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Soft e-Separation Axioms in Neutrosophic soft Topological Spaces

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Abstract

In this paper, the idea of neutrosophic soft e-neighbourhood and neutrosophic soft e-separation axioms in neutrosophic soft topological spaces are introduces. 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 $(i = 0, 1, 2, 3, 4)$.
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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 neutrosphic soft e-separation axioms in neutrosophic soft topological spaces. Also, we discuss some relations of neutrosphic 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_sSs'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 $\mu_{\tilde{H}(q)}(y)\le\mu_{\tilde{G}(q)}(y)$, $\sigma_{\tilde{H}(q)}(y)\le\sigma_{\tilde{G}(q)}(y)$ & $\nu_{\tilde{H}(q)}(y)\ge\nu_{\tilde{G}(q)}(y) : y\in Y : q\in Q$.

(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_sSt) 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_sSts) in Y. The τ elements are called neutrosophic soft open sets (briefly, N_sSos) in Y. A N_sSs $(\tilde{H},Q)$ is called a neutrosophic soft closed set (briefly, N_sScs) if its complement $(\tilde{H},Q)^c$ is N_sSos.

Definition 2.4 A set $(\tilde{H},Q)$ is said to be a neutrosophic soft regular (resp. δ & e) open set (briefly, N_sSros[5] (resp. $N_sS\delta os$ [1] & N_sSeos [13])) if $(\tilde{H},Q)=N_sSint(N_sScl(\tilde{H},Q))$ (resp. $(\tilde{H},Q)=N_sS\delta int(\tilde{H},Q)$ & $(\tilde{H},Q)\subseteq N_sScl\big(N_sS\delta int(\tilde{H},Q)\big)\cup N_sSint\big(N_sS\delta cl(\tilde{H},Q)\big)$).

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

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

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

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_sS's $(\tilde{H},Q)$ on Y as follows:

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

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

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

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

Definition 2.8 [22] Let $y^q_{(\varepsilon,\zeta,\eta)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')}$ be two N_sSp's. For the N_sSp's $y^q_{(\varepsilon,\zeta,\eta)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')}$ over a common universe Y, we say that N_sSp's are distinct points, if $y^q_{(\varepsilon,\zeta,\eta)} \cap y^{q'}_{(\varepsilon',\zeta',\eta')} = 0_{(Y,Q)}$. It is clear that $y^q_{(\varepsilon,\zeta,\eta)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')}$ 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 $\big((\tilde{H}, Q), \tau_{(\tilde{H},Q)}, Q\big)$ 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 $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}, Q)$, if there exists a N_sSeos $(\tilde{G}, Q)$ such that $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{G}, Q) \subseteq (\tilde{H}, Q)$.

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 $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}, Q)$. Then, $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}, Q) \subseteq (\tilde{H}, Q)$. Thus $(\tilde{H}, Q)$ is a N_sSe-nbd of $y^q_{(\varepsilon,\zeta,\eta)}$.

Conversely, let $(\tilde{H}, Q)$ be a N_sSenbd of its N_sSp's. Let $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}, Q)$. Since $(\tilde{H}, Q)$ is a N_sSe-nbd of the N_sSp $y^q_{(\varepsilon,\zeta,\eta)}$, there exists $(\tilde{G}, Q) \in \tau$ such that $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{G}, Q) \subseteq (\tilde{H}, Q)$. Since $(\tilde{H}, Q) = \bigcup\{y^q_{(\varepsilon,\zeta,\eta)} : y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}, Q)\}$, 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 $y^q_{(\varepsilon,\zeta,\eta)}$ denoted by $\bigcup(y^q_{(\varepsilon,\zeta,\eta)}, Q)$, is the family of all its N_sSe-nbd's.

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

(i) If $(\tilde{H}, Q) \in \bigcup(y^q_{(\varepsilon,\zeta,\eta)}, Q)$, then $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}, Q)$.

(ii) If $(\tilde{H}, Q) \in \bigcup(y^q_{(\varepsilon,\zeta,\eta)}, Q)$ and $(\tilde{H}, Q) \subseteq (\tilde{K}, Q)$, then $(\tilde{K}, Q) \in \bigcup(y^q_{(\varepsilon,\zeta,\eta)}, Q)$.

(iii) $(\tilde{H}, Q)$ and $(\tilde{G}, Q) \in \bigcup(y^q_{(\varepsilon,\zeta,\eta)}, Q)$, then $(\tilde{H}, Q) \cap (\tilde{G}, Q) \in \bigcup(y^q_{(\varepsilon,\zeta,\eta)}, Q)$.

(iv) If $(\tilde{H}, Q) \in \bigcup(y^q_{(\varepsilon,\zeta,\eta)}, Q)$, then there exists a $(\tilde{G}, Q) \in \bigcup(y^q_{(\varepsilon,\zeta,\eta)}, Q)$ such that $(\tilde{G}, Q) \in \bigcup(z^{q'}_{(\varepsilon',\zeta',\eta')}, Q)$ for each $z^{q'}_{(\varepsilon',\zeta',\eta')} \in (\tilde{G}, Q)$.

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

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

Definition 3.2 Let (Y, τ, Q) be N_sSts over Y. Let $y^q_{(\varepsilon,\zeta,\eta)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')}$ be distinct N_sSp's. If there exist N_sSeos's $(\tilde{H}, Q)$ and $(\tilde{G}, Q)$ such that $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}, Q)$ and $y^q_{(\varepsilon,\zeta,\eta)} \cap (\tilde{G}, Q) = 0_{(Y,Q)}$ or $z^{q'}_{(\varepsilon',\zeta',\eta')} \in (\tilde{G}, Q)$ and $z^{q'}_{(\varepsilon',\zeta',\eta')} \cap (\tilde{H}, Q) = 0_{(Y,Q)}$, 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 $y^q_{(\varepsilon,\zeta,\eta)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')}$ be distinct N_sSp's. If there exist N_sSeos's $(\tilde{H}, Q)$ and $(\tilde{G}, Q)$ such that $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}, Q)$, $y^q_{(\varepsilon,\zeta,\eta)} \cap (\tilde{G}, Q) = 0_{(Y,Q)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')} \in (\tilde{G}, Q)$, $z^{q'}_{(\varepsilon',\zeta',\eta')} \cap (\tilde{H}, Q) = 0_{(Y,Q)}$, 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 $y^q_{(\varepsilon,\zeta,\eta)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')}$ be distinct N_sSp's. If there exist N_sSeos's $(\tilde{H}, Q)$ and $(\tilde{G}, Q)$ such that $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}, Q)$, $z^{q'}_{(\varepsilon',\zeta',\eta')} \in (\tilde{G}, Q)$ 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 $y^{q_1}_{1(0.1,0.4,0.7)}$, $y^{q_2}_{1(0.2,0.5,0.6)}$, $y^{q_1}_{2(0.3,0.3,0.5)}$ and $y^{q_2}_{2(0.4,0.4,0.4)}$ be N_sSp's. Then the family $\tau = \{0_{(Y,Q)}, 1_{(Y,Q)}, (\tilde{\psi}_1, Q), (\tilde{\psi}_2, Q), (\tilde{\psi}_3, Q), (\tilde{\psi}_4, Q), (\tilde{\psi}_5, Q), (\tilde{\psi}_6, Q), (\tilde{\psi}_7, Q),$

$(\tilde{\psi_8}, Q)\}$, where

$$(\tilde{\psi_1}, Q) = \{y^{q_1}_{1(0.1,0.4,0.7)}\}$$
$$(\tilde{\psi_2}, Q) = \{y^{q_2}_{1(0.2,0.5,0.6)}\}$$
$$(\tilde{\psi_3}, Q) = \{y^{q_1}_{2(0.3,0.3,0.5)}\}$$
$$(\tilde{\psi_4}, Q) = (\tilde{\psi_1}, Q) \cup (\tilde{\psi_2}, Q)$$
$$(\tilde{\psi_5}, Q) = (\tilde{\psi_1}, Q) \cup (\tilde{\psi_3}, Q)$$
$$(\tilde{\psi_6}, Q) = (\tilde{\psi_2}, Q) \cup (\tilde{\psi_3}, Q)$$
$$(\tilde{\psi_7}, Q) = (\tilde{\psi_1}, Q) \cup (\tilde{\psi_2}, Q) \cup (\tilde{\psi_3}, Q)$$
$$(\tilde{\psi_8}, Q) = \{y^{q_1}_{1(0.1,0.4,0.7)}, y^{q_2}_{1(0.2,0.5,0.6)}, y^{q_1}_{2(0.3,0.3,0.5)}, y^{q_2}_{2(0.4,0.4,0.4)}\}$$

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 $y^{q_1}_{1(0.1,0.4,0.7)}$ and $y^{q_2}_{2(0.4,0.4,0.4)}$, (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 $n^q_{(\varepsilon_n,\zeta_n,\eta_n)}$ are N_sSp's. Here we can give $(\varepsilon_n, \zeta_n, \eta_n)$ appropriate values and the N_sSp's $n^q_{(\varepsilon_n,\zeta_n,\eta_n)}$, $m^q_{(\varepsilon_m,\zeta_m,\eta_m)}$ 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 $N^q = \{n^q_{(\varepsilon_n,\zeta_n,\eta_n)}\}$. 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, $Q = \{q_1, e_2\}$ be a parameters set and $y^{q_1}_{1(0.1,0.4,0.7)}$, $y^{q_2}_{1(0.2,0.5,0.6)}$, $y^{q_1}_{2(0.3,0.3,0.5)}$ and $y^{q_2}_{2(0.4,0.4,0.4)}$ be N_sSp's. Then the family $\tau = \{0_{(Y,Q)}, 1_{(Y,Q)}, (\tilde{\psi_1}, Q), (\tilde{\psi_2}, Q), (\tilde{\psi_3}, Q), ..., (\tilde{\psi_{15}}, Q)\}$, where

$$(\tilde{\psi_1}, Q) = \{y^{q_1}_{1(0.1,0.4,0.7)}\}$$
$$(\tilde{\psi_2}, Q) = \{y^{q_2}_{1(0.2,0.5,0.6)}\}$$
$$(\tilde{\psi_3}, Q) = \{y^{q_1}_{2(0.3,0.3,0.5)}\}$$
$$(\tilde{\psi_4}, Q) = \{y^{q_2}_{2(0.4,0.4,0.4)}\}$$
$$(\tilde{\psi_5}, Q) = (\tilde{\psi_1}, Q) \cup (\tilde{\psi_2}, Q)$$
$$(\tilde{\psi_6}, Q) = (\tilde{\psi_1}, Q) \cup (\tilde{\psi_3}, Q)$$
$$(\tilde{\psi_7}, Q) = (\tilde{\psi_1}, Q) \cup (\tilde{\psi_4}, Q)$$
$$(\tilde{\psi_8}, Q) = (\tilde{\psi_2}, Q) \cup (\tilde{\psi_3}, Q)$$
$$(\tilde{\psi_9}, Q) = (\tilde{\psi_2}, Q) \cup (\tilde{\psi_4}, Q)$$
$$(\tilde{\psi_{10}}, Q) = (\tilde{\psi_3}, Q) \cup (\tilde{\psi_4}, Q)$$
$$(\tilde{\psi_{11}}, Q) = (\tilde{\psi_1}, Q) \cup (\tilde{\psi_2}, Q) \cup (\tilde{\psi_3}, Q)$$
$$(\tilde{\psi_{12}}, Q) = (\tilde{\psi_1}, Q) \cup (\tilde{\psi_2}, Q) \cup (\tilde{\psi_4}, Q)$$
$$(\tilde{\psi_{13}}, Q) = (\tilde{\psi_2}, Q) \cup (\tilde{\psi_3}, Q) \cup (\tilde{\psi_4}, Q)$$
$$(\tilde{\psi_{14}}, Q) = (\tilde{\psi_1}, Q) \cup (\tilde{\psi_3}, Q) \cup (\tilde{\psi_4}, Q)$$
$$(\tilde{\psi_{15}}, Q) = \{y^{q_1}_{1(0.1,0.4,0.7)}, y^{q_2}_{1(0.2,0.5,0.6)}, y^{q_1}_{2(0.3,0.3,0.5)}, y^{q_2}_{2(0.4,0.4,0.4)}\}$$

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

Conversely, suppose that each N_sSp $y^q_{(\varepsilon,\zeta,\eta)}$ is a N_sSecs. Then $(y^q_{(\varepsilon,\zeta,\eta)})^c$ is a N_sSeos. Let $y^q_{(\varepsilon,\zeta,\eta)} \cap z^{q'}_{(\varepsilon',\zeta',\eta')} = 0_{(Y,Q)}$. Thus, $z^{q'}_{(\varepsilon',\zeta',\eta')} \in (y^q_{(\varepsilon,\zeta,\eta)})^c$ and $y^q_{(\varepsilon,\zeta,\eta)} \cap (y^q_{(\varepsilon,\zeta,\eta)})^c = 0_{(Y,Q)}$. 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 $y^q_{(\varepsilon,\zeta,\eta)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')}$, there exists a N_sSeos $(\tilde{H},Q)$ containing $y^q_{(\varepsilon,\zeta,\eta)}$ but not $z^{q'}_{(\varepsilon',\zeta',\eta')}$ such that $z^{q'}_{(\varepsilon',\zeta',\eta')}$ does not belong to $N_sScl(\tilde{H},Q)$.

Proof. Let $y^q_{(\varepsilon,\zeta,\eta)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')}$ 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 $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H},Q)$, $z^{q'}_{(\varepsilon',\zeta',\eta')} \in (\tilde{G},Q)$. Since $y^q_{(\varepsilon,\zeta,\eta)} \cap z^{q'}_{(\varepsilon',\zeta',\eta')} = 0_{(Y,Q)}$ and $(\tilde{H},Q) \cap \tilde{G},Q) = 0_{(Y,Q)}$, $z^{q'}_{(\varepsilon',\zeta',\eta')}$ does not belong to $(\tilde{H},Q)$. It implies that $z^{q'}_{(\varepsilon',\zeta',\eta')}$ does not belong to $N_sScl(\tilde{H},Q)$.

Conversely suppose that, for distinct N_sSp's $y^q_{(\varepsilon,\zeta,\eta)}$, $z^{q'}_{(\varepsilon',\zeta',\eta')}$, there exists a N_sSeos $(\tilde{H},Q)$ containing $y^q_{(\varepsilon,\zeta,\eta)}$ but not $z^{q'}_{(\varepsilon',\zeta',\eta')}$ such that $z^{q'}_{(\alpha',\beta',\gamma)'}$ does not belong to $N_sScl(\tilde{H},Q)$. Then $z^{q'}_{(\varepsilon',\zeta',\eta')} \in (N_sScl(\tilde{H},Q))^c$, *i.e.*, $(\tilde{H},Q)$ and $(N_sScl(\tilde{H},Q))^c$ are disjoint N_sSeos's containing $y^q_{(\varepsilon,\zeta,\eta)}$, $z^{q'}_{(\varepsilon',\zeta',\eta')}$ respectively. ∎

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

Proof. Suppose that $y^q_{(\varepsilon,\zeta,\eta)} \cap z^{q'}_{(\varepsilon',\zeta',\eta')} = 0_{(Y,Q)}$. Since (Y,τ,Q) is a N_sSe-T_1- space, $y^q_{(\varepsilon,\zeta,\eta)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')}$ are N_sSecs's in τ. Then $y^q_{(\varepsilon,\zeta,\eta)} \in (z^{q'}_{(\varepsilon',\zeta',\eta')})^c \in \tau$. Thus there exists a N_sSeos $(\tilde{G},Q)$ in τ such that $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{G},Q) \subseteq N_sScl(\tilde{G},Q) \subseteq (z^{q'}_{(\varepsilon',\zeta',\eta')})^c$. So, we have $z^{q'}_{(\varepsilon',\zeta',\eta')} \in (N_sScl(\tilde{G},Q))^c$, $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{G},Q)$ 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 $y^q_{(\varepsilon,\zeta,\eta)}$ and $z^{q'}_{(\varepsilon',\zeta',\eta')}$ 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 $y^q_{(\varepsilon,\zeta,\eta)} \cap (\tilde{H},Q) = 0_{(Y,Q)}$. If there exist N_sSeos's $(\tilde{M}_1,Q)$ and $(\tilde{M}_2,Q)$ such that $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{M}_1,Q)$, $(\tilde{H},Q) \subseteq (\tilde{M}_2,Q)$ 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 $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H},Q) \in \tau$, there exists $(\tilde{M},Q) \in \tau$ such that $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{M},Q) \subseteq N_sScl(\tilde{M},Q) \subseteq (\tilde{H},Q)$.

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

Conversely, let $y^q_{(\varepsilon,\zeta,\eta)} \cap (\tilde{K},Q) = 0_{(Y,Q)}$ and $(\tilde{K},Q)$ be a N_sSecs. Then $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{K},Q)^c$ and from the condition of the theorem, we have $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{M},Q) \subseteq N_sScl(\tilde{M},Q) \subseteq (\tilde{K},Q)^c$. Thus $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{M},Q)$, $(\tilde{K},Q) \subseteq (N_sScl(\tilde{M},Q))^c$ 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 $\big((\tilde{H}, Q), \tau_{(\tilde{H},Q)}, E\big)$ is a N_sSe-T_i-space for $i = 0, 1, 2, 3$.

Proof. Let $y^q_{(\varepsilon,\zeta,\eta)}$, $z^{q'}_{(\varepsilon',\zeta',\eta')} \in \big((\tilde{H}, Q), \tau_{(\tilde{H},Q)}, E\big)$ such that $y^q_{(\varepsilon,\zeta,\eta)} \cap z^{q'}_{(\varepsilon',\zeta',\eta')} = 0_{(Y,Q)}$. 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 $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}_1, Q)$, $z^{q'}_{(\varepsilon',\zeta',\eta')} \in (\tilde{H}_2, Q)$. Thus, $y^q_{(\varepsilon,\zeta,\eta)} \in (\tilde{H}_1, Q) \cap (\tilde{H}, Q)$ and $z^{q'}_{(\varepsilon',\zeta',\eta')} \in (\tilde{H}_2, Q) \cap (\tilde{H}, Q)$. 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 $\big((\tilde{K}, Q), \tau_{(\tilde{K},Q)}, Q\big)$ 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 $\big((\tilde{K}, Q), \tau_{(\tilde{K},Q)}, Q\big)$ 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 $\big((\tilde{M}_1, Q) \cap (\tilde{K}, Q)\big) \cap \big((\tilde{M}_2, Q) \cap (\tilde{K}, Q)\big) = 0_{(Y,Q)}$. This implies that $\big((\tilde{K}, Q), \tau_{(\tilde{K},Q)}, E\big)$ 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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