MATH 572

Monkey Pox in the United States

Forecasting the effectiveness of educational intervention

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Group Contributions

Hedieh Kalachahi (1467616): Initial project idea, sensitivity analysis research, final draft review, and data source research.

Saira Faiz (1775398): First proposal draft, initial research, final draft review, and project planning

Colby Jamieson (1714722): Proposal review and drafting, research objectives, initial model, and mathematical analysis.

Abstract

Monkeypox is one of the viral diseases which can result in mild to severe illness depending on the individual immunity in humans. This was used to be transmitted through animals (specially rodents) to humans or through humans to human, but in the most recent global outbreak reported a tremendous increase in the disease due to human-to-human contact. Which requires a through research of the disease to see effect of different prevention and control strategies.

In this project, we have developed a mathematical model to check the transmission dynamics of the monkeypox and the impact of education as a prevention measure. We have developed two models, firstly, the simple Susceptible-Exposed-Infectious-Recovered (SEIR) model. Which is used to fit the parameters and then the model is expanded to use education or information to the public as a control to manage the outbreak when effective treatment or vaccination is not available. while the second have education effect on all of the three compartments susceptible-exposed-infectious-recovered. For the analysis purpose, firstly we fitted the data using parameter fitting for prediction purpose and then used the sensitivity analysis to determine which are the key factors that influence the infections.

The results show that even a small amount of education can have a significant impact on educing the spread of monkey pox. Educating just 0.4% of the susceptible population per day could lead to a 98% decrease in total infections. However, the model has limitations that should be addressed in future work, such as stratifying the population into different risk groups and better

aligning the education rate with real-world interventions. Despite these limitations, the study highlights the potential of education programs in preventing the spread of infectious diseases.

Introduction

The monkeypox virus was first discovered in humans in 1970 and has since become endemic in the Democratic Republic of Congo and has spread to other nearby countries in central and west Africa (Parker & Buller, 2013).The disease has garnered more attention recently due to numerous outbreaks around the world, especially in the United States. It is also notable for its similarity to smallpox, a disease that killed an estimated 300 million since the year 1900 (Mohr).

Monkeypox can be transmitted from contact between humans and infected rodents; however, the most recent outbreaks have occurred primarily due to close human-to-human contact. Transmission usually occurs from direct contact with infected rashes, scabs, and bodily fluid, but can also be transmitted by respiratory secretions. Typically, illness is moderate and resolves within 2-4 weeks, with those who are immune compromised having more severe symptoms, with the possibility of death (Peter, et al., 2022).

To model the transmission of the virus and effectiveness of educational interventions, a compartmental mathematical model evaluated at different levels of intervention is developed. Once the model is calibrated, simulations will indicate how effective an educational programme would be in reducing the transmission of the virus.

Given different levels of educational effectiveness and coverage, the project objectives are to determine:

- Total population infected.
- Total days until population is disease-free.

Methods

A simple SEIR model is used to first describe infection dynamics without intervention. With data from the Center for Disease Control and Prevention collected during the 2022 United States monkeypox outbreak, we fit our initial model to determine the infection rate parameter.

The initial model comprises of four compartments:

- Susceptible population
- Exposed hosts
- Infected hosts
- Recovered

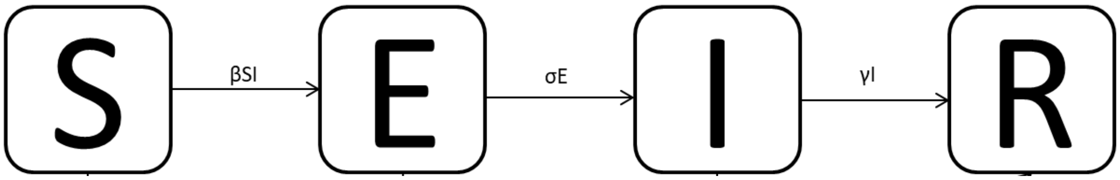


Figure 1 The original SEIR model is fit to data and estimates the infection rate parameter β.

Each compartment has parameters that control the rate of flow of hosts from one compartment to the others. Beta (β) is the rate at which the susceptible population is exposed to the virus and will eventually become infected. Sigma (σ) is the rate at which people in the exposed compartment become infected, and contagious. Lastly, gamma (γ) is the recovery rate.

Parameter	Symbol	Value
Infection rate	β	0.0006
Latency rate	σ	0.83
Recovery rate	γ	0.20

Figure 2 Parameter values for initial SEIR model. (Peter, et al., 2021)

With model parameter calibrated, the initial model is expanded to include compartments for those within the population who receive infection prevention education. People in the susceptible, exposed, and infected compartments flow into the educated stream at a constant rate alpha (α), and are assumed to have a smaller infection rate and to not spread the disease when infected. The recovery rate and latency period are assumed to remain the same.

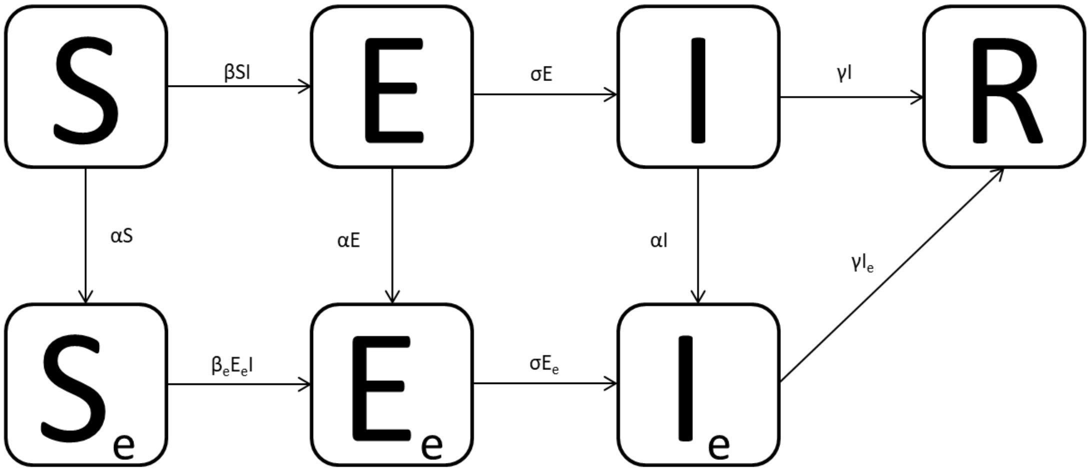


Figure 3 The modified model adds compartments for those who have received the educational intervention.

System of Equations:

$$\frac{dS}{dt} = -\alpha S - \beta SI$$

$$\frac{dS_e}{dt} = \alpha S - \beta_E S_E I$$

$$\frac{dE}{dt} = \beta SI - \alpha E - \sigma E$$

$$\frac{dE_e}{dt} = \beta_E S_E I + \alpha E - \sigma E_e$$

$$\frac{dI}{dt} = \sigma E - \alpha I - \gamma I$$

$$\frac{dI_e}{dt} = \sigma E_e + \alpha I - \gamma I_e$$

$$\frac{dR}{dt} = \gamma I + \gamma I_e$$

Variables and Parameters:

Population variables:

S – susceptible

S_e – susceptible population that received educational intervention

E – exposed

E_e – exposed population that received educational intervention

I – Infected

I_e – infected population that received educational intervention

Parameters:

β – infectious rate for susceptible population

β_e – infectious rate for susceptible population that received educational intervention

σ – exposed to infected rate

γ – recovery rate

α – education rate

Alpha is considered a parameter that can be influenced by public policy; and therefore, is set to different levels and analyzed, to be interpreted as the coverage a particular intervention would have in the population. The infectious rate of the educated stream is also set to differing levels and interpreted as intervention efficacy. Efficacy ranges from 0% to 4%; therefore, we test interventions at selected levels in this interval.

Intervention Type	Risk Reduction
Abstinence	0%
Comprehensive	4%
All types	1%

Figure 4 Estimated risk reduction by intervention type [citation].

To ensure that the model is comprehensive enough to be useful but simple enough to be computationally feasible and interpretable, a number of assumptions are made:

1. Horizontal transmission through direct contact with infected
2. Homogeneous individual mixing
3. Rate of transfer proportional to population size of compartment
4. Infected individuals have latency period
5. Full acquired immunity
6. No input or output of individuals through birth, migration, or death

7. Those infected that receives education quarantines and do not spread the disease that is why recovered individual do not go to the susceptible compartment.
8. People in each compartment receives education at a constant rate.
9. Recovery rate is constant for each infected compartment
10. Individuals represented in data are considered not educated
11. Effectiveness of educational interventions studied are comparable to proposed mpox intervention
12. There is no vaccine

The model is run on each selected combination of intervention coverage and accuracy. The total infected is determined to be the number in the recovered compartment after the outbreak has run its course. This is our indication of intervention effectiveness by total number of people affected. The number of days between day 0 and when there are no new infections will be considered the length of the outbreak. To determine the degree to which the intervention effectiveness and coverage affects infections, a sensitivity analysis is performed. With these results the objectives of this study will be reached.

Results and Discussion:

Model Fitting

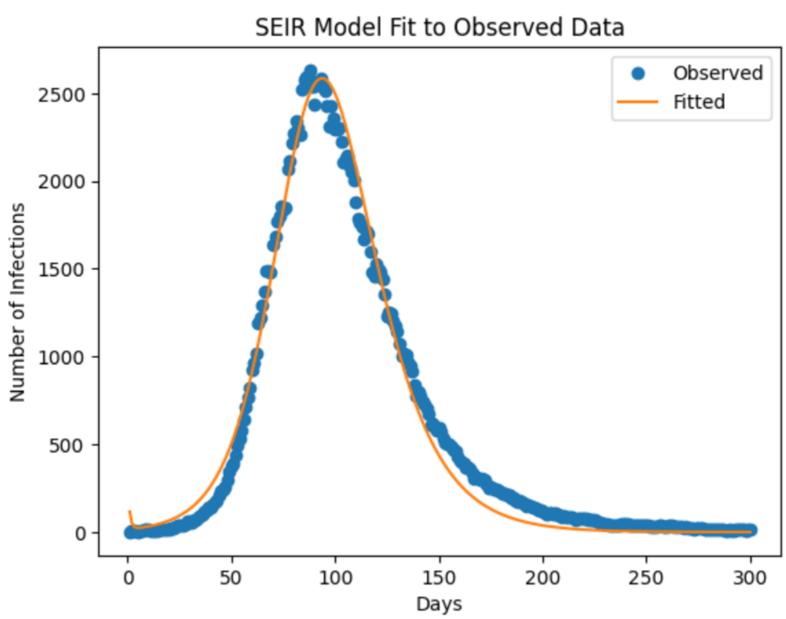


Figure 3 The model is fit to real infection data to find optimal parameter values.

The data was collected from the centers for disease control and prevention (CDC, n.d.) from May 2022. We used 300 days data relating to the US cases for fitting purpose to find the optimal values of the parameters to match the observed data of the monkey pox. We applied non-linear least squares method for the fitting purpose to extract the parameter values.

Which was then used for prediction purpose about the future number of infections to evaluate the impact of education on the outbreak of the disease.

Parameter	Optimized value
Infected (β)	0.00000841
Latency rate (σ)	0.095
Recovery rate (γ)	0.891

Figure 4 Optimized parameter values

Model fitting was successful and the optimized parameter values were found. When comparing optimal values to initial guesses, the infection and latency rates decreased while the recovery rate decreased. All parameters remained within an appropriate bound.

Effect of different levels of education on the number of people infected.

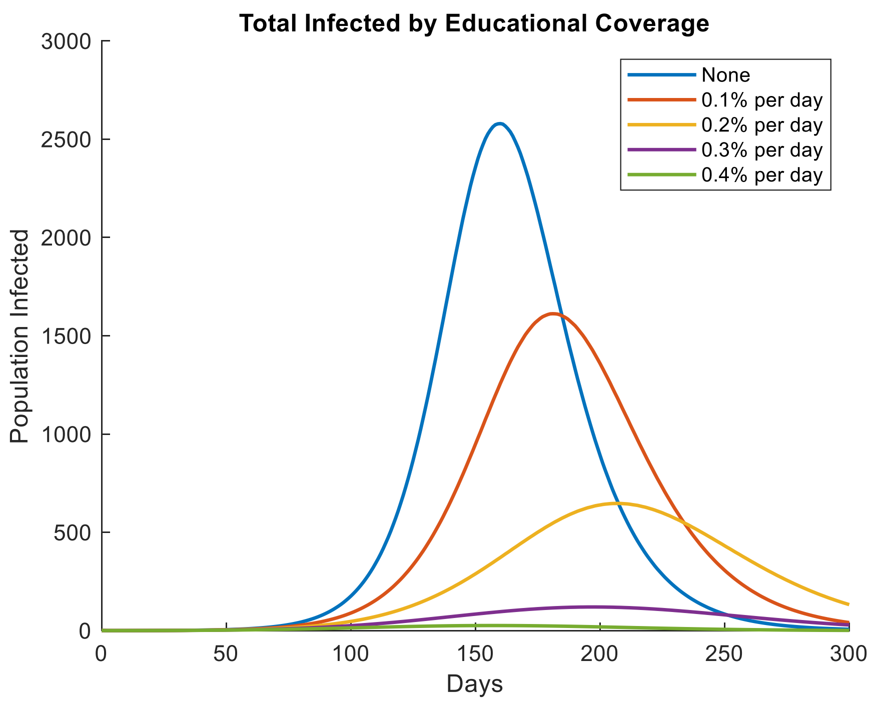


Figure 5 Education significantly decreases peak infections.

Monkey pox is transmitted by physical contact from animal to humans or humans to humans that is why we believe that if there introduce the educational interventions, where people are educated about the importance of good hygiene and maintaining safe distance from infected people and animals and quarantine, it will help in reducing the number of infected people.

For out model we used four level of education from 0.1% to 0.4% along with the base model without education intervention. As it is visible that the number of infected people were highest without any education intervention, however, as we introduced the education, cases reduced, and graph become flatter with the 0.4% education intervention.

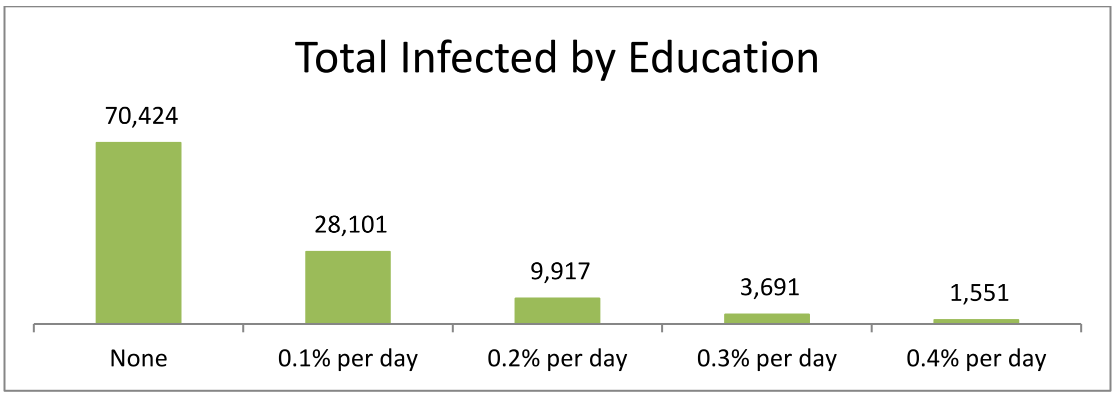


Figure 6 Education significantly decreases total infected

The results are well clear and visible in this graph, where it was seen that when there was no education per day, the total number of infected individuals were 70,424. It decreased to 28,101 infected individuals by increasing education level 0.1% per day. Further, it reduced to 9,917 individuals at 0.2%, 3,691 cases at 0.3% and 1,551 when the education level was 0.4%.

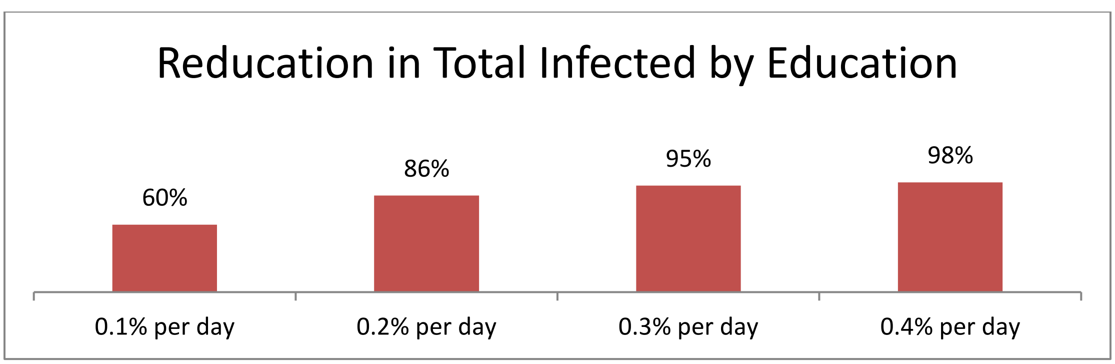
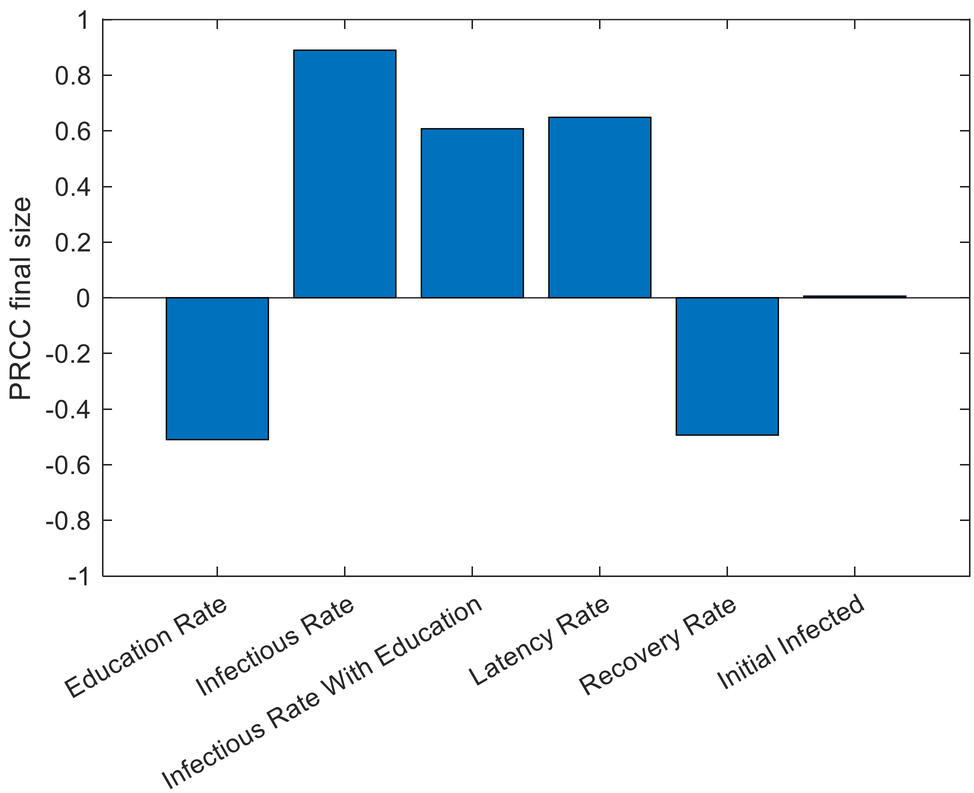


Figure 7 An education rate of 0.4% per day decreases total infections by 98 per cent.

This graph validates the above results. Where 0.1%-0.4% education decreased infected individuals by 60% to 98%.

Sensitivity Analysis:



For this model, we also used the sensitivity analysis to assess the impact of change in different parameters to the output of the model to see which parameter has the greatest impact on the transmission of the monkeypox.

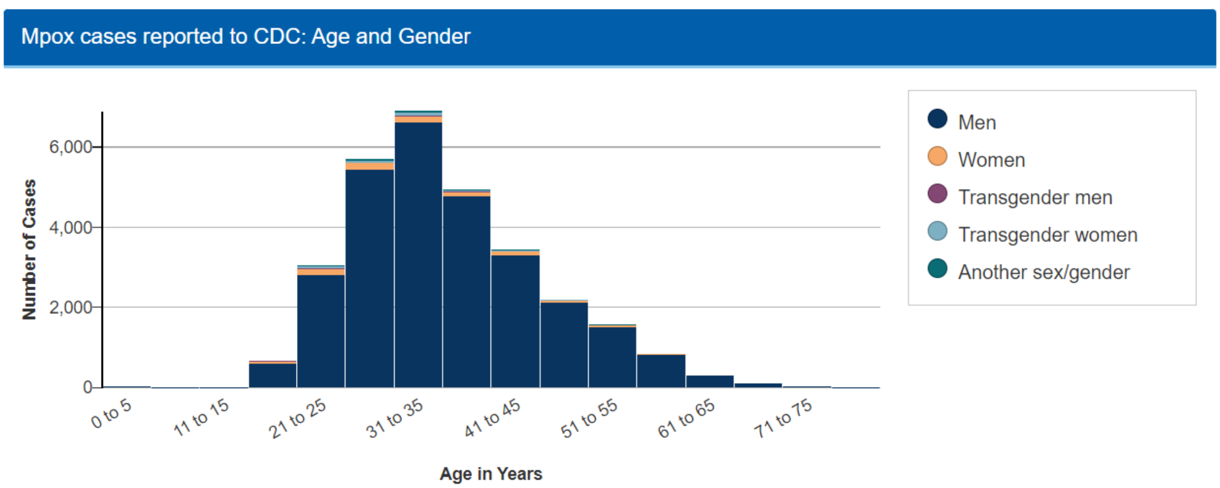
We can see from the above graph that the education and the recovery rate have a negative impact on the total number of infected people. This means that an increase in the education and the recovery rate will has the negative from the monkey pox will lead to a decrease in the total number of infected individuals. This suggests that education and effective treatment can play an important role in reducing the spread of monkeypox.

Latency rate has the positive relation with infections which means that an increase in the latency period will increase the number of infected people. This indicates that it has significance influence on the monkeypox transmission.

Finally, infectious rate with education has less of an effect than original infectious rate " means that the effect of the infectious rate on the total number of infected individuals is reduced when education is taken into account. This suggests that education can mitigate the impact of a high infectious rate on the spread of monkeypox.

Limitations

Most of the latest monkeypox cases are appearing from the gay and bisexual population of men, which is clearly shown in the following graph (Gay, n.d.)



However, there is not well-maintained data on gender base so that we can fir our model to find the parameter on this base and get better prediction.

There is no treatment/ vaccination invented specifically for the monkeypox, and moreover, there is no data available relating to the vaccinated people and control measure for an implemented policy of quarantine. This will help in better understanding and accurately predicting the dynamics of transmission of monkey pox.

The data sets for monkey pox are limited and primarily well-maintained in select countries. Due to the relatively small sample size, the data may contain significant noise and outliers that could potentially impact the accuracy of the parameter values.

To fit our model, we utilized data pertaining to infected individuals in the US. However, as no research related to the region was available, we obtained initial parameter values from research conducted in African countries.

Future directions

We should include cost of the education, since in the situation of limited resources, the balance between the between the lower number of infected people and the cost of the awareness campaign should be evaluated for an optimal control policy.

we should also access the effect of the intervention such kind of vaccination and quarantine measures to see how they could affect transmission of the disease.

Since this disease is more prevalent in the males (Mpox, 2023) who are gay, bisexual and other man who have sex with men, so next if we get the data available on the basis of different sexes then we can investigate the dynamics of the transmission in the targeted male population.

Conclusion

Overall, these findings suggest that a comprehensive approach to monkeypox prevention and control should include measures to increase education and awareness about the disease, improve access to effective treatment, and target interventions towards the key parameters that influence transmission. There should be targeted research to create a vaccination specific to the monkeypox.

References

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Title: Advice to the minister of health, a summary of the project about monkeypox in the US and forecasting the effectiveness of educational intervention

Purpose: To provide a summary of the project "Monkeypox in the Us and forecasting the effectiveness of educational intervention"

Situation:

- In December 2022, I requested Minister of Health to grant me permission to take the MATH 572 course in University of Alberta.
- The Minister granted the permission to complete the MATH 572 course and had requested to provide the summary of the final project.
- A summary of the final project: "Monkeypox in the US and forecasting the effectiveness of educational intervention" is required.

Analysis:

- A mathematical model was developed to assess the transmission dynamics of monkeypox and how educating the people will affect the number of people infected.
- Monkeypox is transmitted through physical contact with the animals through the bodily fluids such as urine, salvia and blood. The main source of monkeypox are rodents and mammals.
- Since it spreads through physical contact, it could be reduced by educating people about the importance of good hygiene and maintaining safe distance from infected people and animals.
- This study highlights the poorly maintained data, specifically relating to the male gender where this disease is more prevalent as compare to others.

Stakeholders Reaction:

- External stakeholders may request policy direction on education and public awareness of the disease and surveillances and reporting of monkeypox cases as a control measure to manage a disease outbreak.

Communication/Key Messages:

- A slight increase in education efforts can make a significant impact in controlling the spread of monkeypox. If we increase the education of susceptible individuals from 0.1% to 0.4, this will help in decease of total infections from 60% to 98% and will significantly flatten the infections curve.

Prepared by:
Saira Faiz

Appendix A: Project Proposal

MATH 572

Monkey Pox in the United States

Forecasting the effectiveness of educational intervention

Hedieh Kalachahi (1467616), Saira Faiz (1775398), & Colby Jamieson (1714722)

4-11-2023

Description

To model the transmission and prevention of the monkeypox virus, we propose a compartmental mathematical model evaluated at different levels of intervention. The project will aim to construct a model specific to a local outbreak of monkeypox in Alberta. The intended audience are government officials wanting a description of the threat the virus poses to Albertans and if a public education intervention might be effective in reducing transmission.

Background

The monkeypox virus was first discovered in humans in 1970 and has since become endemic in the Democratic Republic of Congo and has spread to other nearby countries in central and west Africa (Parker & Buller, 2013).The disease has garnered more attention recently due to numerous outbreaks around the world and its similarity to smallpox, a disease that killed an estimated 300 million since the year 1900 (Mohr).

Monkeypox can be transmitted from contact between humans and infected rodents; however, the most recent outbreaks have occurred primarily due to human-to-human contact. Transmission usually occurs from direct contact with infected rashes, scabs, and bodily fluid, but can also be transmitted by respiratory secretions. Once transmitted, infection results in flu-like symptoms and the characteristic rash, turning into painful blisters. Typically, illness is moderate and resolves within 2-4 weeks, with those who are immune compromised having more severe symptoms, with the possibility of death (Peter, et al., 2022).

There is currently no vaccine or treatment specific to monkeypox. There are however vaccines and treatments developed for smallpox that are effective (Peter, et al., 2022).

Research Objectives

The objective of this research is to understand the transmission dynamics of local outbreaks of monkeypox and to investigate the effect of public education about the virus on specific disease attributes, such as:

- Peak infections,
- final size, and
- endemic & disease-free equilibria

The research will be conducted for the purposes of public policy making and would include answers to questions such as:

- How many infections could we expect at one time during the peak of the outbreak?
- Will the pandemic end or become endemic?
- How many Albertans could be affected by the disease before the pandemic ends?
- Will public education have a significant effect on the impact the disease outbreak has on Albertans?

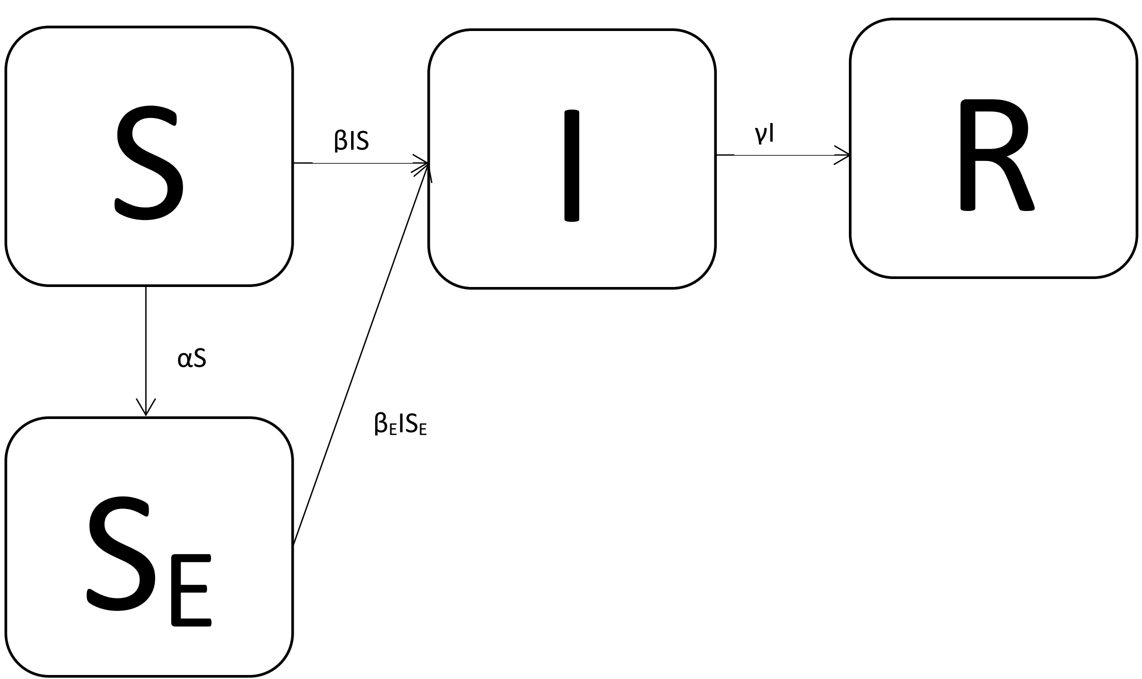
Method

To achieve the research objectives set out in this proposal, a compartmental model of monkeypox is proposed. The model will be constructed using Matlab and results will be presented in a report and presentation aimed at public health policy decision-makers. The research questions will be answered by mathematical analysis of model results. This analysis will include peak infections, final size, and equilibria that will be evaluated at various levels of intervention and input levels.

Preliminary Model

The preliminary model proposed is a simplified version of previous monkey pox modelling (Peter, et al., 2021). The purpose of the proposed model is to describe local outbreak dynamics in Alberta; therefore, compartment for rodent transmission is removed, as it is assumed that a local spread would likely be human to human.

To study the dynamic effects of a realistic intervention during a local outbreak, a compartment



for educated susceptible population is added. Once the simplified model is run and calibrated, other compartments may be added or removed; such as age groups, birth and death rates, high risk susceptible population, quarantined population, or infected population yet to be contagious.

System of Equations:

$$\frac{dS}{dt} = -\beta SI$$

$$\frac{dS_E}{dt} = \alpha S - \beta_E I S_E$$

$$\frac{dI}{dt} = I(\beta S + \beta_E S_E) - \gamma I$$

$$\frac{dR}{dt} = \gamma I$$

Variables and Parameters:

S – Number of uneducated susceptible population

S_E – Number of educated susceptible population

β – infectious rate for uneducated population

β_E – infectious rate for educated population

I – number of infected population

R – number of recovered population

α – education rate

γ – recovery rate

Sensitivity Analysis

A global sensitivity analysis will be performed to discern the impact on outputs relating to uncertainties of model inputs.

Data Sources

To date, no suitable data sources for model fitting have been found.

Mathematical Analysis

Mathematical analysis will include a final size estimate, finding the total people infected from the number of initial susceptible minus the susceptible at the end of the pandemic (S_0 - S_∞). This will be determined mostly by the basic reproduction number.

Peak infections will be analyzed given different levels of intervention, and inputs.

Local stability analysis will be performed to determine which equilibrium points are stable or unstable. This will include a phase-line analysis, bi-furcation diagram, and the basic reproduction number level that results in either a disease-free or endemic equilibrium.

Group Contributions

Hedieh Kalachahi (1467616): Initial project idea, sensitivity analysis research, final draft review, and data source research.

Saira Faiz (1775398): First proposal draft, initial research, final draft review, and project planning

Colby Jamieson (1714722): Proposal review and drafting, research objectives, initial model, and mathematical analysis