

# Examining Treatment Strategies for Cholera Incorporating Spatial Dynamics

Group: Plague Doctors

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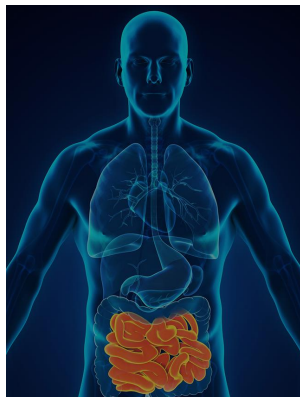
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- Treatments have not always gone as planned in history
- Cholera

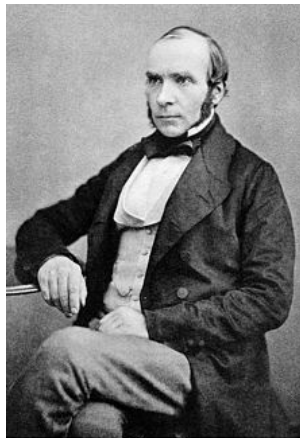
# Some Biology on Cholera

- *Vibrio cholerae*
- Colonize small intestines
- 10 percent of infected develop symptoms
- Causes dehydration



# Outbreaks in London (19<sup>th</sup> Century)

- 1832, 1849, 1854, 1866
- Miasma Theory
- John Snow



*John Snow*

# Developing a Single-Patch Model

- Entire population ( $N$ ) included
- 3 Compartments : S, I, R
- Compartment values are proportional
- Environment (Water)

# SIRW Model Assumptions

- Birth Rate = Natural Death Rate and is constant
- Homogenous susceptibility to cholera across population
- No waning immunity
- No latency period
- Only infected individuals can infect the water sources
- Water source is still

# SIRW Model



- Using the method of Next Generation Matrix (van den Driessche and Watmough, 2002)

$$F = \begin{pmatrix} \beta_i & \beta_w \\ 0 & 0 \end{pmatrix}$$
$$V = \begin{pmatrix} \frac{1}{\gamma + \mu} & 0 \\ \frac{1}{\gamma + \mu} & \frac{1}{\sigma} \end{pmatrix}$$

- $R_0$  is computed as the spectral radius of  $FV^{-1}$ :

$$\begin{aligned} \mathcal{R}_0 &= \rho(FV^{-1}) \\ &= \frac{\beta_i + \beta_w}{\gamma + \mu} \end{aligned}$$



- Two equilibria:

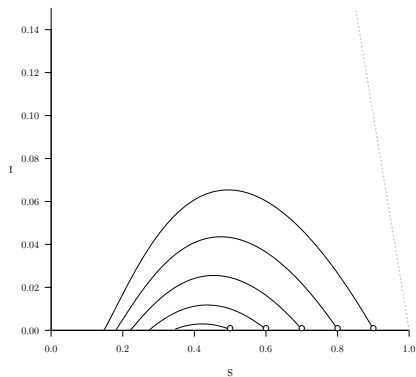
① DFE:  $(S, I, R) = (1, 0, 0)$

② EE:  $(s^*, i^*, r^*) = (\frac{1}{R_0}, \frac{\mu}{\gamma + \mu}(1 - s^*), i^*)$

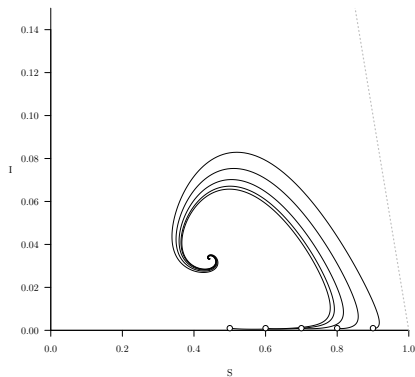
- The DFE is stable when  $\mathcal{R}_0 < 1$
- The EE is stable when  $\mathcal{R}_0 > 1$

# SIWR Model Phase Portrait

Base Model without Vital Dynamics  $\mathcal{R}_0 = 2.4$

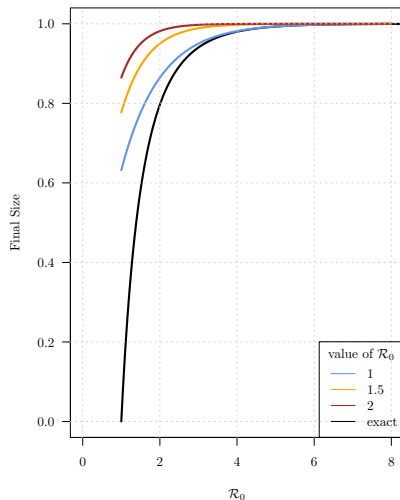


Base Model with Vital Dynamics  $\mathcal{R}_0 = 2.55$



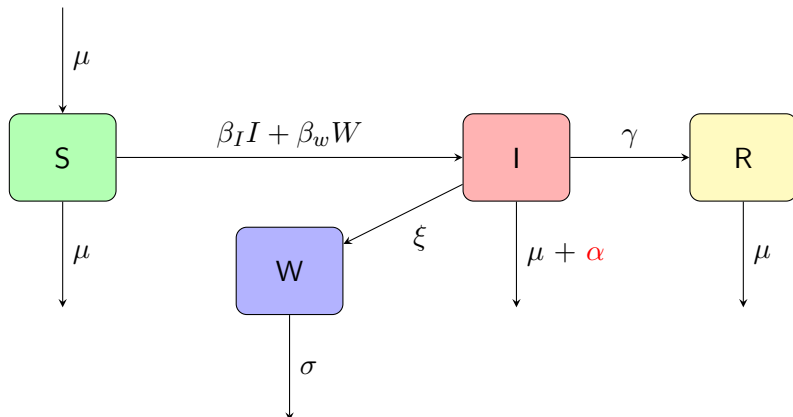
# Final Size

- Assuming  $\mu = 0$  and  $\mathcal{R}_0 > 1$ , final size formula still holds:
- $Z = 1 - e^{-\mathcal{R}_0 Z}$

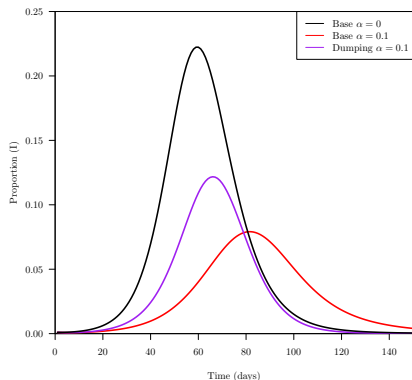


# Effects of the 19th Century Treatments

- Added parameter death caused by cholera ( $\alpha$ )



# Effects of the 19th Century Treatments



- Estimated death rate of cholera in the 19th century ranges from a small percentage up to fifty percent
- Including disease induced death is "beneficial" if death rate by cholera is high (Why?)
- Improper sanitation increases peak prevalence

# Multi-Patch Model

$$\frac{dS_i}{dt} = \mu N - \mu S_i - \beta_i S_i I_i - \phi \beta_i S_i \sum_j^n I_j - \beta_w S_i W_i - \psi \beta_w S_i \sum_j^n W_j$$

$$\frac{dI_i}{dt} = \beta_i S_i I_i + \beta_i \phi S_i \sum_j^n I_j + \beta_w S_i W_i + \beta_i \psi S_i \sum_j^n W_j - I_i(\gamma + \mu + \alpha)$$

$$\frac{dR_i}{dt} = \gamma I_i - \mu R_i$$

$$\frac{dW_i}{dt} = \xi I_i + \beta_i \psi I_i \sum_j^n W_j - \sigma W_i$$

# Multi-Patch Model Assumptions

- No dispersal of individuals
- Infected individuals can infect the susceptible in neighboring patches
- All patches neighbouring  $i$  have the same transmission rate to patch  $i$

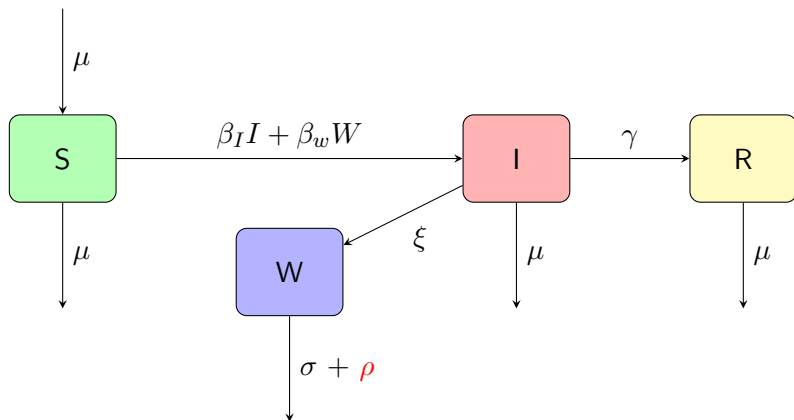
# Multi-Patch Model Simulation



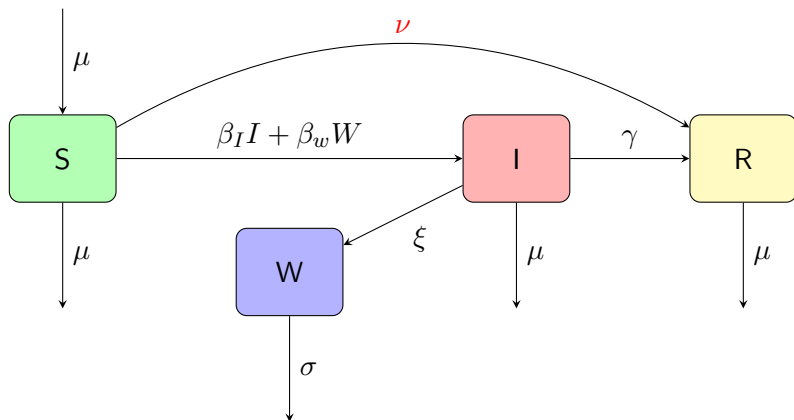
# Treatment Strategies For Cholera

- 1 Sanitation of Water
- 2 Vaccinations
- 3 Antibiotics

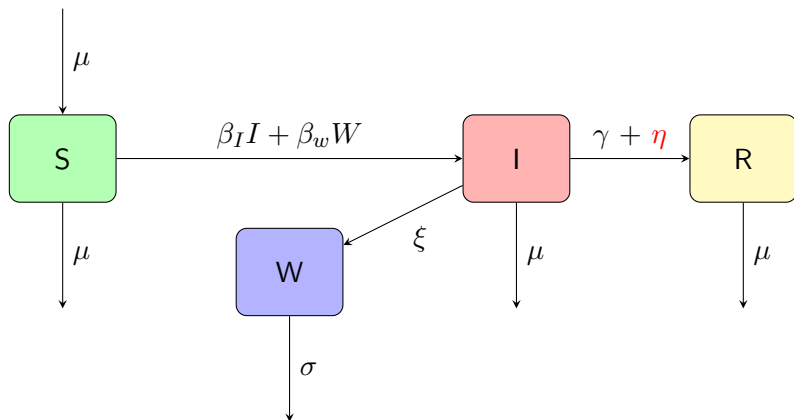
# Sanitation of Water



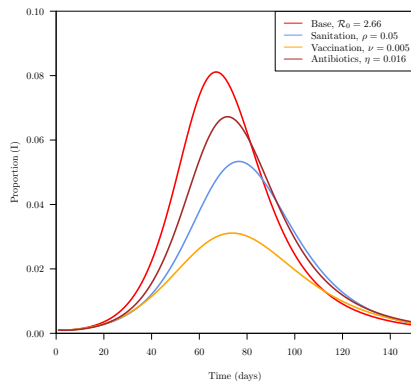
# Vaccinations



# Antibiotics



# Comparing the Treatment Strategies



# Conclusions and Further Research

- 19th century outbreaks
- Significance of the using multi-patch model
- Our treatment simulations suggest. . .
- Further research on the spread of water borne diseases like cholera can be done in areas like. . .

Thank you!

# References I