Climate Change and One Health

Update Course in Clinical Tropical Medicine & Travelers' Health 2025

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Kayoko Shioda, PhD, DVM, MPH

Assistant Professor of Global Health
Boston University
kshioda@bu.edu

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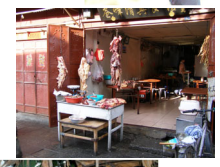
Outline of the Talk

- **What is One Health?**
- **Example: Antimicrobial resistant bacteria (AMR)**
  - How do animals contribute to AMR?
  - Why does animal AMR matter to humans?
  - How does climate change fit into all of this?
  - How could this affect the U.S.?



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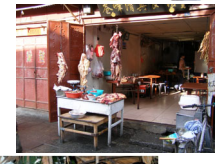

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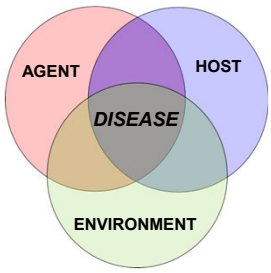
Epidemiological Triad

A Model of Disease Causation



Epidemiological triad highlights how the occurrence of disease is determined by the interplay between 3 key components

- **Agent:** microorganism or pathogen
- **Host:** humans/animals
- **Environment:** climate, sanitation, living conditions, etc.

Snieszko (1974)

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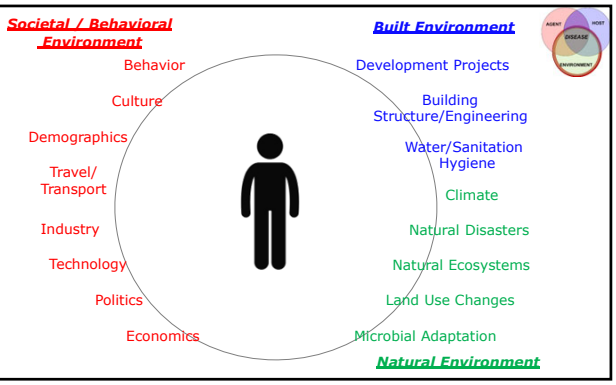

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Introduction to One Health

(From One Health Trust)

- **Interconnection** between human, animal, and environmental health
- Many emerging infectious diseases originate at the **human-animal-environment interface**
- **Environmental factors** play critical roles in transmission
- **Collaboration** across sectors is essential

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How do animals contribute to AMR?

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What is the Link Between Animals and AMR?

(Van Boeckel, *et al. Science* 2017)

- **73%** of all antimicrobials sold on Earth are used in animals raised for food
  - Growing due to increasing demand for meat
- **Mass medication** of animals with antimicrobials critical to human medicine
  - 3rd-generation cephalosporins
  - fluoroquinolones
- Long-term use in animal feed for **growth promotion**
  - Colistin
  - Tetracyclines
  - Macrolides

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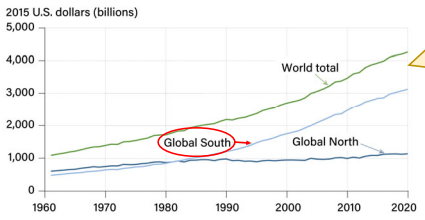
Increasing Livestock Production in the Global South

(Fuglie, *et al.* USDA 2024)

Value of world agriculture output



World agricultural output increased by **4-fold** over 6 decades, with most of the increase in the **Global South**

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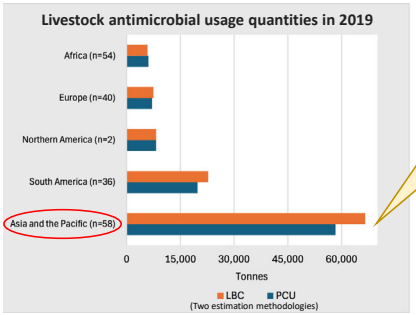
Regional Differences in Livestock Antimicrobial Use

(Acosta, *et al. Nat Comm* 2025)



The **Asia-Pacific region** alone accounts for **over half** of the global total, driven by intensive animal farming and rising meat demand

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High Livestock Ownership in LMICs

(Deka, *et al.* ILRI 2011)

- In Jharkhand, India, **>90%** of households keep livestock, contributing to 20-60% of household livelihoods
- Antimicrobial use is largely **unregulated**

(Photos from ILRI)

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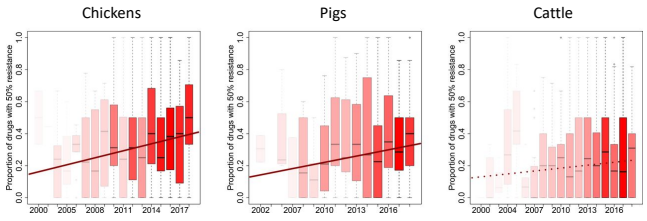
Rising AMR Rates in LMIC Farm Animals

(Van Boeckel, *et al. Science* 2019)

Proportion of antimicrobial compounds with >50% resistance in LMICs (2000–2018)



15% → 41%

13% → 34%

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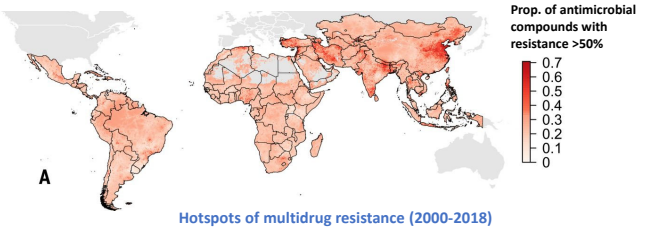
Geographic Variations in Resistance in LMICs

(Van Boeckel, *et al. Science* 2019)



Hotspots of multidrug resistance (2000-2018)

- South and northeast India
- Northeast China
- North Pakistan
- Iran
- Turkey
- South coast of Brazil
- Egypt
- the Red River delta in Vietnam
- Mexico City
- Johannesburg

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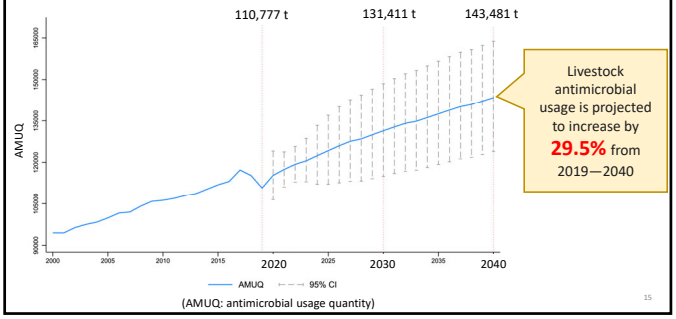
Projected Increase in Livestock Antimicrobial Use

(Acosta, *et al. Nat Comm* 2025)

Global livestock antimicrobial usage projections under the business-as-usual scenario



(AMUQ: antimicrobial usage quantity)

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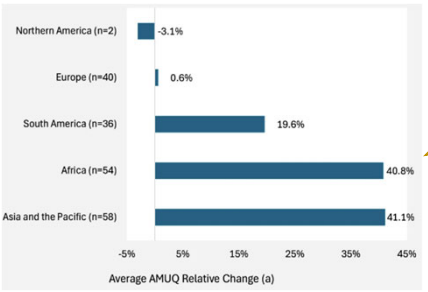
Regional Differences in Projected Increases

(Acosta, *et al. Nat Comm* 2025)

Relative change in livestock AMUQ per region (2019–2040)



Expected substantial rises in **Asia and the Pacific**, **Africa**, and **South America**

(AMUQ: antimicrobial usage quantity)

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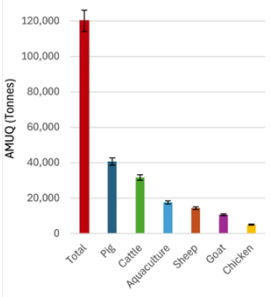
Future antimicrobial use by species

(Acosta, *et al. Nat Comm* 2025)

Projected antimicrobial use in 2040



Pigs are the dominant consumers of Abx → ~**34%** of the total antimicrobial usage quantity

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Global effort to reduce antibiotic use in the agri-food system

UN General Assembly High-Level Meeting on antimicrobial resistance 2024

المـؤتـمـر الوزاري الثـالث لمقاومة مضادات الميكروبات
Third Global High-Level Ministerial Conference on Antimicrobial Resistance

79th United Nations General Assembly

- Committed to a **significant reduction** in global antimicrobial use in the agrifood system by **2030**

Muscat Ministerial Manifesto

- 47 countries have pledged to **decrease** antimicrobial use in agrifood systems by at least **30-50% by 2030**
- **Preserve** critically important antimicrobials for human medicine
- **End** the use of medically important antimicrobials for **growth promotion** in animal

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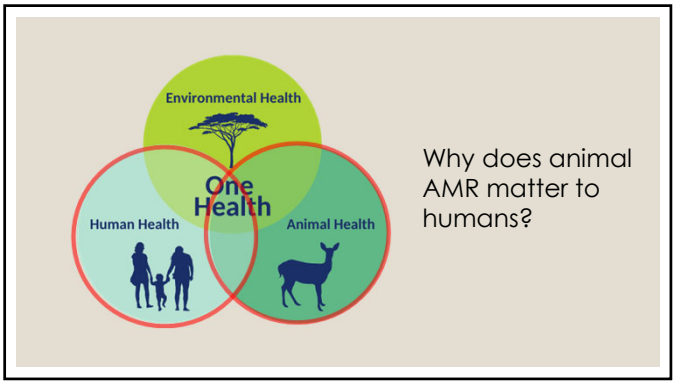
Environmental Health
One Health
Human Health
Animal Health
Why does animal AMR matter to humans?

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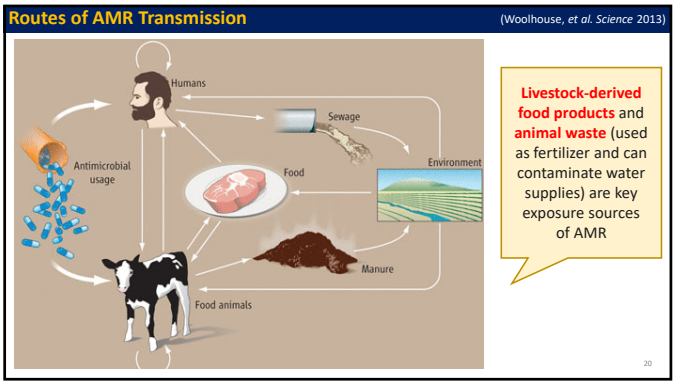
Routes of AMR Transmission
(Woolhouse, et al. Science 2013)
Humans
Sewage
Environment
Antimicrobial usage
Food
Manure
Food animals
Livestock-derived food products and animal waste (used as fertilizer and can contaminate water supplies) are key exposure sources of AMR
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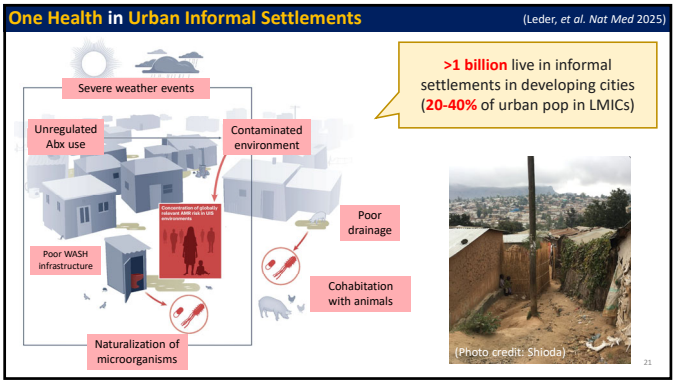
One Health in Urban Informal Settlements
(Leder, et al. Nat Med 2025)
Severe weather events
Unregulated Abx use
Contaminated environment
Poor drainage
Poor WASH infrastructure
Cohabitation with animals
Naturalization of microorganisms
>1 billion live in informal settlements in developing cities (20-40% of urban pop in LMICs)
(Photo credit: Shioda)
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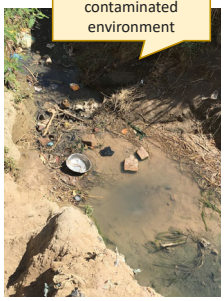
One Health in Urban Informal Settlements

Examples from Malawi

Cohabitation with animals

Poor drainage and contaminated environment



(Photo credit: Shioda)

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Informal Production of Animal Product in LMICs

In Maputo, Mozambique

- 70% of chicken production is informal
- 90% of households purchase foods from the informal sector

(Credit: Lamer and Levy)

(Credit: Shioda)

(Credit: Lamer and Levy)

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Informal Wet Markets in LMICs

(Photo credit: Shioda)

Examples from Malawi

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Contamination at informal wet markets

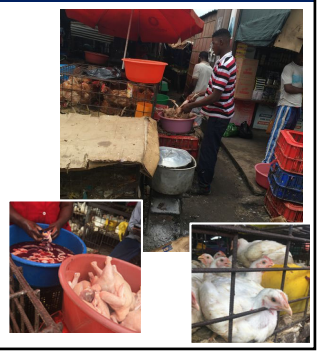
(Lamar, *et al. EHP* 2023; Olson *et al. mSystems* 2025)

Chicken meat contamination at informal wet market in Maputo

- **100%** with *C. jejuni/coli*
- **17%** with *Salmonella* spp.

Chicken meat contained high-risk antimicrobial resistance genes (**ARGs**)

Open-air, live markets are a **critical juncture** in the spread of pathogenic bacteria and ARGs in a community



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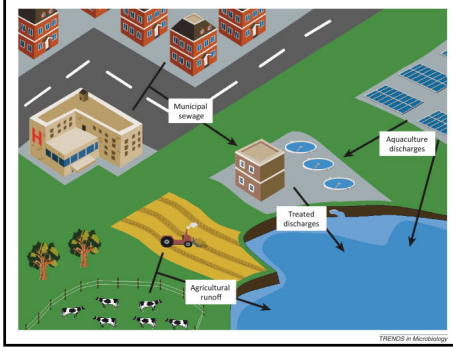
Antimicrobial Resistance Genes in Aquatic Environments

(Marti, *et al. Trends Microb.* 2014)



Anthropogenic activities disseminate ARGs in aquatic environments

- Aquaculture
- Municipal sewage
- Hospital wastewater
- Agricultural runoff

Ideal settings for the **horizontal exchange** of mobile genetic elements

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How does climate change fit into all of this?

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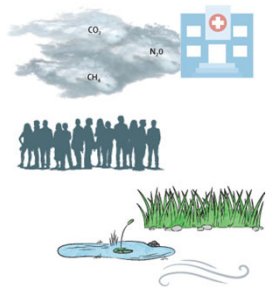
Climate Change Drives AMR

(van Bavel, *et al. Lancet PH*. 2024)



Climate change driving AMR

Climate change can:

- Modify **pathogen** habitat, distribution, evolution, and transmission
- Affect **practices and Abx use** in agriculture, aquaculture, and food production systems
- Alter **entire ecosystems**
  - Emergence/spread of ARGs
  - Thawing permafrost

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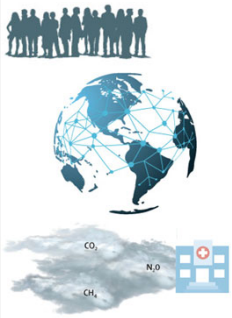
How Does Climate Change Play a Role?

(van Bavel, *et al. Lancet PH*. 2024)



Harmful synergies

Climate change and AMR drive the re-emergence and expansion of IDs together

- Increasing water temp. and salinity gradients due to sea level rise
  → Vibrio-associated diseases with high levels of AMR
- Warmer temperature and climate variability
  (as well as land use change, inadequate prevention, drug resistance, socioeconomic status, health policy, etc.)
  → Re-emergence of malaria above particular latitudes (e.g., in the east African highlands)

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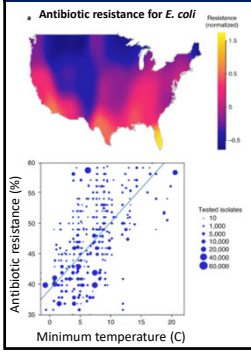
AMR Increases with Local Temperature

(MacFadden, *et al. Nat Climate Change*. 2018)



Increase in temperature of 10 °C was associated with an **increase in AMR**

- 4.2% for *Escherichia coli*
- 2.2% for *Klebsiella pneumoniae*
- 2.7% for *Staphylococcus aureus*

(*Adjusted for confounders)

Potential mechanisms

Higher temperature leads to:

- ↑ Horizontal gene transfer
- ↑ Bacterial growth in humans, animals, and the environment
- ↑ Carriage/transmission of resistant strains
- ↑ Transmission from food, agriculture, and environmental sources

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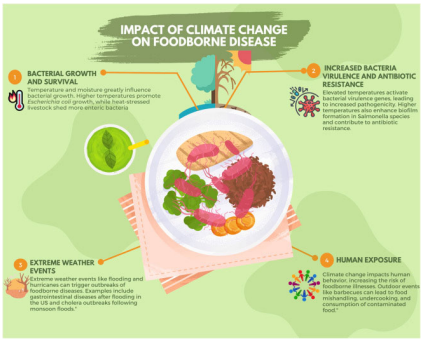
Climate Change and Food Safety

(Taiwo, *et al. Appl Food Res.* 2025)



Warmer temperatures promote bacterial survival and growth in food, water, and the environment

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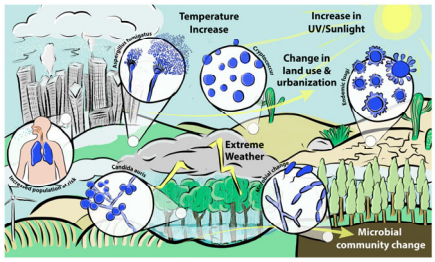
Climate Change and Fungal Infections

(van Rhijn, *et al. J . Fungi.* 2021)

- Warming allows fungi to adapt to **higher body temp**
- Extreme weather events **redistribute spores**
- Also expose the population to **contaminated air/water**
- Increased UV exposure drive **mutations**
- **Deforestation** increase human-fungal contact
- Changes in soil and **vegetation** alter local microbial communities



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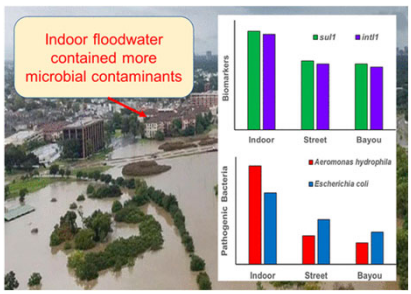
Flooding Increases AMR Risks

(Yu, *et al. Env Sci & Tech Letters.* 2018)



- Hurricane Harvey flooded numerous wastewater treatment plants in Houston (August 2017)
- **Increased** key indicator genes of anthropogenic sources of AMR
- Facilitated the **proliferation and survival** of AMR bacteria and ARGs in residential floodwaters

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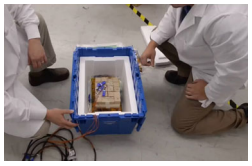
Impact of Climate Change on Medicine

(Kaplan, *et al. One Health* 2025)

Climate change can:

- Alter **environmental degradation** of medicines
- Degrade the **quality** of medicine
  - Heat-susceptible drugs



Use of antimicrobials with sub-therapeutic levels of active pharmaceutical ingredient can create **selection pressure** that drives resistance

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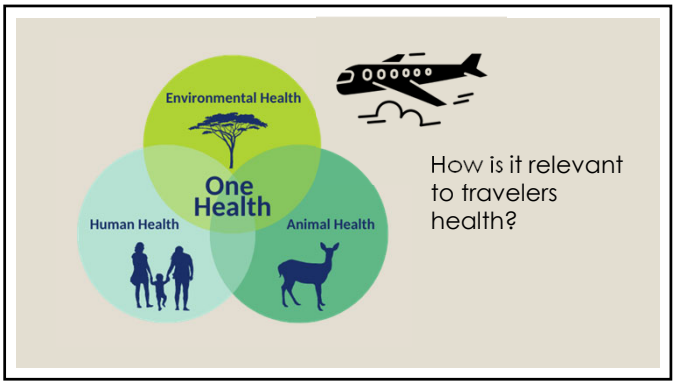

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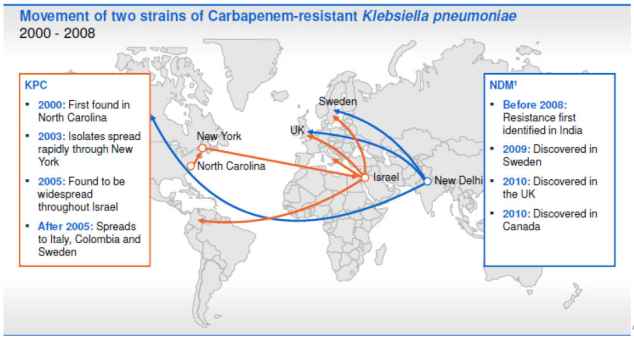
International Travel Facilitates Spread of AMR

Movement of two strains of Carbapenem-resistant *Klebsiella pneumoniae*
2000 - 2008



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Resistant Bacteria Travel with Humans

(Ruppe E *et al. Clin Infect Dis* 2015)

Study in Paris from 2012–2013

- **574** people who traveled to **high-risk countries** provided pre- and post-travel specimens
- **51%** acquired **multidrug-resistant Enterobacteriaceae (MDR-E)**
- Most common after travel to:
  - South Asia (72%)
  - Sub-Saharan Africa (48%)
  - Latin America (31%)

Travel to tropical regions should be considered a **risk factor of MDR-E carriage** during the first 3 months after return, but not beyond

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One Health Solutions for AMR in an Era of Climate Change

- Biotechnological, public health, One Health, and nanotechnological advancements
  - Climate change adaptation/mitigation
  - Surveillance of AMR
  - Management of drug-resistant diseases
- Resilient farming

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Toward Solutions at the Human–Animal–Environment Interface

- **Policy Action**
  - Strengthen **regulation** of antimicrobial use in livestock and aquaculture
  - Invest in AMR and One Health **surveillance** systems, especially in LMICs
  - Support climate-resilient **infrastructure** for food safety and WASH
- **Research and Innovation**
  - Advance **interdisciplinary studies** on climate–AMR–health intersections
  - Improve **diagnostics and alternatives** to antibiotics in animal production
  - **Monitor ARGs** in environmental reservoirs and informal food systems
- **Capacity Building**
  - Train local stakeholders in AMR **stewardship** and risk **communication**
  - Foster **collaboration** between animal, environmental, and human health sectors
  - Promote **climate-smart farming** and sustainable food systems

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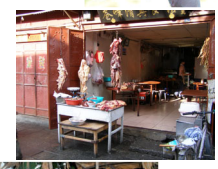
- **Example 2: Vector-borne diseases**
  - **Rift Valley Fever virus prediction**



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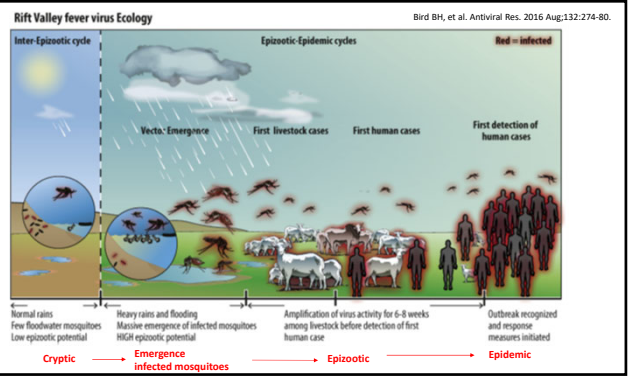

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Great Rift Valley

- Series of contiguous trenches, ~4300 miles
- Beqaa Valley, Lebanon to Mozambique

https://en.wikipedia.org

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Rift Valley Fever symptoms

Humans
- Mild disease (ILI)
- Ocular disease
- Meningoencephalitis
- Hemorrhagic disease
- Death
- Asymptomatic infection

Ruminants
- Abortion
- Death
- Asymptomatic infection


(FAO)


(SwissTPH, ILRI, FAO)

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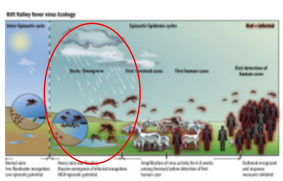
RVF Forecasting

RVF outbreaks in endemic areas since 1950s

- Associated with cyclical patterns of El Niño/Southern Oscillation (**ENSO**)
- → Resulting in elevated and widespread **rainfall** across RVF endemic Africa



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Climate Variability: El Niño and La Niña

El Niño

- Refers to **warmer** than normal sea surface temperatures (SST) across much of equatorial eastern & central Pacific
  - Time between El Niño events is irregular but tend to recur every 3-7 years
  - Usually last a year, up to two years

La Niña

- Refers to **cooler** than normal SST across much of equatorial eastern & central Pacific

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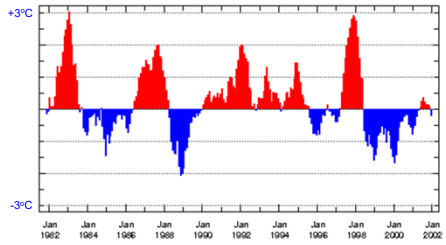
Nino 3.4 Sea Surface Temperature Index



El Niño or La Niña Event

identified when 5-month running-average of NINO 3.4 Index exceeds +0.4°C for El Niño; or -0.4°C for La Niña for ≥ 6 consecutive months

http://portal.iri.columbia.edu/portal/server.pl

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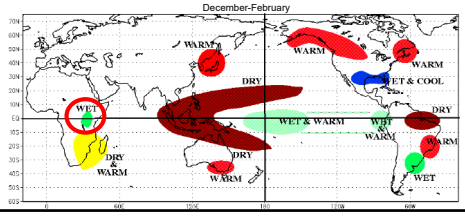
RVF Forecasting

RVF outbreaks since 1950s associated with cyclical patterns of **ENSO** resulting in elevated and widespread **rainfall** across **RVF endemic Africa**

El Niño Winter
December-February



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Flooding North Eastern Province, Kenya at onset of RVF epidemic, December 2006

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Prediction and Assessment of RVF Activity in East and Southern Africa 2006–2008

Satellite measurements of:

1. Global and regional elevated **sea surface temperatures**
2. Elevated **rainfall**
3. Satellite derived-normalized difference **vegetation index**

Together used to predicted, with **2–4 months lead times**, areas where human and animal RVF outbreaks were expected and occurred in the Horn of Africa, Sudan, and Southern Africa between September 2006 to March 2008

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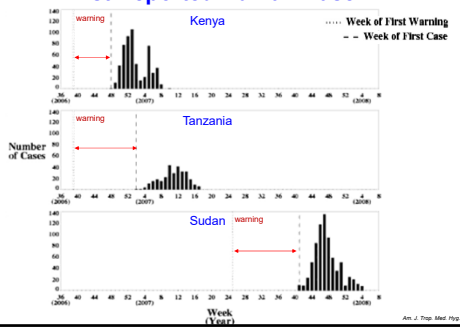
Timing of First RVF Early Warning Alert and First Reported Human Case



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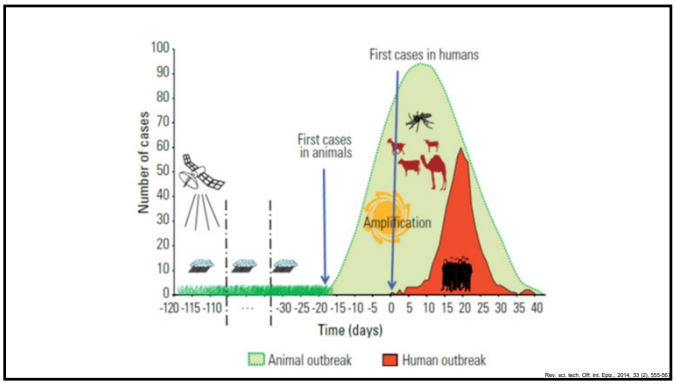
RVF Forecasting

Prediction of outbreaks with enough lag time allows **preventive measures** to be taken:

- **Control of mosquito larvae**, particularly in flooded or soon to be flooded wetlands
- **Vaccination** of at risk livestock
- Vaccination should be halted when epizootic commences!!!
  Problems with needle reuse and multiple dose vials have facilitated spread among livestock and increased risk to human populations

52



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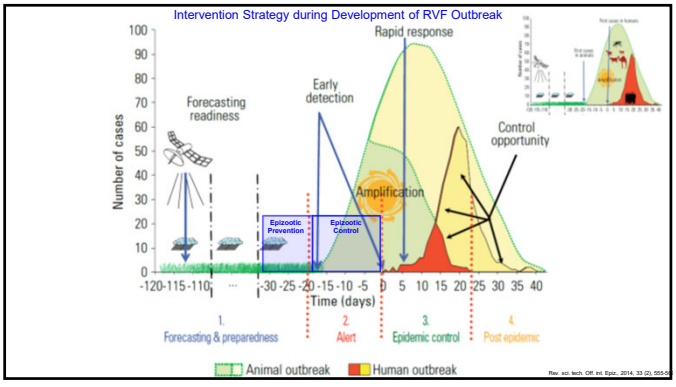

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Environmental Health
One Health
Human Health
Animal Health
Efforts at
BOSTON UNIVERSITY

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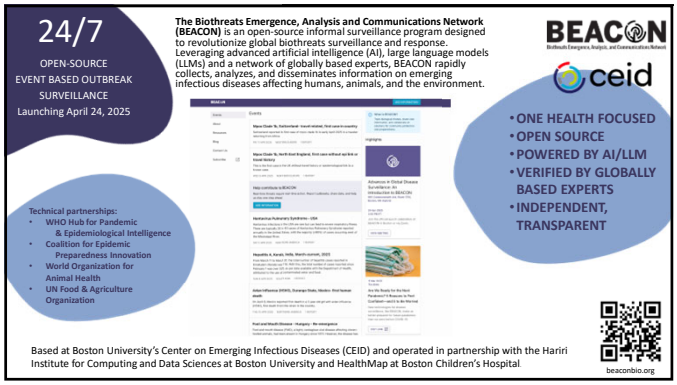
24/7
OPEN-SOURCE
EVENT BASED OUTBREAK
SURVEILLANCE
Launching April 24, 2025
The Biothreats Emergence, Analysis and Communications Network (BEACON) is an open-source informal surveillance program designed to revolutionize global biothreats surveillance and response. Leveraging advanced artificial intelligence (AI), large language models (LLMs) and a network of globally based experts, BEACON rapidly collects, analyzes, and disseminates information on emerging infectious diseases affecting humans, animals, and the environment.
BEACON
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• ONE HEALTH FOCUSED
• OPEN SOURCE
• POWERED BY AI/LLM
• VERIFIED BY GLOBALLY BASED EXPERTS
• INDEPENDENT, TRANSPARENT
Technical partnerships:
• WHO Hub for Pandemic & Epidemiological Intelligence
• Coalition for Epidemic Preparedness Innovation
• World Organization for Animal Health
• UN Food & Agriculture Organization
Based at Boston University's Center on Emerging Infectious Diseases (CEID) and operated in partnership with the Hariri Institute for Computing and Data Sciences at Boston University and HealthMap at Boston Children's Hospital.
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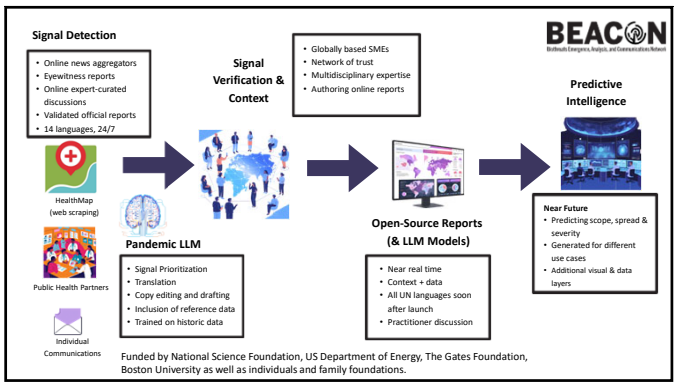
Signal Detection
• Online news aggregators
• Eyewitness reports
• Online expert-curated discussions
• Validated official reports
• 14 languages, 24/7
HealthMap (web scraping)
Public Health Partners
Individual Communications
Signal Verification & Context
• Globally based SMEs
• Network of trust
• Multidisciplinary expertise
• Authoring online reports
Pandemic LLM
• Signal Prioritization
• Translation
• Copy editing and drafting
• Inclusion of reference data
• Trained on historic data
Open-Source Reports (& LLM Models)
• Near real time
• Context + data
• All UN languages soon after launch
• Practitioner discussion
Predictive Intelligence
Near Future
• Predicting scope, spread & severity
• Generated for different use cases
• Additional visual & data layers
BEACON
Funded by National Science Foundation, US Department of Energy, The Gates Foundation, Boston University as well as individuals and family foundations.

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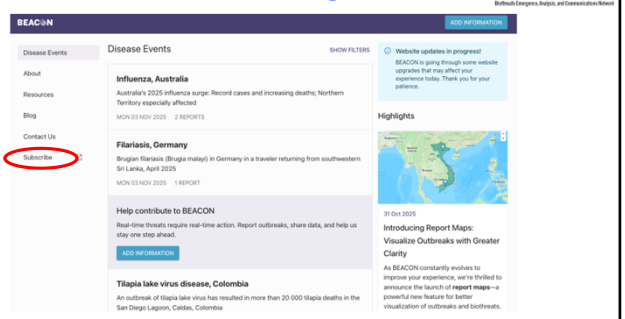

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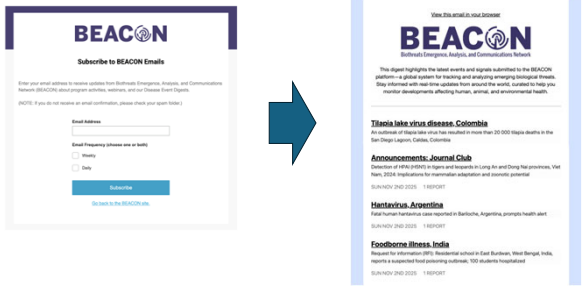

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Thank you so much!

kshioda@bu.edu

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Shioda Research Group

Postdoc associates/staff
- Billy Chen
- Katherine Jia
- Annie Shapiro
- Quinn Adams

MS/MPH students
- Redvers Kadzungwa
- Kanako Fuyama
- Gina Lombard
- Selin Kubali
- Reetha Kabbalu Mylaru
- Tianci Chen

PhD/MD students
- Heavenlight Paulo
- Shae Gantt
- Selin Kubali
- Jonathan Muhvich

Undergrad student
- Mario RodriguesFleury Rosa

Alumni

Vikas Barnwal; Nico D'Angelo; Toshiaki Komura; Richard Quach; Koki Takabatake; Miwa Watanabe; Grissel Lopes; Aarushi Tuli; Anushka Reddy Marri

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