Development on Mathematical Models of Type 2 Diabetes Mellitus (DM) in Individuals with A Genetic History

Afiatun Maghfirah[1], *Marwan* Ramli[2*], *Basri* A. Gani[3], and *Muhammad* Ikhwan[2]

[1]Mathematics Graduate Program, Universitas Syiah Kuala, Banda Aceh, Nangroe Aceh Darussalam, Indonesia
[2]Department of Mathematics, Universitas Syiah Kuala, Banda Aceh, Nangroe Aceh Darussalam, Indonesia
[3]Department of Oral Biology, Universitas Syiah Kuala, Banda Aceh, Nangroe Aceh Darussalam, Indonesia

Abstract. Diabetes Mellitus (DM) type 2 is one type of DM that is suffered by many DM sufferers. Type 2 DM can pass on to its offspring so it is necessary to prevent the emergence of type 2 DM. Prevention can be done such as exercise, weight loss, and dietary regulation. This study is a development of previous research with a primary focus on individuals who have a genetic history of having suffered from type 2 DM and it is recommended to choose one of the three prevention parameters involved. The next model development is to find the free equilibrium point values of DM type 2 and DM type 2 and the model will be analyzed for stability at the equilibrium point. The analysis of the basic reproduction number (R0) using the next generation matrix yielded the following values for each assumption: 0.1599; 0.1586; 0.1590; and 0.1582. Weight loss factors were discovered to play a significant influence in preventing type 2 diabetes among the three parameters studied.

1 Introduction

Biological dysfunction is a condition that occurs in humans so that it can be considered a disease, which is an abnormal state in an organism caused by dangerous deviations from the state of the functional structure of human organs [1, 2]. The disease itself can come from changes or environmental influences, bacteria, viruses, or even due to genes derived from offspring who have suffered from the disease [3]. One of the biggest roles that cause almost all diseases is genetic [4].

The role of genetics in the process of disease emergence including the emergence of common disorders in individuals is larger or may be smaller in scope due to differences that occur in DNA [4]. One disease caused by family history or genetic factors is diabetes mellitus. Diabetes Mellitus (DM) is a metabolic disease characterized by hyperglycemia and impaired carbohydrate, fat, and protein metabolism due to lack of work or insulin secretion

* Corresponding author: marwan.math@usk.ac.id

[5–8]. DM is referred to as a life-threatening disease because its development is relatively fast, making it one of the many global challenges that must be faced in the 21st century [9], [10]. DM sufferers will feel an abnormality in metabolism resulting in polyuria (excessive urination with high sugar levels), polydipsia (excessive thirst), and polyphagia (high hunger) which is characterized by an increase in high sugar, so that it can cause hyperglycemia conditions (blood sugar levels ≥ 180 mg / dl) [11, 12].

There are types of DM caused in addition to lifestyle factors, namely genetic factors. The number of people with type 2 DM accounts for 90% of the total DM sufferers [9], [13–16]. Type 2 diabetes is a chronic disease in metabolic disorders caused by insulin resistance [14, 17]. Type 2 diabetes will appear if insulin levels in an individual's body are not enough to maintain normal glucose levels due to a decrease in insulin's ability to assist in secreting glucose. Research focused on the surge in people with type 2 diabetes because genetic factors play a big role, contributing about 40-70% in the risk of developing this condition. [18, 19]. The heritability of type 2 DM has an influence that ranges from 30-70%. Evidence from genetic studies confirms that β cell dysfunction plays a central role in the development of this disease. The involvement of genetic factors and the interaction between environmental factors, especially a sedentary lifestyle and obesity, increase the risk of developing type 2 DM [20]. According to the American Diabetes Association report, people with type 2 diabetes account for about 90-95% of total DM sufferers, and are expected to increase from 6.9 million people in 2010 to 30 million people in 2030. This fact has the potential to increase the number of individuals with a history of type 2 DM that can be passed on to their offspring. If a person has a family history of type 2 DM, the risk will be higher when reaching the age of ≥ 45 years. Therefore, it is highly recommended for such individuals to adopt a healthy lifestyle as a preventive measure [21, 22].

Individuals who have a family history of type 2 diabetes can take preventive steps by avoiding the factors that trigger the disease. In addition, it is recommended to adopt a recommended healthy lifestyle, including regular exercise, weight loss, and dietary regulation [23]. By following these recommendations, it is hoped that individuals can avoid a diagnosis of type 2 DM, so that the number of people with type 2 DM in the future can be suppressed. Faced with this problem, mathematical models can provide solutions related to the factors that most influence the success of individuals with a history of disease to avoid type 2 DM. Some mathematical models that have been used in the context of type 2 DM are the glucose-insulin model [11] to prevent cancer in patients with type 2 DM, the mathematical model to prevent the occurrence of type 2 DM disease without compartment separation [24], and the mathematical model built to see the characteristics and decisions to be taken in different cases of type 2 DM problems [25]. These models can help in the understanding and treatment of problems related to type 2 DM.

The mathematical model that will be used in this problem is a development of the previous model [26] which aims to reduce the rate of people with complications of type 2 DM so that the disability rate and mortality rate will decrease. The model will be developed by adding several new compartments along with other parameters. The compartment that will be added by dividing groups who are prone to suffer from type 2 DM into 3 parts, namely groups who are susceptible to suffering from type 2 DM at the age of < 45 years who have a genetic history (S_{g1}), groups who are susceptible to suffer from type 2 DM at the age of ≥ 45 years who have a genetic history (S_{g2}), and groups who are susceptible to suffer from type 2 DM who do not have a genetic history (S).

Based on the addition of some of these compartments, several parameters will be added that will be reviewed for the magnitude of the effect on success for individuals who have a history of disease so that these individuals do not suffer from type 2 DM. The parameters are exercise (ε_1), weight loss (ε_2), and diet regulation (ε_3). This model does not aim to cure individuals who are experiencing type 2 DM, but rather to prevent the emergence of this

disease, especially in individuals with a related family history. By comparing the three factors or parameters that have the greatest impact, it is expected to help individuals avoid the risk of developing type 2 DM. If prevention efforts are successful, the number of cases of type 2 DM may decrease over time.

2 Method

Development of a mathematical model by adding several compartments that focus on prevention that can be done by vulnerable individuals who have a genetic history of having suffered from type 2 DM. The added compartment is a vulnerable subpopulation with a genetic history of type 2 DM aged < 45 years (S_{g1}) and a vulnerable subpopulation with a genetic history of type 2 DM aged ≥ 45 years (S_{g1}). The model was developed to look for dominant parameters that are thought to have an impact on susceptible individuals who have a genetic history of having suffered from type 2 DM. The total population in this model is symbolized as N. Subpopulation contained in this model, namely Subpopulation susceptible to suffer from type 2 DM at the age of < 45 years who have a genetic history (S_{g1}), Subpopulation susceptible to suffer from type 2 DM at the age of ≥ 45 years who have a genetic history (S_{g2}), Subpopulation susceptible to type 2 DM disease (S), Subpopulation with type 2 DM without complications (D), Subpopulation of people with type 2 diabetes with complications (C), Subpopulation of people with complications supported by habitual factors (H), and Subpopulation of people with complications supported by environmental factors (E). The total rate of change in the population is as follows:

$$N = S_{g1} + S_{g2} + S + D + C + H + E \tag{1}$$

Individuals who have a genetic history of suffering from type 2 DM will be in the vulnerable subpopulation group and have a genetic history of type 2 DM aged < 45 years (S_{g1}) and if they are 45 years old, the individual will be in the vulnerable subpopulation group and have a genetic history of type 2 DM aged ≥ 45 years (S_{g2}). Individuals who do not have a genetic history of suffering from type 2 DM will be in the subpopulation group susceptible to type 2 DM (S). Individuals with a genetic history are given the option to prevent the onset of type 2 DM by choosing exercise (ε_1), weight loss (ε_2), or dietary regulation (ε_3). If the individual does not follow one of the options given, then it is at risk of experiencing type 2 DM so that it will be in the group of people with type 2 DM without complications (D). Similarly, individuals who are in subpopulations susceptible to type 2 DM (S) if they interact that can cause type 2 DM (β) such as maintaining a lifestyle, it can trigger to be in the group of people with type 2 diabetes without complications (D).

Patients with type 2 diabetes can experience an increase in blood sugar if blood sugar levels ≥ 180 mg / dl so that it will trigger complications, both macrovascular or microvascular complications. This will bring the individual to the group of people with type 2 DM with complications (C). A person with type 2 diabetes with complications has the possibility of dying as a result of the complications. However, the individual also has a chance to recover from its complications, but not recover from type 2 DM, namely by choosing treatment factors that can help in the recovery process. The factors that can be chosen are habitual factors so that they will be in the group of patients with type 2 DM with complications who choose habitual factors (H) or environmental factors so that they will be in the group of patients with type 2 DM with complications who choose environmental factors (E). The mathematical model can be built as follows:

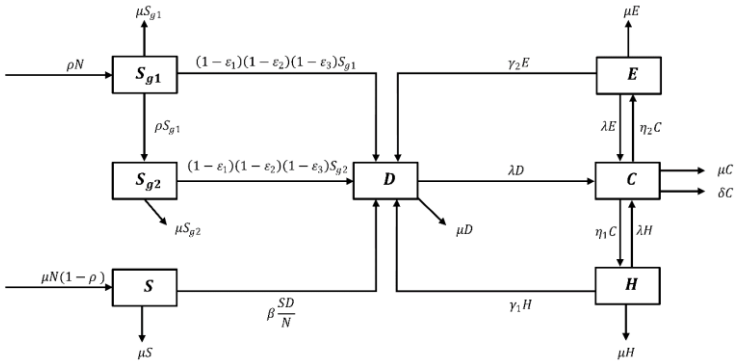

Fig. 1. Transfer diagram depiction of Type 2 Diabetes Mellitus (DM)

Table 1. Symbols, variables, and parameters used in the research model

Symbols / Parameters	Explanation
N	Number of individuals in a population
S_{g1}	Number of susceptible individuals suffering from type 2 Diabetes Mellitus (DM) at the age of < 45 years who have a genetic history
S_{g2}	Number of susceptible individuals suffering from type 2 Diabetes Mellitus (DM) at the age of ≥ 45 years who have a genetic history
S	Number of individuals who are susceptible to type 2 Diabetes Mellitus (DM)
D	Number of individuals with uncomplicated type 2 Diabetes Mellitus (DM)
C	Number of individuals with type 2 Diabetes Mellitus (DM) with complications
H	Number of individual people with complications supported by habitual factors
E	Number of individual people with complications supported by environmental factors
μ	Natural birth and death rates of individual populations
ρ	The proportion of many individuals who have genetic factors in people with diabetes mellitus
ε_1	The individual has a genetic history of applying exercise to prevent type 2 Diabetes Mellitus
ε_2	The level of individuals having a genetic history of applying weight loss to prevent type 2 Diabetes Mellitus
ε_3	The individual has a genetic history of applying dietary regulation to prevent type 2 Diabetes Mellitus
β	The level of behavioral interactions that can lead to the onset of type 2 Diabetes Mellitus
λ	The degree of occurrence of complications
γ_1	The cure rate of complications becomes uncomplicated by using habitual factors
γ_2	The cure rate of complications becomes without complications using environmental factors
δ	Death rate from complications
η_1	Individual rates of complications supported by habitual factors
η_2	Individual rates of complications supported by environmental factors

Based on the description of the transfer diagram regarding type 2 Diabetes Mellitus (DM), an equation system can be formed as follows, namely:

$$\frac{dS_{g1}}{dt} = \rho N - \mu S_{g1} - (1-\varepsilon_1)(1-\varepsilon_2)(1-\varepsilon_3)S_{g1} - \rho S_{g1} \quad (2)$$

$$\frac{dS_{g2}}{dt} = \rho S_{g1} - \mu S_{g2} - (1-\varepsilon_1)(1-\varepsilon_2)(1-\varepsilon_3)S_{g1} \quad (3)$$

$$\frac{dS}{dt} = \mu N(1-\rho) - \beta \frac{SD}{N} - \mu S \quad (4)$$

$$\frac{dD}{dt} = (1-\varepsilon_1)(1-\varepsilon_2)(1-\varepsilon_3)(S_{g1}+S_{g2}) + \beta\frac{SD}{N} + \gamma_1 H + \gamma_2 E - (\lambda+\mu)D(5)$$

$$\frac{dC}{dt} = \lambda D + \lambda E + \lambda H - \mu C - \delta C - \eta_1 C - \eta_2 C \quad (6)$$

$$\frac{dH}{dt} = \eta_1 C - \gamma_1 H - \mu H - \lambda H \quad (7)$$

$$\frac{dE}{dt} = \eta_2 C - \gamma_2 E - \mu E - \lambda E \quad (8)$$

If each Eqs.2 through Eqs.8 is divided by the total number of populations (N) or it can be formed as follows:

$$s_{g1} = \frac{S_{g1}}{N}; s_{g2} = \frac{S_{g2}}{N}; s = \frac{S}{N}; d = \frac{D}{N}; c = \frac{C}{N}; h = \frac{H}{N}; e = \frac{E}{N} \quad (9)$$

Therefore, if substituted for Eqs.2 to Eqs.8, then the system of equations will take the form:

$$\frac{ds_{g1}}{dt} = \rho - \mu s_{g1} - (1-\varepsilon_1)(1-\varepsilon_2)(1-\varepsilon_3)s_{g1} - \rho s_{g1} \quad (10)$$

$$\frac{ds_{g2}}{dt} = \rho s_{g1} - \mu s_{g2} - (1-\varepsilon_1)(1-\varepsilon_2)(1-\varepsilon_3)s_{g1} \quad (11)$$

$$\frac{ds}{dt} = \mu(1-\rho) - \beta s d - \mu s \quad (12)$$

$$\frac{dd}{dt} = (1-\varepsilon_1)(1-\varepsilon_2)(1-\varepsilon_3)(s_{g1}+s_{g2}) + \beta s d + \gamma_1 h + \gamma_2 e - (\lambda+\mu)d \quad (13)$$

$$\frac{dc}{dt} = \lambda d + \lambda e + \lambda h - \mu c - \delta c - \eta_1 c - \eta_2 c \quad (14)$$

$$\frac{dh}{dt} = \eta_1 c - \gamma_1 h - \mu h - \lambda h \quad (15)$$

$$\frac{de}{dt} = \eta_2 c - \gamma_2 e - \mu e - \lambda e \quad (16)$$

Table 2. Parameter values used in the research model

Parameter	Value	Reference
μ	0.02	[27]
ρ	0.077	[28]
β	0.48	[29]
λ	0.85	[30]
δ	0.178	[31]
η_1	0.19	[26]
η_2	0.08	[26]
γ_1	0.37141	[28]
γ_2	0.08	[32]
ε_1	[0.45; 0.10; 0.10; 0.11]	Assumption
ε_2	[0.10; 0.35; 0.11; 0.75]	Assumption
ε_3	[0.11; 0.11; 0.55; 0.10]	Assumption

3 Results and Discussion

3.1 Equilibrium Point

This research model in the form of a non-linear system has two types of equilibrium points, namely DM type 2 free equilibrium points and DM type 2 equilibrium points. The equilibrium point is sought by making every equation constant to time, which means that there is no effect of change back over time. The free equilibrium point of type 2 DM is obtained as follows, namely:

$$E_0 = (s_{g1}^*, s_{g2}^*, s^*, 0,0,0,0) \quad (17)$$

where, $s_{g1}^* = \frac{\rho}{\mu+(1-\varepsilon_1)(1-\varepsilon_2)(1-\varepsilon_3)+\rho}, s_{g2}^* = \frac{\rho^2}{(\mu+(1-\varepsilon_1)(1-\varepsilon_2)(1-\varepsilon_3))(1+\rho)},$

$$\text{dan } s^* = (1-\rho).$$

As for the type 2 DM equilibrium points obtained are as follows, namely:

$$E_1 = (s_{g1}{}^*, s_{g2}{}^*, s^*, d^*, c^*, h^*, e^*) \quad (18)$$

where,

$s_{g1}{}^* = \frac{\rho}{\mu+(1-\varepsilon_1)+(1-\varepsilon_2)+(1-\varepsilon_3)+\rho}$, $s_{g2}{}^* = \frac{\rho^2}{(\mu+(1-\varepsilon_1)+(1-\varepsilon_2)+(1-\varepsilon_3))(1+\rho)}$, $s^* = (1-\rho)$, $d^* = \frac{(1-\varepsilon_1)+(1-\varepsilon_2)+(1-\varepsilon_3)(s_{g1}{}^*+s_{g2}{}^*)+\gamma_1 h^*+\gamma_2 e^*}{\lambda+\mu-\beta s^*}$, $c^* = \frac{\lambda d^*+\lambda e^*+\lambda h^*}{\mu+\eta_1+\eta_2}$, $h^* = \frac{\eta_1 c^*}{\gamma_1+\mu+\lambda}$, and $e^* = \frac{\eta_2 c^*}{\gamma_2+\mu+\lambda}$.

3.2 Basic Reproduction Number (R_0)

The basic reproduction number is an indicator of the severity of the disease in a region. The basic reproductive number (R_0) is divided into two: $R_0 < 1$ indicates the disease will decrease over time, while $R_0 > 1$ indicates the disease will get worse over time. To find the basic reproduction number (R_0) can be done using the next generation matrix method. The equation involved to find R_0 is as follows, namely:

$$\frac{dD}{dt} = (1-\varepsilon_1)(1-\varepsilon_2)(1-\varepsilon_3)(S_{g1}+S_{g2}) + \beta\frac{SD}{N} + \gamma_1 H + \gamma_2 E - (\lambda+\mu)D \quad (19)$$

$$\frac{dC}{dt} = \lambda D + \lambda E + \lambda H - \mu C - \delta C - \eta_1 C - \eta_2 C \quad (20)$$

$$\frac{dH}{dt} = \eta_1 C - \gamma_1 H - \mu H - \lambda H \quad (21)$$

$$\frac{d}{dt} = \eta_2 C - \gamma_2 E - \mu E - \lambda E \quad (22)$$

Then from the equation by following the steps of the next generation matrix method [33], it will get R_0 as follows, namely:

$$R_0 = \frac{\begin{array}{l}(\beta S(\delta\lambda^2+2\delta\lambda\mu-\delta\lambda\gamma_1-\delta\lambda\gamma_2+\delta\mu^2-\delta\mu\gamma_1-\delta\mu\gamma_2+\delta\gamma_1\gamma_2+\lambda^2\mu \\ +2\lambda\mu^2+\lambda\mu\eta_1+\lambda\mu\eta_2-\lambda\mu\gamma_1-\lambda\mu\gamma_2-\lambda\eta_1\gamma_1-\lambda\eta_2\gamma_2+\mu^3+\mu^2\eta_1 \\ +\mu^2\eta_2-\mu^2\gamma_1-\mu^2\gamma_2-\mu\eta_1\gamma_2-\mu\eta_2\gamma_1-\mu\eta_2\gamma_2+\mu\gamma_1\gamma_2+\eta_1\gamma_1\gamma_2+\eta_2\gamma_1\gamma_2)\end{array}}{\begin{array}{l}(N(\delta\lambda^3+3\delta\lambda^2\mu-\delta\lambda^2\gamma_2+3\delta\lambda^2\mu-2\delta\lambda\mu\gamma_1-2\delta\lambda\mu\gamma_2+\delta\lambda\gamma_1\gamma_2+\delta\mu^3 \\ -\delta\mu^2\gamma_1-\delta\mu^2\gamma_2+\delta\mu\gamma_1\gamma_2+\lambda^3\mu+3\lambda^2\mu^2+\lambda^2\mu\eta_1+\lambda^2\mu\eta_2-\lambda^2\mu\gamma_1-\lambda^2\mu\gamma_2 \\ -2\lambda^2\eta_1\gamma_1-2\lambda^2\eta_2\gamma_2+3\lambda\mu^3+2\lambda\mu^2\eta_1+2\lambda\mu^2\eta_2-2\lambda\mu^2\gamma_1-2\lambda\mu^2\gamma_2-3\lambda\mu\eta_1\gamma_1 \\ -\lambda\mu\eta_1\gamma_2-\lambda\mu\eta_2\gamma_1-3\lambda\mu\eta_2\gamma_2+\lambda\mu\gamma_1\gamma_2+2\lambda\eta_1\gamma_1\gamma_2+2\lambda\eta_2\gamma_1\gamma_2+\mu^4+\mu^3\eta_1+\mu^3\eta_2\end{array}} \quad \text{z} \quad (23)$$

Table 3. The value of basic reproduction number (R_0)

ε_1, ε_2, and ε_3	R_0
$\varepsilon_1 = 0.45$, $\varepsilon_2 = 0.10$, and $\varepsilon_3 = 0.11$	0.1599
$\varepsilon_1 = 0.10$, $\varepsilon_2 = 0.25$, and $\varepsilon_3 = 0.11$	0.1586
$\varepsilon_1 = 0.01$, $\varepsilon_2 = 0.14$, and $\varepsilon_3 = 0.37$	0.1590
$\varepsilon_1 = 0.11$, $\varepsilon_2 = 0.75$, and $\varepsilon_3 = 0.10$	0.1582

Based on the various values tested, it can be seen that the $R_0 < 1$ values indicate a decrease in the potential for the spread of type 2 DM along with prevention efforts by individuals. In preventing this disease, a healthy lifestyle becomes a key factor. By undergoing exercise routines, efforts to lose weight, and managing a balanced diet, the risk of type 2 diabetes can be controlled, having a positive impact on overall public health. By maintaining an R_0 value of < 1, the spread of the disease can be limited or even reduced, protecting many people from the risk of type 2 DM. The positive effects of this prevention are not only on individuals, but also reach the community at large. Reduced disease prevalence can reduce the burden on health systems, reduce medical care costs, and improve overall quality of life.

3.3 Stability Analysis

The research model used involves a nonlinear system, so a linearization step is needed for the system to form a Jacobian matrix. A Jacobian matrix consists of partial derivatives of variables against related functions. After the linearization process is complete and the Jacobian matrix is formed, the next step is to calculate the eigenvalue of the matrix. This eigenvalue is used to analyze the stability of the identified equilibrium point. Here are the eigenvalues obtained:

Table 4. Eigenvalues at DM type 2 free equilibrium point

λ_{ei}, (i = 1,2,...,7)	$\varepsilon_1 = 0.45$, $\varepsilon_2 = 0.10$, and $\varepsilon_3 = 0.11$	$\varepsilon_1 = 0.10$, $\varepsilon_2 = 0.25$, and $\varepsilon_3 = 0.11$	$\varepsilon_1 = 0.01$, $\varepsilon_2 = 0.14$, and $\varepsilon_3 = 0.37$	$\varepsilon_1 = 0.11$, $\varepsilon_2 = 0.75$, and $\varepsilon_3 = 0.10$
λ_{e1}	-0.013932104	-0.013932104	-0.013932104	-0.0139321040
λ_{e2}	-0.126989794	-0.126989794	-0.126989794	-0.1269897944
λ_{e3}	-0.138410104	-0.138410104	-0.138410104	-0.1384101040
λ_{e4}	-0.180307104	-0.302701707	-0.302701707	-0.2200335877
λ_{e5}	-0.302701707	-0.540433588	-0.380233588	-0.3027017071
λ_{e6}	-0.460333588	-0.597289810	-0.597289810	-0.59728981045
λ_{e7}	-0.597289810	-0.742932104	-0.742932104	-0.7189011040
	Asymptotically Stable	Asymptotically Stable	Asymptotically Stable	Asymptotically Stable

Table 5. Eigenvalues at the equilibrium point of the DM state type 2

λ_{ei}, (i = 1,2,...,7)	$\varepsilon_1 = 0.45$, $\varepsilon_2 = 0.10$, and $\varepsilon_3 = 0.11$	$\varepsilon_1 = 0.10$, $\varepsilon_2 = 0.25$, and $\varepsilon_3 = 0.11$	$\varepsilon_1 = 0.01$, $\varepsilon_2 = 0.14$, and $\varepsilon_3 = 0.37$	$\varepsilon_1 = 0.11$, $\varepsilon_2 = 0.75$, and $\varepsilon_3 = 0.10$
λ_{e1}	-0.083085647	-0.08345632218	-0.0825586601	-0.080351739855
λ_{e2}	-0.186375	-0.20536436650	-0.20550634147	-0.205856056866
λ_{e3}	-0.20542297409	-0.54219	-0.38199	-0.22179
λ_{e4}	-0.46209	-0.749	-0.749	-0.724969
λ_{e5}	-0.78333643871	-0.7839161593	-0.7825048356	-0.778924044729
λ_{e6}	-1.009241442	-1.00927265357	-1.0091972389	-1.009014302402
λ_{e7}	-1.4247625667	-1.42468391761	-1.42487426063	-1.425340448060
	Asymptotically Stable	Asymptotically Stable	Asymptotically Stable	Asymptotically Stable

3.4 Graphic Illustration

Fig. 2(a) shows the x-axis representing the time of month, while the y-axis represents the number of individuals illustrated as a group of each subpopulation involved. In Fig. 2(b), a subpopulation of individuals susceptible to type 2 DM is depicted at the age younger than 45 years with a genetic history (S_{g1}). The number of these individuals increased to 34986918 at t = 10. Then, the number remains constant until t = ∞, reaching 35084921 souls. Fig. 2(c) depicts a subpopulation susceptible to type 2 DM at the age starts from 45 years with a genetic history (S_{g2}). The number of individuals in this subpopulation increased by 5826253 to t = 13, then stabilized at t = ∞, reaching 5867904 inhabitants.

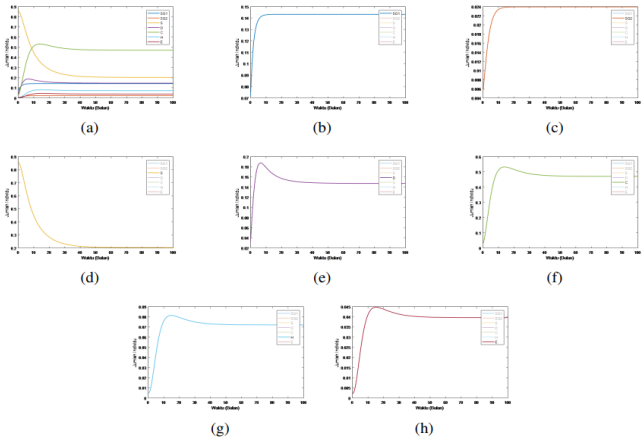

Fig. 2. Graph depicting the condition of the distribution of type 2 Diabetes Mellitus (DM) with $\varepsilon_1 = 0.45$, $\varepsilon_2 = 0.10$, and $\varepsilon_3 = 0.11$

The increase in the number of individuals in S_{g2} is due to the age of individuals reaching ≥ 45 years. The subpopulation susceptible to type 2 DM (S) in Fig. 2(d) experienced a significant decrease to t = 60, from 50128316 to 49834308 people. After that, the number of individuals remains constant until t = ∞. This decrease may be due to individuals not following healthy lifestyle recommendations or engaging in behaviors that increase the risk of type 2 DM. Fig. 2(e) depicts an uncomplicated subpopulation of people with type 2 diabetes (D). The number of individuals in this subpopulation initially increases significantly to t = 7, reaching 45963207 inhabitants. This increase can be caused by individuals with a genetic history who are unable to prevent type 2 DM as well as vulnerable individuals who do not follow the recommendations for a healthy lifestyle. However, the number then drops to t = 54, reaches 36211951 inhabitants, and remains stable at t = ∞, which is 36138449 inhabitants. This decrease may occur due to the presence of individuals who experience a rise in blood sugar levels, resulting in complications. In Fig. 2(f), a subpopulation of people with type 2 DM with complications (C) is depicted. At first, subpopulation C experienced a significant increase up to t = 14, reaching 130514927 inhabitants. However, the number then dropped by 115618536 to t = 55, and remained stable at t = ∞, reaching 115398030 inhabitants. This decrease may be due to individuals choosing habitual or environmental factors to recover from complications, or death from complications. Fig. 2(g) shows a subpopulation of people with complications with the support of habitual factor (H). At first, there was a significant increase up to t = 15, reaching 19950873 of the soul, because individuals who chose habitual factors to recover from complications. However, the number dropped to 17662514 to t = 81, and remained stable to t = ∞, which is 17657614 souls. This decrease may be due to individuals recovering from complications or experiencing relapses while in the healing process. Fig. 2(h) depicts a subpopulation of people with complications with the support of environmental factors (E). A significant increase occurred up to t = 15, from 10966487 to 9726755 souls. However, the number then decreased to 9716955 and remained stable at t = ∞. This decrease may occur as individuals return to experience complications or recover from complications.

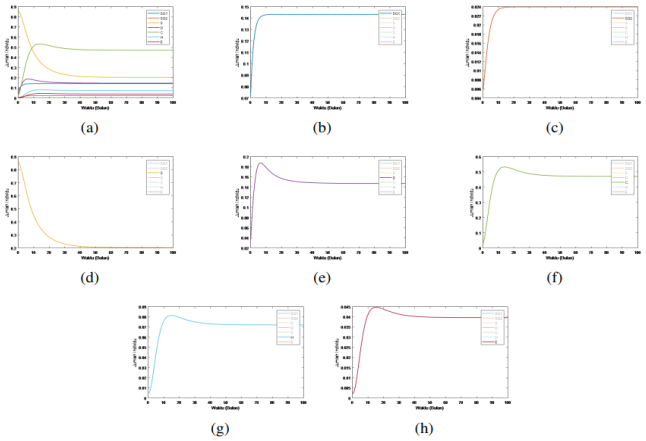

Fig. 3. Graph depicting the condition of the distribution of type 2 Diabetes Mellitus (DM) with $\varepsilon_1 = 0.10$, $\varepsilon_2 = 0.35$, and $\varepsilon_3 = 0.11$

Fig. 3(a) depicts the x-axis as time (months) and the y-axis as the number of individuals that constitute the accumulation of each subpopulation involved. Fig. 3(b) represents a subpopulation of susceptible individuals with type 2 DM at the age younger than 45 years with a genetic history (S_{g1}) who have a genetic history. The number of individuals in S_{g1} rises from 30380797 at t = 0 to 30552302 at t = 7, and will continue to increase constantly until it reaches 30552302 at t = ∞. In Fig. 3(c), there is a subpopulation susceptible to type 2 DM at the age starts from 45 years with a genetic history (S_{g2}). The number of individuals in S_{g2} increases from 4321913 at t = 12 then to 4351314 souls and remains constant until t = ∞. Subpopulations susceptible to type 2 DM (S) are shown in Fig. 3(d). The number of individuals in S continues to decline significantly until it reaches 53264398 at t = 36, and then remains constant until t = ∞. This decrease could be caused by individuals not adhering to healthy lifestyle recommendations or engaging in behaviors that increase the risk of type 2 diabetes. Fig. 3(e) depicts an uncomplicated subpopulation of type 2 DM (D). The number of individuals in this subpopulation initially increases significantly until it reaches 46894231 at t = 6. This increase may be due to individuals with a genetic history who have been unsuccessful in preventing type 2 diabetes and susceptible individuals who do not follow lifestyle recommendations. However, the number later dropped to 36628461 at t = 38 and remained constant at t = ∞. This decrease may occur due to individuals experiencing elevated blood sugar levels and experiencing complications. In Fig. 3(f), a subpopulation of people with type 2 diabetes with complications (C) is depicted. At first, there was a significant increase until it reached 131519453 at t = 13. However, the number later dropped to 117088574 at t = 42 and remained constant at t = ∞. This decrease may be due to individuals choosing habitual or environmental factors to recover from complications, or individuals dying from complications. Fig. 3(g) depicts a subpopulation of people with complications that support habitual factors (H). The number of individuals in this subpopulation initially increases significantly until it reaches 20100327 at t = 14, possibly due to individuals choosing habitual factors for recovery from complications. However, the number later dropped to 17853618 at t = 47 and remained constant at t = ∞. This decrease may be due to individuals recovering from complications or experiencing relapses during the recovery process. In Fig. 3(h), a subpopulation of people with complications is depicted that supports environmental factors (E). The number of individuals in this subpopulation increased from 11039989 at t = 14, then dropped to 9816985 at t = 48 and remained constant at t = ∞. This decrease may be due to individuals experiencing relapses from complications or recovering from complications.

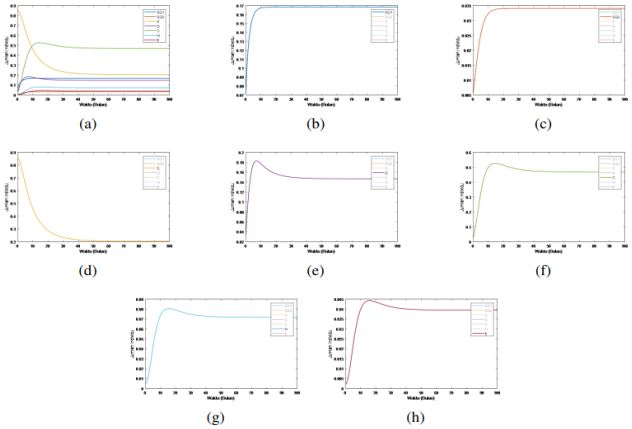

Fig. 4. Graph depicting the condition of the distribution of type 2 Diabetes Mellitus (DM) with $\varepsilon_1 = 0.10$, $\varepsilon_2 = 0.11$, and $\varepsilon_3 = 0.55$

Fig. 4(a) displays the x-axis as time (months) and the y-axis as the number of individuals, which is the accumulation of each subpopulation involved. Fig. 4(b) illustrates a subpopulation of individuals susceptible to type 2 DM at the age younger than 45 years with a genetic history (S_{g1}). The number of individuals in S_{g1} increases by 40989576 people at the time t = 10 then will be constant to 41234582 people until t = ∞. In Fig. 4(c), there is a subpopulation that is susceptible to type 2 DM at the age of ≥ 45 years with a genetic history (S_{g2}). The number of individuals in S_{g2} increases to 8256716 at the time t = 14, then becomes constant by 8347369 souls until t = ∞. This increase in the number of individuals may be due to the presence of individuals who have reached the age of ≥ 45 years. Subpopulations susceptible to type 2 DM (S) are shown in Fig. 4(d). The number of individuals in S continues to decline significantly until it reaches 52798886 at t = 40, then again becomes constant at t = ∞. This decrease may result from individuals not following healthy lifestyle recommendations or engaging in behaviors that increase the risk of type 2 DM. Fig. 4(e) depicts an uncomplicated subpopulation of type 2 DM (D). The number of individuals in this subpopulation initially increases significantly until it reaches 44468667 at t = 6. This increase may be due to individuals with a genetic history who have been unsuccessful in preventing type 2 diabetes and susceptible individuals who do not follow lifestyle recommendations. However, the number later dropped to 36309953 at t = 38 and remained constant at t = ∞. This decrease may occur due to individuals experiencing elevated blood sugar levels and experiencing complications. Fig. 4(f) depicts a subpopulation of people with type 2 diabetes with complications (C). At first, there was a significant increase until it reached 128922385 at t = 14. However, the number later dropped to 116059547 souls at t = 42 and remained constant at t = ∞. This decrease may be due to individuals choosing habitual or environmental factors to recover from complications, or the presence of individuals who die from complications. Fig. 4(g) illustrates a subpopulation of people with complications supported by habitual factors (H). The number of individuals in this subpopulation initially increases significantly until it reaches 197083137 at t = 15, possibly due to individuals choosing habitual factors for recovery from complications. However, the number later dropped to 17755161 at t = 46 and remained constant at t = ∞. This decrease may occur due to individuals recovering from complications or experiencing relapses during the recovery process. In Fig. 4(h), there is a subpopulation of people with complications that support environmental factors (E). The number of individuals in this subpopulation initially increases from 10824384 at t = 15, then drops to 9676054 at t = 61 and remains constant until t = ∞. This

decrease may be due to individuals experiencing relapses from complications or recovering from complications.

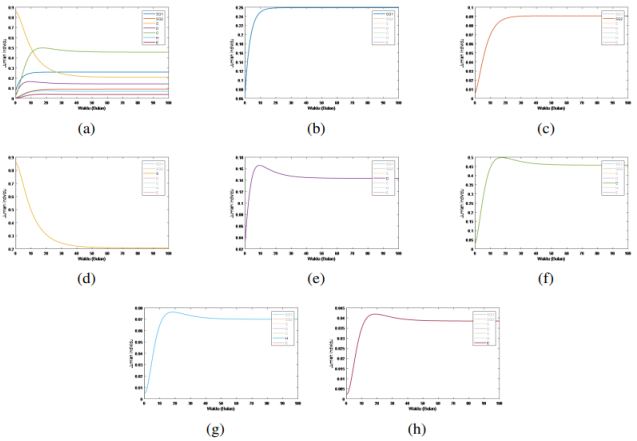

Fig. 5. Graph depicting the condition of the distribution of type 2 Diabetes Mellitus (DM) with $\varepsilon_1 = 0.11$, $\varepsilon_2 = 0.75$, and $\varepsilon_3 = 0.10$

In Fig. 5(a), the x-axis represents time (months) and the y-axis represents the number of individuals, which is the accumulation of each subpopulation involved. Fig. 5(b) shows a subpopulation of individuals susceptible to type 2 DM at the age younger than 45 years with a genetic history (S_{g1}). The number of individuals in S_{g1} increases from 62182632 at $t = 0$ to 63456666 at $t = 12$, and will remain constant until $t = \infty$. In Fig. 5(c), there is a subpopulation susceptible to type 2 DM at the age of ≥ 45 years with a genetic history (S_{g2}). The number of individuals in S_{g2} increases to 21624267 at the time $t = 21$ and then to 22187782 soul until $t = \infty$. This increase in the number of individuals may be due to the presence of individuals who have reached the age of ≥ 45 years. Subpopulations susceptible to type 2 DM (S) are shown in Fig. 5(d). The number of individuals in S continues to decline significantly until it reaches 54268925 at $t = 40$, then again becomes constant until $t = \infty$. This decrease may result from individuals not following healthy lifestyle recommendations or engaging in behaviors that increase the risk of type 2 DM. Fig. 5(e) depicts an uncomplicated subpopulation of type 2 DM (D). The number of individuals in this subpopulation initially increases significantly until it reaches 40573065 at $t = 9$. This increase may be due to individuals with a genetic history who have been unsuccessful in preventing type 2 diabetes and susceptible individuals who do not follow lifestyle recommendations. However, the number then drops to 35158423 at $t = 54$ and remains constant until $t = \infty$. This decrease may occur due to individuals experiencing elevated blood sugar levels and experiencing complications. Fig. 5(f) depicts a subpopulation of people with type 2 diabetes with complications (C). At first, there was a significant increase until it reached 122086706 at $t = 18$. However, the number later dropped to 112163945 at $t = 61$ and remained constant at $t = \infty$. This decrease may be due to individuals choosing habitual or environmental factors to recover from complications, or the presence of individuals who die from complications. Fig. 5(g) illustrates a subpopulation of people with complications supported by habitual factors (H). The number of individuals in this subpopulation initially increased significantly to reach 186719940 at $t = 18$, due to individuals choosing habitual factors for recovery from complications. However, the number then drops to 17179851 at $t = 59$ and remains constant until $t = \infty$. This decrease occurs due to individuals recovering from complications or experiencing relapses during the recovery process. In Fig. 5(h), there is a subpopulation of people with complications that support environmental factors (E). The number of individuals in this subpopulation initially increases

by 10263319 at t = 18, then drops to 9479298 at t = 52 and remains constant until t = ∞. This decrease may be due to individuals experiencing relapses from complications or recovering from complications.

The previous research [28] focused on the prevalence of diabetes mellitus in the United States, while the research continued [26] emphasized factors that could be recommended to assist in the healing of complications in patients with type 2 diabetes mellitus. The development of this research involved dividing the vulnerable subpopulation into three groups based on genetic and non-genetic categories, with subcategories based on age (at the age younger than 45 years and starts from 45 years). This research focused on developing models on preventive measures by implementing three parameters [23]. The results indicated that weight loss was the most effective parameter in preventing type 2 diabetes mellitus in individuals with a genetic history. These findings provide a crucial contribution to developing more specific prevention strategies for individuals with specific genetic risks.

4 Conclusion

This research focuses on developing models to prevent type 2 Diabetes Mellitus (DM) in individuals with a genetic history. The three main parameters used are exercise, weight loss, and dietary regulation, in accordance with the recommendations of the Ministry of Health. Each assumed parameter value used results in stability at an asymptotic stable equilibrium point and a base reproduction number (R_0) of less than 1. The simulation results showed that the weight loss parameter (ε_2) was very influential in reducing the severity of type 2 DM in a region and preventing individuals who had a genetic history of having suffered from type 2 DM. Therefore, individuals with a genetic history are recommended to choose weight loss parameters as they provide more effective results in preventing type 2 DM.

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