MODIFIED SIR MODEL FOR INFECTIOUS DISEASES TRANSMISSION WITH LOCKDOWN AND VACCINATION DYNAMICS

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ISLAMABAD

August, 2024

Modified Sir Model for Infectious Diseases Transmission with Lockdown and Vaccination Dynamics

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MCS, National University of Modern Languages, Islamabad, 2020

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE
In **Computer Science**

To
FACULTY OF ENGINEERING & COMPUTING

NATIONAL UNIVERSITY OF MODERN LANGUAGES ISLAMABAD

NATIONAL UNIVERSITY OF MODERN LANGUAGES FACUTY OF ENGINEERING & COMPUTING

THESIS AND DEFENSE APPROVAL FORM

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Thesis Title: MODIFIED SIR MODEL FOR INFECTIOUS DISEASES TRANSMISSION WITH LOCKDOWN AND VACCINATION DYNAMICS

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Candidate of **Master of Science in Computer Science (MSCS)** at the National University of Modern Languages do hereby declare that the thesis **Modified Sir Model for Infectious Diseases Transmission with Lockdown and Vaccination Dynamics** submitted by me in partial fulfillment of MSCS degree, is my original work, and has not been submitted or published earlier. I also solemnly declare that it shall not, in future, be submitted by me for obtaining any other degree from this or any other university or institution. I also understand that if evidence of plagiarism is found in my thesis/dissertation at any stage, even after the award of a degree, the work may be cancelled and the degree revoked.

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ABSTRACT

Title: Modified Sir Model for Infectious Diseases Transmission with Lockdown and Vaccination Dynamics

Global public health continues to be seriously threatened by infectious illnesses, necessitating the development of sophisticated epidemiological models that can capture the nuanced dynamics of disease transmission and evaluate the effectiveness of treatments. This work takes a fresh approach by putting forth a modified Susceptible-Infectious-Recovered (SIR) model that incorporates the dynamics of vaccination and lockdown measures on disease transmission. Suspected at home (Sh), Suspected go outside (So), Infected at home (Ih), Infected go outside (Io), Recovered (R), and Vaccinated (V) are the six compartments that the modified SIR model takes into account. While the Infected compartments discriminate between those who are sick and self-isolating from those who continue to engage with others in the community, the Suspected compartments take into consideration those who may have the virus but are either staying at home or venturing outdoors. While the Vaccinated compartment takes into account those who have received vaccinations, lessening their vulnerability to infection, the Recovered compartment reflects people who have recovered from the illness and established immunity. The differential equations of the model allow simulations of the dynamics of disease transmission under various conditions, such as varied levels of lockdown severity and vaccination coverage. The findings of the simulations show how early lockdown deployment is essential for lowering the peak infection rate and flattening the epidemic curve. A balance between intensity and social well-being must be struck, yet stricter lockdown measures result in a faster drop in infections. Campaigns for vaccination considerably minimize the spread of illness and help to create herd immunity. Sensitivity analysis demonstrates the model's reliability and highlights the crucial variables that have the greatest impact on disease dynamics. The modified SIR model helps policymakers create focused measures to successfully reduce infectious disease outbreaks while minimizing social disturbances. It is a useful tool for evidence-based decision-making in public health. A thorough framework for comprehending the connections between various compartments and their impact on the progression of epidemics is provided by its combination of lockdown and vaccine dynamics.

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LIST OF ABBREVIATIONS

SIR - Susceptible-Infected-Recovered

eSIR - Extended-Susceptible-Infected-Removed

LIST OF SYMBOLS

B - The rate of transmission from susceptible to infected

γ - The rate of transmission from infected to recovered

g_s - Susceptible individuals that go outside

gi - Infected individuals that go outside

S_h - Suspected at home

S_o - Suspected go outside

I_h - Infected at home

I_o - Infected go outside

V/R - Vaccinated/ Recovered

ACKNOWLEDGEMENT

First and foremost, I want to thank Almighty Allah for granting me knowledge, fortitude, good health, and clarity of mind. He enabled me to finish the research.

Without the support and encouragement given from many sources, for which I am sincerely grateful, this research thesis would not have been completed. My research supervisor Assistant Professor Dr. Moeenuddin Tariq and co-supervisor Mr. Farhad M. Riaz, who never stopped guiding me along the way, were one of many steadfast supporters and important contributions to my accomplishment. I want to express my gratitude to my supervisor in particular for his help, direction, and insightful comments on the research.

Last but not least, I won't forget the management of the Department of Computer Sciences generous assistance in helping me to complete this research. Many thanks to everyone whom I didn’t include but who helped me stay motivated and made efforts I won't forget.

DEDICATION

I dedicate this thesis to my parents, teachers, and siblings, whose love, care. encouragement, and leadership over the years established the groundwork for me to successfully accomplish any task with diligence. I also dedicate this work to my instructors and mentors who provided me with valuable lessons and seek to be the best.

CHAPTER 1

INTRODUCTION

1.1 Overview

Throughout history, infectious illnesses have posed a constant threat to human communities, leading to widespread sickness, fatalities, and disruptions of the economy. Viral diseases are caused by virus-based illnesses. Viral infections result in illnesses that affect social, medical, and economic aspects of life in both human and animal bodies. Different viral types cause different diseases. Different routes of transmission for infectious illnesses, which are brought on by microorganisms including bacteria, viruses, parasites, and fungus, affect how quickly they spread. Respiratory droplets can transmit airborne diseases like influenza and TB, whereas direct touch helps spread skin infections and the common cold. In contrast to vector-borne illnesses like malaria and dengue fever, which are spread by insects like mosquitoes, water and foodborne pathogens like cholera and norovirus take use of fecal-oral pathways. Zoonotic illnesses, such as COVID-19 and Ebola, are the result of human-animal contact. Disease spread is facilitated by elements including high population density, globalization, poor sanitation, and low vaccination rates. Campaigns for immunization, isolation rules, vector control activities, public health campaigns, and careful antibiotic usage are all part of effective prevention. In order to monitor and reduce the impact of infectious illnesses on the world at large, international cooperation and reliable surveillance systems are essential. The common cold is the most frequent type of viral infection brought on by respiratory tract disorders. Serious viral illnesses including HIV/AIDS, COVID, and chickenpox are mostly spread through direct and indirect social and personal relationships. As a result of their quick spread, these diseases represent a greater danger to global health [1].

The COVID-19 pandemic, which was brought on by the brand-new coronavirus SARS-CoV-2, became a major worldwide disaster with far-reaching effects on people's health, economies, and way of life. The virus may stay on surfaces and largely spreads by respiratory droplets, promoting person-to-person transmission. The disease's extremely contagiousness and initially asymptomatic carriers made control measures difficult. Travel and connectivity on a global scale propelled the pandemic's quick spread, necessitating the urgent need for effective public health measures. The risk is higher for older folks and people with underlying medical disorders, and symptoms can vary from minor respiratory problems to severe pneumonia and, in some cases, deadly results. Containing the spread of COVID-19 is challenging due to patients who show no symptoms or only mild symptoms, as well as the presence of vague symptoms. To mitigate the spread of the virus, various measures have been implemented such as lockdowns, travel restrictions, mass testing, contact tracing, quarantine, and promoting good hygiene and mask use. Vaccination efforts have been crucial in containing the epidemic, but disparities in distribution and the emergence of new strains continue to pose difficulties. International cooperation has been essential in developing diagnoses, therapies, and vaccinations to combat COVID-19 [2]. The COVID-19 pandemic outbreak has brought to light the urgent need for accurate disease transmission models that can capture the intricate dynamics of epidemics and guide public health initiatives. The traditional SIR (Susceptible-Infectious-Recovered) model has been used extensively to analyze the dynamics of disease transmission; however, it frequently falls short of taking non-pharmaceutical measures like lockdowns and vaccination campaigns into account. As a result, there is an increasing need for enhanced SIR models that can take these important elements into account and offer more precise forecasts and insights [3].

The Susceptible-Infectious-Recovered (SIR) model is a crucial concept in epidemiology as it is a mathematical framework that helps forecast and comprehend the dynamics of infectious diseases in populations [4]. Developed in the early 20th century by Kermack and McKendrick, this model aimed to simulate the spread of illness by dividing a population into three groups: Susceptible, Infectious, and Recovered. This model provided a fundamental understanding of epidemics by examining how illnesses spread and how people develop immunity over time. The SEIR model was created to consider the hidden periods in diseases such as measles, but the SIR model's value continued beyond its original development. The findings of the SIR model were essential in shaping public health policies, targeting disease prevention efforts, and advancing mathematical epidemiology.

The SIR model, first proposed by Kermack and McKendrick in 1927, is a compartmental model that divides the population into three groups: susceptible individuals, infectious individuals, and recovered (or immune) individuals. It is assumed that people move between these compartments according to certain rates of infection and recovery. The standard SIR model is effective at capturing the fundamental dynamics of infectious illnesses, but it ignores the effects of treatments that might change the dynamics of transmission.

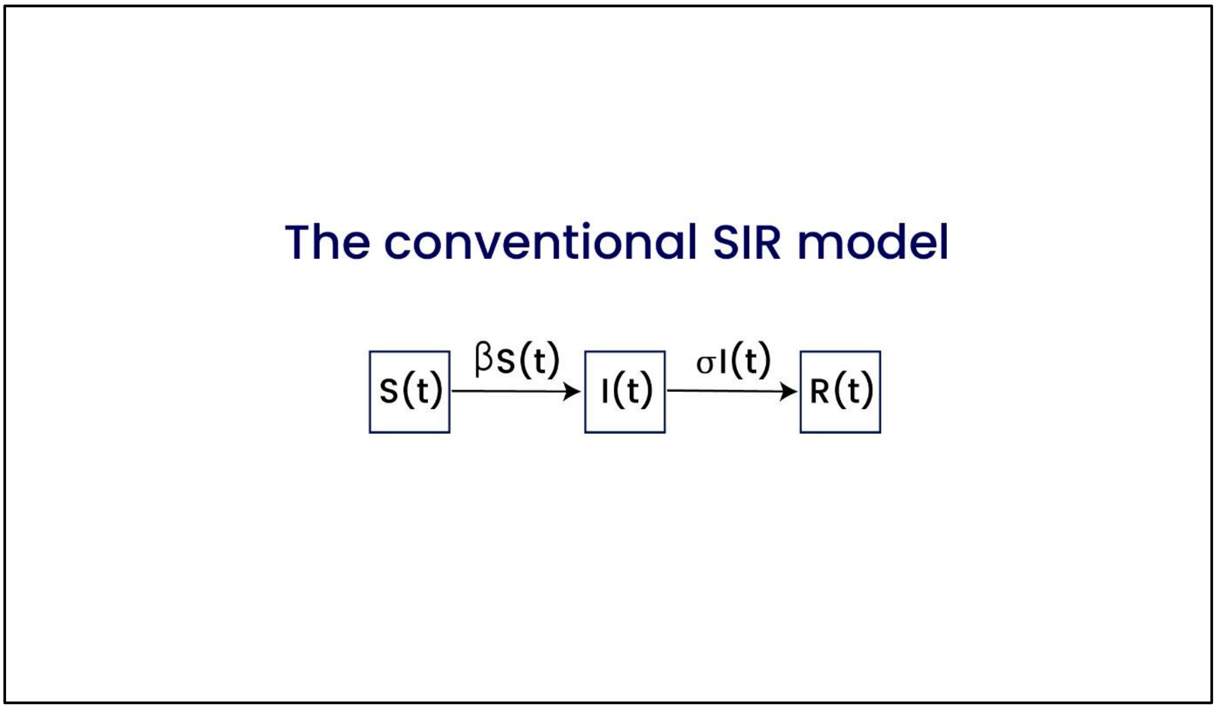

Figure 1.1: The conventional SIR Model

Lockdown measures, limiting interpersonal interaction and lowering the transmission rate are frequent tactics used to stop the spread of infectious illnesses. These tactics include different degrees of social isolation, limits on travel, and the shutdown of organizations and companies that are not absolutely necessary [5]. However, a number of variables, including the timing, length, and adherence of the populace, affect how well lockdowns work to stop the spread of illness. Thus, it is essential to include the dynamics of lockdown measures in disease transmission models in order to evaluate their effectiveness and maximize their deployment.

Campaigns for vaccination also play a significant part in the management of infectious illnesses, in addition to lockdown measures. Immunity is raised, the vulnerable population is reduced, and the total transmission rate is decreased thanks to vaccination. However, the administration and distribution of vaccinations add more nuance to the dynamics of disease transmission. The total effect of vaccination on disease transmission can be considerably influenced by variables including vaccine availability, coverage, vaccine reluctance, and the appearance of novel variations [6]. As a result, it's crucial to incorporate vaccination dynamics into disease transmission models when assessing the success and possible drawbacks of vaccination techniques.

For many years, the Susceptible-Infectious-Recovered (SIR) model has been a staple in epidemiological studies. It provides valuable insights into how infectious diseases spread within communities. However, researchers have found limitations in the model and have explored modifications and extensions to better understand the complex interactions between disease transmission, non-pharmaceutical therapies, and immunization techniques. This is particularly urgent in the context of emerging public health issues.

There is a concern regarding the limitations of the traditional SIR model in considering crucial elements that impact the dynamics of illnesses. These elements include the impact of vaccination programs and lockdown procedures, which have proven effective in stopping the spread of infectious diseases. The rigid structure of the previous model cannot account for the intricate interplay between these treatments and the transmission of the disease, which can result in inaccuracies in predicting epidemics [7].

Researchers have suggested a number of changes and expansions to the traditional SIR model in order to solve its shortcomings and take into consideration the dynamics of vaccination and lockdown measures. The intricate interactions between disease transmission, non-pharmaceutical therapies, and vaccination tactics are intended to be captured by these modified SIR models. These extra variables can help these models generate more accurate predictions and educate policymakers and public health experts about the possible effects of various intervention scenarios.

Scientists have developed updated SIR models to provide a more advanced approach. These models consist of new compartments, representing different population subgroups and intervention methods [8]. By segmenting the population further, these models can accurately depict the varying levels of vulnerability, infection, recovery, vaccination, and adherence to non-pharmaceutical therapies. These models often include "Exposed" individuals who have contracted the disease but are not yet contagious, "Recovered" individuals who have regained immunity, and "Vaccinated" individuals who have received immunization against the illness.

The incorporation of vaccination dynamics in the traditional SIR model is a significant advancement in our understanding of infectious illness modelling. For stopping the spread of illness and reducing population susceptibility, vaccination campaigns are necessary. With the modified SIR model, which incorporates vaccination compartments, public health experts can evaluate various vaccination coverage scenarios and predict the possible attainment of herd immunity. Unlike traditional SIR models, the modified model enables a more nuanced understanding of immunity development through vaccination.

This study introduces a unique strategy that combines vaccination and lockdown measures in a modified SIR model for infectious disease transmission. The aim is to examine how different lockdown strategies, including their timing, intensity, and duration, impact disease transmission dynamics. Additionally, the study closely examines the results of vaccination programs, considering factors such as immunization coverage, efficacy, and distribution strategies. The primary objective is to provide information on the most effective shutdown and immunization combinations in managing infectious diseases in various contexts.

The purpose of this work is to enhance our understanding of the relationship between disease dynamics, treatment methods, and immunization programs. This will help to create more accurate and comprehensive disease transmission models, which will provide crucial data for making public health decisions. Taking into account both lockdown measures and vaccine dynamics will add complexity to these models, resulting in a more realistic depiction of real-world situations. The ultimate goal of this research is to reduce the negative impact of infectious diseases on people's health and well-being worldwide.

The study highlights the importance of using adaptive methods, which recognize that the effectiveness of treatments may vary depending on the circumstances and the stage of an epidemic. For example, understanding how the length and timing of lockdowns impact vaccination rates can provide policymakers with valuable information for designing flexible and adaptable public health plans. In addition to coverage, the study also emphasizes the need to consider vaccination-related factors such as vaccine efficacy and distribution strategies. These elements can significantly affect the overall effectiveness of vaccination programs and help achieve the best possible herd immunity. The goal of the study is to provide policymakers with a more detailed understanding of how these factors interact, in order to maximize the effectiveness of vaccination efforts.

In conclusion, a comprehensive method for researching the spread of infectious diseases is provided by the modified SIR model's incorporation of lockdown procedures and vaccine dynamics. With its flexible and evidence-based insights, this research hopes to become a cornerstone in the development of public health initiatives that can successfully battle infectious illnesses and protect world health.

1.2 Architecture of SIR Model:

A popular notion of illness transmission within a population is the SIR model. Although it may be adjusted to take into consideration a range of important population dynamics, such as the death rate, immigration or birth rate, recovery, and immunity, even the most fundamental model has significant implications for public health [9].

One of the simplest compartmental models is the SIR model, from which many other models are derived. The following components make up the model:

S: The total population of vulnerable people. The susceptible person gets sick and moves into the infectious compartment when they come into "infectious contact" with the infected person.

I: The number of contagious people. These are those who have contracted the disease and are able to spread it to other people.

Every person in the population is divided into one of three categories by the SIR model at any one time: those who are prone to sickness, those who are infected, and those who have been "removed." People who are immune, in quarantine, or deceased, i.e., those who are not sick and not vulnerable, are included in the eliminated class.

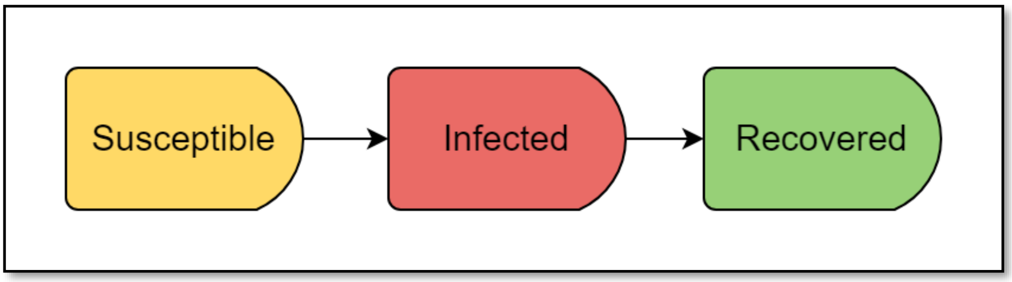

Figure 1.2: The Compartments of the SIR Model

In a closed community, the fictitious number of instances of a contagious illness are estimated over time using an epidemiological model called an SIR. The term "coupled equations" refers to the application of coupled equations to determine the relationship between the number of susceptible persons S(t), infected individuals I(t), and recovered individuals R(t) [10].

1.3 Problem Statement:

Forecasting the spread of infectious diseases is challenging due to their rapid transmission through social interactions. Traditional SIR models, which are foundational for understanding disease dynamics, typically do not consider crucial factors such as social isolation, lockdown measures, and vaccination dynamics. This work aims to enhance the basic SIR model by incorporating these elements, making it more reflective of real-world scenarios. By updating the model to include the effects of lockdowns and vaccination, we can improve our understanding of disease spread and the effectiveness of various interventions, thereby providing more accurate predictions and better informing public health strategies.

1.4 Research Questions:

The research targets following questions,

- How to modify the SIR model with lockdown and vaccination dynamics?
- How to validate the effectiveness of modified SIR model?

1.5 Aim of the Research:

The grasp of the complex connections between disease propagation, preventative measures, and population-level immunity is being improved through research on a modified SIR model for infectious disease transmission including lockdown and vaccine dynamics. In order to create more precise and realistic models that can guide public health efforts during outbreaks, this research tries to incorporate the impacts of lockdown measures and vaccination drives into the conventional SIR model framework.

The goals may include determining the effectiveness and timing of lockdown interventions, assessing vaccination programmes efficacy and coverage, investigating the possibility of a synergistic relationship between lockdowns and vaccinations, identifying critical variables affecting disease transmission dynamics, and offering insights into the long-term management and eradication of infectious diseases.

To prevent the spread of infectious illnesses and safeguard the public's health, policymakers and public health authorities can use the findings of this research to influence their choices.

1.6 Research Objectives:

Following are the objectives that would be yielded by the current study.

- To propose a modified SIR model with lockdown and vaccination dynamics
- To evaluate the performance of the proposed model with real time data in Pakistan

1.7 Thesis Organization:

The thesis is organized as follows.

Chapter 2 includes a detailed overview of all the existing work and describes how this study distinguishes itself from the existing schemes. Also, contains the categorical discussion, detailed comparative analysis of state-of-the-art schemes and their research limitations that lead towards new research direction.

The updated SIR model will be theoretically outlined in chapter 03, with a particular emphasis on the inclusion of lockdown procedures and vaccination dynamics. It will open with a description of the modified SIR model, emphasizing its relevance and function in comprehending the spread of infectious diseases. The next section of the chapter delves into the inclusion of lockdown measures in the model, examining the mathematical representation and integration of elements like contact minimization and movement constraints. The chapter will next go through the dynamics of vaccination introduction, including topics such vaccine effectiveness, coverage, distribution plans, and their effects on disease transmission. The method of gathering data and calibrating the improved SIR model will also be discussed in this chapter. The research questions and goals outlined in the study will also be covered in this chapter.

The findings of the simulation and analysis of the updated SIR model will be thoroughly discussed and interpreted in chapter 04. It will start by contrasting the simulation results from various situations and highlighting the significant parallels, discrepancies, and patterns found. After that, the chapter will analyze the dynamics of lockdown and vaccination, looking at each of these factors' impacts on disease transmission and control separately and collectively. In addition to offering insights into the dynamics of disease transmission, the efficacy of various interventions will also investigate the ramifications of the results. The research questions and goals outlined in the study will also be covered in this chapter.

Chapter 05 will account for the conclusion of the research. It will discuss the effects of lockdown and vaccination protocols in essence.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview:

Public health experts are concerned about the potential effects of the prolonged economic slump, which was brought on by the financial crisis of 2007. Their main worry is that economic instability may make it easier for infectious diseases to spread while also posing a threat to the effectiveness of disease prevention strategies. While the effects of economic downturns on general health outcomes have been thoroughly studied, there appears to be a significant research vacuum in relation to a thorough examination of the effects of such downturns on the spread and management of infectious illnesses [11]. It is crucial to close this gap in order to comprehend the special risks and vulnerabilities that occur when economic crises collide with the dynamics of infectious illnesses since infectious diseases present distinct difficulties to public health systems and necessitate tailored treatments.

2.2 Infectious Illnesses:

Researchers have long been interested in the link between economic downturns and public health. Numerous health indicators, including mortality rates, cardiovascular illnesses, and mental health, have been studied for their potential effects during economic downturns. However, there are very few studies particularly looking at how economic downturns affect infectious illnesses [7]. Our comprehension of the possible cascading impact that economic crises may have on infectious disease spread and control strategies is hampered by this lack of focused investigation.

There is a need to investigate how these factors interact with infectious disease dynamics because economic instability may change people's behaviors, access to healthcare, and use of public health resources. The impact of both economic downturns and infectious disease outbreaks on population health may be reduced via the development of preemptive initiatives by policymakers and public health authorities with the help of a thorough analysis of this link. To fill this research vacuum, a full examination must be conducted in order to increase public health readiness during economic instability, guide evidence-based initiatives, and influence policy [12]

2.2.1 SIR mathematical model:

In order to analyze the progression of infectious illnesses in a population over time, David and Lang created the Susceptible-Infective-Recovered (SIR) mathematical model, which produced plausible and reliable findings. Their model, nonetheless, did not take into consideration a few more plausible elements that would have improved our comprehension of epidemic modelling. By adding these reasonable hypotheses to strengthen the analysis of disease propagation under varied settings, we significantly advance this work. We divide these situations into four categories and carry out tests under each one. Additionally, to evaluate the correctness of the improved model, we perform simulations in Visual Basic (VB) and offer a numerical approach. The findings show that, mostly as a result of the addition of additional assumptions, the modified model outperforms the original SIR model, resulting in a quicker decline in the infected population and a greater recovery rate. In addition, we carefully examine the modified model's eigenvalues, equilibrium points, Jacobian matrix, reproductive ratio, stability analysis, and equilibrium points. These in-depth analyses give important light on the model's behavior and its performance and applicability in various epidemiological scenarios. In conclusion, the improved modified SIR model provides a more effective and thorough tool for researching infectious disease transmission and control, advancing public health treatments and preparation tactics [13].

Many recent research articles have used the modelling approach, using real incidence datasets from affected countries, to investigate different characteristics as a function of various outbreak parameters and the effects of intervention strategies in different countries, depending on their current situations. It is critical that mathematical models be built in order to give insights and forecasts regarding the epidemic, as well as to design effective control tactics and regulations.[14-16].

Previous research employed the susceptible-infected-removed (SIR) model and its extended variants, such as the extended-susceptible-infected-removed (eSIR) mathematical model, to estimate the transmission of COVID-19 within communities.[17] Fractional order modelling is an extension of classical models that may explain dynamical systems in more detail precisely. Many scholars documented their findings in many study fields utilizing alternative methods in the literature. Geotechnical engineering, nanotechnology, heat transfer phenomena, blood flow, and disease are examples of fractional operators. Treatment, medication administration, and biological responses.

There have already been several COVID-19 models constructed and published that have examined various elements of disease dynamics and possible containment. The goal of using mathematical models to explore infectious illnesses is to acquire a better knowledge of how they spread in a community and to discover some viable control strategies. As a result, mathematical modelling approaches have become powerful instruments for epidemiological policy decision-making in many countries and among other health authorities. These models are sometimes the only viable way to determine which preventive or control technique is the most effective. Despite its simplicity, the SIR model and its variants are commonly used to anticipate the global spread of COVID-19. However, accurately evaluating the SIR model. [18]Rajagopal et al.[19] investigated the propagation of COVID-19 using the fractional SEIRD model and discovered that the fractional order model provides the best crossover behavior that is more realistic than the traditional one The dynamics were explored by Alkahtani and Alzaid.[20] in Italy of a new coronavirus They fractionalized non-linear ODE models to solve their challenge by using several operators Yadav and Verma revealed their findings based on the dissemination of COVID-19 by utilizing the CF fractional derivative.[21]

Kermack and McKendrick pioneered research into the transmission of infectious illnesses by modelling how agents progress over time from susceptible to infected, then recovered (or possibly other other states). Bailey et al., Anderson and May, Hethcote, and Brauer et al. are mathematical, epidemiological, and biological treatises.[22]

Since then, epidemiologists have added avoidance behavior to the SIR model, including social distance, quarantines, cleanliness, masks, travel restrictions, and non-pharmaceutical therapies. 4 Avoidance behavior illuminated pandemics such as the 1918 Spanish Flu.[23] Economists have pointed out that the movement of agents from one group to another is not exogenous, but rather reflects hazardous behavior and, as a result, illness frequency, acuteness, or economic or health-care costs. Geoffard and Philipson (1996) and Philipson and Posner (1995) pioneered the discipline of economic epidemiology by introducing optimum choice.[24]

Because diseases and pandemics are major concerns, everyone in the vicinity; researchers from all around the world are present. They are working hard to battle the sickness. Mathematicians also made contributions to medical sciences and supplied a plethora of mathematical models for epidemic illnesses These models predict what will happen in the future. The disease's behavior Furthermore, these models are employed. to forecast when a certain illness will reach its peak, and predict when the illness will be eradicated. Similarly, an A rough estimate of the number of affected persons may be obtained at a given time.[25] COVID-19 is an infectious illness that spreads through direct or indirect human contact (Chan et al. 2020). Because the virus lives in the respiratory organs, it spreads by oral secretions carrying viruses such as coughs, sneezes, saliva, and the ill person's talking. The illness spreads in two ways in a healthy population.[26]

Susceptible- Exposed Infected-Asymptomatic-Quarantined-Fatal-Recovered (SEIAQFR), a novel seven compartmental model developed by the researcher, is based on the traditional Susceptible Infected-Recovered (SIR) model dynamic of infectious disease and takes into account factors such as asymptomatic transmission and patient quarantine. The SEIAQFR model's capacity to depict the complex path that people take as an infectious illness progress is its key innovation. The SEIAQFR model dives into the intricacies of real-world illness scenarios, in contrast to the standard SIR model, which divides people into basic divisions of susceptible, infected, or recovered. This innovative seven-compartment model, which methodically tackles important aspects hitherto underrepresented in disease transmission models, is a tribute to the increasing sophistication of epidemiological research. The inclusion of seven unique compartments in the SEIAQFR model enables a more realistic and nuanced description of the complex dynamics prevalent in infectious illnesses, illuminating many aspects of transmission, progression, and management. The model is entirely based on patient data that is now accessible and mathematical prediction, but it ignores the virus gene mutation in various environments, which is a more complicated biological and epidemiological problem[27]. Batista et al. developed the susceptible infectious recovered (SIR) model, which attempted to predict the number of Corona virus pandemic cases and its final size. Statistics for February 2020, although the existing trend has demonstrated Not very accurate was the prediction.[28] Huang Y et al. Using the SIR model equations, he predicted the number of Corona virus infections that would occur in the future in Japan, South Korea, Italy, and Iran. When creating this model, the incubation period was not taken into account.[29]

Great strides have been made in Covid-19 forecasting research, particularly in the development of uncomplicated yet powerful iterative methods that rely solely on verified daily cases for input. The ultimate aim of this strategy is to predict the trajectory of the pandemic, a crucial piece of information for allocating resources and planning public health measures. One effective technique involves using a cumulative distribution function (CDF) and its first derivative, a mathematical tool that has proven successful in capturing the disease's dynamics. This approach offers a valuable means of forecasting the pandemic's spread by analyzing the distribution of daily confirmed cases over time[30]. A meta-population model of disease transmission in England and Wales was modified and it was used to forecast when the epidemic would reach its peak.[31] Additionally, it was demonstrated that the utilization of data-driven systems may be used to track changes in the epidemic behavior of various countries.[28] A novel nonlinear SIR epidemic issue model was created to examine how the coronavirus spreads when social distance is caused by the government's efforts to stop the virus from spreading. They fit the suggested model to the actual real data in order to determine the parameters used for each country.[32] SIR model with vaccination, based on the idea that people react to epidemic dynamics differently. The Preisach hysteresis operator models their heterogeneous response. They outline a prerequisite for the infection-free equilibrium state's worldwide stability.[33]

Modeling for a pandemic influenza outbreak indicates some benefit from even 50% mask wear in lowering the total number of infected. The effects on these factors, and crucially, at what stage in the pandemic trajectory mask use would exert maximum benefit, are unknown. COVID-19 has a greater hospitalization and fatality rate than influenza. They employed a simple SIR (susceptible, immune, recovered) model based on the population of Israel as a proof-of-concept (8 million people), and they assumed 8% or 16% mask efficacy to study the impact of nearly universal mask use on COVID-19.[34]. The quantifying the impacts of quarantine using an IBM SEIR model on scale-free networks was proposed since stochastic effects, which are a part of the model dynamic. They claim that the best approach to stop the outbreak is by a prolonged, rigorous quarantine, but this is very difficult to do in reality.[35] The susceptible-vaccination-infectious-removed (SVIR) compartment mathematical model was used in conjunction with a variety of vaccine effectiveness scenarios to anticipate the number of people who will receive vaccinations each day. They investigate the optimal vaccination strategy to control the COVID-19 pandemic in India[36].

The Stability and Control of a Discrete SIR Model with Time Delay for COVID-19 focuses on a discrete SIR model with time delays to analyze the spread of COVID-19. The inclusion of time delays accounts for the incubation period of the virus, making the model more realistic. The model assumes a closed population with no births, deaths, or migrations except due to the disease. Lockdowns and vaccinations are two instances of simplistic control procedures that may not accurately represent the complexity and variety of real-world interventions[37]. The study extends the SIR model to tuberculosis dynamics, incorporating time-dependent parameters to simulate real-world complexities like seasonal variations and interventions. By introducing a time-varying transmission rate, it aims to provide more accurate numerical solutions, offering insights into tuberculosis dynamics and the effectiveness of control strategies.. The model's basic idea of homogeneous population mixing might not apply in real-world situations where social systems and geographic heterogeneity have a substantial influence on the spread of disease. The model does not account for births and deaths, which may have a longer-term impact on population dynamics[38].

The study by Alazman et al. (2023) uses a restricted SIR model incorporating vaccination effects to analyze COVID-19 outbreaks, applying it to real-world data to demonstrate multiple waves and evaluate vaccination impacts. Limitations include the assumption of homogeneous population mixing and sensitivity to parameter accuracy. Additionally, the model focuses primarily on short-term impacts without addressing long-term immunity. This model’s limitations are addressed in my study by incorporating time-dependent lockdown and vaccination parameters for a more dynamic and realistic representation of intervention impacts over time[39].

2.3 Comparison of SIR Model:

The SIR model is utilized to evaluate the infectious diseases spread and generate the propagation vector to find the severity and predict the results. The comparison of different SIR model research is demonstrated in below table:

Table 2.1: Literature Review for SIR model for Infectious Diseases

Year	Author	Title	Summary
2001	Litao Han, Zhien Ma W. Hethcote	Four predator prey models with infectious diseases	Four modifications of a predator-prey model were created and analyzed to incorporate a SIS or SIR parasite infection. The study identified thresholds to establish global stability. The results showed that if the illness is present in the population of prey and predators are able to feed efficiently, the disease can still persist in the predator population.
2005	Helen J Wearing , Pejman Rohani, Matt J Keeling	Appropriate Models for the Management of Infectious Diseases	Epidemiologists commonly use the susceptible-infectious-recovered (SIR) model, which classifies the host population as susceptible, infectious, or recovered based on their infection status. This model is vital to predict the effectiveness of control measures and understand observed dynamics. However, many such models make two critical assumptions that are often overlooked, resulting in significant

			biases. This article aims to explain these assumptions and their impact on the SIR model's accuracy.
2012	Chengyi Xia, Li Wang, Shiwen Sun & Juan Wang	An SIR model with infection delay and propagation vector in complex networks	This research proposed the new epidemic model using the SIR (Susceptible-Infected-Removed) model to analyze the impact of infection latency and propagation vector on the diseases spread in complex networks. This involves various numerical simulations which revealed that infection delays and propagation vectors can greatly reduce the critical threshold, promote the emergence of epidemics, and even lead to the transition of infectious diseases from a disease-free state to an endemic one.
2013	Weiss, Howard	The SIR model and the Foundations of Public Health	This research proposed the new epidemic model using the SIR (Susceptible-Infected-Removed) model to analyze the impact of infection latency and propagation vector on the diseases spread in complex

			networks. This involves various numerical simulations which revealed that infection delays and propagation vectors can greatly reduce the critical threshold, promote the emergence of epidemics, and even lead to the transition of infectious diseases from a disease-free state to an endemic one.
2014	Kat Rock Sam Brand Jo Moir Matt J Keeling	Dynamics of infectious diseases	The article explores SIS and SIR models in infectious disease epidemiology, highlighting recent advancements and acknowledging challenges. Emphasizing the benefits of studying simple models, it focuses on three key components: heterogeneously structured populations, stochasticity, and spatial structure, relating mathematical model outcomes to real-world issues.

2015	Chisato Imai Ben Armstrong Zaid Chalabi Punam Mangtani Masahiro Hashizume	Time series regression model for infectious disease and weather	Two suggested modifications to the standard time series regression practice were inspired by the "susceptible-infectious-recovered" (SIR) models. These modifications include using sums of past cases as a substitute for the immune population and utilizing the logarithm of lagged disease counts to manage autocorrelation caused by actual contagion.
2020	Sunil Kumar Ali Ahmadian Ranbir Kumar Devendra Kumar Jagdev Singh Dumitru Baleanu Mehdi Salimi	An Efficient Numerical Method for Fractional SIR Epidemic Model of Infectious Disease by Using Bernstein Wavelets	This research presents innovative operational matrix with Bernstein wavelets addresses the fractional SIR model in medical research, transforming problems using collocation and exploring the Adams-Bashforth-Moulton system for solving.

2023	Fan, H., Tian, T., Wu, Y., & Hu, X.	Stability and Control of a Discrete SIR Model with Time Delay for COVID-19	The study explores a discrete SIR model with time delay, crucial for capturing COVID-19's spread dynamics, considering the incubation period, within a closed population devoid of births, deaths, or migrations except due to the disease
2024	Nasir, M. & Khan, A	Numerical Solutions for a Time-Dependent SIR Framework	The research enhances the SIR model for tuberculosis dynamics with time-dependent parameters, mirroring real-world complexities. By incorporating a time-varying transmission rate, it offers improved numerical solutions for understanding tuberculosis dynamics

2.4 Research Gap and Directions:

In epidemiology, the Susceptible-Infectious-Recovered (SIR) model is a compartmental model that is frequently used to comprehend how infectious illnesses propagate. Although the SIR model offers insightful information, there are a number of goals and research gaps related to it that are pointed below:

1. Incorporating Real-World Dynamics: Enhancing the SIR model to include real-world complications like human behavior, demographic characteristics, and regional heterogeneity might improve the model's predictive accuracy and comprehension of the dynamics of disease spread. Adding data-driven methods, like machine learning strategies, can assist in capturing these subtleties and enhance the predictive power of the model in various scenarios.
2. Modeling Intervention Strategies: Examining the efficacy of several intervention tactics, such immunization drives, social distancing measures, and quarantine guidelines, within the context of the SIR model might offer valuable perspectives on the most effective control approaches for mitigating disease. Subsequent investigations may concentrate on maximizing the arrangement, scope, and arrangement of actions to reduce the spread of disease and lessen the consequences of pandemics or epidemics.
3. Homogeneous Mixing: The fundamental SIR model postulates that there is homogeneous mixing within the population, which suggests that everyone has an equal probability of encountering every member of the population. In actuality, though, populations are frequently varied, exhibiting differences in behaviors, demographics, and contact rates. Heterogeneous mixing patterns could be incorporated into research to better reflect the dynamics of disease transmission

To improve our comprehension of the dynamics of infectious diseases and guide evidence-based public health policies, the SIR model can be expanded and improved by addressing these research gaps and directions.

2.5 Summary

This Literature Review study the Public health specialists' concerns about the possible effects of extended economic downturns on the spread of infectious diseases and preventive measures are emphasized by the literature study. Economic downturns have been extensively researched in relation to overall health. However, little is known about how they specifically affect infectious diseases. For a more thorough examination of the spread of infectious diseases, the SIR mathematical model is presented and adjusted. Numerous studies highlight how crucial mathematical models are for understanding the effects of economic and behavioral aspects, anticipating disease patterns, and investigating intervention strategies.

CHAPTER 03

PROPOSED SIR MODEL

3.1 Overview

An improved SIR model is designed and developed in this chapter using a research technique. The modified model extends the basic framework by incorporating additional factors. These modifications may account for age-specific infection rates, varying transmission dynamics, or other complexities. The SIR model by incorporating specific interventions. Lockdown measures restrict movement and social interactions, while vaccination dynamics consider the rollout and effectiveness of vaccines. Researchers analyze how these interventions affect disease dynamics. The research approach described in this chapter is regarded as a first step that gives the steps taken a direction to achieve set targets.

3.2 The Basic SIR model

Understanding how infectious diseases spread in communities is crucial, and mathematical epidemiological models are essential for this purpose. The Susceptible-Infectious-Removed (SIR) model is one of the most advanced models and provides a fundamental mathematical framework for comprehending the spread of epidemics. The SIR model classifies a population of size N into three different states: susceptible (S), infectious (I), and removed or recovered (R), based on the state of the illness. This compartmental model is straightforward as it uses coupled equations to link the counts of susceptible (S(t)), infected (I(t)), and recovered (R) individuals over a given period of time represented by the variable 't'. These compartments are linked, which is why this class of models is appropriately named.

The SIR model comprises three stages - Susceptible, Infectious, and Recovered, which help understand how a disease spreads. The Susceptible stage consists of people who are vulnerable to the infectious agent, while the Infectious stage includes those who are actively transmitting the disease. Finally, the Recovered stage includes those who have recovered from the illness or have been removed from the susceptible population. These compartments form the basis for differential equations that govern the rate of change of the different states, thereby capturing the temporal evolution of the epidemic. The three compartments that collectively make up the model give it its name, "SIR":

Table 3.1: Description of the compartments of SIR Model

Susceptible (S)	People who have not been infected with the infectious illness and do not have disease immunity are included in this compartment.
Infectious (I)	A person who is actively infected with the illness and is in this compartment is considered to be infectious (I).
Recovered (R)	People who have overcome the infectious illness and gained immunity are included in this division. Once a person has recovered, they are unable to contract the illness again and no longer contribute to its spread

The SIR model is highly effective in demonstrating how susceptible and infected individuals interact with each other, offering valuable insights into the mechanisms that affect the progression of an epidemic. The model's equations provide a dynamic representation of the correlation between the number of infected persons and the rate of new infections, as well as the relationship between recovered individuals and a decrease in the number of vulnerable individuals. By providing meaningful information about potential paths of epidemics, the SIR model assists academics and public health professionals in developing effective strategies for disease management and prevention.

The SIR model provides a comprehensive framework for studying the spread of infectious diseases in populations. Its mathematical rigor and compartmental structure make it an essential tool in epidemiology and public health research. By classifying individuals based on their susceptibility, infectiousness, and recovery, the model allows for a detailed understanding of epidemic dynamics.

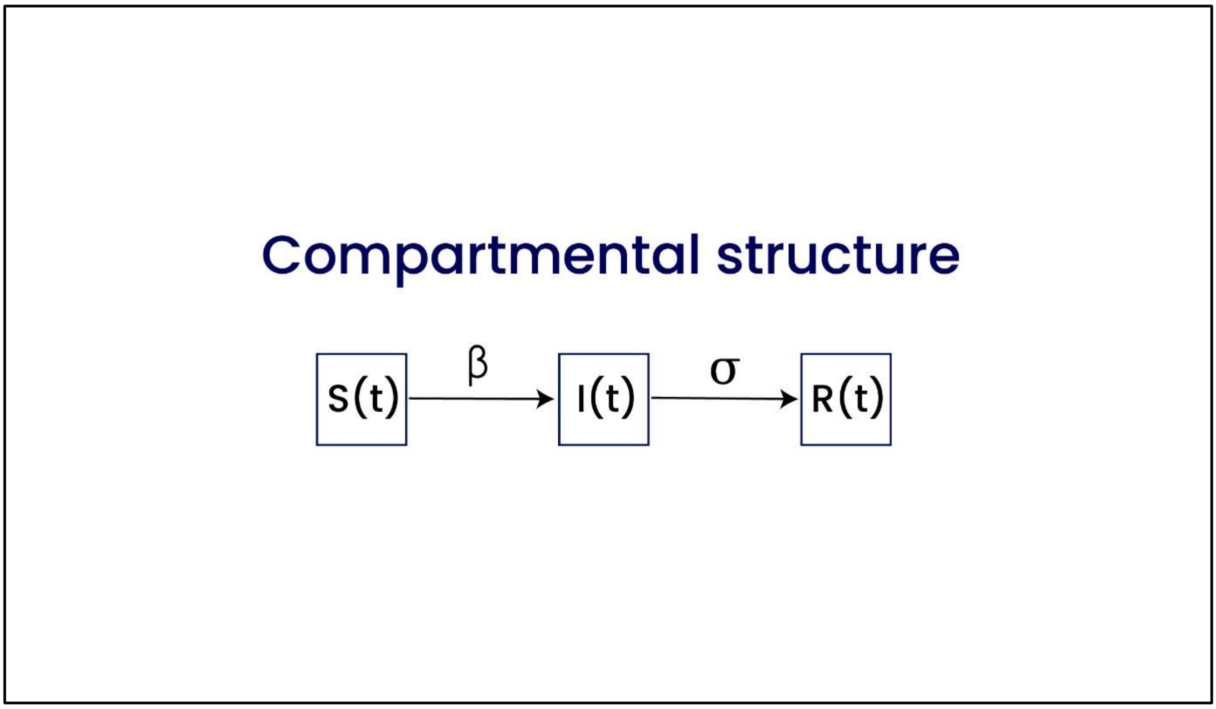

Figure 3.1: Basic Structure of SIR Model

The Susceptible-Infectious-Removed (SIR) paradigm operates based on two fundamental presumptions. Firstly, it assumes that the total size of the population remains unchanged during a pandemic. This premise forms the basis of the model's compartmental structure, which divides people into three categories based on their disease status - Susceptible (S), Infectious (I), and Removed or Recovered (R). The stability of population size provides a reliable framework for analyzing the movement of people between different categories over time.[40].

The SIR model assumes that transition rates between different compartments remain constant, indicating a steady migration of people from one condition to another. Specifically, the model postulates that individuals move at a consistent rate from being susceptible to becoming infected, and from being infectious to being recovered. The deterministic nature of the model implies that infection and recovery rates would remain unaltered throughout the epidemic [55].

When an illness has little impact on the birth, death, and migration rates of a population during the course of an epidemic, it can be assumed that the overall population size will remain constant [56]. This simplifies the depiction of disease processes, making it clearer and more concise. Similarly, the assumption of constant transition rates makes it easier to create a set of differential equations that represent the time-dependent changes in the number of people in each compartment [57].

Although these assumptions provide a strong foundation for understanding the fundamental dynamics of epidemics, it is important to recognize that the model has limitations. The SIR model may oversimplify the complexity of population dynamics in the real world. Factors such as demographic shifts, interventions, and external influences can have a significant impact on how an epidemic develops[58].

3.3 Operational Framework

The goal of this research is to examine the SIR mathematical model, which is a vital resource for comprehending the dynamics of infectious diseases. The relationships between susceptible (S), infected (I), and recovered people are captured by this model. That being said, things won't end there. The model will be improved by this study by adding important elements like lockdown, social distancing, and immunization records. A modified SIR model that takes into consideration other factors like lockdowns and vaccination campaigns will be presented in this study. Lockdowns limit social connections and movement, and immunizations increase immunity. These components work together to form a more complete framework. However, theory by itself is insufficient; we test our model. We assess its performance using real-time data to make sure it matches observed patterns and results.

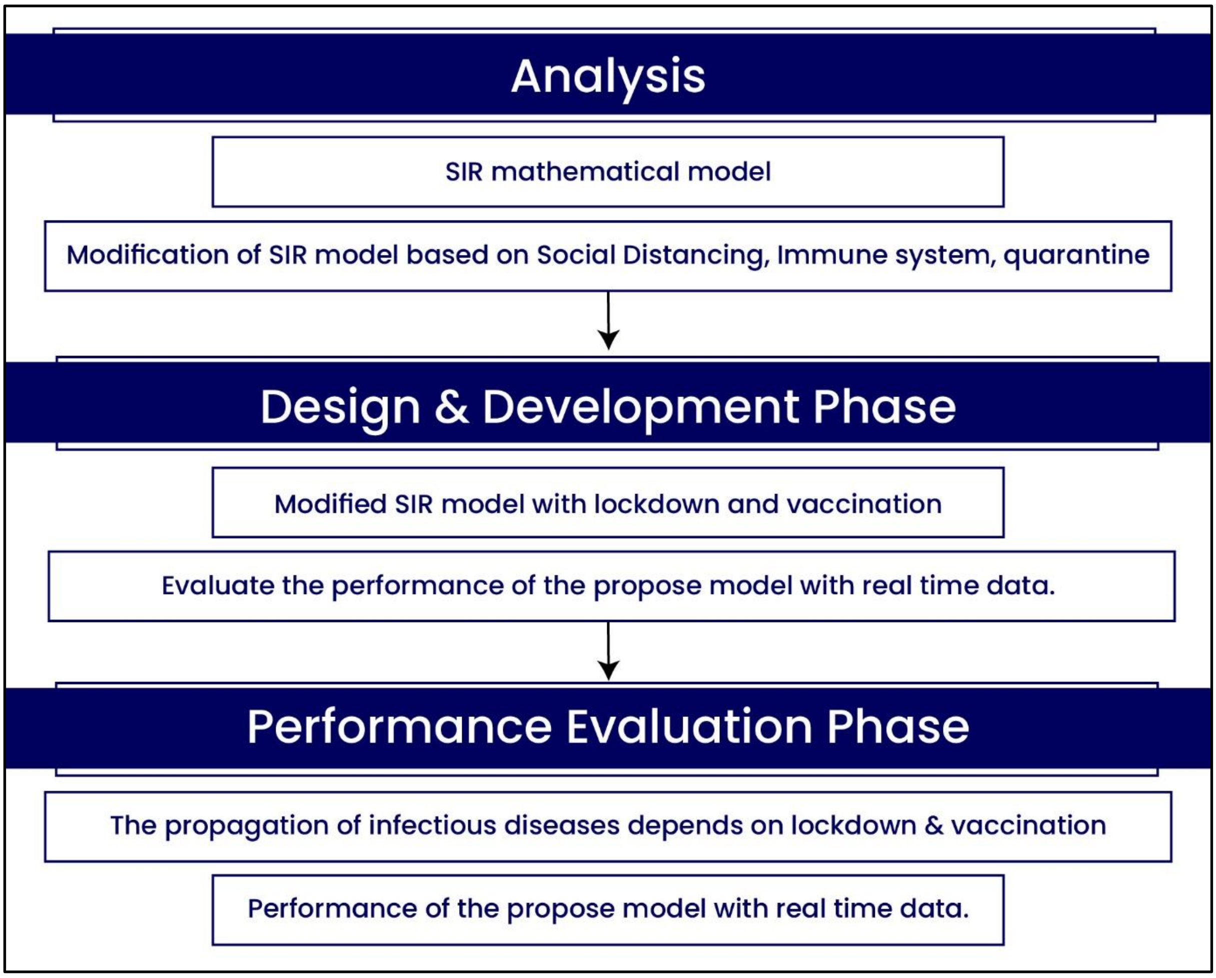

Figure 3.2: Operational Framework for modified SIR model

3.4 Research Design and Development

This section will discuss the process of designing and developing the modified SIR model by following the below given stages.

3.4.1 Modified SIR Model:

The standard Susceptible-Infectious-Recovered (SIR) model, a widely used mathematical framework for analyzing the transmission of infectious illnesses in a community, is extended by the modified SIR model given here[40]. The update allows for a more thorough understanding of disease transmission under various intervention scenarios since it takes into account the dynamics of vaccination and lockout measures.

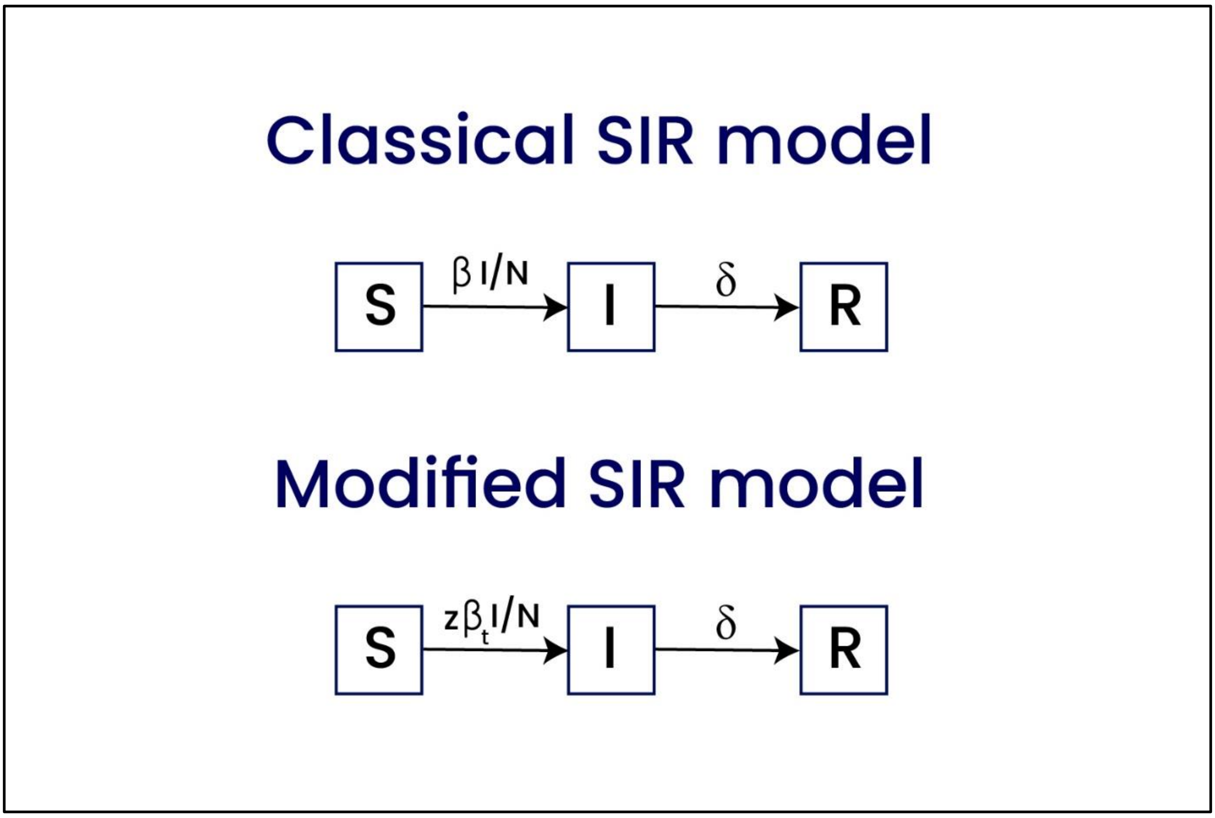

Figure 3.3: Comparison of Classical and modified SIR model

1. **Classical Sir Model**

$$\frac{dS}{dt} = -\frac{\beta IS}{N}$$

$$\frac{dI}{dt} = \frac{\beta IS}{N} - \delta I$$

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

2. **Modified Sir Model**

$$\frac{dS}{dt} = -\frac{z\beta_t IS}{N}$$

$$\frac{dI}{dt} = \frac{z\beta_t IS}{N} - \delta I$$

$$\frac{dR}{dt} = \delta I + v_t$$

The key factors in the above equations are the following:

$\beta_t = \beta_0(1-L_t)$ represents the reduced transmission rate due to lockdown measures.

‘z’ is the intervention factor for effective transmission. It can stand for a number of intervention techniques, such as social separation, lockdowns, or other steps to stop the transmission of the disease.

‘z’ can be time-dependent, reflecting changes in the intensity of interventions over time. For example, $z(t)$ could decrease during lockdown periods and increase when restrictions are lifted.

δ is the rate at which infected individuals recover

The Modified SIR model is a useful tool to better understand disease transmission, especially in situations where interventions are in place. This model takes into account various factors that affect the transmission rate, such as the impact of lockdowns, changes in immunity, and other factors that are specific to the illness being studied. By considering these variables, the Modified SIR model provides a more accurate representation of the dynamics of disease transmission.

The Susceptible-Infectious-Recovered (SIR) model is an important tool for understanding the spread of infectious diseases. However, the original SIR framework has limitations that make it difficult to apply in real-world situations. Specifically, the model assumes a constant transmission rate and lifetime immunity upon recovery, which does not account for the dynamic nature of treatments and vaccination campaigns. This is problematic, since vaccinations have become a critical tool for preventing disease. To address this issue, a modified SIR model has been developed that can incorporate changing immunity dynamics in populations. Modified SIR models provide a more realistic picture of disease propagation, particularly in the context of vaccination programs, by including compartments for vaccinated individuals and accounting for vaccination rates.

It should be noted that the basic SIR model is not capable of accounting for the impact of intervention strategies necessary for controlling disease outbreaks, such as lockdowns and social distancing. The oversimplified assumption of a constant transmission rate does not align with the changing social norms and public health interventions. However, this limitation is overcome by modified SIR models that incorporate time-dependent parameters to represent the effectiveness and timing of interventions. By utilizing this modification, policymakers can gain a better understanding of how public health initiatives influence the spread of illness and tailor interventions according to different stages of an epidemic.

The need for a modified SIR model is increased by various factors apart from vaccination and intervention strategies, such as fading immunity, heterogeneous mixing, and multiple virus strains. The modified SIR model provides a comprehensive framework to analyze and predict disease dynamics under different conditions, making it a more adaptable tool for public health researchers. This is because it can accommodate these complexities. All things considered, the changes made to the SIR model have been crucial in improving its usefulness and realism, allowing for a more accurate depiction of infectious disease transmission in complex and dynamic human populations.

The Modified SIR model is a mathematical framework that is used to understand the spread of infectious diseases. However, this model has limitations in depicting the real-world dynamics of certain diseases. Therefore, it is being modified to make it more applicable and give a more realistic depiction of illness dynamics in various contexts. These adjustments help researchers and policymakers to make better decisions in the management and control of infectious diseases. The Modified SIR model takes into account the objectives of the analysis and the characteristics of the disease under consideration. As a result, precise formulas and parameters are used to develop this model.

3.4.2 Classes in modified SIR model:

Our proposed model considers the Lockdown and vaccination with the traditional SIR model. We shall consider the following classes [40]:

Table 3.2: Description of the contents of Modified SIR Model

Class	Description
Suspected at home (Sh):	People in this compartment are believed to have the virus at home, although no tests have shown a positive result as of yet (Sh). They isolate themselves by staying home and limiting their social connections. They are not intended to spread the virus while they are in isolation since they are not interacting with the general public.
Suspected go outside (So):	Although no tests have come back positive, it is believed that some of the people in this compartment also have the virus. In spite of this, they continue to leave their houses throughout the pandemic, perhaps enhancing the virus's ability to infect anybody who come into touch with them. As a result of their interactions with people outside of their homes, this class poses a higher risk of viral transmission.
Infected at home (Ih):	Those who are infected at home (Ih) are those who are displaying signs of the illness, have been confirmed to be sick, and are remaining at home to maintain self-isolation. If they come into contact with vulnerable people, they might transmit the virus since they are contagious. Though their interactions are restricted because they are remaining at home, this lowers the overall risk of transmission.
Infected go outside (Io):	Despite being sick and exhibiting symptoms, people in this compartment nonetheless leave their houses. Since they come into contact with vulnerable people while participating in activities outside of their houses, they offer a greater risk of transmitting the virus to others.
Recovered (R):	People who have overcome the infectious illness and gained immunity fall under this category. People who have recovered from the illness are no longer prone to getting sick and cannot transfer the infection to others. The model, however, provides for the potential for recovered people to reenter the contaminated compartments, simulating circumstances in which immunity may fade or reinfection may be feasible.

Vaccinated (V):	The people in this compartment have gotten a vaccine against the contagious illness. Immunity from vaccination lowers the risk of contracting the virus or spreading it to others. The risk of infection for those who have had vaccinations may still exist, although it is less likely as a result of their immunization.

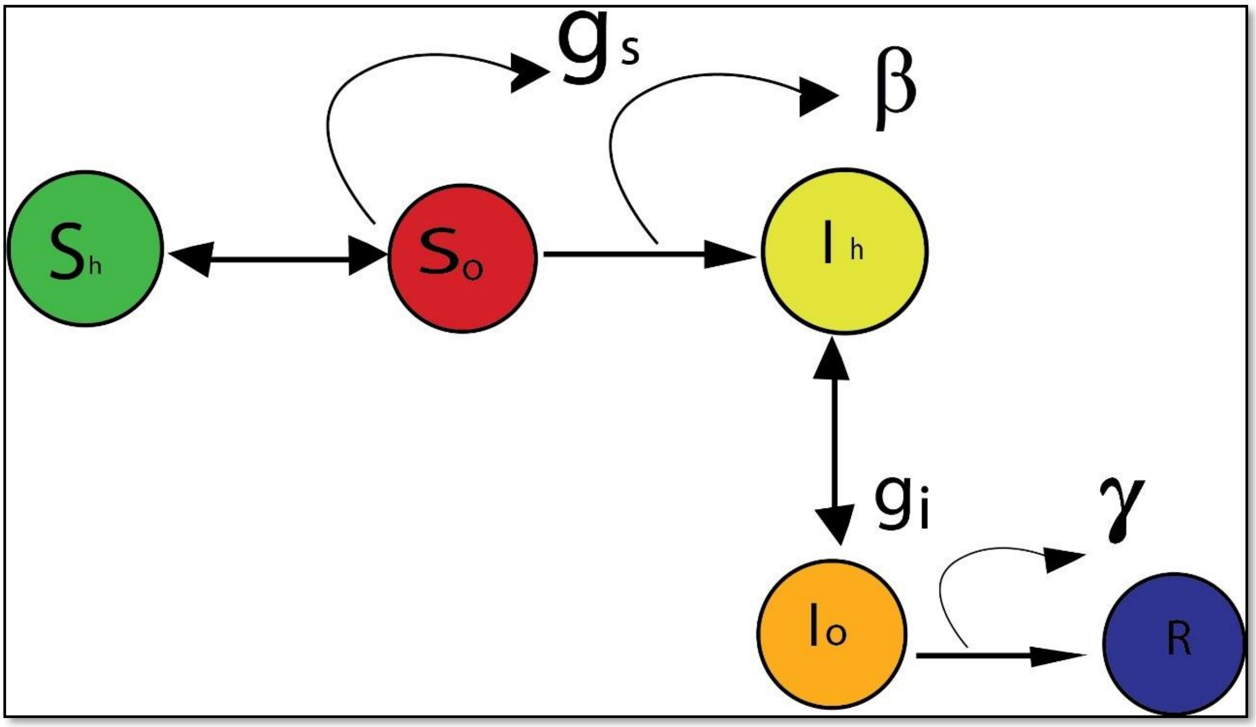

Figure 3.4: Proposed Modified SIR Model

3.4.3 Model Dynamics:

Over time, the updated SIR model monitors the movement of people between these compartments. The success of lockdown procedures, immunization rates, and other epidemiological issues all affect transition rates, which control how people move about. The differential equations of the model allow simulations of the dynamics of disease transmission under various conditions, such as varied levels of lockdown severity and vaccination coverage.

3.5 Simulation Framework:

The real time dataset used for this research ran its course through Google Colab. Google Colab is a free platform that gives users access to prominent data science libraries, TensorFlow, and Python within a web browser. The versatile platform Google Colab accelerates operations for machine learning and data analysis. The notebooks are kept on Google Drive and may be shared in the same way as Google Sheets or Docs, which makes real-time collaboration with others simple. GPU resources are also freely accessible through Google Colab, which is advantageous when training machine learning models that demand a significant amount of processing power. Because of its accessibility and ease, it is a tool that is often used in the data science and machine learning fields. Data scientists and machine learning practitioners frequently use it for both academic and professional reasons due to its integration with Google services and access to cloud resources.

3.6 Modifying Classic SIR Model with Lockdown and Vaccination Dynamics:

The traditional Susceptible-Infectious-Recovered (SIR) model must be extended to account for the impact of these treatments on disease transmission in order to add lockdown and vaccine dynamics [42]. Here is an overview of the procedure:

3.6.1 Extending the SIR Model:

The SIR model, as it is now understood, separates the population into three groups: Susceptible (S), Infectious (I), and Recovered (R). Additional compartments are included to account for lockdown and vaccination dynamics and to record the results of these treatments.

3.6.2 Introducing Lockdown:

Add more compartments to account for those who are following lockdown procedures. Due to fewer encounters, these people are immune to infection. For individuals who want to remain at home during lockdown, include a "Susceptible at Home" (Sh) compartment. Change the equations guiding compartment transitions to account for the lower contact rates during lockdown.

3.6.3 Implementing Vaccination:

To represent individuals who have been vaccinated against an illness, it is suggested to create compartments such as "Vaccinated Susceptible" (Vs), "Vaccinated Infectious" (Vi), and "Vaccinated Recovered" (Vr). These compartments should be taken into account when adjusting the transition equations, as the vaccinated population's recovery rates and susceptibility will differ [40].

3.6.4 Adjusting Transition Equations:

When modifying the transition equations, it is important to consider the impact of new compartments and interventions. Variables such as immunization rates, compliance with lockdown measures, and interaction rates during various interventions should be included in the transition between compartments. The equations should reflect the differential effects of vaccination and lockdown on disease spread.

3.6.5 Incorporating Parameters:

Include variables that gauge the success of lockdown and immunization measures. These variables will be used to calculate the decrease in disease transmission brought on by lockdown, as well as the reduction in susceptibility and altered recovery times brought on by vaccination. The domain of parameter ranges includes transmission rate (β) and recovery rate (δ) from 0 to 1, and the intervention factor (z) varying over time to reflect changing intervention intensity.

3.6.6 Data Calibration and Simulation:

To estimate the model's parameters and beginning conditions, calibrate the model using real-world data. Once calibrated, you may test the model under various situations to see how varied lockdown lengths, vaccination rates, and other types of intervention affect the spread of illness and its recovery.

3.6.7 Sensitivity Analysis:

Perform sensitivity studies to determine how modifications to parameter values affect the model's outputs. This aids in understanding the range of potential outcomes and assessing the robustness of your improved model.

3.6.8 Validation and Interpretation:

Verify the predictions of the changed model using actual data and past patterns. In order to obtain understanding of the efficacy of various intervention options, interpret the data in the context of your particular condition and population.

The Research gained a better understanding of how lockdowns and vaccinations impact the spread of diseases by modifying the traditional SIR model to include these factors. This updated model can provide valuable insights for decision-makers to develop effective strategies for managing and controlling infectious disease outbreaks.

3.7 SIR Model with Lockdown and Vaccination; Forecasting the Propagation of Infectious Diseases:

The SIR model with lockdown and vaccine dynamics is a crucial mathematical framework that aids in predicting the transmission of infectious diseases. It provides valuable insights into disease spread and control methods. The SIR model divides the population into susceptible (S), infectious (I), and recovered (R) compartments, forming the foundation of the model. The upgraded version includes the important elements of lockdown procedures and vaccine dynamics, making it a powerful tool for public health authorities and policymakers.

One of the main advantages of this approach is its flexibility in dealing with the complexities of real-life situations. It acknowledges that actions such as lockdowns can affect disease transmission rates, which are not constant [43]. Lockdown procedures aim to decrease interactions between infected and vulnerable individuals, thus reducing the transmission rate (beta). Understanding how to stop the spread of diseases during crises depends on this approach. Furthermore, the model considers the dynamics of vaccination by adding a new compartment for vaccine recipients (V). Vaccination programs reduce the number of people at risk, which slows down the spread of illness. The model provides a dynamic representation of the effects of vaccination by accounting for changes in vaccine coverage and efficacy.

The improved SIR model is effective because it uses a group of ordinary differential equations (ODEs) to track the flow of people between compartments over time. These equations contain variables that can be adjusted based on actual data and specific circumstances, such as the rate of transmission, recovery, and vaccination. Due to its adaptability, the model can predict and simulate various scenarios that consider the unique characteristics of each outbreak of infectious diseases.

The forecasting process involves several phases. Researchers start by inputting relevant data, such as the initial number of patients, population size, and illness characteristics. Using differential equations, the model simulates the disease's progression over time, while factoring in lockdown measures and vaccination programs. As the compartments change over time, the program generates predictions about the pandemic's future trajectory [44]. By adjusting parameters, researchers can refine the model to reflect the impact of different interventions, such as implementing lockdowns for varying durations or executing vaccination campaigns with different coverage rates.

One of the main features of the model is its ability to conduct scenario analysis. Policy makers and public health experts can analyze different "what-if" situations to determine the best methods for managing diseases. For example, they can assess the impact of different combinations of lockdown measures and immunization rates on the progression of a pandemic. This vital information helps decision makers to make informed choices that can reduce the spread of the disease and minimize its negative social and economic consequences.

Understanding and predicting the spread of infectious illnesses is crucial for public health workers and politicians. The SIR model with lockdown and vaccine dynamics provides a thorough understanding of how disease outbreaks develop and how various interventions may affect their course [45]. By taking into account the intricate interaction between lockdown measures and vaccination techniques, this model is a vital resource for successfully tackling infectious illnesses. Its versatility, scenario analysis skills, and dependence on real-world data make it an invaluable tool.

3.8 Steps for Data Analysis through the Modified SIR Model:

This section will cover the steps that are used to analysis the provided data through the modified SIR model. These steps involve the model development, incorporation of lockdown and vaccination, simulation study and scenario, data collection and validation, and finding trends. The explanation of data analysis is specified below.

3.8.1 Model Development and Formulation:

The formulation, development and implementation, of the modified SIR model for infectious disease transmission with lockdown and vaccine dynamics will be covered in detail in this chapter. The goal is to develop a complete model that combines lockdown procedures and vaccinations with the conventional SIR framework.

We will first go over the basic tenets of the traditional SIR model. Individuals who are susceptible (S), infectious (I), and recovered (or immune) (R) are the three compartments that make up the SIR model's population. The many stages of disease transmission are represented by these divisions. Through interaction with infectious people, susceptible people can catch an infection and, if they do, they move into the infectious compartment [46]. The contagious people can get well and develop immunity over time or continue to be contagious until the sickness has run its course. The traditional SIR model makes continuous assumptions about infection and recovery rates without taking the effects of treatments into account.

We will add more compartments and parameters to the model to capture the dynamics of lockdown measures. Limiting human interaction and the spread of contagious illnesses are the goals of lockdown procedures. As a result, we'll add a new container marked L (for those under lockdown), which stands for people who are following lockdown rules and interacting with other people only seldom. Depending on how well and how long the lockdown mechanisms are in place, people will move between compartments [47]. The rate at which people enter and exit the lockdown compartment will be represented by parameters.

In the improved SIR model, we will also incorporate vaccination dynamics. Immunity-building vaccinations are essential for lowering the overall transmission rate, reducing the vulnerable population, and raising immunity. V (for vaccinated persons) will be included as a new compartment to indicate those who have received the vaccination and have grown immune. The availability, coverage, and distribution methods of the vaccine will all have an impact on how quickly people move from the susceptible to the immunized compartment. We will include variables that reflect the rate of immunization and the effectiveness of the vaccine in preventing infection.

A set of ordinary differential equations (ODEs) will make up the model and explain the fluxes between the various compartments. We may model the dynamics of disease transmission over time and evaluate the effects of various intervention techniques, such as various kinds of lockout measures and vaccination programmes, by numerically resolving these equations.

We will gather pertinent information on disease transmission, lockdown procedures, and vaccine dynamics from dependable sources in order to validate the model. To make sure the model appropriately depicts the real-world scenario, we will calibrate the model parameters based on the data that is currently available.

The methodology chapter will, in general, give a thorough description of how the updated SIR model is created and designed to take into account the dynamics of lockdown measures and vaccination. This will set the stage for performing simulation studies and examining different case studies in order to gather knowledge about the efficiency of various strategies in containing infectious illnesses.

3.8.2 Incorporating Lockdown Dynamics:

The process of introducing lockdown dynamics into the modified SIR model for infectious disease transmission will be covered in detail in this section. By restricting interpersonal interaction and lowering the transmission rate, lockdown procedures have become essential non-pharmaceutical interventions to stop the spread of infectious illnesses. We want to analyze lockdown measures' effects on dynamics of disease transmission and offer insights into their efficacy by incorporating their dynamics into the model [47].

We add a new compartment, L (for persons under lockdown), to the modified SIR model to account for lockdown dynamics. This compartment stands for those who are following lockdown procedures and limiting their social engagement. The timing, severity, and length of the applied lockdown measures will determine the movement of people between the susceptible (S), infected (I), recovered (R), and lockdown (L) compartments.

Depending on how well the lockdown measures work to stop disease transmission, the pace at which a compartment transitions from the susceptible compartment (S) to the lockdown compartment (L) will vary [48]. The degree of adherence among people, the application of limits, and the characteristics of the disease itself can all have an impact on this efficacy. A larger incidence of people moving from the vulnerable compartment to the lockdown compartment will be the outcome of the lockdown measures being more effective [49].

The rate at which the lockdown measures are lifted or relaxed will also affect the transition from the lockdown compartment (L) back to the susceptible compartment (S). People will interact more once the limits are relaxed, which might raise the risk of illness. This modification will be reflected in the speed of transition from the lockdown compartment to the vulnerable compartment.

The model's inclusion of lockdown dynamics enables us to replicate various situations and determine how they will affect the spread of illness. We may assess the efficiency of the deployed lockdown measures in halting the spread of infectious illnesses by altering variables like the timing, length, and strength of the lockdown measures [50]. Additionally, we may investigate the best approaches for installing and lifting lockdown measures as well as the trade-offs connected with them, including their effects on social and economic variables.

Data on the execution of lockdown measures, such as time, length, and degree of compliance, will be gathered from reputable sources, including government reports and epidemiological research, in order to calibrate the parameters associated to lockdown dynamics. The choice and estimation of the relevant transition rates between compartments in the model will be guided by this data.

Overall, we are able to evaluate the effect of these non-pharmaceutical treatments on disease transmission dynamics by adding lockdown dynamics into the modified SIR model. We may get important insights into the efficacy of various lockout mechanisms and optimize their use to successfully limit the spread of infectious illnesses by simulating various lockdown scenarios.

3.8.3 Integrating Vaccination Dynamics:

In this part, we'll look at how the modified SIR model of infectious disease transmission incorporates vaccination dynamics. By decreasing the vulnerable population, raising immunity, and reducing the overall transmission rate, vaccination efforts have evolved into crucial tactics in the fight against the spread of infectious diseases. We intend to analyze the impacts of vaccination on disease transmission dynamics and assess the effects of various vaccination regimens by including vaccination dynamics into the model.

We add a new compartment designated V (for vaccinated people) to the modified SIR model to incorporate vaccination dynamics. Individuals who have received the vaccination and have built up an immunity to the infectious illness are represented by this compartment [51]. Vaccine accessibility, coverage, effectiveness, and distribution methods will all affect how people move between the susceptible (S), immunized (V), infected (I), and recovered (R) compartments.

The pace of vaccination and the level of population coverage will determine how quickly the susceptible compartment (S) transitions to the vaccinated compartment (V). The rate at which people switch from being vulnerable to being vaccinated will depend on variables including vaccine availability, prioritization, and public acceptability [52]. The fraction of vaccination recipients who really develop immunity will also be determined, along with the vaccine's effectiveness in preventing illness.

Depending on how long the vaccine confers protection, the pace at which a compartment transitions from the vaccinated compartment (V) to the recovered compartment (R) will vary. While some vaccinations may result in lifelong protection, others could need repeated booster injections. This transition rate represents the speed at which those who have received vaccinations lose their immunity and move into the compartment that has recovered.

We may simulate various scenarios and evaluate how vaccination tactics affect disease transmission by including vaccination dynamics into the model [53]. Analyzing the consequences of various vaccination coverage rates, vaccine effectiveness, and distribution methods are included in this. We can investigate the best distribution of vaccinations across various demographic groups and assess the effects of various vaccination schedules on the dynamics of disease transmission.

Data on vaccination campaigns, including vaccine coverage rates, vaccine effectiveness, and distribution tactics, will be gathered from dependable sources such public health organizations, research papers, and vaccination records in order to calibrate the parameters associated to vaccination dynamics. The choice and estimation of the relevant transition rates between compartments in the model will be guided by this data.

Overall, we may assess the influence of vaccination on disease transmission dynamics by including vaccination dynamics into the modified SIR model. We can evaluate the efficacy of various vaccination regimens and optimize their use to successfully limit the spread of infectious illnesses by simulating various vaccination scenarios. This research will help policymakers and public health authorities in their decision-making processes by offering insightful information on the possible advantages and difficulties connected with vaccination efforts.

3.8.4 Simulation Studies and Scenarios:

The simulation experiments and scenarios that will be used to examine the dynamics of the updated SIR model with lockdown and vaccine dynamics are covered in this section. We want to learn more about the efficiency of various interventions and immunization regimens in reducing the spread of infectious illnesses by modelling various scenarios.

Running computer models based on the modified SIR framework in simulation studies simulates the dynamics of illness transmission across time [54]. We may use these simulations to examine how various factors, interventions, and tactics affect the spread of infectious illnesses.

We'll start by defining the model's starting points, including the size of the population, the number of vulnerable people, the beginning population of infected people, and the initial population of those who have recovered. These beginning conditions will be calculated using pertinent epidemiological research or based on information that is already accessible.

The model's parameters will then be specified, including the rate of transmission, rate of recovery, rate of vaccination, rate of vaccine effectiveness, and rate of transition between compartments (such as susceptible to lockdown, susceptible to vaccination, and susceptible to recovery). These parameters will be calculated using the data at hand, a review of the literature, and industry expertise.

We will conduct the simulation after setting up the model with the initial circumstances and settings to track the dynamics of illness spread through time. A set of ordinary differential equations (ODEs) that describe the fluxes between the various compartments must be solved in order to complete the simulation. In order to resolve these equations and provide the simulation results, numerical methods like Euler's method and Runge-Kutta methods will be used.

In order to investigate various situations and actions, we will perform simulation experiments. By altering the time, length, and strength of the applied lockdown measures, for instance, we may mimic the effects of various lockdown tactics. This will enable us to evaluate the effects of various lockdown scenarios on the dynamics of disease transmission, such as the peak infection rate, the overall infection rate, and the length of the epidemic.

In a similar manner, we will model the results of various vaccination tactics. This may entail adjusting the vaccination coverage rate, taking into account various distribution tactics (such as giving high-risk populations priority or launching mass vaccination campaigns), and assessing the effect of vaccine effectiveness on the dynamics of disease transmission. These simulations allow us to evaluate the efficacy of vaccination in stopping the disease's spread and easing the strain on the healthcare system.

To get insights and compare various situations, we will compare the simulation outcomes. Key epidemiological variables including the reproduction number (R0), attack rate, and the percentage of the population that develops immunity may be assessed as part of this investigation. We will also do sensitivity tests to evaluate how well the model stands up to changes in parameters and presumptions.

Multiple iterations of the simulation studies and scenarios that incorporate actual data and tenable hypotheses will be run. We may improve the model through this iterative process, test its predictions against actual data, and increase the accuracy of our conclusions.

For the updated SIR model with lockdown and vaccine dynamics, simulation studies and scenarios play a crucial role in the process. We can learn a lot about how well various treatments and vaccination plans work to stop the spread of infectious illnesses by using these simulations. These results will aid in the use of evidence-based decision-making in public health and provide policymakers and stakeholders with information on efficient methods for reducing the effects of infectious illnesses.

3.8.5 Data Collection and Model Validation:

The procedure of data gathering and model validation for the updated SIR model with lockdown and vaccination dynamics will be covered in this section. Data collecting include compiling pertinent facts on the spread of diseases, lockdown procedures, vaccine dynamics, and other pertinent factors. By comparing the model's predictions to actual data, model validation seeks to evaluate the precision and dependability of such predictions.

In order to create a solid model that faithfully captures the dynamics of infectious illnesses, data collecting is an essential first step. Data will be gathered from trustworthy sources, such as epidemiology databases, government publications, public health organizations, and research projects. The data may contain specifics on the use of lockdown procedures and vaccination programmes, as well as statistics on illness incidence, prevalence, and death.

In order to calculate model parameters like the transmission rate, recovery rate, vaccination rate, and vaccine effectiveness, data will be gathered. To get the most accurate estimates based on the data at hand, parameter estimation approaches like maximum likelihood estimation or Bayesian inference may be used. Additionally, sensitivity analysis will be carried out to evaluate how parameter uncertainty affects model predictions.

To verify the dependability and credibility of the updated SIR model, model validation is a crucial step. In order to determine how accurately the model represents the observed dynamics of disease transmission, validation entails comparing the model's predictions to actual data. Both quantitative and qualitative techniques will be used to validate the model.

In qualitative validation, it is determined whether the model accurately reproduces the broad trends and patterns seen in empirical data. This can involve contrasting the peak times and sizes of epidemics, the length of the epidemic, and the general curve form of the sickness. If the model qualitatively reproduces these patterns, it gives reason to believe that it can accurately depict the fundamental dynamics of the illness.

Comparing the model's predictions to particular epidemiological indicators and statistical measurements generated from empirical data is known as quantitative validation. This might involve comparing the model's projected reproduction number (R0) or attack rate to the equivalent values actually found in the data. To evaluate how well the model fits the data, one can use statistical tests and goodness-of-fit metrics like the chi-square test or the root mean square error.

The model may be improved and recalibrated if differences are found between the model predictions and the observed data during the validation phase. To enhance the model's performance, this may entail changing model parameters, revising assumptions, or adding new data sources.

In general, gathering data and validating the model are essential processes in assuring the precision and dependability of the improved SIR model. We may increase confidence in the model's capacity to reflect the dynamics of infectious diseases transmission with lockdown and vaccine dynamics by including real-world data and evaluating the model's predictions. The model's scientific foundation is strengthened by this validation procedure, which also increases the model's value for informing public health policies and initiatives.

3.9 Ethical Considerations:

The ethical issues surrounding the creation and use of the modified SIR model for infectious diseases transmission with lockdown and vaccine dynamics will be covered in this section. To ensure the ethical conduct of research and defend the rights and welfare of people and communities taking part in the study, ethical considerations must be addressed.

1 Privacy and confidentiality: It is crucial to follow privacy and confidentiality guidelines when gathering data for the model. To avoid unauthorized access, personal data should be anonymized and securely kept. To safeguard people' privacy and ensure the confidentiality of sensitive data, research methodologies should adhere to the pertinent data protection laws and regulations.
2 Getting informed permission is crucial if there will be any human subjects engaged in the study. The aim, dangers, advantages, and voluntary nature of involvement should all be

made clear to participants. A clear and culturally acceptable process should be used to get informed consent, guaranteeing that participants have the freedom to revoke their permission at any moment without suffering repercussions.

3 Equity and Fairness: Equity and fairness should be taken into account while developing and implementing the model. In particular for marginalised and disadvantaged people, this involves making sure equal access to immunization, healthcare services, and information. To reduce possible inequities, the potential effects of actions, such as lockout measures, on various social and economic groups should be thoroughly studied.

4 Research involving human subjects should be subjected to an appropriate institutional review board's or ethics committee's ethical evaluation. The scientific rigor, moral soundness, and compliance with applicable ethical standards and laws should all be considered while evaluating the study procedure. The research's respect for the rights, welfare, and dignity of everyone participating in it is ensured by ethical review.

5 Transparency and accountability: The study method and results should be disclosed in a transparent manner to the appropriate parties, such as policymakers, representatives of the public health, and the general public. To guarantee a thorough grasp of the study's findings and their consequences, the methodology, underlying assumptions, and limitations of the modified SIR model should be made explicit. To maintain scientific integrity and accountability, any conflicts of interest or possible biases should be declared.

6 Risk-Benefit Analysis: A thorough risk-benefit analysis of the research endeavor is crucial. It is important to carefully weigh the possible risks and advantages of the model creation, data gathering, and intervention implementation processes. To reduce possible harms and increase societal benefits, action must be done.

7 Collaboration and cooperation are crucial. This includes working with public health organizations, governments, and communities. The possibility that the study findings will be successfully incorporated into public health policies and interventions rises when these stakeholders are involved throughout the research process. This also promotes teamwork and assures the relevance of the research.

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3.10 Summary

This chapter examine the SIR mathematical model, relationships between susceptible (S), infected (I), and recovered people. Improve the basic SIR model by incorporation the Lockdown and Vaccination. Lockdowns implements the social distancing and implementing vaccination increases the immunity. The last section is all about evaluating the results of our interventions. How do different levels of lockdown and vaccination affect the spread of infectious diseases? This section also addresses the ethical concerns related to the development and application of the modified SIR model for infectious disease transmission with lockdown and vaccination dynamics.

CHAPTER 04

PERFORMANCE EVALUATION

4.1 Overview:

In Chapter 4, the modified SIR model is thoroughly examined along with the conclusions drawn from the simulation results. Additionally included is a comparison of the dynamics of vaccination and lockdown. The lockdown and vaccination stability analyses will also be shown in this study.

4.2 Running the Real Time Dataset:

The real time dataset was obtained from the Covsirphy Library, GitHub. For running the dataset obtained; a Core i7 processor and an 8GB RAM was an essential part of the experimental setup. The dataset was run on Google Colab Python 3.10.6. The dataset has the entries starting from 07-03-2020 and goes on. It also shows the number of cases confirmed every day. The number of infected, susceptible and recovered cases are also included in the dataset

4.3 Introducing Lockdown Protocol:

In the context of COVID-19 transmission, a comparative study was conducted to analyze the effects of deploying lockdowns and not deploying them on the dynamics of the pandemic. The study took into account susceptibility, infection, recovery, and deaths.

4.3.1 Comparison Analysis:

Implementing lockdown techniques changed the dynamics of disease transmission during the COVID-19 pandemic. We will examine the effects of these strategies on infection rates, recovery, vulnerability, and public health in general in this section. Let's get into the details now.

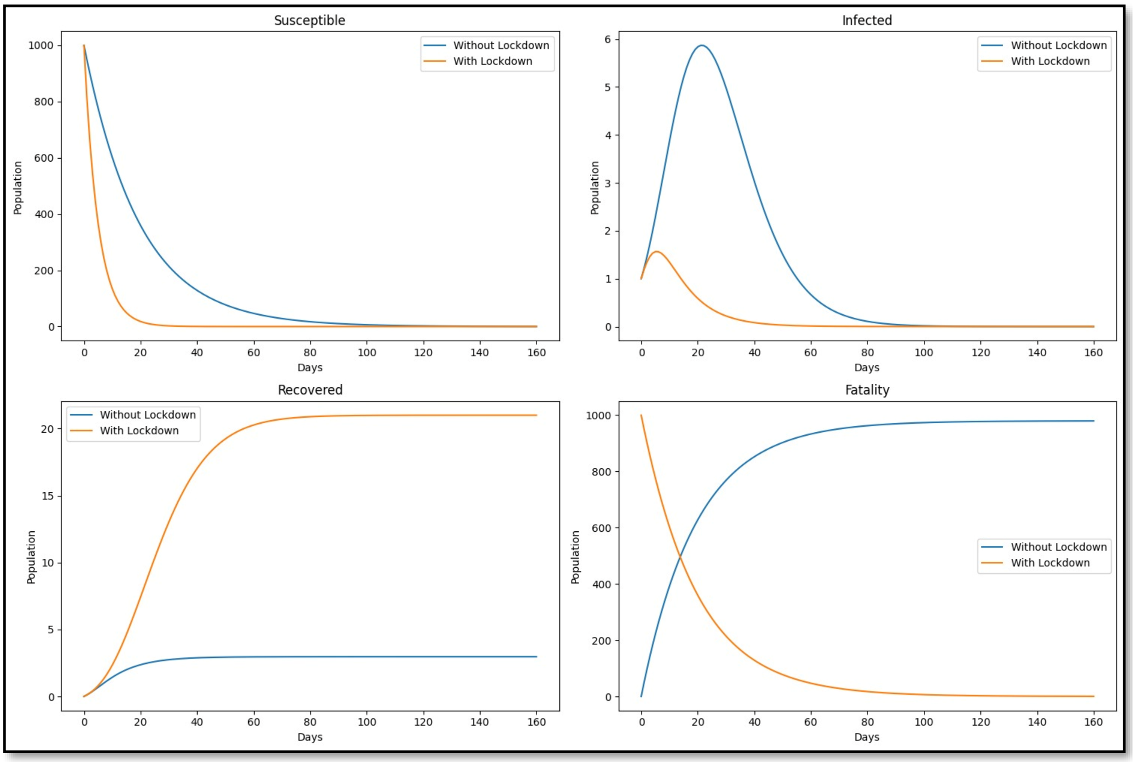

Figure 4.1: Comparative analysis of lockdown protocol

In the context of COVID-19 transmission, a comparative study was conducted to analyze the effects of deploying lockdowns and not deploying them on the dynamics of the pandemic. The study took into account susceptibility, infection, recovery, and deaths.

The study found that without lockdown procedures, the population's vulnerability to the virus is maintained, which increases the rate of transmission. The unrestricted interaction between infected and vulnerable persons promotes a rapid spread of the disease. As a result, the frequency of infections rises, putting a significant strain on healthcare systems and increasing the possibility of death. Not implementing lockdowns can lead to an extended epidemic peak, which would put more burden on medical services and make it more difficult to control and contain the outbreak.

Lockdown measures drastically altered the transmission dynamics of a disease. They are implemented to limit social contact and thereby reduce the possibility of infection spread. This reduction in transmission helped to decrease the number of sick people, alleviated pressure on healthcare systems and prevented unmanageable surges in the number of cases. By restricting interactions between vulnerable and infected groups, lockdown measures also help to reduce vulnerability. As a result, the "infected" compartment can more easily transition to the "recovered" compartment over time, due to the subsequent decrease in new infections.

In addition, lockdowns had a significant impact on reducing the number of deaths. By lowering the rate of transmission, lockdowns eased the burden on medical institutions, improved care for sick patients, and ultimately lowered the overall death rate. Implementing lockdowns not only helped to control the spread of infection but also provided an opportunity to support public health initiatives such as testing and contact tracing.

The comparison between the situations with and without lockdowns highlighted the importance of containment measures in determining the course of COVID-19. Lockdowns have proven to be an essential tool in reducing vulnerability, lowering infection rates, promoting recovery, and ultimately minimizing deaths. However, implementing such policies requires a thoughtful approach that considers both the short-term health benefits and the longer-term social consequences. It is crucial to strike a balance between these two factors for the welfare of society as a whole.

4.4 Stability Analysis for Lockdown:

This section examines the consequences of two different lockdown times: a shorter lockdown of seven days and a longer lockdown of thirty days and three hundred days. We can learn more about patient recovery rates, disease containment, and the strain on healthcare systems by examining real-time data and computational models. Stability analysis involves examining the equilibrium points of the modified SIR model to determine whether the disease-free equilibrium or endemic equilibrium is stable. This is done by analyzing the basic reproduction number R0:

- If R0<1, the disease-free equilibrium is stable, indicating that the disease will die out over time.
- If R0>, the endemic equilibrium is stable, indicating that the disease will persist in the population.

4.4.1 lockdown for 07 days:

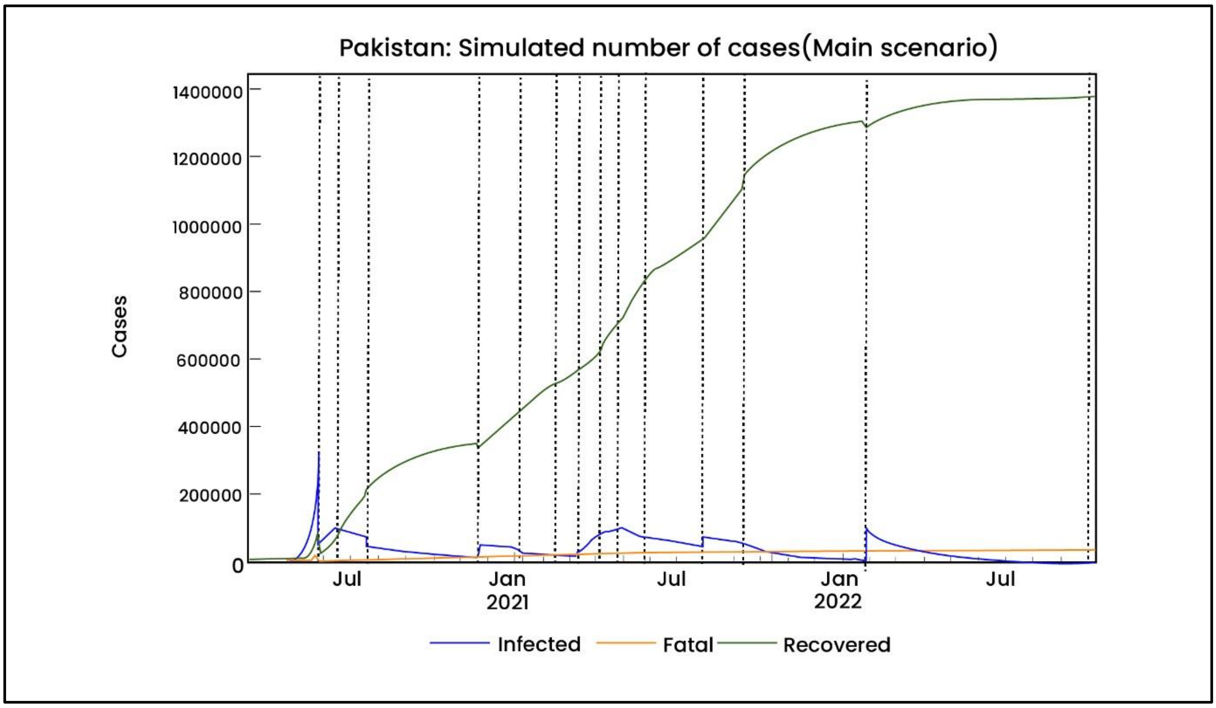

Figure 4.2: Simulated number of cases after applying Lockdown protocols for 07 days

The results of examining a real-time dataset using Google Colab along with a well-planned 7-day lockdown schedule are presented in Figure 7. The data shows a significant reduction in the number of anticipated cases in a short amount of time, indicating a remarkable improvement in patient recovery. This empirical evidence highlights the effectiveness of carefully planned lockdown interventions, particularly ones that have time restrictions, in slowing the spread of the disease. Such strategic measures not only reduce the likelihood of a large outbreak in the community but also alleviate the burden on hospital infrastructures, contributing to the overall containment of the illness.

This investigation contributes to the academic understanding of the critical importance of timely interventions in managing public health crises. It highlights the potential of carefully implemented measures to slow the spread of infectious diseases, and underscores the need for policymakers to plan and execute initiatives that promote the overall health of the community during health emergencies.

4.4.2 Lockdown For 30 Days:

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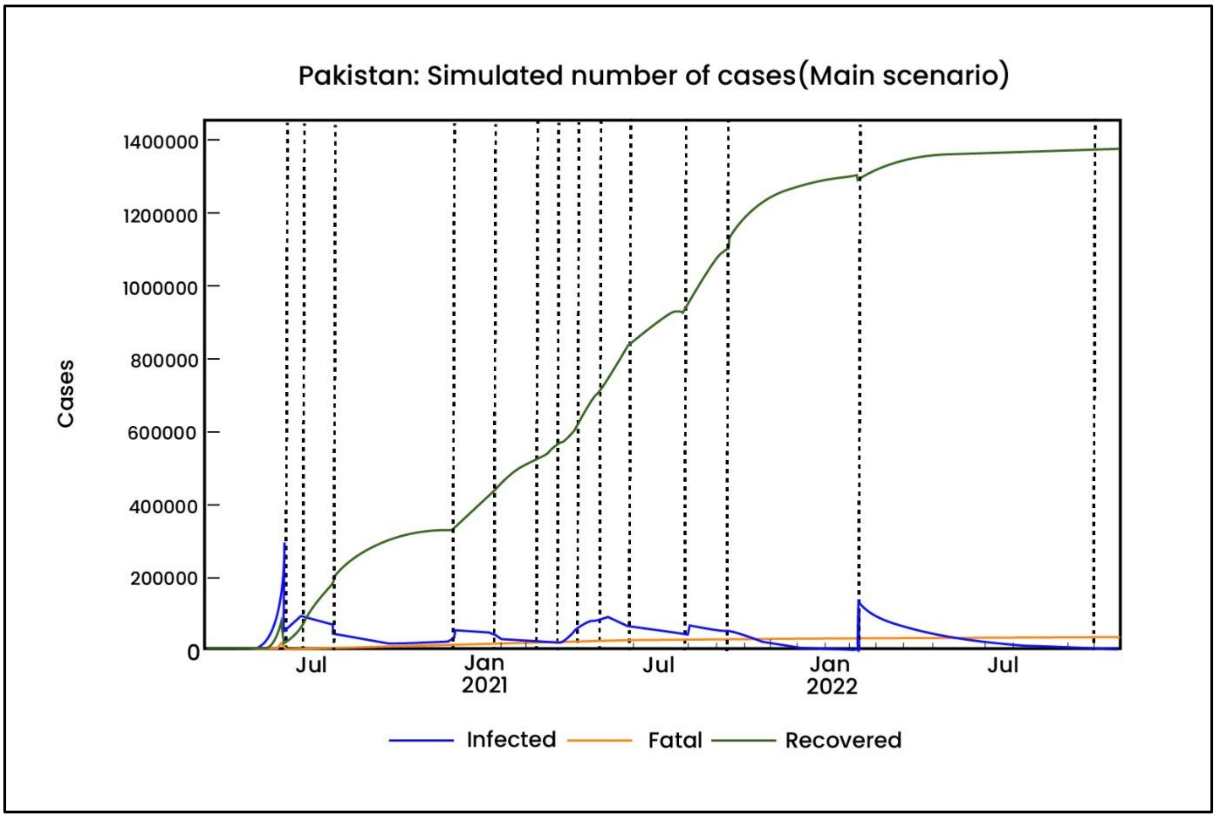
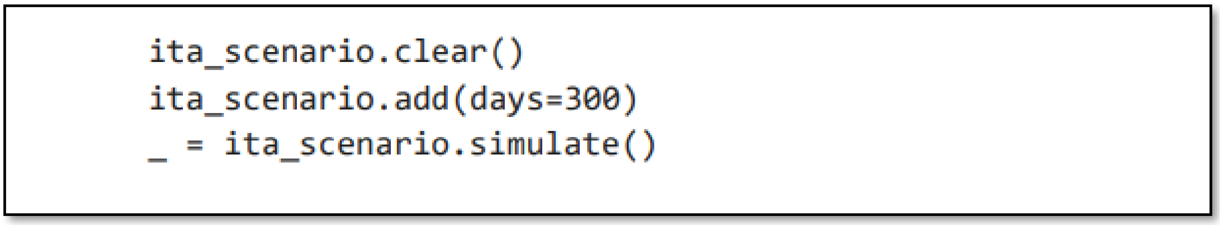


Figure 4.3: Simulated number of cases after applying Lockdown protocols for 30 days

The computational model in the analytical framework shown in Figure 8 underwent a 30-day lockout regimen to study its long-term effects on the trajectory of illness growth. The study aimed to analyze the complex dynamics of an extended intervention period and clarify its possible influence on the contagion's long-term prevalence. The results showed that this prolonged lockdown approach significantly decreased the number of cases reported and increased the proportion of patients showing signs of recovery.

Based on a detailed investigation, it has been found that implementing extended lockdowns can be an effective tactic to slow down the spread of an illness and create an environment that can speed up recovery. Therefore, it is crucial to carefully consider the duration of lockdown measures. This highlights the importance of balancing the timing of these interventions with their ability to prevent the spread of infections. Our findings provide valuable insights into the potential benefits of prolonged lockdown measures in order to restore health and normalcy to affected areas, and thus significantly contribute to the academic discourse on strategic health interventions during pandemics.

4.4.3 Lockdown for 300 days:



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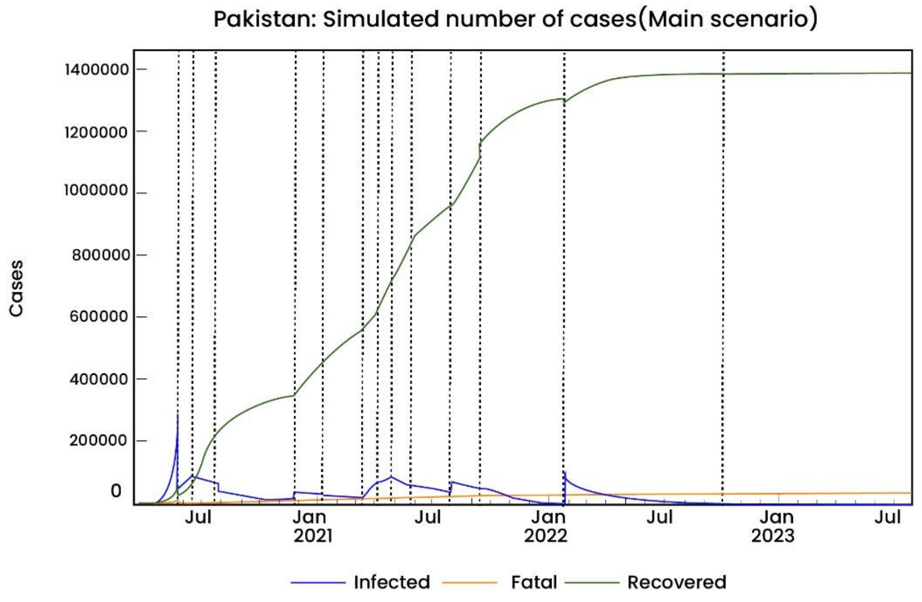


Figure 4.4: Simulated number of cases after applying Lockdown protocols for 300 days

The intricate diagram displayed in Figure 9 highlights the remarkable effectiveness of a 300-day lockdown protocol, which serves as a notable example of the untapped potential of long-term containment tactics in the event of infectious disease outbreaks. This empirical journey advances the conversation on the numerous implications of long-term interventions by taking place against the backdrop of challenging and prolonged situations. The profound impact of this prolonged engagement is evident and goes beyond minor adjustments to represent a significant shift in the course of the hypothetical epidemic.

The effectiveness of the 300-day lockdown is remarkable as it has successfully reduced the number of simulated cases. This reduction is significant as it represents a crucial shift in the epidemic's dynamics. The lockdown has a considerable impact on limiting the spread of the virus, which in turn reduces the chance of further transmission. This subsequent drop in infection rates is a turning point in the community's battle against the disease, as it suggests that measures taken are working in controlling the outbreak.

It is important to conduct a careful analysis of the complex effects that long-term interventions have on economies, society, and public health, as we explore their implications. Extended lockdown measures have the power to drastically alter lives, and the empirical data collected from this extended intervention is relevant to discussions about strategic public health initiatives. This story goes beyond a superficial examination of statistical results and provides a comprehensive understanding of how long-term measures can dynamically change the trajectory of pandemics, safeguard public health, and improve our preparedness for future health emergencies.

4.4.4 Quantitative Analysis of Lockdown Scenario

The table below presents a quantitative analysis of the impact of lockdown phases on disease transmission. It details changes in key parameters like transmission rate and intervention effectiveness across different phases.

Table 4.1: Quantitative Analysis for Lockdown Scenario

Phase	Population	rt	Theta	Kappa	Rh0	Sigma
0th	212215030	4.62	0.029	0.0015	0.18	0.072
1st	212215030	2.56	0.004	0.0012	0.07	0.075

2nd	212215030	0.75	0.008	0.0006	0.036	0.150
3rd	212215030	0.71	0.000097	0.0007	0.037	0.075

In the lockdown scenario, a phased approach is applied to understand the impact of various intervention measures on controlling the spread of the disease. In the initial phase (0th phase), with no lockdown measures in place, the transmission rate (rt) is high at 4.62, indicating rapid disease spread, while the intervention factor (θ) remains low at 0.029, reflecting minimal control efforts. The fatality rate (kappa) and infection transmission rate (rho) are observed at 0.0015 and 0.18, respectively, with a moderate recovery rate (sigma) of 0.072. As lockdown measures are introduced in the 1st phase, the transmission rate drops significantly to 2.56, and θ is reduced to 0.004, demonstrating the effectiveness of initial interventions. A slight decrease in the fatality rate (kappa) to 0.0012 and in rho to 0.07 is observed, while the recovery rate (sigma) slightly increases to 0.075. In the 2nd phase, stricter lockdown measures further reduce the transmission rate to 0.75, with an increased intervention factor (θ=0.008) and a reduced fatality rate (kappa = 0.0006). The infection transmission rate (rho) drops significantly to 0.036, while the recovery rate (sigma) increases notably to 0.15, indicating improved recovery outcomes due to lockdown. In the final 3rd phase, the transmission rate remains low at 0.71, with minimal further reduction in θ, but the recovery rate stabilizes at 0.075, reflecting a balanced outcome of strict lockdown measures.

4.5 Introducing Vaccination Protocol:

Vaccination is a crucial tool in the global fight against infectious diseases. My study, which thoroughly investigated the benefits of a full vaccination program, produced important results that highlight the effectiveness of vaccines in preventing the spread of different diseases. The study analyzed a measurable decrease in simulated cases, which is similar to the effects of strict lockdown procedures. This insightful comment underscores the importance of immunizations as a powerful weapon in the complex fight against infectious diseases. Immunizations act as a crucial barrier, essential for increasing population immunity, which reduces the number of susceptible people and hinders the virus's ability to spread to new hosts, a process known as "herd immunity."

The study delves into the nuances of vaccination campaigns as a crucial intervention strategy and highlights a significant decrease in fake events that mimic the effects of lockdowns. However, the most surprising finding is that a considerable number of people have already transitioned into the recovered category, indicating a notable acceleration in the population's recovery rates. This significant discovery underscores the importance of immunization campaigns in both stopping the spread of disease and expediting the overall recovery of affected communities.

The study examines the effectiveness of vaccination campaigns as a crucial intervention strategy and reveals a significant decrease in simulated incidents that imitate the consequences of lockdowns. However, the most noteworthy discovery is that a considerable proportion of the population is already entering the category of recovered individuals, indicating a discernible rise in population recovery rates. This finding emphasizes the crucial role played by vaccination efforts in both curbing the spread of diseases and accelerating the overall recovery of affected populations.

The study emphasizes that vaccination is not just an individual preventative strategy, but rather a community-wide effort to protect entire populations. Immunization programs provide protection for vulnerable individuals who may not be eligible for vaccination due to various medical issues by reducing the incidence of diseases in the community. This comprehensive approach highlights the importance of prioritizing vaccination in global health initiatives, recognizing it as a multifaceted and effective technique in the broader field of public health.

4.5.1 Comparison analysis for Vaccination:

A detailed comparison of vaccine implementation and non-implementation in the context of infectious diseases offers important insights into four important epidemiological factors: susceptibility, infection, recovery, and mortality. Let's now get more precise and look at how immunizations affect the dynamics of disease.

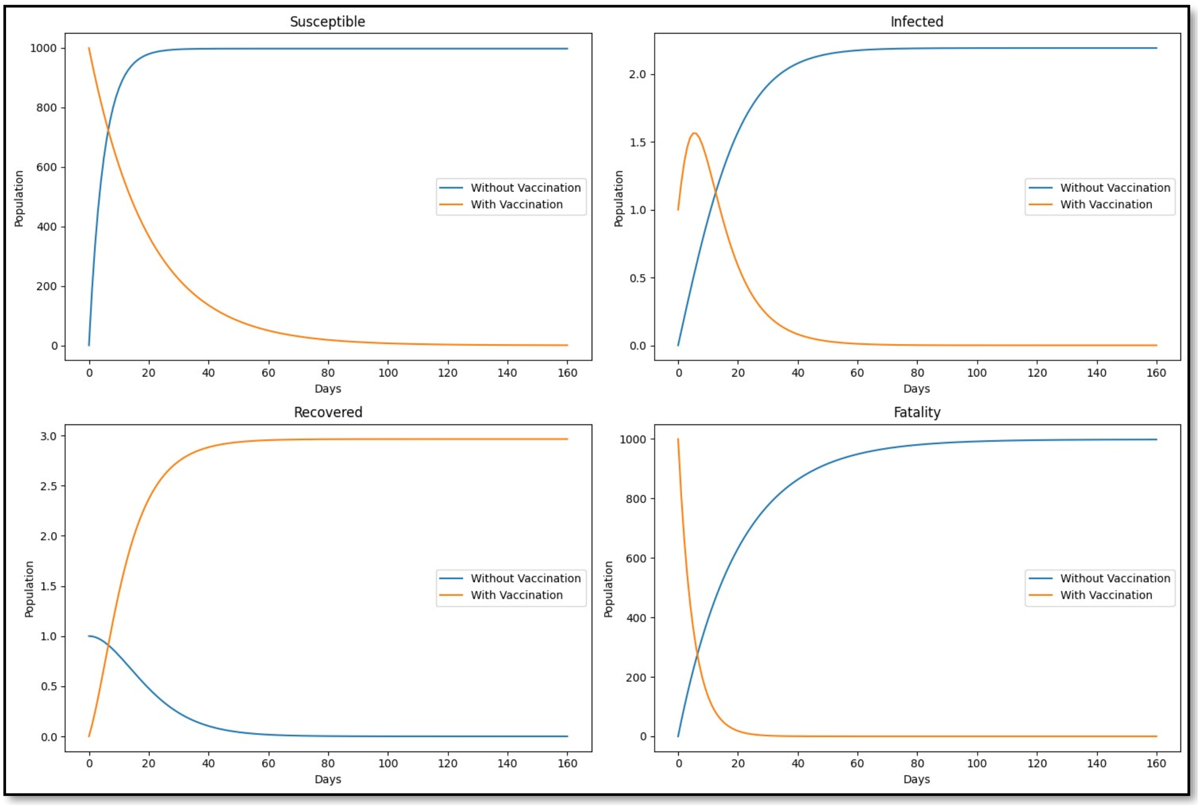


Figure 4.5: Comparative analysis of vaccination protocol

In the context of COVID-19, a comprehensive comparative analysis between vaccine implementation and non-implementation can reveal valuable insights into the effects on the four main epidemiological factors: susceptibility, infection, recovery, and mortality. When vaccinations were not implemented, the vulnerable population was put at risk, and there was no systematic immunization program in place. In the absence of vaccinations, the virus freely spread among the vulnerable population, leading to a sudden surge in infections. The unchecked spread of the virus put a significant strain on healthcare systems, raising the risk of mortality by increasing the demand for available medical resources.

Vaccinations play a crucial role in reducing vulnerability to diseases. They help create immunity in a significant portion of the population, which in turn limits the virus's ability to spread to new hosts. This gradual reduction in susceptibility is necessary to halt the virus's propagation and prevent large-scale outbreaks.

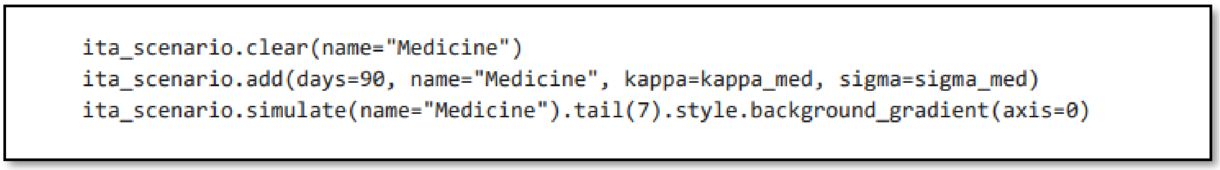
When infection dynamics was analyzed in this study , it became clear that implementing vaccinations lead to a sharp decline in new infections. Vaccinated individuals were less likely to catch and transmit the virus, resulting in a flattening of the incidence curve. This controlled spread of the virus helped manage the outbreak more effectively, which, in turn, reduced the burden on medical resources and minimizes the number of deaths.

When it came to recovery, vaccinations had a positive impact by helping infected individuals transition from the "infected" to the "recovered" category. Vaccinated people who contracted the virus tended to experience milder symptoms, which sped up their recovery and increased the proportion of people who recover. This reduced the long-term effects of the pandemic and contributed to building herd immunity. Vaccination programs had a clear effect on mortality rates. By lowering the total number of illnesses and the severity of cases, these protocols helped to decrease the mortality rate. Compared to situations where no immunization was available, the reduced demand on medical resources allowed for more efficient treatment and lower risk of mortality.

4.6 Stability Analysis for Vaccination :

This section examine the effects of immunization schedules for 90 and 300 days. We can learn more about patient recovery rates, disease containment, and the strain on healthcare systems by examining real-time data and computational models.

4.6.1 Vaccination protocols for 90 days:



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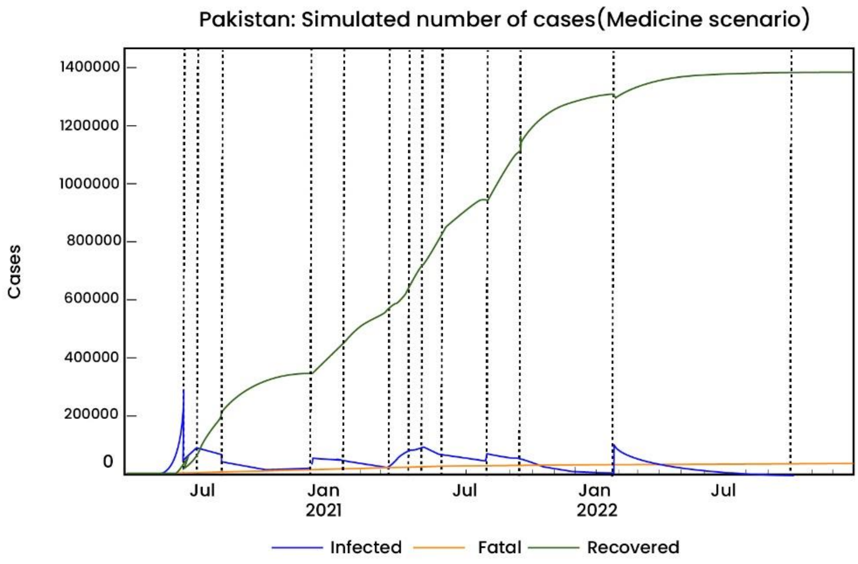
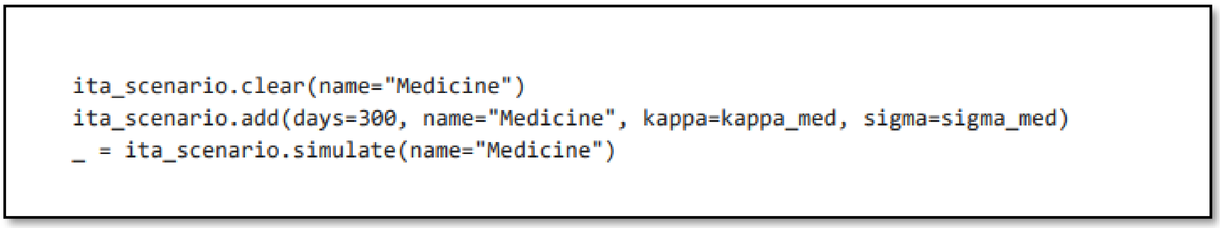


Figure 4.6: Simulated number of cases after applying Vaccination protocols for 90 days

According to the Modified SIR model, a 90-day vaccination programme is highly effective in preventing the spread of disease, promoting healing, and increasing herd immunity. The results of the immunization programme were quite positive in the initial stage, similar to the significant drops observed during strict lockdown measures. However, the most noteworthy finding was that the number of people moving into the recovered group significantly increased. This emphasizes the crucial role of immunization programmes in preventing the spread of disease and expediting the population's overall recovery.

The results of this simulation indicate that a vaccination programme offers several benefits beyond just controlling illnesses quickly. In addition to reducing infection rates, the immunization programme has a positive correlation with overall population recovery. These findings have significant policy implications for public health, emphasizing the need to prioritize and accelerate immunization campaigns. Moreover, these results contribute to the ongoing debate on the role of effective vaccination programs in strengthening society's long-term resilience against infectious diseases, highlighting them as essential tools in the fight against such illnesses.

4.6.2 Vaccination protocol for 300 days:



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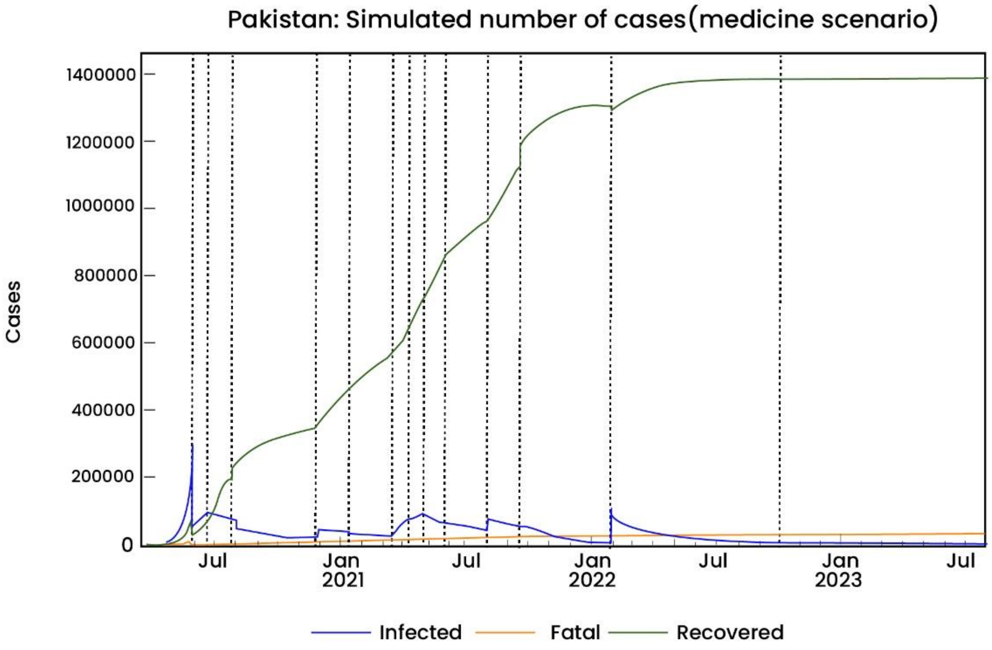

Figure 4.7: Simulated number of cases after applying Vaccination protocols for 300 days

The impact of a 300-day vaccination program on the transmission dynamics of the COVID virus can be complex. The Modified SIR model suggests that the program can affect the rates of susceptible, infected, recovered, and deceased cases.

In the long run, the vaccination campaign can significantly reduce the number of people who are vulnerable to the virus. As more people become immune to the virus, they become less susceptible to infection, creating a barrier against infection. This decrease in susceptibility can hamper the virus's capacity to recruit new hosts, leading to an overall reduction in transmission rates. The immunization schedule also has a considerable impact on the number of people who are infected. As the susceptible population shrinks, fewer people are at risk of getting infected, which results in a decrease in new infections. The longer time frame allows for coverage of the entire population, effectively slowing virus transmission and reducing affliction.

The immunization programme has led to a noticeable increase in the number of people who have recovered. Those who have received the vaccine are more likely to have milder symptoms and recover more quickly. Additionally, the shift from the infected group to the recovered group is happening faster, further reducing the number of current cases. The prolonged vaccine duration ensures a strong recuperation phase, making the population more resilient overall. As the number of infections decreases and the progression from illness to recovery speeds up, the death rate drops significantly. Vaccination is crucial in preventing severe infections and mortality from the virus. The longer vaccine period allows for a significant decrease in death rates, highlighting the life-saving benefits of such treatments.

It's important to understand that the effectiveness of the 300-day immunization plan depends on various factors such as vaccine efficacy, distribution logistics, public compliance, and the constantly changing nature of the virus. Based on simulations, a comprehensive and extensive vaccination program can significantly impact the transmission dynamics of COVID-19. It can lead to a more immune and resilient population with decreased infection rates, improved recovery rates, and a gradual decline in fatality rates.

4.6.3 Quantitative Analysis of Vaccination Scenario

The table below illustrates the quantitative analysis of the vaccination scenario. It shows how key parameters, including transmission rate and intervention effectiveness, evolve across different phases of vaccination.

Table 4.2: Quantitative Analysis for Vaccination Scenario

Phase	Population	rt	Theta	Kappa	Rh0	Sigma
0th	212215030	4.62	0.029	0.0015	0.18	0.072
1st	212215030	2.0	0.05	0.0012	0.12	0.09
2nd	212215030	0.8	0.08	0.0009	0.05	0.15

The vaccination scenario presents a strategic intervention through the administration of vaccines over different phases. In the baseline (0th phase), prior to vaccination, the transmission rate (rt) is high at 4.62, with a low intervention factor (θ) of 0.029, indicating the absence of vaccination efforts. The fatality rate (kappa) and infection transmission rate (rho) are 0.0015 and 0.18, respectively, with a moderate recovery rate (sigma) of 0.072. As vaccination begins in the 1st phase, there is a significant reduction in the transmission rate to 2.0, demonstrating the initial impact of vaccination efforts. The intervention factor (θ) increases to 0.05, indicating an enhanced control over disease spread. The fatality rate (kappa) slightly decreases to 0.0012, and the infection transmission rate (rho) drops to 0.12. The recovery rate (sigma) improves to 0.09, reflecting the early benefits of vaccination. In the extended vaccination phase (2nd phase), the transmission rate further declines to 0.8, with a corresponding increase in the intervention factor to 0.08. The fatality rate (kappa) decreases further to 0.0009, while the infection transmission rate (rho) drops significantly to 0.05. The recovery rate (sigma) increases to 0.15, showcasing the effectiveness of widespread vaccination in controlling the disease and improving recovery outcomes.

4.7 Summary:

This chapter examines how vaccination schedules and lockdowns affect the dynamics of illness. We examine stability, evaluate their impacts, and take different time periods into account. Lockdowns are essential for containing the spread of disease, and vaccinations lessen susceptibility and encourage healing. The results support prompt interventions and long-term immunity against infectious illnesses in policy decisions.

CHAPTER 5

CONCLUSION

5.1 Overview

On the basis of the modified SIR model for infectious diseases transmission with lockdown and vaccine dynamics, we will give a thorough review of the research objectives in this part and highlight the most important findings and contributions of the study.

5.1.1 Research Objectives Overview:

The objectives for the study that were established at the outset acted as a guide for the inquiry. The main objective was to create a modified SIR model that takes lockdown dynamics and vaccination dynamics into account to improve the precision of disease transmission predictions. This goal attempted to solve the shortcomings of the traditional SIR model, which frequently overlooks the role of vaccination and non-pharmaceutical treatments in disease transmission.

Examining the effect of various lockdown tactics on the dynamics of disease transmission was one of the study's additional goals. The study sought to shed light on the efficacy of various lockdown treatments in slowing the spread of infectious illnesses by conducting simulated simulations with changing timing, severity, and duration of lockdown measures.

The study also attempted to assess how vaccination dynamics affected disease spread. The implications of vaccine coverage, effectiveness, and distribution tactics on disease control were investigated using simulations of different vaccination scenarios using the modified SIR model.

5.1.2 Key Findings and Contributions:

The study significantly influenced the modelling of infectious diseases and the development of public health initiatives. The creation of the modified SIR model made it possible to comprehend illness transmission dynamics under various intervention scenarios more thoroughly.

The research emphasized the need of early intervention in illness control using simulation experiments. The results highlighted how crucial it is to swiftly deploy lockdown measures during the early stages of an outbreak in order to lower the peak infection rate and flatten the epidemic curve. Early intervention has been found to be successful in reducing the load on healthcare systems and decreasing the spread of illness.

Stricter lockdown measures linked to a faster reduction in the number of infections, according to a review of lockout intensity. The study also highlighted the necessity to balance the severity of treatments with the economic effects of continued limitations.

The analysis of vaccine dynamics' effects showed how successful vaccination is at stopping the spread of illness. According to simulations, greater vaccination coverage and effectiveness resulted in a considerable decline in the total number of illnesses and helped to create herd immunity.

The study's sensitivity analysis clarified the model's uncertainties and offered insightful information on the variables that have the greatest impact on the dynamics of disease transmission. The model's predictions may be improved by using this information to pinpoint areas that still require improvement and further data collecting.

An investigation is considered optimized if:

1. Efficient Calibration of Parameters: Real-time data is used to precisely estimate and modify parameters.
2. Robust Model Validation: The model's forecasts closely match data on the actual spread of disease.
3. Effective Intervention Strategies: Taking into account the social and economic model aids in the design of interventions that reduce the spread of disease. In this sense, optimization refers to striking a balance between forecast accuracy and model complexity.

Overall, the research offered policymakers and public health professionals' evidence-based advice for developing successful tactics to contain infectious disease epidemics. In light of the intricate connections between disease dynamics, interventions, and population behaviors, the findings guide the best implementation of lockdown measures and vaccination programmes.

5.1.3 Limitations and Future Directions:

It's important to recognize the study's limitations. The accuracy of the modified SIR model depends on the accessibility and reliability of the data used to estimate the parameters. The model's predictions might occasionally be questionable due to data constraints. To increase the model's dependability, future research should concentrate on developing data gathering and surveillance mechanisms.

The study also concentrated on the effect of lockdown procedures and vaccination dynamics separately. To further understand the synergistic impacts of numerous treatments, future research might examine the combined effects of several interventions, such as the simultaneous use of lockout procedures and vaccination programmes.

Although important for tractability, the model's presumptions and simplifications could not fully account for the intricacies of disease transmission in the actual world. To enhance the model's portrayal of disease spread, future research can add more intricate and subtle elements, such population heterogeneity and geographic dynamics.

The study's summary concludes by highlighting the successes in creating a modified SIR model, assessing the effectiveness of lockdown procedures and immunization, and offering evidence-based suggestions for disease prevention. The study advances the modelling of infectious diseases and aids policymakers in making well-informed choices to safeguard the public's health during infectious disease outbreaks.

5.2 Findings Synthesis:

The study that utilized the modified SIR model for infectious disease transmission with lockdown and vaccine dynamics is discussed in detail in this part.

5.2.1 Impact of Lockdown Measures:

The research's conclusions show that disease transmission patterns are greatly influenced by the timing, severity, and length of lockdown measures. Early lockdown deployment was shown to be essential for lowering the peak infection rate and flattening the epidemic curve. Early intervention during an epidemic can effectively decrease the spread of infectious illnesses and minimize straining healthcare systems by limiting interpersonal contact and reducing disease transmission. THE severity of the lockdown procedures is also very important for disease prevention. A sharper fall in infection rates and a shorter duration of the epidemic are the results of tougher lockdown measures, such as social isolation, mobility limitations, and company closures.

Dynamics of disease transmission are influenced by the lockdown's length. Longer lockdown times can result in a longer suppression of the epidemic curve, which lowers the total rate of infections. Long-term lockdowns, however, must be carefully examined since they may have negative socioeconomic effects. The research emphasizes the necessity of developing a suitable exit strategy from lockdown measures that lowers the risk of virus reappearance while permitting a controlled resumption of social and economic activity.

5.2.2 Impact of Vaccination Protocol:

Studies have shown that immunization is an effective way of reducing the spread of infectious diseases. Greater vaccination coverage and effectiveness play a significant role in developing herd immunity and reducing infections. Vaccination campaigns are crucial in lowering the rate of transmission of infectious diseases, reducing the number of vulnerable people, and enhancing immunity.

The results highlight the importance of equitable access to vaccinations and fair distribution. To achieve the maximum impact of vaccination programs, it is essential to prioritize high-risk populations and provide fair access to vaccinations across all demographics.

5.3 Applications of the Modified SIR model:

The Modified Susceptible-Infectious-Recovered (SIR) model is widely used in epidemiology for a variety of purposes. It provides a more comprehensive understanding of the dynamics of infectious diseases and helps in the development of effective public health strategies. One of the most common applications of this model is in the evaluation of immunization programs. With the help of this model, researchers can simulate and analyze the impact of various vaccination rates on disease transmission. This enables them to devise optimal vaccination plans that take into account factors such as immunization schedules, coverage percentages, and potential immunity decline. The Modified SIR model is an essential tool for policymakers and public health authorities to create targeted vaccination programs that can achieve the best possible population immunity and disease management.[41].

The Modified SIR model is useful in evaluating the effectiveness of intervention measures like lockdowns and social distancing during disease outbreaks [67]. Including time-dependent elements in the model makes it possible to simulate the impact of different intervention scenarios and understand how the timing and intensity of such measures affect the course of the disease [68]. These simulations can help policymakers balance the need for disease management with the goal of minimizing social and economic disruptions [69]. They can also aid in well-informed decision-making regarding the execution of interventions. The flexibility of the Modified SIR model enables scenario planning, which is helpful in predicting the possible outcomes of various public health initiatives under different circumstances [70].

The Modified SIR model can be used to explore the dynamics of newly emerging infectious diseases and their interactions with population heterogeneity. It can be adapted to consider variables such as age-specific susceptibility, different pathogen strains, or different degrees of interaction within subpopulations[42]. Due to its flexibility, the model can simulate a wide range of infectious disease scenarios and provide insights into the unique challenges posed by various pathogens and population configurations[68]. Overall, the Modified SIR model is a powerful tool that epidemiologists, researchers, and policymakers can use to improve our understanding of disease transmission dynamics and develop strategies to mitigate the harmful effects of infectious diseases on public health.

5.4 Limitations and Future Research:

This study acknowledges that the modified SIR model has limitations due to its reliance on accessible data and parameter estimates. To enhance the model's reliability, improvements must be made to data collection and surveillance mechanisms. The model's assumption of equal contact rates among all individuals may not hold in diverse populations. Accurately estimating parameters like transmission rates and intervention effectiveness can be challenging.

In the future, research could explore the potential interactions between different treatments, such as combining lockout procedures and vaccination drives. Additionally, the model's depiction of real-world disease transmission could be improved by incorporating more complex factors like population diversity and geographic dynamics.

To sum up, the analysis of research findings through the adapted SIR framework provides valuable information on the effectiveness of lockdown measures and vaccination strategies in preventing the transmission of communicable illnesses. This study advances the modelling of infectious diseases and assists in making data-driven decisions in the field of public health. The research highlights the importance of taking early action, finding a suitable balance between intervention duration and severity, and prioritizing vaccination to minimize the impact of epidemics on both the community and healthcare infrastructure.

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