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On Neutrosophic pδs-irresolute Functions in Neutrosophic Topological Spaces

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Abstract: In general topology the notion of pδs-irresolute and αδs-irresolute functions were introduced by Beceren and Noiri. In the present paper, these concepts of pδs-irresolute (briefly, Npδs-irresolute) and αδs-irresolute (briefly, Nαδs-irresolute) functions are explored for the first time in neutrosophic topological spaces (NTS) as generalized version. We proved that every Nαδs-irresolute function is Npδs-irresolute function but not conversely. Some characterizations, counter examples, and fundamental features are also presented. By neutrosophic pre-open, neutrosophic δ-open, and neutrosophic δ-semi-open sets, some new fundamental properties of such functions are provided. Furthermore, under Npδs-irresolute functions, the behavior of neutrosophic semi-connected, neutrosophic pre-connected, neutrosophic pre-T_2, neutrosophic δ-semi-T_2, neutrosophic pre-compact, and neutrosophic s-closed spaces are investigated.

Keywords: Neutrosophic Set; Neutrosophic δ-cluster Point; Neutrosophic δ-open Set; Neutrosophic-δ-semi Open Set; Neutrosophic pre-open Set; Neutrosophic α-open Set; Neutrosophic pδs-irresolute Function; Neutrosophic αδs-irresolute function, Neutrosophic δ-semi T_2 space, Neutrosophic Pre-connected Space; Neutrosophic Pre-compact Space.

1. Introduction and Literature Review

Based on classical data general topology is intended to find applications in various fields such as robotics, network design, data analysis, material science, physics, and biology. It helps us understand shapes, connectivity, and spatial relationships in complex systems. Two key mappings for describing topological properties in topological spaces are continuity and irresolute functions. The concept of irresoluteness has constituted the basis of many precious researches in general topology. The results of these studies have been reflected in numerous applications, and they have played important roles in many facets of real life. But as technology has advanced and the industry has undergone a revolution, people's requirements have also evolved, and as a result, general topology has lagged in practical applications. Besides, these findings' effects on actual practices have diminished. The phenomena of making decisions accurately is nowadays the most complicated task in the real world due to the presence of parameters of uncertainty and imprecise. Furthermore, in several other fields, including economics, engineering, the environment, social science, medical science, etc., classical approaches are inadequate for addressing several real-world issues. Thus, it is now necessary for scientists to re-examine some of the basic problems in mathematics and discover new kinds of spaces and functions, according to the new theories proposed (see [16-22]). In these topological spaces, irresolute functions have taken up a significant amount of characteristics.

Zadeh [9] proposed the novel concept of fuzzy set (FS) in handling vague, imprecise, and uncertain types of data in 1965. Later, the paper Chang [1] paved the way for the subsequent development of numerous fuzzy topological concepts. As a generalization of a fuzzy set, Atanassov [8] created an intuitionistic fuzzy set (IFS) in 1986. His theory thereafter became widely acknowledged as an essential resource in the fields of mathematics, engineering [15], and medicine [18]. Coker [3] defined intuitionistic fuzzy topological spaces using the concept of intuitionistic fuzzy sets in 1997 and studied some engrossing results. In 1995, the idea of the neutrosophic set (in short, NS) was proposed by Smarandache [11] as a generalization of the intuitionistic fuzzy set (IFS). Neutrosophic logic [11], neutrosophic vector space [29], neutrosophic topological space [12], neutrosophic group theory [30], neutrosophic ring theory [31], and dombi neutrosophic graph [32] are only a few of the many academics who have contributed to the field of neutrosophic theory. The idea of a neutrosophic set and its wide range of applications are being developed by numerous academicians. The attributes of neutrosophic logic and applications were developed by EI-Hamed E.A. et al [2]. Salama and AL-Blowi [12] initiated the thought of neutrosophic topological spaces (shortly, NTS) utilizing a neutrosophic set. The notion of the univalent neutrosophic number (SVN-number) has been introduced in a different mode by investigating its structural aspects by Bera et al. [23]. They have constructed an assignment issue model in the neutrosophic context, along with the solution methodology. A Data Envelopment Analysis (DEA) model has been introduced by Yang et al. [24] with neutrosophic sets. The healthcare system has adopted this new concept. As a result, they have produced beneficial real-world outcomes. Triangular neutrosophic numbers (TNNs) are used as the information on decision-making units in Edalatpanah's attempt to create a novel DEA model in [25]. The use of neutrosophic logic in the confirmatory data analysis of the life satisfaction measure was first presented by Duran et al. [26]. The idea of an algorithm-based neutrosophic soft matrix has been applied by Dhar [27] to address some of the issues with disease diagnosis brought on by the emergence of different symptoms in patients.

The idea of quadripartitioned neutrosophic Pythagorean sets has been applied to Lie algebras by Radha and Stanis Arul Mary [28]. Arokiarani I. et al. [5] coined the concept of neutrosophic semi-open sets in NTS. Subsequently, several authors intended and introduced various types of open sets in NTS. Weaker and stronger forms of open and closed sets play a vital role in neutrosophic topology because the significance of NS is rapidly rising in many areas of applications and they are the present research area of many researchers over the entire Globe. The concept of neutrosophic pre-open sets was conceived by Arokiarani I. [5], as a weaker version of α-open set in NTS. Kannan and Chandrasekar [34] studied the concept of neutrosophic pre-α, semi-α, pre-β irresolute open and closed mappings, and Priya and Chandrasekar [33] proposed neutrosophic αgs-continuity and irresolute maps. It has been observed that neutrosophic α-open sets and neutrosophic δ-semi-open sets introduced by Vadivel A. et al. [7] play a vital role in our present research.

1.1 Research Gaps and Contribution of the Paper

During the literature survey, we observe that

i). Neutrosophic topological spaces and topological properties have almost been established. However, very little study has been addressed on the preservation aspects of these properties under irresolute functions.

ii). Only some works have been done on continuous and irresolute functions with the help of neutrosophic semi-open, regular open, pre-open, α-open, β-open sets.

iii). We notice that only a few papers used Nδ-open and Nδ-semi-open sets to describe continuity. This motivated us to introduce the novel idea of pδs-irresolute and αδs-irresolute functions in a neutrosophic environment.

In the present work we contribute the following notions to fill the gaps:

i). We define the idea of Npδs-irresolute and Nαδs-irresolute functions in neutrosophic topological spaces. Further, we prove that every neutrosophic αδs-irresolute function is Npδs-irresolute function. But with a counter-example, we show the converse is false.

ii). Moreover, some characterizations, counterexamples and basic properties of Npδs-irresolute function are investigated.

iii). Finally, the behaviors of neutrosophic semi-connected, neutrosophic pre-connected, neutrosophic pre-T_2, neutrosophic δ-semi T_2, neutrosophic pre-compact, neutrosophic s-closed spaces are examined in the light of Npδs-irresolute function.

1.2 Roadmap of the Paper

This work is organized into the following five sections: we presented the introduction and literature review in the first section. Section 2 focuses on common definitions and preliminaries. Section 3 describes the concept of pδs-irresolute and αδs-irresolute functions in neutrosophic topological spaces. We proved that every neutrosophic αδs-irresolute function is pδs-irresolute function but not conversely. Some characterizations, counterexamples, and basic properties are also investigated. In Section 4, the behavior of neutrosophic semi-connected, neutrosophic pre-connected, neutrosophic pre-T_2, neutrosophic δ-semi T_2, neutrosophic pre-compact, neutrosophic s-closed spaces are examined in the light of neutrosophic pδs-irresolute function. Finally, a concluding remark on our work and future research direction has been presented in Section 5.

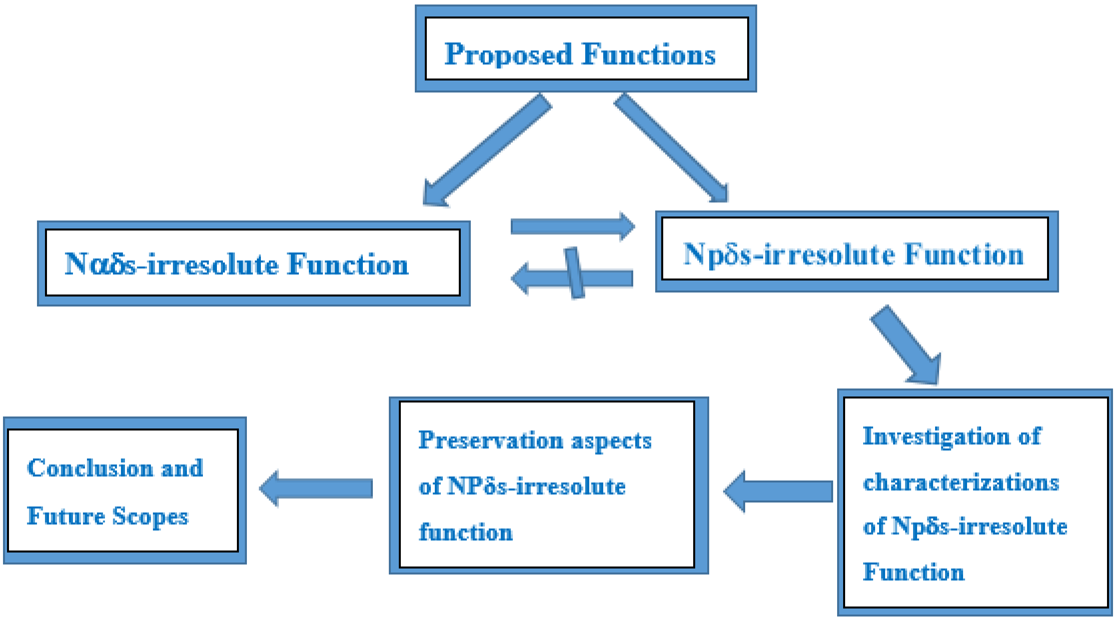

Figure 1. Flow chart of the proposed work.

2. Mathematical Preliminaries

This section consists of some common notations and definitions which have been involved in the course of the paper. Throughout the paper, the function $\psi:(X,\tau_X)\to (Y,\nu_Y)$ will represent a single-valued neutrosophic function from a neutrosophic topological space (in short, NTS) (X,τ_X) into another neutrosophic topological space (Y,ν_Y) and ordered pairs (X,τ_X) and (Y,ν_Y) stand neutosophic topological spaces X and Y respectably. For any neutrosophic subset $W \subset X$, NInt(W), NSInt(W), NCl(W) and NSCl(W) represent the neutrosophic interior of W, neutrosophic semi interior of W, neutrosophic closure of W and neutrosophic semi-closure of W respectively.

Definition 2.1. [9] Let U be a universe of discourse. Then the fuzzy set on U is described as F= (x, μ(x)): x∈X} where, μ(x) ∈[0,1], denotes the degree of membership of x∈X.

Definition 2.2. [4] Let U be an initial universe and E be a set of parameters. Let P(U) denote the power set of U and $A \subset E$. Then the pair (F, A) is called a soft set over U, where F is a mapping given by F: $A\to P(U)$ such that $F(e) \in P(U)$.

Definition 2.3. [13] Let U be an initial universe and E be a set of parameters. Let F(U) denote the set of all fuzzy sets of U. Then the fuzzy soft set F_A can be represented by the set of ordered pairs F_A = {(x, γ_A(x)): x∈E, γ_A(x)∈F(U) }.

Definition 2.4. [8] Let U be a universe of discourse. Then the intuitionistic fuzzy set on U is described as F= (x, μ(x), ν(x)): x∈X, where, μ(x), ν(x)∈[0,1], indicating the degrees of membership and non-membership respectively such that $0 \leq \mu(x)+\nu(x) \leq 1$ and the hesitant/ indeterminant part =1-μ(x)-ν(x).

Definition 2.5. [11] Let X be a universe of discourse. Then the neutrosophic set is de ned by N={ (x, τ(x), λ(x), η(x)), x∈X }, where, τ(x), λ(x), η(x)∈[0,1], indicating the degrees of truth, indeterminacy and falsehood respectively that satisfy $0 \leq \inf(\tau) + \inf(\lambda)+ \inf(\eta) \leq \sup(\tau) + \sup(\lambda)+\sup(\eta) \leq 3$.

Definition 2.6. [15] A Neutrosophic point (N-point) $S_{(t,i,f)}$ of NTS (X,τ_X) is a neutrosophic set defined by

$$S_{(t,i,f)}(x) = \begin{cases} (t,i,f), if\ x = s \\ (0,1,1), if\ x \neq s \end{cases}$$

where, t, i, f ∈[0,1] such that $0 < t+i+f \leq 3$. In this context, 'S' is referred to as the support of the N-point and (t, i, f) is the value of the N-point.
A N-point $S_{(t,i,f)}$ ∈ N={ (x, τ(x), λ(x), η(x)), x∈X } iff t ≤ τ(s), i ≥ λ(s) and f ≥ η(s).

Definition 2.7. [7] If W is a neutrosophic subset of a NTS (X,τ_X). Then a N-point $S_{(t,i,f)}$ of X is said to be Nδ-cluster point of W iff for every regular open q-nbd G of $S_{(t,i,f)}$ is q-coincident with W. The collection of all possible Nδ-cluster points of W is called the Nδ-closure of W which we denote by NCl_δ(W) and q-neighbourhood and q-coincident is defined in [2].

Definition 2.8. [7] If W is a neutrosophic subset of a NTS (X, X). Then W is said to be Nδ-closed if NCl_δ(W) = W and the complement of Nδ-closed set will be called Nδ-open set in X. The set of all Nδ-open (respectively, Nδ-closed) sets of X is denoted by NδO(X) (respectively, NδC(X)).

Definition 2.9. [7] A neutrosophic subset W of a NTS (X, τ_X) is called Nδ-semi-open if there exists a Nδ-open set G of X such that G⊆W⊆Ncl(G). The complement of a Nδ-semi-open set is called Nδ-semi-closed set in X and a neutrosophic subset V is said to be Nδ-semi-closed set in X if there exists a Nδ-closed set F of X such that Nint(F) ⊆V ⊆F. We denote the collection of all possible Nδ-semi-open (resp. Nδ-semi-closed) subsets of X by NδSO(X) (resp. NδSC(X)).

Definition 2.10. [5] Any neutrosophic subset W of a NTS (X, X) is called
a) Neutrosophic semi-open [briefly, NSO] set if W⊆Ncl(Nint(W)).
b) Neutrosophic pre-open [briefly, NPO] set if W⊆Nint(Ncl(W)).
c) Neutrosophic regular open [briefly, NRO] set if W=Nint(Ncl(W)).
d) Neutrosophic α-open [briefly, NαO] set if W⊆Nint(Ncl(Nint(W))).

The complement of NSO(resp. NPO, NRO, NαO) set is called a neutrosophic semi [resp. Pre, regular, α] closed [shortly, NSC(resp. NPC, NRC, NαC)] set in X. The family of all possible NSO [resp. NPO, NRO, NαO, NPC, NRC, NαC] sets of X are denoted by NSO(X) [resp.NPO(X),NRO(X), NαO(X), NPC(X),NRC(X),NαC(X)].

3. Characterizations of Npδs-irresolute Function and Basic Properties

In this research work, the notion of Npδs-irresolute functions is initiated and studied in neutrosophic topological spaces as a generalized version of neutrosophic αδsirresolute functions. Some characterizations, counterexamples, and fundamental features are also investigated.

Definition 3.1. A neutrosophic function $\psi:(X,\tau_X)\rightarrow(Y,\nu_Y)$ is called

a) Neutrosophic pδs-irresolute (in short, Npδs-irresolute) function if for each Nδ-semi open set W of Y, $\psi^{-1}(W)$ is neutroophic pre-open(shortly, NP-open) set in X.
b) Neutrosophic αδs-irresolute (briefly. Nαδs-irresolute) function if for each Nδ-semi open set W of Y, $\psi^{-1}(W)$ is neutroophic α-open (in short, Nα-open) set in X.

Theorem 3.2. Every Nαδs-irresolute fu nction ψ: $(X,\tau_X)\rightarrow(Y,\nu_Y)$ is Npδs-irresolute function.
Proof. Let H be an arbitrary neutrosophic δ-semi open set in Y. As ψ is Nαδs-irresolute, $\psi^{-1}(H)\in N\alpha O(X)$. Being N$\alpha$-open set is NP-open set, $\psi^{-1}(H)\in PO(X)$ which makes ψ a Npδs-irresolute function.

Remark 3.3. From the above it is clear that: ***Nαδs-irresoluteness ⇒ Npδs-irresoluteness*** but the reverse implication is not true which can be seen from the following example:

Example 3.4. Let us consider two neutrosophic topological spaces (X,τ_X) and (Y,ν_Y), where, X={x,y,z} and Y={a,b,c} with two neutrosophic topologies τ_X and ν_Y defined by $\tau_X=\{0_X,1_X, W_1, W_2\}$ $\nu_Y=\{0_Y,1_Y, V_1\}$, where, V_1={⟨ a, 0.25, 0.55, 0.85⟩, ⟨ b, 0.15, 0.55, 0.75⟩, ⟨ c, 0.25, 0.55, 0.65⟩}, W_1={⟨ x, 0.25, 0.55, 0.85⟩, ⟨ y, 0.35, 0.55, 0.75⟩, ⟨ z, 0.4, 0.5, 0.6⟩}, W_2={⟨ x, 0.15, 0.55, 0.95⟩, ⟨ y, 0.15, 0.55, 0.95⟩,⟨ z, 0.45, 0.55, 0.65⟩}, W_3={⟨ x, 0.15, 0.55, 0.95⟩, ⟨ y, 0.15, 0.55, 0.95⟩,⟨ z, 0.45, 0.55, 0.65⟩}. If $\psi:(X,\tau_X)\rightarrow(Y,\nu_Y)$ is a neutrosophic function defined by $\psi(x)=a$, $\psi(y)=b$, $\psi(z)=c$, then ψ is Npδs-irresolute function but it is not Nαδs-irresolute function since $\psi^{-1}(V_1)$ is neutrosophic pre-open but not neutrosophic α-open set of (X,τ_X).

Theorem 3.5. If $\psi:(X,\tau_X)\rightarrow(Y,\nu_Y)$ is a function between two topological spaces, then the following are equivalent:

i). ψ is NPδs-irresolute function.
ii). For each u∈X and for each Nδ-semi open set B of Y containing $\psi(u)$, ∃ a neutrosophic pre-open set A of X with u∈A such that $\psi(A)\subset B$.
iii). $\psi^{-1}(B)\subset NCl(NInt(NCl(\psi^{-1}(B))))\cup NInt(NCl_\delta(\psi^{-1}(B)))$, for every Nδ-semi open subset B of Y.
iv). $\psi^{-1}(F)$ is neutrosophic pre-closed in X, for every Nδ-semi closed subset F of Y.
v). $NInt(NCl(NInt(\psi^{-1}(NSCl_\delta(B))))) \cap NCl(NInt_\delta(\psi^{-1}(NSCl_\delta(B)))) \subset \psi^{-1}(NSCl_\delta(B))$, for every neutrosophic subset B of Y.
vi). $\psi[NInt(NCl(NInt(A))) \cap NCl(NInt_\delta(A))]\subset NSCl_\delta(\psi(A))$, for every neutrosophic subset A of X.

Proof.

(i) →(ii): Let u∈ X and B be arbitrary Nδ-semi open set of Y such that $\psi(u)\in B$. Then $\psi^{-1}(B)$ is NP-open in X containing u. Let $A=\psi^{-1}(B)$. So, using (i), A is an NP-open subset of X including u and $\psi(A)\subset B$.

(ii) →(iii): Let B be arbitrary Nδ-semi open set in Y and $u\in\psi^{-1}(B)$. From (ii), ∃ an NP-open set A of M including u satisfying $\psi(A)\subset B$. So, we have $u\in A\subset NCl(NInt(NCl(A)))\cup NInt(NCl_\delta(A)) \subset NCl(NInt(NCl(\psi^{-1}(B))))\cup NInt(NCl_\delta(\psi^{-1}(B)))$. Hence, $\psi^{-1}(B)\subset NCl(NInt(NCl(\psi^{-1}(B))))\cup NInt(NCl_\delta(\psi^{-1}(B)))$.

(iii)→(iv): Suppose that $F\subset Y$ and it is Nδ-semi closed subset in Y. Let D=Y-F. Then D is Nδsemi open in Y. using (iii), $\psi^{-1}(D)\subset NCl(NInt(NCl(\psi^{-1}(D))))\cup NInt(NCl\delta(\psi^{-1}(D)))$. Thus, $\psi^{-1}(F)=\psi^{-1}(Y-D)=X-\psi^{-1}(D)\supset X-[NCl(NInt(NCl(\psi^{-1}(D)))\cup NInt(NCl\delta(\psi^{-1}(D)))]=NInt(NCl(NInt(\psi^{-1}(D))))\cap NCl(NInt_\delta(\psi^{-1}(D)))$. Thus, $\psi^{-1}(F)$ is NP-closed set in X.

(iv) →(v): Suppose that $B\subset Y$. As $NSCl_\delta(B)$ is Nδ-semi closed in Y, by (iv), $\psi^{-1}(NSCl_\delta(B))$ is NP-closed in X from which it follows that, $NInt(NCl(NInt(\psi^{-1}(NSCl_\delta(B))))) \cap NCl(NInt_\delta(\psi^{-1}(NSCl_\delta(B)))) \subset\psi^{-1}(NSCl_\delta(B))$.

(v) →(vi): Suppose that A ⊂ X. By virtue of (v), NInt(NCl(NInt(A))) ∩ NCl(NInt$_\delta$(A)) ⊂NInt(NCl (NInt (ψ^{-1}(ψ(A))))) ∩ NCl(NInt$_\delta$(ψ^{-1}(ψ(A))))⊂ψ^{-1}(NSCl$_\delta$(ψ(A))) and so, ψ[NInt(NCl (NInt(A)))∩ NCl (NInt$_\delta$(A))]⊂ NSCl$_\delta$(ψ(A)).

(vi) →(i): Let D be arbitrary Nδ-semi open set in Y. Since ψ^{-1} (Y-D)=X-ψ^{-1}(D) is a neutrosophic subset of X. using (6), we have, ψ[NInt(NCl(NInt(ψ^{-1}(Y-D))))∩NCl(NInt$_\delta$(ψ^{-1}(Y-D)))] ⊂ NSCl$_\delta$(ψ(ψ^{-1}(Y-D)))⊂NSCl$_\delta$((Y-D))=Y-NSInt$_\delta$(D)=Y-D and hence, X-[NCl(NInt(NCl(ψ^{-1}(D)))) ∪ NInt(NCl$_\delta$(ψ^{-1}(D)))] =NInt(NCl(NInt (X-ψ^{-1}(D)))) ∩NCl(NInt$_\delta$(X-ψ^{-1}(D))) =NInt(NCl(NInt(ψ^{-1} (Y-D)))) ∩ NCl(NInt$_\delta$(ψ^{-1}(Y-D)))) ⊂ ψ^{-1}(Y-D) =X-ψ^{-1}(D). Thus, ψ^{-1}(D) ⊂ NCl(NInt(NCl(ψ^{-1} (D)))) ∪NInt(NCl$_\delta$(ψ^{-1}(D))). This implies that ψ^{-1} (D) is NP-open set in X. Thus, ψ is NPδs-irresolute function.

Lemma 3.6. [2]: Let W_1 and W_2 be neutrosophic subsets of a NTS (X,τ_X). If W_1 is NSO set in (X,τ_X)and W_2 is NPO set in (X,τ_X), then $W_1 \cap W_2$ is a NPO set in (W_1,τ_{W_1}).

Theorem 3.7. If the neutrosophic function ψ: (X,τ_X) → (Y,τ_Y) is NPδs-irresolute function and D⊂X is NS-open in X, then the restriction $\psi_{|D}$: D→Y is necessarily NPδs-irresolute function on D.

Proof: Suppose that G is an arbitrary Nδ-semi open subset of N. As ψ is NPδs-irresolute, ψ^{-1}(G) is NP-open in X. D being NS-open set in X, so in the light of Lemma 3.6, $\psi_{|D}^{-1}$(G) = D ∩ψ^{-1}(G) is NP-open set in D and thus, $\psi_{|D}^{-1}$ is NPδs-irresolute function on D.

Lemma 3.8. Suppose W_1 and W_2 are two neutrosophic subsets of a NTS (X,τ_X) such that $W_1 \subset W_2 \subset X$. If W_1∈NPO(W_2) and W_2∈NδO(X), then W_1∈NPO(X).

Proof. Obvious and hence omitted.

Theorem 3.9. Let {Aμ:μ ∈Λ} be a pre-open cover of a topological space (X,τ_X). Then ψ: (X,τ_X) → (Y,τ_Y) is the NPδs-irresolute function if for each μ ∈Λ, the neutrosophic restriction function. ψ_{A_μ}:A_μ →Y is Npδs-irresolute function.

Proof. Let G ⊂ N be arbitrary Nδ-semi ˙open. By hyp˙othesis, $\psi_{A_\mu}$is NPδs-irresolute function. So, $(\psi_{A_\mu})^{-1}$ (G) is NP-˙open in A_μ. Since for each μ ∈Λ, A_μ is NP-open set in M, Lemma 3.8, ensures that $(\psi_{A_\mu})^{-1}$ (G) will be NP-open in M. Now ψ^{-1}(G) = M ∩ψ^{-1}(G) = ∪{A_μ∩ψ^{-1} (G): μ∈Λ} = ∪{ $(\psi_{A_\mu})^{-1}$ (G) : μ ∈ Λ}. Because the union of the arbitrary number of NP-open sets is necessarily NP-open, ψ^{-1} (G) will be NP-open set in M. Thus ψ becomes NPδs-irresolute function.

Theorem 3.10. If ψ: (X,τ_X) → (Y,τ_Y) is NPδs-irresolute function and ϕ : (Y,τ_Y)→ (Z,τ_Z) is Nδ-irresolute function. Then ϕ∘ψ: (X,τ_X)→ (Z,τ_Z) is NPδs-irresolute functi˙on.

Proof. Suppose that W ⊂Z is Nδ-semi open in Z. Now ϕ being Nδ-irres˙olute function, ϕ^{-1}(W) is Nδ-semi open subset of Y. By given hypothesis ψ is NPδs-irresolute function, therefore, $(\phi\circ\psi)^{-1}$ (W)= ψ^{-1} (ϕ^{-1} (W)) is NP-open in X. Thus, the composition ϕ∘ψ is NPδs-irresolute function.

Theorem 3.11. If ψ: (X,τ_X) → (Y,τ_Y) is NP-irresolute function and ϕ : (Y,τ_Y)→ (Z,τ_Z) is NPδs-irresolute function. Then ϕ∘ψ: (X,τ_X)→ (Z,τ_Z) is NPδs-irresolute function.

Proof. Suppose that W ⊂Z is Nδ-semi open in Z. Now ϕ being NPδs-irresolute function, ϕ^{-1}(W) is NP-open subset in Y. By condition ψ is NP-irresolute function, therefore, $(\phi\circ\psi)^{-1}$(W) =ψ^{-1} (ϕ^{-1} (W)) is NP-open in X. Thus, the composition ϕ∘ψ is NPδs-irresolute function.

Theorem 3.12. If ψ: (X,τ_X) → (Y,τ_Y) is NPδs-irresolute function and ϕ : (Y,τ_Y)→ (Z,τ_Z) is Nδ-semi continuous function. Then ϕ∘ψ: (X,τ_X)→ (Z,τ_Z) is NP-continuous function.

Proof. Suppose that W ⊂Z is arbitrary neutrosophic open in Z. Now ϕ being Nδ-semi continuous function, ϕ^{-1} (W) is Nδ-semi open set in Y. By given condition ψ is NPδs-irresolute function, therefore, $(\phi\circ\psi)^{-1}$ (W) = ψ^{-1} (ϕ^{-1} (W)) is pre-open in X. Thus, the composition ϕ∘ψ is NP-continuous function.

Lemma 3.13. Let {X_r:r∈Λ} be an arbitrary collection of NTS and U_{r_i} be a non-empty neutrosophic subset of X_{r_i} for each i=1,2,3,.....n. Then M= $\pi_{r\neq r_i}X_r\times\pi_{i=1}^{n}U_{r_i}$ will be a non-empty neutrosophic δsemi-open (respectably, neutrosophic pre-open) subset of ΠX_r ⇔ U_{r_i} is neutrosophic δsemi-open (respectably, neutrosophic pre-open) in X_{r_i}, for all i=1,2,3,.....,n.
Proof. Obvious and hence omitted.

Theorem 3.14. Let ψ: (X,τ_X) → (Y,τ_Y) be a mapping and the graph g: X→ X×Y of ψ, defined by g(u)=(u,ψ(u)) for each u∈X, be pδs-irresolute, then ψ is pδs-irresolute function.
Proof. Suppose that u∈X is an arbitrary member. Let W be Nδs-open subset of Y with ψ (u)∈W. With the Lemma 3.13, X×W will be NPδs-open subset of X×Y which contains g(u). By assumption g is NPδs-irresolute. So, ∃ an NP-open subset F of X which contains u such that g(u)∈X×W which implies that ψ(F)⊂W. Consequently, ψ is NPδs-irresolute function.

Theorem 3.15. Let the product function ψ: $\Pi_{r\in\Delta}M_r$ →$\Pi_{r\in\Delta}N_r$ is NPδs-irresolute function from the product space $\Pi_{r\in\Delta}M_r$ into another product space $\Pi_{r\in\Delta}N_r$, then for each r ∈Δ, ψ_r : M_r →N_r is NPδs-irresolute.
Proof. Let r_0∈Δ be any fixed index and G_{r_0} be an arbitrary neutrosophic δ-semi-open subset of N_{r_0} which includes ψ(t). So, by virtue of 3.13, $\Pi_{r\in\Delta}N_r\times G_{r_0}$ is neutrosophic δ-semi open set of $\Pi_{r\in\Delta}N_r$ where, $r_0 \neq r\in\Delta$. As ψ is NPδs-irresolute function, $\psi^{-1}(\Pi_{r\in\Delta}N_r\times G_{r_0})= \Pi_{r\in\Delta}M_r\times\psi_{r_0}^{-1}\left(G_{r_0}\right)$ is NP-open subset in $\Pi_{r\in\Delta}M_r$. Hence, by Lemma 3.13, $\psi_{r_0}^{-1}\left(G_{r_0}\right)$ is NP-open in M_{r_0}. Thus, for each r ∈Δ, ψ_r is NPδs-irresolute function.

4. Preservation Properties and Applications of NPδs-irresolute Function

In this section, the behavior of neutrosophic semi-connected, neutrosophic pre-connected, neutrosophic pre-T_2, neutrosophic δ-semi-T_2, neutrosophic pre-compact, neutrosophic closed spaces are examined in the light of NPδs-irresolute function. Also, the preservation aspects are investigated.

Definition 4.1. The neutrosophic topological space (X,τ_X) is called neutrosophic semi-connected (shortly, NS-connected) if X cannot be decomposed as the union of two nonempty neutrosophic semi-open sets which are disjoint.

Definition 4.2. The neutrosophic topological space (X,τ_X) is called neutrosophic pre-connected (shortly, NP-connected) if X cannot be represented as the union of two nonempty neutrosophic pre-open sets which are disjoint.

Lemma 4.3. Let (X,τ_X) be a neutrosophic topological space and W⊂X. Then W is neutrosophic δ-semi-open if W is a neutrosophic semi-clo-open set.

Lemma 4.4. Let (X,τ_X) be a neutrosophic topological space and W⊂X. Then NSCl(W) is neutrosophic semi-cloopen if W is a neutrosophic semi-open set.

Lemma 4.5. Let W be a neutrosophic subset of a neutrosophic topological space (X,τ_X). Then NSCl(W) is a neutrosophic δ-semi open set if W is a neutrosophic semi-open set in X.

Proof. Since W is neutrosophic semi-open, by virtue of 4.4, NSCl(W) is semi-cloopen. By Lemma 4.3, every neutrosophic semi-clo-open set is neutrosophic δ-semi open. Thus NSCl(W) is neutrosophic δ-semi open in X.

Theorem 4.6. Let ψ: $(X,\tau_X) \rightarrow (Y,\tau_Y)$ be NPδs-irresolute and surjection function. Then (Y,τ_Y) is NS-connected if (X,τ_X) is NP-connected space.
Proof. If possible let Y be not NS-connected. So, there are two non-empty NS-open sets G and H such that Y=G∪H and G∩H=ϕ. by 4.4, NSCl(G) will be NS-open in Y such that NSCl(G)∩H=ϕ. Then NSCl(G)∩NSCl(H)=ϕ. By means of 4.5, NSCl(G) and NSCl(H) will be NδS-open sets and N=NSCl(G)∪NSCl(H) from which it follows that $X=\psi^{-1}(NSCl(G))\cup \psi^{-1}(NSCl(H))$ and $\psi^{-1}(NSCl(G))\cap\psi^{-1}(NSCl(H))=\phi$. Because of NPδs-irresolute function ψ, $\psi^{-1}(NSCl(G))$ and $\psi^{-1}(NSCl(H))$ must be non-empty NS-open sets. Thus (X,τ_X) is not NP-connected, a contradiction to the hypothesis. Hence, Y is NS-connected.

Definition 4.7. A NTS (X,τ_X) will be called

a) Neutrosophic pre-T_0 (shortly, NP-T_0) if for every distinct neutrosophic points $S_{(t,i,f)}$ and $P_{(t,i,f)}$ in X, ∃ a non-empty NP-open set W such that either $S_{(t,i,f)} \in W$, $P_{(t,i,f)} \notin W$ or $P_{(t,i,f)} \in W$, $S_{(t,i,f)} \notin W$.
b) Neutrosophic pre-T_1 (shortly, NP-T_1) if for every distinct neutrosophic points $S_{(t,i,f)}$ and $P_{(t,i,f)}$ in M, ∃ two non-empty NP-open sets W_1 and W_2 containing s and $P_{(t,i,f)}$ respectably, such that $P_{(t,i,f)} \notin W_1$ and $S_{(t,i,f)} \notin W_2$.
c) Neutrosophic pre-T_2 (shortly, NP-T_2) if for every distinct neutrosophic points $S_{(t,i,f)}$ and $P_{(t,i,f)}$ in M, ∃ two non-empty NP-open sets W_1 and W_2 in M which are disjoint in such a way that $S_{(t,i,f)} \in W_1$ and $P_{(t,i,f)} \in W_2$.

Definition 4.8. A NTS $(X,\tau X)$ will be called neutrosophic δ-semi-T_2 (shortly, NδS-T_2) if for every pair of distinct neutrosophic points $S_{(t,i,f)}$ and $P_{(t,i,f)}$ in X, ∃ two non-empty NδS-open sets W_1 and W_2 in X which are disjoint in such a way that $S_{(t,i,f)} \in W_1$ and $P_{(t,i,f)} \in W_2$.

Theorem 4.9. Let ψ: $(X,\tau_X) \rightarrow (Y,\tau_Y)$ be NPδs-irresolute and surjection function. If (Y,τ_Y) is Nδ-semi-T_i Space, then (X,τ_X) is NP-T_i Space, for each i=0,1,2.
Proof. We prove the theorem for i=2. Suppose s and t are any two distinct pairs of neutrosophic points of M. Then ψ(s)≠ψ(t). Since Y is Nδ-semi-T_2 space. So, ∃ non-empty disjoint Nδ-semi open sets W_1 and W_2 of Y such that $\psi(s) \in W_1$ and $\psi(t) \in W_2$ respectably. Since ψ is NPδs-irresolute, ∃ two NP-open sets U_1 and U_2 of X containing respectably s and t that satisfy $\psi(U_1)\subset W_1$, $\psi(U_2)\subset W_2$. $\Rightarrow U_1\subset \psi^{-1}(W_1)$ and $U_2 \subset \psi^{-1}(W_2) \Rightarrow U_1 \cap U_2 \subset \psi^{-1}(W_1) \cap h^{-1}(W_2) = h^{-1}(W_1 \cap W_2) = \psi^{-1}(\phi) = \phi$. So, $U_1 \cap U_2 = \phi$. Consequently, (X,τ_X) is NP-T_2 space.

Proposition 4.10. Suppose that ψ: $(X,\tau_X) \rightarrow (Y,\tau_Y)$ be NPδs-irresolute function. If (Y,τ_Y) is neutrosophic δ-semi-T_2 space, then the set G={(s,t): ψ(s)=ψ(t), s∈X,t∈X} is NP-closed in the product space X×X.
Proof. Suppose that (s,t)∉G. So, ψ(s)≠ψ(t). Since (Y,τ_Y) is neutrosophic δ-semi-T_2 space. So, ∃ two non-empty disjoint neutrosophic δ-semi open sets W_1 and W_2 in Y such that $\psi(s) \in W_1$ and $\psi(t) \in W_2$ respectably. As ψ is NPδs-irresolute, ∃ two NP-open sets U_1 and U_2 in X with $s \in U_1$ and $t \in U_2$ that satisfy $\psi(U_1) \subset W_1$ and $\psi(U_2) \subset W_2$. Let $H = U_1 \times U_2$, then H is NP-open set in X×X such that (s,t)∈ H and G ∩ H=ϕ ⇒ NPCl(G)⊂G. Hence G is an NP-closed set of X×X.

Definition 4.11: Let ψ: $(X,\tau_X) \rightarrow (Y,\tau_Y)$ be any neutrosophic function, then the graph G of ψ denoted by G(ψ)={(z,ψ(z)):z∈X} will be called NPδs-closed if for each (z,t)∈(X×Y)−G(ψ), there is a $W_1 \in NPO(X)$ with $z \in W_1$ and $W_2 \in N\delta SO(Y)$ that contains t in such a way that $(W_1 \times W_2) \cap G(\psi) = \phi$.

Proposition 4.12: If ψ: $(X,\tau_X) \rightarrow (Y,\tau_Y)$ is NPδs-irresolute function and (Y,τ_Y) is neutrosophic δ-semi T_2-space, then the graph of ψ i.e. G(ψ) is NPδs-closed in X×Y.

Proof. Suppose that (s,t)∈(X×X) −G(ψ). So, ψ(s) ≠ t. Now Y being neutrosophic δ-semi T_2-space, there are neutrosophic δ-semi open sets W_1 and W_2 of Y with ψ(s)∈W_1 and t∈W_2, respectably. As ψ is NPδs-irresolute, there is a NP-open subset H_1 in X with s∈H_1 that satisfies ψ(H_1)⊂W_1. So, ψ(H_1)∩W_2=ϕ and consequently (H_1×W_1)∩G(ψ)=ϕ. Hence, G(ψ) is NPδs-closed in X×Y.

Theorem 4.13. If ψ: $(X,\tau_X) \rightarrow (Y,\tau_Y)$ is NPδs-irresolute and injection function. Then X is NP-T_2-space, if the graph G(ψ)={(z,ψ(z)):z∈M} of ψ is NPδs-closed.

Proof. Suppose z and t are arbitrary elements of X. So, ψ(z) ≠ ψ(t). So,(z,ψ(t)) ∈(X×Y)−G(ψ). Now G(ψ) being NPδs-closed, there is a NP-open set W_1 of X with z∈W_1 and a Nδsemi open set W_2 of Y with ψ(z)∈W_2 satisfying ψ(W_1) ∩W_2=ϕ. As ψ is NPδs-irresolute, there is a NP-open subset H_1 in X with t∈H_1 that satisfies ψ(H_1)⊂W_2. So, ψ(W_1∩H_1)⊂ ψ(W_1) ∩ ψ(H_1)=ϕ which shows W_1∩H_1=ϕ and so, X is NP-T_2-space.

Definition 4.14. The neutrosophic subset W of a NTS (X,τ_X) is said to be neutrosophic pre-compact (shortly, NP-compact) relative to (X,τ_X) if, for every neutrosophic pre-open cover {V_r : r∈Λ, an indexing set} of W, there exists a finite subset Δ of Λ such that $W\subset\cup_{r\in\Delta} V_r$. The neutrosophic topological space (X,τ_X) is NP-compact if X is NP-compact relative to (X,τ_X).

Definition 4.15. The neutrosophic subset W of a NTS (X,τ_X) is said to be neutrosophic semi-compact (shortly, NS-compact) relative to (X,τ_X) if for every neutrosophic semi-open cover {U_r :r∈Λ, an indexing set} of W, there exists a finite subset Δ of Λ such that $W\subset\cup_{r\in\Delta} U_r$. The neutrosophic topological space (X,τ_X) is NS-compact if X is NS-compact relative to (X,τ_X).

Theorem 4.16. If ψ: $(X,\tau_X) \rightarrow (Y,\tau_Y)$ is NPδs-irresolute and W is NP-compact subset concerning X. Then ψ(W) is neutrosophic semi-closed for Y.

Proof. Consider the neutrosophic semi-open cover {V_r : r∈Λ, an indexing set } of ψ(W) where, V_r is NS-open in Y for each r∈Λ, Under 4.5, NSCl(V_r) will be Nδ-semi open set in N. Being ψ an NPδs-irresolute function, ψ^{-1}(NSCl(V_r)) becomes NP-open in X, for each r∈Λ. Since ψ(W)⊂ $\cup_{r\in\Lambda}V_r\subset\cup_{r\in\Lambda}$(NSCl($V_r$)).Then, W⊂$\psi^{-1}$(ψ(W))⊂$\psi^{-1}$($\cup_{r\in\Lambda}$(NSCl($V_r$))) which implies that W⊂$\cup_{r\in\Lambda}\psi^{-1}$ ((NSCl(V_r))). By hypothesis W is an NP-compact for X, so W has a finite NP-open sub-cover i.e. there exists a finite subset Δ of Λ satisfying W ⊂ $\cup_{r\in\Delta}\psi^{-1}$((NSCl($V_r$))) ⇒ ψ(W) ⊂ $\cup_{r\in\Delta}$ NSCl(V_r). So, ψ(W)) is semi-closed relative to Y.

Theorem 4.17. If ψ: $(X,\tau_X) \rightarrow (Y,\tau_Y)$ is NPδs-irresolute and surjection function. Then Y will be neutrosophic semi-closed if X is NP-compact.

Proof. Consider the neutrosophic semi-open cover {V_r : r∈Λ, an indexing set} of Y=ψ(X) where V_r is neutrosophic semi-open in Y for each r. By 4.5, NSCl(V_r) will be Nδ-semi open set in Y. Being ψ an NPδs-irresolute and surjection function, so for each r∈Λ, ψ^{-1}(NSCl(Vr)) is NP-open in X. As Y=ψ(X)⊂$\cup_{r\in\Lambda}$ V_r⊂$\cup_{r\in\Lambda}$(NSCl(V_r)). Then X=ψ^{-1}(ψ(X))⊂ψ^{-1}($\cup_{r\in\Lambda}$(NSCl(V_r))). This implies that M⊂ $\cup_{r\in\Lambda}\psi^{-1}$((NSCl($V_r$))). Being X an NP-compact, it has a finite NP-open sub cover i.e. there exists a finite subset Δ of Λ satisfying X ⊂ $\cup_{r\in\Delta}$ ψ^{-1}((NSCl(V_r))) which gives Y=ψ(X) ⊂ $\cup_{r\in\Delta}$(NSCl(V_r)). So, Y is neutrosophic semi-closed.

5. Conclusion

Because of the presence of indeterminacy in neutrosophic set theory and the corresponding membership functions being crucial, it has many real-life applications. In this paper, we describe the concept of Nαδs-irresolute and NPδs-irresolute functions in neutrosophic topological spaces and prove that every Nαδs-irresolute function is NPδs-irresolute function but not conversely. Some characterizations, counterexamples, and basic properties are also investigated. Finally, the behavior of neutrosophic semi-connected, neutrosophic pre-connected, neutrosophic pre-T2, neutrosophic δ-semi-T2, neutrosophic pre-compact, and neutrosophic s-closed spaces are examined in the light of NPδs-irresolute function. Irresoluteness and continuity feature distinguished positions in the characterization of topological spaces. As a result, this concept, in the future, can be a vital tool in describing various topological structures. Moreover, several neutrosophic irresolute functions such as Nbδs-irresolute, Nβδs-irresolute, Nβ*δs-irresolute, Ne*δs-irresolute functions can be explored as generalized functions in the light of neutrosophic b-open, neutrosophic β-open, neutrosophic β*-open and neutrosophic e*-open sets in NTS and the concepts can be generalized in neutrosophic bitopological spaces.

Declarations

Ethics Approval and Consent to Participate

The results/data/figures in this manuscript have not been published elsewhere, nor are they under consideration by another publisher. All the material is owned by the authors, and/or no permissions are required.

Consent for Publication

This article does not contain any studies with human participants or animals performed by any of the authors.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing Interests

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All authors contributed equally to this research.

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