



FRACTIONAL-ORDER SEIR MODEL FOR EBOLA VIRUS TRANSMISSION DYNAMICS ANALYSIS: AN ANALYTICAL AND NUMERICAL APPROACHES

Sharmin Sultana Shanta^{1,2} and M. Ali Akbar²

¹ Mathematics Discipline, Khulna University, Khulna, Bangladesh.

² Department of Applied Mathematics, University of Rajshahi, Bangladesh.

Emails: ¹sharmin3349@gmail.com, ²ali_math74@yahoo.com

Corresponding Author: **M. Ali Akbar**

<https://doi.org/10.26782/jmcms.2025.09.00010>

(Received: June 05, 2025; Revised: August 12, 2025; Accepted: August 29, 2025)

Abstract

The Ebola virus is a highly contagious disease that originates from wild animals and transmits to humans through direct contact with tainted blood, bodily fluids, or contaminated materials. In this article, we investigate the transmission dynamics of the Ebola virus through the fractional-order SEIR model. We aim to find the analytical solution of the fractional model along with its numerical solution. The Laplace Adomian decomposition method (LADM) is implemented to find the analytical solution of the model, and the accuracy of the results is verified numerically via the fractional Runge-Kutta 4th order (RK4) scheme. The findings reveal the potential role of a fractional-order parameter that influences the behavior of the epidemic. The LADM and RK4 solutions indicate coherence when the fractional parameter gets closer to 1. The results could help control the real-world epidemic scenarios.

Keywords: Mathematical model; Laplace Adomian decomposition method (LADM); Runge-Kutta 4th order (RK4) method.

I. Introduction

A terrible transmissible disease, Ebola virus disease (EVD), is caused by the Ebola virus and is classified as part of the Filoviridae family [XIII]. In 1976, Sudan and the Democratic Republic of the Congo (DRC) became the first place where the disease had been identified, which is close to the Ebola River [XIV]. The initial mortality rates were very high (88%), which showed an extreme fatality rate of the virus [X]. Fruit bats, particularly those belonging to the Pteropodidae family, are considered to be the natural reservoir to carry the zoonotic pathogen Ebola virus [XXIV]. People get the contract the Ebola virus by coming into direct contact with infected animals such as bats, and it is also transmitted from individual to individual by direct contact with body fluids, blood, or contaminated substances [XXIX].

Sharmin Sultana Shanta et al.

Numerous challenges have inhibited the epidemic responses, including limited healthcare resources, delayed diagnosis, and community mistrust, which increase transmission [VII]. The treatment for EVD is historically limited to supportive care, but there have been significant advances in recent years. Experimental treatments such as monoclonal antibodies (ZMapp) and antiviral drugs (remdesivir) have shown outstanding performance in clinical trials [XXVII]. The rVSV-ZEBOV vaccine has been demonstrating high efficacy in ring vaccination trials and has become the first licensed Ebola vaccine [XVI]. Despite these advances, challenges continue in vaccine deployment, public acceptance, and coverage in remote areas [XX]. To prevent future outbreaks of EVD, proper monitoring and rapid response capacity are essential.

Mathematical models are widely used in physics [XXX, XXVI], economics [XXXII, XIX], engineering [XI, XXV], and social sciences [XXXI] to model complex systems and predict outcomes. Mathematical modelling is also an essential tool to understand the transmission of infectious diseases, like Malaria [V], Nipah virus [XII], Dengue [XV], Chickenpox [XVII], and many others. Therefore, mathematical modelling can play an important role in this regard. Modelling can help predict the outbreak patterns and take up control strategies after observing the transmission fatality rate and complex interaction of the host and other factors [XXIII]. A recently developed mathematical model has been used in EVD transmission with four infection factors and incubation delay [XXVIII]. Data fitting identifies early vaccination and minimizes the contact rates; these are the key to controlling the outbreak. A nonlinear Ebola transmission model has considered environmental contamination, where numerical simulations with cost-effectiveness analysis indicate the most efficient control strategy [II]. Although many existing studies use integer-order differential equations to analyze the Ebola virus transmission, these models hardly capture the memory and heredity effects inherent in real-world biological systems. But fractional-order models include memory effect and hereditary properties that make them more accurate for modeling real-world phenomena [VIII, XXII]. The FDE provides better modeling, especially for biological systems that describe past states and influence the current dynamics. This improves prediction and control strategies compared to classical integer-order models. Some previous studies have used fractional-order models and investigated them using numerical techniques, such as the Caputo-Fabrizio method. In [I], the numerical simulation of a fractional-order Ebola model with five compartments with low and high sensitivity is investigated. A Caputo Fabrizio fractional order model has been formulated to analyze the Ebola virus transmission between dogs and individual humans, where the role of scavenging behavior in pet dogs is identified [III]. The model has emphasized the need for dog quarantine and improved hospitalization to control the outbreak. Fractional differential equations can also be unravelled using other approaches, such as the Laplace transform method [IX, IV], the homotopy perturbation method (HPM) [XXI], the variational iteration method (VIM) [VI], etc. Analytical solutions for nonlinear fractional SEIR models for the Ebola virus disease, environmental pollution, etc., using the Laplace Adomian decomposition method remain limited. Furthermore, solving such models analytically is challenging due to their nonlinear and memory-dependent nature. Therefore, this study aims to analyze the general fractional-order SEIR model for the Ebola virus transmission by employing the

Sharmin Sultana Shanta et al.

Caputo fractional derivative, which captures the memory-dependent dynamics of disease progression. The system is then analytically investigated using the fractional Laplace Adomian decomposition method (FLADM). The fractional Runge-Kutta 4th order (RK4) method has been used to compare the results to verify the validity of the analytical solutions. Besides that, we examine whether the fractional-order parameter p affects the dynamics of the disease and emphasize the FLADM's efficiency and reliability (as an analytical tool in epidemiological analysis). The FLADM can efficiently address both linear and nonlinear fractional differential equations smoothly and accurately.

II. Model

In this study, we consider the general Kermack-McKendrick-type SEIR model. A modified version of this model was studied by Islam et al. (2024) [XVIII] with the vaccination effect. According to the disease's dynamics, the population is divided into four compartments. Susceptible individuals $S(t)$ may get the Ebola virus and move into the exposed class $E(t)$ at a rate β . At this stage, they are infected but not yet infectious. The individuals then progress to the infectious class $I(t)$ at rate γ by showing symptoms. Recovery leads to the final compartment $R(t)$, which includes individuals who recover from the infection at rate μ . Susceptible individuals can acquire immunity by vaccination at a rate ν and then move directly to the R class. For simplicity, we assume that there is no demography, and so the total population remains constant during the period under consideration.

Thus, $N(t) = S(t) + E(t) + I(t) + R(t)$.

Therefore, the model becomes

$$\begin{cases} \frac{dS(t)}{dt} = -\beta S(t)I(t) - \nu S(t), \\ \frac{dE(t)}{dt} = \beta S(t)I(t) - \gamma E(t), \\ \frac{dI(t)}{dt} = \gamma E(t) - \mu I(t), \\ \frac{dR(t)}{dt} = \mu I(t) + \nu S(t), \end{cases} \quad (1)$$

with initial conditions:

$$S(0) = S_0, E(0) = E_0, I(0) = I_0, R(0) = R_0. \quad (2)$$

Now, considering Caputo's fractional derivative of order $0 < p \leq 1$, the associated fractional order model of system (1) can be considered as follows:

$$\begin{cases} {}^C D_t^p S(t) = -\beta S(t)I(t) - \nu S(t), \\ {}^C D_t^p E(t) = \beta S(t)I(t) - \gamma E(t), \\ {}^C D_t^p I(t) = \gamma E(t) - \mu I(t), \\ {}^C D_t^p R(t) = \mu I(t) + \nu S(t), \end{cases} \quad (3)$$

$$\text{with initial conditions: } S(0) = z_1, E(0) = z_2, I(0) = z_3, R(0) = z_4. \quad (4)$$

Sharmin Sultana Shanta et al.

The Global Stability of the Equilibrium Point

The equilibrium point of models (1) and (3) is the same, which is $(S^*, E^*, I^*, R^*) = (0, 0, 0, N)$ or $(N, 0, 0, 0)$. This is obvious because demography is absent in the system. Now, to prove the global stability of this equilibrium point, we consider the following Lyapunov function:

$$V(S, E, I) = E + I + \frac{\beta}{2\mu} S^2.$$

Now

$$\begin{aligned}\dot{V} &= \dot{E} + \dot{I} + \frac{\beta}{\mu} S\dot{S}. \\ &= (\beta SI - \gamma E) + (\gamma E - \mu I) + \frac{\beta}{\mu} S(-\beta SI - \nu S). \\ &= \beta SI - \mu I - \frac{\beta^2}{\mu} S^2 I - \frac{\beta \nu}{\mu} S. \\ &= I \left(\beta S - \mu - \frac{\beta^2}{\mu} S^2 \right) - \frac{\beta \nu}{\mu} S \leq 0, \text{ as long as } \beta > 0, \mu > 0, \nu > 0, S > 0, \\ &\text{and } I > 0.\end{aligned}$$

Since $\dot{V} \leq 0$, therefore (S^*, E^*, I^*, R^*) is globally stable.

Basic Reproduction Number ($\mathfrak{R}_0$)

The infectious vector of model (1) is (E, I) . Therefore, the new infections and transition vectors are

$$F = \begin{pmatrix} 0 & \beta S \\ 0 & 0 \end{pmatrix} \text{ and } V = \begin{pmatrix} \gamma & 0 \\ -\gamma & \mu \end{pmatrix}.$$

At the equilibrium point (S^*, E^*, I^*, R^*) ,

$$F - V = \begin{pmatrix} 0 & \beta N \\ 0 & 0 \end{pmatrix} - \begin{pmatrix} \gamma & 0 \\ -\gamma & \mu \end{pmatrix}.$$

The next-generation matrix is $K = FV^{-1}$, where $V^{-1} = \frac{1}{\gamma\mu} \begin{pmatrix} \mu & 0 \\ \gamma & \gamma \end{pmatrix}$.

The eigenvalues of K are the roots of its characteristic polynomial, and the spectral radius (the largest eigenvalue) is the basic reproduction number:

$$\mathfrak{R}_0 = \frac{\beta N}{\mu}.$$

Sensitivity of $\mathfrak{R}_0$ to parameters

The basic reproduction number $\mathfrak{R}_0$ of model (1) has only two parameters β and μ . The sensitivity of $\mathfrak{R}_0$ to these parameters can be calculated as follows:

$$\begin{aligned}\Gamma_{\beta}^{\mathfrak{R}_0} &= \frac{\partial \mathfrak{R}_0}{\partial \beta} \cdot \frac{\beta}{\mathfrak{R}_0} \\ &= \frac{N}{\mu} \cdot \frac{\beta}{\frac{\beta N}{\mu}} \\ \text{So, } \Gamma_{\beta}^{\mathfrak{R}_0} &= 1,\end{aligned}$$

Sharmin Sultana Shanta et al.

and

$$\begin{aligned}\Gamma_{\mu}^{\mathfrak{R}_0} &= \frac{\partial \mathfrak{R}_0}{\partial \mu} \cdot \frac{\mu}{\mathfrak{R}_0} \\ &= -\frac{\beta N}{\mu^2} \cdot \frac{\mu}{\frac{\beta N}{\mu}}\end{aligned}$$

Therefore, $\Gamma_{\mu}^{\mathfrak{R}_0} = -1$.

See Section IV for the interpretation of this analysis.

III. Methodology

We implement the fractional Laplace transform with the Adomian decomposition method (FLADM) to equation (3), an effective approach for assessing nonlinear fractional models. The method simplifies the process of managing nonlinear terms, which makes it further convenient. The FLADM gives solutions in a series.

Laplace Adomian Decomposition Method

The Laplace transform of model (3) is:

$$\begin{aligned}L\{ {}^c D^p S(t) \} &= L\{ -\beta S(t)I(t) - \nu S(t) \}, \\ L\{ {}^c D^p E(t) \} &= L\{ \beta S(t)I(t) - \gamma E(t) \}, \\ L\{ {}^c D^p I(t) \} &= L\{ \gamma E(t) - \mu I(t) \}, \\ L\{ {}^c D^p R(t) \} &= L\{ \mu I(t) + \nu S(t) \}.\end{aligned}\tag{5}$$

Since

$$L\{ {}^c D_t^p y(t) \} = s^p Y(s) - s^{p-1} y(0),$$

Therefore, we obtain from (5):

$$\begin{aligned}s^p L\{ S(t) \} - sS(0) &= L\{ -\beta S(t)I(t) - \nu S(t) \}, \\ s^p L\{ E(t) \} - sE(0) &= L\{ \beta S(t)I(t) - \gamma E(t) \}, \\ s^p L\{ I(t) \} - sI(0) &= L\{ \gamma E(t) - \mu I(t) \}, \\ s^p L\{ R(t) \} - sR(0) &= L\{ \mu I(t) + \nu S(t) \},\end{aligned}\tag{6}$$

Using the initial conditions from (4), (6) becomes

$$\begin{aligned}L\{ S(t) \} &= z_1 s^{-1} + s^{-p} [L\{ -\beta S(t)I(t) - \nu S(t) \}], \\ L\{ E(t) \} &= z_2 s^{-1} + s^{-p} [L\{ \beta S(t)I(t) - \gamma E(t) \}], \\ L\{ I(t) \} &= z_3 s^{-1} + s^{-p} [L\{ \gamma E(t) - \mu I(t) \}], \\ L\{ R(t) \} &= z_4 s^{-1} + s^{-p} [L\{ \mu I(t) + \nu S(t) \}].\end{aligned}\tag{7}$$

The solution can be presented by an infinite series as follows:

$$\begin{aligned}S(t) &= \sum_{n=0}^{\infty} S_n(t), E(t) = \sum_{n=0}^{\infty} E_n(t), I(t) = \sum_{n=0}^{\infty} I_n(t), \text{ and} \\ R(t) &= \sum_{n=0}^{\infty} R_n(t).\end{aligned}$$

Sharmin Sultana Shanta et al.

We can decompose the nonlinear terms as:

$$S(t)I(t) = \sum_{n=0}^{\infty} A_n, \text{ where } A_n \text{'s are Adomian polynomials.}$$

The general Adomian polynomial is:

$$A_n = \frac{1}{\Gamma(n+1)} \frac{d^n}{d\kappa^n} \left[\sum_{q=0}^n \kappa^q I_q(t) \sum_{q=0}^n \kappa^q S_q(t) \right].$$

$$\text{The first-order Adomian polynomial is: } A_0(t) = S_0(t) I_0(t)$$

$$\text{The second-order Adomian polynomial is: } A_1(t) = S_0(t)I_1(t) + S_1(t)I_0(t).$$

Now, substituting the series and Adomian polynomials in Eq. (7), we get

$$\begin{aligned} L\{\sum_{n=0}^{\infty} S_{(n+1)}(t)\} &= z_1 s^{-1} + s^{-p} L\{-\beta \sum_{n=0}^{\infty} A_n - \nu S_n(t)\}, \\ L\{\sum_{n=0}^{\infty} E_{(n+1)}(t)\} &= z_2 s^{-1} + s^{-p} L\{\beta \sum_{n=0}^{\infty} A_n - \gamma E_n(t)\}, \\ L\{\sum_{n=0}^{\infty} I_{(n+1)}(t)\} &= z_3 s^{-1} + s^{-p} L\{\gamma E_n(t) - \mu I_n(t)\}, \\ L\{\sum_{n=0}^{\infty} R_{(n+1)}(t)\} &= z_4 s^{-1} + s^{-p} L\{\mu I_n(t) + \nu S_n(t)\}, \end{aligned} \quad (8)$$

Now, implementing the inverse Laplace transform, from (6)-(8), we get the following:

$$\begin{aligned} \sum_{n=0}^{\infty} S_{(n+1)}(t) &= z_1 + L^{-1}[s^{-p} L\{-\beta \sum_{n=0}^{\infty} A_n - \nu S_n(t)\}], \\ \sum_{n=0}^{\infty} E_{(n+1)}(t) &= z_2 + L^{-1}[s^{-p} L\{\beta \sum_{n=0}^{\infty} A_n - \gamma E_n(t)\}], \\ \sum_{n=0}^{\infty} I_{(n+1)}(t) &= z_3 + L^{-1}[s^{-p} L\{\gamma E_n(t) - \mu I_n(t)\}], \\ \sum_{n=0}^{\infty} R_{(n+1)}(t) &= z_4 + L^{-1}[s^{-p} L\{\mu I_n(t) + \nu S_n(t)\}], \end{aligned} \quad (9)$$

From Eq. (9), the initial approximations are:

$$S_0(t) = z_1, E_0(t) = z_2, I_0(t) = z_3, R_0(t) = z_4. \quad (10)$$

For $n = 0$, the first-order approximations are:

$$\begin{aligned} S_1(t) &= \{-\beta A_0(t) - \nu S_0(t)\} \frac{t^p}{\Gamma(1+p)}, \\ E_1(t) &= \{\beta A_0(t) - \gamma E_0(t)\} \frac{t^p}{\Gamma(1+p)}, \\ I_1(t) &= \{\gamma E_0(t) - \mu I_0(t)\} \frac{t^p}{\Gamma(1+p)}, \\ R_1(t) &= \{\mu I_0(t) + \nu S_0(t)\} \frac{t^p}{\Gamma(1+p)}. \end{aligned} \quad (11)$$

For $n = 1$, the second-order approximations are:

$$\begin{aligned}
 S_2(t) &= \{-\beta A_1(t) - \nu S_1(t)\} \frac{t^{2p}}{\Gamma(1+2p)}, \\
 E_2(t) &= \{\beta A_1(t) - \gamma E_1(t)\} \frac{t^{2p}}{\Gamma(1+2p)}, \\
 I_2(t) &= \{\gamma E_1(t) - \mu I_1(t)\} \frac{t^{2p}}{\Gamma(1+2p)}, \\
 R_2(t) &= \{\mu I_1(t) + \nu S_1(t)\} \frac{t^{2p}}{\Gamma(1+2p)}.
 \end{aligned} \tag{12}$$

Therefore, from equations (10)-(12), the approximate solution with three terms is given by:

$$\begin{aligned}
 S(t) &\approx S_0(t) + S_1(t) + S_2(t). \\
 E(t) &\approx E_0(t) + E_1(t) + E_2(t). \\
 I(t) &\approx I_0(t) + I_1(t) + I_2(t). \\
 R(t) &\approx R_0(t) + R_1(t) + R_2(t).
 \end{aligned} \tag{13}$$

IV. Results and Discussion

In this section, we show the analytical solution (13) geometrically. For this, we consider the transmission rate $\beta = 5.48 \times 10^{-4}$, the rate of development from exposed to infected $\gamma = 4.93 \times 10^{-4}$, the recovery rate $\mu = 0.27 \times 10^{-3}$, and the vaccination rate $\nu = 1.37 \times 10^{-4}$. The initial population distribution is: susceptible individuals $S(0) = 0.88$, exposed individuals $E(0) = 0.07$, infected individuals $I(0) = 0.05$, and recovered individuals $R(0) = 0.00$ [XVIII]. Using these values, series (13) becomes:

$$\begin{aligned}
 S(t) &= 0.88 + 1.3739 \times 10^{-8} \frac{t^{2p}}{\Gamma(2p+1)} - 0.00014 \frac{t^p}{\Gamma(p+1)}, \\
 E(t) &= 0.07 + 1.1211 \times 10^{-8} \frac{t^{2p}}{\Gamma(2p+1)} - 0.00001 \frac{t^p}{\Gamma(p+1)}, \\
 I(t) &= 0.05 - 1.0838 \times 10^{-8} \frac{t^{2p}}{\Gamma(2p+1)} + 0.00002 \frac{t^p}{\Gamma(p+1)}, \\
 R(t) &= 0.00 - 1.4111 \times 10^{-8} \frac{t^{2p}}{\Gamma(2p+1)} + 0.00013 \frac{t^p}{\Gamma(p+1)}.
 \end{aligned} \tag{14}$$

Figures 1-4 illustrate the comparative dynamics of the susceptible, exposed, infected, and recovered populations, respectively, over 60 days under three different fractional orders of the Caputo derivative for $p = 0.79$, $p = 0.89$, and $p = 0.99$. These figures provide a visual comparison between the analytical solutions obtained via the FLADM and the numerical solutions computed using the fractional Runge-Kutta 4th order (FRK4) method (a suitable numerical scheme).

The evolution of the susceptible population for $S(t)$ for $p = 0.79$, $p = 0.89$, and $p = 0.99$ is depicted in Figure 1 (1a, 1b, and 1c), respectively. In all cases, the

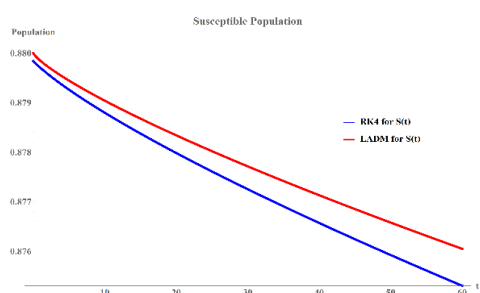
Sharmin Sultana Shanta et al.

susceptible population decreases over time as individuals transition to the exposed class. At fractional order $p = 0.99$, the LADM nicely agrees with the fractional RK4 technique. The FLADM is shown in red, and the numerical solution is shown in blue.

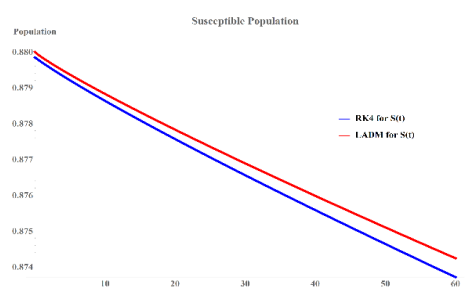
Figure 2 (2a, 2b, and 2c) demonstrates that the exposed population drops over time ($p = 0.79$ and $p = 0.89$, respectively). The slower decay for $p = 0.99$ again highlights the influence of the fractional order on the disease progression. The analytical and numerical results closely align for fractional order $p = 0.99$; this demonstrates the validity and accuracy of the FLADM.

Figure 3 (3a, 3b, and 3c) displays the change in the infected population over time. The correspondence between the analytical and numerical solutions remains consistent $p = 0.99$, which validates the robustness of the method. Figure 4 (4a, 4b, and 4c) displays the dynamics of the recovered population over time. At $p = 0.99$, LADM approaches the numerical solutions obtained from the RK4 method.

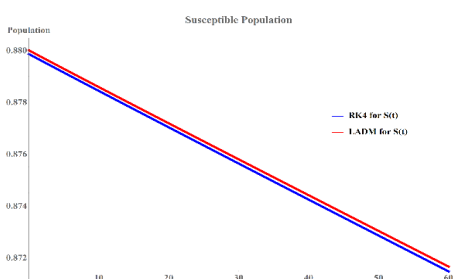
Figure 5 shows the sensitivity (elasticity) of $\mathcal{R}_0$ for parameters β and μ , which indicates that a 10% increase in β will increase $\mathcal{R}_0$ by 10%, and a 10% decrease in β will decrease $\mathcal{R}_0$ by 10%.



(a) Comparison of analytical and numerical solutions over 60 days with $p = 0.79$.

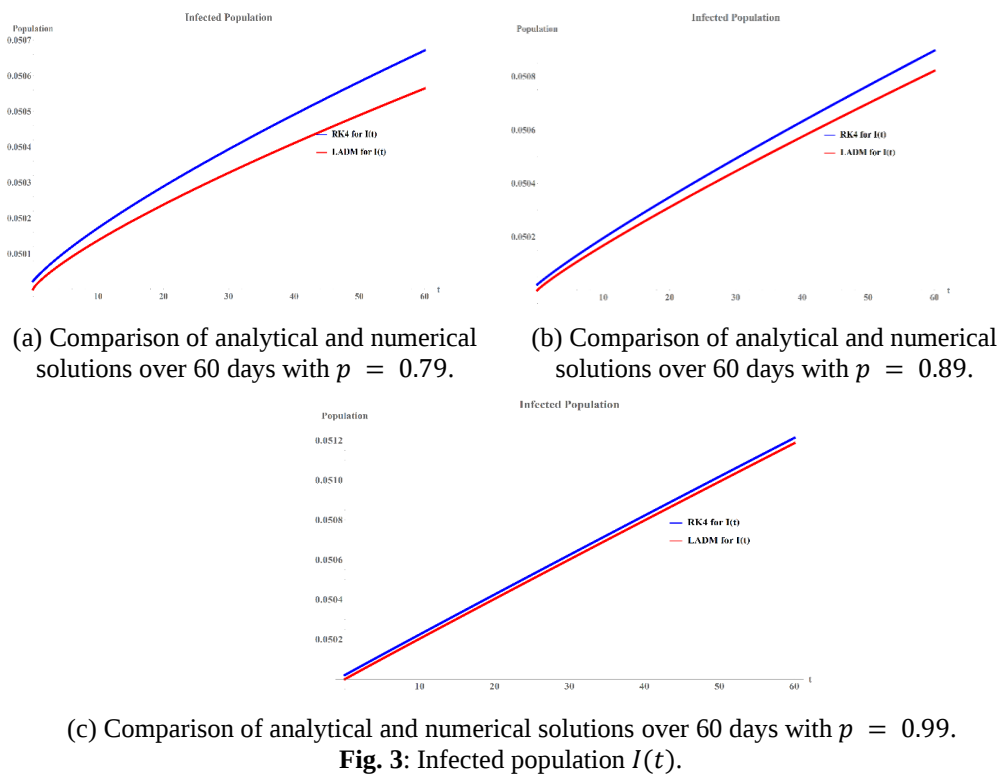
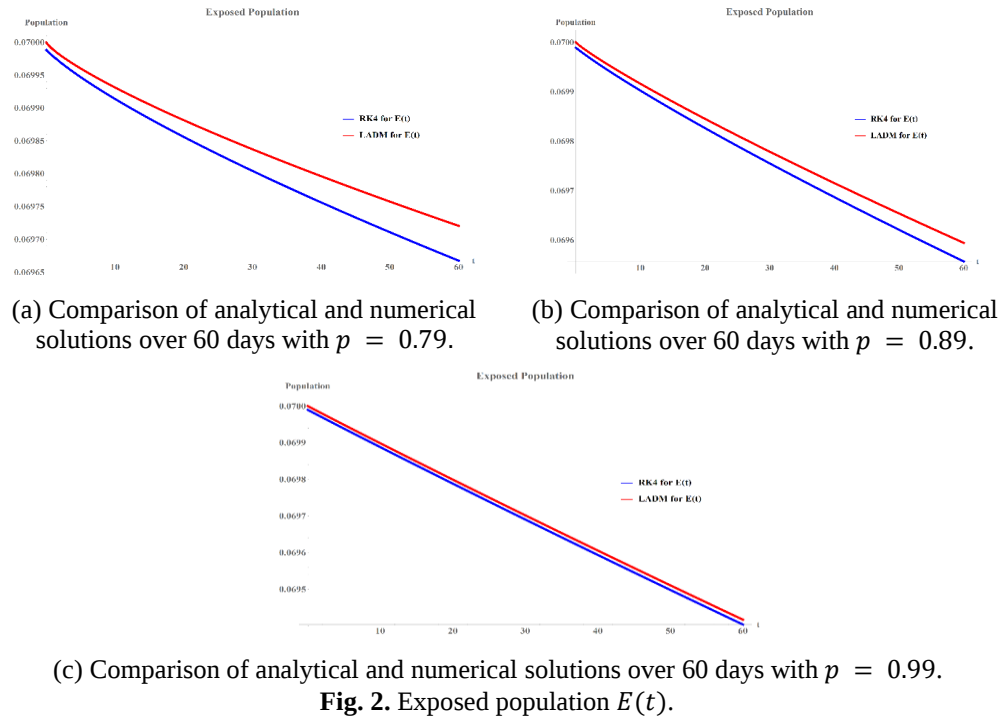


(b) Comparison of analytical and numerical solutions over 60 days with $p = 0.89$.



(c) Comparison of analytical and numerical solutions over 60 days with $p = 0.99$

Fig. 1. Graphical depiction of susceptible population $S(t)$.



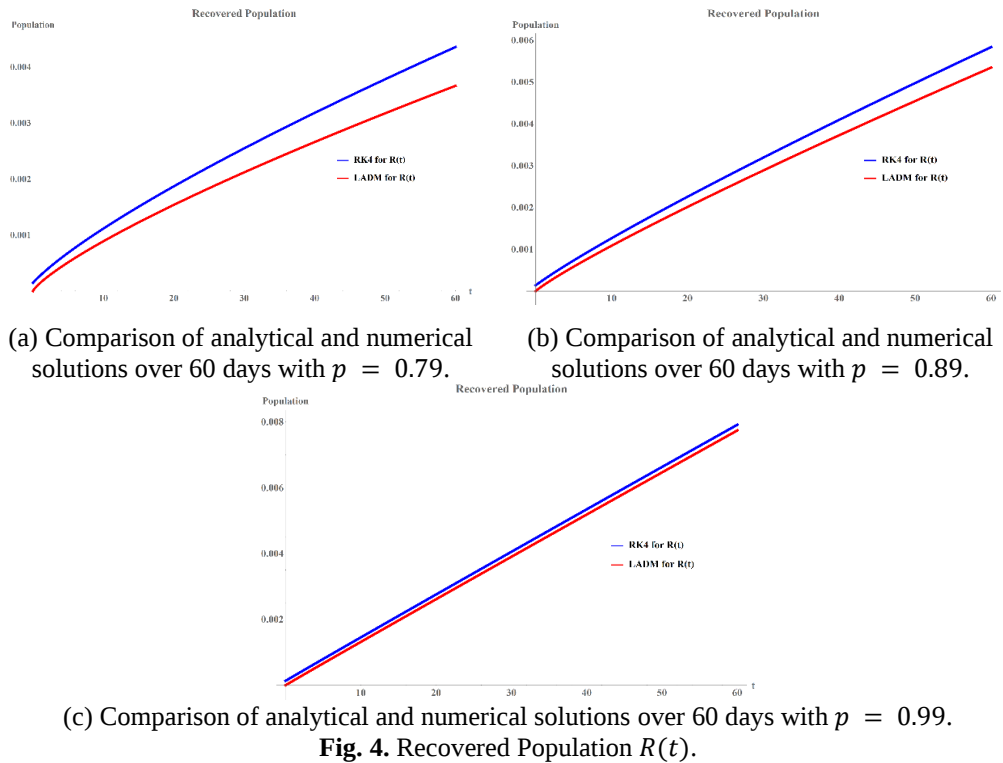


Fig. 4. Recovered Population $R(t)$.

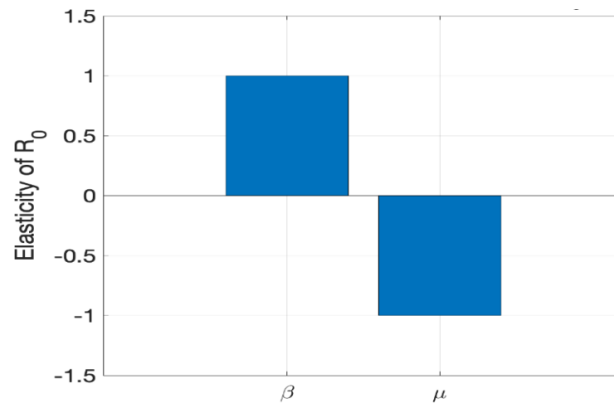


Fig. 5. Normalized sensitivity (elasticity) of R_0 .

Overall, these comparisons emphasize the effectiveness of the FLADM in showing the behavior of the fractional SEIR model. The influence of the fractional-order derivative p is evident in each compartment, which underlines the importance of fractional modelling in capturing memory-dependent dynamics in epidemiological modelling.

Sharmin Sultana Shanta et al.

V. Conclusion

In this study, we deal with a fractional-order SEIR model with vaccination in the Caputo derivative to investigate the transmission dynamics of the Ebola virus disease. The model successfully captures the memory-dependent and heritable features of disease progression. The fractional Laplace Adomian decomposition method is found to be an efficient, compatible, and flexible method for unraveling the analytical solutions of the model. The strong agreement between the analytical responses and the computational results (obtained using the fractional Runge-Kutta 4th order (RK4) approach) verifies their validity and reliability. The graphical simulations over 60 days show that the fractional-order parameter p significantly affects the behavior of each compartment, *i.e.*, susceptible, exposed, infected, and recovered. The results demonstrate a strong agreement between the LADM and RK4 solutions at $p = 0.99$. Notably, as p approaches 1, the behavior of the fractional model aligns more closely with the classical model, underscoring the role of fractional derivatives in refining disease modelling. This study clearly demonstrates that the FLADM is capable of producing accurate analytical approximations and is a powerful tool for understanding complex epidemiological systems governed by memory effects. This research emphasizes the significance of fractional-order modelling in public health, especially to improve prediction ability to assist in the development of effective strategies (to control infectious diseases such as Ebola). The results presented here can serve as a foundation for future work on fractional-order models applied to a wide range of epidemiological and biological problems. One limitation of the present model is that it does not incorporate birth and mortality rates. Introducing such rates might create challenges to solving the system analytically, which could also be one of the future works.

VI. Acknowledgement

The first author was financially supported by the Ministry of Science and Technology, Government of the People's Republic of Bangladesh, in the PhD degree with the NST Fellowship 2024-25, Grant No. 39.00.0000.012.02.009.24.30, Merit No.: 06, Serial No.: 03, Date-30.01.2025. The author sincerely acknowledges this support.

Conflict of Interest:

There was no relevant conflict of interest regarding this article.

References

- I. Abdul-Wahhab, Renna D., Mohannad M. Eisa, and Sanaa L. Khalaf. "The study of stability analysis of the Ebola virus via fractional model." *Partial Differential Equations in Applied Mathematics* 11 (2024): 100792. 10.1016/j.padiff.2024.100792

Sharmin Sultana Shanta et al.

- II. Adu, Isaac Kwasi, et al. "Modelling the dynamics of Ebola disease transmission with optimal control analysis." *Modeling Earth Systems and Environment* 10.4 (2024): 4731-4757. 10.1007/s40808-024-02020-4
- III. Adu, Isaac K., et al. "A fractional order Ebola transmission model for dogs and humans." *Scientific African* 24 (2024): e02230. 10.1016/j.sciaf.2024.e02230
- IV. Al-deiakeh, Rawya, et al. "On the Laplace Residual Series Method and Its Application to Time-Fractional Fisher's Equations." *Fractal and Fractional* 9.5 (2025): 275. 10.3390/fractalfract9050275
- V. Alhaj, Mohamed Salah, and Farai Nyabadza. "A mathematical model of malaria transmission in conflict-affected regions and the implications on malaria interventions." *Scientific African* (2025): e02746. 10.1016/j.sciaf.2025.e02746
- VI. Altaie, Huda Omran, et al. "A hybrid analytical method for fractional order Klein-Gordon and Burgers equations." *Partial Differential Equations in Applied Mathematics* (2025): 101220. 10.1016/j.padiff.2025.101220
- VII. Arthur, Ronan F., et al. "The lasting influence of Ebola: a qualitative study of community-level behaviors, trust, and perceptions three years after the 2014-16 Ebola epidemic in Liberia." *BMC Public Health* 23.1 (2023): 682. 10.1186/s12889-023-15559-1
- VIII. Bansal, Jatin, et al. "Investigation of monkeypox disease transmission with vaccination effects using fractional order mathematical model under Atangana-Baleanu Caputo derivative." *Modeling Earth Systems and Environment* 11.1 (2025): 40. 10.1007/s40808-024-02202-0
- IX. Bekela, Alemu Senbeta, and Alemayehu Tamir Deresse. "A hybrid yang transforms adomian decomposition method for solving time-fractional nonlinear partial differential equation." *BMC Research Notes* 17.1 (2024): 226. 10.1186/s13104-024-06877-7
- X. Breman, Joel G., et al. "The epidemiology of Ebola hemorrhagic fever in Zaire, 1976." *Ebola virus haemorrhagic fever* 103 (1978): 124.
- XI. Chen, Chao, Shibin Yao, and Jian Zhou. "Comparison of rock spalling evaluation in underground openings: Uncertainty-based mathematical model and empirical method." *Deep Resources Engineering* (2025): 100171. 10.1016/j.deepr.2025.100171
- XII. Dutta, Protyusha, Guruprasad Samanta, and Juan J. Nieto. "Nipah virus transmission dynamics: equilibrium states, sensitivity and uncertainty analysis." *Nonlinear Dynamics* 113.9 (2025): 10617-10657. 10.1007/s11071-024-10549-3
- XIII. Feldmann, Heinz, and Thomas W. Geisbert. "Ebola haemorrhagic fever." *The Lancet* 377.9768 (2011): 849-862. 10.1016/S0140-6736(10)60667-8
- XIV. Georges, Alain-Jean, et al. "Ebola hemorrhagic fever outbreaks in Gabon, 1994–1997: epidemiologic and health control issues." *The Journal of infectious diseases* 179.Supplement_1 (1999): S65-S75. 10.1086/514290

- XV. Gürbüz, Burcu, et al. "Dynamical behavior and bifurcation analysis for a theoretical model of dengue fever transmission with incubation period and delayed recovery." *Mathematics and Computers in Simulation* 234 (2025): 497-513. 10.1016/j.matcom.2025.03.008
- XVI. Henao-Restrepo, Ana Maria, et al. "Efficacy and effectiveness of an rVSV-vectored vaccine in preventing Ebola virus disease: final results from the Guinea ring vaccination, open-label, cluster-randomised trial (Ebola Ça Suffit!)." *The Lancet* 389.10068 (2017): 505-518. 10.1016/S0140-6736(16)32621-6
- XVII. Ibrahim, Kabiru Garba, et al. "Mathematical analysis of chickenpox population dynamics unveiling the impact of booster in enhancing recovery of infected individuals." *Modeling Earth Systems and Environment* 11.1 (2025): 46. 10.1007/s40808-024-02219-5
- XVIII. Islam, Md Rezaul, Forhad Mahmud, and M. Ali Akbar. "Insights into the Ebola epidemic model and vaccination strategies: An analytical approximate approach." *Partial Differential Equations in Applied Mathematics* 11 (2024): 100799. 10.1016/j.padiff.2024.100799
- XIX. Jaber, Mohamad Y., and Jaakko Peltokorpi. "Economic order/production quantity (EOQ/EPQ) models with product recovery: A review of mathematical modeling (1967–2022)." *Applied Mathematical Modelling* 129 (2024): 655-672. 10.1016/j.apm.2024.02.022
- XX. Jendrossek, Mario, et al. "Health care worker vaccination against Ebola: Vaccine acceptance and employment duration in Sierra Leone." *Vaccine* 37.8 (2019): 1101-1108. 10.1016/j.vaccine.2018.12.060
- XXI. Karim, Rezaul, et al. "A study on fractional-order mathematical and parameter analysis for CAR T-cell therapy for leukemia using homotopy perturbation method." *Partial Differential Equations in Applied Mathematics* 14 (2025): 101152. 10.1016/j.padiff.2025.101152
- XXII. Khatun, Mst Munny, Khaled A. Gepreel, and M. Ali Akbar. "Dynamics of solitons of the β -fractional doubly dispersive model: Stability and phase portrait analysis." *Indian Journal of Physics* (2025): 1-16. 10.1007/s12648-025-03602-3
- XXIII. Legrand, Judith, et al. "Understanding the dynamics of Ebola epidemics." *Epidemiology & Infection* 135.4 (2007): 610-621. 10.1017/S0950268806007217
- XXIV. Leroy, Eric M., et al. "Fruit bats as reservoirs of Ebola virus." *Nature* 438.7068 (2005): 575-576. 10.1038/438575a
- XXV. Li, Bing, et al. "Developing a multiomics data-based mathematical model to predict colorectal cancer recurrence and metastasis." *BMC Medical Informatics and Decision Making* 25. Suppl 2 (2025): 188. 10.1186/s12911-025-03012-9
- XXVI. Miah, Saikh Shahjahan, M. Ali Akbar, and Kamruzzaman Khan. "Solitary wave solutions and stability analysis of the fractional Sawada-Kotera equation using the extended modified auxiliary equation mapping method." *Journal of Umm Al-Qura University for Applied Sciences* (2025): 1-14. 10.1007/s43994-025-00230-9

Sharmin Sultana Shanta et al.

- XXVII. Mulangu, Sabue, et al. "A randomized, controlled trial of Ebola virus disease therapeutics." *New England journal of medicine* 381.24 (2019): 2293-2303. 10.1056/NEJMoa1910993
- XXVIII. Ren, Huarong, and Rui Xu. "Prevention and control of Ebola virus transmission: mathematical modelling and data fitting." *Journal of Mathematical Biology* 89.2 (2024): 25. 10.1007/s00285-024-02122-8
- XXIX. Rewar, Suresh, and Dashrath Mirdha. "Transmission of Ebola virus disease: an overview." *Annals of global health* 80.6 (2014): 444-451. 10.1016/j.aogh.2015.02.005
- XXX. Shivaranjini, S., & Srivastava, N. (2025). Semi-analytical approach for solving the mathematical model of solid-phase diffusion in electrodes: An application of modified differential transforms method. *Partial Differential Equations in Applied Mathematics*, 101107. 10.1016/j.padiff.2025.101107
- XXXI. Vokhobjonovich, Mullajonov Rustamjon. "Mathematical modeling of the system's motion, the stability of which is being studied." *International Journal of Social Science & Interdisciplinary Research* ISSN: 2277-3630 Impact factor: 8.036 14.01 (2025): 1-4.
<https://gejournal.net/index.php/IJSSIR/article/view/2544>
- XXXII. Ziyadullaevna, Rakhimova Umida. "Samuelson hicks's dynamic economic model." *Shokh library* (2025). <https://www.ijmrd.in/index.php/imjrd>