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Analysis of drug diffusion in human connective tissue in neutrosophic environment

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Abstract: Neutrosophic sets play a crucial role in handling uncertainty, ambiguity, and indeterminacy in numerous theories. They are a kind of extension of the two types of fuzzy sets and intuitionistic fuzzy sets. In the context of modeling drug diffusion within human connective tissues, a differential equation is employed within the neutrosophic framework, utilizing Hukuhara differentiability. We establish the initial conditions and parameters in the form of Type 2 triangular single-valued neutrosophic numbers. This study explores the stability and existence of equilibrium points, providing precise solutions. To conduct numerical simulations across various values of the (α, β, γ)-cut of the triangular neutrosophic number, we utilize MATLAB 2018a.

Keywords: Drug diffusion human model, Single valued triangular neutrosophic number of type 2, Hukuhara differentiability, (α, β, γ)-cut, Neutrosophic differential equation, Stability Analysis, Numerical study.

1. Introduction

The importance of mathematical modeling in the context of drug delivery within human tissues is increasing due to substantial advancements in information technology. This field has now become a consistently explored area in both academic research and commercial applications. Much like other

scientific disciplines, the development of pharmaceutical technology involves the prediction of how the delivered substance flows and behaves kinematically. The design, distribution, dose, and delivery of numerous pharmaceuticals inside the human body can all be optimized using mathematical formulas. Within a neutrosophic framework, the dynamics of drug release and transport processes can be elucidated with significantly greater precision than in classical contexts. The neutrosophic environment is aptly utilized to represent dynamic systems that may have inherent uncertainty. The concept of a fuzzy set, where each element is associated with a membership degree, was first introduced by L. Zadeh [1]. Subsequently, K. T. Atanassov extended this idea to intuitionistic fuzzy sets (IFS) [3], and F. Smarandache further expanded it to neutrosophic sets (NS) [6, 8, 9]. Apart from membership degrees, Intuitionistic Fuzzy Sets (IFS) also incorporate degrees of non-membership. In recent years, there has been extensive research on fuzzy differential equations, which are characterized by imprecise parameters [4, 5, 7, 10, 11, 12, 13, 18]. Subsequently, these differential equations were explained in an intuitive context [14, 18, 38]. Neutrosophic differential equations (NDE) [17, 23, 24] were developed to accommodate the uncertainty associated with the parameters. In contrast to Kaleva [4], who first introduced the idea of differential equations inside a fuzzy framework, Hukuhara [16] adapted the idea of differences and differentiation in interval-valued functions in order to solve the problem of unsolvable boundary value problems. Dey et al. [33] described topological subspace and produced several significant findings based on single valued neutrosophic numbers. Karak et al. [37] has applied the theory of single valued neutrosophic numbers to transportation problems. Acharya et al. [38] explored a prey refuge harvesting model employing intuitionistic fuzzy sets. In a different study [30], it was found that multi-criteria group decision-making problems could be applied to assess pollution characteristics in megacities using a trapezoidal neutrosophic set. In the realm of mathematical research, neutrosophic integral calculus plays a pivotal role. Biswas et al. [29] have used the concept of neutrosophic Riemann integral at (α,β,γ)-levels. Biswas et al. [31] have alsostudied the Gaussian quadrature methods to evaluate numerical integration of netrosophic valued function. Gahlot et al. [25] have developed several distinctive types of single-valued neutrosophic numbers and employed them in multi-criteria decision-making. Sumanth and his team [21] found that a first-order neutrosophic differential equation, incorporating neutrosophic numbers, can be applied in bacterial culture models. Subsequently, Sumathi et al. [22] discussed methods for solving a second-order neutrosophic differential equation with a boundary condition, utilizing a trapezoidal neutrosophic number. In the article [39], they have studied the fractional order derivative in neutrosophic number and discussed nonlinear ecological model with Allee effect. As an extension of the Z-number, Borah [40] introduced the quadric partitioned single neutrosophic Z-number and investigated the operator and score function in the context of three multi-criteria decision-making scenarios during the COVID-19 pandemic. In our research, we focused on modeling drug diffusion in a neutrosophic environment within human tissues. We considered single-valued triangular neutrosophic numbers of type 2 to represent both the initial conditions for the drug diffusion quantity in the bloodstream at time t (g(t)) and the drug concentration in the bloodstream (). Additionally, we conducted stability analyses for the equilibrium points of the Neutrosophic Differential Equations (NDE) and obtained precise solutions for them. To validate our findings, we employed Matlab numerical simulations (version 2018a).

1.1. Arrangement of the article:

Section 2 presents essential prerequisites. In Section 3, we outline the model for drug transportation within neutrophilic human connective tissues. Section 4 delves into the precise solutions of the model and conducts a stability analysis. Section 5 focuses on numerical simulations for different (α, β, γ)-cut values of the type 2 single-valued triangular neutrosophic number. Finally, Section 6 provides a summary of the paper.

1.2. Motivation and novelty:

Several natural factors or those related to human activities may affect the parameters of a biological model and this may lead to certain vagueness, impreciseness or indeterminacy in the values of the parameters. Various approaches are considered to tackle such situations, including interval differential equations (IDE), fuzzy differential equations (FDE), intuitionistic fuzzy differential equations (IFDE), and more. In IDE, parameters are constrained to specific intervals. Conversely, in the FDE method, parameters are assigned precise membership values. IFDE takes into account both membership and non-membership values of the parameters. However, the neutrosophic differential equation (NDE) is essential for addressing the inherent uncertainty in parameter values.

2. Preliminaries:

Definition 2.1: "Single valued neutrosophic set [19]:

A neutrosophic set $\widetilde{X}_{ne}$ on the universe U is defined as

$$\widetilde{X}_{ne} = \{x: \left(\xi_{\widetilde{X}_{ne}}(x), \eta_{\widetilde{X}_{ne}}(x), \varsigma_{\widetilde{X}_{ne}}(x)\right); x \in U\}$$

where $\xi_{\widetilde{X}_{ne}}(x): U \to [0,1]$, $\eta_{\widetilde{X}_{ne}}(x): U \to [0,1]$ and $\varsigma_{\widetilde{X}_{ne}}(x): U \to [0,1]$ represent the truth membership function, indeterminacy membership function and falsity membership function respectively such that $0 \leq \xi_{\widetilde{X}_{ne}}(x) + \eta_{\widetilde{X}_{ne}}(x) + \varsigma_{\widetilde{X}_{ne}}(x) \leq 3$."

Definition 2.2: "(α, β, γ-cut) neutrosophic set [21]: The (α, β, γ-cut) neutrosophic set $\widetilde{X}_{ne_{(\alpha,\beta,\gamma)}}$ is defined as $\widetilde{X}_{ne_{(\alpha,\beta,\gamma)}} = \{\left(\xi_{\widetilde{X}_{ne}}(x), \eta_{\widetilde{X}_{ne}}(x), \varsigma_{\widetilde{X}_{ne}}(x)\right): x \in U, \xi_{\widetilde{X}_{ne}}(x) \geq \alpha, \eta_{\widetilde{X}_{ne}}(x) \leq \beta, \varsigma_{\widetilde{X}_{ne}}(x) \leq \gamma\}$ where α, β, γ are fixed numbers in [0,1] such that $\alpha + \beta + \gamma \leq 3$."

Definition 2.3: Triangular single valued neutrosophic number of type 2 (TrSVNN type 2) [19]:

Let us consider a TrSVNN of type 2 as $\widetilde{X}_{ne} = \langle[n_{11}, n_{12}, n_{13}; m_{11}, m_{12}, m_{13}; \rho, \sigma]\rangle$ whose truth, indeterminacy and falsity membership function are as follows

$$\xi_{\widetilde{X}_{ne}}(x) = \begin{cases} \dfrac{x - n_{11}}{n_{12} - n_{11}}; & n_{11} \leq x < n_{12} \\ 1 \quad ; & x = n_{12} \\ \dfrac{n_{13} - x}{n_{13} - n_{12}}; & n_{12} < x \leq n_{13} \\ 0 & \text{otherwise} \end{cases}$$

$$\eta_{\widetilde{X}_{ne}}(x) = \begin{cases} \dfrac{m_{12} - x + \rho(x - m_{11})}{m_{12} - m_{11}}; & m_{11} \leq x < m_{12} \\ \rho \quad ; & x = m_{12} \\ \dfrac{x - m_{12} + \rho\,(m_{13} - x)}{m_{13} - m_{12}}; & m_{12} < x \leq m_{13} \\ 0 \quad ; & \text{otherwise} \end{cases}$$

$$\varsigma_{\tilde{x}_{ne}}(x)=\begin{cases}\dfrac{m_{12}-x+\sigma(x-m_{11})}{m_{12}-m_{11}}; & m_{11}\le x<m_{12}\\ \rho \quad ; & x=m_{12}\\ \dfrac{x-m_{12}+\sigma\,(m_{13}-x)}{m_{13}-m_{12}}; & m_{12}<x\le m_{13}\\ 0 \quad ; & \text{otherwise}\end{cases}$$

where,

$0\le \xi_{\tilde{x}_{ne}}(x)+\eta_{\tilde{x}_{ne}}(x)+\varsigma_{\tilde{x}_{ne}}(x)\le 2,\ \ x\in \tilde{X}_{neu}\ ,\ \rho,\ \sigma\in(0,1]$

The parametric form of TrSVNN type 2 is

$$(\tilde{X}_{ne})_{\alpha,\beta,\gamma}=[\xi_{ne1}(\alpha),\xi_{ne2}(\alpha);\eta_{ne1}(\beta),\eta_{ne2}(\beta);\varsigma_{ne1}(\gamma),\varsigma_{ne2}(\gamma)]$$

where

$$\xi_{ne1}(\alpha)=n_{11}+\alpha(n_{12}-n_{11}),$$

$\xi_{ne2}(\alpha)=n_{13}-\alpha(n_{13}-n_{12}),$

$\eta_{ne1}(\beta)=\frac{m_{12}-\rho m_{11}-\beta(m_{12}-m_{11})}{1-\rho},$

$\eta_{ne2}(\beta)=\frac{m_{12}-\rho m_{13}+\beta(m_{13}-m_{12})}{1-\rho},$

$\varsigma_{ne1}(\gamma)=\frac{m_{12}-\sigma m_{11}-\gamma(m_{12}-m_{11})}{1-\sigma},$

$\varsigma_{ne2}(\gamma)=\frac{m_{12}-\sigma m_{13}+\gamma(m_{13}-m_{12})}{1-\sigma}.$

Example 1: Consider the TrSVNN of type 2,$\tilde{X}_{ne}=(20,25,28;24,26,32;0.4,0.5)$.

The parametric form of TrSVNN of type 2 is represented as,

$\xi_{ne1}(\alpha)=20+5\alpha,\xi_{ne2}(\alpha)=28-3\alpha,\eta_{ne1}(\beta)=\frac{8.2-\beta}{0.3},\eta_{ne2}(\beta)=\frac{13.2+6\beta}{0.6},\varsigma_{ne1}(\gamma)=\frac{14-2\beta}{0.5},\varsigma_{ne2}(\gamma)=\frac{10+6\beta}{0.5}.$

Definition 2.4 Hukuhara derivative on neutrosophic function [15]: "Let $g_{ne}:(a,b)\to NF(R)$ be a neutrosophic valued function and $l_0, l_0+h\in(a,b)$. gis hukuhara differentiable at l_0, if ∃ an element $g'_{ne}(l_0)\in NF(R)$ such that for all $h>0$,

$\lim_{h\to0}\frac{g_{ne}(l_0+h)\ominus g_{ne}(l_0)}{h}=\lim_{h\to0}\frac{g_{ne}(l_0)\ominus g_{ne}(l_0-h)}{h}=g'_{ne}(l_0)$is satisfied."

Remark [24]: "Let $g_{ne}:(a,b)\to NF(R)$ be a neutrosophic valued function. Let$g_{ne}(t,\alpha,\beta,\gamma)=\langle[g_{ne1}(t,\alpha),g_{ne2}(t,\alpha)],[g'_{ne1}(t,\beta),g'_{ne2}(t,\beta)],[g''_{ne1}(t,\gamma),g''_{ne2}(t,\gamma)]\rangle$is its α,β,γ-cut . If$g_{ne}$is hukuhara differentiable at l_0 such that

$\dot{g}_{ne}(l_0,\alpha)=[\min\{\dot{g}_{neu\,1}(l_0:\alpha),\dot{g}_{neu\,2}(l_0:\alpha)\},\max\{\dot{g}_{neu\,1}(l_0:\alpha),\{\dot{g}_{neu\,2}(l_0:\alpha)\}]$ if

$\dot{g}_{neu\,1}(l_0:\alpha),\dot{g}_{neu\,2}(l_0:\alpha)$ exist.

$\dot{g}'(l_0:\beta)=[\min\{\dot{g}'_{ne\,1}(l_0:\beta),\dot{g}'_{ne\,2}(l_0:\beta)\},\max\{\dot{g}'_{ne1}(l_0:\beta),\dot{g}'_{ne\,2}(l_0:\beta)\}]$,if$\dot{g}'_{ne\,1}(l_0:\beta),\dot{g}'_{ne\,2}(l_0:\beta)$ exist.

$\dot{g}''(l_0:\gamma)=[\min\{g''_{ne1}(l_0:\gamma),g''_{ne2}(l_0:\gamma)\},\max\{g''_{ne1}(l_0:\gamma),g''_{ne2}(l_0:\gamma)\}]$,if$g''_{ne1}(l_0:\gamma),g''_{ne2}(l_0:\gamma)$ exist.

Definition 2.5. Neutrosophic differential equation (NDE) [22]: "A first order initial value problem of the form $\frac{df(t)}{dx}=kf_1(t),\ f(t_0)=f_{1_0}$ is called a neutrosophic differential equation if any one or both of k and f_0 are neutrosophic numbers.

Let the solution of the above neutrosophic differential equation be f(x) and its (α,β,γ)- cut be

$$f_1(t,\alpha,\beta,\gamma) = \langle [f_{11}(t,\alpha), f_{12}(t,\alpha)], [f'_{11}(t,\beta), f'_{12}(t,\beta)], [f''_{11}(t,\gamma), f''_{12}(t,\gamma)] \rangle$$

In general the solution is considered to be strong if

i) $\frac{df_{11}(t,\alpha)}{d\alpha} > 0, \frac{df_{12}(t,\alpha)}{d\alpha} < 0, \forall\, \alpha \in [0,1],\ f_{11}(t,1) \le f_{12}(t,1).$

ii) $\frac{df'_{11}(t,\beta)}{d\beta} < 0, \frac{df'_{12}(t,\beta)}{d\beta} > 0, \forall\, \beta \in [0,1],\ f'_{11}(t,0) \le f'_{12}(t,0).$

iii) $\frac{df''_{11}(t,\gamma)}{d\gamma} < 0, \frac{df''_{12}(t,\gamma)}{d\gamma} > 0, \forall\, \gamma \in [0,1],\ f''_{11}(t,0) \le f''_{12}(t,0).$

Otherwise, the solution is a weak solution."

2.1 Properties on neutrosophic number [23]:

Proposition 2.1.1 Let ũ and ṽ be two neutrosophic numbers then,

(i) $(\tilde{u} \oplus \tilde{v})_{(\alpha,\beta,\gamma)} = \tilde{u}_{(\alpha,\beta,\gamma)} \oplus \tilde{v}_{(\alpha,\beta,\gamma)}$.

(ii) $(\tilde{u} \ominus \tilde{v})_{(\alpha,\beta,\gamma)} = \tilde{u}_{(\alpha,\beta,\gamma)} \ominus \tilde{v}_{(\alpha,\beta,\gamma)}$.

(iii) $(\tilde{u} \otimes \tilde{v})_{(\alpha,\beta,\gamma)} = \tilde{u}_{(\alpha,\beta,\gamma)} \otimes \tilde{v}_{(\alpha,\beta,\gamma)}$.

(iv) $(\lambda\tilde{u})_{(\alpha,\beta,\gamma)} = \lambda\tilde{u}_{(\alpha,\beta,\gamma)}$, for $\lambda \neq 0 \in \mathbb{R}$.

Example 2: If $\tilde{p}_{ne} = (14,18,22; 17,21,25; 0.5,0.4)$ and $\tilde{q}_{ne} = (12,15,18; 13,20,26; 0.5,0.4)$ are two TrSVNN of type 2, then following properties are given as,

i) Addition: $\tilde{p}_{ne} + \tilde{q}_{ne} = (26,33,40; 30,41,51; 0.5,0.4)$.

ii) Substraction: $\tilde{p}_{ne} - \tilde{q}_{ne} = (2,3,4; 4,1,1; 0.5,0.4)$.

iii) Multiplication: :$\tilde{p}_{ne} \times \tilde{q}_{ne} = (168,270,396; 221,420,650; 0.5,0.4)$.

iv) Multiplication by a constant: $\lambda\tilde{p}_{ne} = (42,54,66; 51,63,75; 0.5,0.4)$,where λ=3.

3. Mathematical formulation:

In biological processes, the relation between the amount of drug intake and concentration of drug in human body at different sites through various compartments has substantial impact on the drug diffusion process. Thus, owing to its necessity to study the dynamics of the quatmtity of drug diffusion within blood at time t along with its concentration we consider the following differential equation

$$u\frac{dg(t)}{dt} = -\lambda g(t), \qquad g(t_0) = g_0,\ \ t \in [t_0, \infty) \qquad \text{.....(1)}$$

Where, g(t) is the amount of drug diffusion at time t, u is the body's blood volume and λ (> 0) is the rate of concentration of drug.$g_0$is the amount of drug diffusion at initial time $t = t_0$.

4. In neutrosophic environment the analysis of the drug diffusion human tissues model system:

From (1), we have considered the following three cases:

i) The amount of drug diffusion in blood at initial time t_0i.e.$\tilde{g}_0$ is TrSVNN Type 2.

ii) The concentration of drug in the blood stream $\tilde{\lambda}$is neutrosophic number TrSVNN Type 2

iii) Both $\tilde{g}_0$ and $\tilde{\lambda}$ are TrSVNN Type 2.

4.1 Case 1: Amount of drug diffusion in blood at initial time t_0i.e. $\tilde{g}_0$ is TrSVNN Type 2.

The system of NDDE (1) can be written as

$$u\frac{dg_1(t,\alpha)}{dt} = -\lambda g_2(t,\alpha),$$

$$u\frac{dg_2(t,\alpha)}{dt} = -\lambda g_1(t,\alpha),$$

$$u\frac{dg_1'(t,\beta)}{dt} = -\lambda g'_2(t,\beta),$$
$$u\frac{dg_2'(t,\beta)}{dt} = -\lambda g'_1(t,\beta),$$
$$u\frac{dg''_1(t,\gamma)}{dt} = -\lambda g''_2(t,\gamma),$$
$$u\frac{dg''_2(t,\gamma)}{dt} = -\lambda g''_1(t,\gamma), \quad \text{……..(2)}$$

where α,β,γ –cut of g(t) is $\langle [g_1(t,\alpha), g_2(t,\alpha)], [g'_1(t,\beta), g'_2(t,\beta)], [g''_1(t,\gamma), g''_2(t,\gamma)] \rangle$ and the initial conditions $\tilde{g}_0$are: $g_i(0,\alpha) = g_{0i}(\alpha)$; $g_i'(0,\beta) = g'_{0i}(\beta)$; $g''_i(0,\gamma) = g''_{0i}(\gamma)$; $i = 1,2$.

The particular solution of (2), we have

$$g_1(t,\alpha) = \frac{1}{2}\left(g_{01}(\alpha) + g_{02}(\alpha)\right)e^{-\frac{\lambda t}{u}} - \frac{1}{2}(g_{02}(\alpha) - g_{01}(\alpha))e^{\frac{\lambda t}{u}},$$
$$g_2(t,\alpha) = \frac{1}{2}\left(g_{02}(\alpha) - g_{01}(\alpha)\right)e^{\frac{\lambda t}{u}} + \frac{1}{2}(g_{01}(\alpha) + g_{02}(\alpha))\, e^{-\frac{\lambda t}{u}},$$
$$g'_1(t,\beta) = \frac{1}{2}\left(g'_{01}(\beta) + g'_{02}(\beta)\right)e^{-\frac{\lambda t}{u}} - \frac{1}{2}(g'_{02}(\beta) - g'_{01}(\beta))e^{\frac{\lambda t}{u}},$$
$$g'_2(t,\beta) = \frac{1}{2}\left(g'_{02}(\beta) - g'_{01}(\beta)\right)e^{\frac{\lambda t}{u}} + \frac{1}{2}(g'_{01}(\beta) + g'_{02}(\beta))\, e^{-\frac{\lambda t}{u}},$$
$$g''_1(t,\gamma) = \frac{1}{2}\left(g''_{01}(\gamma) + g''_{02}(\gamma)\right)e^{-\frac{\lambda t}{u}} - \frac{1}{2}(g''_{02}(\gamma) - g''_{01}(\gamma))e^{\frac{\lambda t}{u}},$$
$$g''_2(t,\gamma) = \frac{1}{2}\left(g''_{02}(\gamma) - g''_{01}(\gamma)\right)e^{\frac{\lambda t}{u}} + \frac{1}{2}\left(g''_{01}(\gamma) + g''_{02}(\gamma)\right)e^{-\frac{\lambda t}{u}}. \quad \text{……(3)}$$

Equilibrium point: We get one equilibrium point say $E_1^* = (0,0,0,0,0,0)$ for the model (2).

Stability Analysis:

Lemma 1: E_1^* is unstable.

Proof: The variational matrix V_{11} at E_1^* which is given by

$$V_{11} = \begin{pmatrix} 0 & -\frac{\lambda}{u} & 0 & 0 & 0 & 0 \\ -\frac{\lambda}{u} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{\lambda}{u} & 0 & 0 \\ 0 & 0 & -\frac{\lambda}{u} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -\frac{\lambda}{u} \\ 0 & 0 & 0 & 0 & -\frac{\lambda}{u} & 0 \end{pmatrix}.$$

The characteristic equation becomes,

$y_1^6 - 3\frac{\lambda^2}{u^2}y_1^4 + 3\frac{\lambda^4}{u^4}y_1^2 - \frac{\lambda^6}{u^6} = 0$ where y_1 is the eigenvalue of V_{11}.

Obviously, the eigenvalues of the matrix V_{11} are $\frac{\lambda}{u}, -\frac{\lambda}{u}, \frac{\lambda}{u}, -\frac{\lambda}{u}, \frac{\lambda}{u}, -\frac{\lambda}{u}$, the equilibrium point E_1^* is saddle node and the system is unstable at E_1^*.

4.2 Case 2: The concentration of the drug in the bloodstream is represented as a Neutrosophic number of TrSVNN Type 2.

Considering the NDDE (1) becomes the following system as

$$u\frac{dg_1(t,\alpha)}{dt} = -\lambda_2(\alpha)g_1(t,\alpha),$$
$$u\frac{dg_2(t,\alpha)}{dt} = -\lambda_1(\alpha)g_2(t,\alpha),$$
$$u\frac{dg''_1(t,\beta)}{dt} = -\lambda'_2(\beta)g''_1(t,\beta),$$

$$u\frac{dg_2''(t,\beta)}{dt} = -\lambda'_1(\beta)g'_2(t,\beta),$$
$$u\frac{dg''_1(t,\gamma)}{dt} = -\lambda''_2(\gamma)g''_1(t,\gamma),$$
$$u\frac{dg''_2(t,\gamma)}{dt} = -\lambda''_1(\gamma)g''_2(t,\gamma). \quad \text{……..(4)}$$

With initial condition,

$g_i(0,\alpha) = g'_i(0,\beta) = g''_i(0,\gamma) = g_0, i = 1,2.$

Solving the above differential equation (4), we get the exact solution as

$$g_1(t,\alpha) = g_0 e^{-\frac{\lambda_2(\alpha)}{u}t}; g_2(t,\alpha) = g_0 e^{-\frac{\lambda_1(\alpha)}{u}t},$$
$$g'_1(t,\beta) = g_0 e^{-\frac{\lambda'_2(\beta)}{u}t}; \quad g'_2(t,\beta) = g_0 e^{-\frac{\lambda'_1(\beta)}{u}t},$$
$$g''_1(t,\gamma) = g_0 e^{-\frac{\lambda''_2(\gamma)}{u}t} \; ; \quad g''_2(t,\gamma) = g_0 e^{-\frac{\lambda''_1(\gamma)}{u}t}. \quad \text{……(5)}$$

Equilibrium point: We get one equilibrium point say $E_2^* = (0,0,0,0,0,0)$ of the system (4).

Stability Analysis:

Lemma – 2: E_2^* is LAS (Locally asymptotically stable).

Proof: The variational matrixV_{12} at $E_2^*$is given by,

$$V_{12} = \begin{pmatrix} -\frac{\lambda_2(\alpha)}{u} & 0 & 0 & 0 & 0 & 0 \\ 0 & -\frac{\lambda_1(\alpha)}{u} & 0 & 0 & 0 & 0 \\ 0 & 0 & -\frac{\lambda'_2(\beta)}{u} & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{\lambda'_1(\beta)}{u} & 0 & 0 \\ 0 & 0 & 0 & 0 & -\frac{\lambda''_2(\gamma)}{u} & 0 \\ 0 & 0 & 0 & 0 & 0 & -\frac{\lambda''_1(\gamma)}{u} \end{pmatrix}.$$

The eigenvalue of the matrixV_{12} are $-\frac{\lambda_2(\alpha)}{u}, -\frac{\lambda_1(\alpha)}{u}, -\frac{\lambda'_2(\beta)}{u}, -\frac{\lambda'_1(\beta)}{u}, -\frac{\lambda''_2(\gamma)}{u}, -\frac{\lambda''_1(\gamma)}{u}$.

Obviously, the equilibrium point $E_2^*$is LAS.

4.3 Case 3: Both $\tilde{g}_0$ and $\tilde{\lambda}$ are TrSVNN Type 2.

In this case the system (1) as follows,

$$u\frac{dg_1(t,\alpha)}{dt} = -\lambda_2(\alpha)g_1(t,\alpha),$$
$$u\frac{dg_2(t,\alpha)}{dt} = -\lambda_1(\alpha)g_2(t,\alpha),$$
$$u\frac{dg'_1(t,\beta)}{dt} = -\lambda'_2(\beta)g'_1(t,\beta),$$
$$u\frac{dg'_2(t,\beta)}{dt} = -\lambda'_1(\beta)g'_2(t,\beta),$$
$$u\frac{dg''_1(t,\gamma)}{dt} = -\lambda''_2(\gamma)g''_1(t,\gamma),$$
$$u\frac{dg''_2(t,\gamma)}{dt} = -\lambda''_1(\gamma)g''_2(t,\gamma). \quad \text{……..(6)}$$

Considering the initial situation,,

$g_i(0,\alpha) = g_{0i}(\alpha); \; g'_i(0,\beta) = g'_{0i}(\beta); \; g''_i(0,\gamma) = g''_{0i}(\gamma); \; i = 1,2.$

We obtain the precise respond to as by solving the differential equations of model system (6).

$$g_1(t,\alpha) = g_{01}(\alpha)e^{-\frac{\lambda_2(\alpha)}{u}t}; g_2(t,\alpha) = g_{02}(\alpha)e^{-\frac{\lambda_1(\alpha)}{u}t};$$
$$g'_1(t,\beta) = g'_{01}(\beta)e^{-\frac{\lambda'_2(\beta)}{u}t}; \; g'_2(t,\beta) = g'_{02}(\beta)e^{-\frac{\lambda'_1(\beta)}{u}t}$$

$$g''_1(t,\gamma) = g''_{01}(\gamma)e^{-\frac{\lambda''_2(\gamma)}{u}t} \;;\quad g''_2(t,\gamma) = g''_{02}(\gamma)e^{-\frac{\lambda''_1(\gamma)}{u}t}. \qquad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Equilibrium point: We get one equilibrium point say $E_3^* = (0,0,0,0,0,0)$ for the model (6).

Stability Analysis:

Lemma – 3: E_3^* is LAS.

Proof: Proof similar to that in Lemma - 2.

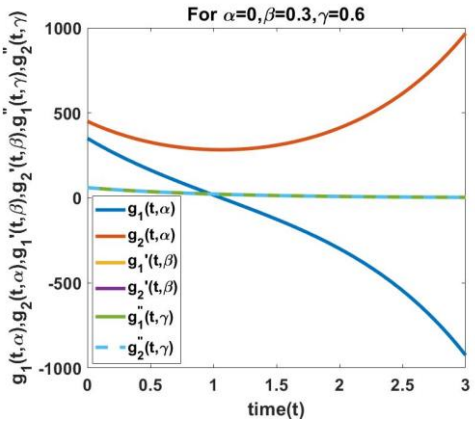
5. Numerical study: We have conducted extensive numerical simulations to substantiate and verify the outcomes of our analysis regarding the drug diffusion model NDDE. These simulations have been carried out using Matlab (version 2018a) and Matcont.

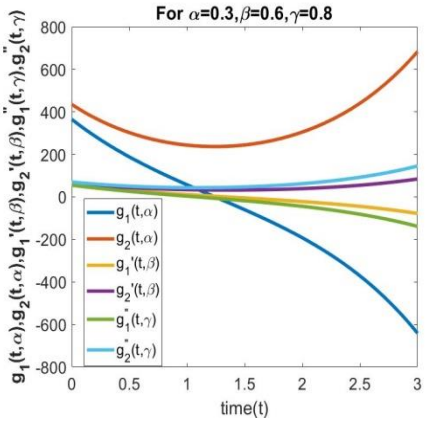
Part A: Study of the nature of NDDE when initial conditions are TrSVNN-Type 2

Let us assume the TrSVNN type 2initial condition $\widetilde{g_0} = (350,400,450; 50,60,40; 0.3,0.6)$..The parametric representation of the triangular single valued Neutrosophic number of type2 can be formulated as follows:

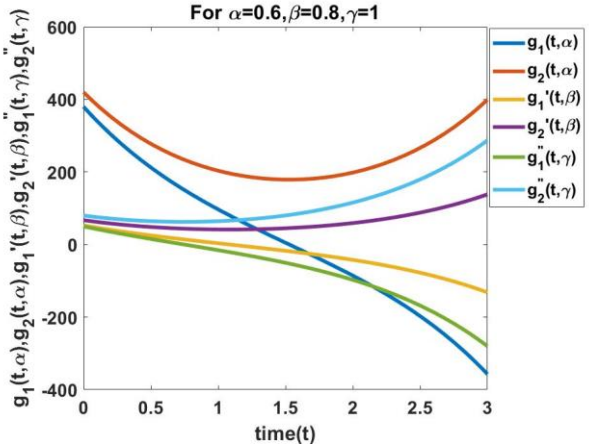
$$g_{01}(\alpha) = 350 + 50\alpha\,, g_{02}(\alpha) = 400 - 50\alpha; g'_{01}(\beta) = \frac{450-100\beta}{7}, g'_{02}(\beta) = \frac{390+100\beta}{7}\,;$$
$$g''_{01}(\gamma) = 75 - 25\gamma; g''_{02}(\gamma) = 30 + 25\gamma; \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

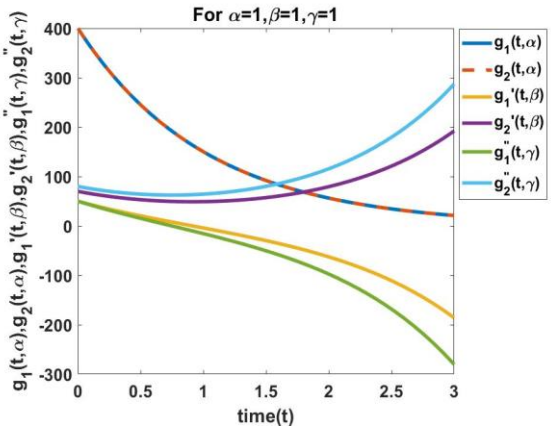
Applying the value provided in equation (8) with $u = 1$ we construct Figure 1(a), (b), (c), (d), for$\alpha = 0, \beta = 0.3, \gamma = 0.6, \alpha = 0.3,\ \beta = 0.6, \gamma = 0.8,\ \alpha = 0.6, \beta = 0.8\ \gamma = 1$, and $\alpha = 1, \beta = 1, \gamma = 1$ respectively.





(a) (b)





(c) (d)

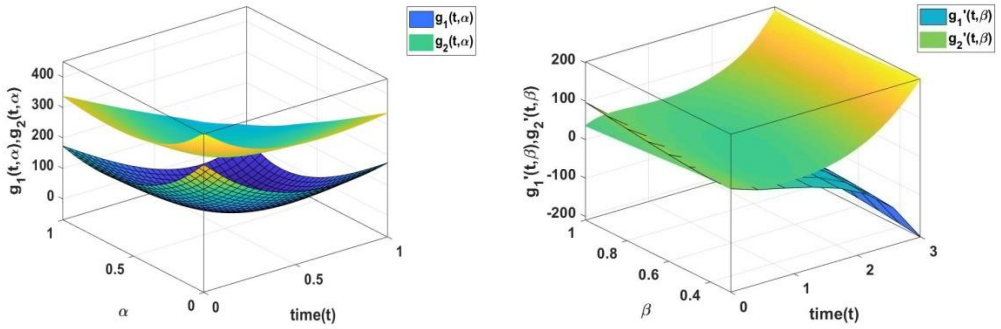
Figure 1. Neutrosophic fuzzy solution: Figure 1(a) for α=0,β=0.3,γ=0.6; Figure 1(b) for α=0.3,β=0.6,γ=0.8; Figure 1(c) for α=0.6,β=0.8,γ=1; Figure 1(d) for α=1,β=1,γ=1 where t ∈ [0,3].

Here, in Figure 1(a) we see that$g_1(t,\alpha) \le g_2(t,\alpha)$; $g'_1(t,\beta) = g'_2(t,\beta)$; $g''_1(t,\gamma) = g''_2(t,\gamma)$.
In Figure 1(b), Figure 1(c), Figure 1(d) we observe that $g_1(t,\alpha) \le g_2(t,\alpha)$; $g'_1(t,\beta) \le g'_2(t,\beta)$; $g''_1(t,\gamma) \le g''_2(t,\gamma)$for t ∈ [0,3].Clearly, Figure1 shows the dynamical behaviour of $g_1(t,\alpha), g_2(t,\alpha), g'_1(t,\beta), g'_2(t,\beta); g''_1(t,\gamma), g''_2(t,\gamma)$ relative to time (t) for t ∈ [0,3] , for$\alpha = 0, \beta = 0.3, \gamma = 0.6, \alpha = 0.3,\ \beta = 0.6, \gamma = 0.8, \alpha = 0.6, \beta = 0.8\ \gamma = 1$, and $\alpha = 1, \beta = 1, \gamma = 1$
Now, setting $u = 1$ and $t = 1$ with the initial conditions specified in equation (8),we list the solution of (2) in Table 1 where α ∈ [0,1], β ∈ [0.3,1] and γ ∈ [0.6,1].

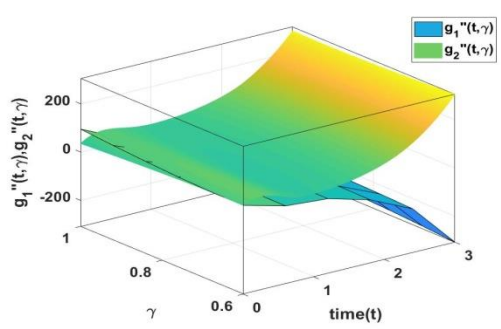
α	$g_1(t,\alpha)$	$g_2(t,\alpha)$	β	$g'_1(t,\beta)$	$g'_2(t,\beta)$	γ	$g''_1(t,\gamma)$	$g''_2(t,\gamma)$
0	16.9016	283.3473						
0.1	30.2239	270.0250						
0.2	43.5462	256.7027						
0.3	56.8685	243.3804	0.3	22.5187	22.5187			
0.4	70.1908	230.0581	0.4	18.7123	26.3250			
0.5	83.5130	216.7358	0.5	14.9059	30.1314			
0.6	96.8353	203.4136	0.6	11.0996	33.9378	0.6	22.5187	22.5187
0.7	110.1576	190.0913	0.7	7.2932	37.7441	0.7	12.9961	32.9795
0.8	123.4799	176.7690	0.8	3.4868	41.5505	0.8	3.4735	43.4404
0.9	136.8022	163.4467	0.9	-0.3195	45.3569	0.9	-6.0491	53.9012
1	150.1244	150.1244	1	-4.1259	49.1632	1	-15.5716	64.3621

Table 1 displays Neutrosophic fuzzy solution for system (2) at time t=1.

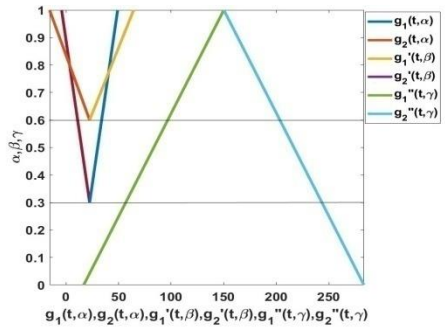
Table 1 reflects that $g_1(t,\alpha)$ is increasing, $g_2(t,\alpha)$ is decreasing; $g'_1(t,\beta)$ exhibits decreasing while $g'_2(t,\beta)$ displays an increasing; $g''_1(t,\gamma)$ exhibits decreasing whereas $g''_2(t,\gamma)$ demonstrate increasing for α ∈ [0,1], β ∈ [0.3,1]and γ ∈ [0.6,1] at t=1.



(a) (b)



(c)



(d)

Figure 2: (3D plot)

Figure 2(a): Pictorial diagram of 3D plot of $g_1(t,\alpha), g_2(t,\alpha)$ with respect to time(t) and α where t ∈ [0,3], α∈ [0,1];

Figure 2(b): Pictorial diagram of 3D plot of $g'_1(t,\beta), g'_2(t,\beta)$ with respect to time(t) and β where t ∈ [0,3], β∈ [0.3,1];

Figure 2(c): Pictorial diagram of 3D plot of $g''_1(t,\gamma), g''_2(t,\gamma)$ with respect to time(t) and γ where t ∈ [0,3], γ∈ [0.6,1];

Figure 2(d): Pictorial diagram of 3D plot of $g_1(t,\alpha), g_2(t,\alpha), g'_1(t,\beta), g'_2(t,\beta), g''_1(t,\gamma), g''_2(t,\gamma)$ with respect to time(t) and α,β,γ where $\alpha \in [0,1], \beta \in [0.3,1], \gamma \in [0.6,1]$.

Figure 1, Figure 2 and Table 1 clearly depicts that, for all values of α within the interval [0,1], $g_1(t,\alpha)$ exhibits strictly increasing whereas $g_2(t,\alpha)$ displays strictly decreasing i.e. $g_1(t,1) \le g_2(t,1)$; for all values of β within the interval[0.3,1], $g'_1(t,\beta)$ demonstrate strictly decreasing whereas $g'_2(t,\beta)$ exhibits strictly increasing i.e $g'_1(t,0.3) \le g'_2(t,0.3)$; for all values of γ within the interval [0.6,1], $g''_1(t,\gamma)$ display strictly decreasing whereas $g''_2(t,\gamma)$ exhibits strictly increasing,$g''_1(t,0.6) \le g''_2(t,0.6)$.

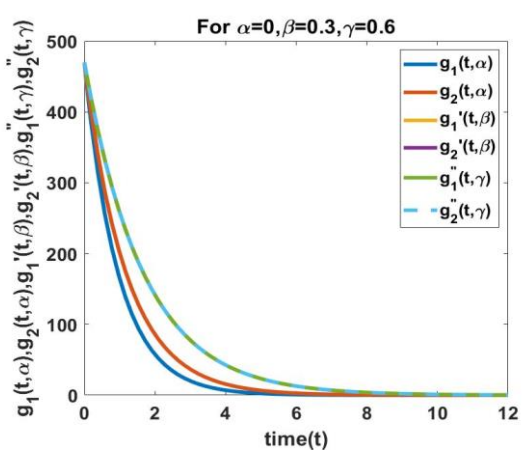
Part B: Study of the nature of NDDE when $\tilde{\lambda}$ isTrSVNN-Type 2

Let us assume the TrSVNN Type 2 values of $\tilde{\lambda}$ to be $\lambda_{neu} = (0.85,0.95,1.05; 0.5,0.6,0.7; 0.3,0.6)$

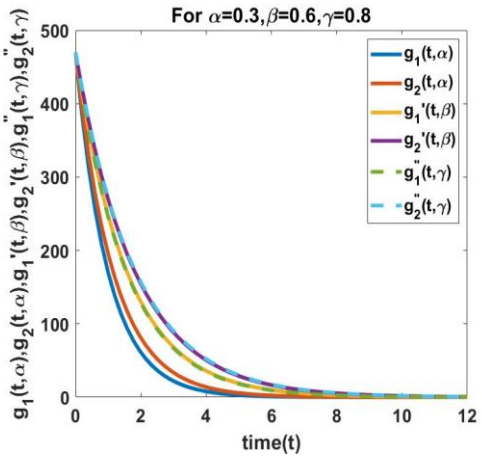
Its parametric form is given by,

$\lambda_1(\alpha) = 0.85 + 0.1\alpha; \lambda_2(\alpha) = 1.05 - 0.1\alpha; \lambda'_1(\beta) = \frac{4.5-\beta}{7};$

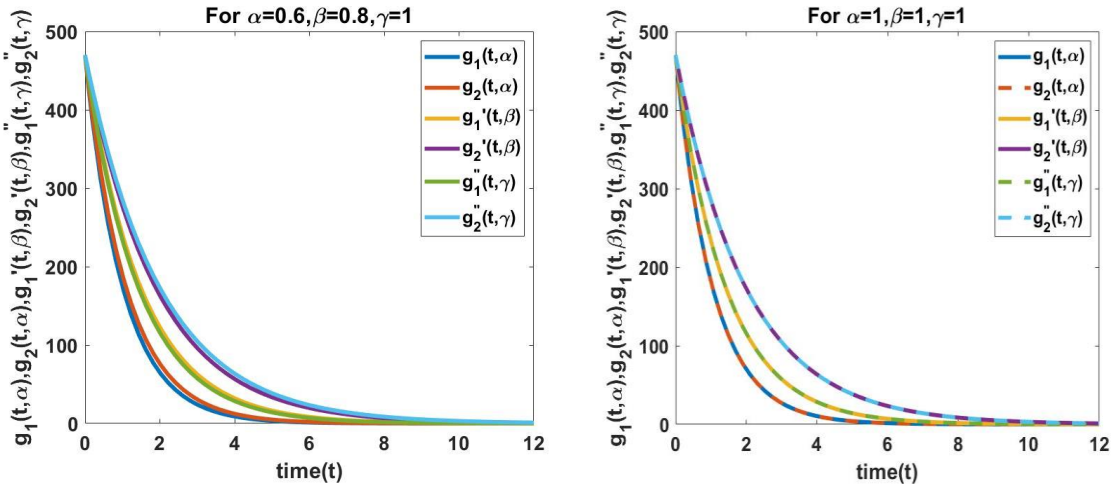
$\lambda'_2(\beta) = \frac{3.9+\beta}{7}; \lambda''_1(\gamma) = \frac{3-\gamma}{4}; \lambda''_2(\gamma) = \frac{1.8+\gamma}{4}$ ……(9)



(a)



(b)



(c) (d)

Figure 3. Neutrosophic fuzzy solution: Figure 3(a) for α=0,β=0.3,γ=0.6; Figure 3(b) for α=0.6,β=0.8,γ=1; Figure 3(c) for α=0.3,β=0.5,γ=0.8; Figure 3(d) for α=1,β=1,γ=1 where t ∈ [0,12].

In Figure 3(a), we see that $g_1(t,\alpha) \leq g_2(t,\alpha)$; $g'_1(t,\beta) = g'_2(t,\beta)$; $g''_1(t,\gamma) = g''_2(t,\gamma)$.
Figure 3(b), Figure 3(c) shows that $g_1(t,\alpha) \leq g_2(t,\alpha)$; $g'_1(t,\beta) \leq g'_2(t,\beta)$; $g''_1(t,\gamma) \leq g''_2(t,\gamma)$ and Figure 3(d) shows that$g_1(t,\alpha) = g_2(t,\alpha)$, $g'_1(t,\beta) = g'_2(t,\beta)$;$g''_1(t,\gamma) = g''_2(t,\gamma)$; for t ∈ [0,12]. From Figure 3 we observe that the system (4) is LAS at E_3^*.

Taking u=1, t=6 with TrSVNN Type 2 values of $\tilde{\lambda}$ described in (9), the solutions for equation (4) are exhibited in Table 2 where α ∈ [0,1], β ∈ [0.3,1] and γ ∈ [0.6,1].

α	$g_1(t,\alpha)$	$g_2(t,\alpha)$	β	$g'_1(t,\beta)$	$g'_2(t,\beta)$	γ	$g''_1(t,\gamma)$	$g''_2(t,\gamma)$
0	0.8634	2.8658						
0.1	0.9168	2.6989						
0.2	0.9735	2.5417						
0.3	1.0336	2.3937	0.3	12.8423	12.8423			
0.4	1.0975	2.2544	0.4	11.7874	13.9916			
0.5	1.1654	2.1231	0.5	10.8191	15.2437			
0.6	1.2374	1.9995	0.6	9.9304	16.6080	0.6	12.8423	12.8423
0.7	1.3139	1.8831	0.7	9.1147	18.0943	0.7	11.0535	14.9206
0.8	1.3951	1.7734	0.8	8.3660	19.7136	0.8	9.5139	17.3352
0.9	1.4814	1.6702	0.9	7.6789	21.4778	0.9	8.1887	20.1406
1	1.5729	1.5729	1	7.0481	23.4000	1	7.0481	23.4000

Table 2 displays Neutrosophic fuzzy solution for the system described by (4) when t=6.

Table 2 reflects that $g_1(t,\alpha)$ exhibits increasing,$g_2(t,\alpha)$ demonstrate decreasing; $g'_1(t,\beta)$ display decreasing whereas $g'_2(t,\beta)$ exhibits increasing;$g''_1(t,\gamma)$ display decreasing and $g''_2(t,\gamma)$ demonstrate increasing for α ∈ [0,1], β ∈ [0.3,1]andγ ∈ [0.6,1] and t=6.

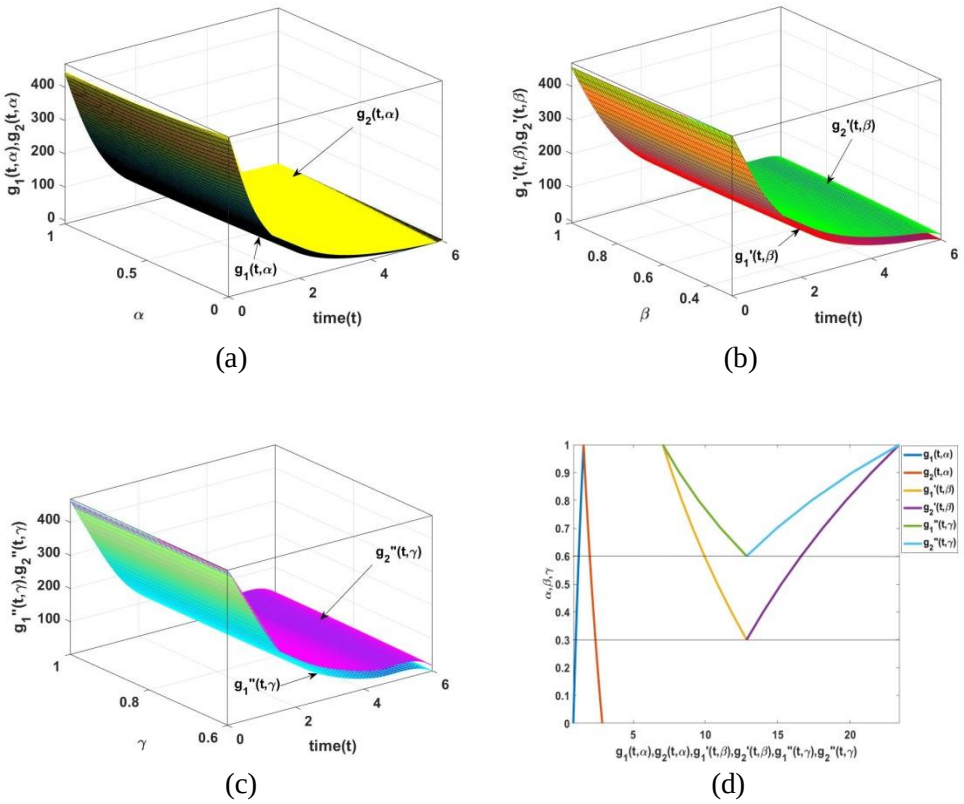


Figure. 4: (3D plot)

Figure 4(a): Pictorial diagram of 3D plot of $g_1(t,\alpha), g_2(t,\alpha)$ with respect to time(t) and α where t ∈ [0,6], α∈ [0,1];

Figure 4(b): Pictorial diagram of 3D plot of $g'_1(t,\beta), g'_2(t,\beta)$ with respect to time(t) and β where t ∈ [0,6], β∈ [0.3,1];

Figure 4(c): Pictorial diagram of 3D plot of $g''_1(t,\gamma), g''_2(t,\gamma)$ with respect to time(t) and γ where t ∈ [0,6], γ∈ [0.6,1];

Figure 4(d): Pictorial diagram of 3D plot of $g_1(t,\alpha), g_2(t,\alpha), g'_1(t,\beta), g'_2(t,\beta), g''_1(t,\gamma), g''_2(t,\gamma)$ with respect to time(t) and α,β,γ where $\alpha \in [0,1], \beta \in [0.3,1], \gamma \in [0.6,1]$.

Figure 3, Figure 4 and Table 2 clearly depicts that for all values of α within the interval [0,1], $g_1(t,\alpha)$ exhibits strictly increasing whereas $g_2(t,\alpha)$ displays strictly decreasing i.e. $g_1(t,1) \leq g_2(t,1)$; for all values of β within the interval[0.3,1],$g'_1(t,\beta)$ demonstrate strictly decreasing whereas $g'_2(t,\beta)$ exhibits strictly increasing i.e $g'_1(t,0.3) \leq g'_2(t,0.3)$; for all values of γ∈ [0.6,1], $g''_1(t,\gamma)$ display strictly decreasing whereas $g''_2(t,\gamma)$ exhibits strictly increasing,$g''_1(t,0.6) \leq g''_2(t,0.6)$.

Part C: Study the nature of NDDE when initial condition and $\tilde{\lambda}$ are TrSVNN-Type 2.

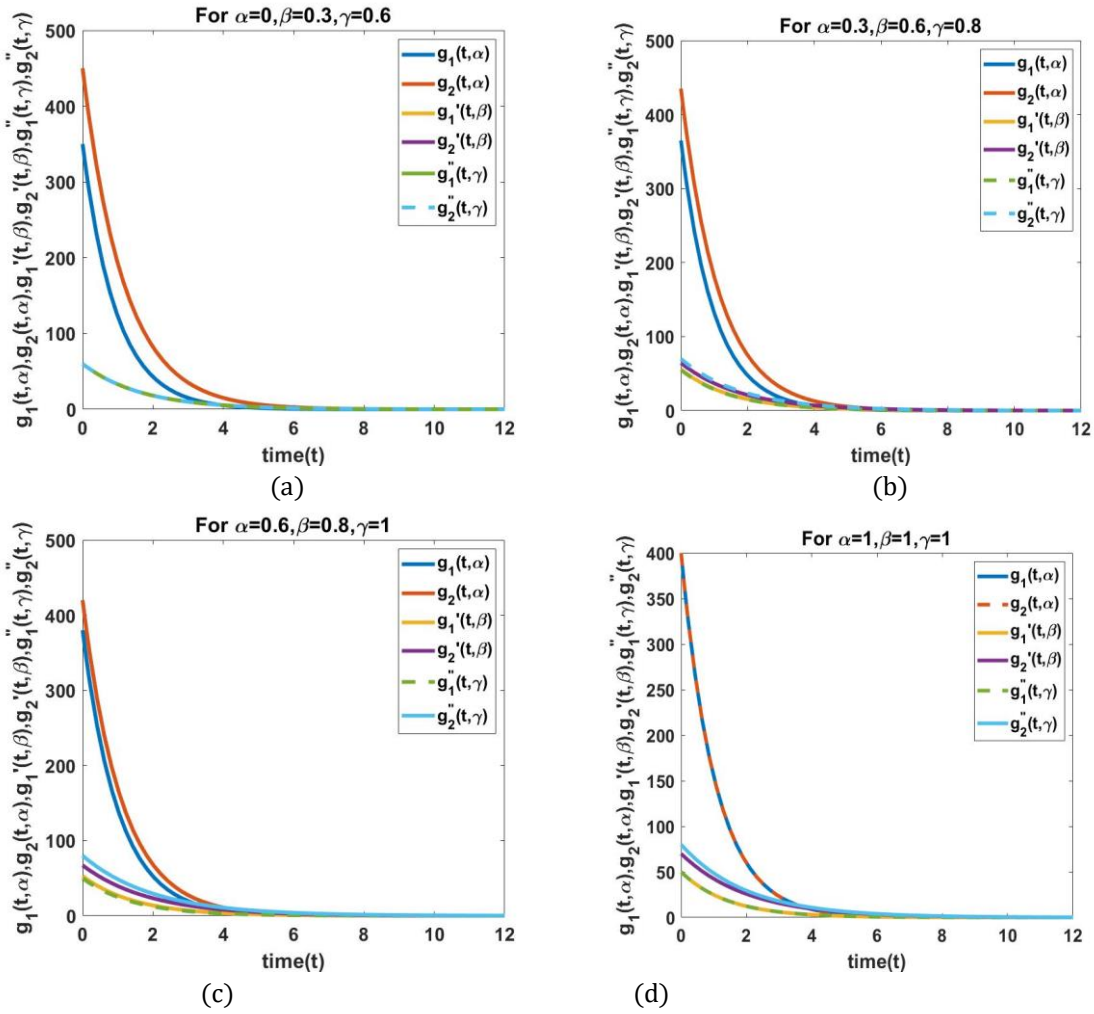


Figure 5: Neutrosophic fuzzy solution: Figure 5(a) for α=0,β=0.3,γ=0.6; Figure 5(b) for α=0.3,β=0.6,γ=0.8; Figure 5(c)for α=0.6,β=0.8,γ=1;Figure5(d) for α=1,β=1,γ=1 where t ∈ [0,12]

.

In Figure 5(a) we see that $g_1(t,\alpha) \leq g_2(t,\alpha)$; $g'_1(t,\beta) = g'_2(t,\beta)$;$g''_1(t,\gamma) = g''_2(t,\gamma)$; Figure 5(b), Figure 5(c) and Figure 5(d) shows that $g_1(t,\alpha) \leq g_2(t,\alpha)$; $g'_1(t,\beta) \leq g'_2(t,\beta)$;$g''_1(t,\gamma) \leq g''_2(t,\gamma)$ for t ∈ [0,12]. From Figure 5 we observe that E_3^* is LAS.

Considering u=1, t=8 with initial conditions stated in (8) as well as (9), the solutions for equation (6) are shown in Table 3 where α ∈ [0,1], β ∈ [0.3,1] and γ ∈ [0.6,1].

α	$g_1(t,\alpha)$	$g_2(t,\alpha)$	β	$g'_1(t,\beta)$	$g'_2(t,\beta)$	γ	$g''_1(t,\gamma)$	$g''_2(t,\gamma)$
0	0.0789	0.5015						
0.1	0.0867	0.4578						
0.2	0.0952	0.4179						
0.3	0.1046	0.3814	0.3	0.4938	0.4938			
0.4	0.1148	0.3481	0.4	0.4300	0.5668			
0.5	0.1261	0.3176	0.5	0.3742	0.6502			
0.6	0.1384	0.2898	0.6	0.3255	0.7454	0.6	0.4938	0.4938
0.7	0.1519	0.2644	0.7	0.2829	0.8543	0.7	0.3875	0.6534
0.8	0.1666	0.2411	0.8	0.2457	0.9785	0.8	0.3034	0.8594
0.9	0.1828	0.2199	0.9	0.2132	1.1203	0.9	0.2372	1.1247
1	0.2005	0.2005	1	0.1849	1.2821	1	0.1849	1.4653

Table 3 displays Neutrosophic fuzzy solution for the system described by (6) when t=8.

Table 3 reflects that $g_1(t,\alpha)$ exhibits increasing,$g_2(t,\alpha)$ demonstrate decreasing; $g'_1(t,\beta)$ display decreasing whereas $g'_2(t,\beta)$ exhibits increasing; $g''_1(t,\gamma)$ display decreasing and $g''_2(t,\gamma)$ demonstrate increasing for $\alpha \in [0,1], \beta \in [0.3,1]and\gamma \in [0.6,1]$ and t=8.

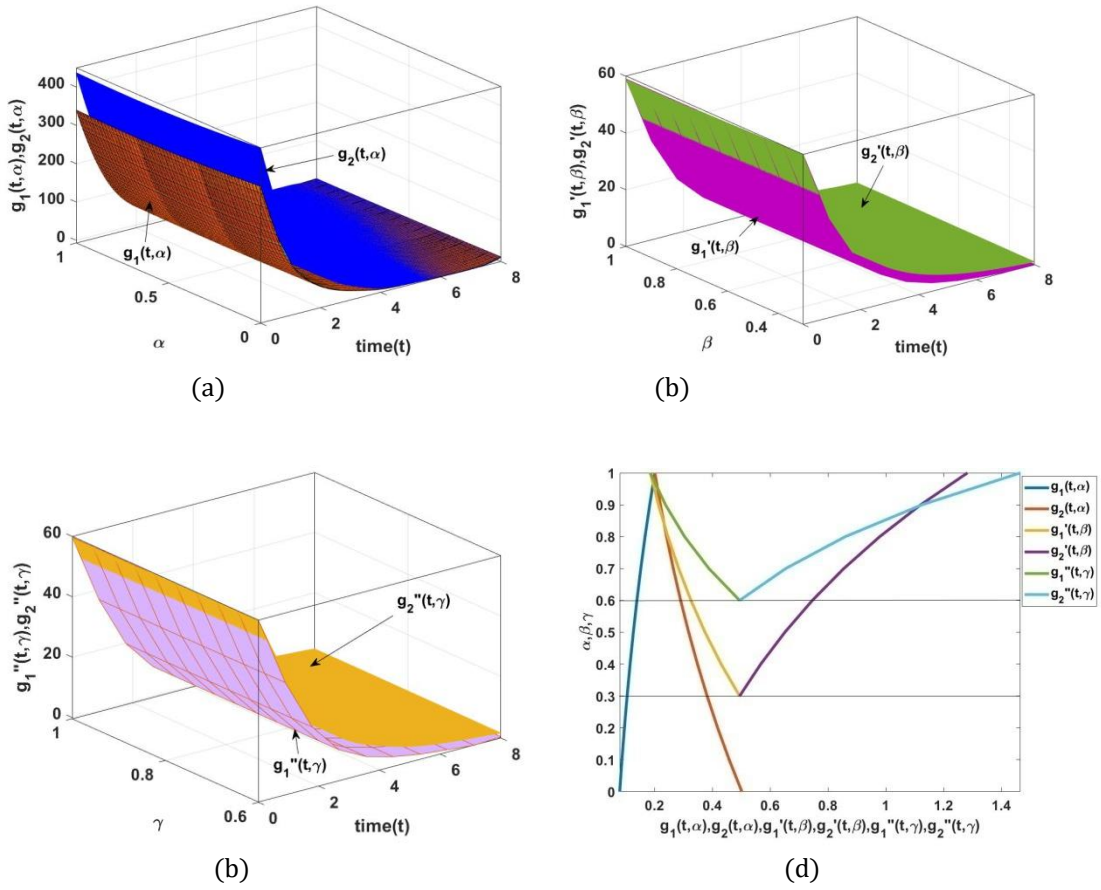


Figure 6. (3D plot).

Figure 6(a): Pictorial diagram of 3D plot of $g_1(t,\alpha), g_2(t,\alpha)$ with respect to time(t) and α where $t \in [0,8]$, $\alpha \in [0,1]$;

Figure 6(b): Pictorial diagram of 3D plot of $g'_1(t,\beta), g'_2(t,\beta)$ with respect to time(t) and β where $t \in [0,8]$, $\beta \in [0.3,1]$;

Figure 6(c): Pictorial diagram of 3D plot of $g''_1(t,\gamma), g''_2(t,\gamma)$ with respect to time(t) and γ where $t \in [0,8]$, $\gamma \in [0.6,1]$;

Figure 6(d): Pictorial diagram of 3D plot of $g_1(t,\alpha), g_2(t,\alpha), g'_1(t,\beta), g'_2(t,\beta), g''_1(t,\gamma), g''_2(t,\gamma)$ with respect to time(t) and α,β,γ where $\alpha \in [0,1], \beta \in [0.3,1], \gamma \in [0.6,1]$.

From Figure 5, Figure 6 and Table 3 clearly depicts, for all values of α within the interval [0,1], $g_1(t,\alpha)$ exhibits strictly increasing whereas $g_2(t,\alpha)$ displays strictly decreasing i.e. $g_1(t,1) \leq g_2(t,1)$; for all values of β within the interval[0.3,1],$g'_1(t,\beta)$ demonstrate strictly decreasing whereas $g'_2(t,\beta)$ exhibits strictly increasing i.e $g'_1(t,0.3) \leq g'_2(t,0.3)$; for all values of $\gamma \in [0.6,1]$, $g''_1(t,\gamma)$ display strictly decreasing whereas $g''_2(t,\gamma)$ exhibits strictly increasing,$g''_1(t,0.6) \leq g''_2(t,0.6)$. Hence by definition 2.6, the solution to equation (1), $\tilde{g}(t,\alpha,\beta,\gamma)$ qualifies as a robust Neutrosophic fuzzy solution.

6. Comparison of the model in both environment:

The suggested system on drug diffusion in connective tissue plays an important role in determination of the amount of drug in blood stream with passage of time. However, due to certain parameters like

environment factors, etc there arises an uncertainty in such biological models. To overcome such uncertainties, we adopt the concept of Neutrosophic environment and convert the given differential equations of the proposed biological model toneutrosophic differential equations (NDE) by taking three cases: (i) the quantity of drug diffusion within blood at initial time t_0i.e. $\tilde{g}_0$ is TrSVNN Type 2, (ii) the concentration of drug within bloodstream $\tilde{\lambda}$is neutrosophic number TrSVNN Type 2, (iii) both $\tilde{g}_0$ and $\tilde{\lambda}$ are TrSVNN Type 2.We have generated the exact solution and stability criteria for each of the three cases. The results and theorems have been verified numerically and graphically. From Table 1, Figure 1 and Figure 2 we observe that all the solutions are strong neutrosophic solutions of the converted system (2) when t=1. From Figure 3 as well as Figure 4 we see that all solutions are strong neutrosophic solutions of the converted system (3) when $t = 6$ using Table 2. Similar conclusions are drawn are for converted system (4) from Table 3, Figure 5 and Figure 6 when t=8.

7. Conclusion

In a neutrosophic situation, we have effectively handled the differential equation relating to medication dispersion in human connective tissues. The initial condition and the parameter are represented by single-valued triangular neutrosophic numbers. Neutrosophic values are considered for the initial state, aiming to capture the nuances of truth and falsity in the dynamics of drug diffusion within human tissues. As an example, when α is set to 0.3, the membership degree or truth value of $\tilde{g}(t, \alpha, \beta, \gamma)$ needs to exceed 0.3. In other words, the drug diffusion level $g(t)$ at time t, as defined in equation (7), should be true in more than 30 out of 1000 instances. To achieve this, the truth values of the initial condition, where $g(t_0) = g_0$, should be $g_{01} = 345$ within the range [350, 400) and $g_{02} =$ 385 within the range (400, 450]. Similarly, when $\beta = 0.6$ the value of $\tilde{g}(t, \alpha, \beta, \gamma)$in case of indeterminacy must be less than 0.6 and when $\gamma = 0.8$ the falsity membership must be less than 0.8. Corresponding values of the initial conditions are evaluated from (8). Thus, in a neutrosophic environment, the values of the initial conditions are more appropriately applicable in all the three possibilities, i.e truth, indeterminacy and falsity. Analogous explanations hold for the TrSVNN Type 2 values of $\widetilde{g_0} = (350,400,450; 50,60,40; 0.3,0.6)$ and $\tilde{\lambda} =$ $(0.85,0.95,1.05; 0.5,0.6,0.7;0.3,0.6)$. The above discussion enables us to determine whether a drug is potent enough to be used in regard to its therapeutic advantages. In a broader sense, this study enables us to understand the appropriateness of pharmaceutical intervention in various kinds of human and animal pathogenesis.In future more research works can be carried out on bio-mathematical modelling using several types of neutrosophic numbers.

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