Figure 2. Over time, the dynamics of various population groups susceptible, exposed, infected, vaccinated, and recovered are represented through distinct curves. The blue line (Susceptible) decreases sharply at the beginning, indicating a rapid reduction in the number of individuals who are susceptible to infection. The yellow line (Exposed) shows the number of individuals who have been exposed to the infection and are in the incubation period. The red line (Infected) represents individuals who are actively infected and can transmit the disease to others; this peaks and then declines as the individuals either recover or die. The green line (Recovered) increases over time, indicating individuals who have recovered from the infection and have gained immunity. The cyan line (Vaccinated) shows the portion of the population that has been vaccinated over time. All data points for these curves are derived from the values presented in **Table 2**.

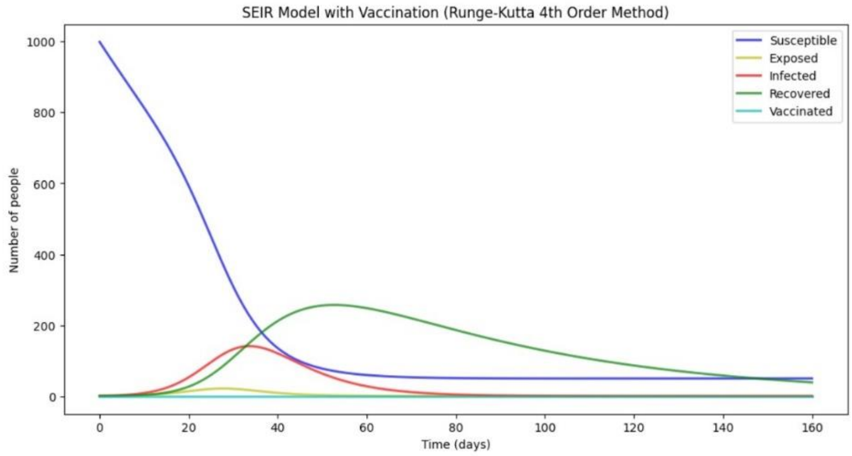


Figure 3. Population dynamics in Ghana, including susceptible, exposed, infected, vaccinated, and recovered states, as experienced across time. Various shades of hue denote distinct demographics: The colors blue, yellow, red, cyan, and green represent different stages of infection and recovery.

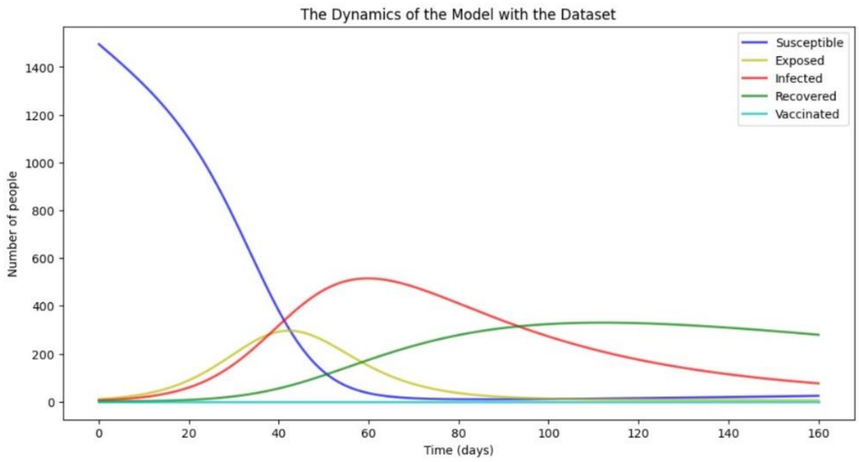


Figure 4. Epicurve of influenza cases in WHO AFR countries, areas, and territories by influenza type from the WHO African region (WHO AFR) provided virological data.

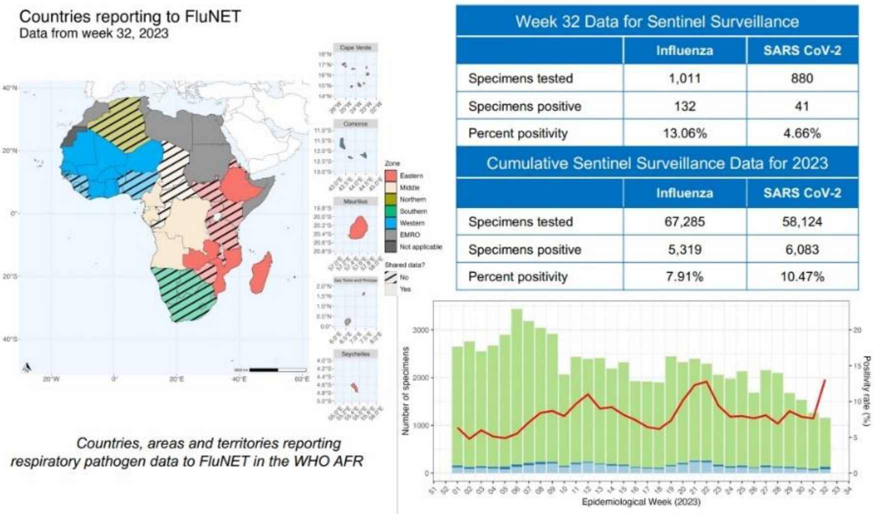


Figure 5. The dynamics of the infected population with and without increased vaccination, with purple indicating a large number of infected individuals becoming vaccinated and red indicating no vaccination.

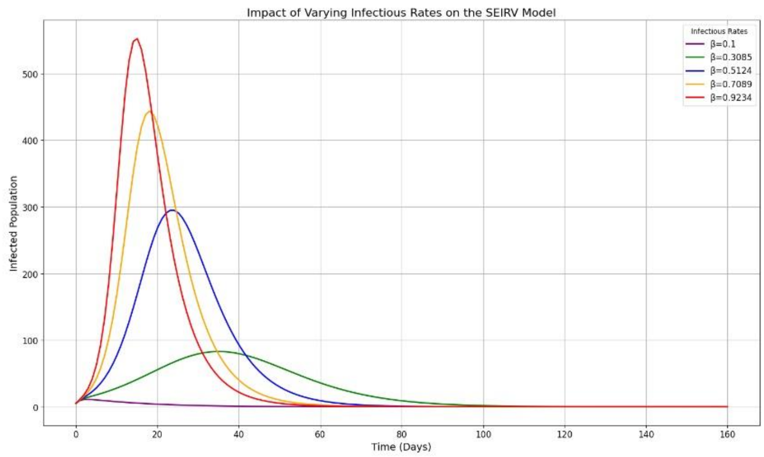


Figure 6. The dynamics of the vaccinated population demonstrate that greater rates lead to more rapid and extensive vaccination coverage in a population.

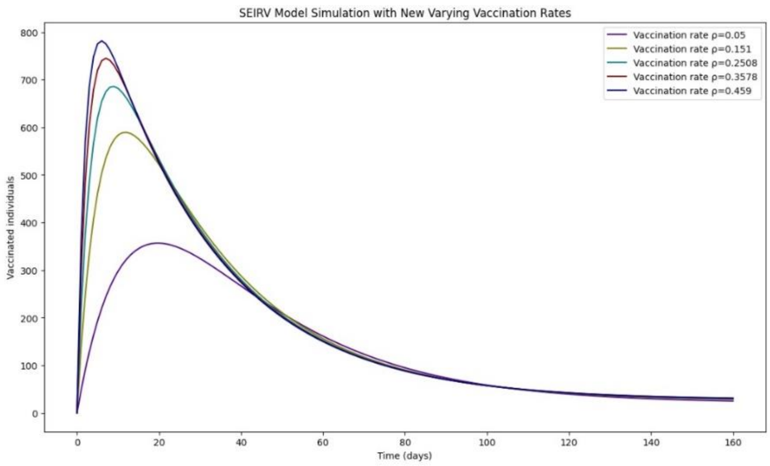
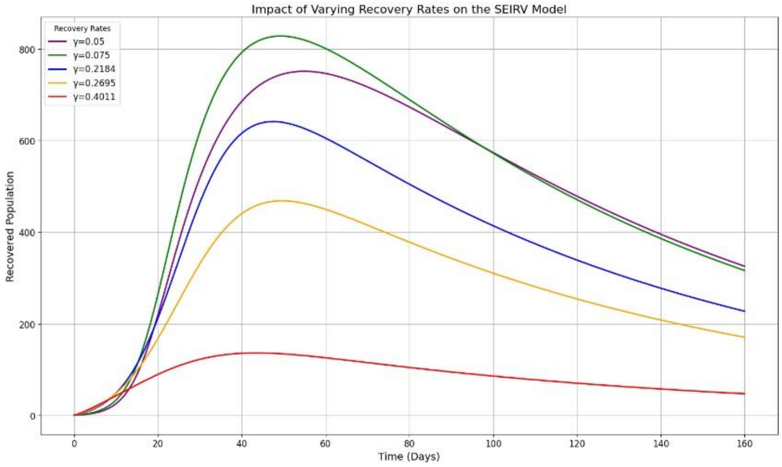


Figure 7. The rate of recovery of the diseased population according to γ dynamics. Potential effects on the seasonal flu situation as a result of a faster recovery rate in the non-vaccinated population are shown in this graphic.



Algorithm 1. Introduces the RK4 algorithm, which is used to solve differential equations of first order.

Algorithm 1: RK4 Algorithm

Data: Consider, IVP

$$\begin{cases} \frac{dy}{dt} = F(x,y), \forall x \in [a,b] \\ y(a) = y_0 \end{cases}$$

Time step:$t_i = t_0 + ih$, where h is the time step size

Result: Numerical solution, y

```
Initialize: s_0 = a
for i = 1 : I do
    The next time space t_{i+1}
    Compose y(t_{i+1})
    Compute
    if i = 1 then
        Compute K_1 = h * F(t_i, s_i),
        K_2 = h * F(t_i + n/2, s_i + K_1/2),
        K_3 = h * F(t_i + n/2, s_i + K_2/2),
        K_4 = h * F(t_i + n, s_i + K_3)
    Update
    s_{i+1} = s_i + 1/6 [K_1 + 2K_2 + 2K_3 + K_4]
Solution for y
```

Discussion

A highly successful method for predicting and controlling the condition of viral infections like seasonal influenza can be achieved by theoretical epidemic analysis, provided that the parameters can be approximated correctly. We modified the SEIR-V model to reflect an epidemic by including the hospitalized-vaccination compartment for patients who have been diagnosed with an infection. Due to data limitations, the model's parameters were selected at random, with the most recent influenza data used to establish the assumptions. Simultaneously, we determine the fundamental reproduction number to ensure the system is stable.

Table 2 was used to find that $\mathcal{R}_0 = 4.78 \times 10^{-6}$ which means that the system is stable. Present conditions in Ghana are likely to cause the seasonal inluenza virus, according to our findings ($\mathcal{R}_0 > 1$ in **Table 3**). It is possible that our calculations may not accurately represent the parameter and value of zero because this is a continuous process that is prone to fluctuations; this is one limitation of our work. In this infographic, we've highlighted how important vaccination patients and programs are for limiting the spread of the seasonal fluvirus in Ghana. The fact that the virus can incubate for a long time, leaving asymptomatic patients, and that it is still potent enough to spread even during this time makes it difficult to discover infected people. Therefore, the only way to make sure that no one gets sick is to put everyone on protection (i.e. Vaccination and quarantine).

Another thing we have noticed is that the rates of recovery for both vaccinated and non-vaccinated individuals help to reduce the infection. From what we can see, our epidemic paradigm was useful in predicting and controlling the seasonal flu outbreak in Ghana. Even limiting our analysis to Ghana, the resulting model and theoretical framework would be useful for any nation. It is our hope that this analysis will help the general population, policymakers, and the government better prepare for and respond to the spread of influenza.

Conflicts of interest

The authors declare that they have no financial or non-financial conflicts of interest related to the work done in the manuscript.

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References

1- World Health Organization (WHO). [Online] Available : https://www.who.int/news-room/fact-sheets/detail/influenza-(seasonal).

2- World Health Organization (WHO). Available: https://www.afro.who.int/countries/ghana.

3- Xiang Y, Jia Y, Chen L, Guo L, Shu B, Long E. COVID-19 epidemic prediction and the impact of public health interventions: A review of COVID-19 epidemic models. Infectious Disease Modelling 2021; 6:324-342.

4- Pan America Health Organization. Influenza, SARS-CoV-2, RSV and other respiratory viruses. (PAHO) [Online] available at: https://www.paho.org/en/topics/influenza-sars-cov-2-rsv.

5- European Centre for Disease Prevention and Control. Factsheet about seasonal influenza. (ECDC) available at: https://www.ecdc.europa.eu/en/seasonal-influenza/facts/factsheet.

6- National Advisory Committee on Immunization. Canadian immunization guide chapter on influenza and statement on seasonal influenza vaccine for 2016–2017. Ottawa (ON): Public Health Agency of Canada, 2016.

7- European Centre for Disease Prevention and Control. European External influenza virus quality assessment programme. ECDC 2020 data. Stockholm and Copenhagen: European Centre for Disease Prevention and Control and WHO Regional Office for Europe. ECDC and WHO 2022. Contract No.: WHO/EURO:2022-4757-44520-63020.

8- Waldock J, Zheng L, Remarque EJ, Civet A, Hu B, Jalloh SL, et al. Assay harmonization and use of biological standards to improve the reproducibility of the hemagglutination inhibition assay: a FLUCOP collaborative study. Msphere 2021; 6(4): e00567-21.

9- Chen Z, Bancej C, Lee L, Champredon D. Antigenic drift and epidemiological severity of seasonal influenza in Canada. Scientific Reports 2022; 12(1):15625.

10- Brown, Lorena E, and Anne Kelso. Prospects for an influenza vaccine that induces cross-protective cytotoxic T lymphocytes. Immunology and cell biology 2009; 87(4):300-308.

11- Raihen MN, Akter S, Tabassum F, Jahan F, Begum S. A Statistical Analysis of Excess Mortality Mean at Covid-19 in 2020-2021. Computational Journal of Mathematical and Statistical Sciences 2023; 2(2):223-239.

12- Raihen MN, Akter S, Tabassum F, Jahan F, Sardar M. A statistical analysis of positive excess mortality at Covid-19 in 2020-2021. Journal of Mathematics and Statistics Studies 2023; 4(3):07-17.

13- Adekola HA, Adekunle IA, Ekberongbe HO, Onitilo SA, Abdullahi IN. Mathematical modeling for infectious viral disease: The COVID-19 perspective. Journal of public affairs 2020; 20(4): e2306.

14- Adekunle IA, Onanuga AT, Akinola OO, Ogunbanjo OW. Modelling spatial variations of coronavirus disease (COVID-19) in Africa. Science of the Total Environment 2020; 729:138998.

15- Brauer F. Mathematical epidemiology: Past, present, and future. Infectious Disease Modelling 2027; 2(2):113-127.

16- Charlton CL, Babady E, Ginocchio CC, Hatchette TF, Jerris RC, Li Y, et al. Practical guidance for clinical microbiology laboratories: viruses causing acute respiratory tract infections. Clinical microbiology reviews 2018; 32(1):10-1128.

17- Greenberg SB, Krilov LR, Drew WL, Rubin SJ. Cumitech 21, Laboratory diagnosis of viral respiratory disease. Coordinating ed., WL Drew and SJ Rubin. American Society of Microbiology, Washington, DC 1986; 2.

18- Gessner BD, Shindo N, Briand S. Seasonal influenza epidemiology in sub-Saharan Africa: a systematic review. The Lancet infectious diseases 2011; 11(3):223-235.

19-Mahama PN, Kabo_Bah AT, Blanford JI, Yamba EI, Antwi-Agyei P. Reviewing the Past, Present, and Future Risks of Pathogens in Ghana and What This Means for Rethinking Infectious Disease Surveillance for Sub-Saharan Africa. Journal of Tropical Medicine 2022, 2022.

20- World Health Organization (WHO) [Online] available at: FluNet Summary, https://www.who.int/tools/flunet/flunet-summary.

21- Asante IA, Fox AT, Behene E, Awuku_larbi Y, Kotey EN, Nyarko S et al. Epidemiology of influenza in Ghana, 2011 to 2019. PLOS Global Public Health 2022; 2(12): e0001104.

22- Petrova VN, Colin AR. The evolution of seasonal influenza viruses. Nature Reviews Microbiology 2018; 16(1):47-60.

23- Casagrandi, R, Bolzoni L, Levin SA, Andreasen V. The SIRC model and influenza A. Mathematical biosciences 2006; 200(2):152-169.

24- Nigmatulina, KR. Modeling and responding to pandemic influenza: Importance of population distributional attributes and non-pharmaceutical interventions. Diss. Massachusetts Institute of Technology 2009.

25- Murray and James Dickson. An introduction. Heidelberg: Springer 2002.

26- Martcheva M. An introduction to mathematical epidemiology. Vol. 61. New York: Springer 2015.

27- Nishiura H. Correcting the actual reproduction number: a simple method to estimate R 0 from early epidemic growth data. International journal of environmental research and public health 2010; 7(1):291-302.

28- Affi, P. Sensitivity Analysis of the SEIR Epidemic Compartmental Model.

International Journal of Science and Research 2018:352-357.

29- Diekmann O, Heesterbeek JAP, and Roberts MG. The construction of next-generation matrices for compartmental epidemic models. Journal of the royal society interface 2010; 7(47):873-885.

30- Worldometers. [Online]. Available at: https://www.worldometers.info/coronavirus/.

31- World population review. [Online]. Available at: https://worldpopulationreview.com/.

32- Olaniyi S, Lawal MA, and Obabiyi OS. Stability and sensitivity analysis of a deterministic epidemiological model with pseudo-recovery. IAENG International Journal of Applied Mathematics 2016; 46(2):160-167.

33- Wikipedia. [Online]. Available at: https://en.wikipedia.org/wiki/Demographics_of_Ghana.

34- Ghana Statistical Service (GSS). [online] Available at: https://census2021.statsghana.gov.gh/.

Raihen MN, Ahammed MM, Akter S. Evaluating the impact of seasonal influenza virus: A comprehensive epidemiological forecast and analysis in Ghana from 2021 to 2023. Microbes Infect Dis 2024; 5(2): 463-478.