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A Continuum Model Based on SIR Equations for Epidemic Spread Analysis

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ABSTRACT: To comprehend how epidemics develop and assess the efficacy of medical treatments, infectious disease modeling is crucial. The SIR model, which separates the population into susceptible, infected, and recovered groups, is one example of the mathematical and statistical models that scientists and policymakers use to describe the dynamics of infection transmission among individuals within a society. These models may also be expanded to incorporate other components, such vaccination, alterations in social behavior, and the results of medical treatments. This work focuses on analyzing the spread of Oropouche fever using the SEIR model with a protective factor that simulates the impact of interventions. The results demonstrate how interventions contribute to reducing the number of infections and delaying the peak of the epidemic. The work also examines the use of the SIRD model in two versions: the classic (without vaccination) and the modified (with vaccination). The numerical results clearly demonstrate the role of vaccination in reducing morbidity and mortality rates, highlighting the importance of mathematical modeling in designing effective strategies to combat epidemics.

Keywords: SIR, SIRD, SEIR, Vaccines, Oropouche.

1. INTRODUCTION

In order to guide public health measures and comprehend the dynamics of infectious disease dissemination, mathematical modeling is essential. Models like SEIR (susceptible-susceptible-infected-recovered) and SIRD (susceptible-infected-recovered-deceased) offer important insights into how epidemics behave under different circumstances by creating differential equations that characterize the interactions between susceptible, susceptible, infected, recovered, and deceased individuals. These models assist in forecasting outbreak paths, estimating important epidemiological characteristics, and assessing the efficacy of control strategies including immunization, isolation, and behavioral modifications. Specifically, the SIRD model more accurately depicts mortality trends, but the SEIR model includes a latent period, which makes it more realistic for illnesses with an incubation phase. By incorporating real-world data, these frameworks allow researchers and policymakers to simulate scenarios and design evidence-based strategies to mitigate the effects of an epidemic. In his comprehensive study, Hethcote (2000) reviewed classical epidemiological models, including the SIR and SEIR, focusing on the concepts of epidemic thresholds and their applications to various diseases such as measles and whooping cough. Brauer (2017) also discussed the evolution of epidemiological modeling, noting the importance of incorporating real-world data into models to improve the accuracy of predictions and inform public health decisions. In this paper, we examine the same mathematical models but for other epidemics, with some modifications to suit the course of the epidemic, as well as preventive and therapeutic approaches, and analyze the results to determine their impact on limiting the spread of the epidemic. [4][6][7]

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2. SIRD MODEL FOR COVID-19

The significance of mathematical models in comprehending and forecasting the transmission of infectious illnesses has been brought to light by the COVID-19 pandemic. Despite its widespread usage, the SIR (Susceptible-Infected-Recovered) model frequently needs to be modified in order to better reflect the realities of severe epidemics. By including a category for died persons (D), the SIRD model broadens the scope of the SIR model and makes it possible to follow illness outcomes more precisely, particularly in situations with high mortality rates. This adjustment enhances the calculation of epidemic dynamics and aids in assessing the results of treatments like immunization, isolation, and behavioral modifications. As an illustration, some researchers have developed a comprehensive epidemiological model to simulate the effects of lockdowns and social distancing during the early COVID-19 outbreak in Italy, demonstrating the role of timely interventions in reducing mortality. Similarly, others have developed a comprehensive epidemiological model to simulate the effects of lockdowns and social distancing during the early COVID-19 outbreak in Italy, demonstrating the role of timely interventions in reducing mortality. Similarly, a comprehensive epidemiological model has been developed to simulate the effects of lockdowns and social distancing during the early COVID-19 outbreak in Italy. A data-driven SIRD framework was used to estimate case fatality rates and transmission dynamics in China, providing early insights into the course of the outbreak. These studies highlight the importance of extended models such as SIRD in guiding public health strategies. [3][5]

$$\frac{dS}{dt} = -r\frac{IS}{N} \quad , \tag{1}$$

$$\frac{dI}{dt} = r\frac{IS}{N} - aI - kI \quad , \tag{2}$$

$$\frac{dR}{dt} = aI \quad , \tag{3}$$

$$\frac{dD}{dt} = kI \quad . \tag{4}$$

Additionally, we used N = S + I + R + D + Z to augment the population size in order to preserve the population mass. We also calculated the spread intensity.

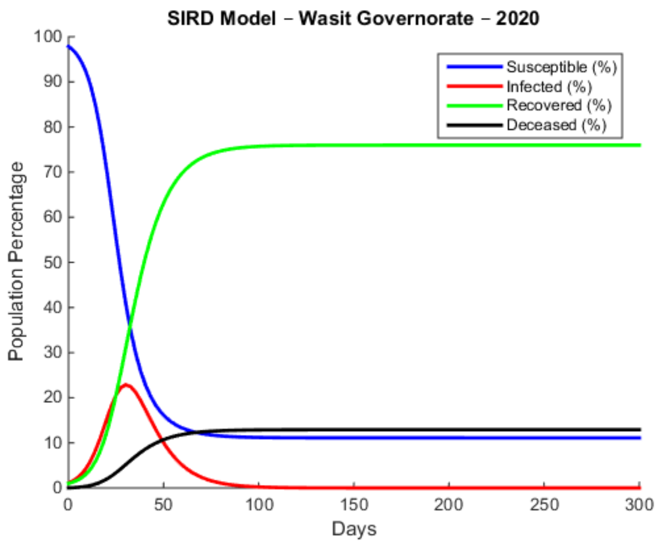

Fig .1. A simulation of the COVID-19 outbreaks in Wasit Governorate using the SIRD model in MATLAB. Over 300 days, the graph displays the proportion of the population in each category. The model illustrates the dynamics of the disease's spread, with infections peaking, followed by a slow decline due to recovery or death, according to statistics from the Iraqi Health Organization.

3. EFFECT OF VACCINE ON THE SIRD MODEL

By reducing the number of susceptible individuals in a community, vaccination is one of the best ways to contain infectious disease epidemics. Vaccination reduces the peak of infection and shortens the duration of an epidemic when included in compartmentalized models such as the SIRD model. Numerous studies have shown that even modest vaccination rates can significantly influence disease dynamics and avoid overwhelming the healthcare system [2].

$$\frac{dS}{dt} = -r\frac{IS}{N} - vS \quad , \tag{5}$$

$$\frac{dI}{dt} = r\frac{IS}{N} - aI - kI \quad , \tag{6}$$

$$\frac{dR}{dt} = aI + vS \, , \tag{7}$$

$$\frac{dD}{dt} = kI \, . \tag{8}$$

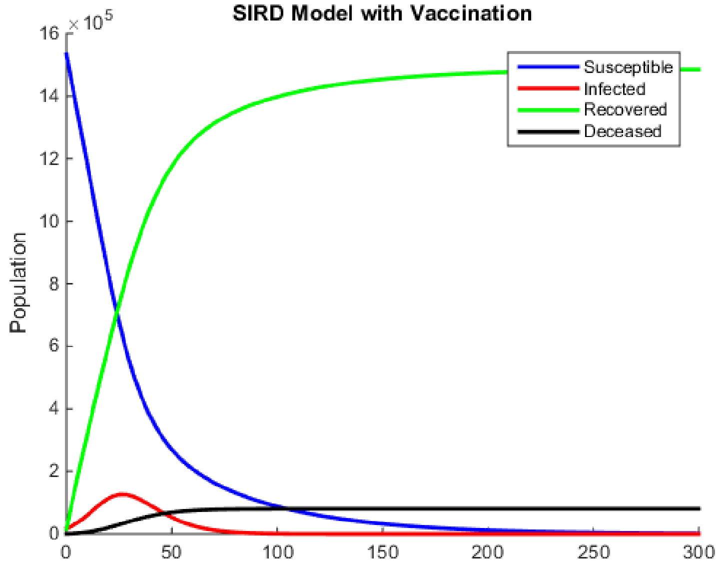

Fig.2. The SIRD model compares the number of vaccinated and unvaccinated individuals having an infection across time. The solid red curve shows the infection trend when vaccination is introduced, whereas the dashed red curve shows the dynamics of infection when vaccination is not administered. The noticeable decline in the peak number of infections and the acceleration of the epidemic curve's decline show that vaccination is effective in stopping the spread of illness.

4. MATHEMATICAL MODEL OF OROPOUCHE FEVER

A developing virus called Oropouche fever is spread by insects, mainly by the Culicoides paraensis biting mosquito. Researchers initially characterized the virus in Trinidad in 1955, when the first human instance of this sickness was documented (Anderson 1961oropouche). Since then, a number of international nations have reported isolated occurrences.

In order to comprehend disease dynamics and the effect of preventative actions on lowering its transmission particularly in the absence of a specific therapy or licensed vaccine this study attempts to construct a mathematical model to assess the spread of Oropouche fever.

Like many viral infections carried by arthropods, Oropouche fever has a certain incubation period during which infected people are asymptomatic and not contagious. For susceptible people (E) who have contracted the infection but are not yet contagious, we introduce an extra category. As a result, we use an SEIR-type model rather of the fundamental SIR frame work. [1]

$$\frac{dS}{dt} = -rSI\ , \tag{9}$$

$$\frac{dE}{dt} = rSI - kE\ , \tag{10}$$

$$\frac{dI}{dt} = kE - aI\ , \tag{11}$$

$$\frac{dR}{dt} = aI\ . \tag{12}$$

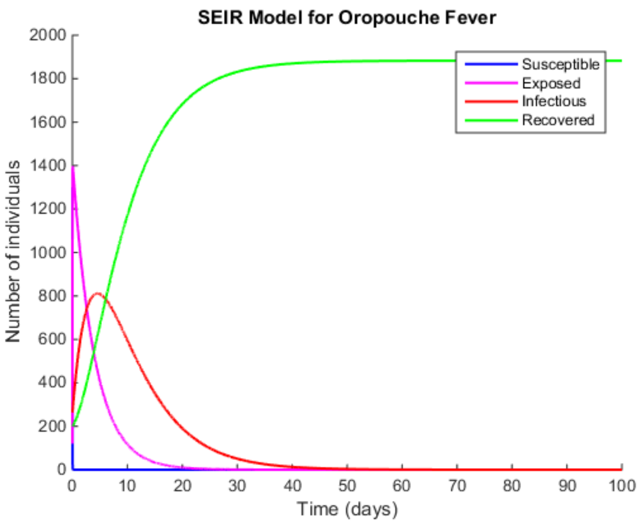

Fig.3. Oropouche fever using the SEIR model without any preventive measures. After about day 20, there is a sharp drop in the number of susceptible people and a steady rise in the number of recovered people, causing the number of infected cases to climb quickly before falling.

5. EFFECT OF PREVENTIVE MEASURES ON DISEASE SPREAD

Controlling the dynamics of infectious illness spread requires the use of preventive interventions. There is currently no approved vaccine or specific antiviral treatment for Oropouche Fever, a relatively new illness. As a result, vector control is still the best method for preventing the spread. Until the appropriate treatment is found, initial measures must be taken.

$$\frac{dS}{dt} = -r(1-q)SI, \tag{13}$$

$$\frac{dE}{dt} = r(1-q)SI - kE\ , \tag{14}$$

$$\frac{dI}{dt} = kE - aI\ , \tag{15}$$

$$\frac{dR}{dt} = aI\ . \tag{16}$$

Where:

q: proportion reduction in transmission due to preventive measures.

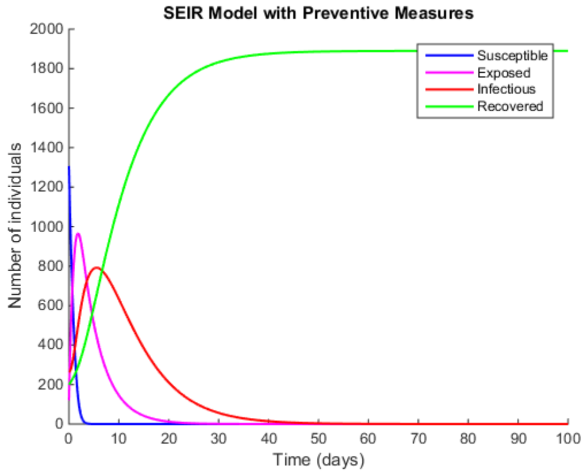

Fig.4. Oropouche fever using the SEIR model, with precautions taken to reduce transmission. Since more people are still at risk, the peak infection rate is lower and happens sooner, indicating that treatments are successful in slowing the spread of the illness, but only somewhat because they are preventative measures.

6. CONCLUTION

This study has demonstrated the importance of mathematical models such as SEIR and SIRD in analyzing and understanding the spread of infectious diseases. These models provide valuable tools for estimating the effects of interventions, including vaccination, quarantine, and behavioral changes, thereby reducing illness and mortality. By simulating real-world scenarios, they help policymakers design effective strategies and allocate resources efficiently. Our results highlight the ability of these models to delay epidemic peaks and lower infection rates, underscoring their practical role in epidemic preparedness. Ultimately, mathematical modeling remains essential in shaping evidence-based decisions for combating future outbreaks.

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