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# Mathematical Analysis of COVID-19 Fractional Model Incorporating Vaccination, Quarantine and Isolation Measures

Remigius Okeke Aja[1], William Atokolo[2,†], David Omale[2], Godwin Onuche Acheneje[2], Jeremiah Amos[2] and Agbata Celestine Benedict[3]

**Abstract** This study investigates the role of vaccination, quarantine, and isolation in controlling the spread of COVID-19 using a fractional-order mathematical model. The model consists of six non-linear fractional-order differential equations in the Caputo sense. Stability analysis is conducted using the Ulam-Hyers and modified Ulam-Hyers criteria, and the existence and uniqueness of solutions are explored with the Schauder and Banach fixed-point theorems. The model's dynamical behavior is analyzed using the fractional Euler method. Dimensional consistency is maintained during the fractionalization process, distinguishing this study from many contemporary investigations. The results show that increasing vaccination rates, improving quarantine protocols, and enhancing isolation facilities are effective strategies for reducing COVID-19 transmission.

**Keywords** Vaccination, quarantined, isolation, existence and uniqueness, Ulam-Hyers stability, Schauder and Banach fixed point theorem

**MSC(2010)** 00A71

## 1. Introduction

Since the start of March 2020 till now, the coronavirus has been causing new infections; as of right now, 1,575,186 cases have been reported in Pakistan [1,2]. Of the overall number of cases, 98% of the infected people have recovered, while 30,631 deaths have been reported, making up 2% of the total cases. There have been several waves of coronavirus infection since March 2020; the most recent wave, or sixth wave, was seen between May–September 2022 [2]. If we examine the data provided in [2], we can see that there were multiple infections in the past, and that the number of infections has steadily declined in the most recent wave. One of the causes is that, in the past, people were ignorant of the problem and vaccines were not available on the market. Vaccination is a helpful method of defending people from illness. The coronavirus infection posed a significant threat to global health

[†]the corresponding author.
Email address:williamsatokolo@gmail.com(William Atokolo)
[1]Department of Mathematics, Michael Okpara University of Agriculture, Umudike, 440101, Nigeria
[2]Department of Mathematical Sciences, Prince Abubakar Audu University, Anyigba, 272102, Nigeria
[3]Department of Mathematics and Statistics, Confluence University of Science and Technology, Osara, 264103, Nigeria

because there was no known cure or preventative measure, despite the availability of immunizations. A notable reduction in the number of coronavirus infection cases has occurred thanks to the efforts of scientists and researchers developing vaccinations. The following list of mathematical models make use of the control strategies: [3, 4]. A model for coronavirus infection incorporating control methods was shown in [3]. Several control mechanisms were considered in the research on the coronavirus, using the fractional-order model presented in [4]. There are several varieties of coronavirus vaccines on the market, including those made by Moderna, Pfizer, Johnson and Johnson, China, and others [5]. Notably, there is still a declining vaccination rate despite the fact that none of the vaccinations created to date is 100% effective. As a result, a disclaimer regarding vaccinations has been included in the most recent vaccine campaigns. It is impossible to develop vaccinations against coronavirus infection in certain parts of the world's less developed nations due to the lack of financial resources. One to ten people have been immunized in each of the 70 low-income nations in the world [6]. International organizations are working to reduce the coronavirus cases by distributing vaccinations equally.

It is important to emphasize that the unequal distribution of vaccinations cannot be corrected quickly, necessitating the investigation of more realistic immunization rates. Vaccines are thought to be the most effective means of controlling the elimination of disease, but their availability is restricted and influenced by a number of factors during the implementation process. Quarantining the unconfirmed cases of COVID-19 and isolating the confirmed cases for treatment are also effective in controlling the spread of COVID-19 in a population. International researchers working on vaccine methods have contributed valuable written resources to the literature. For instance, the authors of [6] researched the dynamics of epidemic diseases and created vaccination regimens for both single- and double-dose vaccinations. The authors of [7] formulated a vaccination model that took tactics for treatment and vaccine saturation into account. The topic of disease-containing vaccines and the impact of media campaigns was examined in [8]. In [9], the study of the vaccination model with subsequent infection following vaccination coverage and immunization was presented. The effects of therapy and vaccination on the coronavirus were investigated in [10]. The impact of vaccine methods on the eradication of disease and the availability of vaccines were discussed in [11–13]. A number of mathematical models were discussed in [14, 15] that study the bifurcation and local and global asymptotic dynamics of the coronavirus epidemic. A detailed discussion of the vaccination model including its efficiency and impact may be found in [16]. The literature has established mathematical models with integer and non-integer orders to comprehend infectious diseases, including COVID-19 specifically [17–19]. As an illustration, a model that uses actual data was developed and examined in [20]. A mathematical model was presented in [21] based on the distributions of the instances with asymptomatic and symptomatic compartments. In [22], the coronavirus treatment model was covered. The coronavirus vaccination model, including its defense mechanisms, was displayed in [23]. Martinez-Guerra and Flores-Flores [24] discussed the COVID-19 algorithm that is used to find undetected cases. In [25], a non-integer method for coronavirus analysis using actual cases from Pakistan was investigated. In order to comprehend the new Omicron variant, the SARS-CoV-2 formulation with fractional derivative was shown in [26].

A stability study and discussion of the second coronavirus infection wave was examined in [27]. A fractional-order model was used in [28] to analyze the coro-