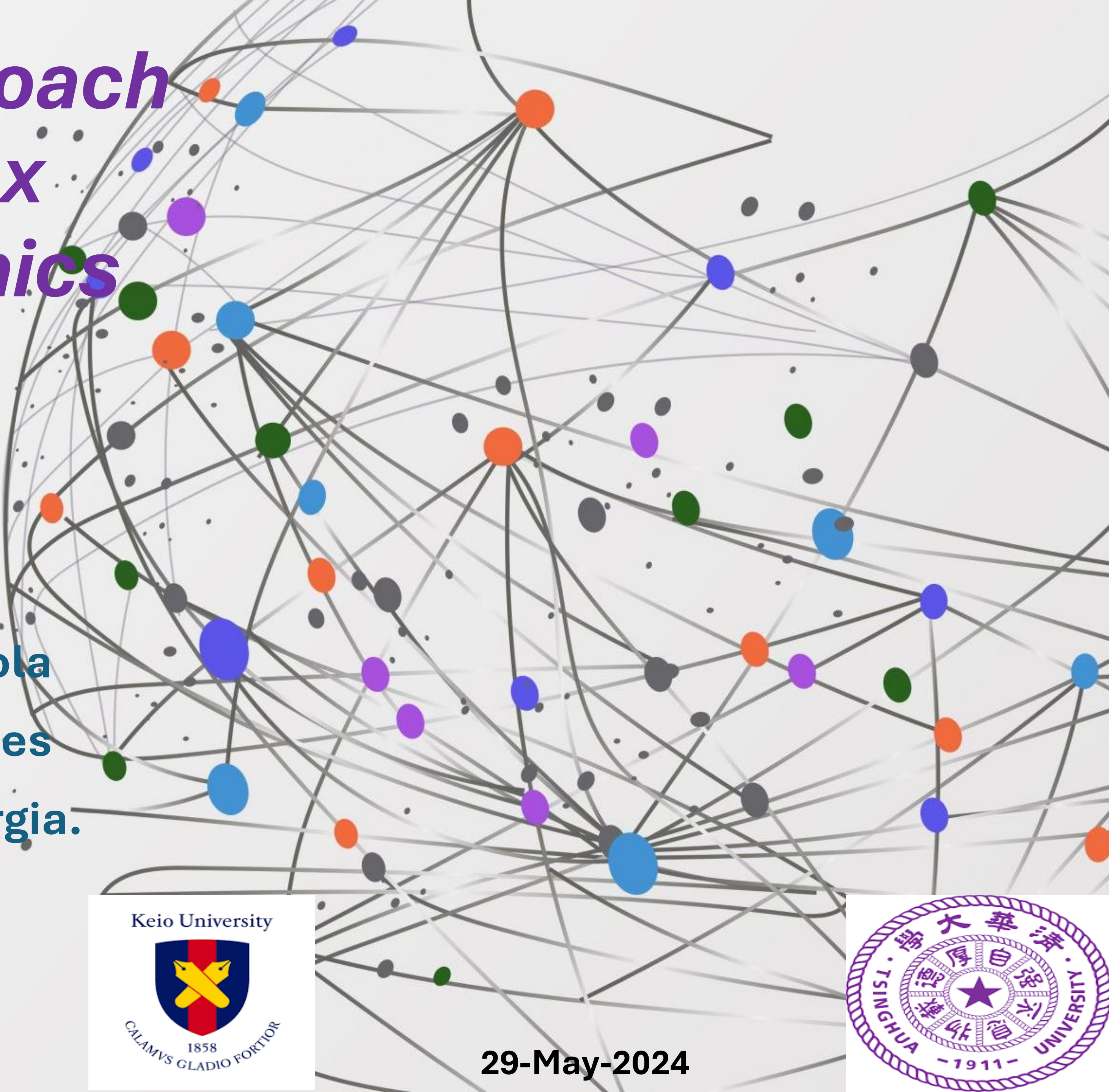
Epidemiological approach for mitigating Mpox transmission dynamics



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BU-Keio – Tsinghua workshop

29-May-2024

Outline

- BACKGROUND
- MODEL
- SENSITIVITY ANALYSIS
- SCENARIOS ANALYSIS
- PROBABILITY OF MAJOR OUTBREAK
- HERD IMMUNITY
- CONCLUSION AND RECOMMENDATION

Background

Mpox is a viral zoonotic disease. It was initially observed in central and western Africa

First identified in 1958 in monkeys. First human case recorded in 1970 in DRC.

Host: Rodents, Mammals and primates

Symptoms includes fever, rash, and swollen lymph nodes etc.

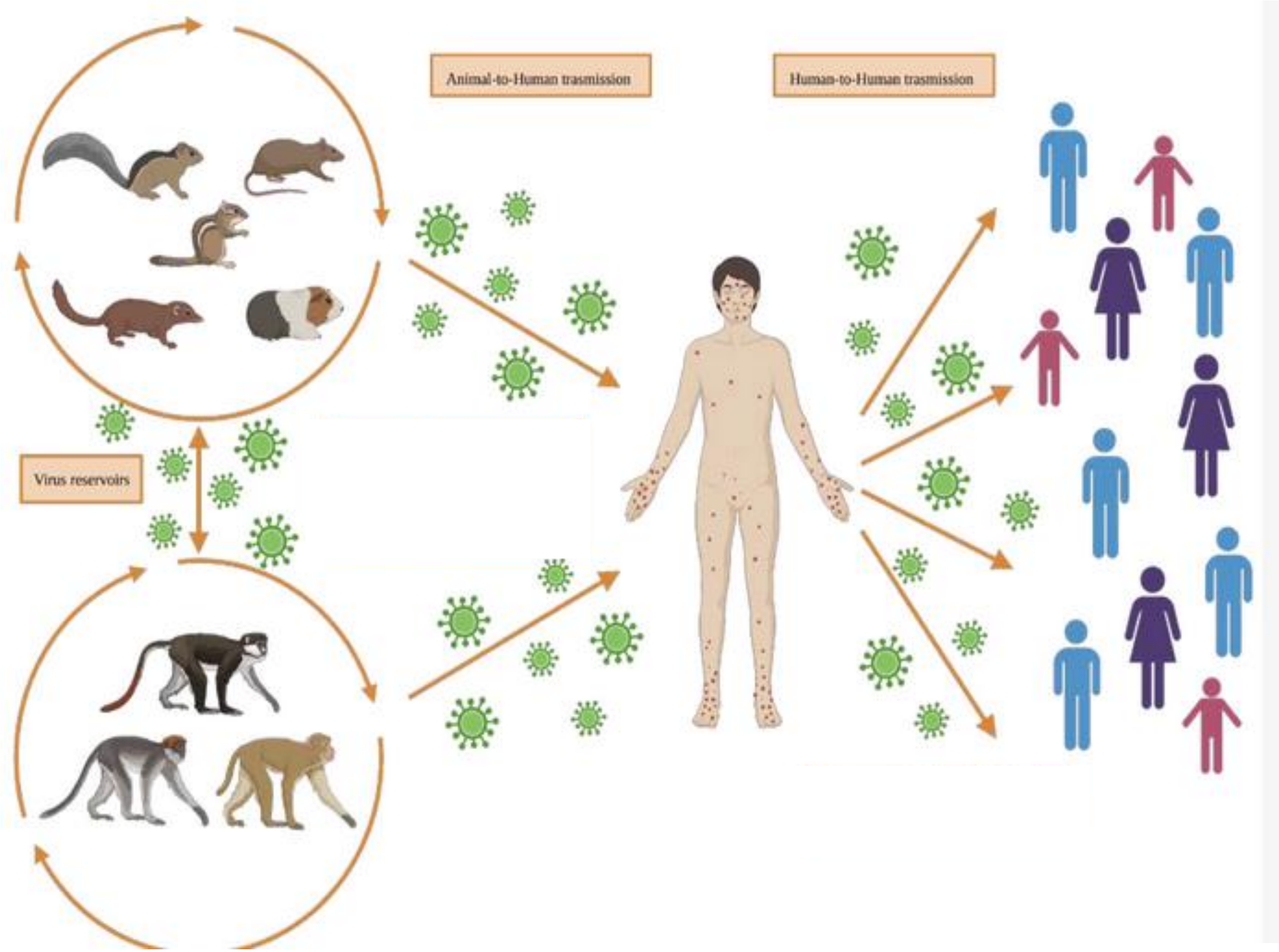
Often affect countries with tropical rainforests where the virus's animal hosts are found

Dynamics

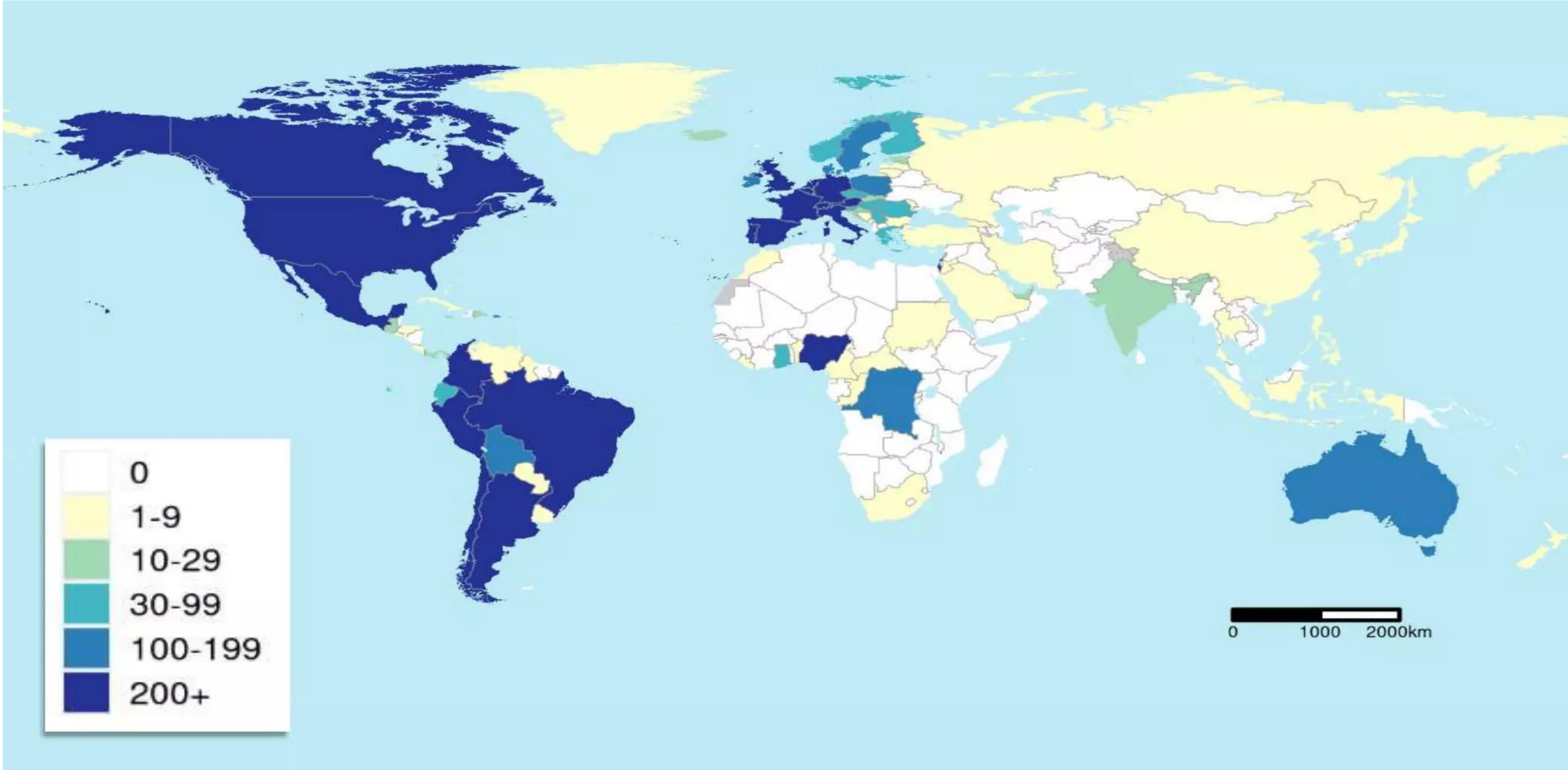
Transmission: Animal – to-human; Human-to-human transmission can through respiratory droplets.

Public Health Impact: The disease can lead to significant health issues, especially in regions with poor access to medical care.

Recent outbreaks have raised concerns due to their potential to spread beyond endemic areas, prompting increased surveillance and research.

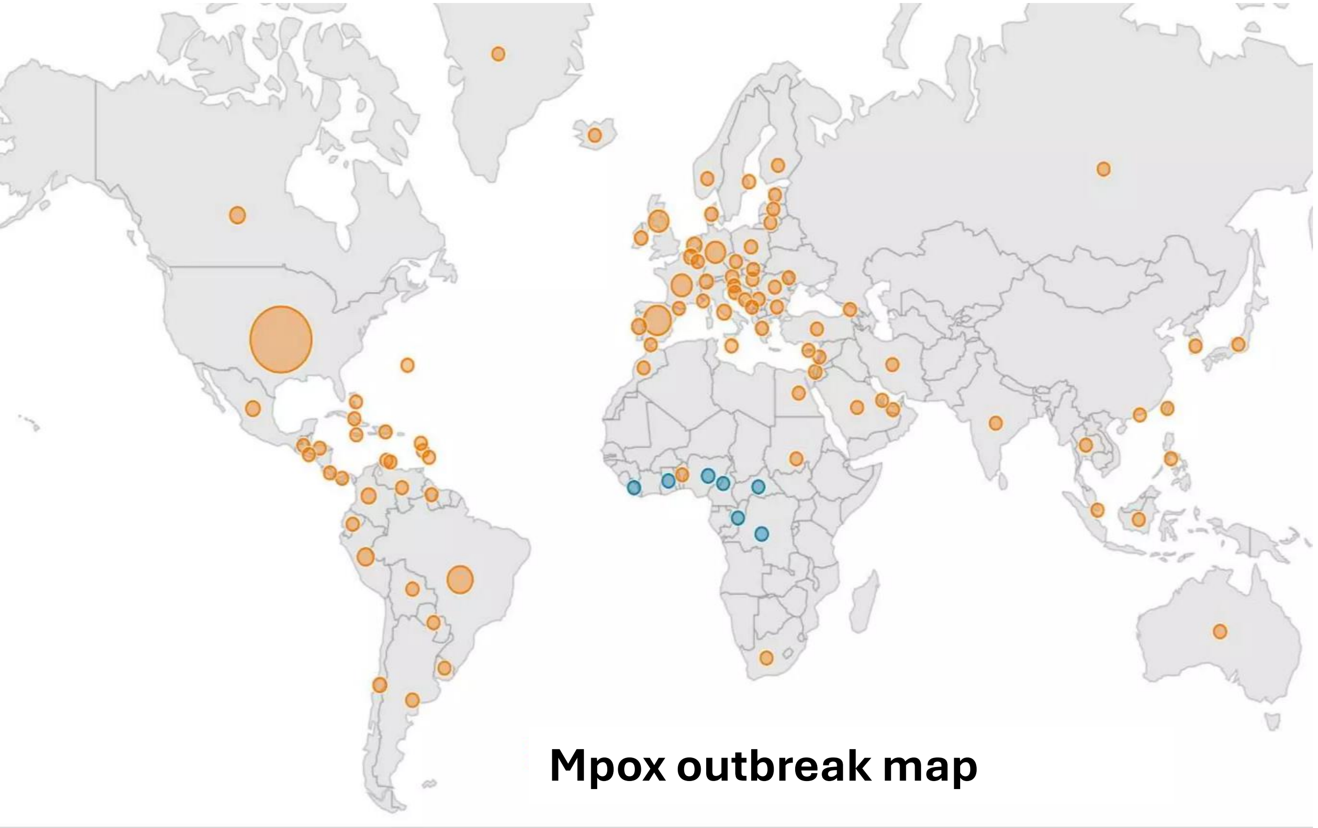


World Mpox spatial distribution

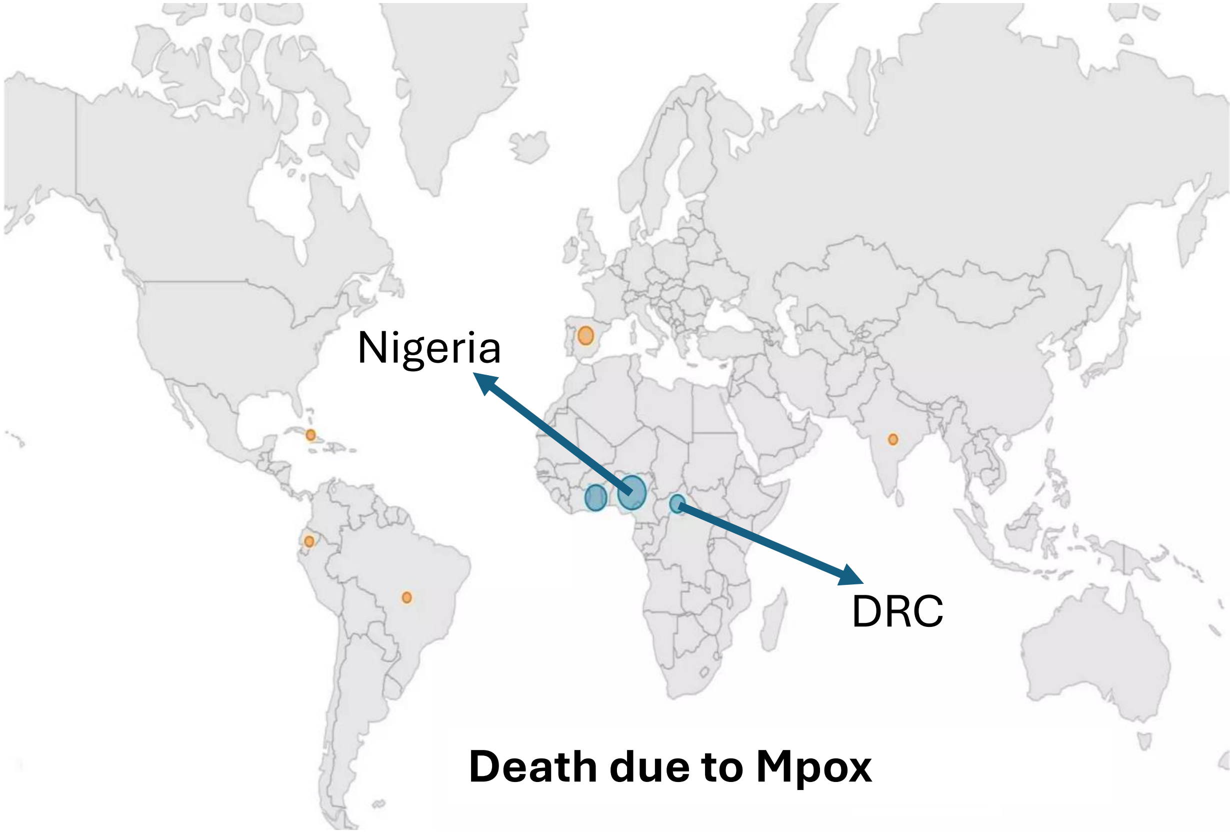


Source: WHO

Mpox cases



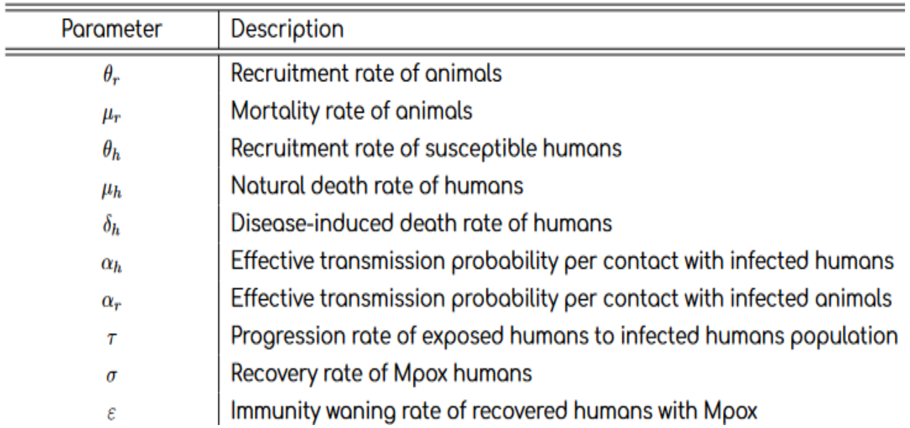
Mpox outbreak map



Death due to Mpox

Main Goal

To formulate a mathematical model to provide improve understanding on the dynamic of the Mpox transmission and an approach of mitigation.



Parameter	Description
θ_r	Recruitment rate of animals
μ_r	Mortality rate of animals
θ_h	Recruitment rate of susceptible humans
μ_h	Natural death rate of humans
δ_h	Disease-induced death rate of humans
α_h	Effective transmission probability per contact with infected humans
α_r	Effective transmission probability per contact with infected animals
τ	Progression rate of exposed humans to infected humans population
σ	Recovery rate of Mpox humans
ε	Immunity waning rate of recovered humans with Mpox

$$S_h' = \theta_h + \epsilon R_h - (\omega + \mu_h + \phi_1) S_h + \psi V_h;$$

$$V_h' = \omega S_h - (1-\gamma)\phi_1 V_h - \mu_h V_h - \phi V_h;$$

$$E_h' = \phi_1 S_h + (1-\gamma)\phi_1 V_h - (\tau + \mu_h) E_h;$$

$$I_h' = \tau E_h - (\sigma + \mu_h + \delta_h) I_h;$$

$$R_h' = \sigma I_h - (\mu_h + \epsilon) R_h;$$

$$D_h' = \delta_h I_h;$$

$$S_r' = \theta_r - (\theta_2 + \mu_r) S_r;$$

$$I_r' = \theta_2 S_r - \mu_r I_r;$$

$$\phi_1 = \frac{\alpha_h I_h + \alpha_r I_r}{N_h}; \quad \phi_2 = \frac{\alpha_r I_r}{N_r}$$

Infective contact rates

Main Goal

To formulate a mathematical model to provide improve understanding on the dynamic of the Mpox transmission and provide an approach of mitigation.

Vaccination rate

Vaccine efficacy

Vaccine waning rate

$$S_h' = \theta_h + \epsilon R_h - (\omega + \mu_h + \phi_1)S_h + \psi V_h;$$

$$V_h' = \omega S_h - (1-\gamma)\phi_1 V_h - \mu_h V_h - \phi V_h;$$

$$E_h' = \phi_1 S_h + (1-\gamma)\phi_1 V_h - (\tau + \mu_h)E_h;$$

$$I_h' = \tau E_h - (\sigma + \mu_h + \delta_h)I_h;$$

$$R_h' = \sigma I_h - (\mu_h + \epsilon)R_h;$$

$$D_h' = \delta_h I_h;$$

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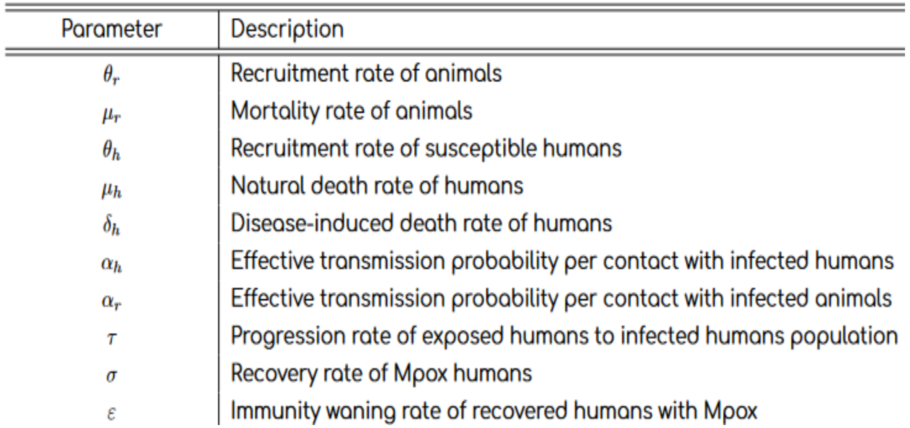

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$$\phi_1 = \frac{\alpha_h I_h + \alpha_r I_r}{N_h}; \quad \phi_2 = \frac{\alpha_r I_r}{N_r}$$

Infective contact rates

Reproduction Number: without vaccination

- $R_0^h = \frac{\alpha_h \tau}{(\mu_h+\tau)(\mu_h+\delta_h+\sigma)}$; Human

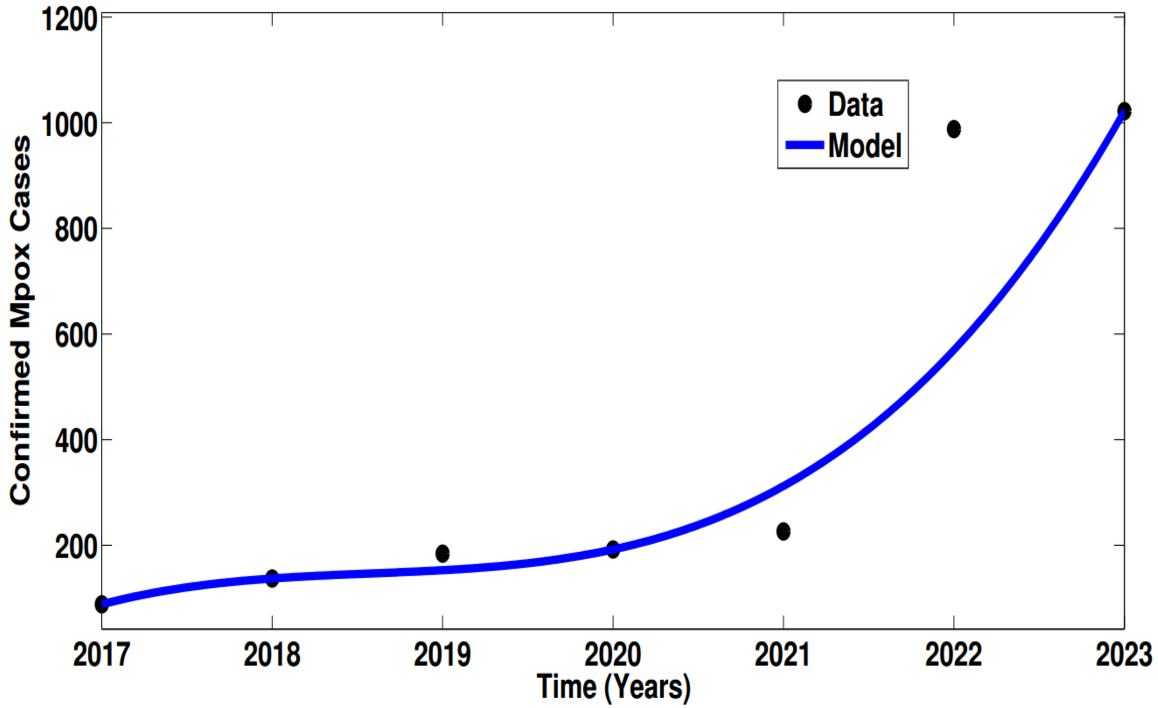
- $R_0^r = \frac{\alpha_r}{\mu_r}$; Animal

- $R_0 = \max\left(R_0^h, R_0^r\right) = \max\left(\frac{\alpha_h \tau}{(\mu_h+\tau)(\mu_h+\delta_h+\sigma)}, \frac{\alpha_r}{\mu_r}\right)$

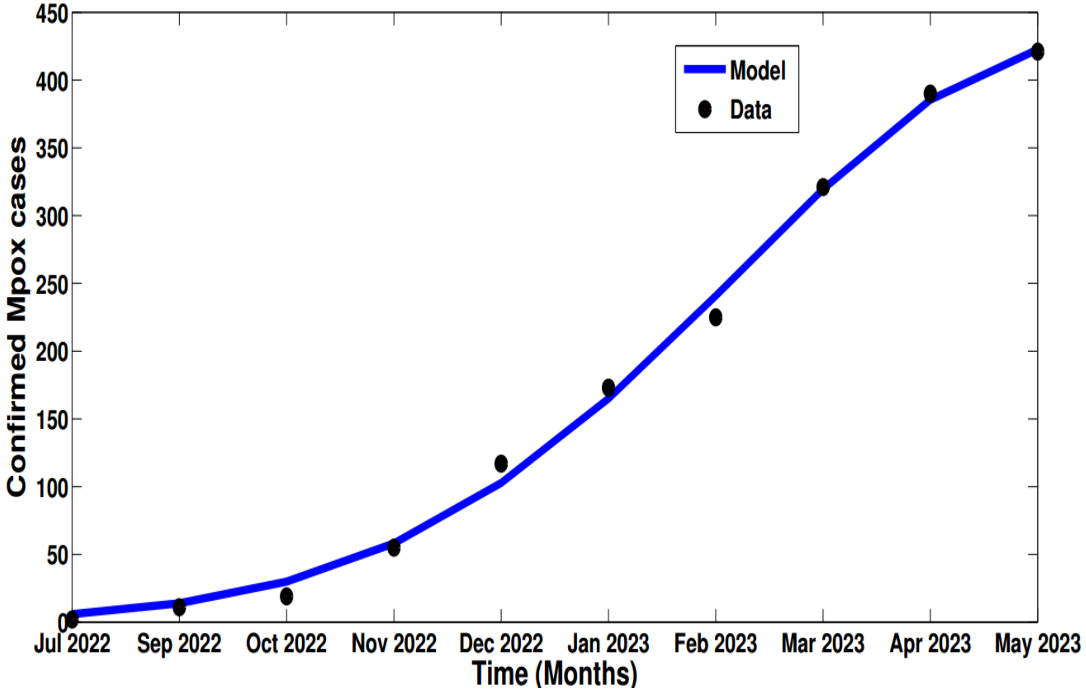
Reproduction Number: with vaccination

- $R_h^c = \frac{[S_h^* + (1-\gamma)V_h^*]\alpha_h \tau}{(\mu_h + \tau)(\mu_h + \delta_h + \sigma)}$; Human
- $R_r^c = \frac{\alpha_r}{\mu_r}$; Animal
- $R_0^c = \max(R_h^c, R_r^c) = \max(\frac{[S_h^* + (1-\gamma)V_h^*]\alpha_h \tau}{(\mu_h + \tau)(\mu_h + \delta_h + \sigma)}, \frac{\alpha_r}{\mu_r})$
- $S_h^* = \frac{\theta_h(\mu_h + \psi)}{\mu_h(\mu_h + \omega + \psi)}$ $V_h^* = \frac{\theta_h \omega}{\mu_h(\mu_h + \omega + \psi)}$

Case studies: Nigeria and DRC



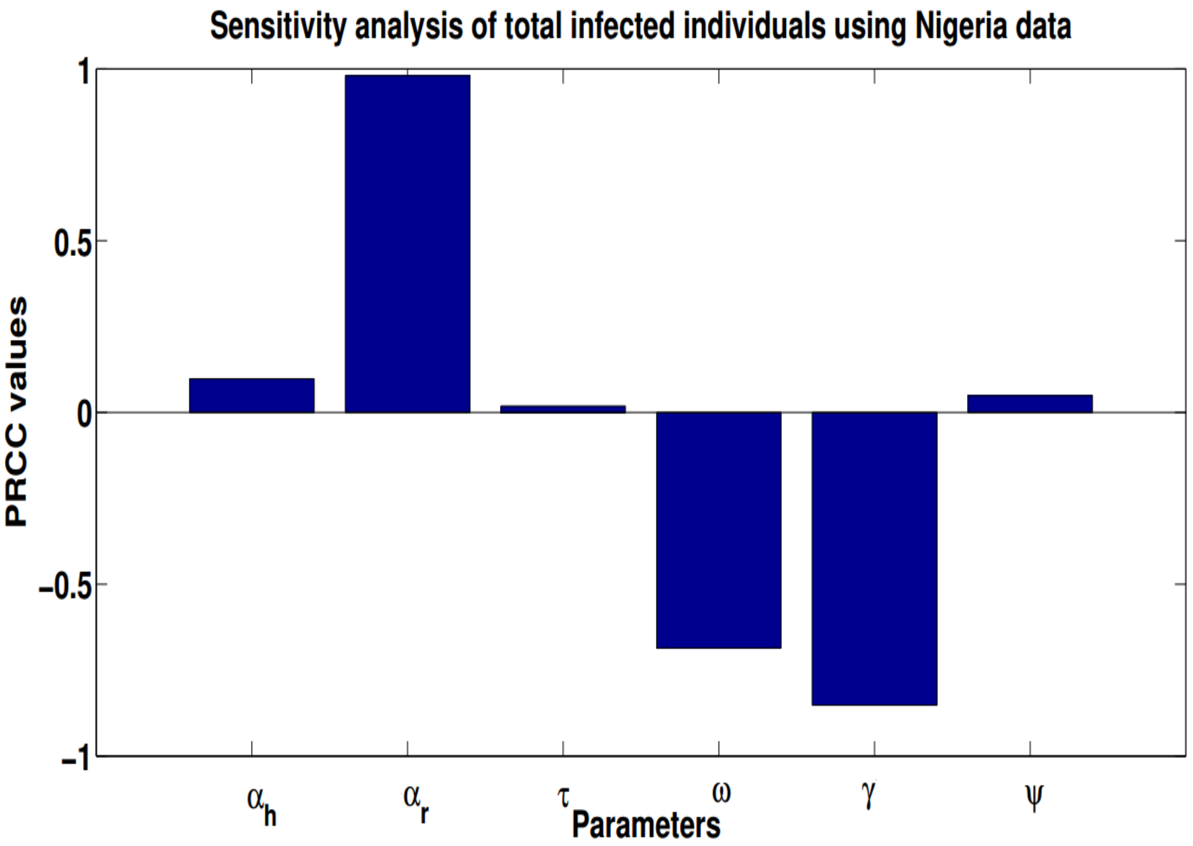
Nigeria

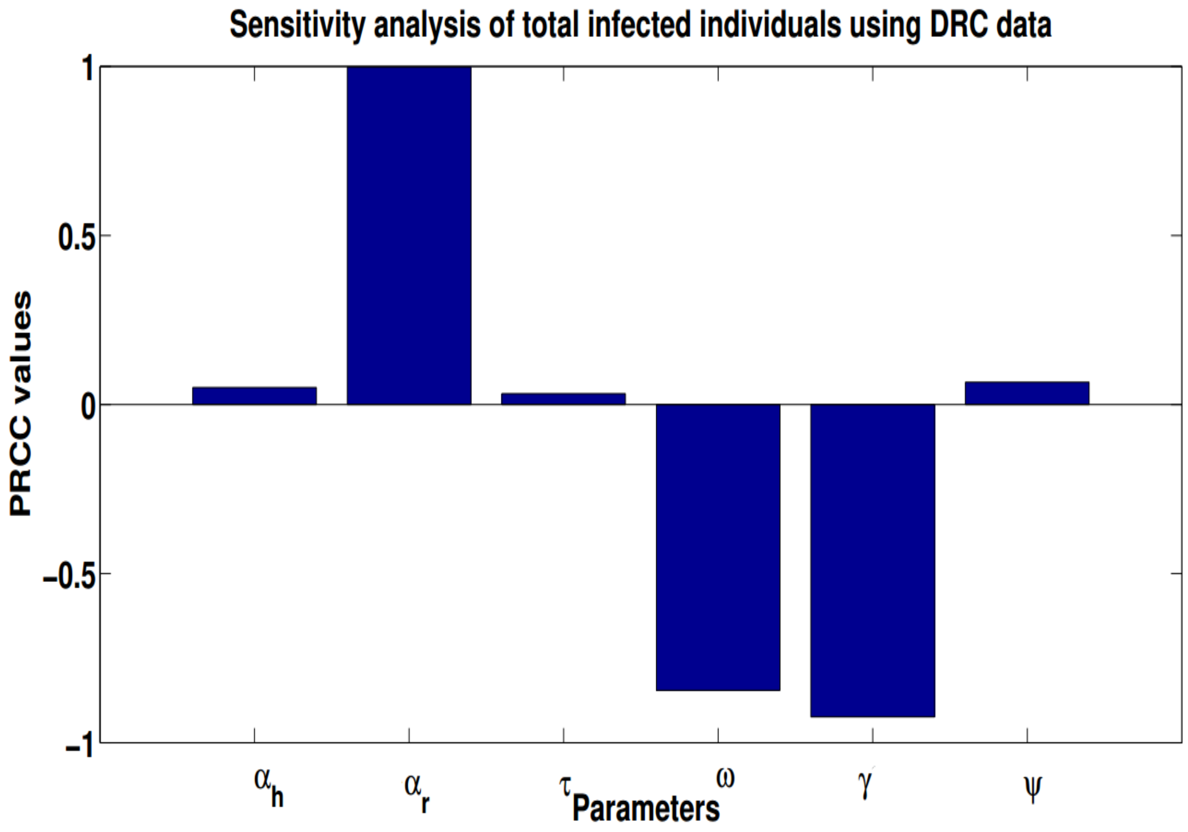


DRC

$$R_0 = \{R_{0N}, R_{0D}\}$$

Sensitivity Analysis

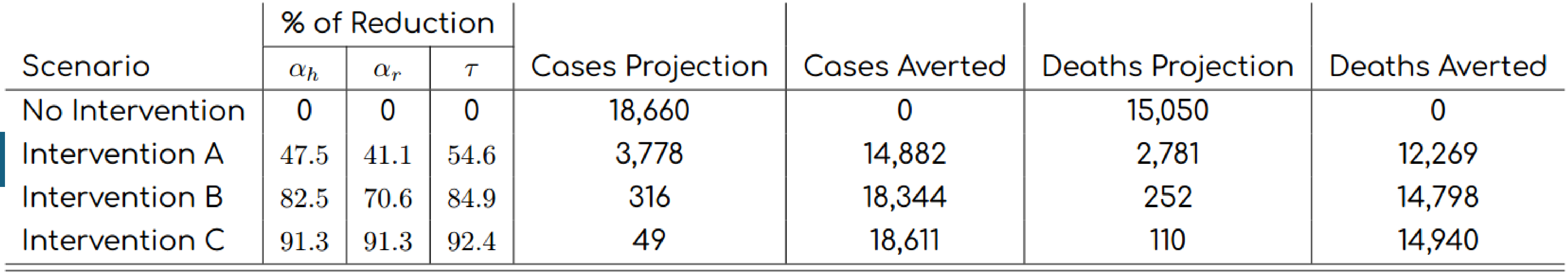

Sensitivity analysis of total infected individuals using Nigeria data


Sensitivity analysis of total infected individuals using DRC data

The Partial rank correlation coefficient shows the relationship between the parameter and the model.

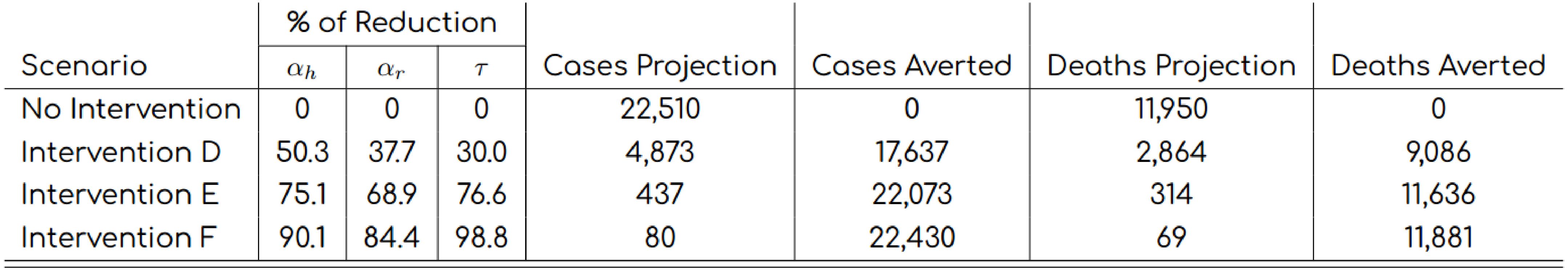
Scenario Analysis

Nigeria



Scenario	% of Reduction			Cases Projection	Cases Averted	Deaths Projection	Deaths Averted
	α_h	α_r	τ				
No Intervention	0	0	0	18,660	0	15,050	0
Intervention A	47.5	41.1	54.6	3,778	14,882	2,781	12,269
Intervention B	82.5	70.6	84.9	316	18,344	252	14,798
Intervention C	91.3	91.3	92.4	49	18,611	110	14,940

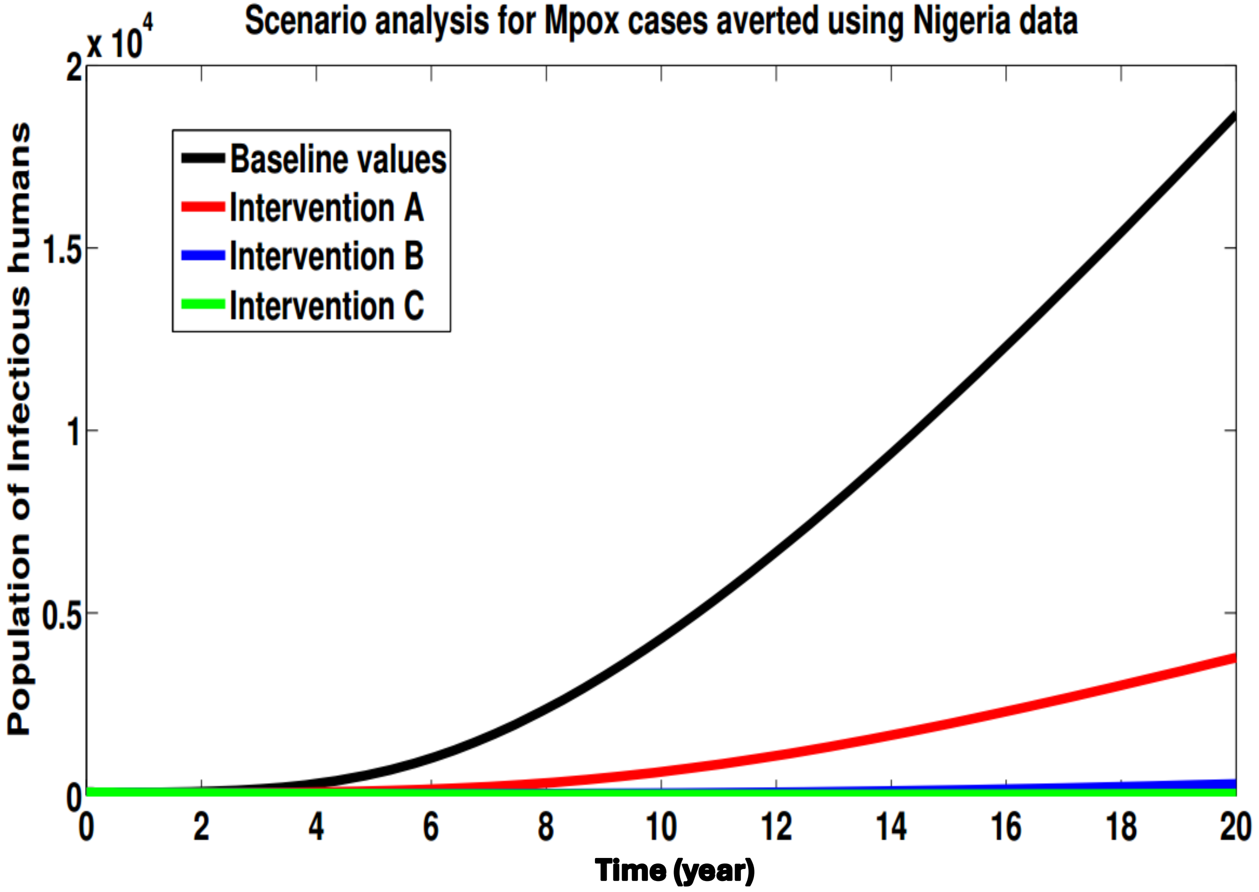
DRC

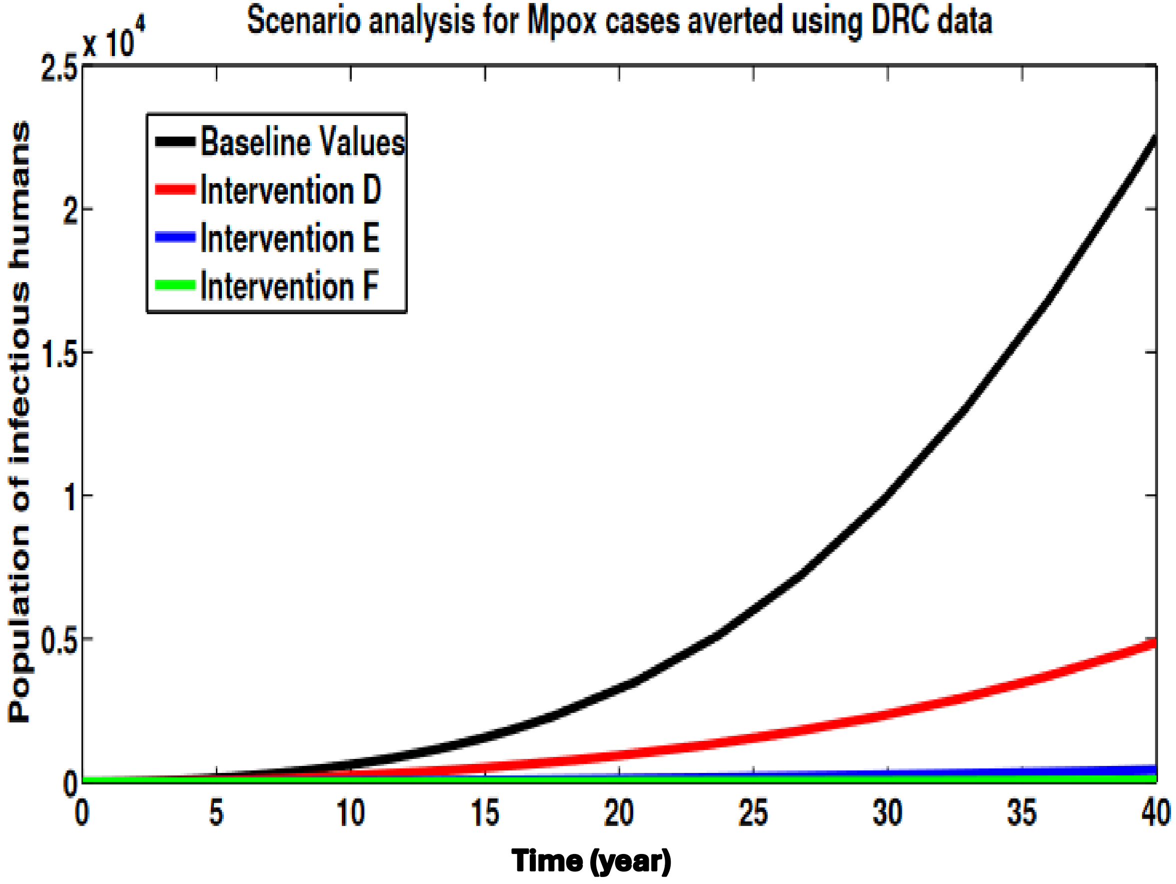


Scenario	% of Reduction			Cases Projection	Cases Averted	Deaths Projection	Deaths Averted
	α_h	α_r	τ				
No Intervention	0	0	0	22,510	0	11,950	0
Intervention D	50.3	37.7	30.0	4,873	17,637	2,864	9,086
Intervention E	75.1	68.9	76.6	437	22,073	314	11,636
Intervention F	90.1	84.4	98.8	80	22,430	69	11,881

Transmission probability and human projection rate

Graphical Representation





College of
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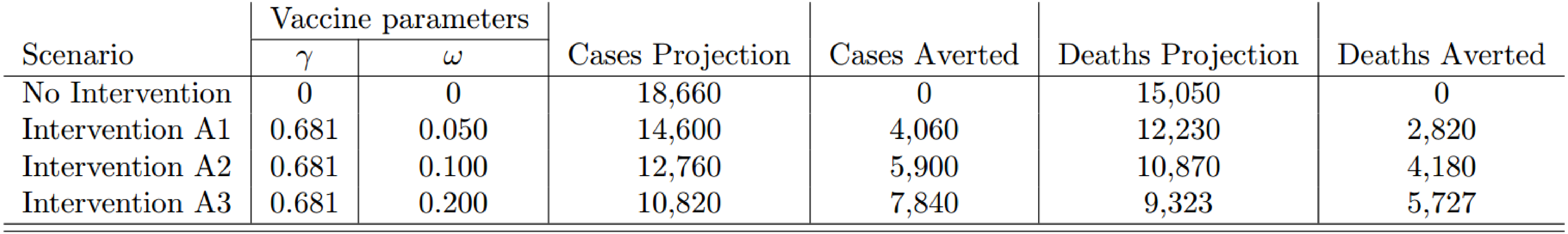
UNIVERSITY OF GEORGIA

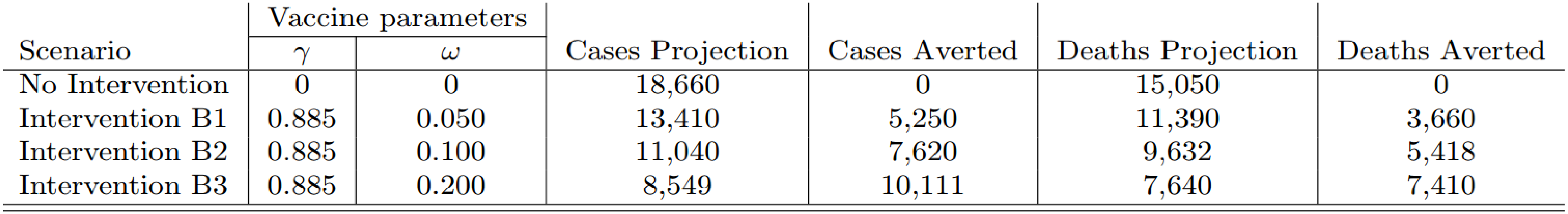
Center for
Applied
Pathogen
Epidemiology
and Outbreak Control

Vaccination



Scenario	Vaccine parameters		Cases Projection	Cases Averted	Deaths Projection	Deaths Averted
	γ	ω				
No Intervention	0	0	18,660	0	15,050	0
Intervention A1	0.681	0.050	14,600	4,060	12,230	2,820
Intervention A2	0.681	0.100	12,760	5,900	10,870	4,180
Intervention A3	0.681	0.200	10,820	7,840	9,323	5,727

Vaccine effectiveness of 68% (one dose)



Scenario	Vaccine parameters		Cases Projection	Cases Averted	Deaths Projection	Deaths Averted
	γ	ω				
No Intervention	0	0	18,660	0	15,050	0
Intervention B1	0.885	0.050	13,410	5,250	11,390	3,660
Intervention B2	0.885	0.100	11,040	7,620	9,632	5,418
Intervention B3	0.885	0.200	8,549	10,111	7,640	7,410

Vaccine effectiveness of 85.5% (double doses)

Double doses provides more protection against the virus compared to the single dose.

Probability of Outbreak: without vaccine

The probability of an outbreak starting from m infectious hosts is estimated by

$$P_m = \left(1 - \frac{1}{R_0}\right)^m$$

$$\left.\begin{array}{l} R_{0N} = 1.2027 \\ R_{0D} = 1.1038 \end{array}\right\} \Longrightarrow \boxed{\text{Endemic}}$$

we have $R_0 = \{R_{0N}, R_{0D}\} > 1$, this confirm that the disease is endemic in both Nigeria and DRC with high probability of outbreak.

Probability of Outbreak: incorporating vaccine

$$P_m^c = \left(1 - \frac{1}{R_0^c}\right)^{2m},$$

$$\left.\begin{aligned} R_{0N}^c &= 0.6887 \\ R_{0D}^c &= 0.6349 \end{aligned}\right\}$$ Single dose

$$\left.\begin{aligned} R_{0N}^c &= 0.5361 \\ R_{0D}^c &= 0.4943 \end{aligned}\right\}$$ double doses

We have $R_0^c = \{R_{0N}^c, R_{0D}^c\} < 1$, this confirm that the disease is not endemic with low probability of outbreak.

The higher the number of observed cases, the greater the probability of major outbreak within the region.

Herd Immunity

It’s an indirect method of protection that is effective against infectious diseases.

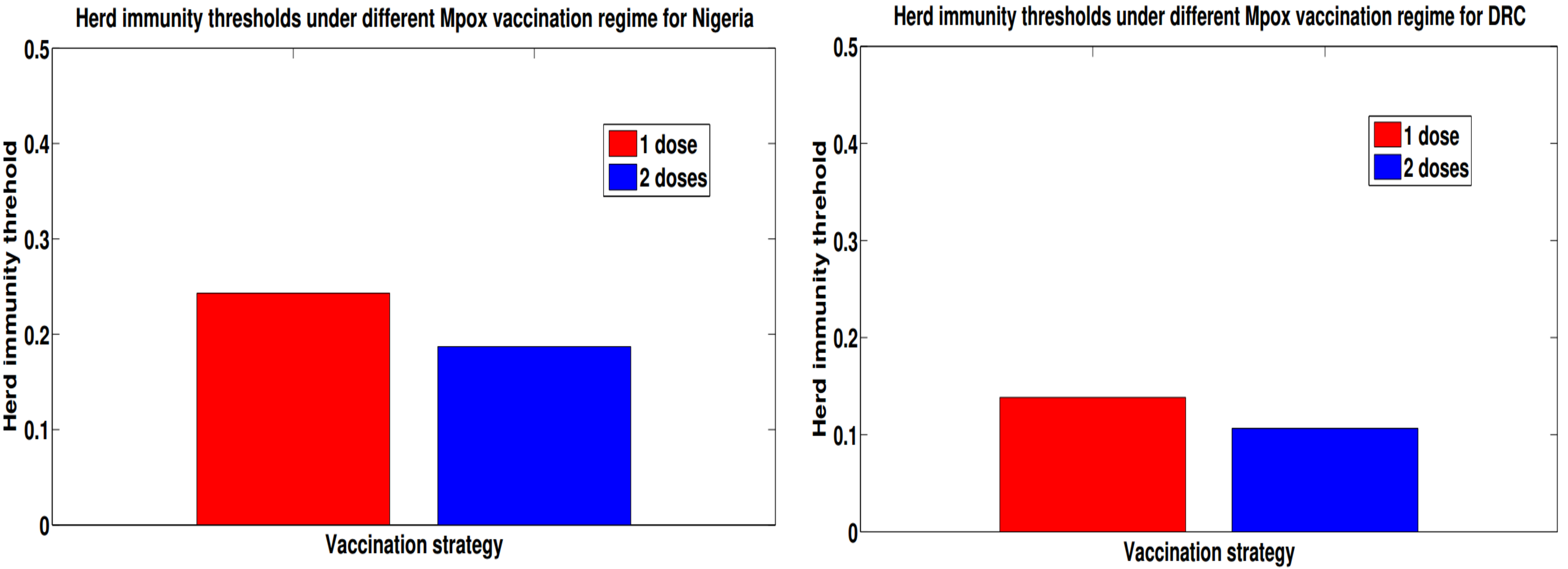
The vaccine induced herd immunity is given as

$$\Phi_N = \frac{R_{0N}}{R_{0N} - R_{0N}^c}(1 - \frac{1}{R_{0N}})$$

$$\Phi_D = \frac{R_{0D}}{R_{0D} - R_{0D}^c}(1 - \frac{1}{R_{0D}})$$

with $R_{0N}^v, R_{0N}^v \in (0,1)$

Herd Immunity



23.43% of the total susceptible population would have to be vaccinated in order to eliminate Mpox from Nigeria, whereas, for double doses, at least 18.70% of the total susceptible population would have to be vaccinated in order to eliminate Mpox from Nigeria.

Summary

- The work presented a model to assess the dynamics of Mpox transmission and control measure.
- Parameter estimation was carried out to identified the values for model simulation.
- It was observed that the probability of outbreak in the absence of vaccination.
- Sensitivity analysis was conducted using PRCC and decreases with the vaccine rate and efficacy.
- Finally, it assess the scenario for herd immunity which indicate the efficiency of vaccine.

Thank you for your attention.