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To cite this article: P. Revathi *et al* 2021 *J. Phys.: Conf. Ser.* **2070** 012028

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Soft e -Separation Axioms in Neutrosophic soft Topological Spaces

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May 29, 2021

Abstract

In this paper, the idea of neutrosophic soft e -neighbourhood and neutrosophic soft e -separation axioms in neutrosophic soft topological spaces are introduced. Later, we discussed about the concept of neutrosophic soft e -separation axioms of neutrosophic soft topological spaces is diffused in different results with respect to neutrosophic soft points. Furthermore, we discuss the properties of neutrosophic soft e - T_i -spaces ($i = 0, 1, 2, 3, 4$) and the relations between them.

Keywords and phrases: N_sSe -neighbourhood, N_sSe -separation axioms, N_sSe - T_i -space ($i = 0, 1, 2, 3, 4$).

AMS (2000) subject classification: 03E72, 54A05, 54A40.

1 Introduction

In Mathematics, the concept of fuzzy set was first introduced by Zadeh [27] and its topological structure was undertaken by Chang [6]. In 1983, Atanassov [3] initiated intuitionistic fuzzy set and its topological structure was introduced by Coker [7]. Molodstov [12] initiated the soft set theory as a new mathematical tool in 1999. Shabir and Naz [16] presented soft topological spaces in soft sets.

Smarandache [17] introduced the concepts of neutrosophy and neutrosophic set and its topological structure by Salama and Alblowi [14] in 2012. Maji [11] defined the Neutrosophic soft sets and modified by Deli and Broumi [8]. Its topological structures was presented by Bera [5]. δ -open sets defined by Saha [18] in fuzzy topological spaces, Vadivel et al. [20] in neutrosophic topological space. In 2019, Ahu Acikgoz and Ferhat Esenbel [1] defined neutrosophic soft δ -topology.

The notion of e -open sets by Ekici [9] in a general topology, Seenivasan et. al. [15] in fuzzy topological space, Chandrasekar et al. [21] in intuitionistic fuzzy topological space, Vadivel et.al. [19] in neutrosophic topological spaces and recently, Revathi et al. [13] in neutrosophic soft topological spaces. Gunduz Aras et al. [22] studied separation axioms on neutrosophic soft topological spaces in 2019. Khattak et al. [23] introduced soft b -separation axioms in neutrosophic soft topological structures. In 2020, Acikgoz et al. [25] studied an approach to pre-separation axioms in neutrosophic soft topological spaces.

The aim of this paper is to define the notions of neutrosophic soft e -neighbourhood and neutrosophic soft e -separation axioms in neutrosophic soft topological spaces. Also, we discuss some relations of neutrosophic soft e -separation axioms with respect to neutrosophic soft points. Furthermore, we analyze properties of neutrosophic soft e - T_i -spaces ($i = 0, 1, 2, 3, 4$) and focus on some relations between them.

2 Preliminaries

Definition 2.1 [8] Let Y be an initial universe, Q be a set of parameters. Let $P(Y)$ denotes the set of all neutrosophic sets of Y . Then a neutrosophic soft set $(\tilde{H}, Q)$ over Y (briefly, N_sSs) is defined by $(\tilde{H}, Q) = \{(q, \langle y, \mu_{\tilde{H}(q)}(y), \sigma_{\tilde{H}(q)}(y), \nu_{\tilde{H}(q)}(y) \rangle : y \in Y) : q \in Q\}$, where $\mu_{\tilde{H}(q)}(y), \sigma_{\tilde{H}(q)}(y), \nu_{\tilde{H}(q)}(y) \in [0, 1]$ are respectively called the degree of membership function, the degree of indeterminacy function and the degree of non-membership function of $\tilde{H}(q)$. Since the supremum of each μ, σ, ν is 1, the inequality $0 \leq \mu_{\tilde{H}(q)}(y) + \sigma_{\tilde{H}(q)}(y) + \nu_{\tilde{H}(q)}(y) \leq 3$ is obvious.

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Definition 2.2 [5, 11] Let Y be an initial universe & the $N_s S$'s $(\tilde{H}, Q)$ & $(\tilde{G}, Q)$ are in the form $(\tilde{H}, Q) = \{(q, \langle y, \mu_{\tilde{H}(q)}(y), \sigma_{\tilde{H}(q)}(y), \nu_{\tilde{H}(q)}(y) \rangle : y \in Y) : q \in Q\}$ & $(\tilde{G}, Q) = \{(q, \langle y, \mu_{\tilde{G}(q)}(y), \sigma_{\tilde{G}(q)}(y), \nu_{\tilde{G}(q)}(y) \rangle : y \in Y) : q \in Q\}$, then

- (i) $0_{(Y, Q)} = \{(q, \langle y, 0, 0, 1 \rangle : y \in Y) : q \in Q\}$ and $1_{(Y, Q)} = \{(q, \langle y, 1, 1, 0 \rangle : y \in Y) : q \in Q\}$
- (ii) $(\tilde{H}, Q) \subseteq (\tilde{G}, Q)$ iff $\mu_{\tilde{H}(q)}(y) \leq \mu_{\tilde{G}(q)}(y), \sigma_{\tilde{H}(q)}(y) \leq \sigma_{\tilde{G}(q)}(y)$ & $\nu_{\tilde{H}(q)}(y) \geq \nu_{\tilde{G}(q)}(y) : y \in Y : q \in Q$.
- (iii) $(\tilde{H}, Q) = (\tilde{G}, Q)$ iff $(\tilde{H}, Q) \subseteq (\tilde{G}, Q)$ and $(\tilde{G}, Q) \subseteq (\tilde{H}, Q)$.
- (iv) $(\tilde{H}, Q)^c = \{(q, \langle y, \nu_{\tilde{H}(q)}(y), 1 - \sigma_{\tilde{H}(q)}(y), \mu_{\tilde{H}(q)}(y) \rangle : y \in Y) : q \in Q\}$.
- (v) $(\tilde{H}, Q) \cup (\tilde{G}, Q) = \{(q, \langle y, \max(\mu_{\tilde{H}(q)}(y), \mu_{\tilde{G}(q)}(y)), \max(\sigma_{\tilde{H}(q)}(y), \sigma_{\tilde{G}(q)}(y)), \min(\nu_{\tilde{H}(q)}(y), \nu_{\tilde{G}(q)}(y)) \rangle : y \in Y) : q \in Q\}$.
- (vi) $(\tilde{H}, Q) \cap (\tilde{G}, Q) = \{(q, \langle y, \min(\mu_{\tilde{H}(q)}(y), \mu_{\tilde{G}(q)}(y)), \min(\sigma_{\tilde{H}(q)}(y), \sigma_{\tilde{G}(q)}(y)), \max(\nu_{\tilde{H}(q)}(y), \nu_{\tilde{G}(q)}(y)) \rangle : y \in Y) : q \in Q\}$.

Definition 2.3 [5] A neutrosophic soft topology (briefly, $N_s St$) on an initial universe Y is a family τ of neutrosophic soft subsets $(\tilde{H}, Q)$ of Y where Q is a set of parameters, satisfying

- (i) $0_{(Y, Q)}, 1_{(Y, Q)} \in \tau$.
- (ii) $[(\tilde{H}, Q) \cap (\tilde{G}, Q)] \in \tau$ for any $(\tilde{H}, Q), (\tilde{G}, Q) \in \tau$.
- (iii) $\bigcup_{\rho \in A} (\tilde{H}, Q)_\rho \in \tau, \forall (\tilde{H}, Q)_\rho : \rho \in A \subseteq \tau$.

Then (Y, τ, Q) is called a neutrosophic soft topological space (briefly, $N_s Sts$) in Y . The τ elements are called neutrosophic soft open sets (briefly, $N_s Sos$) in Y . A $N_s S$ $(\tilde{H}, Q)$ is called a neutrosophic soft closed set (briefly, $N_s Scs$) if its complement $(\tilde{H}, Q)^c$ is $N_s Sos$.

Definition 2.4 A set $(\tilde{H}, Q)$ is said to be a neutrosophic soft regular (resp. δ & e) open set (briefly, $N_s Sros$ [5] (resp. $N_s S\delta os$ [1] & $N_s Seos$ [13])) if $(\tilde{H}, Q) = N_s Sint(N_s Scl(\tilde{H}, Q))$ (resp. $(\tilde{H}, Q) = N_s S\delta int(\tilde{H}, Q)$ & $(\tilde{H}, Q) \subseteq N_s Scl(N_s S\delta int(\tilde{H}, Q)) \cup N_s Sint(N_s S\delta cl(\tilde{H}, Q))$).

The complement of a respected open sets are their respective closed sets.

Definition 2.5 [22] Let $N_s S$'s $(\tilde{H}, Q)$ be the family of all $N_s S$'s over the universe set Y and let $y \in Y, 0 \leq \varepsilon, \zeta, \eta \leq 1, q \in Q$. Then the $N_s S$'s $y_{(\varepsilon, \zeta, \eta)}^q$ is called a neutrosophic soft point (briefly, $N_s Sp$) and is defined as follows: For each $z \in Y$,

$$y_{(\varepsilon, \zeta, \eta)}^q(q')(z) = \begin{cases} (\varepsilon, \zeta, \eta) & \text{if } q' = q \text{ and } z = y \\ (0, 0, 1) & \text{if } q' \neq q \text{ or } z \neq y. \end{cases}$$

Definition 2.6 [22] Suppose that the universe set Y is given by $Y = \{y_1, y_2\}$ and the set of parameters $Q = \{q_1, q_2\}$. Let us consider $N_s S$'s $(\tilde{H}, Q)$ on Y as follows:

$$\begin{aligned} (\tilde{H}_1, q_1) &= \{\langle y_1, (0.3, 0.7, 0.6) \rangle, \langle y_2, (0.4, 0.3, 0.8) \rangle\} \\ (\tilde{H}_1, q_2) &= \{\langle y_1, (0.4, 0.6, 0.8) \rangle, \langle y_2, (0.3, 0.7, 0.2) \rangle\} \end{aligned}$$

It is clear that $(\tilde{H}_1, Q)$ is the union of its $N_s Sp$'s $y_{1(0.3, 0.7, 0.6)}^{q_1}, y_{1(0.4, 0.6, 0.8)}^{q_2}, y_{2(0.4, 0.3, 0.8)}^{q_1}, y_{2(0.3, 0.7, 0.2)}^{q_2}$. Here,

$$\begin{aligned} y_{1(0.3, 0.7, 0.6)}^{q_1} &= \left\{ \begin{array}{l} q_1 = \langle y_1, (0.3, 0.7, 0.6) \rangle, \langle y_2, (0, 0, 1) \rangle \\ q_2 = \langle y_1, (0, 0, 1) \rangle, \langle y_2, (0, 0, 1) \rangle \end{array} \right\} \\ y_{1(0.4, 0.6, 0.8)}^{q_2} &= \left\{ \begin{array}{l} q_1 = \langle y_1, (0, 0, 1) \rangle, \langle y_2, (0, 0, 1) \rangle \\ q_2 = \langle y_1, (0.4, 0.6, 0.8) \rangle, \langle y_2, (0, 0, 1) \rangle \end{array} \right\} \\ y_{2(0.4, 0.3, 0.8)}^{q_1} &= \left\{ \begin{array}{l} q_1 = \langle y_1, (0, 0, 1) \rangle, \langle y_2, (0.4, 0.3, 0.8) \rangle \\ q_2 = \langle y_1, (0, 0, 1) \rangle, \langle y_2, (0, 0, 1) \rangle \end{array} \right\} \\ y_{2(0.3, 0.7, 0.2)}^{q_2} &= \left\{ \begin{array}{l} q_1 = \langle y_1, (0, 0, 1) \rangle, \langle y_2, (0, 0, 1) \rangle \\ q_2 = \langle y_1, (0, 0, 1) \rangle, \langle y_2, (0.3, 0.7, 0.2) \rangle \end{array} \right\} \end{aligned}$$

Definition 2.7 [22] Let $(\tilde{H}, Q)$ be a $N_s S$'s over the universe set Y . We say that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q)$ read as belonging to the $N_s S$'s $(\tilde{H}, Q)$, whenever $\varepsilon \leq \mu_{\tilde{H}(q)}(y), \zeta \leq \sigma_{\tilde{H}(q)}(y)$ and $\eta \geq \nu_{\tilde{H}(q)}(y)$.

Definition 2.8 [22] Let $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$ be two N_sSp 's. For the N_sSp 's $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$ over a common universe Y , we say that N_sSp 's are distinct points, if $y_{(\varepsilon, \zeta, \eta)}^q \cap y_{(\varepsilon', \zeta', \eta')}^{q'} = 0_{(Y, Q)}$. It is clear that $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$ are distinct N_sSp 's iff $y \neq z$ and $q' \neq q$.

Definition 2.9 [22] Let (Y, τ, Q) be a N_sSts over Y and $(\tilde{H}, Q)$ be an arbitrary N_sS 's. Then $\tau_{(\tilde{H}, Q)} = \{(\tilde{H}, Q) \cap (\tilde{G}, Q) : (\tilde{G}, Q) \in \tau\}$ is said to be N_sSt on $(\tilde{H}, Q)$ and $((\tilde{H}, Q), \tau_{(\tilde{H}, Q)}, Q)$ is called a neutrosophic soft topological subspace (briefly, N_sStss) of (Y, τ, Q) .

3 Neutrosophic soft e -separation structures

Definition 3.1 Let (Y, τ, Q) be N_sSts over Y . A N_sS 's $(\tilde{H}, Q)$ in (Y, τ, Q) is called a neutrosophic soft e -neighbourhood (briefly, $N_sSe-nbd$) of the N_sSp $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q)$, if there exists a N_sSeos $(\tilde{G}, Q)$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{G}, Q) \subseteq (\tilde{H}, Q)$.

Theorem 3.1 Let (Y, τ, Q) be N_sSts over Y and $(\tilde{H}, Q)$ be a N_sS 's on Y . Then $(\tilde{H}, Q)$ is a N_sSeos iff $(\tilde{H}, Q)$ is a $N_sSe-nbd$ of its N_sSp 's.

Proof. Let $(\tilde{H}, Q)$ be a N_sSeos and $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q)$. Then, $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q) \subseteq (\tilde{H}, Q)$. Thus $(\tilde{H}, Q)$ is a $N_sSe-nbd$ of $y_{(\varepsilon, \zeta, \eta)}^q$.

Conversely, let $(\tilde{H}, Q)$ be a $N_sSe-nbd$ of its N_sSp 's. Let $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q)$. Since $(\tilde{H}, Q)$ is a $N_sSe-nbd$ of the N_sSp $y_{(\varepsilon, \zeta, \eta)}^q$, there exists $(\tilde{G}, Q) \in \tau$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{G}, Q) \subseteq (\tilde{H}, Q)$. Since $(\tilde{H}, Q) = \bigcup \{y_{(\varepsilon, \zeta, \eta)}^q : y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q)\}$, it follows that $(\tilde{H}, Q)$ is a union of N_sSeo sets. Then $(\tilde{H}, Q)$ is a N_sSeos . ■

The $N_sSe-nbd$ system of a N_sSp $y_{(\varepsilon, \zeta, \eta)}^q$ denoted by $\bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$, is the family of all its $N_sSe-nbd$'s.

Theorem 3.2 The $N_sSe-nbd$ system $\bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$ at $y_{(\varepsilon, \zeta, \eta)}^q$ in a N_sSts (Y, τ, Q) has the following properties:

- (i) If $(\tilde{H}, Q) \in \bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$, then $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q)$.
- (ii) If $(\tilde{H}, Q) \in \bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$ and $(\tilde{H}, Q) \subseteq (\tilde{K}, Q)$, then $(\tilde{K}, Q) \in \bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$.
- (iii) $(\tilde{H}, Q)$ and $(\tilde{G}, Q) \in \bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$, then $(\tilde{H}, Q) \cap (\tilde{G}, Q) \in \bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$.
- (iv) If $(\tilde{H}, Q) \in \bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$, then there exists a $(\tilde{G}, Q) \in \bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$ such that $(\tilde{G}, Q) \in \bigcup (z_{(\varepsilon', \zeta', \eta')}^{q'}, Q)$ for each $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (\tilde{G}, Q)$.

Proof. The proofs of (i), (ii) and (iii) are obvious from the definition 2.6.

- (iv) Suppose $(\tilde{H}, Q) \in \bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$. Then there exists a N_sSeos $(\tilde{G}, Q)$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{G}, Q) \subseteq (\tilde{H}, Q)$. Thus by theorem 3.1, $(\tilde{G}, Q) \in \bigcup (y_{(\varepsilon, \zeta, \eta)}^q, Q)$. So for each $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (\tilde{G}, Q)$, $(\tilde{G}, Q) \in \bigcup (z_{(\varepsilon', \zeta', \eta')}^{q'}, Q)$. ■

Definition 3.2 Let (Y, τ, Q) be N_sSts over Y . Let $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$ be distinct N_sSp 's. If there exist N_sSeos 's $(\tilde{H}, Q)$ and $(\tilde{G}, Q)$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q)$ and $y_{(\varepsilon, \zeta, \eta)}^q \cap (\tilde{G}, Q) = 0_{(Y, Q)}$ or $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (\tilde{G}, Q)$ and $z_{(\varepsilon', \zeta', \eta')}^{q'} \cap (\tilde{H}, Q) = 0_{(Y, Q)}$, then (Y, τ, Q) is called a neutrosophic soft $e-T_0$ -space (briefly, N_sSe-T_0 -space).

Definition 3.3 Let (Y, τ, Q) be N_sSts over Y . Let $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$ be distinct N_sSp 's. If there exist N_sSeos 's $(\tilde{H}, Q)$ and $(\tilde{G}, Q)$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q)$, $y_{(\varepsilon, \zeta, \eta)}^q \cap (\tilde{G}, Q) = 0_{(Y, Q)}$ and $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (\tilde{G}, Q)$, $z_{(\varepsilon', \zeta', \eta')}^{q'} \cap (\tilde{H}, Q) = 0_{(Y, Q)}$, then (Y, τ, Q) is called a neutrosophic soft $e-T_1$ -space (briefly, N_sSe-T_1 -space).

Definition 3.4 Let (Y, τ, Q) be N_sSts over Y . Let $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$ be distinct N_sSp 's. If there exist N_sSeos 's $(\tilde{H}, Q)$ and $(\tilde{G}, Q)$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q)$, $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (\tilde{G}, Q)$ and $(\tilde{H}, Q) \cap (\tilde{G}, Q) = 0_{(Y, Q)}$, then (Y, τ, Q) is called a neutrosophic soft $e-T_2$ -space (briefly, N_sSe-T_2 -space).

Example 3.1 Let $Y = \{y_1, y_2\}$ be a universe set, $Q = \{q_1, e_2\}$ be a parameters set and $y_{1(0.1, 0.4, 0.7)}^{q_1}$, $y_{1(0.2, 0.5, 0.6)}^{q_2}$, $y_{2(0.3, 0.3, 0.5)}^{q_1}$ and $y_{2(0.4, 0.4, 0.4)}^{q_2}$ be N_sSp 's. Then the family $\tau = \{0_{(Y, Q)}, 1_{(Y, Q)}, (\psi_1, Q), (\psi_2, Q), (\psi_3, Q), (\psi_4, Q), (\psi_5, Q), (\psi_6, Q), (\psi_7, Q),$

$(\tilde{\psi}_8, Q)\}$, where

$$\begin{aligned}(\tilde{\psi}_1, Q) &= \{y_{1(0.1,0.4,0.7)}^{q_1}\} \\(\tilde{\psi}_2, Q) &= \{y_{1(0.2,0.5,0.6)}^{q_2}\} \\(\tilde{\psi}_3, Q) &= \{y_{2(0.3,0.3,0.5)}^{q_1}\} \\(\tilde{\psi}_4, Q) &= (\tilde{\psi}_1, Q) \cup (\tilde{\psi}_2, Q) \\(\tilde{\psi}_5, Q) &= (\tilde{\psi}_1, Q) \cup (\tilde{\psi}_3, Q) \\(\tilde{\psi}_6, Q) &= (\tilde{\psi}_2, Q) \cup (\tilde{\psi}_3, Q) \\(\tilde{\psi}_7, Q) &= (\tilde{\psi}_1, Q) \cup (\tilde{\psi}_2, Q) \cup (\tilde{\psi}_3, Q) \\(\tilde{\psi}_8, Q) &= \{y_{1(0.1,0.4,0.7)}^{q_1}, y_{1(0.2,0.5,0.6)}^{q_2}, y_{2(0.3,0.3,0.5)}^{q_1}, y_{2(0.4,0.4,0.4)}^{q_2}\}\end{aligned}$$

ia a N_sSt over Y . Hence, (Y, τ, Q) is a N_sSts over Y . Also, (Y, τ, Q) is a N_sSe-T_0 -space but not a N_sSe-T_1 -space because for N_sSp 's $y_{1(0.1,0.4,0.7)}^{q_1}$ and $y_{2(0.4,0.4,0.4)}^{q_2}$, (Y, τ, Q) is not a N_sSe-T_1 -space.

Example 3.2 Let $Y = N$ be a set of natural numbers and $Q = \{q\}$ be a parameter set. Here $n_{(\varepsilon_n, \zeta_n, \eta_n)}^q$ are N_sSp 's. Here we can give $(\varepsilon_n, \zeta_n, \eta_n)$ appropriate values and the N_sSp 's $n_{(\varepsilon_n, \zeta_n, \eta_n)}^q, m_{(\varepsilon_m, \zeta_m, \eta_m)}^q$ are distinct N_sSp 's iff $n \neq m$. It is clear that there is one-to-one compatibility between the set of natural numbers and the set of N_sSp 's $N^q = \{n_{(\varepsilon_n, \zeta_n, \eta_n)}^q\}$. Then we give cofinite topology on this set. Then N_sS 's $(\tilde{\psi}, Q)$ is a N_sSeos iff the finite N_sSp 's are discarded from N^q . Hence, (Y, τ, Q) is a N_sSe-T_1 -space but not a N_sSe-T_2 -space.

Example 3.3 Let $Y = \{y_1, y_2\}$ be a universe set, $Q = \{q_1, q_2\}$ be a parameters set and $y_{1(0.1,0.4,0.7)}^{q_1}, y_{1(0.2,0.5,0.6)}^{q_2}, y_{2(0.3,0.3,0.5)}^{q_1}$ and $y_{2(0.4,0.4,0.4)}^{q_2}$ be N_sSp 's. Then the family $\tau = \{0_{(Y,Q)}, 1_{(Y,Q)}, (\tilde{\psi}_1, Q), (\tilde{\psi}_2, Q), (\tilde{\psi}_3, Q), \dots, (\tilde{\psi}_{15}, Q)\}$, where

$$\begin{aligned}(\tilde{\psi}_1, Q) &= \{y_{1(0.1,0.4,0.7)}^{q_1}\} \\(\tilde{\psi}_2, Q) &= \{y_{1(0.2,0.5,0.6)}^{q_2}\} \\(\tilde{\psi}_3, Q) &= \{y_{2(0.3,0.3,0.5)}^{q_1}\} \\(\tilde{\psi}_4, Q) &= \{y_{2(0.4,0.4,0.4)}^{q_2}\} \\(\tilde{\psi}_5, Q) &= (\tilde{\psi}_1, Q) \cup (\tilde{\psi}_2, Q) \\(\tilde{\psi}_6, Q) &= (\tilde{\psi}_1, Q) \cup (\tilde{\psi}_3, Q) \\(\tilde{\psi}_7, Q) &= (\tilde{\psi}_1, Q) \cup (\tilde{\psi}_4, Q) \\(\tilde{\psi}_8, Q) &= (\tilde{\psi}_2, Q) \cup (\tilde{\psi}_3, Q) \\(\tilde{\psi}_9, Q) &= (\tilde{\psi}_2, Q) \cup (\tilde{\psi}_4, Q) \\(\tilde{\psi}_{10}, Q) &= (\tilde{\psi}_3, Q) \cup (\tilde{\psi}_4, Q) \\(\tilde{\psi}_{11}, Q) &= (\tilde{\psi}_1, Q) \cup (\tilde{\psi}_2, Q) \cup (\tilde{\psi}_3, Q) \\(\tilde{\psi}_{12}, Q) &= (\tilde{\psi}_1, Q) \cup (\tilde{\psi}_2, Q) \cup (\tilde{\psi}_4, Q) \\(\tilde{\psi}_{13}, Q) &= (\tilde{\psi}_2, Q) \cup (\tilde{\psi}_3, Q) \cup (\tilde{\psi}_4, Q) \\(\tilde{\psi}_{14}, Q) &= (\tilde{\psi}_1, Q) \cup (\tilde{\psi}_3, Q) \cup (\tilde{\psi}_4, Q) \\(\tilde{\psi}_{15}, Q) &= \{y_{1(0.1,0.4,0.7)}^{q_1}, y_{1(0.2,0.5,0.6)}^{q_2}, y_{2(0.3,0.3,0.5)}^{q_1}, y_{2(0.4,0.4,0.4)}^{q_2}\}\end{aligned}$$

ia a N_sSt over Y . Hence, (Y, τ, Q) is a N_sSts over Y . Also, (Y, τ, Q) is a N_sSe-T_2 -space.

Theorem 3.3 Let (Y, τ, Q) be a N_sSts over Y . Then (Y, τ, Q) is a N_sSe-T_1 -space iff each N_sSp is a N_sSecs .

Proof. Let (Y, τ, Q) be a N_sSe-T_1 -space and $y_{(\varepsilon, \zeta, \eta)}^q$ be an arbitrary N_sSp . Let $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (y_{(\varepsilon, \zeta, \eta)}^q)^c$. Then $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$ are distinct N_sSp 's. Thus $y \neq z$ or $q' \neq q$. Since (Y, τ, Q) is a N_sSe-T_1 -space, there exists a N_sSeos $(\tilde{G}, Q)$ such that $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (\tilde{G}, Q)$ and $y_{(\varepsilon, \zeta, \eta)}^q \cap (\tilde{G}, Q) = 0_{(Y,Q)}$. Since $y_{(\varepsilon, \zeta, \eta)}^q \cap (\tilde{G}, Q) = 0_{(Y,Q)}$, we have $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (\tilde{G}, Q) \subseteq (y_{(\varepsilon, \zeta, \eta)}^q)^c$. Thus $(y_{(\varepsilon, \zeta, \eta)}^q)^c$ is a N_sSeos , ie, $y_{(\varepsilon, \zeta, \eta)}^q$ is a N_sSecs .

Conversely, suppose that each N_sSp $y_{(\varepsilon, \zeta, \eta)}^q$ is a N_sSecs . Then $(y_{(\varepsilon, \zeta, \eta)}^q)^c$ is a N_sSeos . Let $y_{(\varepsilon, \zeta, \eta)}^q \cap z_{(\varepsilon', \zeta', \eta')}^{q'} = 0_{(Y,Q)}$. Thus, $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (y_{(\varepsilon, \zeta, \eta)}^q)^c$ and $y_{(\varepsilon, \zeta, \eta)}^q \cap (y_{(\varepsilon, \zeta, \eta)}^q)^c = 0_{(Y,Q)}$. So (Y, τ, Q) is a N_sSe-T_1 -space on Y . ■

Theorem 3.4 Let (Y, τ, Q) be a N_sSts over Y . Then (Y, τ, Q) is a N_sSe-T_2 -space iff for distinct N_sSp 's $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$, there exists a N_sSeos $(\tilde{H}, Q)$ containing $y_{(\varepsilon, \zeta, \eta)}^q$ but not $z_{(\varepsilon', \zeta', \eta')}^{q'}$ such that $z_{(\varepsilon', \zeta', \eta')}^{q'}$ does not belong to $N_sScl(\tilde{H}, Q)$.

Proof. Let $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$ be two N_sSp 's in N_sSe-T_2 -space (Y, τ, Q) . Then there exist disjoint N_sSeos 's $(\tilde{H}, Q)$, $(\tilde{G}, Q)$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q)$, $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (\tilde{G}, Q)$. Since $y_{(\varepsilon, \zeta, \eta)}^q \cap z_{(\varepsilon', \zeta', \eta')}^{q'} = 0_{(Y, Q)}$ and $(\tilde{H}, Q) \cap (\tilde{G}, Q) = 0_{(Y, Q)}$, $z_{(\varepsilon', \zeta', \eta')}^{q'}$ does not belong to $(\tilde{H}, Q)$. It implies that $z_{(\varepsilon', \zeta', \eta')}^{q'}$ does not belong to $N_sScl(\tilde{H}, Q)$.

Conversely suppose that, for distinct N_sSp 's $y_{(\varepsilon, \zeta, \eta)}^q$, $z_{(\varepsilon', \zeta', \eta')}^{q'}$, there exists a N_sSeos $(\tilde{H}, Q)$ containing $y_{(\varepsilon, \zeta, \eta)}^q$ but not $z_{(\varepsilon', \zeta', \eta')}^{q'}$ such that $z_{(\varepsilon', \zeta', \eta')}^{q'}$ does not belong to $N_sScl(\tilde{H}, Q)$. Then $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (N_sScl(\tilde{H}, Q))^c$, i.e., $(\tilde{H}, Q)$ and $(N_sScl(\tilde{H}, Q))^c$ are disjoint N_sSeos 's containing $y_{(\varepsilon, \zeta, \eta)}^q$, $z_{(\varepsilon', \zeta', \eta')}^{q'}$ respectively. ■

Theorem 3.5 Let (Y, τ, Q) be a N_sSe-T_1 -space for every N_sSp $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q) \in \tau$. If there exists a N_sSeos $(\tilde{G}, Q)$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{G}, Q) \subseteq N_sScl(\tilde{G}, Q) \subseteq (\tilde{H}, Q)$, then (Y, τ, Q) is a N_sSe-T_2 -space.

Proof. Suppose that $y_{(\varepsilon, \zeta, \eta)}^q \cap z_{(\varepsilon', \zeta', \eta')}^{q'} = 0_{(Y, Q)}$. Since (Y, τ, Q) is a N_sSe-T_1 -space, $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$ are N_sSecs 's in τ . Then $y_{(\varepsilon, \zeta, \eta)}^q \in (z_{(\varepsilon', \zeta', \eta')}^{q'})^c \in \tau$. Thus there exists a N_sSeos $(\tilde{G}, Q)$ in τ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{G}, Q) \subseteq N_sScl(\tilde{G}, Q) \subseteq (z_{(\varepsilon', \zeta', \eta')}^{q'})^c$. So, we have $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (N_sScl(\tilde{G}, Q))^c$, $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{G}, Q)$ and $(\tilde{G}, Q) \cap (N_sScl(\tilde{G}, Q))^c = 0_{(Y, Q)}$, i.e., (Y, τ, Q) is a N_sSe-T_2 -space. ■

Remark 3.1 Let (Y, τ, Q) be a N_sSe-T_i -space for $i = 0, 1, 2$. For each $y \neq z$, neutrosophic points $y_{(\varepsilon, \zeta, \eta)}$ and $z_{(\varepsilon', \zeta', \eta')}$ have neighbourhoods satisfying conditions of $e-T_i$ -space in N_sSts (Y, τ^q) for each $q \in Q$ because $y_{(\varepsilon, \zeta, \eta)}^q$ and $z_{(\varepsilon', \zeta', \eta')}^{q'}$ are distinct N_sSp 's.

Definition 3.5 Let (Y, τ, Q) be N_sSts over Y . Let $(\tilde{H}, Q)$ be a N_sSecs and $y_{(\varepsilon, \zeta, \eta)}^q \cap (\tilde{H}, Q) = 0_{(Y, Q)}$. If there exist N_sSeos 's $(\tilde{M}_1, Q)$ and $(\tilde{M}_2, Q)$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{M}_1, Q)$, $(\tilde{H}, Q) \subseteq (\tilde{M}_2, Q)$ and $(\tilde{M}_1, Q) \cap (\tilde{M}_2, Q) = 0_{(Y, Q)}$, then (Y, τ, Q) is called a neutrosophic soft e -regular (briefly, N_sSe -regular) space. (Y, τ, Q) is said to be a neutrosophic soft $e-T_3$ -space (briefly, N_sSe-T_3 -space) if it is both a N_sSe -regular and N_sSe-T_1 -space.

Theorem 3.6 Let (Y, τ, Q) be N_sSts over Y . (Y, τ, Q) is a N_sSe-T_3 -space iff for every $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q) \in \tau$, there exists $(\tilde{M}, Q) \in \tau$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{M}, Q) \subseteq N_sScl(\tilde{M}, Q) \subseteq (\tilde{H}, Q)$.

Proof. Let (Y, τ, Q) be a N_sSe-T_3 -space and $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}, Q) \in \tau$. Since (Y, τ, Q) is a N_sSe-T_3 -space for the N_sSp $y_{(\varepsilon, \zeta, \eta)}^q$ and N_sSecs $(\tilde{H}, Q)^c$, there exist $(\tilde{M}_1, Q)$, $(\tilde{M}_2, Q) \in \tau$ such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{M}_1, Q)$, $(\tilde{H}, Q)^c \subseteq (\tilde{M}_2, Q)$ and $(\tilde{M}_1, Q) \cap (\tilde{M}_2, Q) = 0_{(Y, Q)}$. Then we have $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{M}_1, Q) \subseteq (\tilde{M}_2, Q)^c \subseteq (\tilde{H}, Q)$. Since $(\tilde{M}_2, Q)^c$ is a N_sSecs , $N_sScl(\tilde{M}_1, Q) \subseteq (\tilde{M}_2, Q)^c$.

Conversely, let $y_{(\varepsilon, \zeta, \eta)}^q \cap (\tilde{K}, Q) = 0_{(Y, Q)}$ and $(\tilde{K}, Q)$ be a N_sSecs . Then $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{K}, Q)^c$ and from the condition of the theorem, we have $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{M}, Q) \subseteq N_sScl(\tilde{M}, Q) \subseteq (\tilde{K}, Q)^c$. Thus $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{M}, Q)$, $(\tilde{K}, Q) \subseteq (N_sScl(\tilde{M}, Q))^c$ and $(\tilde{M}, Q) \cap (N_sScl(\tilde{M}, Q))^c = 0_{(Y, Q)}$. So (Y, τ, Q) is a N_sSe-T_3 -space. ■

Definition 3.6 A N_sSts (Y, τ, Q) over Y is called a neutrosophic soft e -normal (briefly, N_sSe -normal) space, if for every pair of disjoint N_sSecs 's $(\tilde{H}_1, Q)$, $(\tilde{H}_2, Q)$, there exist disjoint N_sSeos 's $(\tilde{K}_1, Q)$, $(\tilde{K}_2, Q)$ such that $(\tilde{H}_1, Q) \subseteq (\tilde{K}_1, Q)$ and $(\tilde{H}_2, Q) \subseteq (\tilde{K}_2, Q)$. (Y, τ, Q) is said to be a neutrosophic soft $e-T_4$ -space (briefly, N_sSe-T_4 -space) if it is both a N_sSe -normal and N_sSe-T_1 -space.

Theorem 3.7 Let (Y, τ, Q) be a N_sSts over Y . Then (Y, τ, Q) is a N_sSe-T_4 -space iff for each N_sSecs $(\tilde{H}, Q)$ and N_sSeos $(\tilde{K}, Q)$ with $(\tilde{H}, Q) \subseteq (\tilde{K}, Q)$, there exists a N_sSeos $(\tilde{M}, Q)$ such that $(\tilde{H}, Q) \subseteq (\tilde{M}, Q) \subseteq N_sScl(\tilde{M}, Q) \subseteq (\tilde{K}, Q)$.

Proof. Let (Y, τ, Q) be a N_sSe-T_4 -space. Let $(\tilde{H}, Q)$ be a N_sSecs and let $(\tilde{H}, Q) \subseteq (\tilde{K}, Q) \in \tau$. Then $(\tilde{K}, Q)^c$ is a N_sSecs and $(\tilde{H}, Q) \cap (\tilde{K}, Q)^c = 0_{(Y, Q)}$. Since (Y, τ, Q) is a N_sSe-T_4 -space, there exist N_sSeos 's $(\tilde{M}_1, Q)$ and $(\tilde{M}_2, Q)$ such that $(\tilde{H}, Q) \subseteq (\tilde{M}_1, Q)$, $(\tilde{K}, Q)^c \subseteq (\tilde{M}_2, Q)$ and $(\tilde{M}_1, Q) \cap (\tilde{M}_2, Q) = 0_{(Y, Q)}$. Thus $(\tilde{H}, Q) \subseteq (\tilde{M}_1, Q) \subseteq (\tilde{M}_2, Q)^c \subseteq (\tilde{K}, Q)$, $(\tilde{M}_2, Q)^c$ is a N_sSecs and $(\tilde{M}_1, Q) \subseteq (\tilde{M}_2, Q)^c$. So, $(\tilde{H}, Q) \subseteq (\tilde{M}_1, Q) \subseteq N_sScl(\tilde{M}_1, Q) \subseteq (\tilde{K}, Q)$.

Conversely, let $(\tilde{H}_1, Q)$, $(\tilde{H}_2, Q)$ be two disjoint N_sSecs 's. Then $(\tilde{H}_1, Q) \subseteq (\tilde{H}_2, Q)^c$. From the condition of theorem, there exists a N_sSeos $(\tilde{M}, Q)$ such that $(\tilde{H}_1, Q) \subseteq (\tilde{M}, Q) \subseteq N_sScl(\tilde{M}_1, Q) \subseteq (\tilde{H}_2, Q)^c$. Thus $(\tilde{M}, Q)$, $(N_sScl(\tilde{M}, Q))^c$ are N_sSeos 's and $(\tilde{H}_1, Q) \subseteq (\tilde{M}, Q)$, $(\tilde{H}_2, Q) \subseteq (N_sScl(\tilde{M}, Q))^c$ and $(\tilde{M}, Q) \cap (N_sScl(\tilde{M}, Q))^c = 0_{(Y, Q)}$. So (Y, τ, Q) is a N_sSe-T_4 -space. ■

Theorem 3.8 Let (Y, τ, Q) be a N_sSts over Y . If (Y, τ, Q) is a N_sSe-T_i -space, then the $N_sStss ((\tilde{H}, Q), \tau_{(\tilde{H}, Q)}, E)$ is a N_sSe-T_i -space for $i = 0, 1, 2, 3$.

Proof. Let $y_{(\varepsilon, \zeta, \eta)}^q, z_{(\varepsilon', \zeta', \eta')}^{q'} \in ((\tilde{H}, Q), \tau_{(\tilde{H}, Q)}, E)$ such that $y_{(\varepsilon, \zeta, \eta)}^q \cap z_{(\varepsilon', \zeta', \eta')}^{q'} = 0_{(Y, Q)}$. Then there exist N_sSeos 's $(\tilde{H}_1, Q)$ and $(\tilde{H}_2, Q)$ satisfying the conditions of N_sSe-T_i -space such that $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}_1, Q)$, $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (\tilde{H}_2, Q)$. Thus, $y_{(\varepsilon, \zeta, \eta)}^q \in (\tilde{H}_1, Q) \cap (\tilde{H}, Q)$ and $z_{(\varepsilon', \zeta', \eta')}^{q'} \in (\tilde{H}_2, Q) \cap (\tilde{H}, Q)$. Also, the N_sSeos 's $(\tilde{H}_1, Q) \cap (\tilde{H}, Q)$, $(\tilde{H}_2, Q) \cap (\tilde{H}, Q)$ in $\tau_{(\tilde{H}, Q)}$ satisfy the conditions of N_sSe-T_i -space for $i = 0, 1, 2, 3$. ■

Theorem 3.9 Let (Y, τ, Q) be a N_sSts over Y . If (Y, τ, Q) is a N_sSe-T_4 -space and $(\tilde{K}, Q)$ is a N_sSecs in (Y, τ, Q) , then $((\tilde{K}, Q), \tau_{(\tilde{K}, Q)}, Q)$ is a N_sSe-T_4 -space.

Proof. Let (Y, τ, Q) be a N_sSe-T_4 -space and $(\tilde{K}, Q)$ be a N_sSecs in (Y, τ, Q) . Let $(\tilde{K}_1, Q)$ and $(\tilde{K}_2, Q)$ be two N_sSecs 's in $((\tilde{K}, Q), \tau_{(\tilde{K}, Q)}, Q)$ such that $(\tilde{K}_1, Q) \cap (\tilde{K}_2, Q) = 0_{(Y, Q)}$. When $(\tilde{K}, Q)$ is a N_sSecs in (Y, τ, Q) , $(\tilde{K}_1, Q)$ and $(\tilde{K}_2, Q)$ are N_sSecs 's in (Y, τ, Q) . Since (Y, τ, Q) is a N_sSe-T_4 -space, there exist N_sSeos 's $(\tilde{M}_1, Q)$ and $(\tilde{M}_2, Q)$ such that $(\tilde{K}_1, Q) \subseteq (\tilde{M}_1, Q)$, $(\tilde{K}_2, Q) \subseteq (\tilde{M}_2, Q)$ and $(\tilde{M}_1, Q) \cap (\tilde{M}_2, Q) = 0_{(Y, Q)}$. Then $(\tilde{K}_1, Q) = (\tilde{M}_1, Q) \cap (\tilde{K}, Q)$, $(\tilde{K}_2, Q) = (\tilde{M}_2, Q) \cap (\tilde{K}, Q)$ and $((\tilde{M}_1, Q) \cap (\tilde{K}, Q)) \cap ((\tilde{M}_2, Q) \cap (\tilde{K}, Q)) = 0_{(Y, Q)}$. This implies that $((\tilde{K}, Q), \tau_{(\tilde{K}, Q)}, E)$ is a N_sSe-T_4 -space. ■

4 Conclusion

In this paper, we have introduced and studied N_sSe -separation axioms in N_sSts with respect to N_sSp 's. We further investigated several interesting properties of N_sSe-T_i -spaces ($i = 0, 1, 2, 3, 4$) and some relations between them. In future, the work can be extended to investigate neutrosophic soft e -compactness, neutrosophic soft e -connectedness and neutrosophic soft contra e -continuous functions.

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