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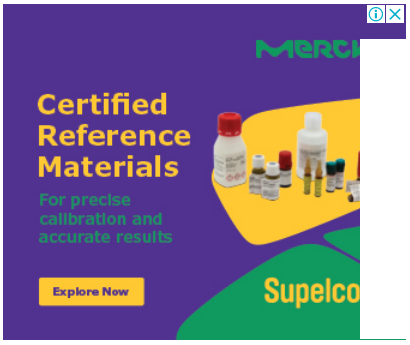

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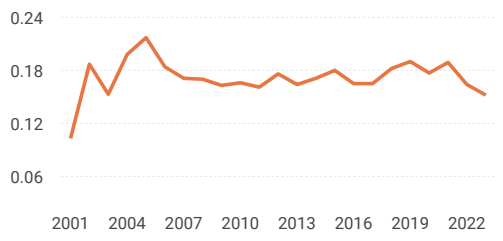

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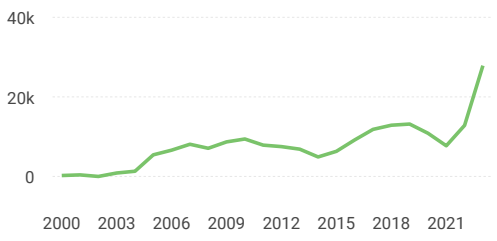

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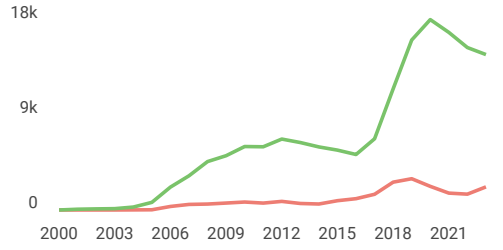

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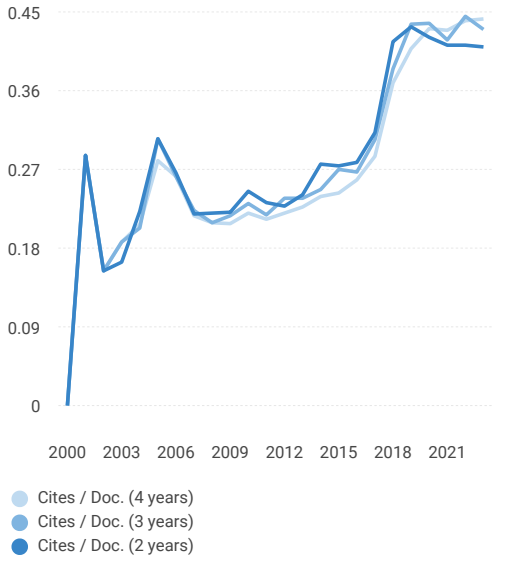

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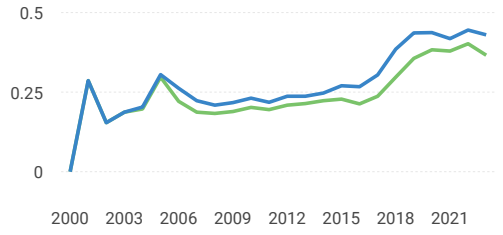

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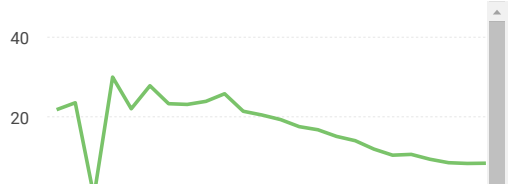

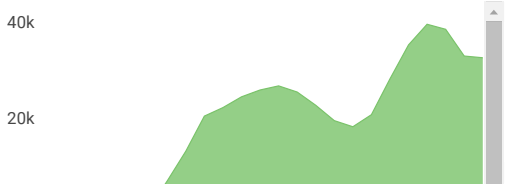

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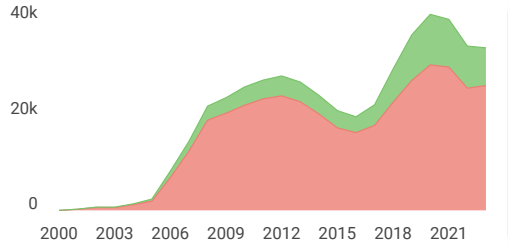

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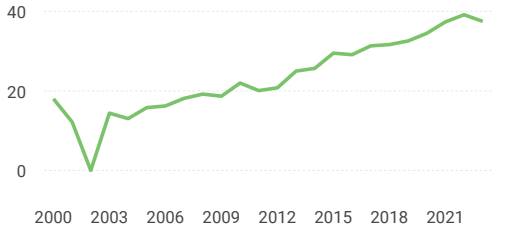

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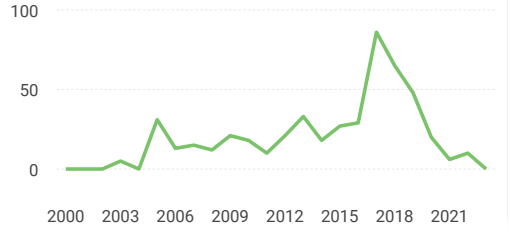

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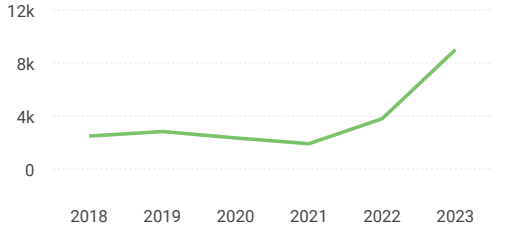

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Surakarta, Indonesia • 21 October 2022

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Preface: The 7th International Conference on Science and Applied Science (ICSAS 2022)

The 7th International Conference on Science and Applied Science (ICSAS 2022) was the sixth conference which was organized by the Physics Department, Universitas Sebelas Maret. On this occasion, the ICSAS 2022 was held virtually on 31 October, 2022, due to the COVID-19 pandemic. The ICSAS 2022 conference is aimed to bring together scholars, leading researchers, and experts from diverse backgrounds and application areas in science. Special emphasis is placed on promoting interaction between the science theoretical, experimental, and other topics related to physics.

In ICSAS 2022, there are 8 parallel sessions and four keynote speakers. The keynote speakers are Assoc. Prof. Mohsen M. Farahat from Central Metallurgical Research and Development Institute, Cairo, Cairo, Egypt; Prof. M. Aziz from Tokyo University, Japan; Prof. Madya Ts. Dr. Mohd Khairul Bin Ahmad from Universiti Tun Hussein Onn Malaysia, and Dr. Eng. Hendri Widiyandari from Universitas Sebelas Maret. While for the conference participants, there is 131 participant which was submitted abstract via the conference system. Then, the 112 full papers have been submitted from the participant, and after the reviewed process, 83 papers have been presented in the ICSAS 2022. And then for the final decision, 49 papers published in AIP Conference Proceedings.

We would like to thank all of the participants attending this conference and also to the committee for their contribution to this high-level conference and its overall success. We also would like to thank the reviewers for their positive contribution to maintain the quality of the articles presented at this conference.

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Fourth- and Fifth-Order Runge-Kutta Methods for Solving a Susceptible-Exposed-Infected-Recovered Mathematical Model of the Spread of COVID-19

Dewi Isabella Palma[1, a)] and Sudi Mungkasi[2, b)]

[1]*Department of Mathematics Education, FKIP, Sanata Dharma University, Yogyakarta, Indonesia*
[2]*Department of Mathematics, FST, Sanata Dharma University, Yogyakarta, Indonesia*

[a)] Corresponding author: dewiisabella5@gmail.com
[b)] sudi@usd.ac.id

Abstract. In this paper, we describe the dynamics of the spread of the COVID-19 disease. In this paper, a mathematical model of the problem is rewritten. Mathematical models can be used to find strategies to prevent the Coronavirus disease spread. A Susceptible-Exposed-Infected-Recovered (SEIR) mathematical model in the spread of COVID-19 disease is solved using fourth- and fifth-order Runge-Kutta methods. The simulation results of the two methods show the same pattern of solution behavior as the results of the reference solution obtained using the ODE45 algorithm in the MATLAB software. Theoretically, the accuracy of the fourth-order Runge-Kutta method is not better than that of the fifth-order Runge-Kutta method. We show the correctness of this theory through simulations in this paper by solving the SEIR mathematical model for the COVID-19 disease.

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INTRODUCTION

COVID-19 or Coronavirus disease 2019 is one of the diseases caused by a virus that attacks the respiratory system. This virus is different from viruses that infect other respiratory systems such as Middle East Respiratory Syndrome (MERS) which has the same type of virus, namely, Coronavirus [1, 2]. The period of spread, the causes of transmission and the symptoms caused by Coronavirus infection are explained in several studies [2–5]. In some cases, a subject may be asymptomatic, although they are infected. In addition, this virus infection can also cause critical conditions to death.

The area where the Coronavirus spread began in Wuhan, China in December 2019. The spread of the virus has rapidly occurred in several regions of the country, so World Health Organization (WHO) has designated the disease caused by this virus to be a COVID-19 (Coronavirus disease 2019) pandemic. One of the impacted countries is Indonesia. The spread of the Coronavirus in Indonesia is still ongoing today. The number of cases of spread in Indonesia has decreased [6]. One of the factors for the decline in the number of cases is the vaccination program organized by the government. However, the lack of public awareness of health protocols has led to the emergence of new spread clusters, even though there is already a vaccination program. Although giving a vaccine does not guarantee 100% a person to be immune, the vaccine can prevent infections, serious diseases, and deaths [7]. Currently, many types of vaccines have been developed for the Coronavirus such as Sinovac, Pfizer, Astra Zeneca, etc. In this study, we consider the mathematical model proposed by Wintachai and Prathom [4].

The spread of COVID-19 has been studied more widely by many studies, both in the field of mathematics and health. One of the mathematical models suitable for understanding the dynamics of this epidemic is the SEIR (*Susceptible-Exposed-Infected-Recovered*) model. Variables S, E, I, and R are defined as the four human sub-populations in the SEIR model. In this case, the variable of fraction for human susceptible to the disease is $S(t)$, the variable of fraction for human exposed to the disease is $E(t)$, the variable of fraction for the infected people is $I(t)$, and the variable of fraction for recovered people is $R(t)$.

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One of numerical methods capable of solving mathematical models in the form of ordinary differential equations is the Runge-Kutta method. The method was developed by Carl Runge and Wilhelm Kutta. Based on this, the Runge-Kutta method has several types, namely the second-order Runge-Kutta, the third-order Runge-Kutta, the fourth-order Runge-Kutta, the fifth-order Runge-Kutta, and so on. Fardinah [8] stated that the level of accuracy in this method is influenced by the order, so the greater the order, the more accurate the results obtained. The formula of the Runge-Kutta method can be found in books, such as Chapra and Canale [9].

The research of the spread of COVID-19 is important. By studying the dynamics of the disease, we can predict the spread of COVID-19. There are several reports that have been published about the dynamics of the spread of COVID-19 and simulated or solved models with various approaches [3, 4, 10, 11, 12]. These reports motivate us to use the fourth-order Runge-Kutta and the fifth-order Runge-Kutta methods to solve the SEIR model in this paper.

EXPERIMENTAL DETAILS

The mathematical model of the spread of COVID-19 developed by Wintachai and Prathom [3] is discussed in this paper. To solve the SEIR model, we use two numerical methods, namely the fourth- and fifth-order Runge-Kutta methods. In order to do the computation, we use the MATLAB software.

SEIR Model

In general, SEIR modeling is identical to the SIR model, but in this model a variable is added, namely E (*Exposed*) or individuals who can enter the infected group but have not been fully infected with the disease [13]. In this model, there are four parts of the human subpopulation: specifically the subpopulation that is susceptible to disease is Susceptible (S); the subpopulation that has been infected but has not yet become a patient is Exposed (E); the subpopulation that has become a patient and actively transmits disease is Infectious (I); and the subpopulation that has recovered is Recovered (R). The concept given to the SEIR model takes the form of each state transition as the dynamics of population change [13].

The SEIR model is a mathematical model for disease outbreaks that have an incubation period. Diekmann and Heesterbeck [14] defined that an individual has been infected by a disease but has not been able to transmit the disease to another individual, and their definition is the exposed subpopulation. In the case of COVID-19, there are individuals who have been confirmed positive for the Coronavirus, but do not show symptoms of viral infection [2], so that this population can be categorized in the exposed population. In addition, the assumption in this case is that the population that has recovered will not be re-infected due to the formation of the immune system in the body to prevent the occurrence of viral infections again. Wintachai and Prathom [4] established a system of non-linear differential equations for the COVID-19 spread model as follows:

$$\begin{cases} \frac{dS}{dt} = b_0 - (vp_s + d_0)S - \beta(1 - vp_s)SI, \\ \frac{dE}{dt} = \beta(1 - vp_s)SI - (d_1 + \alpha + (1 - \alpha)vp_e)E, \\ \frac{dI}{dt} = \alpha E - (d_2 + \gamma + (1 - \gamma)vp_i)I, \\ \frac{dR}{dt} = vp_s S + vp_e(1 - \alpha)E + (\gamma + (1 - \gamma)vp_i)I - d_0 R. \end{cases} \tag{1}$$

The schematic diagram of equation system (1) is illustrated by Wang et al. [3]

The representation of the variables and parameters of equation system (1) is shown in Table 1.

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TABLE 1. Parameters and variables of the SEIR model

Parameters and Variables	Description
S	Proportion of susceptible individuals
E	Proportion of exposed individuals
I	Proportion of infectious individuals
R	Proportion of recovered individuals
β	Disease transmission rate
α	Transfer rate from E to I
γ	Transfer rate from I to R
v	Population vaccination rate
p_s	Effective vaccination rate in S
p_e	Effective vaccination rate in E
p_i	Effective vaccination rate in I
b_0	Population birth rate
d_0	Population death rate without COVID-19
d_1	Population death rate of the exposed population plus d_0
d_2	Population death rate of the infectious population plus d_0

The fourth- and fifth-order Runge-Kutta method are used to solve the mathematical model above and described below.

Fourth Order Runge-Kutta Method

The fourth-order Runge-Kutta method is one of the numerical methods often used to solve ordinary differential equations. The method is accurate and simple. In addition, the fourth-order Runge-Kutta method has a high level of accuracy, so that it is widely used by many researchers [4, 14–16]. This method can be described from an expansion of the order of Taylor series method. Chapra and Canale [17] wrote down the fourth-order Runge-Kutta method as follows:

$$y_{i+1} = y_i + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)h, \tag{2}$$

where

$$\begin{aligned} k_1 &= f(x_i, y_i), \\ k_2 &= f\left(x_i + \frac{1}{2}h, y_i + \frac{1}{2}k_1 h\right), \\ k_3 &= f\left(x_i + \frac{1}{2}h, y_i + \frac{1}{2}k_2 h\right), \\ k_4 &= f(x_i + h, y_i + k_3 h). \end{aligned} \tag{3}$$

By paying attention to the initial values of each population S_0, E_0, I_0, and R_0, the fourth-order Runge-Kutta method for solving the SEIR model (1) is:

$$\begin{aligned} S_{i+1} &= S_i + \frac{1}{6}(k_{1S} + 2k_{2S} + 2k_{3S} + k_{4S})h, \\ E_{i+1} &= E_i + \frac{1}{6}(k_{1E} + 2k_{2E} + 2k_{3E} + k_{4E})h, \\ I_{i+1} &= I_i + \frac{1}{6}(k_{1I} + 2k_{2I} + 2k_{3I} + k_{4I})h, \\ R_{i+1} &= R_i + \frac{1}{6}(k_{1R} + 2k_{2R} + 2k_{3R} + k_{4R})h. \end{aligned} \tag{4}$$

Here, h is the time step, i is the iteration index, and:

$$\begin{aligned} k_{1S} &= b_0 - (vp_s + d_0)S_i - \beta(1 - vp_s)S_i I_i \\ k_{1E} &= \beta(1 - vp_s)S_i I_i - (d_1 + \alpha + (1 - \alpha)vp_e)E_i \\ k_{1I} &= \alpha E_i - (d_2 + \gamma + (1 - \gamma)vp_i)I_i \end{aligned} \tag{5}$$

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$$k_{1R} = vp_s S_i + vp_e(1-\alpha)E_i + (\gamma + (1-\gamma)vp_i)I_i - d_0 R_i$$

$$k_{2S} = b_0 - (vp_s + d_0)\left(S_i + \frac{k_{1S}}{2}h\right) - \beta(1-vp_s)\left(S_i + \frac{k_{1S}}{2}h\right)\left(I_i + \frac{k_{1I}}{2}h\right)$$
$$k_{2E} = \beta(1-vp_s)\left(S_i + \frac{k_{1S}}{2}h\right)\left(I_i + \frac{k_{1I}}{2}h\right) - (d_1 + \alpha + (1-\alpha)vp_e)\left(E_i + \frac{k_{1E}}{2}h\right)$$
$$k_{2I} = \alpha\left(E_i + \frac{k_{1E}}{2}h\right) - (d_2 + \gamma + (1-\gamma)vp_i)\left(I_i + \frac{k_{1I}}{2}h\right)$$
$$k_{2R} = vp_s\left(S_i + \frac{k_{1S}}{2}h\right) + vp_e(1-\alpha)\left(E_i + \frac{k_{1E}}{2}h\right) + (\gamma + (1-\gamma)vp_i)\left(I_i + \frac{k_{1I}}{2}h\right) - d_0\left(R_i + \frac{k_{1R}}{2}h\right)$$

$$k_{3S} = b_0 - (vp_s + d_0)\left(S_i + \frac{k_{2S}}{2}h\right) - \beta(1-vp_s)\left(S_i + \frac{k_{2S}}{2}h\right)\left(I_i + \frac{k_{2I}}{2}h\right)$$
$$k_{3E} = \beta(1-vp_s)\left(S_i + \frac{k_{2S}}{2}h\right)\left(I_i + \frac{k_{2I}}{2}h\right) - (d_1 + \alpha + (1-\alpha)vp_e)\left(E_i + \frac{k_{2E}}{2}h\right)$$
$$k_{3I} = \alpha\left(E_i + \frac{k_{2E}}{2}h\right) - (d_2 + \gamma + (1-\gamma)vp_i)\left(I_i + \frac{k_{2I}}{2}h\right)$$
$$k_{3R} = vp_s\left(S_i + \frac{k_{2S}}{2}h\right) + vp_e(1-\alpha)\left(E_i + \frac{k_{2E}}{2}h\right) + (\gamma + (1-\gamma)vp_i)\left(I_i + \frac{k_{2I}}{2}h\right) - d_0\left(R_i + \frac{k_{2R}}{2}h\right)$$

$$k_{4S} = b_0 - (vp_s + d_0)(S_i + k_3 Sh) - \beta(1-vp_s)(S_i + k_3 Sh)(I_i + k_3 Ih)$$
$$k_{4E} = \beta(1-vp_s)(S_i + k_3 Sh)(I_i + k_3 Ih) - (d_1 + \alpha + (1-\alpha)vp_e)(E_i + k_3 Eh)$$
$$k_{4I} = \alpha(E_i + k_3 Eh) - (d_2 + \gamma + (1-\gamma)vp_i)(I_i + k_3 Ih)$$
$$k_{4R} = vp_s(S_i + k_3 Sh) + vp_e(1-\alpha)(E_i + k_3 Eh) + (\gamma + (1-\gamma)vp_i)(I_i + k_3 Ih) - d_0(R_i + k_3 Rh)$$

Fifth-Order Runge-Kutta Method

The fifth-order Runge-Kutta method is a method obtained in the similar way as other Runge-Kutta methods, namely the expansion of the Taylor series. The fifth-order Runge-Kutta method provides better accuracy than the lower-order Runge-Kutta methods. Butcher [17] wrote down the fifth-order Runge-Kutta method as follows:

$$y_{i+1} = y_i + \frac{1}{90}(7k_1 + 32k_3 + 12k_4 + 32k_5 + 7k_6)h, \tag{6}$$

where

$$\begin{aligned} k_1 &= f(x_i, y_i), \\ k_2 &= f\left(x_i + \frac{1}{4}h, y_i + \frac{1}{4}k_1 h\right), \\ k_3 &= f\left(x_i + \frac{1}{4}h, y_i + \frac{1}{8}k_1 h + \frac{1}{8}k_2 h\right), \\ k_4 &= f\left(x_i + \frac{1}{2}h, y_i - \frac{1}{2}k_2 h + k_3 h\right), \\ k_5 &= f\left(x_i + \frac{3}{4}h, y_i + \frac{3}{16}k_1 h + \frac{9}{16}k_4 h\right), \\ k_6 &= f\left(x_i + h, y_i - \frac{3}{7}k_1 h + \frac{2}{7}k_2 h + \frac{12}{7}k_3 h - \frac{12}{7}k_4 h + \frac{8}{7}k_5 h\right). \end{aligned} \tag{7}$$

By paying attention to the initial values of each population S_0, E_0, I_0, and R_0, the fifth-order Runge-Kutta method for solving the SEIR model (1) is:

$$\begin{aligned} S_{i+1} &= S_i + \frac{1}{90}(7k_{1S} + 32k_{3S} + 12k_{4S} + 32k_{5S} + 7k_{6S})h, \\ E_{i+1} &= E_i + \frac{1}{90}(7k_{1E} + 32k_{3E} + 12k_{4E} + 32k_{5E} + 7k_{6E})h, \\ I_{i+1} &= I_i + \frac{1}{90}(7k_{1I} + 32k_{3I} + 12k_{4I} + 32k_{5I} + 7k_{6I})h, \\ R_{i+1} &= R_i + \frac{1}{90}(7k_{1R} + 32k_{3R} + 12k_{4R} + 32k_{5R} + 7k_{6R})h. \end{aligned} \tag{8}$$

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Here, h is the time step, i is the iteration index, and:

$$
\begin{aligned}
k_{1S} &= b_0 - (vp_s + d_0)S_i - \beta(1 - vp_s)S_i I_i \\
k_{1E} &= \beta(1 - vp_s)S_i I_i - (d_1 + \alpha + (1 - \alpha)vp_e)E_i \\
k_{1I} &= \alpha E_i - (d_2 + \gamma + (1 - \gamma)vp_i)I_i \\
k_{1R} &= vp_s S_i + vp_e(1 - \alpha)E_i + (\gamma + (1 - \gamma)vp_i)I_i - d_0 R_i \\
\\
k_{2S} &= b_0 - (vp_s + d_0)\left(S_i + \frac{k_{1S}}{4}h\right) - \beta(1 - vp_s)\left(S_i + \frac{k_{1S}}{4}h\right)\left(I_i + \frac{k_{1I}}{4}h\right) \\
k_{2E} &= \beta(1 - vp_s)\left(S_i + \frac{k_{1S}}{4}h\right)\left(I_i + \frac{k_{1I}}{4}h\right) - (d_1 + \alpha + (1 - \alpha)vp_e)\left(E_i + \frac{k_{1E}}{4}h\right) \\
k_{2I} &= \alpha\left(E_i + \frac{k_{1E}}{4}h\right) - (d_2 + \gamma + (1 - \gamma)vp_i)\left(I_i + \frac{k_{1I}}{4}h\right) \\
k_{2R} &= vp_s\left(S_i + \frac{k_{1S}}{4}h\right) + vp_e(1 - \alpha)\left(E_i + \frac{k_{1E}}{4}h\right) + (\gamma + (1 - \gamma)vp_i)\left(I_i + \frac{k_{1I}}{4}h\right) - d_0\left(R_i + \frac{k_{1R}}{4}h\right) \\
\\
k_{3S} &= b_0 - (vp_s + d_0)\left(S_i + \frac{k_{1S}}{8}h + \frac{k_{2S}}{8}h\right) - \beta(1 - vp_s)\left(S_i + \frac{k_{1S}}{8}h + \frac{k_{2S}}{8}h\right)\left(I_i + \frac{k_{1I}}{8}h + \frac{k_{2I}}{8}h\right) \\
k_{3E} &= \beta(1 - vp_s)\left(S_i + \frac{k_{1S}}{8}h + \frac{k_{2S}}{8}h\right)\left(I_i + \frac{k_{1I}}{8}h + \frac{k_{2I}}{8}h\right) - (d_1 + \alpha + (1 - \alpha)vp_e)\left(E_i + \frac{k_{1E}}{8}h + \frac{k_{2E}}{8}h\right) \\
k_{3I} &= \alpha\left(E_i + \frac{k_{1E}}{8}h + \frac{k_{2E}}{8}h\right) - (d_2 + \gamma + (1 - \gamma)vp_i)\left(I_i + \frac{k_{1I}}{8}h + \frac{k_{2I}}{8}h\right) \\
k_{3R} &= vp_s\left(S_i + \frac{k_{1S}}{8}h + \frac{k_{2S}}{8}h\right) + vp_e(1 - \alpha)\left(E_i + \frac{k_{1E}}{8}h + \frac{k_{2E}}{8}h\right) + (\gamma + (1 - \gamma)vp_i)\left(I_i + \frac{k_{1I}}{8}h + \right. \\
&\qquad \left. \frac{k_{2I}}{8}h\right) - d_0\left(R_i + \frac{k_{1R}}{8}h + \frac{k_{2R}}{8}h\right) \\
\\
k_{4S} &= b_0 - (vp_s + d_0)\left(S_i - \frac{k_{2S}}{2}h + k_{3S}h\right) - \beta(1 - vp_s)\left(S_i - \frac{k_{2S}}{2}h + k_{3S}h\right)\left(I_i - \frac{k_{2I}}{2}h + k_{3I}h\right) \\
k_{4E} &= \beta(1 - vp_s)\left(S_i - \frac{k_{2S}}{2}h + k_{3S}h\right)\left(I_i - \frac{k_{2I}}{2}h + k_{3I}h\right) - (d_1 + \alpha + (1 - \alpha)vp_e)\left(E_i - \frac{k_{2E}}{2}h + k_{3E}h\right) \\
k_{4I} &= \alpha\left(E_i - \frac{k_{2E}}{2}h + k_{3E}h\right) - (d_2 + \gamma + (1 - \gamma)vp_i)\left(I_i - \frac{k_{2I}}{2}h + k_{3I}h\right) \\
k_{4R} &= vp_s\left(S_i - \frac{k_{2S}}{2}h + k_{3S}h\right) + vp_e(1 - \alpha)\left(E_i - \frac{k_{2E}}{2}h + k_{3E}h\right) + (\gamma + (1 - \gamma)vp_i)\left(I_i - \frac{k_{2I}}{2}h + \right. \\
&\qquad \left. k_{3I}h\right) - d_0\left(R_i - \frac{k_{2R}}{2}h + k_{3R}h\right) \\
\\
k_{5S} &= b_0 - (vp_s + d_0)\left(S_i + \frac{3k_{1S}}{16}h + \frac{9k_{4S}}{16}h\right) - \beta(1 - vp_s)\left(S_i + \frac{3k_{1S}}{16}h + \frac{9k_{4S}}{16}h\right)\left(I_i + \frac{3k_{1I}}{16}h + \frac{9k_{4I}}{16}h\right) \\
k_{5E} &= \beta(1 - vp_s)\left(S_i + \frac{3k_{1S}}{16}h + \frac{9k_{4S}}{16}h\right)\left(I_i + \frac{3k_{1I}}{16}h + \frac{9k_{4I}}{16}h\right) - (d_1 + \alpha + (1 - \alpha)vp_e)\left(E_i + \frac{3k_{1E}}{16}h + \right. \\
&\qquad \left. \frac{9k_{4E}}{16}h\right) \\
k_{5I} &= \alpha\left(E_i + \frac{3k_{1E}}{16}h + \frac{9k_{4E}}{16}h\right) - (d_2 + \gamma + (1 - \gamma)vp_i)\left(I_i + \frac{3k_{1I}}{16}h + \frac{9k_{4I}}{16}h\right) \\
k_{5R} &= vp_s\left(S_i + \frac{3k_{1S}}{16}h + \frac{9k_{4S}}{16}h\right) + vp_e(1 - \alpha)\left(E_i + \frac{3k_{1E}}{16}h + \frac{9k_{4E}}{16}h\right) + (\gamma + (1 - \gamma)vp_i)\left(I_i + \frac{3k_{1I}}{16}h + \right. \\
&\qquad \left. \frac{9k_{4I}}{16}h\right) - d_0\left(R_i + \frac{3k_{1R}}{16}h + \frac{9k_{4R}}{16}h\right) \\
\\
k_{6S} &= b_0 - (vp_s + d_0)\left(S_i - \frac{3k_{1S}}{7}h + \frac{2k_{2S}}{7}h + \frac{12k_{3S}}{7}h - \frac{12k_{4S}}{7}h + \frac{8k_{5S}}{7}h\right) - \beta(1 - vp_s)\left(S_i - \frac{3k_{1S}}{7}h + \right. \\
&\qquad \left. \frac{2k_{2S}}{7}h + \frac{12k_{3S}}{7}h - \frac{12k_{4S}}{7}h + \frac{8k_{5S}}{7}h\right)\left(I_i - \frac{3k_{1I}}{7}h + \frac{2k_{2I}}{7}h + \frac{12k_{3I}}{7}h - \frac{12k_{4I}}{7}h + \frac{8k_{5I}}{7}h\right) \\
k_{6E} &= \beta(1 - vp_s)\left(S_i - \frac{3k_{1S}}{7}h + \frac{2k_{2S}}{7}h + \frac{12k_{3S}}{7}h - \frac{12k_{4S}}{7}h + \frac{8k_{5S}}{7}h\right)\left(I_i - \frac{3k_{1I}}{7}h + \frac{2k_{2I}}{7}h + \frac{12k_{3I}}{7}h - \right. \\
&\qquad \left. \frac{12k_{4I}}{7}h + \frac{8k_{5I}}{7}h\right) - (d_1 + \alpha + (1 - \alpha)vp_e)\left(E_i - \frac{3k_{1E}}{7}h + \frac{2k_{2E}}{7}h + \frac{12k_{3E}}{7}h - \frac{12k_{4E}}{7}h + \frac{8k_{5E}}{7}h\right) \\
k_{6I} &= \alpha\left(E_i - \frac{3k_{1E}}{7}h + \frac{2k_{2E}}{7}h + \frac{12k_{3E}}{7}h - \frac{12k_{4E}}{7}h + \frac{8k_{5E}}{7}h\right) - (d_2 + \gamma + (1 - \gamma)vp_i)\left(I_i - \frac{3k_{1I}}{7}h + \right. \\
&\qquad \left. \frac{2k_{2I}}{7}h + \frac{12k_{3I}}{7}h - \frac{12k_{4I}}{7}h + \frac{8k_{5I}}{7}h\right) \\
k_{6R} &= vp_s\left(S_i - \frac{3k_{1S}}{7}h + \frac{2k_{2S}}{7}h + \frac{12k_{3S}}{7}h - \frac{12k_{4S}}{7}h + \frac{8k_{5S}}{7}h\right) + vp_e(1 - \alpha)\left(E_i - \frac{3k_{1E}}{7}h + \frac{2k_{2E}}{7}h + \right. \\
&\qquad \left. \frac{12k_{3E}}{7}h - \frac{12k_{4E}}{7}h + \frac{8k_{5E}}{7}h\right) + (\gamma + (1 - \gamma)vp_i)\left(I_i - \frac{3k_{1I}}{7}h + \frac{2k_{2I}}{7}h + \frac{12k_{3I}}{7}h - \frac{12k_{4I}}{7}h + \frac{8k_{5I}}{7}h\right) -
\end{aligned}
\tag{9}
$$

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$$d_0\left(R_i - \frac{3k_{1R}}{7}h + \frac{2k_{2R}}{7}h + \frac{12k_{3R}}{7}h - \frac{12k_{4R}}{7}h + \frac{8k_{5R}}{7}h\right)$$

RESULTS AND DISCUSSION

This section contains simulation results based on numerical schemes of the fourth- and fifth-order Runge-Kutta methods. The accuracy of both methods is also discussed. The simulations are done using the MATLAB software.

Simulation Results of the Fourth-Order Runge-Kutta Method

Initial and parameter values are needed in solving the model. Table 2 shows the initial and parameter values used.

TABLE 2. Initial Values and Parameter Values

Variables/Parameters	Values
$S(0)$	0.97286
$E(0)$	0.00543
$I(0)$	0.00362
$R(0)$	0.01809
β	0.462
α	1/ 11.5 per day
γ	0.0686 per day
b_0	3.178×10^{-5} per day
d_0	2.377×10^{-5} per day
d_1	2.585×10^{-5} per day
d_2	2.585×10^{-5} per day
v	0.01
p_s	0.7
p_e	0.6
p_i	0.6

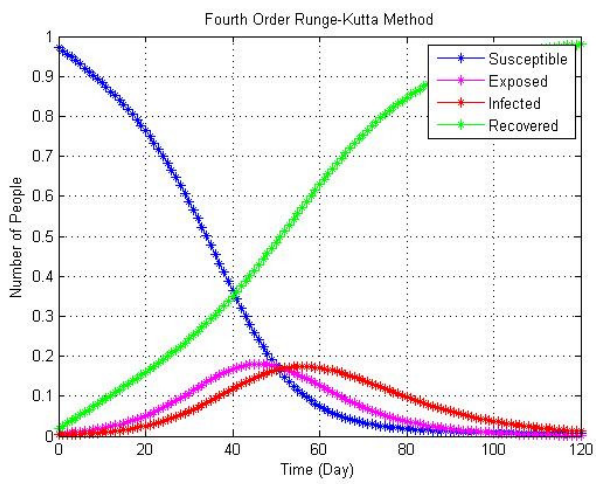

FIGURE 1. Graph of disease spread using the fourth-order Runge-Kutta method with $h = 1$ on the time range $[0,120]$

Figure 1 shows the behavior of the spread of the COVID-19 disease by the SEIR model based on the fourth-order Runge-Kutta method. The results illustrate that the proportion of susceptible populations, namely S has decreased over time. The proportion of the exposed population, namely E, increased until the 47th day and decreased the next day. This also occurs in the proportion of the infected population, namely I, experienced an increase until the 57th day and decreased the next day. Meanwhile, the proportion of the recovered population,

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namely R, has increased over time. This increase in the recovered population is in line with the decline in susceptible population, exposed population and infected population whose proportions are towards zero.

Simulation Results of the Fifth Order Runge-Kutta Method

Similar to the previous simulation, the fifth-order Runge-Kutta method also needs initial and parameter values. The initial and parameter values are the same as those used in the fourth-order Runge-Kutta method, as shown in Table 2.

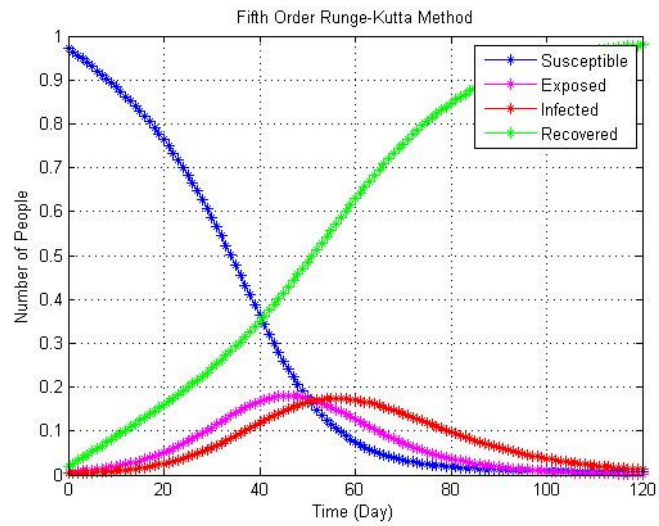

FIGURE 2. Graph of disease spread using the fifth-order Runge-Kutta method with $h = 1$ on the time range [0,120]

Figure 2 shows the simulation results of the spread of COVID-19 disease by the SEIR model using the fifth-order Runge-Kutta method. These results have similarities with the simulation results using the fourth-order Runge-Kutta method. This causes the pattern of the spread and behavior to be the same.

Accuracy Order of Method

Based on the simulation results shown in Figure 1 and Figure 2, the patterns of solution from the two methods are the same. To see which method is more accurate between the fourth-order Runge-Kutta method and the fifth-order Runge-Kutta method, it is necessary to measure the numerical error and the order of accuracy. the ODE45 algorithm in the MATLAB software was chosen as a reference for the analytical results with 'RelTol' and 'AbsTol' of 1×10^{-15}. This is done because until now no exact analytical solution has been found for the SEIR model considered in this paper.

To test numerical errors, an absolute error formula is used. Next, to calculate the order of accuracy, we investigate the results and errors for time steps 1, 0.5, 0.25, 0.125, and 0.0625 and use the accuracy order formula [18], that is,

$$R_i = \frac{\log\left(\frac{E_i}{E_{i+1}}\right)}{\log\left(\frac{\Delta x_i}{\Delta x_{i+1}}\right)} \tag{10}$$

where E_i is an error corresponding to the simulation using the free variable step Δx_i and E_{i+1} is an error corresponding to the simulation using the free variable step Δx_{i+1}.

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TABLE 3. The average error value of the fourth-order Runge-Kutta method

Δt	S	E	I	R
1	1.63×10^{-7}	8.46×10^{-8}	3.60×10^{-8}	1.18×10^{-7}
0.5	1.04×10^{-8}	5.35×10^{-9}	2.40×10^{-9}	7.65×10^{-9}
0.25	6.62×10^{-10}	3.37×10^{-10}	1.56×10^{-10}	4.87×10^{-10}
0.125	4.17×10^{-11}	2.11×10^{-11}	9.91×10^{-12}	3.07×10^{-11}
0.0625	2.61×10^{-12}	1.32×10^{-12}	6.25×10^{-13}	1.93×10^{-12}

TABLE 4. The average error value of the fifth-order Runge-Kutta method

Δt	S	E	I	R
1	3.09×10^{-10}	4.67×10^{-10}	5.86×10^{-10}	4.28×10^{-10}
0.5	1.13×10^{-11}	1.36×10^{-11}	1.79×10^{-11}	1.45×10^{-11}
0.25	3.81×10^{-13}	4.10×10^{-13}	5.56×10^{-13}	4.71×10^{-13}
0.125	1.22×10^{-14}	1.26×10^{-14}	1.71×10^{-14}	1.38×10^{-14}
0.0625	3.12×10^{-16}	3.92×10^{-16}	3.99×10^{-16}	3.58×10^{-16}

From Table 3 and Table 4, the average error value of each compartment is different for each Δt. In addition, the average values of errors of the fourth-order Runge-Kutta method between compartments are greater than the average values of errors of the fifth-order Runge-Kutta method between compartments.

TABLE 5. Accuracy order of the fourth-order Runge-Kutta method

Δt	S	E	I	R
1	-	-	-	-
0.5	3.961	3.983	3.902	3.945
0.25	3.980	3.990	3.949	3.972
0.125	3.990	3.995	3.974	3.986
0.0625	3.995	3.997	3.987	3.992

TABLE 6. Accuracy order of the fifth-order Runge-Kutta method

Δt	S	E	I	R
1	-	-	-	-
0.5	4.771	5.106	5.028	4.881
0.25	4.895	5.046	5.012	4.945
0.125	4.961	5.026	5.023	5.090
0.0625	5.290	5.006	5.421	5.274

The order of accuracy by fourth-order Runge-Kutta method shown in Table 5 is close to a certain value, namely 4, while the order of accuracy by fifth-order Runge-Kutta method in Table 6 is close to 5. These results confirm that the orders of accuracy in our simulations match with the theoretical orders of the numerical methods. It is clear that the accuracy of the fifth-order Runge-Kutta method is better than the accuracy of the fourth-order Runge-Kutta method.

Based on the comparison of the accuracy level values above, the fifth-order Runge-Kutta method can be suggested as a better method to be used to solve the mathematical model of the spread of COVID-19. In addition,

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the fifth-order Runge-Kutta method can also be applied in solving mathematical models of the spread of other diseases [19–21].

CONCLUSION

The solutions produced by the fourth-order Runge-Kutta method and the fifth-order Runge-Kutta method using the MATLAB software show similarities. Thus, it is necessary to look for the values of the numerical errors and the order of accuracy of each method, so we can observe the difference between the two methods. The results of our research confirm that solving the mathematical model of the spread of COVID-19 disease by the fifth-order Runge-Kutta method is indeed more accurate than using the fourth-order Runge-Kutta method.

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