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# A mathematical model investigating the impact of campaign program on the pattern of transmission of anemia in pregnant women

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## Abstract

Anemia, a pervasive global health issue, is on the rise across the globe, impacting both developing and wealthy nations. Anemia, a hematological condition, can manifest at any point in life and is prevalent among pregnant individuals. The worldwide incidence of anemia among women of reproductive age is around 29.4%, with over 40% of pregnant women being affected. Anemia is a widespread issue that significantly contributes to illness and death, particularly in regions where malaria is prevalent. Anemia during pregnancy has a substantial effect on both the health of the fetus and the mother. Anemia has been identified as the cause of 20% of maternal fatalities in Africa. Iron deficiency is the primary cause of anemia. This research presents a comprehensive model that describes the dynamics of anemia in pregnant women and their fetus. The population is categorized into three classes: susceptible, impacted, and treated. A control factor that varies or changes over time, namely a campaign program, is being investigated. The model exhibits an equilibrium point and the stability of such points is assessed. Furthermore, the sensitivity analysis of the equilibrium point is conducted to identify the crucial parameters. Numerical simulations are conducted to observe the dynamic behavior of the model. Evidence demonstrates that the marketing program is successful in reducing the advancement of diseases. The implementation of an early accelerated campaign program greatly reduces the number of pregnant patients, as well as the yearly miscarriages and fatalities. However, discontinuing the applied treatment may reverse this positive outcome and increase the burden. Findings also suggest that the implementation of control measures helps to minimize the prevalence of anemia but may not eliminate the condition.

***Keywords:*** Anemia; Campaign program; Pregnant women; SAT Model; Foetus

## 1. Introduction

Anaemia is a medical condition characterized by a deficiency of red blood cells or hemoglobin, leading to a reduced capacity of the blood to carry oxygen [1]. This global health concern impedes the body's ability to transport oxygen to tissues, posing significant risks to both maternal and fetal health during pregnancy [2, 3]. Modelling and simulation serve as invaluable tools for evaluating the operational implications of integrating point-of-care testing for HIV, syphilis, malaria, and anaemia in antenatal care dispensaries in western Kenya. By employing discrete-event simulation modelling [4, 5, 6]. It is crucial to recognize that anaemia is not merely a local issue but a common global health challenge affecting populations across various socioeconomic backgrounds. The prevalence of anaemia among pregnant women is influenced by multifaceted factors, including socio-economic status, nutritional deficiencies, and inadequate reproductive health education. This study aims to alleviate the long-term effects of anaemia and contribute to improved maternal and neonatal health outcomes. Campaign programs emerge as pivotal strategies to combat the widespread impact of anaemia during pregnancy. However, anaemia in pregnant women is a complex global health issue with far-reaching consequences for maternal and fetal well-being [7, 8, 9]. This study employs modelling and simulation to explore the potential impact of campaign programs on anaemia prevalence, providing a comprehensive understanding of the dynamics involved.

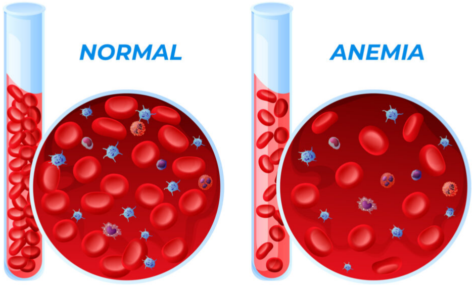

**Figure 1:** Anemia in pregnant women [10].

A noteworthy concern highlighted by[10] is the substantial burden of anaemia on maternal health, posing risks to both mothers and developing fetuses (Fig. 1). The associated adverse outcomes, including preterm birth and low birth weight, underscore the urgency for effective prevention and control measures. The study un-

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*Corresponding author. Email: kidowu@purdue.edu derscores the importance of developing practical tactics to reduce the risk of anaemia during pregnancy, emphasizing the potential impact of campaign programs on the prevalence of this condition. Furthermore, [11] studied the economic burden of anaemia in pregnancy, particularly in developing countries. The World Health Organization's estimation in 2011 revealed that approximately 38.2% of pregnant women globally were affected by anaemia, underscoring the need for urgent intervention strategies. Through modelling and simulation, this research aims to contribute valuable insights toward devising effective strategies for anaemia prevention, recognizing the significance of targeted efforts in reducing its prevalence among expectant mothers.

Pregnant women across Africa encounter a significant public health challenge in the form of anaemia, affecting 58% of them. This condition arises from various factors, including socioeconomic challenges, limited access to healthcare, and nutritional deficiencies. Iron deficiency is a major contributor, necessitating dietary diversification and iron supplements [12, 13, 14]. The Nigeria Demographic and Health Survey (NDHS) and the World Health Organization (WHO) report a high prevalence of anaemia among pregnant women in Nigeria, with recent NDHS data from 2018 indicating a 45% anaemia rate, primarily due to iron deficiency. Contributing factors include malaria, poor nutrition, and constrained healthcare access. Addressing anaemia requires solutions like iron supplementation, enriched diets, and improved maternity healthcare. To enhance mother and child health outcomes, public health initiatives must raise awareness, expand healthcare access, and implement preventive measures [15, 16]. In the United States, 18% of pregnant women experience anaemia, a significant public health concern according to the Centers for Disease Control and Prevention (CDC) [17, 18].[19] reveals variations in anaemia prevalence linked to factors such as maternal age, socioeconomic position, and race/ethnicity. Iron deficiency, a common cause, poses risks like low birth weight and preterm birth for both mother and fetus. Comprehensive prenatal care, including screenings, dietary counseling, and targeted therapies, is crucial. Although less common in the U.S. than in other countries, sustained awareness campaigns and educational programs are necessary. Modeling and simulating the impact of a campaign program on anaemia prevalence provide crucial information for ongoing public health initiatives.[20] emphasize the need for tailored interventions, considering factors like dietary habits and socioeconomic status. A modeling approach should assess the potential impact of campaigns, addressing regional variations and local determinants. Central America, facing unique challenges, requires a comprehensive campaign program considering specific healthcare disparities. Understanding and addressing these factors can guide tailored interventions to mitigate anaemia's impact on maternal and fetal health [21, 22, 23].

According to a study [24] conducted on anaemia prevalence in pregnant women in Central America, using electronic health records (EHRs) for assessment. The research underscores anaemia's significant health concern in the region, emphasizing the need to identify at-risk populations for effective intervention strategies. Targeted campaigns and programs are crucial, with the study highlighting their paramount impact in reducing anaemia prevalence. While specific details of the campaign's impact were not provided, the study underscores the importance of public health initiatives in combating anaemia among pregnant women, emphasizing the need for further investigation into the campaign's strategies and outcomes. [25] investigated anemia prevalence in pregnant women, emphasizing a community-based approach. Findings revealed varying risk levels among pregnant women based on education, highlighting the critical role of education in influencing anemia prevalence. A proposed modeling and simulation of the impact of a campaign program could prioritize educational interventions for susceptible populations. Focusing on enhancing awareness, nutritional knowledge, and healthcare access for women with lower educational backgrounds could significantly mitigate anemia prevalence during pregnancy, fostering improved maternal and child health outcomes.

Mat Daud etal. [26] explored anaemia prevalence in pregnant women, utilizing mathematical modeling to analyze its dynamics. The study identifies anemia as a critical health concern during pregnancy, contributing quantitatively to factors like nutrition, physiology, and interventions. Simulations predict anemia trends and evaluate intervention effectiveness, offering comprehensive insights. A study conducted on 11,574 pregnant women in Sub-Saharan Africa, revealed a concerning prevalence of anaemia, affecting 50% in both urban and rural areas. susceptible groups included younger mothers, those with no formal education, the poorest quintile, those with five or more children, married individuals, and those lacking health insurance, emphasizing the need for targeted interventions [27]. Mathematical modelling of infectious diseases is an effective approach to studying the dynamics of infectious diseases and predicting the effect of controls and preventions [28, 29, 30]. A comprehensive modeling and simulation approach could assess the potential impact of targeted campaign programs on reducing anaemia prevalence, addressing specific risk factors and tailoring strategies based on geographical nuances and socioeconomic contexts.

## 2. Model formulation and description

The prevalence model for anemia in children under the age of five, developed by [31], was modified to incorporate the conception rate (c) instead of the birth rate (b) (Fig. 2). This modification allows for the modeling of anemia prevalence in pregnant women. The entire number of pregnant women is denoted as the N(t) and is categorized into three distinct divisions or categories: susceptible S(t), affected A(t), and treated T(t). Pregnant women who are susceptible to anemia develop the condition over time. Pregnant women who are affected by the condition necessitate medical intervention and a transition to the treated category. Thus, the dynamics of anemia may be represented by eq. 1.

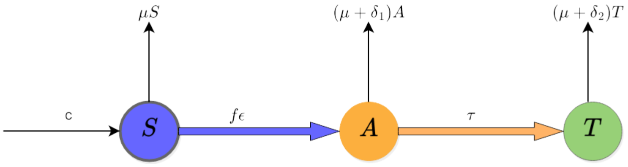

**Figure 2:** Model of anemia in pregnant women

$$\begin{cases} \dot{S} &= c - (\epsilon f(t) + \mu)S \\ \dot{A} &= \epsilon f(t)S - (\tau + \delta_1 + \mu)A \\ \dot{T} &= \tau A - (\delta_2 + \mu)T \end{cases} \tag{1}$$

The variable c represents the rate of successful conceptions, whereas the symbol $\mu$ denotes the rate of spontaneous miscarriages among pregnant women.

**Table 1:** Variables corresponding to anemia model (1).

| Variable | Description |
|---|---|
| S | Susceptible pregnant women |
| A | Affected pregnant women |
| T | Treated pregnant women |
| N | Total number of pregnant women |

**Table 2:** Parameters corresponding to anemia model (1)

| Parameter | Explanation |
|---|---|
| c | Conception rate of pregnant women |
| $\mu$ | Natural miscarriage rate in pregnant women |
| $f$ | Proportion of susceptible pregnant women who are likely tobecome affected |
| $m(t)$ | Rate of time-sensitive campaign programs |
| $\epsilon$ | The anemic rate or the rate of infection among expectant women who are susceptible |
| $\tau$ | Rate of Intervention/treatment |
| $\delta_1$ | Mortality/Death rate in the A category as a result of anemia |
| $\delta_2$ | Mortality/Death rate in the T category as a result of anemia |

The parameters $\epsilon$ and $\tau$ represent the rate of anemia and the rate of treatment, respectively. The occurrence of miscarriage in pregnant women owing to anemia is considered to happen in two compartments, A and T, with rates $\delta_1$ and $\delta_2$, respectively. Therefore, the annual occurrence of miscarriage in pregnant women caused by anemia may be readily determined using the formula $\delta_1$A + $\delta_2$T. The metric f represents the proportion of susceptible pregnant women who are at risk of developing anemia. Therefore, the susceptible class will rise as the proportion f decreases. The change of the parameter f is presumed to be mostly impacted by time, which in turn is affected by the pace of the campaign program, denoted as $m(t)$. Hence, the parameter $f$ that varies with time is defined as follows: The function $f(t)$ is equal to one minus the value of $m(t)$. Therefore, if the campaign program rate is raised, $f(t)$ will have a downward trend over time. Nevertheless, $m(t)$ may be altered at any given moment to accurately represent the escalation or stoppage of the campaign program. Define $m_0$ as the initial campaign program rate, denoted by $m(t)$. The state variables and parameters for model (1) are given in Table 1 and Table 2, respectively. The model (1) is a linear non-homogeneous system that may be expressed concisely in the following manner:

$$\dot{X} = AX + F \tag{2}$$

The matrices in (2) are

$$\mathbf{X} = \begin{pmatrix} S(t) \\ A(t) \\ T(t) \end{pmatrix}, \mathbf{A} = \begin{pmatrix} -v_1 & 0 & 0 \\ \epsilon f & -v_2 & 0 \\ 0 & \tau & -v_3 \end{pmatrix}, \mathbf{F} = \begin{pmatrix} c \\ 0 \\ 0 \end{pmatrix}$$

Where $v_1 = \epsilon f + \mu, v_2 = \tau + \delta_1 + \mu$ and $v_3 = \delta_2 + \mu$.

## 3. Model analysis

### 3.1. Well-posedness

To examine the effect of a campaign program and therapy on the prevalence of anemia, it is necessary to ensure that the solutions of model (1) are both positive and bounded, as required by biological considerations. In order to determine the positivity of S(t), we may examine the first equation of model (1), which is expressed as $\dot{S} = c - v_1 S$.

recall $P = -v_1$ and $Q = c$

finding the integrating factor

$I.F = e^{\int P(t)dt}$
$I.F = e^{\int -v_1 dt}$
$I.F = e^{-v_1 t}$

Now, multiplying the integrating factor on both sides of the given differential equation

$$\bar{S}(e^{-v_1 t}) + v_1 S(e^{-v_1 t}) = c(e^{-v_1 t})$$

integrating both sides

$$\int \dot{S}(e^{-v_1 t}) + \int v_1 S(e^{-v_1 t}) = \int c(e^{-v_1 t})$$

$$S(t) = \left[\frac{\bar{S}}{v_1} + S\right] e^{-v_1 t} = \frac{c(e^{-v_1 t})}{v_1} + S(0)$$

$$S(t) = \left[\frac{\bar{S} + v_1 S}{v_1}\right] e^{-v_1 t} = \frac{c(e^{-v_1 t})}{v_1} + S(0)$$

It follows that

$$S(t) = \frac{c}{v_1} + \left[S(0) - \frac{c}{v_1}\right] e^{-k_1 t}$$

It is evident that if the initial value of S, denoted as S(0), is greater than or equal to zero, then the value of S at any time t will be non-negative. Similarly, if $A(0) \geq 0$ and $T(0) \geq 0$, the model (1) will have a single solution that is non-negative for all $t > 0$. To determine the boundedness of the solutions, the equations of the model (1) are summed together:

$$\dot{S} + \dot{A} + \dot{T} = c - (\epsilon f + \mu)S + \epsilon f S - (\tau + \delta_1 + \mu)A + \tau A - (\delta_2 + \mu)T$$

Hence

$$\dot{N} \leq c - \mu N$$

where,

$$\dot{N} = c - \mu(S + A + T)$$

$$\dot{N} \leq c - \mu N \;\; considering \;\; \delta_1 T \;\; and \;\; \delta_2 T$$

$$\therefore \dot{N} \leq c - \mu N$$

which implies

$$\lim_{t \to \infty} sup \;\; N \leq \frac{c}{\mu}$$

Therefore, $\frac{c}{\mu}$, serves as a threshold for the function N(t). This implies that N(t) is limited for any values of t greater than zero. This indicates a biologically plausible area for our model (1) as outlined below:

$$\Omega = \left\{(S, A, T) : S, A, T \geq 0, N \leq \frac{c}{\mu}\right\}$$

Therefore, it is obvious that the unique solution of model (1) exists globally.

### 3.2. Equilibrium

For model (1), denote the equilibrium point as $\zeta(\bar{S}, \bar{A}, \bar{T})$. Determination of i$\zeta$ requires to set $\bar{S}$, $\bar{A}$and $\bar{T}$ to zero according to Differential equations with boundary value problem by Zill D.G and Cullon M.R (2009). It follows

$$\begin{cases} c - v_1 \bar{S} = 0 \\ \epsilon f \bar{S} - v_2 \bar{A} = 0 \\ \tau \bar{A} - v_3 \bar{T} = 0 \end{cases} \tag{3}$$

Solution of (3) is given by

$c = v_1 \bar{S}$
$\bar{S} = \dfrac{c}{v_1}$
$\epsilon f \bar{s} - v_2 \bar{A}$=0

$$\epsilon f\bar{s} = v_2\bar{A}$$
$$\bar{A} = \frac{\epsilon f\bar{S}}{v_2}$$
$$\tau\bar{A} - v_3\bar{T} = 0$$
$$\tau\bar{A} = v_3\bar{T}$$
$$\bar{T} = \frac{\tau\bar{A}}{v_3}$$

and,

$$\bar{S} = \frac{c}{v_1} \quad ,\bar{A} = \frac{\epsilon f c}{v_1 v_2} \quad \therefore \bar{T} = \frac{\tau\epsilon f c}{v_1 v_2 v_3}$$

$$\therefore \zeta(\bar{S},\bar{A},\bar{T}) \equiv \zeta\left(\frac{c}{v_1}, \frac{c\epsilon f}{v_1 v_2}, \frac{c\epsilon f\tau}{v_1 v_2 v_3}\right)$$

### 3.3. Stability

Following Zill D.G and Cullon M.R (2009) differential equations with boundary value problems, the Jacobian matrix J is $\zeta(\bar{S},\bar{A},\bar{T})$ is given as

$$\begin{pmatrix} \frac{\partial\bar{S}}{\partial S} & \frac{\partial\bar{S}}{\partial A} & \frac{\partial\bar{S}}{\partial T} \\ \frac{\partial\bar{A}}{\partial S} & \frac{\partial\bar{A}}{\partial A} & \frac{\partial\bar{A}}{\partial T} \\ \frac{\partial\bar{T}}{\partial S} & \frac{\partial\bar{T}}{\partial A} & \frac{\partial\bar{T}}{\partial T} \end{pmatrix}$$

From (3)

$$\bar{S} = c - v_1 S \quad \bar{A} = \epsilon f\bar{S} - v_2\bar{A} \quad ,\bar{T} = \tau\bar{A} - v_3\bar{T}$$
$$\frac{\partial\bar{S}}{\partial S} = -v_1 \quad \frac{\partial\bar{S}}{\partial A} = 0 \quad \frac{\partial\bar{S}}{\partial T} = 0$$

$$\frac{\partial\bar{A}}{\partial S} = -\epsilon f \quad \frac{\partial\bar{A}}{\partial A} = -v_2 \quad \frac{\partial\bar{A}}{\partial T} = 0$$

$$\frac{\partial\bar{T}}{\partial S} = 0 \quad \frac{\partial\bar{T}}{\partial A} = \tau \quad \frac{\partial\bar{T}}{\partial T} = -v_3$$

$$\therefore J(\zeta) = \begin{pmatrix} -v_1 & 0 & 0 \\ \epsilon f & -v_2 & 0 \\ 0 & \tau & -v_3 \end{pmatrix} \tag{4}$$

The characteristic equation of (4) is

$$\begin{pmatrix} -v_1 - \lambda & 0 & 0 \\ \epsilon f & -v_2 - \lambda & 0 \\ 0 & \tau & -v_3 - \lambda \end{pmatrix} \tag{5}$$

The determinant for (5) is given as

$$-v_1 - \lambda\begin{vmatrix} -v_2 - \lambda & 0 \\ \tau & -v_3 - \lambda \end{vmatrix} - 0\begin{vmatrix} \epsilon f & 0 \\ 0 & -v_3 - \lambda \end{vmatrix} + 0\begin{vmatrix} \epsilon f & -v_2 - \lambda \\ 0 & \tau \end{vmatrix} = 0$$

$$= -v_1 - \lambda\big((-v_2 - \lambda)(-v_3 - \lambda) - 0\big) - 0 + 0$$
$$= -v_1 - \lambda\big((-v_2 - \lambda)(-v_3 - \lambda)\big)$$
$$0 = (-v_1 - \lambda)(-v_2 - \lambda)(-v_3 - \lambda)$$
$$\lambda = -v_1, -v_2, -v_3$$

$\therefore\ \lambda = -v_1, -v_2, -v_3$ which shows $\zeta(\bar{S},\bar{A},\bar{T})$ is asymptotically stable since the eigenvalues of (4) are real, distinct and most importantly negative Eigenvalues determine the stability properties of the equilibrium. An equilibrium asymptotically stable if all eigenvalues have negative real part. Therefore (1) is stable given $\lambda = -v_1, -v_2, -v_3$

### 3.4. Sensitivity analysis

Sensitivity indices allow for the quantification of changes in any variable. These indices demonstrate the significance of factors in the course of a disease. The sensitivity indices of $\bar{S}$, $\bar{A}$, and $\bar{T}$ are shown in Table 3, utilizing the following definitions: A concise explanation or description of a concept or term.Let u be a state variable that is differentiable with respect to a parameter p. The normalized forward sensitivity index of u is defined as:

$$\alpha_p^u = \frac{\partial u}{\partial p}\frac{p}{u}$$

**Table 3:** Sensitivity of equilibrium point.

| Parameter | Sensitivity index of $\bar{S}$ | Sensitivity index of $\bar{A}$ | Sensitivity index of $\bar{T}$ |
|---|---|---|---|
| c | +1 | +1 | +1 |
| $\mu$ | -0.37 | -0.37 | -0.53 |
| $m(t)$ | +0.27 | -0.16 | -0.16 |
| $\epsilon$ | -0.63 | +0.37 | +0.37 |
| $\tau$ | | -0.46 | +0.54 |
| $\delta_1$ | | -0.54 | -0.54 |
| $\delta_2$ | | | -0.70 |

#### 3.4.1. Outcomes of sensitivity analysis

Based on the information provided in Table 3 and Fig. 3, it is evident that the birth and mortality rates (specifically, $c, \mu, \delta_1 \quad and \quad \delta_2$), as well as the campaign program rate $m(t)$, anemic rate $\epsilon$, and treatment rate $\tau$, are the most significant parameters affecting the equilibrium point $\zeta(\bar{S},\bar{A},\bar{T})$. Any rise or fall in these parameters will result in a change in the value of the equilibrium point. An increase in the campaign program rate will result in a 27% rise in $\bar{S}$, but both $\bar{A}$ and $\bar{T}$ will fall by 16%. Similarly, if the anemic rate $\epsilon$ increases, it will result in a 63% fall in $\bar{S}$ and a 37% rise in both $\bar{A}$ and $\bar{T}$. In addition, a higher treatment rate $\tau$ will decrease $\bar{A}$ by 46% and raise $\bar{T}$ by 54%.

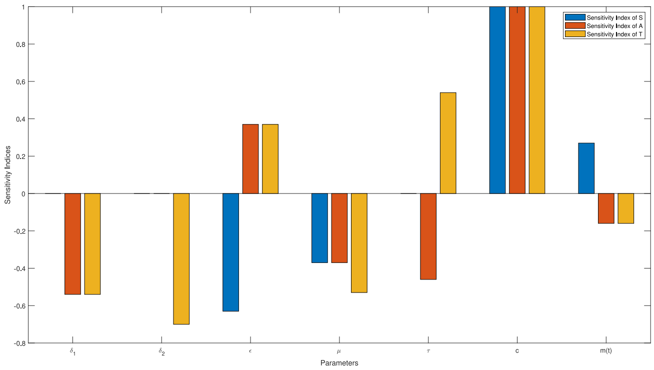

**Figure 3:** Sensitivity of equilibrium point. The bars in blue, orange and yellow correspond to $\bar{S}$, $\bar{A}$ and $\bar{T}$ respectively.

## 4. Interventions

The observation period for model (1) spans 10 years. Let $t_i$ represent the time points (in years) of the whole observation period, where $t_0$ is the beginning time and $t_{10}$ is the final time. The profile of $m(t)$ is modified at different times to accurately represent the influence of the time-dependent campaign program rate. In model (1), designate $t_2$ and $t_4$ as the pivotal moments when activities on the campaign program are launched (sped up or stopped). The user's text consists of two backslashes. In the baseline scenario, the campaign program rate $m_0$ remains constant for the whole duration of the observation period. Thus, $m(t)$ is regarded in the following manner:

$$m(t) = m_0; \quad t_0 \leq t \leq t_{10}.$$

The campaign program might be expedited sooner, based on the severity of the infection. To assess the efficacy of initiating the campaign program earlier, the time-dependent parameter m(t) is initialized:

$$m(t) = \begin{cases} m_0 & ; \quad t_0 \leq t \leq t_2 \\ 4m_0 & ; \quad t_2 < t \leq t_{10} \end{cases}$$

$$m(t) = \begin{cases} m_0 & ; \quad t_0 \leq t \leq t_4 \\ 4m_0 & ; \quad t_4 < t \leq t_{10} \end{cases}$$

The campaign program might be stopped at any point during the duration of the sickness. Considering the concealed information on the campaign program, the characteristics of m(t) may be described as follows:

$$m(t) = \begin{cases} m_0 & ; \quad t_0 \leq t \leq t_2 \\ 4m_0 & ; \quad t_2 < t \leq t_4 \\ 0 & ; \quad t_4 < t \leq t_{10} \end{cases}$$

## 5. Results and discussion

The model (1) employs normalized state variables with respect to the total population N(t), where N=S+A+T=1. Initial values for the state variables are set as S(0)=1, A(0)=0, and T(0)=0. The global miscarriage rate in pregnant women, as reported by sources like Mayo Foundation for Medical Education and Research (MFMER), ranges from 10% to 20%. Therefore, the parameter ÎŒ is chosen to be... In accordance with UNFPA data on teenage pregnancy, childbearing, and intended/unintended pregnancies globally in 2012, and considering recent trends, c is assigned a value of 213.4 million. This is derived from recent trends and calculations. Anaemia rates vary widely, from 53.8% to 90.2% in developing countries and 8.3% to 23% in developed countries, resulting in a 37.6% overall prevalence of pregnancy miscarriage due to anaemia. Parameter e is computed as the average prevalence percentage from 2000 to 2012. Information indicates that 35% of expectant mothers may face a risk of pregnancy complications, such as miscarriage due to anaemia. Based on this, $\delta_1$ and $\delta_2$ are fixed. The values for the remaining parameters, m(t) and $\tau$, are assumed, and the associated parameter values for model (1) are presented in Table 3.

**Table 4:** The parameter values used to simulate the model (1).

| Parameter | Value | Unit | Source |
|---|---|---|---|
| c | 2.134 | per year | Estimated |
| $\mu$ | 0.152 | per year | [32] |
| $m(t)$ | 0.300 | per year | Asumed |
| $\epsilon$ | 0.376 | per year | [32] |
| $\tau$ | 0.300 | per year | Asumed |
| $\delta_1$ | 0.350 | per year | [12] |
| $\delta_2$ | 0.350 | per year | [12] |

### 5.1. Model Baseline Case

The model's baseline instance (Fig. 4) demonstrates that with a campaign's efficacy of 30%, the highest point of impact on the affected group is reached during 3 years. Approximately 92% of pregnant women have symptoms during the peak period. After a decade, 12% of pregnant women remain susceptible, 64% are affected, and 79% require medical intervention. Furthermore, the average fatality rate caused by the illness ranges from 0.15% to 0.20%. Based on Fig. 4, it can be inferred that the illness will continue to exist within a population as the solution set of the model (1) approaches the equilibrium point.

### 5.2. Effect of anemic rate

Fig. 5 illustrates that when the anemic rate is doubled compared to the baseline, the susceptible class decreases by 56%, while the affected and treated classes rise by 17% and 46%, respectively. The average mortality rate has been reported to increase by around 32%. Conversely, if the anemic rate decreases to half of the baseline, the susceptible class will grow by at least 93%. Consequently, there will be a 48% fall in deaths caused by disease, with a 33% reduction in the affected population and a 55% reduction in the treated population.

### 5.3. Impact of campaign program with constant rates

Fig. 6 shows that, in comparison to the baseline scenario, the susceptible class has grown by an average of 45%, while the affected and treated classes have dropped by 10% and 25% respectively, due to the campaign program's 50% efficacy. Furthermore, there is an observed average decrease of 21% in mortality caused by anemia. A campaign program with an efficacy rate of 80% leads to a reduction of 50% and 61% in the affected and treated classes, respectively, compared to the baseline situation. Consequently, the mortality rate caused by illness can be decreased by 55%, while the number of individuals in the susceptible class is doubled.

### 5.4. Effect of launching early campaigns

According to Fig. 7, increasing the campaign program rate by 80% over 4 years will result in a nearly 55% rise in the susceptible class compared to the baseline situation. Consequently, the curves representing the total number of affected, treated, and deceased individuals will fall by 17%, 6%, and 12%, respectively. If the advertising program is conducted two years earlier with the same degree of efficacy, the susceptible class will be twice as large as in the baseline situation. As a result of implementing this method, there is an average decrease of 30% in the affected class and 20% in the treated class. Furthermore, a significant 26% of fatalities might be prevented in this particular situation.

### 5.5. Effect of discontinuation of campaign initiative

According to Fig. 8, the campaign program is implemented with 80% efficiency for a duration of 2 to 4 years, and it is ended immediately after 4 years. As a result, there has been an average decline of around 8% in the susceptible class over the final two years of the observation period. In contrast, the affected class is projected to increase by 12% within 6 to 10 years, and the death rate is expected to climb by 3% shortly after 6 years. By the conclusion of the observation period, the treated class is essentially identical to the base case.

## 6. Conclusion

A comprehensive model for anemia in pregnant women has been suggested using ordinary differential equations to assess the ef-

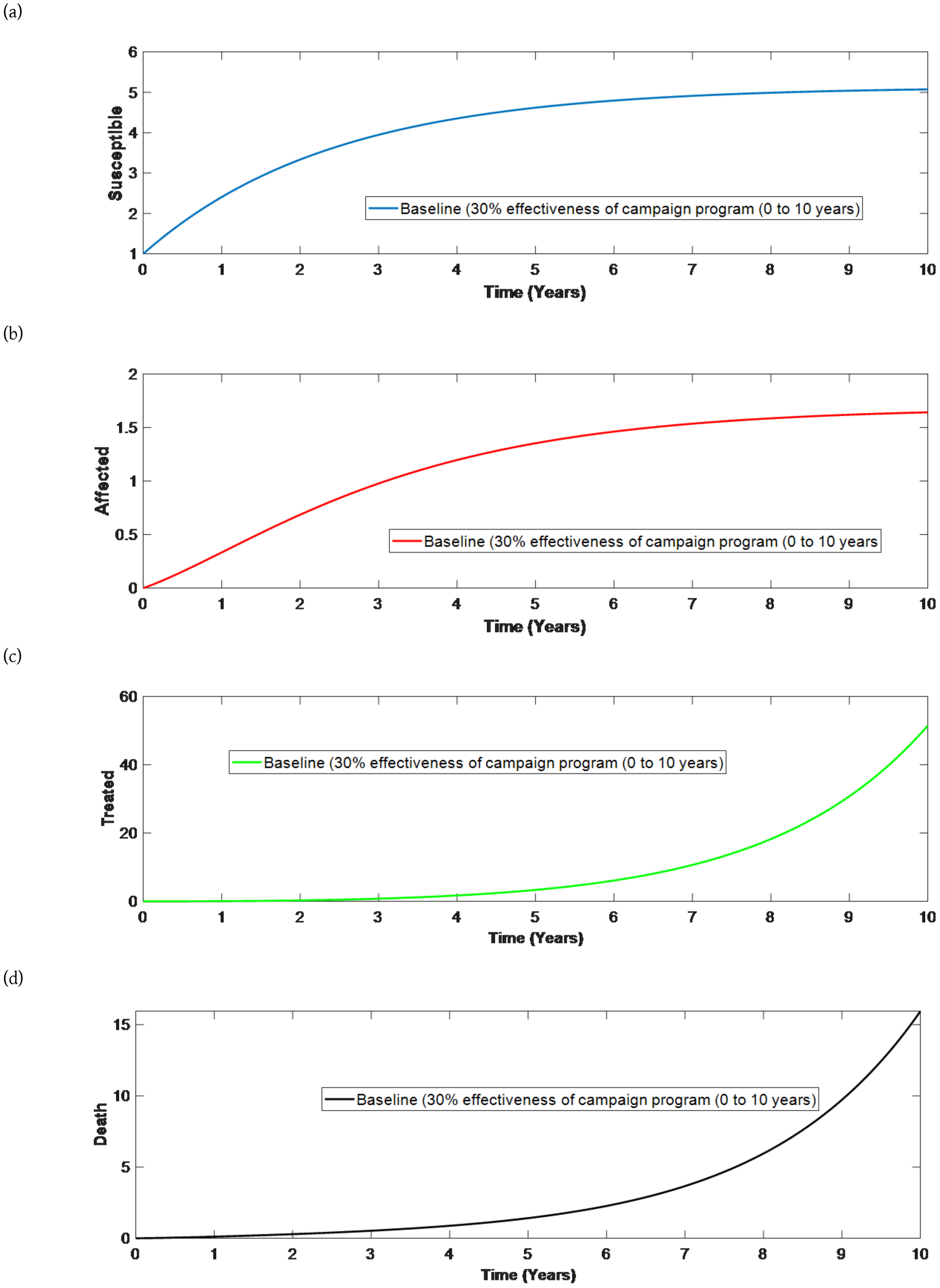

**Figure 4:** The model's baseline scenario illustrates the dynamics of five variables over 10 years: (a) susceptible individuals, (b) affected individuals, (c) treated individuals, and (d) deaths. The simulation is conducted using the initial values of the parameters specified in Table 4.

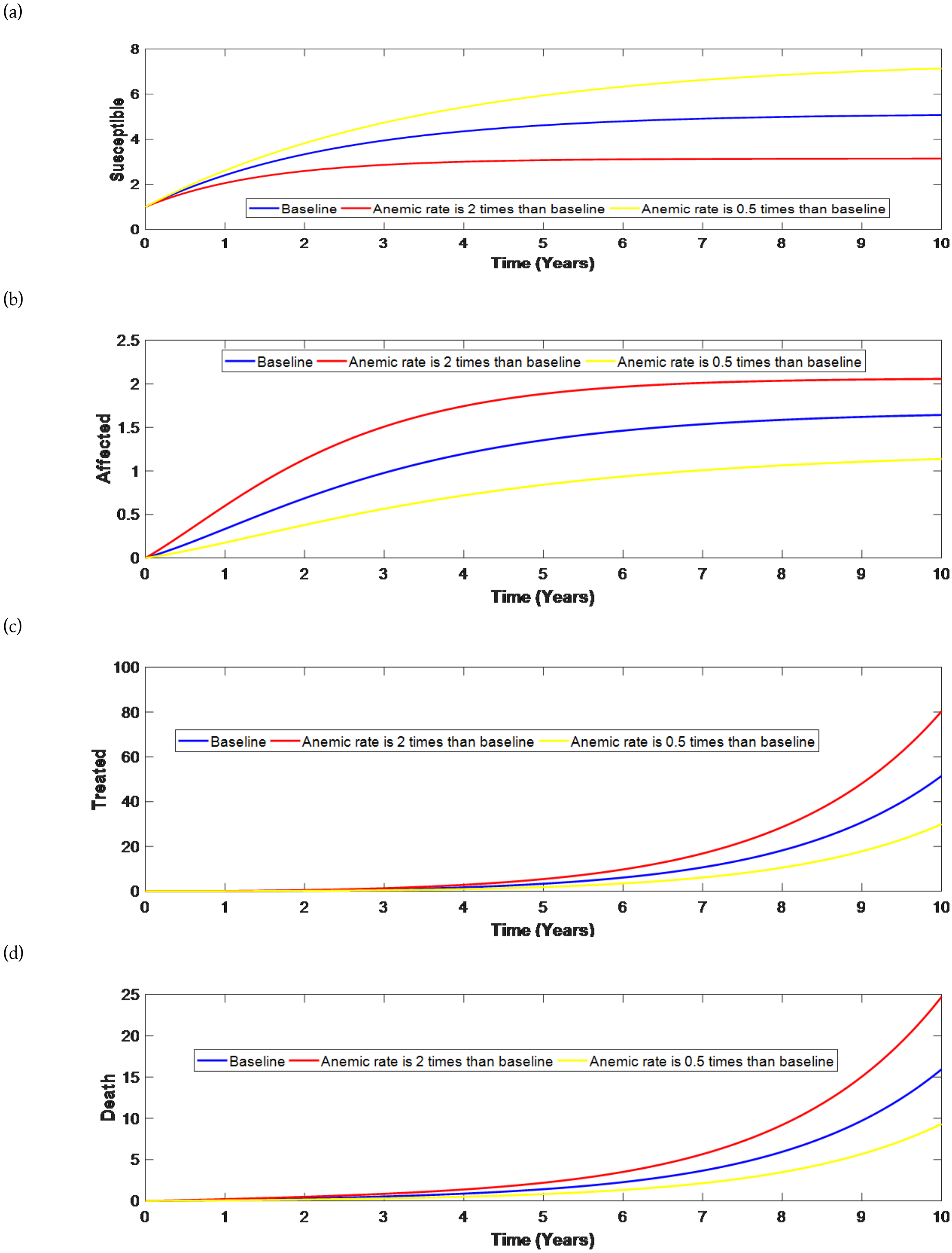

**Figure 5:** The simulations of model (3.1) illustrate the behavior of four groups during 10 years: (a) susceptible, (b) impacted, (c) treated, and (d) death. The simulations use three different values of $\epsilon$: 0.376 (shown in blue), 0.752 (represented in red), and 0.188 (represented in yellow). In addition to the anemic rate, the simulations are conducted with the default values of the remaining parameters provided in Table 4.

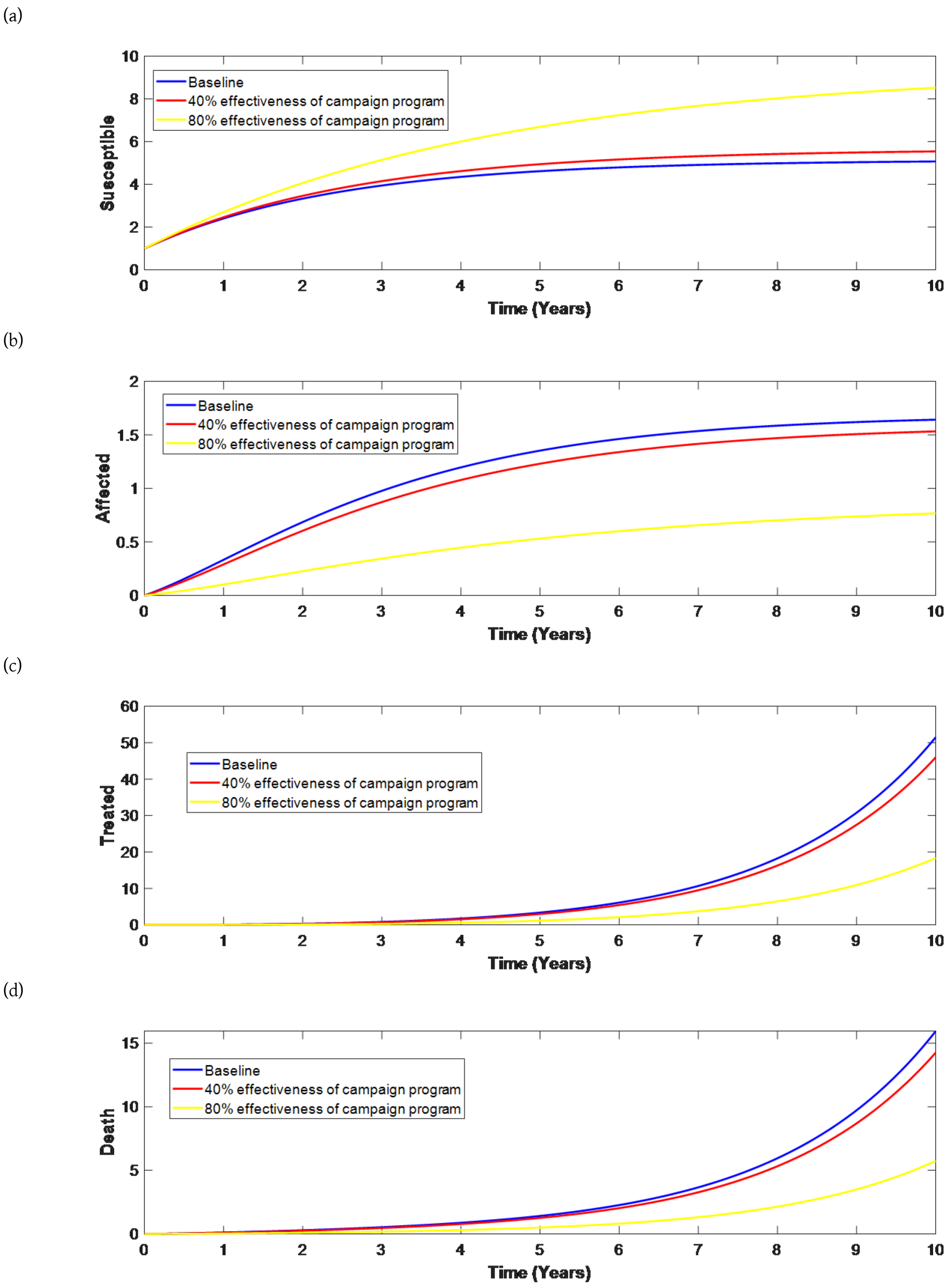

**Figure 6:** Case for campaign program with constant rates. The simulations of model (3.1) depict the dynamics of (a) individuals who are susceptible, (b) individuals who are impacted, (c) individuals who are treated, and (d) individuals who have died during 10 years. These dynamics are influenced by the efficacy of a campaign program, which is represented by different percentages (30% in blue, 40% in red, and 80% in yellow). In addition to the campaign program rate, the simulations are conducted using the default values of the remaining parameters provided in Table 4.

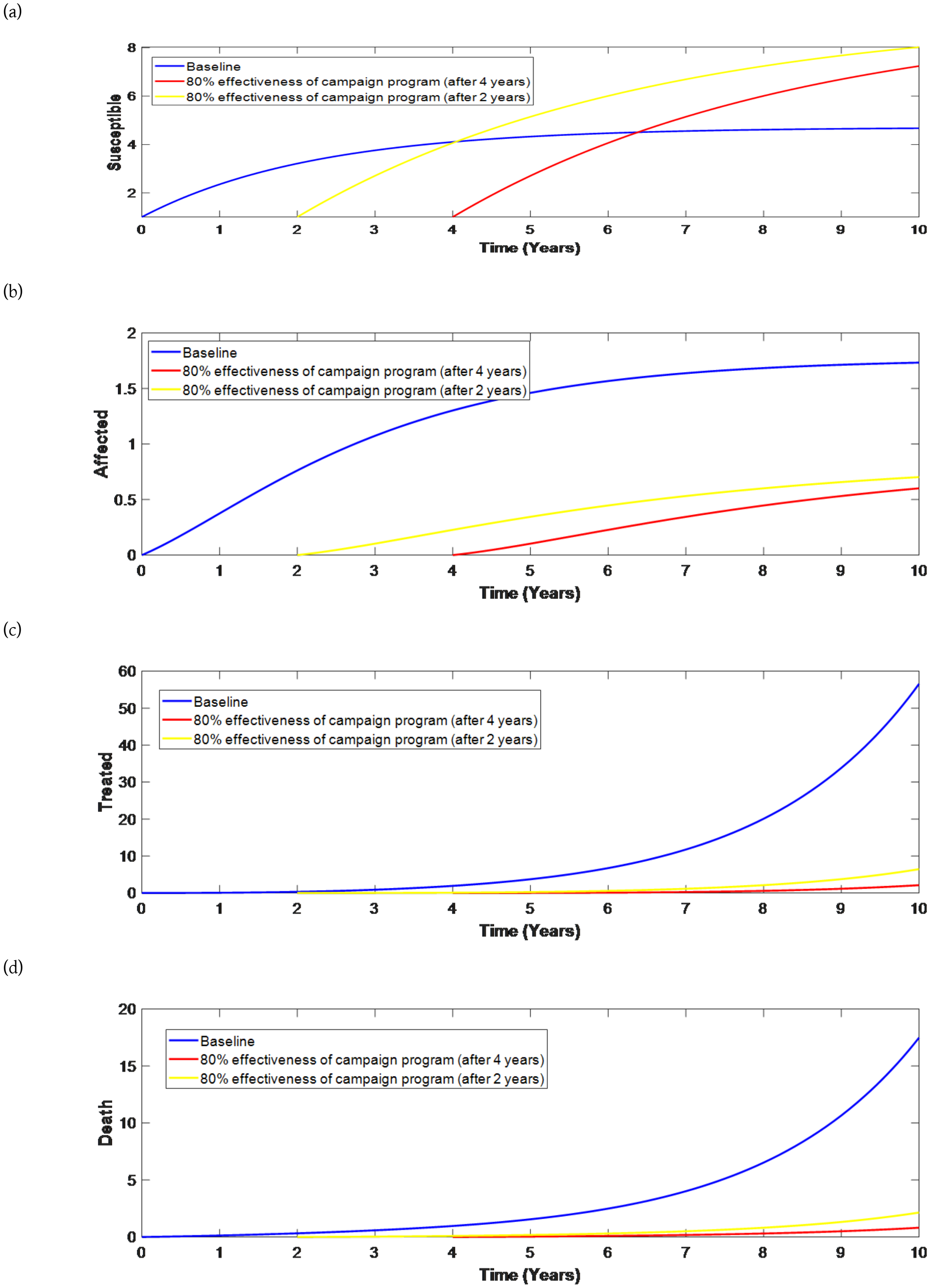

**Figure 7:** The case for launching early campaigns. The simulations of model (2.1) illustrate the dynamics of the following categories over 10 years: (a) susceptible, (b) affected, (c) treated, and (d) death. The simulations take into account a campaign program that is 20% effective throughout the entire observation period (highlighted in red), 80% effective after 4 years (also highlighted in red), and 80% effective after 2 years (highlighted in yellow). In addition to the campaign program rate, the simulations are conducted using the default values of the remaining parameters provided in Table 4

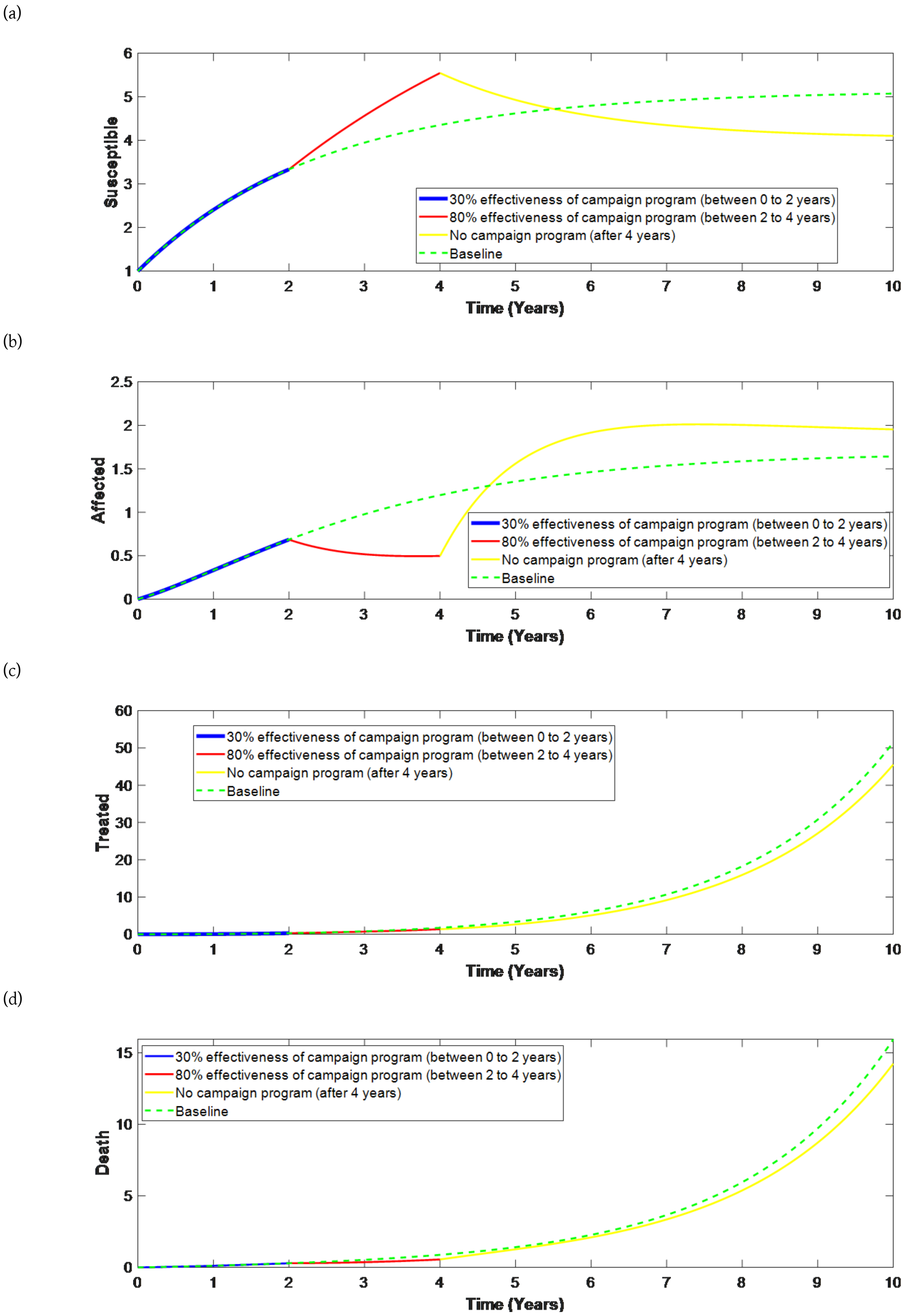

**Figure 8:** Case for discontinuation of campaign initiative. Simulations of model (1) depict the progression of (a) individuals who are susceptible, (b) individuals who are affected, (c) individuals who are treated, and (d) individuals who have died over 10 years. The simulations assume a campaign program that is 30% effective throughout the entire observation period (shown in blue), 80% effective from years 2 to 4 (shown in red), and no campaign program after 4 years. In addition to the campaign program rate, the simulations are conducted using the default values of the remaining parameters provided in Table 4

fects of a campaign program. The model is examined using deductive reasoning in conjunction with computational simulations. An increase in the susceptible population is found when the rate of the advertising program is expedited. Consequently, there is a large decrease in the proportion of pregnant women who are both anemic and receiving therapy. Early adoption of a campaign program with a reasonable level of efficacy can lead to a more favorable outcome. The model demonstrates a favorable effect of the control measure in mitigating miscarriage occurrences in pregnant women. Furthermore, the occurrence of the condition can be managed by maintaining a low incidence of anemia. The model also indicates that anemia will continue to be widespread, but with effective tactics, the impact may be reduced.

An overarching goal of this research is to utilize the existing model to predict the future trajectory of the disease by analyzing anemia prevalence data from various regions or countries. Furthermore, it may be utilized to reassess the prevailing occurrence of a certain region or nation. Although the model's potential insights are being analyzed, it is important to acknowledge its limits. For example, the values utilized in the simulation may not accurately reflect the conditions of the real-world scenario. The model's parameters are determined based on several sources and assumptions. Indeed, the parameters may be undisclosed, leading to minor variations in the outcomes. The model must be revised to incorporate more parameters that contribute to anemia. Alternative functions of a comparable kind can be employed instead of the function assessed for the time-dependent campaign program rate in this model. The outcomes may exhibit minor variations due to the substitution or alteration of the control measure. The model's analysis results can help in comprehending the impact of the advertising program on the risk of anemia in pregnant women. These findings can contribute to the attainment of one of the Sustainable Development Goals (SDGs), which is to reduce child mortality and malnutrition.

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## Competing interest

The authors declare that they have no competing interests.

## Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on plausible request.

## References

[1] Baizhumanova A, Nishimura A, Ito K, Sakamoto J, Karsybekova N, Tsoi I, & Hamajima N, Effectiveness of communication campaign on iron deficiency anaemia in Kyzyl-Orda region, Kazakhstan: a pilot study, *BMC Hematology* 10(1) (2010) 1-8.

[2] Agbomola J O & Loyinmi A C, Modelling the impact of some control strategies on the transmission dynamics of Ebola virus in human-bat population: An optimal control analysis, *Heliyon*, 8 (2022) e12121..

[3] Islam S, Shanta S & Rahman A, Modeling SARS-CoV-2 spread with dynamic isolation, *Math. Appl. Sci. Eng.*, 2 (2021) 219-234.

[4] Johnson R L & Rubenstein S D, Anemia in the emergency department: evaluation and treatment, *Emerg. Med. Pract.*, 15 (2013) 1-5.

[5] Kermack W O & McKendrick A G, A contribution to the mathematical theory of epidemics, *Proc. R. Soc. London. Ser. A, Contain. Pap. a Math. Phys. Character*, 115 (1927) 700-721.

[6] Chowdhury H A, Ahmed K R, Jebunessa F, Akter J, Hossain S & Shahjahan M, Factors associated with maternal anaemia among pregnant women in Dhaka city, *BMC Womens Health*, 15 (2015) 1-6.

[7] Erinle-Ibrahim L M, Oluwatobi I K & Sulola A I, Mathematical modelling of the transmission dynamics of malaria infection with optimal control, *Kathmandu Univ. J. Sci. Eng. Technol.*, 15 (2021).

[8] DeMaeyer E & Adiels-Tegman M, The prevalence of anaemia in the world, *World Heal. Stat. Q. 1985*, 38 (1985) 302-316.

[9] Erinle-Ibrahim L M & Idowu K O, Mathematical modelling of pneumonia dynamics of children under the age of five, *Abacus Mathematics Sci. Ser.*, 48 (2021).

[10] HealthEngine, Anaemia During Pregnancy: Types, Causes, and Treatments | HealthEngine Blog. Available at: https://healthinfo.healthengine.com.au/anaemia-during-pregnancy-types-causes-treatments, (2023) (Accessed: 15 January 2024)

[11] Osungbade K O & Oladunjoye A O, Anaemia in developing countries: burden and prospects of prevention and control, *Anemia*, 3 (2012) 116-129.

[12] Baizhumanova A, Nishimura A, Ito K, Sakamoto J, Karsybekova N, Tsoi I & Hamajima N, Effectiveness of communication campaign on iron deficiency anemia in Kyzyl-Orda region, Kazakhstan: a pilot study, *BMC Hematol.*, 10 (2010) 1-8.

[13] Idowu K O & Loyinmi A C, Impact of Contaminated Surfaces on the Transmission Dynamics of Corona Virus Disease ( Covid-19 ), *Biomed. J. Sci. Tech. Res.*, 51 (2023) 42280-42294. https://doi.org/10.26717/BJSTR.2023.51.008046.

[14] Babajide A O & Oluwatobi I K, On the Elzaki Substitution and Homotopy Pertubation Methods for Solving Partial Differential Equation involving Mixed Partial Derivatives, *FUDMA J. Sci.*, 5 (2021) 159-168.

[15] Olawale-Shosanya S O, Olusanya O O, Joseph A O, Idowu K O, Eriwa O B, Adebare A O & Usman MA. A Meta-Ensemble Predictive Model For The Risk Of Lung Cancer, *Al-Bahir Journal for Engineering and Pure Sciences*, 5(1) (2024)54

[16] Idowu O K & Loyinmi A C, Qualitative analysis of the transmission dynamics and optimal control of covid-19, *Educ. J. Sci. Math. Technol.*,10 (2023) 54-70.

[17] Morenikeji E I, Babajide A O & Oluwatobi I K, Application of Homotopy Perturbation Method to the Mathematical Modelling of Temperature Rise during Microwave Hyperthermia, *FUDMA J. Sci.*, 5 (2021) 273-282.

[18] Kang W, Irvine C, Wang Y, Clark A, Gu Z, Pressman E & O'Brien K O, Hemoglobin distributions and prevalence of anemia in a multiethnic United States pregnant population, Am. J. Clin. Nutr. 117 (2023) 1320-1330.

[19] Siu A L, Screening for iron deficiency anemia and iron supplementation in pregnant women to improve maternal health and birth outcomes: US Preventive Services Task Force recommendation statement, *Ann. Intern. Med.*, 163 (2015) 529-536.

[20] Kinyoki D, Osgood-Zimmerman A E, Bhattacharjee N V, Kassebaum N J & Hay S I, Anemia prevalence in women of reproductive age in low-and middle-income countries between 2000 and 2018, *Nat. Med.*, 27 (2021) 1761-1782.

[21] Idowu K O & Loyinmi A C, The Analytic Solution of Non-Linear Burgers-Huxley Equations Using The Tanh Method, *Al-Bahir J. Eng. Pure Sci.*, 3 (2023) 8.

[22] Idowu K O, Akinwande T G, Fayemi I, Adam U M & Loyinmi A C, Laplace Homotopy Perturbation Method (LHPM) for Solving Systems of N-Dimensional Non-Linear Partial Differential Equation, *Al-Bahir Journal for Engineering and Pure Science*, 3(1) (2023). https://doi.org/10.55810/2313-0083.1031.

[23] Agbomola J O & Loyinmi A C, A Mathematical Model For The Dynamical Behavior Of Ebola Virus Transmission In Human-Bat Population: Implication Of Immediate Discharge Of Recovered Individuals, (2022) preprint. https://doi.org/10.21203/rs.3.rs-1399224/v1

[24] Sharma A J, Ford N D, Bulkley J E, Jenkins L M, Vesco K K & Williams A M, Use of the electronic health record to assess prevalence of anemia and iron deficiency in pregnancy, *J. Nutr.*, 151 (2021) 3588-3595.

[25] Suryanarayana R, Chandrappa M, Santhuram A N, Prathima S & Sheela S R, Prospective study on prevalence of anemia of pregnant women and its outcome: A community based study, *J. Fam. Med. Prim. Care.*, 6 (2017) 739.

[26] Mat Daud A A, Toh C Q & Saidun S, Mathematical modeling and analysis of anemia during pregnancy and postpartum, *Theory Biosci.*, 140 (2021) 87-95.

[27] Nyarko S H, Boateng E N K, Dickson K S, Adzrago D, Addo I Y, Acquah E & Ayebeng C, Geospatial disparities and predictors of anaemia among pregnant women in Sub-Saharan Africa, *BMC Pregnancy Childbirth*, 23 (2023) 743.

[28] Loyinmi A C, Gbodogbe S O & Idowu K O, On the interaction of the human immune system with foreign body: mathematical modeling approach, *Kathmandu Univ. J. Sci. Eng. Technol.*, 17 (2023).

[29] Loyinmi A C & Idowu K O, Semi-Analytic Approach to Solving Rosenau-Hyman and Korteweg-De Vries Equations Using Integral Transform, *Tanzania J. Sci.*, 49 (2023) 26-40.

[30] Erinle-Ibrahim L M, Adebimpe O, Lawal W O & Agbomola J O, A mathematical model and sensitivity analysis of Lassa fever with relapse and reinfection rate, *Tanzania J. Sci.*, 48 (2022) 414-426.

[31] Islam M A I, Modeling the impact of campaign program on the prevalence of anemia in children under five: Anemia model, J. Math. Anal. Model. 2 (2021) 29-40.

[32] Wu Y, Ye H, Liu J, Ma Q, Yuan Y, Pang Q, Liu J, Kong C & Liu M, Prevalence of anemia and sociodemographic characteristics among pregnant and non-pregnant women in southwest China: a longitudinal observational study, BMC Pregnancy Childbirth. 20 (2020) 1-10.