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Developing an Epidemiological Mathematical Model for Type 2 Diabetes Mellitus in Zamfara State, Integrating Lifestyle and Treatment Factors

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ABSTRACT

This research presents a mathematical model comprising a system of ordinary differential equations (ODEs) to investigate the dynamics of a population concerning diabetes and its complications. The model considers the recruitment rate of successive individuals, progression rates between different health states, and the impact of lifestyle factors on disease incidence. The analysis focuses on the existence and uniqueness of solutions within a biologically feasible region. The results demonstrate the existence of an invariant region Ω, where the model is mathematically well-posed, ensuring the positivity of population variables. Furthermore, theorems on the existence and uniqueness of solutions are established, affirming the stability of the model under Lipschitz conditions. The study explores the region of interest for the model parameters and establishes the existence of a unique solution within specified bounds. The disease-free equilibrium is investigated, revealing a stable equilibrium point denoted as E_o, representing a population with diabetes-free individuals. Overall, the research provides a comprehensive analysis of the proposed mathematical model, offering understandings into the dynamics of diabetes and its complications within a population context.

Key words: Epidemiological; Mathematical model; Diabetes mellitus; life style

1. Introduction

Type 2 diabetes mellitus is a significant public health challenge, with a growing global prevalence. Lifestyle factors, such as diet, physical activity and obesity, play a crucial role in its development, while treatment options, including medication and behavioral interventions, are central to its management. Understanding the complex interplay between these factors is essential for effective prevention and control. This research introduces an epidemiological mathematical model designed to unravel the intricate dynamics of Type 2 diabetes mellitus by incorporating lifestyle and treatment variables. By employing mathematical modeling techniques, we seek to shed light on the multifaceted relationships between lifestyle choices, treatment strategies and the epidemiology of this chronic condition. The dynamics of Type 2 diabetes, examining how lifestyle factors contribute to its onset and progression. The impact of various treatment approaches on the course of the disease, including the potential for disease management and prevention and predictive capabilities of the model, enabling us to anticipate future trends in Type 2 diabetes prevalence under different scenarios. Through this research, we aim to enhance our understanding of Type 2 diabetes and contribute to evidence-based strategies for its prevention and management. The integration of lifestyle and treatment factors into our mathematical model promises to provide valuable insights that can ultimately lead to improved health outcomes and more efficient resource allocation in healthcare systems. Diabetes (diabetes mellitus) is a condition of the metabolism. The way our bodies use digested food for energy and growth is referred to as metabolism. The majority of what we eat is converted to glucose. Glucose is a type of sugar found in the blood that serves as our bodies' primary source of energy. A person with diabetes has hyperglycemia (excess glucose in the blood), which occurs when the body does not create enough insulin, produces too much insulin, or has cells that do not respond appropriately to the insulin produced by the pancreas.

Diet to avoid on a Type 2 Diabetes

Because diabetes increases the risk for cardiovascular disease, people with diabetes must be careful with their intake such as the following:

- Sodium: Sodium balance is critical. But consuming too much sodium (usually in the form of salt) can exacerbate health problems that occur frequently in people with Type 2 diabetes, including hypertension, congestive heart failure, liver and kidney problems, heart attack and stroke. Processed foods are high in sodium and should be consumed sparingly.
- Cholesterol: Sources of cholesterol include high-fat dairy products, red meat, organ meats, eggs and shellfish. Eat these foods sparingly.

- Saturated fats: Saturated fats are mostly found in high-fat dairy products, beef, processed meats and pork products. You should also consume these foods sparingly.
- Trans-unsaturated fats: most of these fats are typically found in processed foods, shortening and margarine. Avoid them completely.

Although the Natural foods also called "Superfood" When it comes to providing these key nutrients and controlling blood sugar, it certainly won't hurt to add some nutrient-rich superfoods to your diet. When choosing the superfoods you need to eat each day, be sure to pay consideration to the different carbohydrate and protein values in the different foods. Beans, for example, are a little high in carbohydrate, but they are worthy of occasional inclusion, thanks to the protein they provide without all the saturated fat. Citrus fruits are also higher in carbohydrate, but they provide much-needed vitamin C, potassium, folate and fiber.

Causes of Type 2 Diabetes

The pancreases (an organ behind the stomach) release more insulin while you're healthy, which helps your body store and utilize sugar from the meals you eat. Diabetes develops when one or more of the following conditions occur:

1) Your pancreases do not produce insulin.
2) Your pancreases produce very little insulin, and
3) Your body does not respond to insulin as it should.

People with type 2 diabetes, unlike those with type 1 diabetes, produce insulin; however, the insulin produced by their pancreases is either insufficient or their bodies are unable to recognize and utilized it efficiently (doctors call this insulin resistance).

Glucose (sugar) cannot enter your cells if there isn't enough insulin or if the insulin isn't used properly. This has the potential to harm numerous parts of the body. Also, because cells aren't getting the glucose they require, they don't function properly.

Healthy Life Meal Design

Generating meals designed plan helps you to manage your diabetes, it is generally a good idea to forget about all the latest trends and fad diets and go back to the basics of healthy eating. Whether you have diabetes or any other health condition where your diet is important, a healthy eating plan always has a few things in common. It should focus heavily on lean proteins (or plant-based proteins), non-starchy vegetables, fruits, and minimal added sugar and salt. Above all, it is very imperative to keep your blood glucose level within your target range when you are living with diabetes, and attentive meal planning helps you do this with less room for potentially dangerous errors. Life is complicated, but a wide variety of resources can help you organize the right plan for you and your family. Epidemiology is study of diseases spread in a living organism within the context of its environment (Berkman 2001). Mathematical modeling can be used to study the epidemiology of a disease. Historically,researchers have used mathematical models to identify the spread of infectious diseases such as measles, rubella, HIV (punami 2018), dengue fever (Syafruddin 2013), (Rangkuti, 2014), TB (Side, 2015, 2016), to what just happened such as ebola (Azizah, 2017) and Zika virus (Bonyah, 2016). Along with the development of science, mathematical modeling is not only used to study the spread of infectious diseases, but also non-communicable diseases. Even public illnesses such as drugs can also be modeled (Sutanto, 2017). This can be done because there are similarities characteristic of its spread, that is through social interaction as media spread. Diabetes is a non-communicable disease which has some various "spread" characteristic, one of them through social interactions that lead to lifestyle changes. Diabetes is a chronic disease that is indicated by high blood sugar levels. A person is diagnosed positive for diabetes when its fasting blood sugar level are more than 126 mg/dL or its blood sugar level 2 hours post meal are more than 200 mg/dL. Pancreatic organs that are supposed to produce the hormone insulin cannot work optimally. Without insulin, the body cells cannot absorb and process glucose into energy, so that the blood sugar levels increasing (Diabetes Mellitus type I). Diabetes also occurs due to the body's inability to utilize the available insulin (Diabetes Mellitus type II). Based on 2015 International Diabetes Federation (IDF 2015) data, the prevalence of diabetics is around 9.1 % of the world's population. This action has two main implications. Early detection of diabetes requires preventative measures, and after someone has been diagnosed with diabetes, care and precaution should be taken to prevent or, at the very least, delay the development of complications with the available resources (Akinsola and Temitayo 2019).

Mathematical modeling serves as a tool for examining the epidemiology of diseases

Mathematical modeling serves as a valuable tool for examining the epidemiology of diseases. Throughout history, researchers have employed mathematical models to understand the transmission of infectious diseases like measles (2-4), dengue fever (Syafruddin and Noorani, 2013; Rangkuti et al., 2014; TB Side et al., 2016; Side, 2015), and to analyze recent occurrences such as Ebola and Zika virus (Bonyah and Okosun, 2016). As scientific understanding has advanced, mathematical modeling has expanded its scope beyond infectious diseases to include non-communicable diseases and even public health issues such as drug epidemics, sharing common characteristics in their spread through social interactions and media dissemination. Diabetes, a non-communicable disease characterized by high blood sugar levels, exhibits various "spread" characteristics, particularly through social interactions leading to lifestyle changes. The chronic nature of diabetes is marked by fasting blood sugar levels exceeding 126 mg/dL or blood sugar levels 2 hours post-meal surpassing 200 mg/dL. In Diabetes Mellitus type I, the pancreas fails to optimally produce insulin, preventing the absorption and processing of glucose into energy, resulting in elevated blood sugar levels. Diabetes Mellitus type II, on the other hand, occurs due to the body's inability to effectively utilize available insulin. According to the 2015 International Diabetes Federation data, approximately 9.1% of the global population is affected by diabetes. The World Health Organization (2017) has identified diabetes as the sixth leading cause of death worldwide. Complications associated with diabetes often lead to severe outcomes, including amputations and permanent disabilities. Recognizing the significance of complications in the epidemiology of diabetes, Boutayeb et al. (2004) introduced the Diabetes Complication (DC) model in 2004 to distinguish between diabetics without complications (D) and those with complications (C). However, the DC model assumed a constant incidence of new diabetes cases, contrasting with the World Health Organization's data (2016) indicating a rising trend in diabetes incidence due to lifestyle changes influenced by social interactions. Gary-Webb et al. (2013) emphasized the impact of social interaction as a significant factor in lifestyle changes that elevate the susceptibility of individuals to diabetes.

Objectives of the Study

The aim of this research is to use the mathematical model to gain a deeper understanding of how Type 2 diabetes spreads and how it can be effectively managed and prevented through lifestyle and treatment interventions. Then the specific objectives are:

i. To Understand Disease Dynamics and Analyze the spread and progression of Type 2 diabetes in a population, considering how lifestyle choices and treatment interventions influence its occurrence and prevalence.

ii. To Predict Future Trends in other to Forecast the future trends and prevalence of Type 2 diabetes under different scenarios, such as changes in lifestyle or treatment strategies.

iii. To optimize Treatment Strategies and Assess the effectiveness of various treatment approaches and identify optimal strategies for managing the disease.

2. Method of the Research

The Research population

The study population include diabetic patient that attended the hospitals situated in Zamfara state Federal and state own Hospitals in the state are considered for the research. Only adults with type 2 diabetes attending the Hospitals in the state were included in the study. Pregnant and lactating women and all those who declined to participate were excluded from the study.

Method of Data collection

Mathematical Analysis

The mathematical model formulated have been solve by analytical method and the analysis was made to plot the graph for the model Numerically by fourth order runge kutta method using the matlab software in order to find the validation of the model.

3. Results and Discussion

Mathematical Model

Designing a mathematical model for an epidemiological study involves creating a system of differential equations to represent the dynamics of different compartments. Below is a simplified compartmental model for Type 2 Diabetes Mellitus in Zamfara State, considering the following compartments, $S(t)$ Successive individuals, $D(t)$ **:** Diabetes patience without complication, $C(t)$ **:** Diabetes patience with complication, $\lambda(D)$: Progress rate from diabetes without complication to Complications, α: Recruitment rate of successive individual, $\gamma(c)$: progress rate from C to D, β: Rate of interaction causing incidence, $\frac{\beta SD}{N}$ **:** Number of incidence that occur due to lifestyle factor $\mu(c)$: Natural death rate, but a patience has complication issue, $\delta(c)$: desease induced death rate with complication, $\mu(D)$: Natural death rate, With diabetes disease but not complicated

Model Formulation

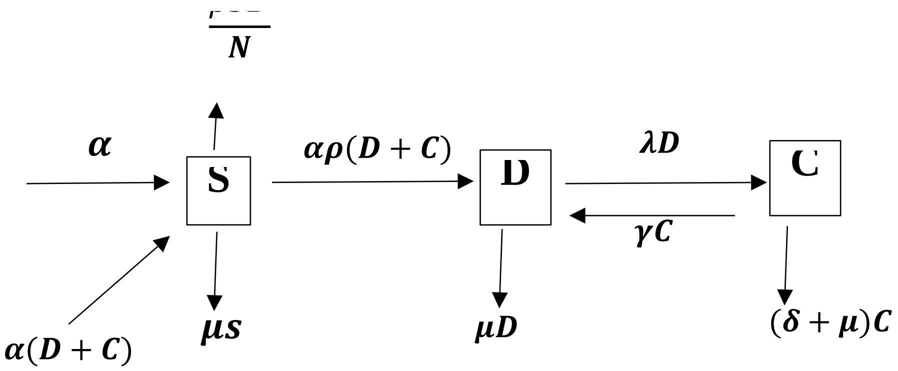

Figure 1. Mathematical model for epidemiological diabetes mellitus

We have generate the following ordinary differential equations (ODE) from the model in figure 1 above

$\frac{dS}{dt} = \alpha + (1-\rho)(D+C) - \frac{\beta SD}{N} - \mu S$

$\frac{dS}{dt} = \alpha + \alpha(D+C) - \alpha\rho(D+C) - \frac{\beta SD}{N} - \mu S$ 1

$\frac{dD}{dt} = \alpha\rho(D+C) - (\lambda+\mu)D + \gamma C$ 2

$\frac{dC}{dt} = \lambda D - (\gamma+\delta+\mu)C$ 3

With the following parameters $S, D, C, \mu, \delta, \alpha, \gamma, , \lambda, \beta > 0$ as

$N = S + D + C + \mu + +\delta + \alpha + \gamma + \lambda + \beta$ is the total population.

Invariant Region

Since the model monitor changes in the human population the variable and parameters are assumed to be positive for all $t \geq 0$

Lemma 1

In the biological feasible region $\Omega = \left\{(S, D, C) \in \frac{\mathbb{R}^3}{N} \leq \frac{Q}{\alpha-\mu}\right\}\ 0 \leq S,\ 0 \leq D,\ 0 \leq C$

Proof

$N = S + D + C$

Where N is the total number of the population

$\frac{dN}{dt} = \frac{d}{dt}(S+D+C) = \frac{dS}{dt} + \frac{dD}{dt} + \frac{dC}{dt}$

Adding equation 1-3 we have

$\alpha + \alpha(D+C) - \alpha\rho(D+C) - \frac{\beta SD}{N} - \mu S + \alpha\rho(D+C) - (\lambda+\mu)D + \gamma C + \lambda D - (\gamma+\delta+\mu)C$

$= \alpha + \alpha D + \alpha C\ - \frac{\beta SD}{N} - \mu S - \mu D + \gamma C - \gamma C - \delta C - \mu C$

$= \alpha + \alpha(D+C)\ - \frac{\beta SD}{N} - \mu S - \mu D - \delta C - \mu C$

$\frac{dN}{dt} = \alpha\ - \frac{\beta SD}{N} - (S+D+C)\mu - \delta C + \alpha(D+C)$

$\frac{dN}{dt} = \alpha\ - \frac{\beta SD}{N} - N\mu - \delta C + \alpha(D+C)$

$\frac{dN}{dt} = \alpha - N\mu - \frac{\beta SD}{N} - \delta C + \alpha(D+C)$

$\frac{dN}{dt} \leq \alpha - N\mu$

Using the formula $\frac{dy}{dx} + P(x)y = Q(x)$

Integrating Factor $= e^{\int p(x)dx}$

Integrating factor $xy = \int I.F\ Q(x)dx$

$p(x) = \mu$, $Q(x) = \alpha$

I.F $\leq e^{\int \mu dt}$ then $\leq e^{\mu t}$ therefore $e^{\mu t} \times N \leq \int e^{\mu t} \times \alpha dt$

$Ne^{\mu t} \leq \frac{e^{\mu t}}{\mu} \times \alpha$ then $Ne^{\mu t} \leq \alpha \frac{e^{\mu t}}{\mu}$

At $t = 0$, We have $N \leq \frac{\alpha}{\mu}$

If $(0) \leq \frac{\alpha}{\mu}$, then $\frac{\alpha}{\mu}$ is the upper bound of N. on the other hand, if $N(0) > \frac{\alpha}{\mu}$, then N will decrease to $\frac{\alpha}{\mu}$. This means that if $N(0) < \frac{\alpha}{\mu}$ then the solution (S, D, C) enters Ω or approaches it asymptotically. Hence it positively invariant under the flow induce by the system 1-3. Thus, in Ω the model 1-3 is well posed mathematically. Hence it is sufficient to study the dynamics of the model in Ω.

Existence and Uniqueness of the Solution

Theorem on existence and uniqueness of the solution of the model 1-3 was formulated and proof established the system of linear equation below was considered.

$$\left.\begin{aligned} x_1' &= f_1(t, x_1, x_2, \dots x_n) \\ x_2' &= f_2(t, x_1, x_2, \dots x_n) \\ &\vdots \\ x_n' &= f_n(t_1, x_1, x_2, \dots x_n) \end{aligned}\right\} \qquad 4$$

Writing equation 4 in compact form as

$$x' = f(t, x) \quad x(t_o) = x_o \qquad 5$$

Theorem 1 (Garba et al. 2016)

Let D denote the region

$|t - t_0| \leq a,\ \|x - x_0\| \leq b, x = (x_1, x_2, x_3, \dots, x_n)\ x_o = (x_{1o}, x_{2o}, x_{3o}, \dots, x_{no})$ 6

And supposed that $f(t, x)$ satisfied the lipschits conditions

$$\|f(t, x_1) - f(t, x_2)\| \leq k\ \|x_1 - x_2\| \qquad 7$$

Whenever the pairs (t, x_1) and (t, x_2) belongs to D where K is a positive constant. Then there is a constant $\delta > 0$ such that there exist a unique continuous vectors solution $x(t)$ of the system (5) in the interval $|t - t_0| \leq \delta$. it is important to note that condition (6) is satisfied by the requirement that $\frac{\delta f_i}{\delta x_j}$ $i, j = 1, 2, \dots, n$ are continuous and bounded in D.

Now returning to our model equation (1) - (3) we are interested in the region

$$0 \leq \alpha \leq R \qquad 8$$

Looking for the bounded solution in the region, and whose partial derivative satisfy $\delta \leq \alpha \leq 0$ where α and δ are positive constants from theorem 1, theorem 2 was obtained.

Theorem 2

Let D denote the region $0 \leq \alpha \leq R$, then equation (1) - (3) has a unique solution

Proof:

To show that $\frac{\delta f_i}{\delta x_j}$ $i, j = 1, 2, \dots, n$ are continuous and bounded in D

Let ; $f_1 = \alpha + \alpha(D + C) - \alpha\rho(D + C) - \frac{\beta SD}{N} - \mu S$ 9

$f_2 = \alpha\rho(D + C) - (\lambda + \mu)D + \gamma C$ 10

$f_3 = \lambda D - (\gamma + \delta + \mu)C$ 11

Using equation (9) we have the following derivative

$$\left|\frac{\delta f_i}{\delta s}\right| = \left|-\mu - \frac{\beta D}{N}\right| < \infty,$$

$$\left|\frac{\delta f_i}{\delta D}\right| = \left|\alpha - \alpha\rho - \frac{\beta S}{N}\right| < \infty$$

$$\left|\frac{\delta f_i}{\delta c}\right| = |\alpha - \alpha\rho| < \infty$$

The above partial derivatives exist, are continuous and are bounded in the same way, other derivatives exist and bounded. Hence by theorem 2 the model 1-3 has unique solution.

Disease free Equilibrium

At the equilibrium point $\frac{dS}{dt} = \frac{dD}{dt} = \frac{dc}{dt} = 0$

Thus, equation 1- 3 becomes

$$\alpha + \alpha(D + C) - \alpha\rho(D + C) - \frac{\beta SD}{N} - \mu S = 0 \quad 12$$

$$\alpha\rho(D + C) - (\lambda + \mu)D + \gamma C = 0 \quad 13$$

$$\lambda D - (\gamma + \delta + \mu)C = 0 \quad 14$$

From equation (13) $\alpha\rho(D + C) - (\lambda + \mu)D + \gamma C = 0$

$$\alpha\rho D - (\lambda + \mu)D = -\gamma C - \alpha\rho C$$

$$[\alpha\rho - (\lambda + \mu)]D = -c[\gamma + \alpha\rho]$$

$$C = -\frac{[\alpha\rho - (\lambda + \mu)]D}{[\gamma + \alpha\rho]} \quad 15$$

Substitute equation 15 in 14

$$\frac{\lambda D + (\gamma + \delta + \mu)[\alpha\rho - (\lambda + \mu)]D}{[\gamma + \alpha\rho]} = 0$$

$$\left[\frac{\lambda D + (\gamma + \delta + \mu)[\alpha\rho - (\lambda + \mu)]}{[\gamma + \alpha\rho]}\right] D = 0$$

That simply means is either $\frac{\lambda D + (\gamma + \delta + \mu)[\alpha\rho - (\lambda + \mu)]}{[\gamma + \alpha\rho]} = 0$ or $D = 0$

When $D = 0$ correspond to the disease free equilibrium, substituting $D = 0$ in equation 13 we have

$$\alpha\rho(0 + C) - (\lambda + \mu)0 + \gamma C = 0$$

$\alpha\rho C + \gamma C = 0$ then, $[\alpha\rho + \gamma]C = 0$

$$C = \frac{0}{\alpha\rho + \gamma}, \therefore C = 0$$

Substituting $D = 0, C = 0$ in equation (12) we have

$$\alpha + \alpha(0 + 0) - \alpha\rho(0 + 0) - \frac{\beta S(0)}{N} - \mu S = 0$$

$$\alpha - \mu S = 0$$

$$S = \frac{\alpha}{\mu}$$

Let E_o denote the disease free equilibrium, thus we have

$$E_o = (S, D, C) = (\frac{\alpha}{\mu}, 0, 0)$$

Application and Discussion

The SDC model, as outlined by Purnami (2018), serves as a valuable tool in analyzing the prevalence of diabetes within Zamfara state. In this study, data obtained from the Zamfara State Ministry of Health for the period January to December 2023 is utilized to estimate model parameters and validate model accuracy. The model considers common diabetes-related complications, such as cardiovascular diseases, chronic kidney disease, lower extremity conditions, visual impairment, and ketoacidosis. Utilizing data from 2023, key parameters are determined, including birth rate, interaction rate, recovery rate of complications, death rate due to complications, occurrence rate of complications, and natural mortality rate. These parameters are integrated into the SDC model equations (1 to 3) to represent the diabetes prevalence dynamics within Zamfara state.

In 2023, data reveals various parameters crucial for modeling diabetes prevalence in Zamfara state: the birth rate (0.00541), interaction rate (0.05421), recovery rate of complications (0.1238), death rate due to complications (0.0023), occurrence rate of complications (0.22586), and the natural mortality rate (0.00255). Additionally, the proportion of genetic disorder births stands at 0.053. Substituting these parameter values into equations 3.5.1 to 3.5.3 of the model, we conduct numerical simulations using MATLAB's fourth-order Runge-Kutta method. For the initial values required by the algorithm (corresponding to the numbers of susceptible individuals (S), those with diabetes (D), and those with complications (C) in 2023, t = 0), we rely on population estimates. With an estimated population of 5,833,500 individuals in Zamfara state according to the National Bureau of Statistics for 2022, roughly 33% (approximately 1.9 million) are aged 40 and above. Of these, 4.8% are diabetic, comprising 92,402.6 without complications and 16,632.5 with complications, leaving the remaining 1,832,652.4 as healthy individuals susceptible to diabetes. Thus, our initial values are determined as follows:

$S(0), D(0), C(0) = (1{,}832{,}652.4, 92{,}402.6, 16{,}632.5)$.

Numerically solving the model equations for the year 2023, the SDC model demonstrates notable accuracy in predicting diabetes prevalence in Zamfara state. The prevalence of diabetes, as per SDC model solutions spanning the 2023-2030 period, is depicted in Figure 2. Specifically, Figure 2 illustrates a prevalence of 4.8% for diabetes in 2023. The escalation in prevalence correlates with a surge in diabetes-related deaths. In 2023, approximately 277 individuals (constituting 0.3%) succumbed to diabetes. This figure is expected to rise annually, with an average increase of 1.6% compared to the previous year's death toll.

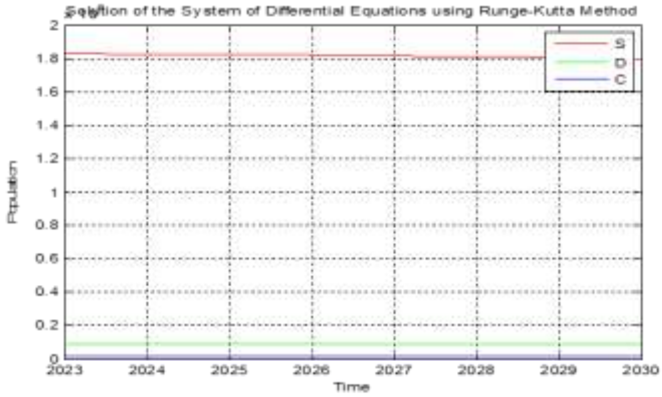

Figure 2: Illustrates the projected prevalence of diabetes

The figure likely starts with a data point representing the prevalence of diabetes in 2023, which serves as the baseline for the projections. From your description, it appears that the prevalence in 2023 is 4.8%. A trend line or curve connects the data points for each year, indicating the projected trajectory of diabetes prevalence over time. The shape of this curve provides insights into the expected trend of diabetes prevalence in Zamfara state. The slope of the trend line reveals the rate of change in diabetes prevalence each year. A steep incline suggests a rapid increase in prevalence, while a flatter slope indicates a slower rise. The endpoint of the trend line represents the projected prevalence of diabetes in the year 2030. This value indicates the anticipated proportion of the population affected by diabetes at the end of the forecasting period. Overall, the figure provides a visual representation of how diabetes prevalence is expected to evolve over the specified timeframe, offering valuable insights for healthcare planning, resource allocation, and public health interventions in Zamfara state.

Discussion:

The section begins by analyzing the socio-demographic characteristics of the respondents, focusing on parameters such as age, gender, knowledge of balanced diet and weight. These factors are crucial for understanding the diverse demographic profile of the patients under study, providing perceptions into potential correlations between socio-demographic variables and diabetes prevalence. Moving forward, the concept of the invariant region is introduced, which serves as a mathematical framework for ensuring the positivity and stability of the model over time. Lemma 1 establishes the conditions for the model to remain within a biologically feasible region (Ω), where the variables and parameters are constrained to be positive. The proof of Lemma 1 demonstrates that under certain conditions, the model dynamics ensure that the population remains within this feasible region, thereby validating the mathematical integrity of the model. Furthermore, the discussion extends to the existence and uniqueness of the solution, a critical aspect in mathematical modeling. Theorem 1 elucidates the conditions under which the model equations possess a unique solution. By satisfying Lipschitz conditions and boundedness criteria, the model ensures the existence of a unique and continuous solution within a specified interval. This theorem provides assurance regarding the mathematical robustness of the model, facilitating accurate predictions and analyses.

Moreover, the concept of the disease-free equilibrium is explored, which represents a stable state where the prevalence of diabetes-related complications is minimal. Equations 1 to 3 characterize the conditions for the disease-free equilibrium, offering insights into the factors influencing its stability. By analyzing these equations, it is evident that the disease-free equilibrium is contingent upon specific parameters such as population size, infection rates, and recovery rates. Understanding the dynamics of the disease-free equilibrium is crucial for devising effective intervention strategies aimed at reducing the burden of diabetes-related complications within the population

Symptoms

Symptoms include increased thirst, frequent urination, hunger, fatigue and blurred vision. In some cases, there may be no symptoms.

Lifestyle modifications

For patients with type 2 diabetes mellitus, lifestyle modifications are essential for managing the condition effectively. Here are some recommended lifestyle changes:

1. Follow a well-balanced diet rich in fruits, vegetables, whole grains, lean proteins, and healthy fats.
2. Limit intake of processed foods, sugary snacks and beverages high in added sugars and Monitor carbohydrate intake and spread them evenly throughout the day to prevent blood sugar spikes.
3. Engage in regular exercise such as brisk walking, swimming, cycling or any other aerobic activities for at least 150 minutes per week and Incorporate strength training exercises at least two days a week to improve muscle strength and metabolism.

4. Regularly monitor blood glucose levels as advised by a healthcare provider and Take prescribed medications regularly and as directed by the healthcare provider. Then inform the healthcare team about any side effects or difficulties with medication adherence.
5. Limit alcohol intake to moderate levels, as excessive alcohol consumption can affect blood sugar control and avoid smoking and exposure to secondhand smoke, as smoking can worsen diabetes complications.

Treatment for type 2 diabetes mellitus

Treatment for type 2 diabetes mellitus typically involves a combination of lifestyle changes, medication and in some cases, insulin therapy. Here are some common treatment options:

1. Lifestyle Modifications: Healthy Diet, Regular Exercise and Weight Management.

2. Oral Medications:

Metformin: Typically the first-line medication for type 2 diabetes, metformin helps lower blood sugar levels by reducing glucose production in the liver and improving insulin sensitivity in the muscles.

Sulfonylureas: These medications stimulate the pancreas to release more insulin, helping lower blood sugar levels.

DPP-4 Inhibitors: These drugs work by increasing insulin release and decreasing glucagon secretion, helping to lower blood sugar levels.

SGLT2 Inhibitors: These medications help lower blood sugar levels by increasing glucose excretion in the urine.

3. Injectable Medications:

GLP-1 Receptor Agonists: These medications stimulate insulin secretion, suppress glucagon secretion, slow gastric emptying, and promote satiety, leading to lower blood sugar levels.

Insulin Therapy: Some individuals with type 2 diabetes may require insulin therapy to achieve target blood sugar levels, particularly if other medications are not sufficient.

4. Combination Therapy: In some cases, healthcare providers may prescribe combination therapy, which involves using two or more medications with different mechanisms of action to improve blood sugar control.

5. Bariatric Surgery: For severely obese individuals with type 2 diabetes, bariatric surgery may be considered as a treatment option to achieve significant weight loss and improve insulin sensitivity.

It's important for individuals with type 2 diabetes to work closely with their healthcare providers to develop a personalized treatment plan that addresses their specific needs, preferences and goals. Regular follow-up appointments and adjustments to the treatment plan may be necessary to achieve optimal blood sugar control and reduce the risk of complications.

4. Conclusion

This research provides valuable perceptions into the dynamics of T2DM within this specific population. The research focused exclusively on Zamfara State, recognizing the unique characteristics of the population and the need for a tailored approach to understanding and managing Type 2 Diabetes Mellitus in this region. The study successfully developed a mathematical model designed to simulate and analyze the epidemiological factors contributing to the prevalence and incidence of T2DM. This model incorporated crucial elements, including lifestyle factors (diet and physical activity) and treatment factors (access to healthcare and adherence to prescribed medications). By incorporating lifestyle and treatment factors into the model, the research aimed to provide a more comprehensive understanding of the determinants influencing the prevalence and progression of Type 2 Diabetes Mellitus. This insight is critical for designing targeted interventions and public health strategies. The research acknowledges limitations related to data availability, emphasizing the importance of ongoing efforts to improve data collection and management systems. The quality and quantity of data are crucial for the accuracy and reliability of the mathematical model. Finally the research contributes to the understanding of Type 2 Diabetes Mellitus in Zamfara State by integrating epidemiological modeling with lifestyle and treatment factors.

5. Recommendation

Based on the findings of the research the following recommendations are proposed to the state holder :

- Implement and sustain robust systems for collecting, updating and monitoring data related to T2DM, lifestyle factors and treatment outcomes in Zamfara State. Regular data updates will enhance the accuracy and effectiveness of the mathematical model.
- Develop and implement targeted public health campaigns to raise awareness about the risk factors associated with T2DM, emphasizing the role of lifestyle choices. Education should focus on promoting healthier diets, regular physical activity and the importance of early detection and treatment.

- Improve accessibility to healthcare services, especially in rural areas, to ensure timely diagnosis and management of T2DM. This includes increasing the number of healthcare facilities, training healthcare professionals and implementing telehealth services to reach remote communities.

By implementing these recommendations, stakeholders can work collaboratively to address the complex interplay of factors influencing Type 2 Diabetes Mellitus in Zamfara State.

Acknowledgement

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