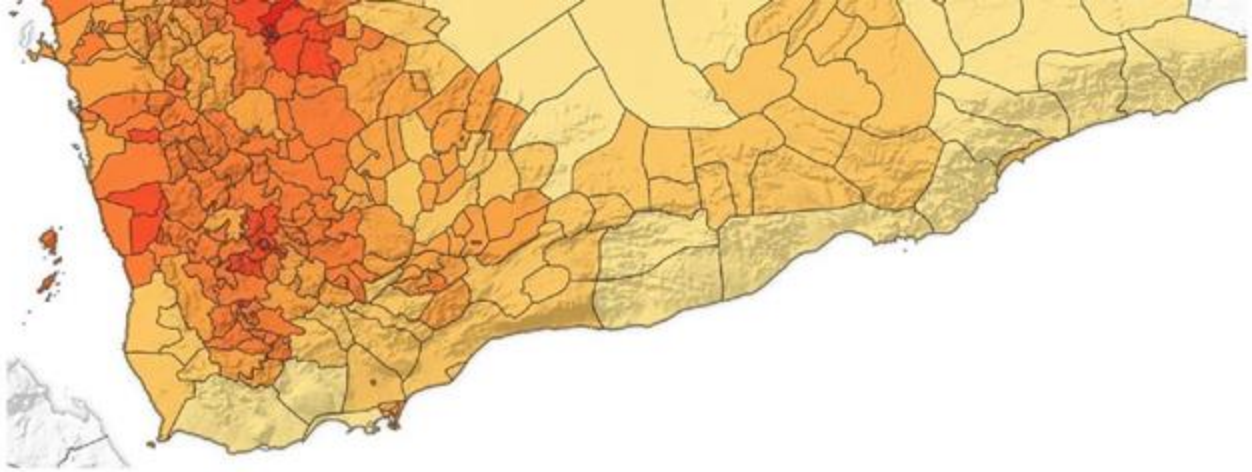
UF UNIVERSITY of FLORIDA

UNIVERSITY OF MARYLAND

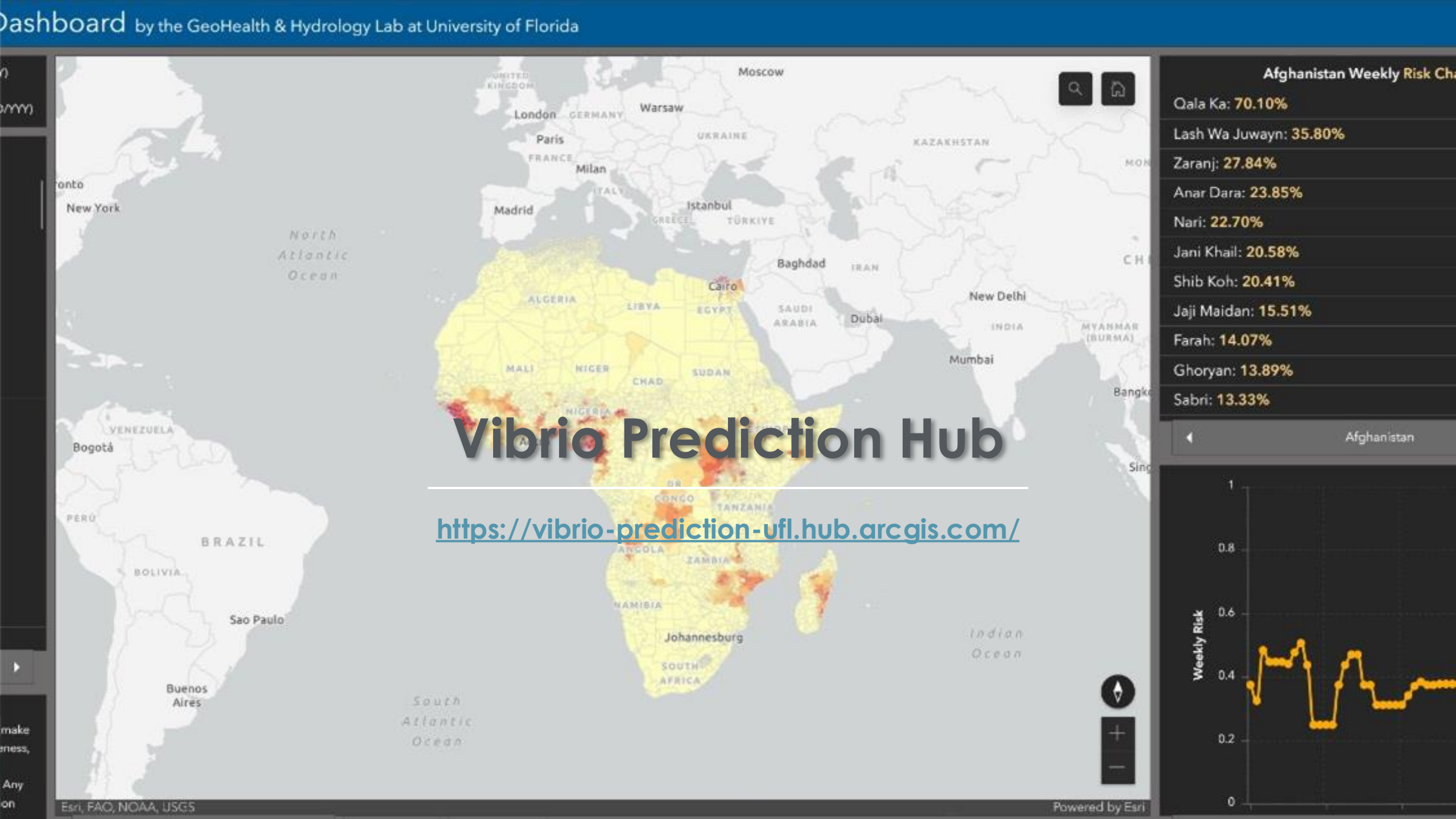
THE UNIVERSITY OF RHODE ISLAND

What actions should be taken for each level of risk?

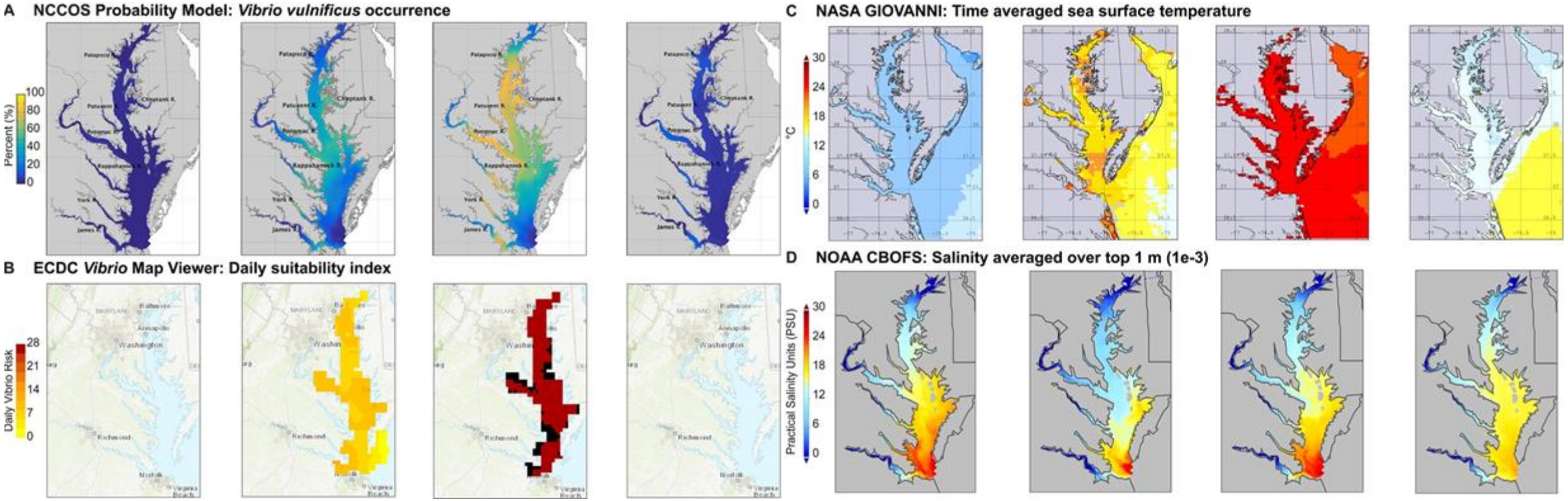
What to Do	Details	Interpretation
Activity 1: High Risk	Improve access to WASH Water samples should be collected and tested for cholera bacteria (if possible) Medical intervention	Immediate need to provide WASH and education for high-risk communities. At this point, if possible, collect water samples to identify hot spots of the presence of cholera bacteria. Medical intervention, with access to doctors and hospitals prioritized.
Activity 2: Medium Risk	Stable WASH Recommend collection of water samples for cholera bacteria Prepare for medical intervention	Provide WASH and education, given the risk exists, but not at an alarming level. At population centers, microbiological analysis of water samples should begin. Medicines should be stockpiled for a possible outbreak.
Activity 3: Low Risk	Sustain WASH	Low cholera risk and an opportunity to develop policies for sustaining WASH and education for the community.



Lessons Learned and Future Applications in Eastern USA


Dashboard by the GeoHealth & Hydrology Lab at University of Florida
Moscow
London
Warsaw
Paris
Milan
Madrid
Istanbul
New York
Baghdad
Cairo
New Delhi
Dubai
Mumbai
Bogotá
Sao Paulo
Buenos Aires
Johannesburg
Vibrio Prediction Hub
https://vibrio-prediction-ufl.hub.arcgis.com/
Afghanistan Weekly Risk Ch
Qala Ka: 70.10%
Lash Wa Juwayn: 35.80%
Zaranj: 27.84%
Anar Dara: 23.85%
Nari: 22.70%
Jani Khail: 20.58%
Shib Koh: 20.41%
Jaji Maidan: 15.51%
Farah: 14.07%
Ghoryan: 13.89%
Sabri: 13.33%
Afghanistan
Weekly Risk
1
0.8
0.6
0.4
0.2
0
Esri, FAO, NOAA, USGS
Powered by Esri

Current Vibrio Models

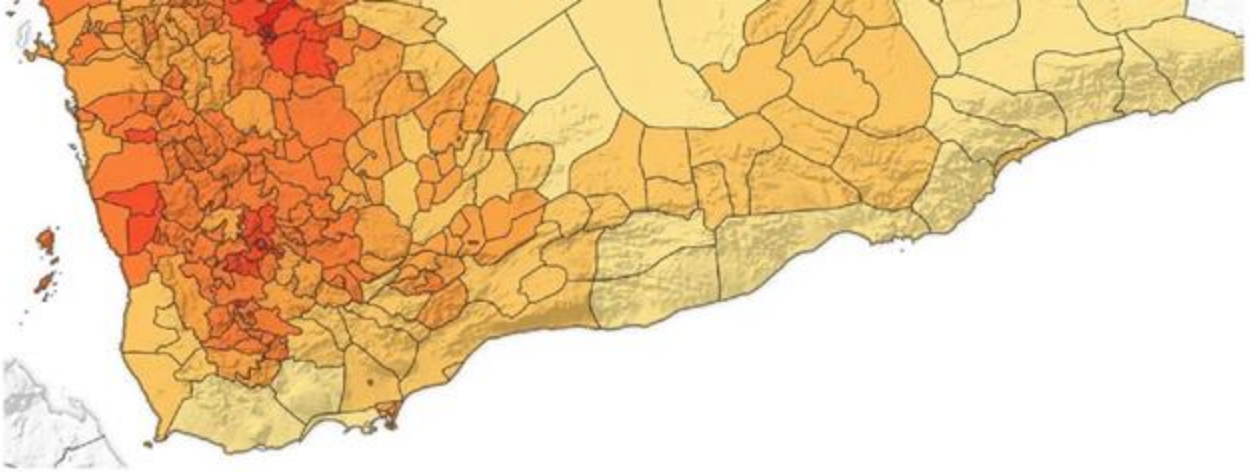


Future Models and Prediction – Using PACE and Future Data Products

Salinity

Sea Surface Temperature

Phytoplankton



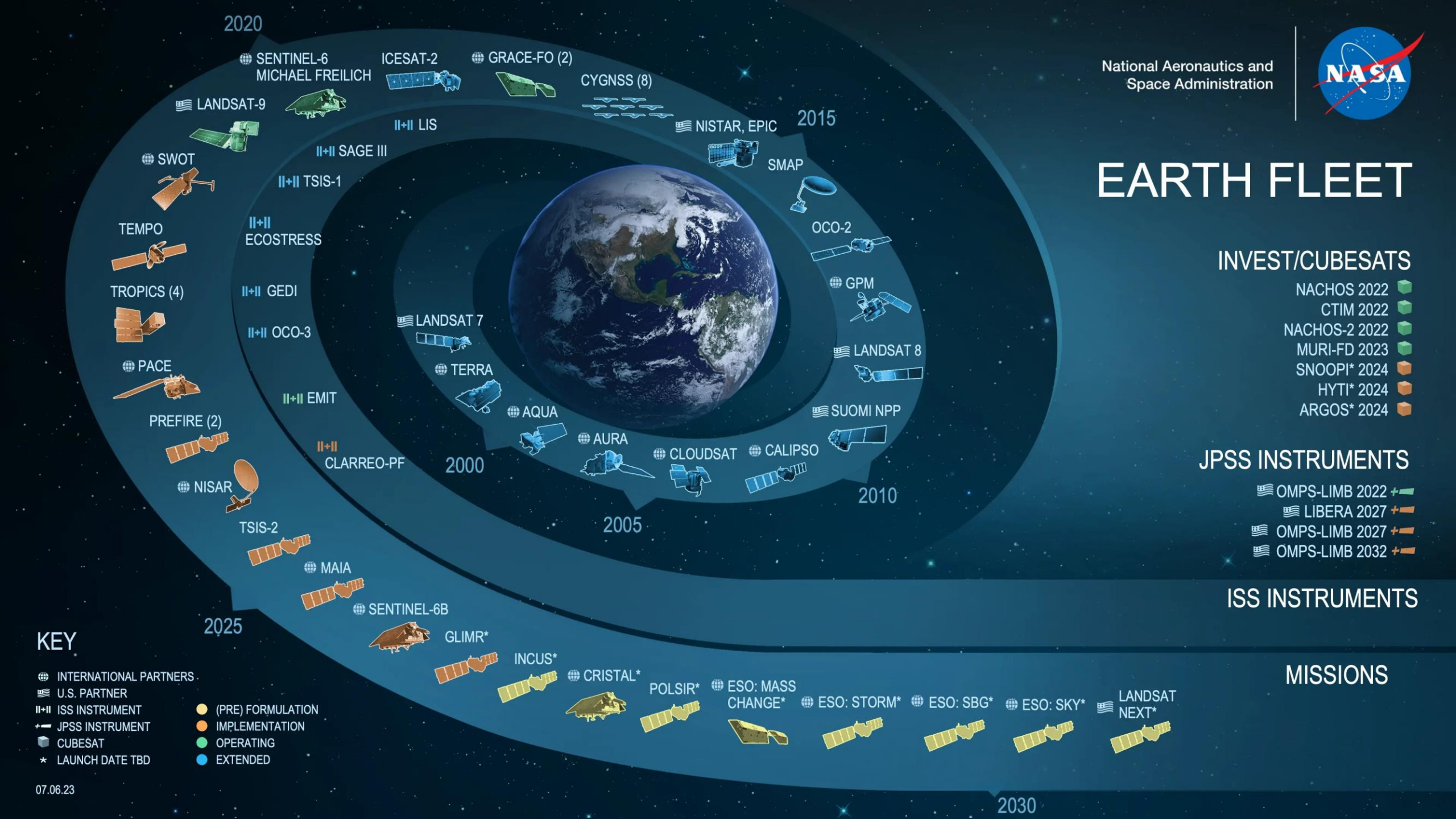
Part 2

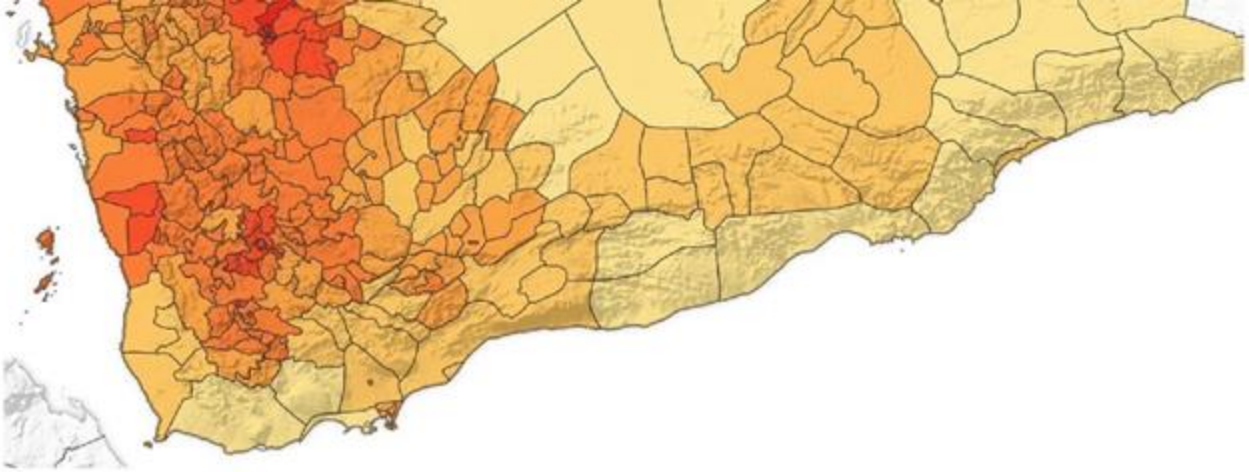
Summary

Summary

Vibrio Prediction

New technologies and decades of research have allowed for real-time monitoring of environmental parameters associated with *Vibrio spp.*	Lessons from our cholera model and mitigation projects have helped us prepare for prediction of *Vibrio spp.* in the US.	Vibiriosis and enteric pathogens are a threat to human health, and earth observation satellites provide an opportunity for interventions


National Aeronautics and Space Administration
NASA
EARTH FLEET
2020
SENTINEL-6 MICHAEL FREILICH
ICESAT-2
GRACE-FO (2)
CYGNSS (8)
LANDSAT-9
LIS
NISTAR, EPIC
2015
SAGE III
SWOT
TSIS-1
SMAP
TEMPO
ECOSTRESS
OCO-2
TROPICS (4)
GEDI
GPM
LANDSAT 7
OCO-3
LANDSAT 8
PACE
TERRA
EMIT
SUOMI NPP
PREFIRE (2)
AQUA
AURA
CLOUDSAT
CALIPSO
CLARREO-PF
2000
2010
NISAR
2005
TSIS-2
MAIA
SENTINEL-6B
2025
GLIMR*
INCUS*
CRISTAL*
POLSIR*
ESO: MASS CHANGE*
ESO: STORM*
ESO: SBG*
ESO: SKY*
LANDSAT NEXT*
2030
INVEST/CUBESATS
NACHOS 2022
CTIM 2022
NACHOS-2 2022
MURI-FD 2023
SNOOPI* 2024
HYTI* 2024
ARGOS* 2024
JPSS INSTRUMENTS
OMPS-LIMB 2022
LIBERA 2027
OMPS-LIMB 2027
OMPS-LIMB 2032
ISS INSTRUMENTS
MISSIONS
KEY
INTERNATIONAL PARTNERS
U.S. PARTNER
ISS INSTRUMENT
JPSS INSTRUMENT
CUBESAT
LAUNCH DATE TBD
(PRE) FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED
07.06.23



The Application of Earth Observations for Assessing Waterborne Disease Risk

Summary

Reviewed Common Waterborne Diseases

- **Diarrhea:** Caused by viral or bacterial infections from water & food. Can also result from food allergies.
  - Dehydration resulting from diarrhea can be life threatening, particularly to young children.
- **Typhoid:** Caused by *Salmonella* bacteria in water and food. Highly contagious.
  - Regular outbreaks in Southeast Asia and Africa.
- **Cholera:** Caused by *Vibrio cholerae* bacteria from contaminated water and poor sanitation.
  - Deadly if not treated immediately. Most prevalent in Southeast Asia, Africa, Haiti.
- ***Escherichia coli (E. coli)*:** Caused by bacterial infection.
- **Giardia:** Caused by parasites infecting intestine. Found in waters worldwide.
- **Hepatitis A:** Caused by Hepatitis A virus. It is a highly contagious liver infection.
- **Polio:** Caused by a virus that mainly affects the nerves in the spinal cord or brain stem.
  - High-risk areas are Africa, the Middle East, and Southern and Central Asia.

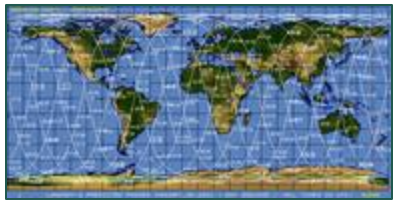
https://www.mayoclinic.org/diseases-conditions/

Identified Environmental Parameters Relevant for Inferring the Presence of Waterborne Pathogens

- These factors affect survival, growth, and spread of pathogens (water-related illnesses):
  - **Water Temperature**
  - **Precipitation/Flooding**
  - Nutrients and Chemicals from **Agricultural and Industrial Runoff (Landcover, Soil Moisture)**
  - **Chlorophyll/Harmful Algal Blooms**
  - **Dissolved Organic Matter**
  - **Salinity**
  - **Solar Radiation**

Introduced Satellite Missions and Earth System Models Relevant for Disease Risk Prediction Models

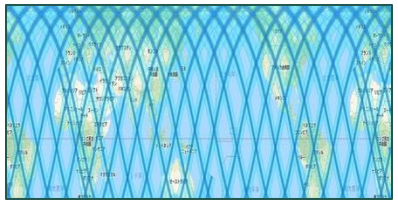
Landsat 8 & 9



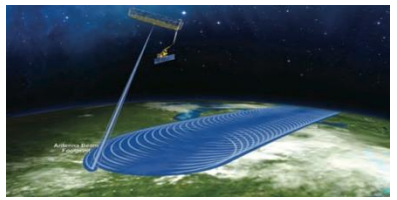
Aqua & Terra

SNPP, JPSS 1 & 2

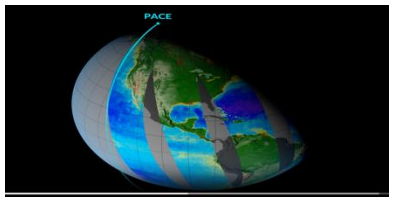
GPM



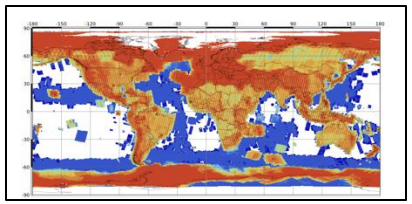
SMAP



PACE

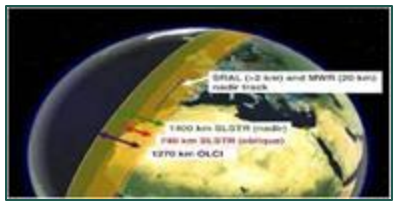


Sentinel-1

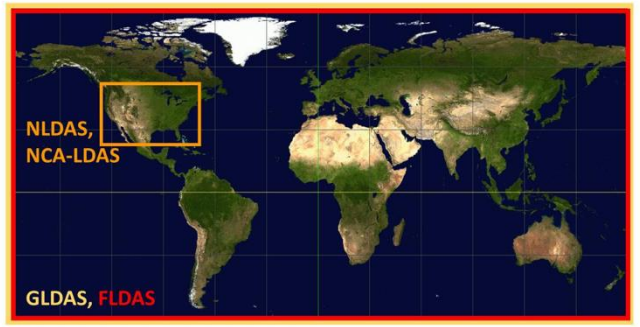


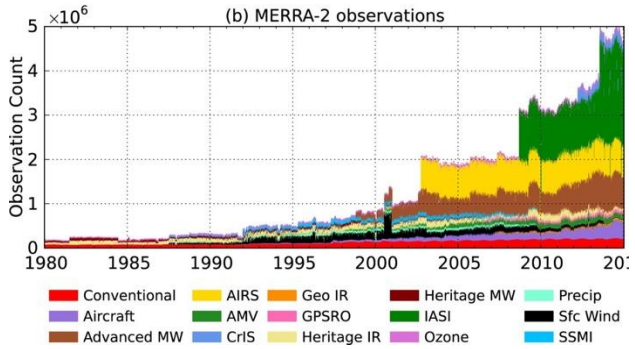
Sentinel-2

Senitnel-3 OLCI



Global and Regional
Land Data Assimilation System (LDAS)

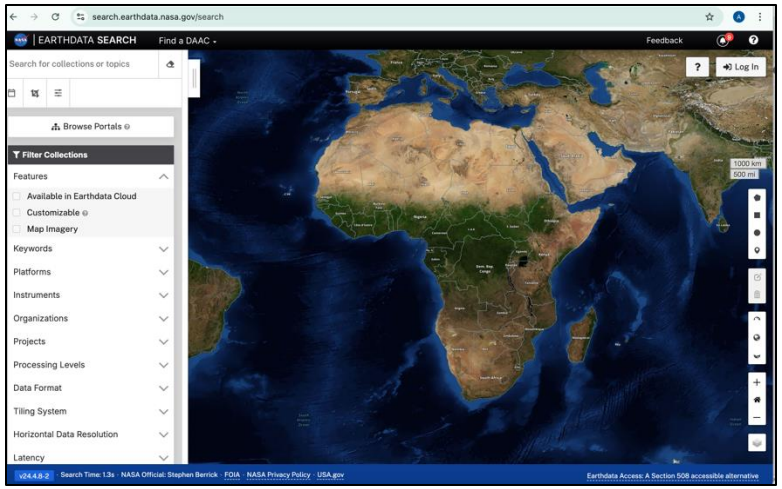




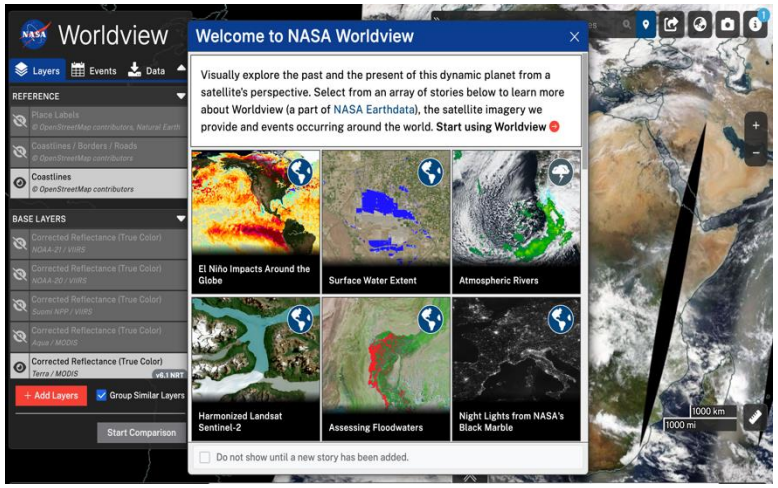
MERRA-2: The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2)

Reviewed Webtools to Search, Access, and Visualize Earth Observation Data

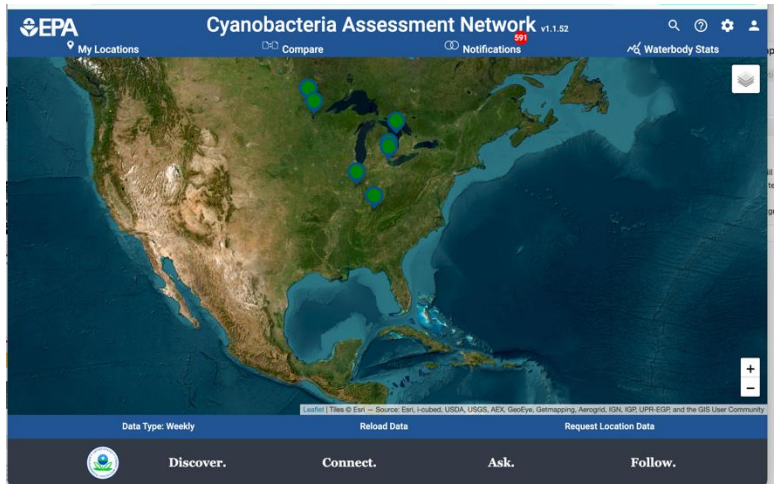
Earthdata Search



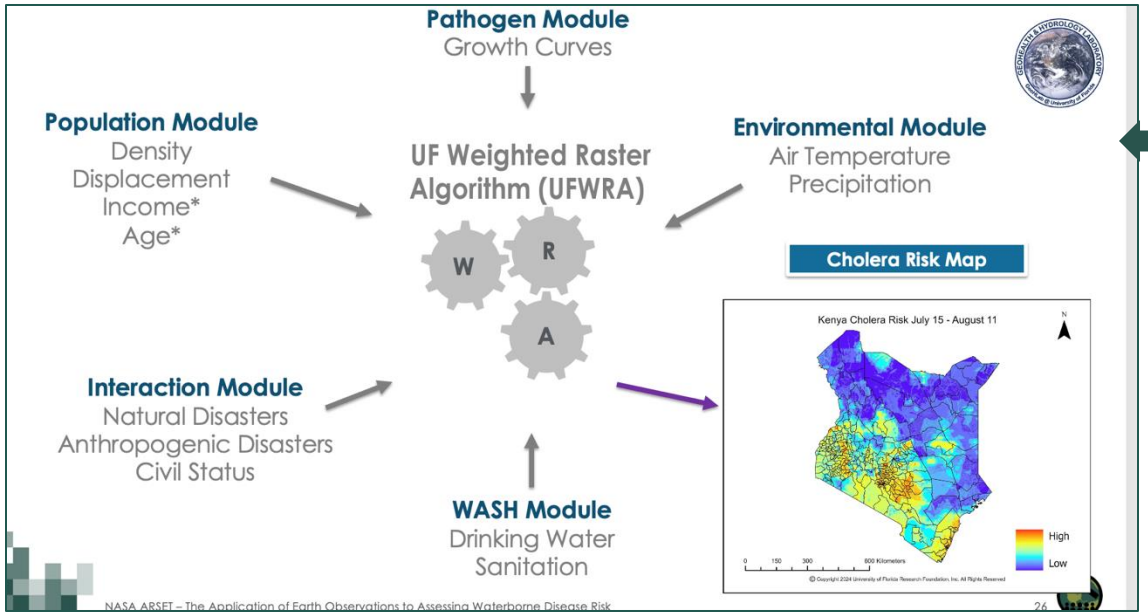
Worldview

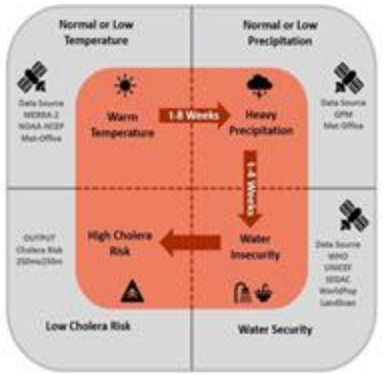


CYaN



Recognized the Use of Earth Observations in *Vibrio cholerae* Prediction Model





Precipitation Data	TRMM & GPM IMERG
Historic and Recent Temperature Data	MERRA-2
*SPEI Data	ERA5

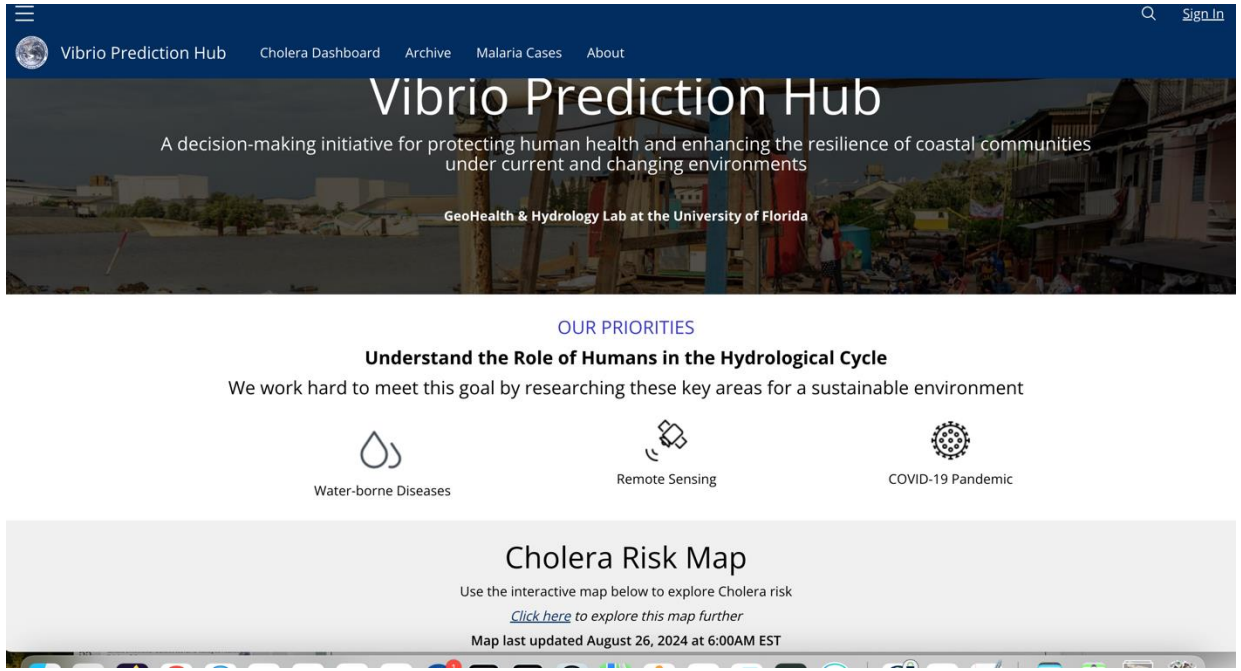
*Standardized Precipitation Evapotranspiration Index

Cholera predictions in Nepal, Haiti, and Yemen

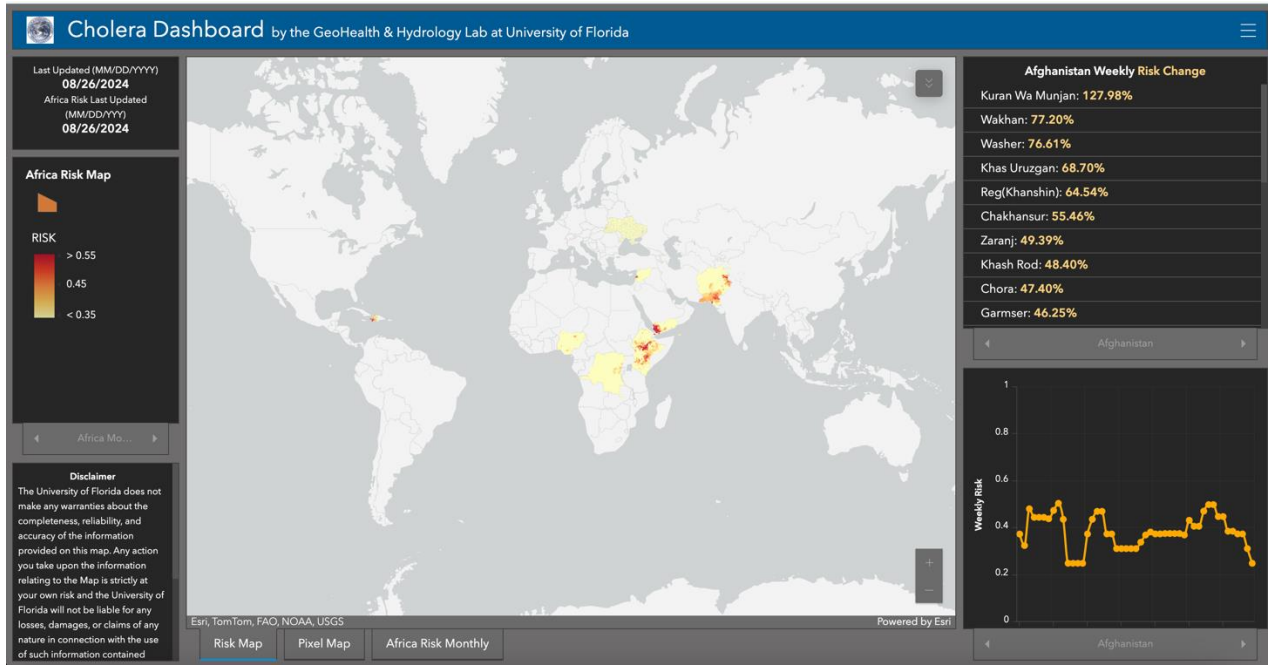
Vibrio Information

GeoHealth & Hydrology Lab at the University of Florida

Vibrio Prediction Hub



Cholera Dashboard



Summary

- Advantages and Limitations of Earth Observations:
  - A wide variety of open source and cost-free environmental data availability
  - Global, consistent spatial and temporal coverage; 10+ to 20+ years of data available
  - Webtools available for data search, access, and visualization
  - Different data sources with varying spatial and temporal resolutions
  - Data gaps due to swath widths
  - Missing data retrievals from optical images in the presence of clouds
- In situ water sample data and disease incidence data are necessary for the development of disease prediction models and their validation.
- Both prolonged wet (floods) and dry (droughts) conditions impact interactions of humans with pathogens:
  - Unsafe WASH conditions due to water insecurity (droughts)
  - Consumption of contaminated water (floods)
- Increasing risk of vibriosis along the Southern and Eastern coasts of the US

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 03/27/2025
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 04/10/2025**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

Trainers:

- Amita Mehta
  - Amita.v.mehta@nasa.gov
- Dr. Antarpreet Jutla
  - ajutla@ufl.edu
- Bailey Magers
  - bmagers@ufl.edu

Coordinator:

- Natasha R. Johnson-Griffin

Editors:

- Suzanne Monthie
- Jonathan O'Brien

Coordinators:

- Brock Blevins
- Sarah Cutshall
- Selwyn Husdson-Odoi

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- DEVELOP
- SERVIR

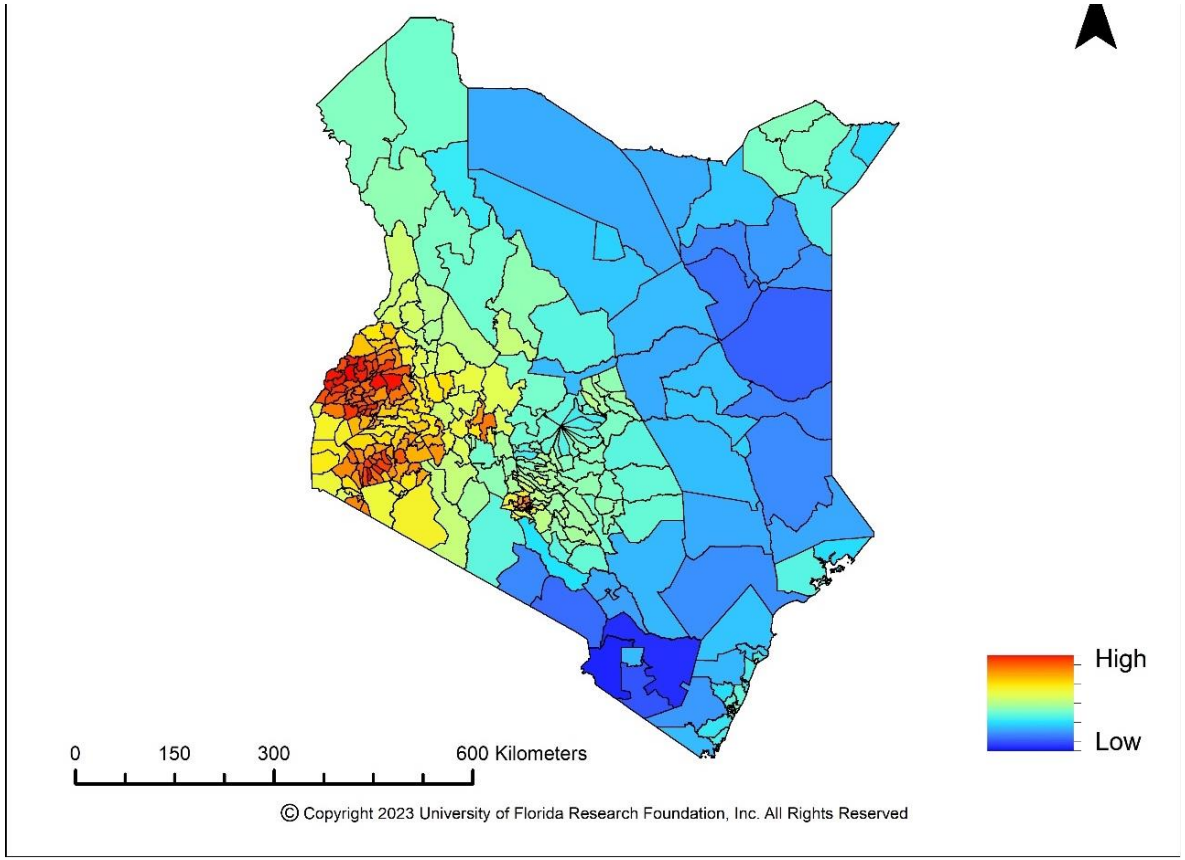
Resources

- GPM Health Appplications
- PACE Applications
- Waterborne Diseases: CDC


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!

Activity 1


High
Low
0
150
300
600 Kilometers
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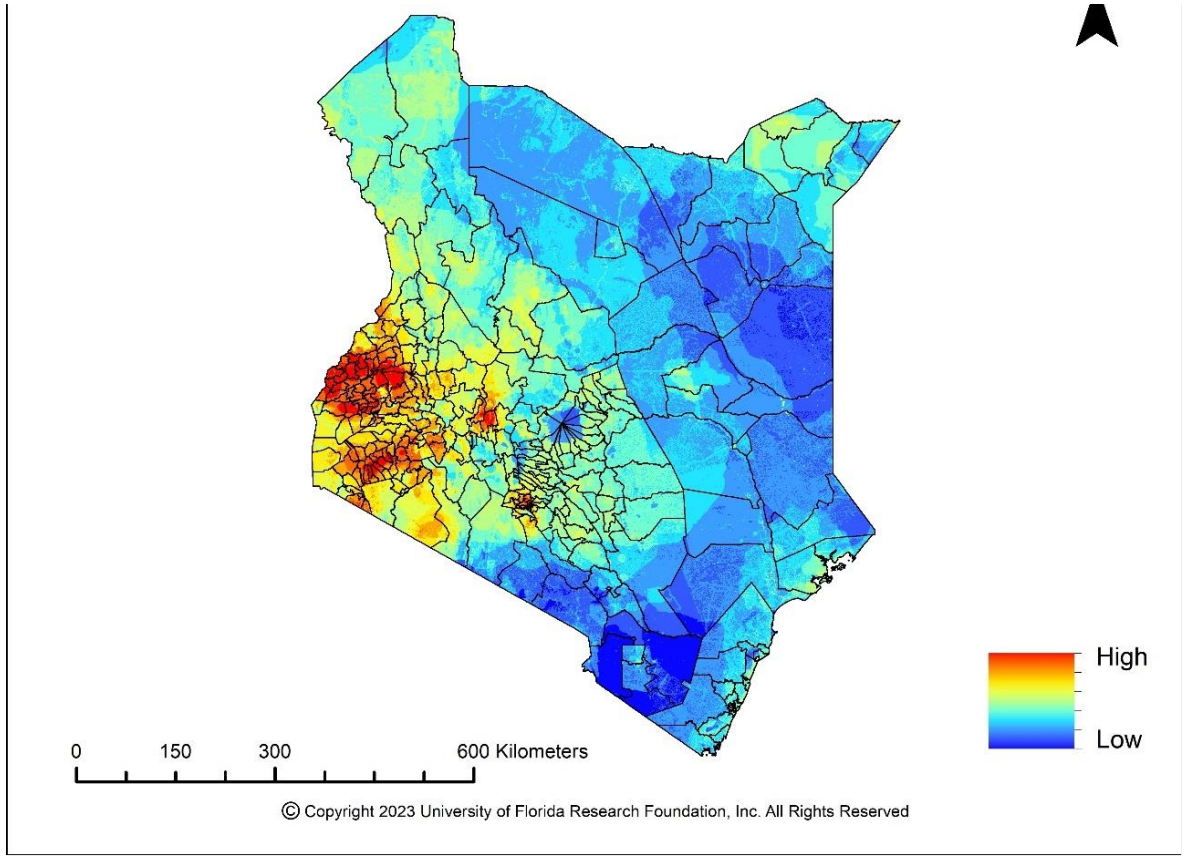
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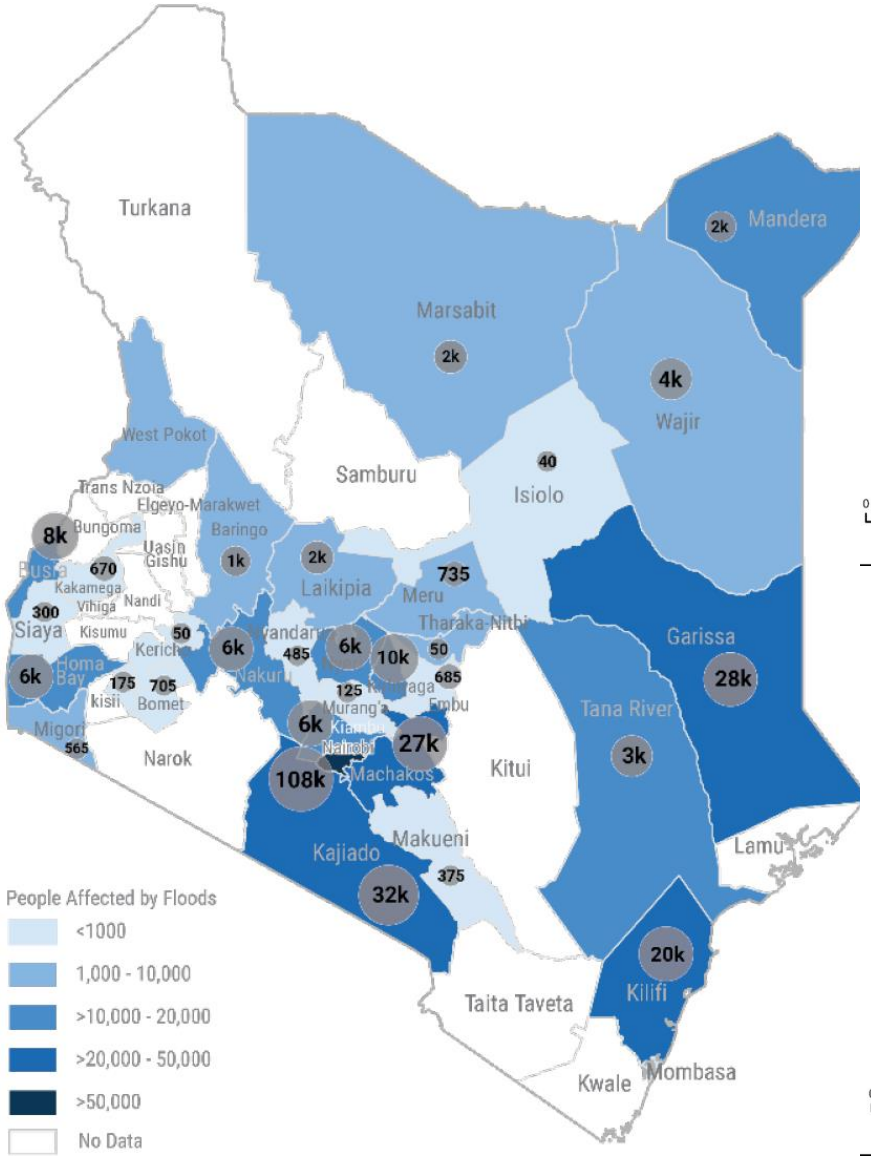
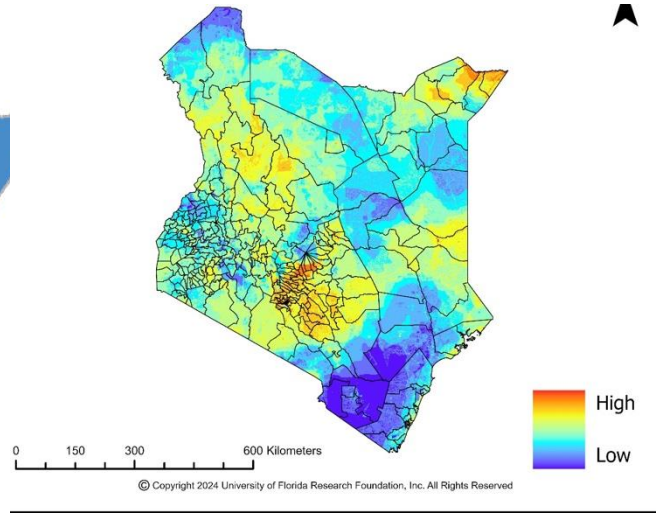
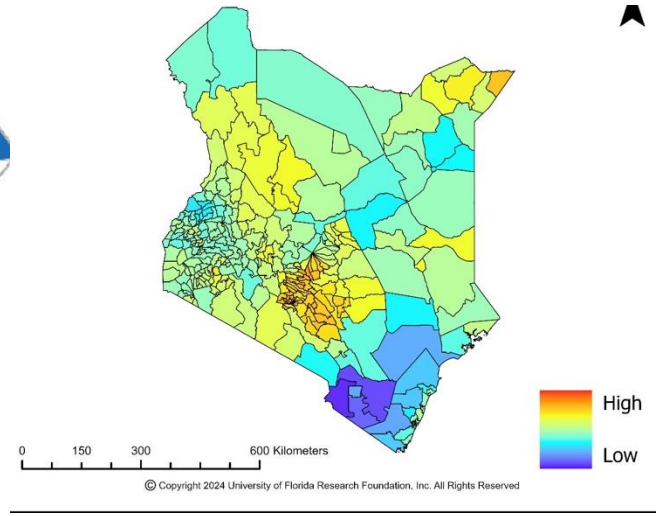


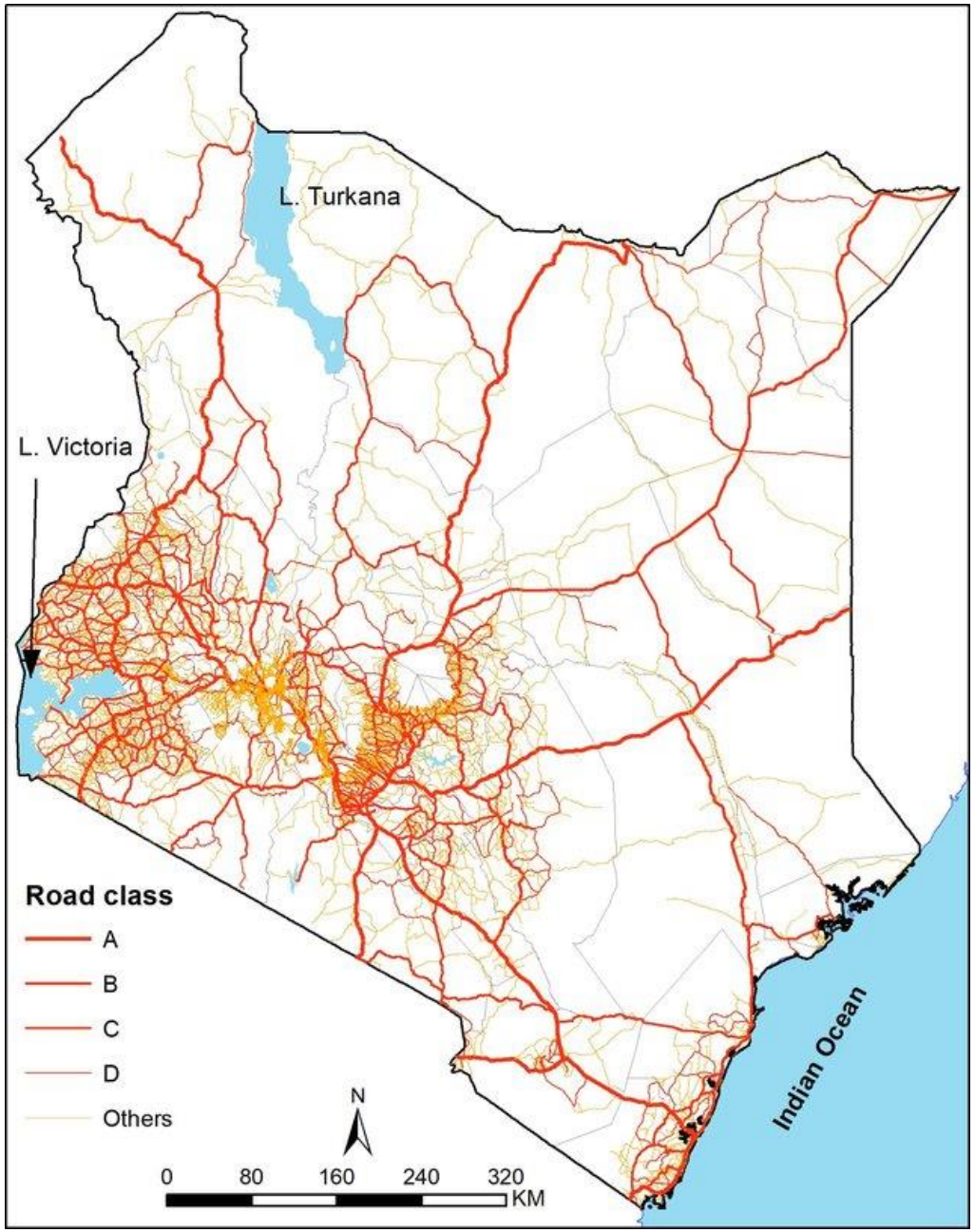




This time, Internally Displaced People (IDP) data due to flooding is given.

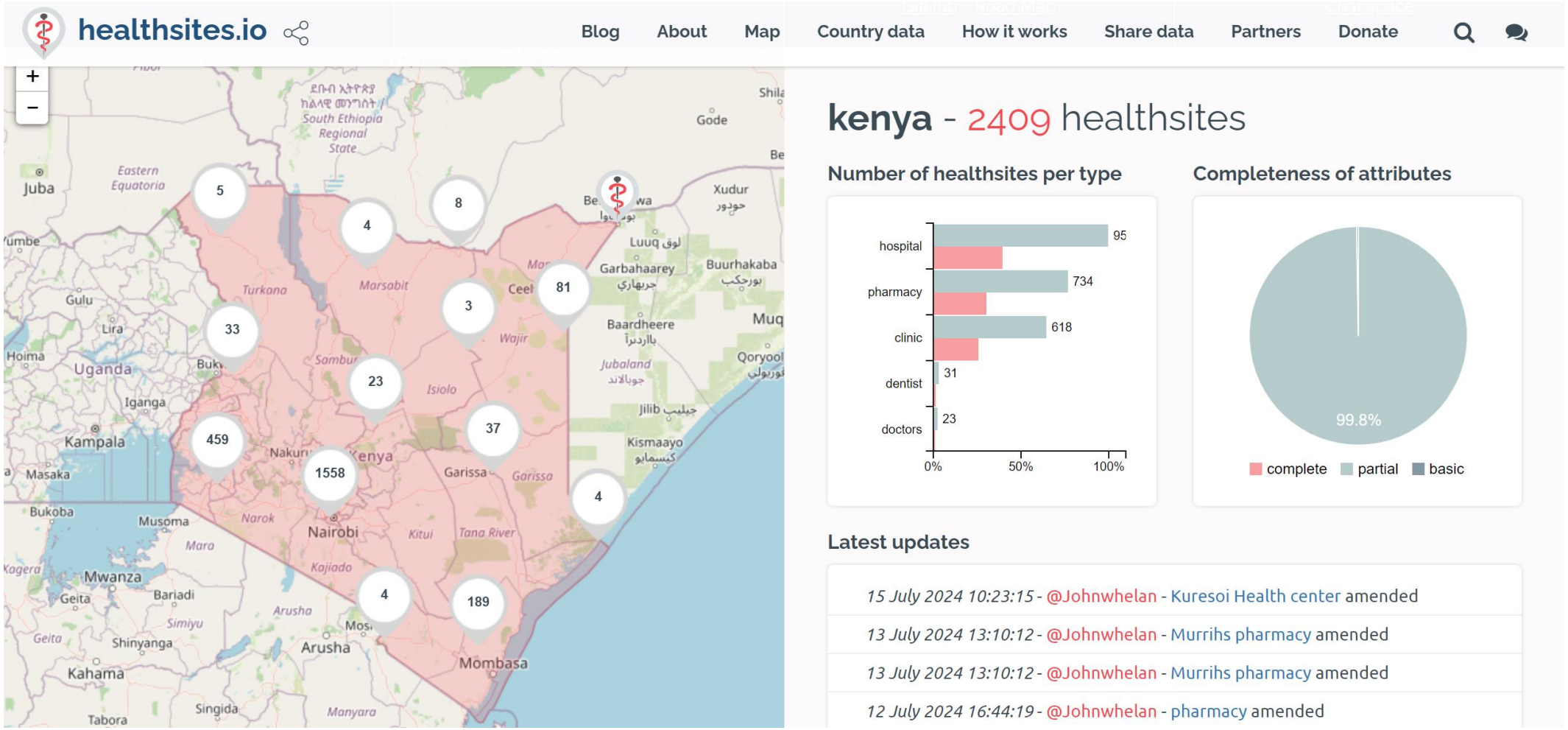
Transportation Data

- Incorporating this data would help us predict areas of greater population movement.
- Could help inform at-risk individuals of routes to lower risk areas.

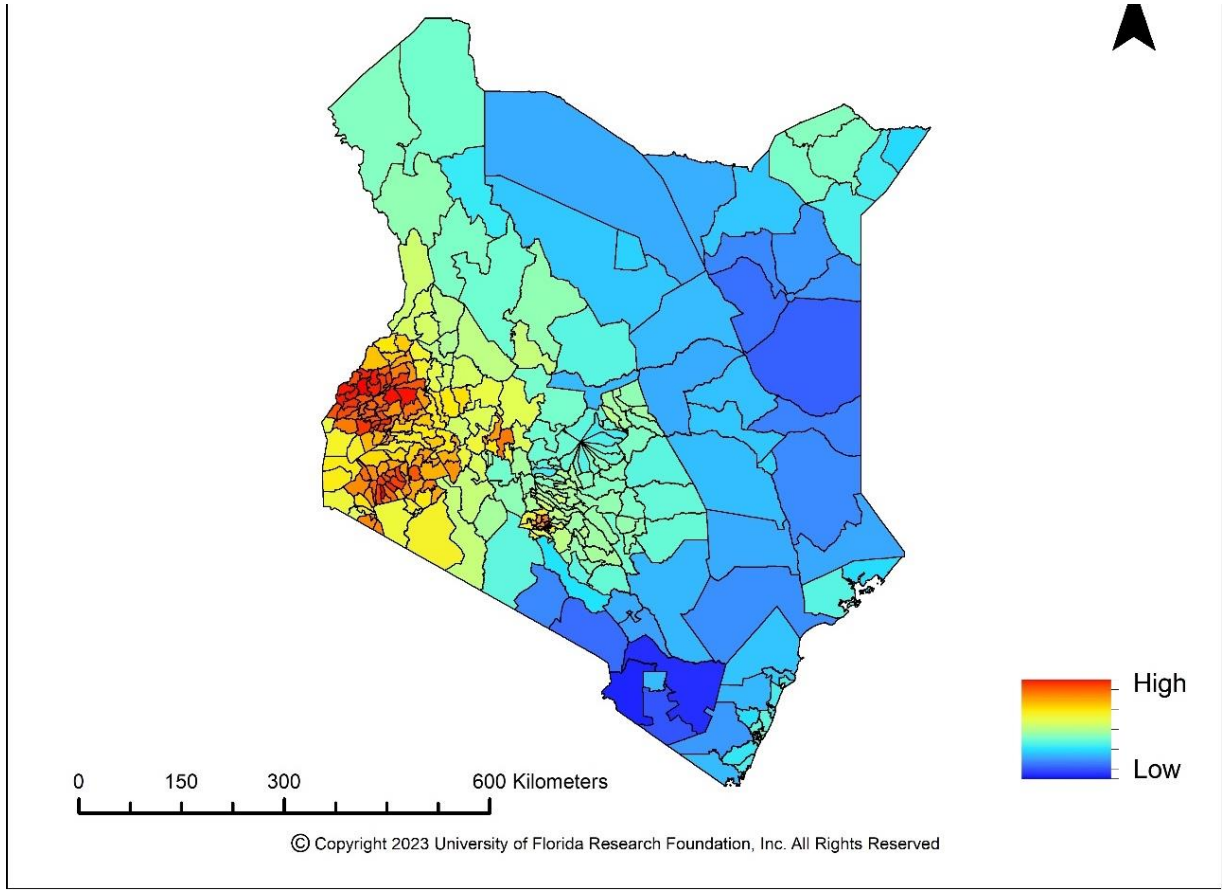


Macharia, Peter & Mumo, Eda & Okiro, Emelda. (2021). Modelling geographical accessibility to urban centres in Kenya in 2019. PLoS ONE. 16. e0251624. 10.1371/journal.pone.0251624.

Hospital and Medical Facility Data



Flood Data


High
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600 Kilometers
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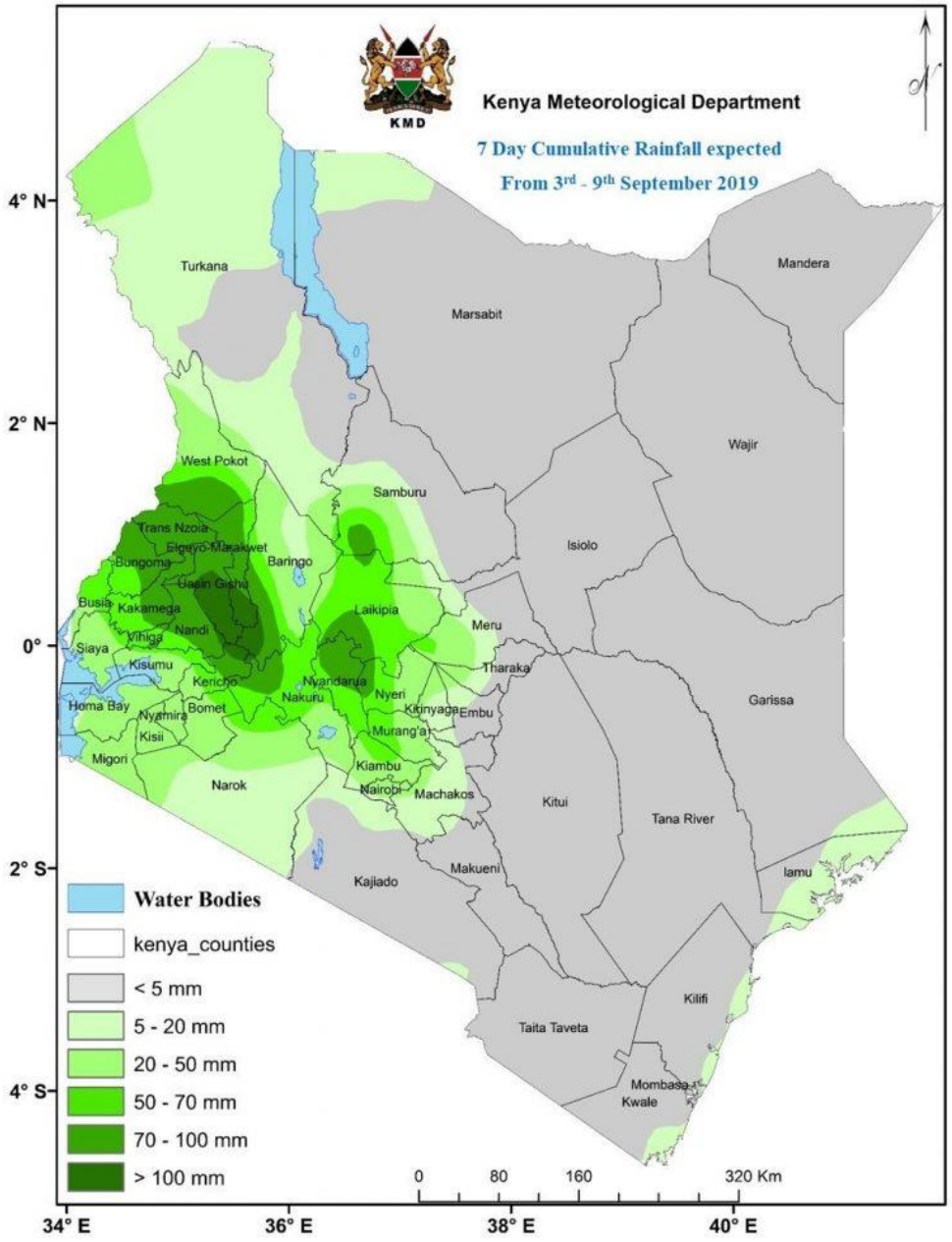
Kenya Meteorological Department
KMD
7 Day Cumulative Rainfall expected
From 3rd - 9th September 2019
Water Bodies
kenya_counties
< 5 mm
5 - 20 mm
20 - 50 mm
50 - 70 mm
70 - 100 mm
> 100 mm
0
80
160
320 Km
4° N
2° N
0°
2° S
4° S
34° E
36° E
38° E
40° E
Turkana
Marsabit
Mandera
Wajir
West Pokot
Samburu
Trans Nzoia
Elgeyo-Marakwet
Baringo
Bungoma
Uasin Gishu
Busia
Kakamega
Laikipia
Isiolo
Meru
Nandi
Vihiga
Siaya
Kisumu
Tharaka
Kericho
Nyandarua
Nakuru
Nyeri
Garissa
Homa Bay
Bomet
Kirinyaga
Embu
Nyamira
Kisii
Murang'a
Migori
Kiambu
Narok
Nairobi
Machakos
Kitui
Tana River
Kajiado
Makueni
Lamu
Kilifi
Taita Taveta
Mombasa
Kwale

Thank You

Contact Us:
Bailey Magers – bmagers@ufl.edu
Dr. Antarpreet Jutla – ajutla@ufl.edu