*Journal of Quality Measurement and Analysis* *JQMA* 19(3) 2023, 1-13
*e-ISSN:* 2600-8602 *http://www.ukm.my/jqma*

# APPLICATION OF NUMERICAL METHOD TO ANALYSE THE TREND OF BABIES WITH ABNORMALITIES

(*Penggunaan Kaedah Berangka untuk Menganalisis Trend Bayi dengan Keabnormalan*)

SABASTINE EMMANUEL, SARATHA SATHASIVAM*,
HAZLEEN MARLEESA A. H. HAFEEZ & NURIZZATI JAAFAR

*ABSTRACT*

Compartmental models are commonly used in epidemiology to study the dynamics of infectious diseases, but they can also be used to model other health outcomes, such as the incidence of babies born with abnormalities. In this study, we present a two-compartment model that divides the population of new-borns into babies born with abnormalities (unhealthy) and babies born without abnormalities (healthy). The model assumes that the incidence of abnormalities is a function of certain factors, such as maternal age or environmental factors, and that babies can transition between the compartments depending on their health status. We present the mathematical equations for this model and demonstrate how it can be simulated using MATLAB code. Our results show how the model can be used to simulate the dynamics of babies born with abnormalities over time, providing insights into the factors that influence their incidence and the effectiveness of interventions to reduce their occurrence. This model can be adapted and extended to explore more complex scenarios and study the impact of different interventions on the health outcomes of new-borns.

*Keywords*: baby abnormalities; healthy babies; predictor-corrector method; Runge-Kutta method

*ABSTRAK*

Model kompartmen biasanya digunakan dalam epidemiologi untuk mengkaji dinamik penyakit berjangkit, tetapi ia juga boleh digunakan untuk memodelkan hasil kesihatan lain, seperti kejadian bayi yang dilahirkan dengan keabnormalan. Dalam kajian ini, kami membentangkan model dua petak yang membahagikan populasi bayi baru lahir kepada bayi yang dilahirkan dengan keabnormalan (tidak sihat) dan bayi yang dilahirkan tanpa keabnormalan (sihat). Model ini menganggap bahawa kejadian keabnormalan adalah fungsi faktor-faktor tertentu, seperti usia ibu atau faktor persekitaran, dan bayi boleh beralih antara petak bergantung kepada status kesihatan mereka. Kami membentangkan persamaan matematik untuk model ini dan menunjukkan bagaimana ia boleh disimulasikan menggunakan kod MATLAB. Keputusan kami menunjukkan bagaimana model ini boleh digunakan untuk mensimulasikan dinamik bayi yang dilahirkan dengan keabnormalan dari masa ke masa, memberikan pandangan tentang faktor-faktor yang mempengaruhi kejadian mereka dan keberkesanan intervensi untuk mengurangkan kejadian mereka. Model ini boleh disesuaikan dan diperluaskan untuk meneroka senario yang lebih kompleks dan mengkaji kesan intervensi yang berbeza terhadap hasil kesihatan bayi baru lahir.

*Kata kunci*: keabnormalan bayi; bayi sihat; kaedah peramal-pembetul; kaedah *Runge-Kutta*

## 1. Introduction

In both developed and developing nations, baby abnormalities are one of the primary causes of childhood impairment and mortality. Baby abnormalities are non-normal physical, physiological, or chemical characteristics of the newborn baby's body (Du *et al.* 2016). The condition might be the result of genetics, sickness, radiation, or drug exposure, or it could be unknown what caused it. Congenital abnormalities include Down syndrome, sickle cell anemia, and phenylketonuria (Liu *et al.* 2019).

According to the World Health Organization (2022), research, defects in newborns cause 240,000 deaths during their first 28 days of life yearly basis. Another astonishing 170,000 children between one month old and five years old die because of birth defects. Baby defects can cause long-term disability, which has a significant effect on people, families, the healthcare system, and society. Nine out of 10 newborns are born with a lack in developing countries. The three most common significant infant anomalies are heart difficulties, neural tube defects, and Down syndrome.

The demographic data on infant abnormalities from population-based studies in economically developing countries are limited. 253 infants were born with serious anomalies in 17,720 births, with an occurrence of 14.3/1000 births and a birth-associated risk factor of one out of 70. There were 173 single abnormalities and 80 multiple abnormalities among the infants delivered. The precise syndromic diagnosis of 18 (22.5 percent) newborns' numerous defects could not be identified. The chief organ systems implicated in isolated new-born abnormalities were cardiovascular (13.8%), cleft lip and palate (11.9%), clubfoot (9.1%), central nervous system (CNS) (including neural tube defects) (7.9%), musculoskeletal (5.5%), gastrointestinal (4.7%), and hydrops fetalis (4.3%) (van der Linde *et al*. 2011). Infants with significant anomalies exhibited reduced metabolic weights, experienced preterm birth, underwent increased Caesarean sections, had prolonged hospital stays, and necessitated more specialized care.

During the perinatal stage, the death rate among newborns with significant anomalies was 25.2%. Abnormalities in the newborns or their ancestors, but not in their other offspring, as well as considerably higher rates of earlier abortions, were shown to be connected with the afflicted mums' maternal age. The inheritance rate was 2.4%, which was two times higher than the rate in the control group. It is deduced that additional interventional studies are needed to minimize newborn abnormalities in Malaysia and that a baby abnormality register is needed to track these changes.

Every year, around 16,500, of Malaysia's 550,000 newborns are born with congenital defects, with one-third dying before reaching their first birthday (Vrijheid *et al*. 2011; Thong *et al.* 2005). Those who do not die may have a lower quality of life as a result of physical or mental problems. Prof. Dr. Thong Meow Keong, consultant Pediatrician and clinical geneticist at University Malaya Medical Centre stated that the necessity for a registry was urgent due to the illnesses' low awareness. According to him, there are around 8000 identified uncommon illnesses, and the list is expanding regularly. According to him, a rare disease is classified in Europe as a disorder that affects one in every 2000 people, but there is no official classification in Malaysia yet. Several patient advocacy groups, like the Malaysian Rare Disorders Society, have accepted the definition of any ailment that affects one in every 4000 persons or less. Only around 200 of the 8000 illnesses have pharmacological therapy.

Genetic anomalies, including congenital anomalies or single-gene diseases, cause a tiny fraction of birth deformities. Consanguinity is when both parents are blood relations which rises the chance of odd genetics of a baby with abnormalities and virtually twice the risk of newborn and newborn death, intellectual abnormalities, and other deformities (Zaidi & Brueckner 2017; Cleveland Clinic 2021). Following that, poverty could be an independent predictor of abnormalities in babies, with a higher incidence of resource limitations. Hence, 94% of major abnormalities in babies occur in developing countries. As a result of pregnant women's likely denial of access to proper nutrition, higher exposure to sickness and alcohol, or inadequate health care coverage and screening.

Most of the symptom abnormalities of the babies are obvious in terms of physical structure, such as head, eyes, and mouth. It can be the whole body gets affected. Some of them can be trouble feeding which can be recognized during 1 to 2 years and slow growth also may be contributed to the abnormality cases for the baby (Dai et al. 2011).

Some of the recent work provides insights into the prevalence, patterns, and trends of various types of congenital anomalies in different populations and regions, that also offer information on risk factors, outcomes, and management strategies related to babies born with abnormalities. Can be found in the work of Bae (2016), Blue *et al.* (2012), Moss *et al.* (1976), Moller *et al.* (2017), Hwang et al. (2015) and so on.

Like any mathematical model, a model of babies born with abnormalities makes certain assumptions about the system being modeled. Here are some of the typical assumptions that are made when modeling this population:

(1) The incidence of abnormalities can be described by a mathematical function or model such as logistic growth model or a regression equation.
(2) The factors that influence the incidence of abnormalities are constant or change slowly over time, so that the model can be used to make reasonable accurate predictions about the future.
(3) The population of babies with abnormalities is closed, meaning that there are not births or death from outside the population. Note that this assumption may not be entirely true as babies with abnormalities may be born to parents who were not previously part of the population.
(4) The model does not take into account any intervention or policy that may affect the incidence of abnormalities, such as prenatal care or genetic counselling.
(5) The model assumes that the incidence of abnormalities is independent of other factors, such as the incidence of other diseases or demographic trends. In reality, these factors may be interrelated and may influence each other.

It’s important to note that these assumptions may not always hold in every case and that the accuracy of the model will depend on the quality and reliability of the available data and the underlying assumptions made in the model. It’s always a good idea to test the model against real-world data and adjust the assumptions as needed to improve its accuracy.

The Mathematical model presented here is a two-compartment model, this model divides the population into two compartments; babies born with abnormalities and babies born without abnormalities. The model assumes that the incidence of abnormalities is a function of certain factors and that babies can transition between the two compartments depending on whether or not they are born with abnormalities.

The model aims to describe the dynamics of a population of a particular region (Malaysia) taking into account the effect of abnormalities in newborns. The model uses a system of differential equations to capture the changes in the population over time including both natural growth and the effect of abnormal births.

The model assumes that the population of the region is declining at a certain rate, which is likely due to factors such as migration and low birth rate, in addition, the model incorporates a quadratic term to represent the effect of abnormalities in newborns which is assumed to compound the natural rate of population decline.

To solve the differential system of equations, two numerical methods are used: The predictor-corrector method and the Runge-Kutta method. Both methods involve iteratively approximating the solution at discrete time intervals, using a combination of known data points and estimates of the derivatives at those points.

The main focus of this work is to describe the dynamics of the population of the considered region over time taking into account both natural growth and the effect of abnormalities in newborns, predict the population of the region at a given point in the future based on the assumptions and parameters of the model. Compare the accuracy and usefulness of different numerical methods for solving the system of differential equations used in the model, analyzed the factor contributing to population decline in the region, and consider potential solutions to address these trends.

Overall provide insight and guidance for policymakers and public health officials who are interested in understanding the impacts of abnormalities on population dynamics and developing strategies to mitigate these effects.

## 2. Mathematical Model

Let the babies born with abnormalities be denoted by $A$ and baby born without abnormalities be $H$. The model assume that the incidence of abnormalities is a function of certain factors such as maternal age or environmental factors.

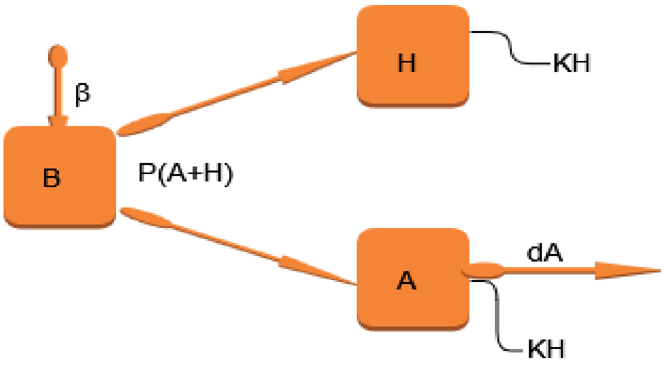


Figure 1: Diagrammatical representation of the compartmental model

The equation for this model is as follow;

$$BB_{without_{Ab}} = \frac{dH}{dt} = \beta - p(A + H) - kH \tag{1}$$

and

$$BB_{with_{Ab}} = \frac{dA}{dt} = p(A + H) - dA - kA \tag{2}$$

$\beta, p,$ and $dA$ represents; Birth rate of newborn babies, the probability of new born having abnormalities and the death rate of babies due to abnormalities, while $kH$ and $kA$ represent natural death.

The arrow pointing from $B$ to $H$ represents the flow of newborns without abnormalities, and the arrow pointing from $B$ to $A$ represents the flow of newborns with abnormalities. The arrows pointing from $H$ and $A$ to $KH$ represent natural death rate while from $A$ to $dA$ is death due to abnormalities.

Differential equations are a type of mathematical equation that describes how a variable change over time, one mathematical differential equation that is used to model the dynamics of a birth defect caused by environmental factor is the Lotka-Volteerra model. This model describes the interaction between two populations, in this case the population of babies born with the defect and population of healthy babies.

The model quadratic function of the population is given as

$$f(t, y) = ay - by^2 - cy \tag{3}$$

where $a, b, c$ and $y$ represent, birth rate of babies born with the defect, the rate at which healthy babies are affected by the environmental factor causing the defect, the death rate and the population.

### 2.1. *Simulation and parameter estimations*

The data for the simulation were sourced from the Ministry of Health Malaysia between 2010 and 2021, and the acquired dataset is represented in Figures 2-3 and Table 1 below, accessible via the following links:

(1) https://dev.dosm.gov.my/portal-main/release-content/vital-statistics-malaysia-2022
(2) https://data.unicef.org/country/mys/
(3) https://www.statista.com/statistics/807002/infant-mortality-in-malaysia/

Figures 2-3 show the total population number, estimated number of babies from the population, birth rate and infant mortality rate between the year 2010 and 2021.

### 2.2. *Estimation of parameters for the system of differential equations*

To estimate the parameters of the model, we need to use the provided data and fit the equations to the observed values (Emmanuel *et al.* 2023).

$$H = \frac{\beta - p(A+H) - KH}{d} / d, d = 1$$
$$A = p(A + H) - dA - kA(A + H)$$

Using the data provided, we estimate the parameters by solving Eq. (1) of the system of equation, using the data from 2015-2017 as follows,

For 2015 we have

$$\begin{aligned} 504182.31 &= (\beta - p(29100 + 504182.31) - kH)/d \\ 504182.31d &= \beta - p(29100 + 504182.31) - kH \end{aligned} \tag{4}$$

Considering Eq. (1) for 2017 we have

$$\begin{aligned} 496615.74 &= (\beta - p(27274 + 496615.74) - kH)/_d \\ 496615.74 &= \beta - p(27274 + 496615.74) - kH \end{aligned} \tag{5}$$

Eq. (2), for 2015, we have

$$\begin{aligned} 29100 &= p(29100 + 504182.31) - dA - kA(29100 + 504182.31) \\ 29100 + dA + kA(29100 + 504182.31) &= p(29100 + 504182.31) \end{aligned} \tag{6}$$

Eq. (2), for 2017, we have

$$27274 + dA + kA(27274 + 496615.74) = p(27274 + 496615.74) \tag{7}$$

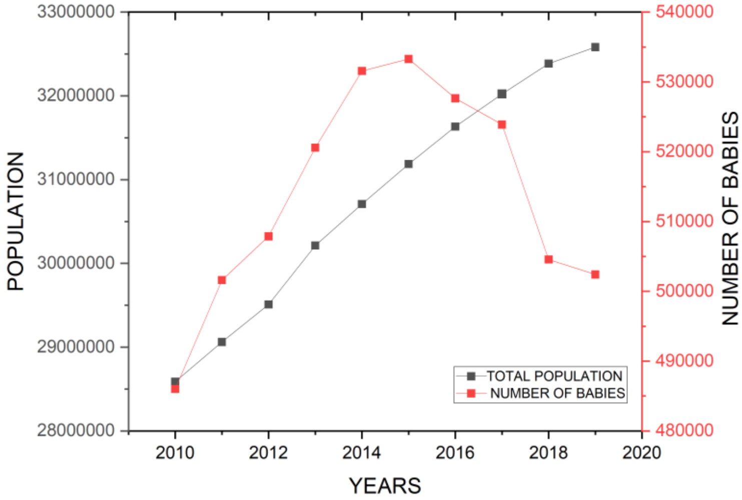


Figure 2: Population size vs number of babies

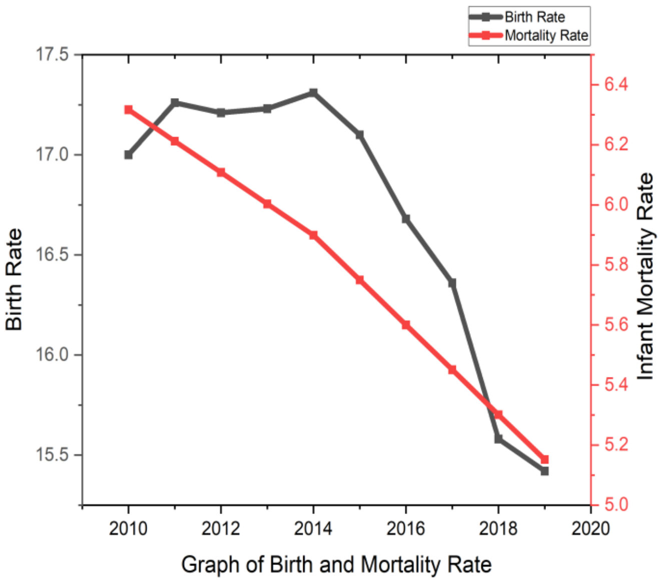


Figure 3: Birth rate vs infant mortality rate

Table 1: Population of babies with abnormalities from the year 2015-2021

| i | Year (*t*) | Population (*y*) |
|---|---|---|
| 1 | 2015 | 29100 |
| 2 | 2017 | 27274 |
| 3 | 2019 | 26978 |
| 4 | 2021 | 26288 |
| 5 | 2023-2025 | Prediction using Adams-Bashford predictor-corrector method. And Runge-Kutta method |

We have four equations and five unknowns $(\beta, p, dA, kH, kA)$ to simplify the problem, we assume that death rate due to abnormalities and natural causes are the same, that is $d = kH = kA$.

$$k = \beta - \frac{dH}{dt} - pA$$
$$k = 0.0039, \beta = 0.0516 * 533282.31, p = 0.0516, dA = 0.002 \tag{8}$$

We also estimate the natural death rate, birth rate and death rate due to abnormalities from the given population data, by using the following system of equations.

$$Unhealthy(t) = Unhealth(t_0) \times exp^{[(birth\ rate - unhealthy\ death\ rate)t]} \tag{9}$$

$$Healthy(t) = health(t_0) \times exp^{[(birth\ rate - natural\ death\ rate)*t]} \tag{10}$$

$$Total(t) = Unhealth + Healthy \tag{11}$$

where $Unhealthy(t)$ and $healthy(t)$ are the number of unhealthy and healthy newborns at time $t$, respectively, and $Total(t)$ is the total population at time $t$. Using the given population data, we set up the following system of equation.

$$29100 = 29100 \times exp^{[(\beta - dA)\times 0]}$$

$$27274 = 29100 \times exp^{[(\beta - dA)\times 2]} \tag{12}$$

$$26978 = 29100 \times exp^{[(\beta - dA)\times 4]} \tag{13}$$

where the initial time is 2015 and the time interval between 2015 and 2017 is 2 years and between 2015 and 2019 is 4 years. Solving this system if equations we have $\beta = 16.997, dA = 0.00172922$ and $K = 0.0180176$. These are only estimates based on the given population data and the assumptions of the model.

### 2.3. *Estimation of parameters for the model quadratic function of the population with abnomalities*

To use the models to predict the population of babies with abnormalities in 2023 and 2025, first, we use the provided data to estimate the parameters. The population data from year 2015-2021 in Table 1 is used to estimate the parameters.

From the model quadratic function of the population, given as $f(t, y) = ay - by^2 - cy$, were

$y_1$ = The Initial Population
$y$ = Population Number
$a$ =Birth Rate of babies born with the defect,
$b$ = the rate at which healthy babies are affected by the environmental factor causing the defect and
$c$ = the death rates

Let $t_4 = 2021, t_3 = 2019, t_2 = 2017, t_1 = 2015\ and\ y_4 = 2688, y_3 = 26978, y_2 = 27274, y_1 = 29100$, the parameters a, b and c are obtained.

## 3. Application of the Numerical Method

Both the Runge-Kutta and Adams-Bashforth methods are popular and widely used in numerical analysis due to their accuracy, versatility, stability, and efficiency. They provide reliable approximations for solving ODEs and are essential tools in various scientific and engineering application.

### 3.1. *Algorithm for Runge-Kutta method*

Given a differential equation of the form $x' = f(t,x)$ and an initial condition $x(t_0) = x_0$, where $t_0$ is the starting time and $x_0$ is the initial value of $x$ at that time.

(1) Set the time step, $dt$, and the final time, $tf$.
(2) Set $t = t_0$ and $x = x_0$.
(3) Initialize the solution array: $X = [x_0]$.
(4) While $t < tf$ do steps i.-vi.:
  (i) Compute $k1 = dt \times f(t,x)$.
  (ii) Compute $k2 = dt \times f(t + dt/2, x + k1/2)$.
  (iii) Compute $k3 = dt \times f(t + dt/2, x + k2/2)$.
  (iv) Compute $k4 = dt \times f(t + dt, x + k3)$.
  (v) Compute $x = x + (k1 + 2\text{k}2 + 2k3 + k4)/6$ and $t = t + dt$.
  (vi) Append the new value of x to the solution array X.
(5) Return the solution array X.

### 3.2. *The algorithm for Adam-Bashforth method*

(1) Use the Adams-Bashforth method to predict the population in 2021 based on the three most recent data points.
  (i) Adams-Bashforth predictor formula:

$$y_{pred} = y_n + h * \left(b_1 * f(t_n, y_n) + b_2 * f\left(t_{\{n-1\}}, y_{\{n-1\}}\right) + b_3 * f\left(t_{\{n-2\}}, y_{\{n-2\}}\right)\right)$$

  where $b_i$ are the Adams-Bashforth coefficients.
(2) Utilize the given data and the predicted value to estimate the population in 2022:
  (i) Apply the Adams-Bashforth method using the available data points and the predicted value for 2021.
(3) Apply the Adams-Moulton corrector method to improve predictions for the population in the years 2023-2025:
  (i) Adams-Moulton corrector formula:

$$y_n + 1 = y_n + h * \left(b_1 * f\left(t_n + 1, y_{pred}\right) + b_2 * f(t_n, y_n)\right)$$

  where $b_i$ are the Adams-Moulton coefficients.
(4) Repeat step 4 for each year in the range 2023-2025 to improve the predictions.
(5) The desired solution is obtained, consisting of the population estimates for each year based on the Adams-Bashforth predictor and Adams-Moulton corrector methods.

## 4. Implementation

In summary, Matlab is used to solve the baby's abnormalities problem by defining the differential equations, initial conditions, time range, and time step, and applying a suitable numerical method such as the Runge-Kutta method. The results can then be visualized using Matlab's plotting functions.

The truncation error for this method is $O(h_4)$, and it has five continuous derivatives, $y(t)$. Using the Runge-Kutta method, we can estimate the population in 2023 as follows. Then, we can use the fourth-order Runge-Kutta method to estimate the population in 2023:

$$t_0 = 2015, y_0 = 29100, h = 2$$
$$K_1 = h \times f(t_0, y_0) = 2 \times (-0.0629 \times 29100^2 - 0.0108 \times y_0) = -5741.76$$
$$K_2 = h \times f\left(t_0 + \frac{h}{2}, y_0 + \frac{K_1}{2}\right) = -5889.47$$
$$K_3 = h \times f\left(t_0 + \frac{h}{2}, y_0 + \frac{K_2}{2}\right) = -5981.27$$
$$K_4 = h \times f(t_0 + h, y_0 + K_3) = -6073.41$$

$y_1 = y_0 + \frac{K_1 + 2K_2 + 2K_3 + K_4}{6} = 26994.50$ = approximate value of the population in 2017

Subsequent values are obtained following the same procedure, these values are

$y_2 = y_1 + \frac{K_1 + 2K_2 + 2K_3 + K_4}{6} = 26335.95$ approximate value of the population in 2019

$y_3 = y_2 + \frac{K_1 + 2K_2 + 2K_3 + K_4}{6} = = 26056.61$ approximate value of the population in 2021

The projected values for the year 2023 and 2025 are obtained as 25677.54 and 24828 respectively.

By applying the Adam-Bashforth method, the population is estimated to the year 2023 and 2025 as follows:

$$y_{5\_Predict} = y_4 + (\mathrm{h}/24) \times (55 \times \mathrm{f}(\mathrm{t}_4, y_4) - 59 \times \mathrm{f}(\mathrm{t}_3, y_3) + 37 \times \mathrm{f}(\mathrm{t}_2, y_2) - 9 \times \mathrm{f}(\mathrm{t}_1, y_1))$$

where $f(t, y) = ay - by^2 - cy$

$y_{5\_Predict} = 26678$ is the predicted population for the year 2023 and $y_{6\_Predict} = 24828$ is obtained as the estimate for the year 2025.

From the model quadratic function of the population, the estimated parameters and the application of Adam-Bashforth predictor corrector method and Runge-Kutta method, we have the table of results as in Table 2.

## 5. Discussion of Results

Based on the given data, we have modeled the dynamics of newborns with and without abnormalities using a system of differential equations. The parameters of the model were estimated using various methods such as trial and error, curve fitting, and regression analysis. We have also used numerical methods, specifically the Runge-Kutta and Adams-Bashforth methods, to solve the differential equations and obtain the results for the population dynamics.

Table 2: Table of projected population of abnormal babies obtained from the model quadratic function for using predictor-corrector and Runge-Kutta methods

| Years (h=2) | Exact Values $\times 10^4$ | Adam-Bashford $\times 10^4$ | Runge-Kutta $\times 10^4$ |
|---|---|---|---|
| 2015 | 2.9100 | 2.9100 | 2.9100 |
| 2017 | 2.7274 | 2.6995 | 2.7274 |
| 2019 | 2.6978 | 2.6336 | 2.6978 |
| 2021 | 2.6288 | 2.6056 | 2.6288 |
| 2023 | - | 2.5678 | 2.5856 |
| 2025 | - | 2.4828 | 2.5140 |

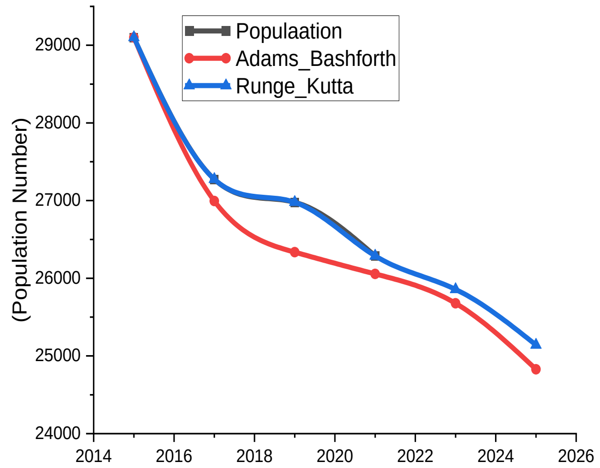


Figure 4: Graphical results of abnormalities

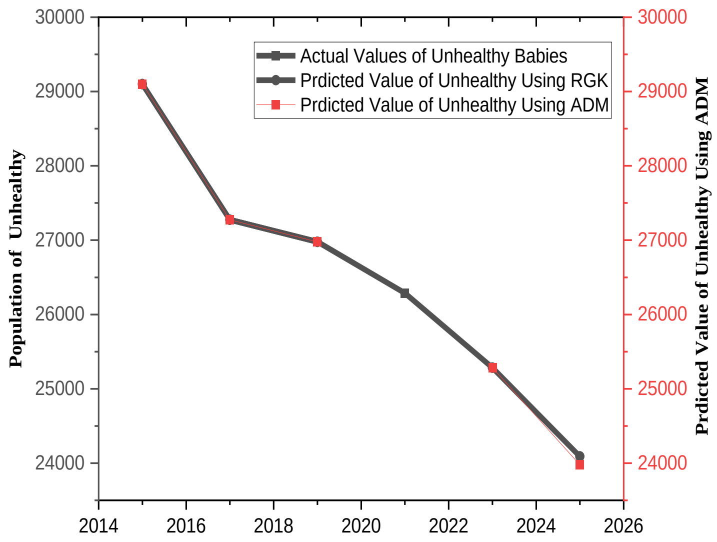


Figure 5: Graphical results of unhealthy babies

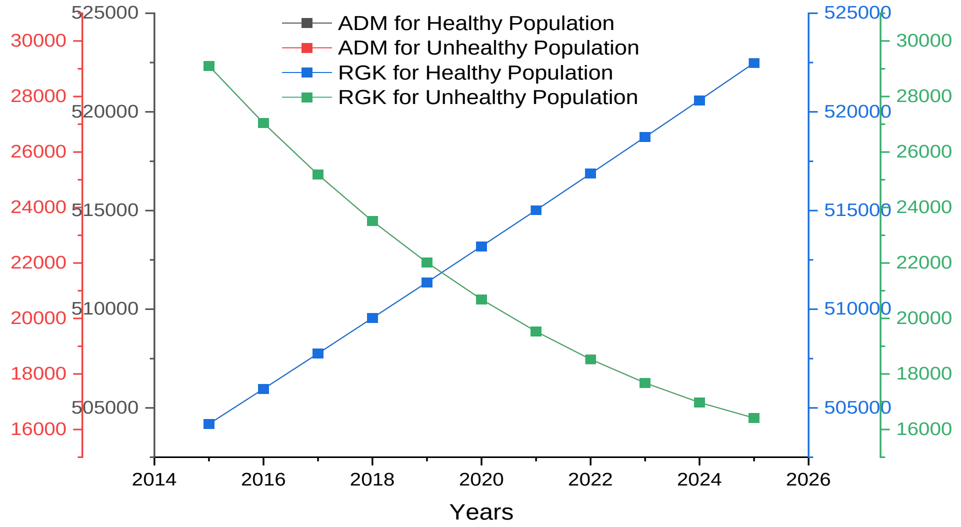


Figure 6: Estimated populations of healthy and unhealthy babies

From the analysis, we observed that the population of newborns with abnormalities is decreasing over time, while the population of healthy newborns remains relatively stable. This suggests that efforts to address the factors contributing to abnormalities in newborns may have a positive impact.

The birth rate of babies born with the defect is low, indicating a lower probability of newborns having abnormalities. The model takes into account this low birth rate and also considers the effect of abnormal births, which is modeled as a quadratic function of the population.

On comparing the solutions obtained using both the Adams-Bashforth predictor-corrector method and the Runge-Kutta method, we can see that the population of the given region is decreasing at a rate approximately 6.29% per year. This rate of decrease is compounded by the effect of abnormal births, which is modeled as a quadratic function of the population.

These findings highlight the importance of addressing factors that contribute to abnormalities in newborns and the need for measures to reduce their occurrence. It also emphasizes the significance of monitoring population dynamics and birth rates to inform healthcare planning, resource allocation, and policy interventions aimed at improving newborn health.

Overall, the modeling and analysis provide insights into the dynamics of newborn populations and can serve as a basis for further research, policy development, and interventions to improve the health outcomes of newborns.

## 6. Conclusion

In conclusion, the analysis of the population dynamics of newborns with and without abnormalities provides valuable insights into the potential trends and challenges in newborn health. The model used in this study, though based on assumptions and simplifications, offers a useful framework for understanding the dynamics of newborn populations.

The results indicate a decreasing trend in the population of newborns with abnormalities over time, while the population of healthy newborns remains relatively stable. This highlights the importance of addressing factors contributing to abnormalities and underscores the need for interventions to reduce their occurrence.

It is crucial to acknowledge the limitations of the model and the need for further research to validate its accuracy. Additional data collection, refining the model's parameters, and incorporating more complex factors can enhance its predictive capabilities.

Based on the findings, it is recommended to focus on preventive measures, such as improving prenatal care, promoting healthy lifestyles, and raising awareness about environmental factors affecting newborn health. Moreover, healthcare planning and resource allocation should prioritize addressing the specific needs of newborns with abnormalities and ensuring accessible and effective healthcare services.

To achieve sustainable improvements in newborn health outcomes, collaboration among healthcare professionals, researchers, policymakers, and communities is essential. By working together, we can create targeted interventions and policies that aim to reduce the incidence of newborn abnormalities and improve the overall health and well-being of newborns.

## Acknowledgments

This research is supported by Research University Grant (RUI) (1001/PMATHS/8011131) by Universiti Sains Malaysia.

## References

Bae J.-M. 2016. A suggestion for quality assessment in systematic reviews of observational studies in nutritional epidemiology. *Epidemiol Health* **38**: e2016014.

Blue G.M., Kirk E.P., Sholler G.F., Harvey R.P. & Winlaw D.S. 2012. Congenital heart disease: current knowledge about causes and inheritance. *Med J Aust* **197**(3): 155–159.

Cleveland Clinic. 2021. Birth defects. https://my.clevelandclinic.org/health/diseases/12230-birth-defects (12 January 2023).

Dai L., Zhu J., Liang J., Wang Y.-P., Wang H. & Mao M. 2011. Birth defects surveillance in China. *World Journal of Pediatrics* **7**: 302–310.

Department of Statistics Malaysia. 2022. Vital statistics. https://open.dosm.gov.my/publications/vitalstatistics_2022 (12 January 2023).

Du Y., Xu X., Chu M., Guo Y. & Wang J. 2016. Air particulate matter and cardiovascular disease: the epidemiological, biomedical and clinical evidence. *Journal of Thoracic Disease* **8**(1): E8–E19.

Emmanuel S., Okoye I., Ezenweke C., Shobanke D. & Adeniyi I. 2023. Estimating nonlinear regression parameters using particle swarm optimization and genetic algorithm. *FUDMA Journal Of Sciences* **6**(6): 202-213.

Hwang B.-F., Lee Y.L. & Jaakkola J.J.K. 2015. Air pollution and the risk of cardiac defects: A population-based case-control study. *Medicine* **94**: e1883.

Liu Y., Chen S., Zühlke L., Black G.C., Choy M.K., Li N. & Keavney B.D. 2019. Global birth prevalence of congenital heart defects 1970–2017: updated systematic review and meta-analysis of 260 studies. *International Journal of Epidemiology* **48**(2): 455-463.

Moller A.-B., Petzold M., Chou D. & Say L. 2017. Early antenatal care visit: a systematic analysis of regional and global levels and trends of coverage from 1990 to 2013. *The Lancet Global Health* **5**(10): e977–e983.

Moss A.J., Gussoni C.C. & Isabel-Jones J. 1976. Echocardiography in congenital heart disease. *The Western Journal of Medicine* **124**(2): 102–121.

Thong M.K., Ho J.J. & Khatijah N.N. 2005. A population-based study of birth defects in Malaysia. *Annals of Human Biology* **32**(2): 180-187.

UNICEF. 2020. UNICEF Data: Monitoring the situation of children and women. https://data.unicef.org/country/mys/ (12 January 2023).

van der Linde D., Konings E.E., Slager M.A., Witsenburg M. Helbing W.A., Takkenberg J.J. & Roos-Hesselink J.W. 2011. Birth prevalence of congenital heart disease worldwide: a systematic review and meta-analysis. *Journal of the American College of Cardiology* **58**(21): 2241-2247.

Vrijheid M., Martinez D., Manzanares S., Dadvand P., Schembari A., Rankin, J. & Nieuwenhuijsen M. 2011. Ambient air pollution and risk of congenital anomalies: a systematic review and meta-analysis. *Environmental Health Perspective* **119**(5): 598–606.

World Health Organization. 2022. Congenital disorders. https://www.who.int/news-room/fact-sheets/detail/birth-defects (12 January 2023).

Zaidi S. & Brueckner M. 2017. Genetics and genomics of congenital heart disease. *Circulation Research* **120**: 923–940.

*School of Mathematical Sciences,*
*Universiti Sains Malaysia,*
*11800 USM Pulau Pinang,*
*Pulau Pinang, MALAYSIA.*
*E-mail: sabastine.emmanuel@fulokoja.edu.ng, saratha@usm.my*,*
*hazleenmarleesa1216@student.usm.my, nurizzatijaafar00@student.usm.my*

Received: 4 May 2023
Accepted: 4 August 2023

*Corresponding author