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Numerical Analysis of a New COVID-19 Control Model Incorporating Three Different Fractional Operators

William Atokolo[1,†], Remigius Okeke Aja[2], David Omale[1], Godwin Onuche Acheneje[1], Rose Veronica Paul[1] and Jeremiah Amos[1]

Abstract The ongoing COVID-19 pandemic, caused by the highly contagious coronavirus, poses significant challenges to public health worldwide. Effective control measures are essential to mitigate the spread of the virus and protect vulnerable populations. This study aims to develop novel mathematical models using fractional derivatives to analyze the dynamics of the COVID-19 outbreak. By employing modified mathematical procedures, we explore the impact of quarantine and isolation as control measures on the disease's transmission dynamics. We investigate a system representing COVID-19 through three different arbitrary-order derivative operators: the Atangana-Baleanu derivative with the generalized Mittag-Leffler function, the Caputo derivative with a power law, and the Caputo-Fabrizio derivative with exponential decay. Using fixed-point theory, we assess the existence and uniqueness of solutions for the arbitrary-order system. Our analysis includes numerical simulations that reveal how varying the fractional order influences the behavior of the epidemic. The results demonstrate that increasing the fractional order generally slows the disease's progression, reflecting the memory effect inherent in fractional derivatives. Specifically, higher values of the fractional order correspond to a more gradual spread, reducing the peak number of infections and extending the outbreak's duration. The work highlights the critical importance of using fractional order models to capture the complex dynamics of disease spread and emphasizes that the implementation of quarantine and isolation for treatment significantly decreases the cumulative number of new cases and the overall transmission rate of COVID-19. This research underscores the effectiveness of utilizing fractional-order models to better understand and control the complex dynamics of disease transmission.

Keywords Existence and uniqueness, fractional operators, numerical analysis, Adams Bashforth Moulton method, fixed point theory

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[†]the corresponding author.
Email address:williamsatokolo@gmail.com(William Atokolo)
[1]Department of Mathematical Sciences, Prince Abubakar Audu University, Anyigba, 272102, Nigeria
[2]Department of Mathematics, Michael Okpara University of Agriculture, Umudike, 440101, Nigeria

1. Introduction

An extension of integer-order derivatives and integrals to arbitrary-order derivatives is known as the calculus of arbitrary-order derivatives. In the field of applied mathematics, fractional calculus has become a potent tool for solving real-world problems. Compared to classical integer-order operators, arbitrary-order operators offer a greater capacity to capture the memory and inheritance aspects of real-world situations.

The applications of arbitrary-order derivatives are extremely varied and include signal processing, biomathematics, engineering, and physics [1, 2], among other domains [3–9]. Numerous arbitrary-order derivatives in fractional calculus (FC) exist and are typically classified into two types in the literature: singular and non-singular.

The most widely used of them are the Riemann-Liouville and Caputo operators [10], which are based on the power law kernel. The idea of arbitrary-order differentiation and integration incorporating a power law kernel has recently undergone historical evolution, where the power law kernel has been examined and modified by a non-singular kernel [11, 12].

In fractional modeling of real-world problems, two widely used derivatives are the Caputo-Fabrizio (CF) derivative, which involves the exponential law kernel [12], and the Atangana-Baleanu (AB) fractional derivative, which was developed based on the Mittag-Leffler kernel with non-local and non-singular properties [11].

Numerous investigators have focused on the scientific applications of these variable-order derivative operators to identify the mathematical systems that these three kinds of kernels are used to describe [13–19].

It can be difficult to pinpoint a specific remedy to an issue at times. Many researchers are naturally more interested in finding fractional operators and using numerical techniques to solve problems as a result of this predicament. The arbitrary-order differential equations can be solved using a variety of numerical methods [20–24].

Researchers have focused more on modeling and analyzing infectious diseases in the bio-mathematical sciences using fractional operators in recent years; some notable studies in this area may be found in [25–32]. Many nations have recently experienced an epidemic of COVID-19, a deadly disease that goes untreated. Since the start of the pandemic, the number of cases of SARS-CoV-2 disease, also known as COVID-19, has been rapidly increasing, making it a serious concern. The recently identified virus from the SARS-CoV-2 virus family is the cause of the respiratory disease COVID-19.

The most typical signs and symptoms of COVID-19 include fever, exhaustion, dry cough, and dyspnea. Human-to-human transmission of the disease is mostly through tiny droplets released during coughing, sneezing, or talking. After being originally discovered in Wuhan, China, in December 2019, the SARS-CoV-2 virus quickly spread to other parts of the world. Numerous people have died as a result of the new outbreak throughout many nations.

Humanity was thrust into a state of extreme fear by the novel COVID-19 outbreak, which compelled people to concentrate their efforts on studying and forecasting the disease's future course. When it comes to understanding how diseases spread, predicting the future, and making decisions to stop the spread of infectious diseases, mathematical systems have been extremely important.