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APPLICATION OF DETERMINISTIC MODEL FOR HYPERTENSION CASES

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ABSTRACT

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World Health Organization (WHO) latest reports about hypertension as a global health problem, due to a spike in cases. One of the roles of mathematics in health is to provide information about the increase in hypertension sufferers. Using a deterministic model is supposed to provide information that can explain how the cases increase. The deterministic model used is divided into two equations. The first equation uses k as a constant. Second, is p for p < 1 and p > 1. The results from both equations are in the form of a logistic curve and show simulation results are similar to condition data for hypertension sufferers. In addition, the extended deterministic model with p <1 indicates that hypertension sufferers increase exponentially, thus an intervention step is needed.

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1. INTRODUCTION

The current hypertension has become a global problem [1]. Based on the World Health Organization (WHO) reports, which shows an increase in hypertension cases in various countries. One of them is that Indonesia has increased cases, since 2000 there have been 30% of sufferers, and increase to 40% in 2020. Furthermore, the grouping is divided into 45% women and 36% men with an age range of 30-79 years [2]. In the same report by the Ministry of Health Indonesian (KEMENKES), hypertension sufferers in 2013 were 25.8% and increased to 34.1% in 2018 [3]. Generally, hypertension reports released by the WHO and the Ministry of Health Indonesian, are based on data analysis by applying statistic method. Used penalized spline method produces a model accuracy of 96% [4]. Another study reported the application of a logistic regression model to analyze factors causing hypertension. The result shows model accuracy of 85.2% for logistic, and 81.5% for Gompertz model [5].

The previously mentioned methods are also deterministic methods, according to [6][7][8][9], if the initial conditions of a phenomenon are known, the final conditions can be known. Use of deterministic methods for hypertension cases, by applying differential equations. Simply stated $x(t)$ and $y(t)$ are an individual with certain symptoms (infected) for a period (t). So it is written as $x(t) + y(t) = N$, where $x(t)$ is rate of change in the number of individuals with symptoms [10][11][12]. Referring to the previous description, the differential equation informs the rate of change in disease over time. The differential form is expressed with the notation dx/dt, which means the rate of change in function x from time to time t. That matter explains the patient's rate can be measured by increasing changes in dt time. Supposing dx/dt be the instantaneous rate of change of susceptible individuals (t), and N be the size of the population, and β be the rate of transmission. That equation certainly makes the relationship clear, as the rate of infection depends on the number of susceptible individuals, and infected individuals at a certain time, and β is constant. As for β is the product of the average number of contacts per individual per unit of time, and the probability of transmission between susceptible and infected individuals. However, the β parameter can be calibrated to the disease case being observed [13].

Data on the increasing number of hypertension sufferers shown by WHO and the Ministry of Health, when viewed from a mathematical perspective, can provide assistance and play an important role in deciding how resources can be allocated. That can be seen from the explanation of the deterministic model by previous researchers, the equation provides an understanding of reducing the spread or increase of a disease. Through interventions to reduce the rate of β disease, as evidenced by reports [14][15] regarding interventions for a disease such as maintaining distance or wearing masks. Besides, considering the rate of decline in the number of individuals suffering from the disease and related to recovery. Then intervention in the form of treatment to reduce the number of sufferers of the disease can help [16]. Based on previous reviews, the application of deterministic methods to hypertension cases is very important to study. Because it can provide information in the form of predictions of hypertension development. The information produced is a basis for policy making or matters related to recommendations for hypertension mitigation control measures.

2. RESEARCH METHODS

Hypertension data used in this study is sourced from the Public Health Office (DINKES) North Halmahera. Data on hypertension was chosen because it is included in the top ten diseases from 2016 to 2023. The flow of mathematical model selection in this study is shown in Figure 1, and the review is as follows. Initially by making a plot of the distribution of hypertension disease data to see the data pattern and choose a model based on the pattern. The chosen model is deterministic because the data shows an increase in hypertension sufferers. This model is divided into two, the first is a simple model with the constant k, and the second is p as a constant. Comparing errors aims to see the level of error of the two models, and the final stage is the interpretation of the two models.

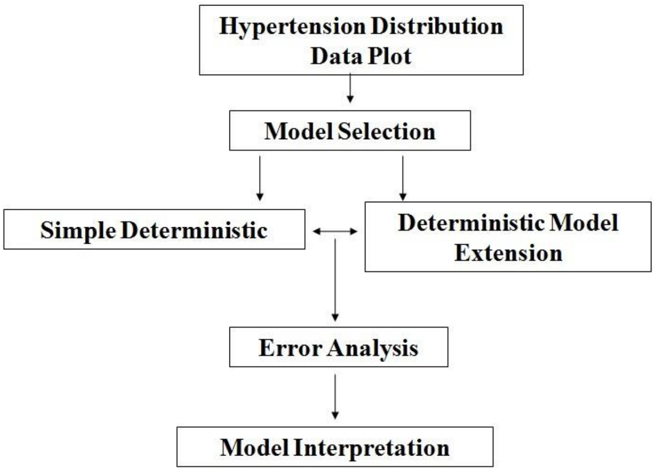

Figure 1. Research Flow

Based on the simple description of the deterministic model in the introduction, then according to [17] and [18] for differential form is:

$$\frac{dx}{dt} = \beta xy \tag{1}$$

Equation (1), β is constant (proportionality), $y = N - x$, then the equation (1) $dx/dt = kxy\, f(x)$ with $f(x) = N - x$; $f(x) = x - N; f(x) = 1 - x/N$ to $\frac{dx}{dt} = kx\left(1 - \frac{x}{N}\right)$. Then change it into integral form $\int \frac{1}{x\left(1-\frac{x}{N}\right)} dx = \int k\, dt$ become $\int \frac{N\, dx}{N\, x - x^2} = \int k\, dt$. Then apply partial solving $\frac{N}{x(N-x)} = \frac{A}{x} + \frac{B}{N-x}$ then $\frac{N}{x(N-x)} = \frac{A(N-x)+B(x)}{x(N-x)}$ into $N = A(N - x)Bx$ (for $x = 0 \to N = A(N - 0) + B0 \to N = NA \to A = 1$ and $x = N \to N = A(N - N) + NB \to N = NB \to B = 1$) so that $\frac{N}{x(N-x)} = \frac{1}{x} + \frac{1}{N-x}$ and $k = \beta N$, by applying variable separation technique in the solution [19][20], produce $\int \left(\frac{1}{x} + \frac{1}{N-x}\right) dt = \int k\, dt$. The integral result is $ln\, x - ln\, (N - x) = kt + c$, then changed with the properties of logarithms $ln\left|\frac{x}{N-x}\right| = kt + c$, then exponentially $\frac{x}{N-x} = e^{kt+c}$. Referring to the exponentiation properties of the previous equation it becomes $\frac{x}{N-x} = e^c e^{kt}$, form an equation $x = (N - x)Ce^{kt}$ due to the traffic transfer rules. Then referring to the distributive property $x\left(1 + Ce^{kt}\right) = N\, Ce^{kt}$ to form $x(t) = \frac{NCe^{kt}}{1+Ce^{kt}}$, because $t = 0$ and $x(0) = x_0$ as a preliminary condition, then $x_0 = \frac{NC}{1+C}$ and produce $C = \frac{x_0}{(N-x_0)}$. Substitute the value of C into the result of the distributive property and you will obtain a particular solution $x \frac{N\left(\frac{x_0}{N-x_0}\right)e^{kt}}{1+\left(\frac{x_0}{N-x_0}\right)e^{kt}}$. As for the simple form of the special solution, $x = \frac{N\, x_0 e^{kt}}{x_0 e^{kt}+N-x_0}$ then multiply $\frac{e^{-kt}}{e^{-kt}}$ become $x = \frac{N\, x_0 e^{kt} e^{-kt}}{(x_0 e^{kt}+N-x_0)e^{-kt}}$ rephrase $\mathrm{d}x = \frac{N\, x_0 e^{kt+(-kt)}}{(x_0 e^{kt}+N-x_0)e^{-kt}}$ or $x = \frac{N\, x_0 e^{0}}{(x_0 e^{kt}+N-x_0)e^{-kt}}$. Remembering the rules of exponents 0, that is, every number is not 0 raised to the power of 0 is 1. If $e^0 = 1$, then the previous equation becomes $x = \frac{N\, x_0}{(x_0 e^{kt}+N-x_0)e^{-kt}}$ if $\left(x_0 + (N - x_0)\right)e^{-kt}$ and applying the distributive addition property yields $x = \frac{N\, x_0}{(x_0 e^{kt} e^{-kt}+N\, e^{-kt}-x_0 e^{-kt})}$ and explained further $x = \frac{N\, x_0}{(x_0 e^{kt+(-kt)}+N\, e^{-kt}-x_0 e^{-kt})}$ in the end is $x = \frac{N\, x_0}{(x_0 e^{0}+N\, e^{-kt}-x_0 e^{-kt})}$. Referring to the previous review of exponential rules, then forms an equation $x = \frac{N\, x_0}{(x_0+N\, e^{-kt}-x_0 e^{-kt})}$ then divided $\frac{x_0}{x_0}$ produce shape $x = \frac{N}{\left(\frac{x_0}{x_0}+\frac{N\, e^{-kt}}{x_0}-\frac{x_0 e^{-kt}}{x_0}\right)}$ The following stage is to describe it again into $x = \frac{N}{1+\frac{N}{x_0}e^{-kt}-e^{-kt}}$ and ultimately produces the following equation form 2.

$$x = \frac{N}{1 + (N/x_0 - 1)e^{-kt}} \tag{2}$$

The output Equation (2) is a logistic curve, with $\boldsymbol{k}$ as a constant parameter. If $\boldsymbol{x}(\mathbf{0}) = \boldsymbol{x}_{\mathbf{0}}$ (Equation (2)), causes $\boldsymbol{dx/dt}$ to always change with $\boldsymbol{t}$, then output an epidemiology model. The basic assumption is that changes in hypertension sufferers occur over a certain time interval $(\boldsymbol{dx/dt/x})$, until $\frac{dx}{dt} = kx\left(1 - \frac{x}{N}\right)$ undergoes a change in the form of expansion [17] into:

$$\frac{dx}{dt} = kx\left(1 - \left(\frac{x}{N}\right)^{p}\right) \tag{3}$$

The parameter $\boldsymbol{p}$ can be varied and is a positive constant, and shows an exponential curve $\boldsymbol{dx/dt}$ which changes with $\boldsymbol{t}$. Based on the previous description, if $\boldsymbol{p = 1}$ then Equation (3) is the same as Equation (2) and produces a logistic form. Where $\boldsymbol{u} = (\boldsymbol{x/N})^{\boldsymbol{p}}$, so Equation (3) becomes:

$$\int \frac{1}{u(1-u)}\, du = \int pk\, dt \tag{4}$$

Then the solution to Equation (4), solved by applying variable separation as described in Equation (1), produces:

$$x = \frac{N}{(1 + Ae^{-pkt})^{1/p}} \tag{5}$$

By applying the initial condition $\boldsymbol{x}(\mathbf{0}) = \boldsymbol{x}_{\mathbf{0}}$ to Equation (5), and $\boldsymbol{A}$ is a constant the final form of the equation is:

$$x = \frac{N}{(1 + ((N - x_0)^p - 1)e^{-kt})^{1/p}} \tag{6}$$

Equation (6) is the model used to analyze hypertension data, besides that it is continued with error analysis from the model referring to [21].

$$E = \frac{\sqrt{\sum_{i=1}^{n}(\hat{x}_i - x_i)^2}}{N} \tag{7}$$

In Equation (7), where the variable $\hat{x}_i$ is the hypertension data, while x_i is the value produced by Equation (2) and Equation (6), then N is the number of data.

3. RESULTS AND DISCUSSION

The hypertension data for North Halmahera regency is summarized in Table 1, and the data shows an increase even though there was a decrease in cases in 2017 and 2023.

Table 1. Hypertension Data

Years	Month												Total Case Number
	1	2	3	4	5	6	7	8	9	10	11	12	
2016	493	515	530	561	615	626	673	683	698	732	757	798	**7681**
2017	150	525	579	520	508	625	570	499	645	546	354	211	**5732**
2018	458	510	542	571	596	600	617	642	687	701	721	758	**7403**
2019	458	515	732	755	787	821	830	864	883	900	930	947	**9422**
2020	17	197	668	254	202	344	313	205	514	350	416	220	**3700**
2021	431	475	496	533	562	587	591	621	635	678	691	700	**7000**

Years	Month												Total Case Number
	1	2	3	4	5	6	7	8	9	10	11	12	
2022	540	600	675	717	739	786	789	810	816	845	910	935	**9162**
2023	556	757	874	997	1000	1034	1058	1098	1121	1134	1176	1198	**12003**

***Source**: Public Health Office (DINKES) North Halmahera.*

Before applying **Equation (6)** for analysis data Table 1, initially by finding k from the results of the integral equation discussed in the introduction. As of $k = ln(N - x) - ln\, x$ then $k = 1.945$. Whereas the parameter p is a positive constant, in the form of $p > 1$ and $p < 1$ **[17]**. The application of **Equation (2)** to analyze the data in **Table 1**, shows the logistic model as follows:

$$x = \frac{62103}{1 + (62103/x_0 - 1)e^{-1.945t}} \tag{8}$$

The output of model **Equation (8)** with $E = 0.244$ the same as the study results **[17]**, and interpreting it from the start has shown improvement until it reaches the balance point. The research report **[22]** informs the study of mathematical models of hypertension cases with mechanical and biochemical factors. The result is a strong interaction between two factors, proven through data analysis by the phenomenon of endothelial dysfunction and the graphic output is the same as **Figure 2**. The studies **[23]** prove the results of the mathematical model, the study of arterial walls in the form of a logistic curve by experimental data for the same case. Previously **[24]** stated that the results of mathematical models for the study of arterial structure related to hypertension provide accurate information about this disease.

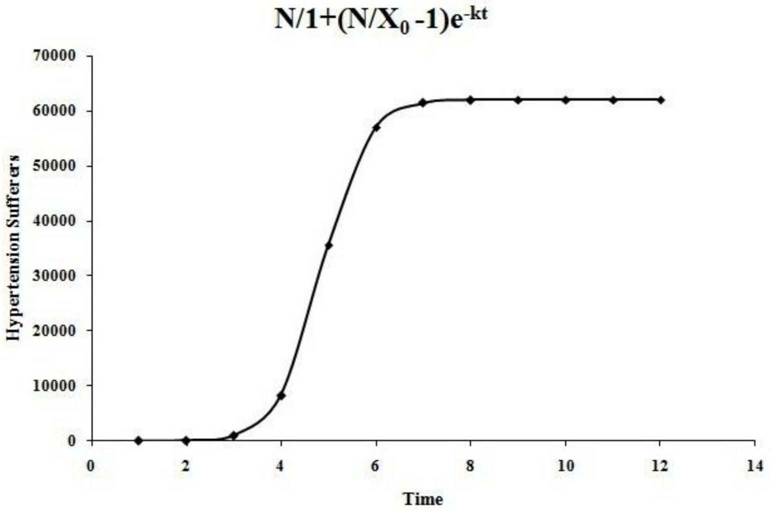

Figure 2. The Curve of Equation (8)

The mathematical model solution produced by **Equation (6)** for the case of hypertension is written into **Equation (9)** as follows:

$$x = \frac{62103}{(1 + ((62103 - x_0)^{0.5} - 1)e^{-1.945.t})^{1/0.5}} \tag{9}$$

Referring to **Equation (9)** with $p = 0.5$ meaning that initially hypertension sufferers slowed down, then experienced an exponential increase and $E = 0.073$ (**Figure 3**).

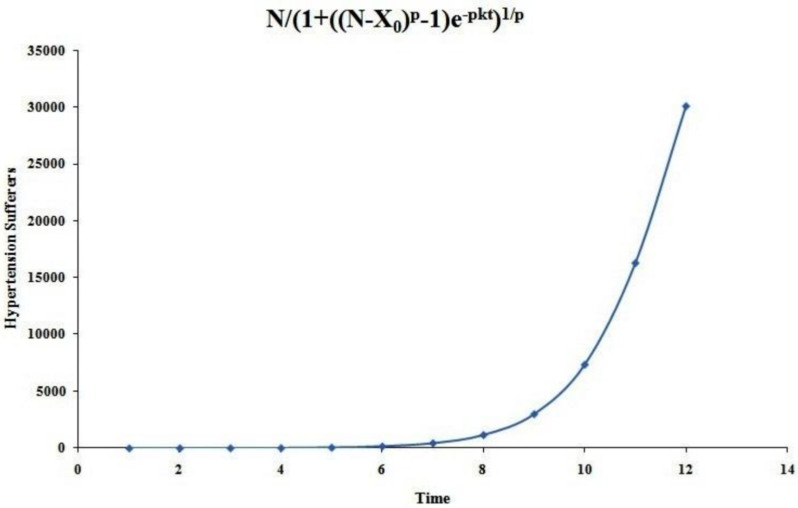

Figure 3. Output of Equation (9) with $p = 0.5$, and Shows an Increase in Hypertension Sufferers

The results of this study are in line with the report [17], according to him, from the beginning the spread of the disease slowed down and then it would increase exponentially quickly ($p < 1$). Previous research [25] reports if it is constant $\xi_0 < 1$, then there will be a spike in disease cases as in Figure 3, due to lack of prevention. Contrariwise $\xi_0 > 1$ the spread of disease will reach its highest value, and has the same meaning as fission with $p > 1$ in this research (Figure 4).

The same model as Equation (9) but with $p = 1$, which is shown by the Equation (10) and $E = 0.107$ as well as in graphic form Figure 4.

$$x = \frac{62103}{(1 + ((62103 - x_0)^1 - 1)e^{-1.945.t})^{1/1}} \tag{10}$$

The curve generated by Equation (10) similar with equation output (8). The crucial of constant value k and p in this research, according [26] provide an understanding of the level of disease spread including the increase and decrease in sufferers.

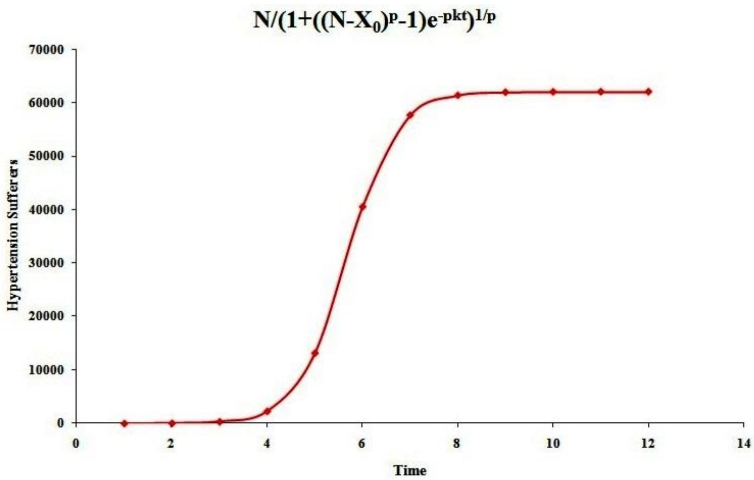

Figure 4. Output of Equation (10) with $p = 1$, and Shows an Increase in Hypertension Sufferers until Reaching the Stationary Point

These results emphasize the importance of studying deterministic models for disease cases stated in the report [27]. In their report, deterministic model results provide information about the pattern of disease distribution. Other researchers [28][29] have shown that the resulting patterns are intended as material for evaluation and long-term disease control strategies. As one of the strategies that has been studied by [30], that is $R_c > 1$ increasing treatment leads to a decrease in disease sufferers, while $R_c < 1$ is the opposite.

For a deeper understanding of the description of the deterministic model, examine the rate change of x in detail. Where equation $\frac{dx}{dt} = kx\left(1 - \frac{x}{N}\right)$ can state that dx/dt varied in terms of the quadratic shape of x.

For N stated as the total number of hypertension sufferers at time t, so that $N(t)$ is a non-negative integer with the results (**Figure 2**, **Figure 3**, and **Figure 4**) of the graph function t, then it makes sense to consider $N(t)$as a continuous function of t. From the known solution **Equation (8)**, if k is positive, then the number of hypertension sufferers will increase exponentially. Meanwhile k is negative, there will be a decrease in sufferers, and if $k = 0$ it remains constant. If $N(t) < 1$ then there are no hypertension sufferer, so k is very important for the behavior of individuals suffering from hypertension. The same thing also put into the parameter p (**Equation (9)** and **Equation (10)**, both for $p < 1$ and $p > 1$ as well as $p = 0$. To determine the parameter k from a population of sufferer certain disease when $t \neq 0$ must be known. Then search k, and $N(t)$ known at each time interval t, then the result is as in **Figure 2**, **Figure 3**, and **Figure 4**. In other words, the calculation of hypertension sufferers at a certain time t, or the time required for the sufferer to reach the specified equilibrium.

4. CONCLUSIONS

In this research, we had information about the deterministic model, with solution analysis of non-linear first-order differential equations and represented by a logistic curve. The simulation results of **Equation (2)** and **Equation (6)**, with each constant k and p. The results of the two equations show similarities, in that they indicate an increase in hypertension cases over ninety-six months. Furthermore, the results obtained are based on model analysis, namely the error value, so **Equation (6)** was chosen because it shows the smallest error value. Besides that, information on the pattern of hypertension is in the form of a logistic curve, so preventive measures are needed to reduce this disease. In addition, the $p > 1$ value confirms that the simulation results show an increase in cases of hypertension sufferers or that the epidemic conditions are met. In this situation, the epidemic will decrease if there is an intervention in the form of drug administration or other prevention.

REFERENCES

[1] P. Nugroho, H. Andrew, K. Kohar, C. A. Noor, and A. L. Sutranto, “Comparison between the world health organization (WHO) and international society of hypertension (ISH) guidelines for hypertension,” *Ann. Med.*, vol. 54, no. 1, pp. 837–845, Dec. 2022, doi: 10.1080/07853890.2022.2044510.

[2] World Health Organization (WHO), *Global Report on Hypertension: The Race Against a Silent Killer*. Genewa: World Health Organization, 2023.

[3] K. K. R. I. (Kemenskes), *Hasil Utama RISKESDAS*. Indonesia, 2018.

[4] T. Adiwati and N. Chamidah, “Modelling of hypertension risk factors using penalized spline to prevent hypertension in Indonesia,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 546, no. 5, p. 052003, Jun. 2019, doi: 10.1088/1757-899X/546/5/052003.

[5] P. Andriani and N. Chamidah, “Modelling of Hypertension Risk Factors Using Logistic Regression to Prevent Hypertension in Indonesia,” *J. Phys. Conf. Ser.*, vol. 1306, no. 1, p. 012027, Aug. 2019, doi: 10.1088/1742-6596/1306/1/012027.

[6] M. N. Dalengkade, M. Yusniar, W. Tjape, F. I. Boleu, and O. Buka, “Penerapan polinomial orde-n dan Malthusian pada studi kasus kajian daya tampung wisatawan,” *JST Jurnal Sains dan Teknol.*, vol. 10, no. 2, pp. 220–229, Nov. 2021, doi: 10.23887/jstundiksha.v10i2.38969.

[7] M. Kaseside, F. Imanuel Boleu, R. Simanjuntak, B. Raymond Toisuta, and M. Nikolaus Dalengkade, “Penerapan model Malthusian, studi kasus: ambang batas destinasi wisata talaga biru,” *JUSTE Journal Sci. Technol.*, vol. 2, no. 1, pp. 52–58, Oct. 2021, doi: 10.51135/justevol2issue1page52-58.

[8] M. N. Dalengkade *et al.*, “Visit profiles and tourism destination thresholds using polynomial and Malthusian,” *BAREKENG J. Ilmu Mat. dan Terap.*, vol. 16, no. 1, pp. 113–120, Mar. 2022, doi: 10.30598/barekengvol16iss1pp113-120.

[9] T. Waezizadeh, A. Mehrpooya, M. Rezaeizadeh, and S. Yarahmadian, “Mathematical models for the effects of hypertension and stress on kidney and their uncertainty,” *Math. Biosci.*, vol. 305, pp. 77–95, Nov. 2018, doi: 10.1016/j.mbs.2018.08.013.

[10] W. O. Kermack and A. G. McKendrick, “A contribution to the mathematical theory of epidemics,” *Proc. R. Soc. London. Ser. A, Contain. Pap. a Math. Phys. Character*, vol. 115, no. 772, pp. 700–721, Aug. 1927, doi: 10.1098/rspa.1927.0118.

[11] N. T. J. Bailey, *The mathematical theory of Infectious Diseases and its Applications*, Second Edi. London: Charles Griffin & Company LTD, 1975.

[12] R. Detels, R. Beaglehole, M. A. Lansang, and M. Gulliford, *Oxford Textbook of Public Health*, no. May. Oxford University Press, 2009. doi: 10.1093/med/9780199218707.001.0001.

[13] M. J. Keeling and P. Rohani, *Modeling Infectioous Diseases: In Human and Animals*. United Kingdom: Princeton University Press, 2008.

[14] T. C. Reluga, “Game theory of social distancing in response to an epidemic,” *PLoS Comput. Biol.*, vol. 6, no. 5, p. e1000793, May 2010, doi: 10.1371/journal.pcbi.1000793.

[15] S. E. Eikenberry *et al.*, “To mask or not to mask: Modeling the potential for face mask use by the general public to curtail the COVID-19 pandemic,” *Infect. Dis. Model.*, vol. 5, pp. 293–308, 2020, doi: 10.1016/j.idm.2020.04.001.

[16] S. Towers, K. Vogt Geisse, Y. Zheng, and Z. Feng, “Antiviral treatment for pandemic influenza: Assessing potential repercussions using a seasonally forced SIR model,” *J. Theor. Biol.*, vol. 289, no. 1, pp. 259–268, Nov. 2011, doi: 10.1016/j.jtbi.2011.08.011.

[17] K. C. Ang, “A simple model for a SARS epidemic,” *Teach. Math. its Appl.*, vol. 23, no. 4, pp. 181–188, Dec. 2004, doi: 10.1093/teamat/23.4.181.

[18] N. C. Grassly and C. Fraser, “Mathematical models of infectious disease transmission,” *Nat. Rev. Microbiol.*, vol. 6, no. 6, pp. 477–487, Jun. 2008, doi: 10.1038/nrmicro1845.

[19] T. P. Dreyer, *Modelling with Ordinary Differential Equations*. Boca Raton: CRC Press, 1993.

[20] F. R. Giordano, W. P. Fox, and S. B. Horton, *A First Course in Mathematical Modeling*, Fifth Edit. USA: Richard Stratton, 2014.

[21] D. A. Lawson, “Stopping distances: an excellent example of empirical modelling,” *Teach. Math. its Appl.*, vol. 20, no. 2, pp. 66–74, Jun. 2001, doi: 10.1093/teamat/20.2.66.

[22] Z. Wilstein, D. M. Alligood, V. L. McLure, and A. C. Miller, “Mathematical model of hypertension-induced arterial remodeling: A chemo-mechanical approach,” *Math. Biosci.*, vol. 303, no. May, pp. 10–25, Sep. 2018, doi: 10.1016/j.mbs.2018.05.002.

[23] A. Tsamis and N. Stergiopulos, “Arterial remodeling in response to hypertension using a constituent-based model,” *Am. J. Physiol. Circ. Physiol.*, vol. 293, no. 5, pp. H3130–H3139, Nov. 2007, doi: 10.1152/ajpheart.00684.2007.

[24] A. Tsamis, N. Stergiopulos, and A. Rachev, “A structure-based model of arterial remodeling in response to sustained hypertension,” *J. Biomech. Eng.*, vol. 131, no. 10, pp. 1–8, Oct. 2009, doi: 10.1115/1.3192142.

[25] C. Castillo-Chavez, S. Fridman, and X. Luo, “Stochastic and deterministic models in epidemiology,” in *World Congress of Nonlinear Analysts ’92*, DE GRUYTER, 1996, pp. 3211–3226. doi: 10.1515/9783110883237.3211.

[26] D. Olabode, J. Culp, A. Fisher, A. Tower, D. Hull-Nye, and X. Wang, “Deterministic and stochastic models for the epidemic dynamics of COVID-19 in Wuhan, China,” *Math. Biosci. Eng.*, vol. 18, no. 1, pp. 950–967, 2021, doi: 10.3934/mbe.2021050.

[27] E. Pelinovsky, A. Kurkin, O. Kurkina, M. Kokoulina, and A. Epifanova, “Logistic equation and COVID-19,” *Chaos, Solitons & Fractals*, vol. 140, p. 110241, Nov. 2020, doi: 10.1016/j.chaos.2020.110241.

[28] E. Aviv-Sharon and A. Aharoni, “Generalized logistic growth modeling of the COVID-19 pandemic in Asia,” *Infect. Dis. Model.*, vol. 5, pp. 502–509, 2020, doi: 10.1016/j.idm.2020.07.003.

[29] N. Balak *et al.*, “A simple mathematical tool to forecast COVID-19 cumulative case numbers,” *Clin. Epidemiol. Glob. Heal.*, vol. 12, no. January, p. 100853, Oct. 2021, doi: 10.1016/j.cegh.2021.100853.

[30] G. K. Mutua, C. G. Ngari, G. G. Muthuri, and D. M. Kitavi, “Mathematical modeling and simulating of Helicobacter pylori treatment and transmission implications on stomach cancer dynamics,” *Commun. Math. Biol. Neurosci.*, vol. 2022, no. August, 2022, doi: 10.28919/cmbn/7542.