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ON ALMOST γ-CONTINUOUS FUNCTIONS IN N-NEUTROSOPHIC CRISP TOPOLOGICAL SPACES

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Abstract In this paper, we extend a class of γ-continuous functions in N-neutrosophic crisp topological spaces into a new class of almost γ-continuous functions in N-neutrosophic crisp topological spaces. In a N-neutrosophic crisp γ-open set, an almost γ-continuous functions is a stronger forms of mapping has equally distributed to their elements in a γ-open set. Also, we investigate and discuss some possible outcomes in almost γ-continuous functions based on N-neutrosophic crisp topological spaces. In addition, an almost γ-continuous functions is related to other open sets such as semi-open, pre-open and β-open sets can bring out a results in N-neutrosophic crisp topological spaces.

1 Introduction

Crisp sets are utilized in our daily routine for the most of our careers. The concepts of neutrosophy and neutrosophic set are the recent tools in a topological space. It was first introduced by Smarandache [11, 12] in the beginning of 20^{th} century. In 2014, Salama, Smarandache and Kroumov [8] has given the essential idea of neutrosophic crisp set in a topological space. After that Al-Omeri [2] likewise explored some essential properties of neutrosophic crisp topological Spaces. Al-Hamido [1] investigate the chance of extending the idea of neutrosophic crisp topological spaces into N-topology and research a portion of their essential properties in N-terms. By utilizing N-terms, we can characterized as $1_{nc}ts$, $2_{nc}ts$, $\cdots$, $N_{nc}ts$.

In 1996, Andrijevic [4] introduced b-open sets and develop some of their works in general topology. Ogata [7] characterized an activity γ on a topological space and presented γ-open sets. Additionally, the thought of γ-open set in topological spaces was first presented by Min [6] and worked in the field of general topology. Basu et al. [5] presented a kind of continuity called γ-continuous function. Vadivel [15] presented γ-open sets in neutrosophic crisp topological spaces via N-terms of topology. Also γ-continuous function in a N-neutrosophic crisp topological spaces was presented in his paper. The concept of almost continuity in a topological spaces was introduced by Singal and Singal [10]. Recently, many authors [3, 13, 19, 20] worked on almost properties of continuous functions in neutrosophic set, neutrosophic crisp set, neutrosophic multifunctions, etc.

Research gap: The extension γ-continuous function in a neutrosophic topological spaces can never be studied before and also in a neutrosophic crisp topological spaces. An almost concept of mappings can be defined by very few due to the stronger content of the set. The concept of N-neutrosophic crisp almost γ-continuous functions in a N-neutrosophic crisp topological spaces cannot be examined before and study in this paper with some of their properties.

In this paper, we discuss a new class of functions called N-neutrosophic crisp almost γ-continuous functions in a N-neutrosophic crisp topological spaces. Also, we study and research about N-neutrosophic crisp almost γ-continuous functions and study some of their properties. Finally, we discuss N-neutrosophic crisp almost γ-continuous functions related to some other open sets in N-neutrosophic crisp topological spaces.

2 Preliminaries

Some basic definitions & properties of N_{nc} topological spaces are discussed in this section.

Definition 2.1. [9] For any non-empty fixed set Y, a neutrosophic crisp set (briefly, ncs) L, is an object having the form $L = \langle L_1, L_2, L_3\rangle$ where L_1, L_2 and L_3 are subsets of Y satisfying any one of the types

(T1) $L_\iota \cap L_\kappa = \phi$, $\iota \neq \kappa$ & $\bigcup_{\iota=1}^{3} L_\iota \subset Y, \forall\, \iota, \kappa = 1, 2, 3.$

(T2) $L_\iota \cap L_\kappa = \phi$, $\iota \neq \kappa$ & $\bigcup_{\iota=1}^{3} L_\iota = Y, \forall\, \iota, \kappa = 1, 2, 3.$

(T3) $\bigcap_{\iota=1}^{3} L_\iota = \phi$ & $\bigcup_{\iota=1}^{3} L_\iota = Y, \forall\, \iota = 1, 2, 3.$

Definition 2.2. [9] Types of ncs's $\emptyset_N$ and Y_N in Y are as

(i) $\emptyset_N$ may be defined as $\emptyset_N = \langle\emptyset, \emptyset, Y\rangle$ or $\langle\emptyset, Y, Y\rangle$ or $\langle\emptyset, Y, \emptyset\rangle$ or $\langle\emptyset, \emptyset, \emptyset\rangle$.

(ii) Y_N may be defined as $Y_N = \langle Y, \emptyset, \emptyset\rangle$ or $\langle Y, Y, \emptyset\rangle$ or $\langle Y, \emptyset, Y\rangle$ or $\langle Y, Y, Y\rangle$.

Definition 2.3. [9] Let Y be a non-empty set & the ncs's L & M in the form $L = \langle L_1, L_2, L_3\rangle$, $M = \langle M_1, M_2, M_3\rangle$, then

(i) $L \subseteq M \Leftrightarrow L_1 \subseteq M_1, L_2 \subseteq M_2$ & $L_3 \supseteq M_3$ or $L_1 \subseteq M_1, L_2 \supseteq M_2$ & $L_3 \supseteq M_3$.

(ii) $L \cap M = \langle L_1 \cap M_1, L_2 \cap M_2, L_3 \cup M_3\rangle$ or $\langle L_1 \cap M_1, L_2 \cup M_2, L_3 \cup M_3\rangle$

(iii) $L \cup M = \langle L_1 \cup M_1, L_2 \cup M_2, L_3 \cap M_3\rangle$ or $\langle L_1 \cup M_1, L_2 \cap M_2, L_3 \cap M_3\rangle$

Definition 2.4. [9] Let $L = \langle L_1, L_2, L_3\rangle$ a ncs on Y, then the complement of L (briefly, L^c) may be defined in three different ways:

(C1) $L^c = \langle {L_1}^c, {L_2}^c, {L_3}^c\rangle$, or

(C2) $L^c = \langle L_3, L_2, L_1\rangle$, or

(C3) $L^c = \langle L_3, {L_2}^c, L_1\rangle$.

Definition 2.5. [8] A neutrosophic crisp topology (briefly, ${}_{nc}t$) on a non-empty set Y is a family Γ of nc subsets of Y satisfying

(i) $\emptyset_N, Y_N \in \Gamma$.

(ii) $L_1 \cap L_2 \in \Gamma\, \forall\, L_1$ & $L_2 \in \Gamma$.

(iii) $\bigcup_{\iota} L_\iota \in \Gamma, \;\forall\;\; L_\iota : \iota \in T \subseteq \Gamma.$

Then (Y, Γ) is a neutrosophic crisp topological space (briefly, $ncts$ for short) in Y. The neutrosophic crisp open sets (briefly, $ncos$) are the elements of Γ in Y. A ncs C is closed (briefly, $nccs$) iff its complement C^c is $ncos$.

Definition 2.6. [1] Let Y be a non-empty set. Then ${}_{nc}\Gamma_1$, ${}_{nc}\Gamma_2$, $\cdots$, ${}_{nc}\Gamma_N$ are N-arbitrary crisp topologies defined on Y and the collection

$$N_{nc}\Gamma = \{G \subseteq Y : G = (\bigcup_{\iota=1}^{N} G_\iota) \cup (\bigcap_{\iota=1}^{N} H_\iota), G_\iota, H_\iota \in {}_{nc}\Gamma_\iota\}$$

is called N_{nc}-topology on Y if the axioms are satisfied:

(i) $\emptyset_N, Y_N \in N_{nc}\Gamma$.

(ii) $\bigcup_{\iota=1}^{\infty} C_\iota \in N_{nc}\Gamma\, \forall\, \{C_\iota\}_{\iota=1}^{\infty} \in N_{nc}\Gamma$.

(iii) $\bigcap_{\iota=1}^{n} C_\iota \in N_{nc}\Gamma\, \forall\, \{C_\iota\}_{\iota=1}^{n} \in N_{nc}\Gamma$.

Then $(Y, N_{nc}\Gamma)$ is called a N_{nc}-topological space (briefly, $N_{nc}ts$) on Y. The N_{nc}-open sets ($N_{nc}os$) are the elements of $N_{nc}\Gamma$ in Y and the complement of $N_{nc}os$ is called N_{nc}-closed sets ($N_{nc}cs$) in Y. The elements of Y are known as N_{nc}-sets ($N_{nc}s$) on Y.

Definition 2.7. [1] Let $(Y, N_{nc}\Gamma)$ be $N_{nc}ts$ on Y and L be an $N_{nc}s$ on Y, then the N_{nc} interior of L (briefly, $N_{nc}int(L)$), N_{nc} closure of L (briefly, $N_{nc}cl(L)$) are defined as

$$N_{nc}int(L) = \cup\{C : C \subseteq L \ \& \ C \text{ is a } N_{nc}os \text{ in } Y\}$$

$$N_{nc}cl(L) = \cap\{A : L \subseteq A \ \& \ A \text{ is a } N_{nc}cs \text{ in } Y\}.$$

Definition 2.8. [1] Let $(Y, N_{nc}\Gamma)$ be any $N_{nc}ts$. Let L be an $N_{nc}s$ in $(Y, N_{nc}\Gamma)$. Then L is said to be a N_{nc}-regular (resp. N_{nc}-pre, N_{nc}-semi, N_{nc}-α, N_{nc}-γ & N_{nc}-β) open set (briefly, $N_{nc}ros$ [15] (resp. $N_{nc}\mathcal{P}os$, $N_{nc}\mathcal{S}os$, $N_{nc}\alpha os$, $N_{nc}\gamma os$ [15] & $N_{nc}\beta os$ [17])) if $L = N_{nc}int(N_{nc}cl(L))$ (resp. $L \subseteq N_{nc}int(N_{nc}cl(L))$, $L \subseteq N_{nc}cl(N_{nc}int(L))$, $L \subseteq N_{nc}int(N_{nc}cl(N_{nc}int(L)))$, $L \subseteq N_{nc}cl(N_{nc}int\ (L)) \cup N_{nc}int(N_{nc}cl(L))$ & $L \subseteq N_{nc}cl(N_{nc}int(N_{nc}cl(L)))$).

The complement of an $N_{nc}\mathcal{P}os$ (resp. $N_{nc}\mathcal{S}os$, $N_{nc}\alpha os$, $N_{nc}ros$, $N_{nc}\gamma os$ & $N_{nc}\beta os$) is called an N_{nc}-pre (resp. N_{nc}-semi, N_{nc}-α, N_{nc}-regular, N_{nc}-γ & N_{nc}-β) closed set (briefly, $N_{nc}\mathcal{P}cs$ (resp. $N_{nc}\mathcal{S}cs$, $N_{nc}\alpha cs$, $N_{nc}rcs$, $N_{nc}\gamma cs$ & $N_{nc}\beta cs$)) in Y.

The family of all $N_{nc}\mathcal{P}os$ (resp. $N_{nc}\mathcal{P}cs$, $N_{nc}\mathcal{S}os$, $N_{nc}\mathcal{S}cs$, $N_{nc}\alpha os$, $N_{nc}\alpha cs$, $N_{nc}\gamma os$, $N_{nc}\gamma cs$, $N_{nc}\beta os$, & $N_{nc}\beta cs$) of Y is denoted by $N_{nc}\mathcal{P}OS(Y)$ (resp. $N_{nc}\mathcal{P}CS(Y)$, $N_{nc}\mathcal{S}O\ S(Y)$, $N_{nc}\mathcal{S}CS(Y)$, $N_{nc}\alpha OS(Y)$, $N_{nc}\alpha CS(Y)$, $N_{nc}\gamma OS(Y)$, $N_{nc}\gamma CS(Y)$, $N_{nc}\beta OS(Y)$ & $N_{nc}\beta CS(Y)$).

Definition 2.9. [14] Let $(Y, N_{nc}\Gamma)$ & $(Z, N_{nc}\Psi)$ be any two $N_{nc}ts$'s. A map $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$ is said to be N_{nc}-continuous (briefly, $N_{nc}Cts$) if the inverse image of every $N_{nc}os$ in $(Z, N_{nc}\Psi)$ is a $N_{nc}os$ in $(Y, N_{nc}\Gamma)$.

Definition 2.10. [18] Let $(Y, N_{nc}\Gamma)$ be $N_{nc}ts$ on Y and L be an $N_{nc}s$ on Y, then the $N_{nc}\delta$ interior of L (briefly, $N_{nc}\delta int(L)$) and $N_{nc}\delta$ closure of L (briefly, $N_{nc}\delta cl(L)$) are defined as

$$N_{nc}\delta int(L) = \cup\{A : A \subseteq L \ \& \ A \text{ is a } N_{nc}ros\}$$

$$N_{nc}\delta cl(L) = \cup\{y \in Y : N_{nc}int(N_{nc}cl(L)) \cap L \neq \phi,\ y \in L \ \& \ L \text{ is a } N_{nc}os\} \text{ or}$$

$$N_{nc}\delta cl(L) = \cap\{A : L \subseteq A \ \& \ A \text{ is a } N_{nc}rcs \text{ in } Y\}.$$

Definition 2.11. [18] Let $(Y, N_{nc}\Gamma)$ be any $N_{nc}ts$. Let L be an $N_{nc}s$ in $(Y, N_{nc}\Gamma)$. Then L is said to be a $N_{nc}\delta$ open set (briefly, $N_{nc}\delta os$) if $L = N_{nc}\delta int(L)$.

The complement of an $N_{nc}\delta os$ is called an N_{nc}-δ closed set (briefly, $N_{nc}\delta cs$) in Y.

3 N_{nc} Almost γ-Continuous Function

Here we study about N_{nc} almost γ-continuous function and its properties in $N_{nc}ts$.

Definition 3.1. [16] Let $(Y, N_{nc}\Gamma)$ & $(Z, N_{nc}\Psi)$ be any two $N_{nc}ts$'s. A map $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$ is said to be $N_{nc}\gamma$-continuous (briefly, $N_{nc}\gamma Cts$) if the inverse image of every $N_{nc}os$ in $(Z, N_{nc}\Psi)$ is a $N_{nc}\gamma os$ in $(Y, N_{nc}\Gamma)$.

Definition 3.2. [16] Let $L = \langle L_1, L_2, L_3\rangle$ a $N_{nc}s$ on Y, then $p = \langle pt_1, pt_2, pt_3\rangle$, $pt_1 \neq pt_2 \neq pt_3 \in Y$ is called a N-neutrosophic crisp point (briefly, $N_{nc}p$).

A $N_{nc}p$, $p = \langle pt_1, pt_2, pt_3\rangle$ belongs to a $N_{nc}s$ $L = \langle L_1, L_2, L_3\rangle$ of Y, denoted by $p \in L$, if it may be defined in two ways

(i) $\{pt_1\} \subseteq L_1$, $\{pt_2\} \subseteq L_2$ & $\{pt_3\} \supseteq L_3$ or

(ii) $\{pt_1\} \subseteq L_1$, $\{pt_2\} \supseteq L_2$ & $\{pt_3\} \supseteq L_3$.

Definition 3.3. A function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$ is called N-neutrosophic crisp almost continuous at a $N_{nc}p$ $p \in Y$ if $\forall$ $N_{nc}os$ M in Z containing $h(p)$, there exists a $N_{nc}os$ L in Y containing $p \ni h(L) \subseteq N_{nc}int(N_{nc}cl(M))$. If h is N-neutrosophic crisp almost continuous at every $N_{nc}p$ of Y, then it is called N-neutrosophic crisp almost continuous (briefly, $N_{nc}aCts$).

Definition 3.4. A function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$ is called N-neutrosophic crisp almost γ-continuous at a $N_{nc}p$, $p \in Y$ if $\forall\, p \in Y$ and each $N_{nc}os$ M of Z containing $h(p)$, there exists a $N_{nc}\gamma os$ L of Y containing $p \ni h(L) \subseteq N_{nc}int(N_{nc}cl(M))$. If h is N-neutrosophic crisp almost γ-continuous at every $N_{nc}p$ of Y, then it is called N-neutrosophic crisp almost γ-continuous (briefly, $N_{nc}a\gamma Cts$).

Remark 3.5. The following implications are easily shown and the converses are not true.

$$\boxed{N_{nc}\gamma Cts} \implies \boxed{N_{nc}a\gamma Cts} \implies \boxed{N_{nc}aCts}$$

Example 3.6. Let $Y = \{l, m, n\}$, ${}_{nc}\Gamma_1 = \{\phi_N, Y_N, A, B, C\}$, ${}_{nc}\Gamma_2 = \{\phi_N, Y_N, D\}$. $A = \langle\{l\}, \{\phi\}, \{m, n\}\rangle$, $B = \langle\{m\}, \{\phi\}, \{l, n\}\rangle$, $C = \langle\{l, m\}, \{\phi\}, \{n\}\rangle$, $D = \langle\{l, n\}, \{\phi\}, \{m\}\rangle$, then we have $2_{nc}\Gamma = \{\phi_N, Y_N, A, B, C, D\}$. ${}_{nc}\Phi_1 = \{\phi_N, Y_N, T, U, V\}$, ${}_{nc}\Phi_2 = \{\phi_N, Y_N, W\}$. $T = \langle\{l\}, \{\phi\}, \{m, n\}\rangle$, $U = \langle\{m\}, \{\phi\}, \{l, n\}\rangle$, $V = \langle\{l, m\}, \{\phi\}, \{n\}\rangle$, $W = \langle\{l, n\}, \{\phi\}, \{m\}\rangle$, then we have $2_{nc}\Phi = \{\phi_N, Y_N, T, U, V, W\}$. Let $h : (Y, 2_{nc}\Gamma) \to (Y, 2_{nc}\Phi)$ be defined as $h(l) = n$, $h(m) = m$ and $h(n) = l$. an identity function. Then h is $2_{nc}a\gamma Cts$ but not $2_{nc}\gamma Cts$, because $\langle\{l\}, \{\phi\}, \{m, n\}\rangle$ is a $2_{nc}os$ in $(Y, 2_{nc}\Phi)$ containing $h(\langle\{n\}, \{\phi\}, \{l, m\}\rangle) = \langle\{l\}, \{\phi\}, \{m, n\}\rangle$, but there exist no $2_{nc}\gamma os$, $\langle\{n\}, \{\phi\}, \{l, m\}\rangle$ in $(Y, 2_{nc}\Gamma)$ containing $\langle\{n\}, \{\phi\}, \{l, m\}\rangle$ such that $h(\langle\{n\}, \{\phi\}, \{l, m\}\rangle) \subseteq \langle\{l\}, \{\phi\}, \{m, n\}\rangle$.

Example 3.7. In Example 3.6, $h(\gamma) = Y$, for all $\gamma \in 2_{nc}\Gamma$. Then h is $2_{nc}aCts$ but not $2_{nc}a\gamma Cts$.

Corollary 3.8. *Let $(Y, N_{nc}\Gamma)$ be any $N_{nc}ts$. Let L be an $N_{nc}s$ in $(Y, N_{nc}\Gamma)$. Then $L \in N_{nc}\mathcal{P}OS(Y)$ if and only if $N_{nc}\mathcal{S}cl(L) = N_{nc}int(N_{nc}cl(L))$.*

Theorem 3.9. *For a function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$, then the statements*

(i) h is $N_{nc}a\gamma Cts$.

(ii) $\forall\, p \in Y$ and each $N_{nc}os$ N of Z containing $h(p)$, there exists a $N_{nc}\gamma os$ L in Y containing $p \ni h(L) \subseteq N_{nc}\mathcal{S}cl(N)$.

(iii) $\forall\, p \in Y$ and each $N_{nc}ros$ N of Z containing $h(p)$, there exists a $N_{nc}\gamma os$ L in Y containing $p \ni h(L) \subseteq N$.

(iv) $\forall\, p \in Y$ and each $N_{nc}\delta os$ N of Z containing $h(p)$, there exists a $N_{nc}\gamma os$ L in Y containing $p \ni h(L) \subseteq N$.

Proof. (i) $\Rightarrow$ (ii) Let $p \in Y$ and Let N be any $N_{nc}os$ of Z containing $h(p)$. By (i), there exists a $N_{nc}\gamma os$ L of Y containing $p \ni h(L) \subseteq N_{nc}int(N_{nc}cl(N))$. Since N is $N_{nc}os$ and hence N is $N_{nc}\mathcal{P}os$. By Corollary 3.1, $N_{nc}int(N_{nc}cl(N)) = N_{nc}\mathcal{S}cl(N)$. Therefore, $h(L) \subseteq N_{nc}\mathcal{S}cl(N)$.

(ii) $\Rightarrow$ (iii) Let $p \in Y$ and Let N be any $N_{nc}ros$ of Z containing $h(p)$. Then N is an $N_{nc}os$ of Z containing $h(p)$. By (ii), there exists a $N_{nc}\gamma os$ L in Y containing $p \ni h(L) \subseteq N_{nc}\mathcal{S}cl(N)$. Since N is $N_{nc}ros$ and hence N is $N_{nc}\mathcal{P}os$. By Corollary 3.1, $N_{nc}\mathcal{S}cl(N) = N_{nc}int(N_{nc}cl(N))$. Therefore, $h(L) \subseteq N_{nc}int(N_{nc}cl(N))$. Since N is $N_{nc}ros$, then $h(L) \subseteq N$.

(iii) $\Rightarrow$ (iv) Let $p \in Y$ and Let N be any $N_{nc}\delta os$ of Z containing $h(p)$. Then for each $h(p) \in N$, there exists a $N_{nc}os$ G containing $h(p) \ni G \subseteq N_{nc}int(N_{nc}cl(G)) \subseteq N$. Since $N_{nc}int(N_{nc}cl(G))$ is $N_{nc}ros$ of Z containing $h(p)$. By (iii), there exists a $N_{nc}\gamma os$ L in Y containing $p \ni h(L) \subseteq N_{nc}int\ (N_{nc}cl(G)) \subseteq N$.

(iv) $\Rightarrow$ (i) Let $p \in Y$ and Let N be any $N_{nc}os$ of Z containing $h(p)$. Then $N_{nc}int(N_{nc}cl(N))$ is $N_{nc}\delta os$ of Z containing $h(p)$. By (iv), there exists a $N_{nc}\gamma os$ L in Y containing $p \ni h(L) \subseteq N_{nc}int(N_{nc}cl(N))$. Therefore, h is $N_{nc}a\gamma Cts$. □

Theorem 3.10. *For a function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$, then the statements are equivalent.*

(i) h is $N_{nc}a\gamma Cts$.

(ii) $h^{-1}(N_{nc}int(N_{nc}cl(N)))$ is $N_{nc}\gamma os$ in Y, for each $N_{nc}os$ N in Z.

(iii) $h^{-1}(N_{nc}cl(N_{nc}int(F)))$ *is* $N_{nc}\gamma cs$ *in* Y*, for each* $N_{nc}cs$ F *in* Z*.*

(iv) $h^{-1}(F)$ *is* $N_{nc}\gamma cs$ *in* Y*, for each* $N_{nc}rcs$ F *of* Z*.*

(v) $h^{-1}(N)$ *is* $N_{nc}\gamma os$ *in* Y*, for each* $N_{nc}ros$ N *of* Z*.*

Proof. (i) ⇒ (ii) Let N be any $N_{nc}os$ in Z. We have to show that $h^{-1}(N_{nc}int\ (N_{nc}cl(N)))$ is $N_{nc}\gamma os$ in Y. Let $p \in h^{-1}(N_{nc}int\ (N_{nc}cl(N)))$. Then $h(p) \in N_{nc}int(N_{nc}cl(N))$ and $N_{nc}int(N_{nc}cl(N))$ is a $N_{nc}ros$ in Z. Since h is $N_{nc}a\gamma Cts$. Then by Theorem 3.9, there exists a $N_{nc}\gamma os$ L of Y containing $p \ni h(L) \subseteq N_{nc}int(N_{nc}cl(N))$. Which implies that $p \in L \subseteq h^{-1}(N_{nc}int(N_{nc}cl(N)))$. Therefore, $h^{-1}(N_{nc}int(N_{nc}cl(N)))$ is $N_{nc}\gamma os$ in Y.

(ii) ⇒ (iii) Let F be any $N_{nc}cs$ of Z. Then $Z \setminus F$ is an $N_{nc}os$ of Z. By (ii), $h^{-1}(N_{nc}int(N_{nc}cl(Z \setminus F)))$ is $N_{nc}\gamma os$ in Y and $h^{-1}(N_{nc}int(N_{nc}cl(Z \setminus F))) = h^{-1}(N_{nc}int(Z \setminus N_{nc}int(F))) = h^{-1}(Z \setminus N_{nc}cl(N_{nc}int(F))) = Y \setminus h^{-1}(N_{nc}cl(N_{nc}int(F)))$ is $N_{nc}\gamma os$ in Y and hence $h^{-1}(N_{nc}cl(N_{nc}int(F)))$ is $N_{nc}\gamma cs$ in Y.

(iii) ⇒ (iv) Let F be any $N_{nc}rcs$ of Z. Then F is a $N_{nc}cs$ of Z. By (iii), $h^{-1}(N_{nc}cl(N_{nc}int(F)))$ is $N_{nc}\gamma cs$ in Y. Since F is $N_{nc}rcs$. Then $h^{-1}(N_{nc}cl\ (N_{nc}int(F))) = h^{-1}(F)$. Therefore, $h^{-1}(F)$ is $N_{nc}\gamma cs$ in Y.

(iv) ⇒ (v) Let N be any $N_{nc}ros$ of Z. Then $Z \setminus N$ is $N_{nc}rcs$ of Z and by (iv), we have $h^{-1}(Z \setminus N) = Y \setminus h^{-1}(N)$ is $N_{nc}\gamma cs$ in Y and hence $h^{-1}(N)$ is $N_{nc}\gamma os$ in Y.

(v) ⇒ (i) Let $p \in Y$ and let N be any $N_{nc}ros$ of Z containing $h(p)$. Then $p \in h^{-1}(N)$. By (v), we have $h^{-1}(N)$ is $N_{nc}\gamma os$ in Y. Therefore, we obtain $h(h^{-1}(N)) \subseteq N$. Hence by Theorem 3.9, h is $N_{nc}a\gamma Cts$. □

Theorem 3.11. *For a function* $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$*, then the statements are equivalent.*

(i) h *is* $N_{nc}a\gamma Cts$*.*

(ii) $h(N_{nc}\gamma cl(L)) \subseteq N_{nc}\delta cl(h(L))$*, for each subset* L *of* Y*.*

(iii) $N_{nc}\gamma cl(h^{-1}(N)) \subseteq h^{-1}(N_{nc}\delta cl(N))$*, for each subset* N *of* Z*.*

(iv) $h^{-1}(L)$ *is* $N_{nc}\gamma cs$ *in* Y*, for each* $N_{nc}\delta cs$ L *of* Z*.*

(v) $h^{-1}(N)$ *is* $N_{nc}\gamma os$ *in* Y*, for each* $N_{nc}\delta os$ N *of* Z*.*

(vi) $h^{-1}(N_{nc}\delta int(N)) \subseteq N_{nc}\gamma int(h^{-1}(N))$*, for each subset* N *of* Z*.*

(vii) $N_{nc}\delta int(h(L)) \subseteq h(N_{nc}\gamma int(L))$*, for each subset* L *of* Y*.*

Proof. (i) ⇒ (ii) Let L be a subset of Y. Since $N_{nc}\delta cl(h(L))$ is $N_{nc}\delta cs$ in Z. Then, we have $L \subseteq h^{-1}(N_{nc}\delta\ cl(h(L)))$. By (i) and Theorem 3.10, $h^{-1}(N_{nc}\delta cl(h(L)))$ is $N_{nc}\gamma cs$ of Y. Hence $N_{nc}\gamma cl(L) \subseteq h^{-1}(N_{nc}\delta cl\ (h(L)))$. Therefore, we obtain $h(N_{nc}\gamma cl(L)) \subseteq N_{nc}\delta cl(h(L))$.

(ii) ⇒ (iii) Let N be any subset of Z. Then $h^{-1}(N)$ is a subset of Y. By (ii), we have $h(N_{nc}\gamma cl(h^{-1}(N))) \subseteq N_{nc}\delta cl(h(h^{-1}(N))) = N_{nc}\delta cl(N)$.

Hence $N_{nc}\gamma cl(h^{-1}(N)) \subseteq h^{-1}(N_{nc}\delta cl(N))$.

(iii) ⇒ (iv) Let L be any $N_{nc}\delta cs$ of Z. By (iii), we have $N_{nc}\gamma cl(h^{-1}(L)) \subseteq h^{-1}(N_{nc}\delta\ cl(L)) = h^{-1}(L)$ and hence $h^{-1}(L)$ is $N_{nc}\gamma cs$ in Y.

(iv) ⇒ (v) Let N be any $N_{nc}\delta os$ of Z. Then $Z \setminus N$ is $N_{nc}\delta cs$ of Z and by (iv), we have $h^{-1}(Z \setminus N) = Y \setminus h^{-1}(N)$ is $N_{nc}\gamma cs$ in Y. Hence $h^{-1}(N)$ is $N_{nc}\gamma os$ in Y.

(v) ⇒ (vi) For each subset N of Z. We have $N_{nc}\delta int(N) \subseteq N$. Then $h^{-1}(N_{nc}\delta int(N)) \subseteq h^{-1}(N)$. By (v), $h^{-1}(N_{nc}\delta int(N))$ is $N_{nc}\gamma os$ in Y. Then $h^{-1}(N_{nc}\delta int(N)) \subseteq N_{nc}\gamma int\ (h^{-1}(N))$.

(vi) ⇒ (vii) Let L be any subset of Y. Then $h(L)$ is a subset of Z. By (vi), we obtain that $h^{-1}(N_{nc}\delta int(h(L))) \subseteq N_{nc}\gamma int(h^{-1}(h(L)))$. Hence $h^{-1}(N_{nc}\delta int(h(L))) \subseteq N_{nc}\gamma int(L)$. Which implies that $N_{nc}\delta int(h(L)) \subseteq h(N_{nc}\gamma int(L))$.

(vii) ⇒ (i) Let $p \in Y$ and N be any $N_{nc}ros$ of Z containing $h(p)$. Then $p \in h^{-1}(N)$ and $h^{-1}(N)$ is a subset of Y. By (vii), we get $N_{nc}\delta int(h(h^{-1}(N))) \subseteq h(N_{nc}\gamma int(h^{-1}(N)))$ implies that $N_{nc}\delta int(N) \subseteq h(N_{nc}\gamma int(h^{-1}(N)))$. Since N is $N_{nc}ros$ and hence N is $N_{nc}\delta os$, then $N \subseteq h(N_{nc}\gamma int(h^{-1}(N)))$ this implies that $h^{-1}(N) \subseteq N_{nc}\gamma\ int(h^{-1}(N))$. Therefore, $h^{-1}(N)$ is $N_{nc}\gamma os$ in Y which contains p and clearly $h(h^{-1}(N)) \subseteq N$. Hence, by Theorem 3.9, h is $N_{nc}a\gamma Cts$. □

Corollary 3.12. *Let $(Y, N_{nc}\Gamma)$ be any $N_{nc}ts$. Let L be an $N_{nc}s$ in $(Y, N_{nc}\Gamma)$ is $N_{nc}\beta os$ if and only if $N_{nc}cl(L)$ is $N_{nc}rcs$.*

Theorem 3.13. *For a function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$, then the properties are equivalent.*

(i) h *is* $N_{nc}a\gamma Cts$.

(ii) $N_{nc}\gamma cl(h^{-1}(N)) \subseteq h^{-1}(N_{nc}cl(N))$, *for each* $N_{nc}\gamma os$ N *of* Z.

(iii) $h^{-1}(N_{nc}int(L)) \subseteq N_{nc}\gamma int(h^{-1}(L))$, *for each* $N_{nc}\gamma cs$ L *of* Z.

(iv) $h^{-1}(N_{nc}int(L)) \subseteq N_{nc}\gamma int(h^{-1}(L))$, *for each* $N_{nc}\mathcal{S}cs$ L *of* Z.

(v) $N_{nc}\gamma cl(h^{-1}(N)) \subseteq h^{-1}(N_{nc}cl(N))$, *for each* $N_{nc}\mathcal{S}os$ N *of* Z.

Proof. (i) ⇒ (ii) Let N be any $N_{nc}\gamma os$ of Z. It follows from Corollary 3.12, that $N_{nc}cl(N)$ is $N_{nc}rcs$ in Z. Since h is $N_{nc}a\gamma Cts$. Then by Theorem 3.10, $h^{-1}(N_{nc}cl(N))$ is $N_{nc}\gamma cs$ in Y. Therefore, we obtain $N_{nc}\gamma cl(h^{-1}(N)) \subseteq h^{-1}(N_{nc}cl(N))$.

(ii) ⇔ (iii) Let L be any $N_{nc}\gamma cs$ of Z. Then $Z \setminus L$ is $N_{nc}\gamma os$ of Z and by (ii), we have $N_{nc}\gamma cl(h^{-1}(Z \setminus L)) \subseteq h^{-1}(N_{nc}cl(Z \setminus L)) \Leftrightarrow N_{nc}\gamma cl(Y \setminus h^{-1}(L)) \subseteq h^{-1}(Z \setminus N_{nc}int(L)) \Leftrightarrow Y \setminus N_{nc}\gamma int(h^{-1}(L)) \subseteq Y \setminus h^{-1}(N_{nc}int(L))$. Therefore, $h^{-1}(N_{nc}int(L)) \subseteq N_{nc}\gamma int(h^{-1}(L))$.

(iii) ⇒ (iv) This is obvious since every $N_{nc}\mathcal{S}cs$ is $N_{nc}\gamma cs$.

(iv) ⇒ (v) Let N be any $N_{nc}\mathcal{S}os$ of Z. Then $Z \setminus N$ is $N_{nc}\mathcal{S}cs$ and by (iv), we have $h^{-1}(N_{nc}int(Z\setminus N)) \subseteq N_{nc}\gamma int(h^{-1}(Z\setminus N)) \Leftrightarrow h^{-1}(Z\setminus N_{nc}cl(N)) \subseteq N_{nc}\gamma int(Y\setminus h^{-1}(N)) \Leftrightarrow Y \setminus h^{-1}(N_{nc}cl(N)) \subseteq Y \setminus N_{nc}\gamma cl\ (h^{-1}(N))$. Therefore, $N_{nc}\gamma cl(h^{-1}(N)) \subseteq h^{-1}(N_{nc}cl(N))$.

(v) ⇒ (i) Let L be any $N_{nc}rcs$ of Z. Then L is $N_{nc}\mathcal{S}os$ of Z. By (v), we have $N_{nc}\gamma cl$ $(h^{-1}(L)) \subseteq h^{-1}(N_{nc}\ cl(L)) = h^{-1}(L)$. This shows that $h^{-1}(L)$ is $N_{nc}\gamma cs$ in Y. Therefore, by Theorem 3.10, h is $N_{nc}a\gamma Cts$. □

Corollary 3.14. *Let $(Y, N_{nc}\Gamma)$ be any $N_{nc}ts$. Let L be an $N_{nc}s$ in $(Y, N_{nc}\Gamma)$. Then*

(i) $L \in N_{nc}\mathcal{S}O(Y)$, *then* $N_{nc}\mathcal{P}cl(L) = N_{nc}cl(L)$.

(ii) $L \in N_{nc}\beta O(Y)$, *then* $N_{nc}\alpha cl(L) = N_{nc}cl(L)$.

(iii) $L \in N_{nc}\beta O(Y)$, *then* $N_{nc}\delta cl(L) = N_{nc}cl(L)$.

Theorem 3.15. *For a function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$, then the statements are equivalent.*

(i) h *is* $N_{nc}a\gamma Cts$.

(ii) $N_{nc}\gamma cl(h^{-1}(N)) \subseteq h^{-1}(N_{nc}cl(N))$, *for each* $N_{nc}\beta os$ N *of* Z.

(iii) $N_{nc}\gamma cl(h^{-1}(N)) \subseteq h^{-1}(N_{nc}\delta cl(N))$, *for each* $N_{nc}\beta os$ N *of* Z.

(iv) $N_{nc}\gamma cl(h^{-1}(N)) \subseteq h^{-1}(N_{nc}\gamma cl(N))$, *for each* $N_{nc}\mathcal{S}os$ N *of* Z.

(v) $N_{nc}\gamma cl(h^{-1}(N)) \subseteq h^{-1}(N_{nc}\mathcal{P}cl(N))$, *for each* $N_{nc}\mathcal{S}os$ N *of* Z.

Proof. (i) ⇒ (ii) Follows from Theorem 3.13 and Corollary 3.14 (ii).

(ii) ⇒ (iii) This is obvious, since $N_{nc}\alpha cl(N) \subseteq N_{nc}\delta cl(N)$ in general.

(iii) ⇒ (iv) and (iv) ⇒ (v) Follows from Corollary 3.14.

(v) ⇒ (i) Follows from Theorem 3.13 and Corollary 3.14 (i). □

Corollary 3.16. *For a function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$, then the statements are equivalent.*

(i) h *is* $N_{nc}a\gamma Cts$.

(ii) $h^{-1}(N_{nc}int(N)) \subseteq N_{nc}\gamma int(h^{-1}(N))$, *for each* $N_{nc}\beta cs$ N *of* Z.

(iii) $h^{-1}(N_{nc}\delta int(N)) \subseteq N_{nc}\gamma int(h^{-1}(N))$, *for each* $N_{nc}\beta cs$ N *of* Z.

(iv) $h^{-1}(N_{nc}\gamma int(N)) \subseteq N_{nc}\gamma int(h^{-1}(N))$, *for each* $N_{nc}\mathcal{S}cs$ N *of* Z.

(v) $h^{-1}(N_{nc}\mathcal{P}int(N)) \subseteq N_{nc}\gamma int(h^{-1}(N))$, *for each* $N_{nc}\mathcal{S}cs$ N *of* Z.

Theorem 3.17. *A function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$ is $N_{nc}a\gamma Cts$ if and only if $h^{-1}(N) \subseteq N_{nc}\gamma int(h^{-1}(N_{nc}int\ (N_{nc}cl(N))))$ for each $N_{nc}\mathcal{P}os$ N of Z.*

Proof. Necessity. Let N be any $N_{nc}\mathcal{P}os$ of Z. Then $N \subseteq N_{nc}int(N_{nc}cl(N))$ and $N_{nc}int(N_{nc}cl(N))$ is $N_{nc}ros$ in Z. Since h is $N_{nc}a\gamma Cts$, by Theorem 3.10, $h^{-1}(N_{nc}int(N_{nc}cl(N)))$ is $N_{nc}\gamma os$ in Y and hence we obtain that $h^{-1}(N) \subseteq h^{-1}(N_{nc}int(N_{nc}cl(N))) = N_{nc}\gamma int(h^{-1}(N_{nc}int(N_{nc}cl(N))))$.

Sufficiency. Let N be any $N_{nc}ros$ of Z. Then N is $N_{nc}\mathcal{P}os$ of Z. By hypothesis, we have $h^{-1}(N) \subseteq N_{nc}\gamma int(h^{-1}(N_{nc}int\ (N_{nc}cl(N)))) = N_{nc}\gamma int(h^{-1}(N))$. Therefore, $h^{-1}(N)$ is $N_{nc}\gamma os$ in Y and hence by Theorem 3.10, h is $N_{nc}a\gamma Cts$. □

Corollary 3.18. *A function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$ is $N_{nc}a\gamma Cts$ if and only if $h^{-1}(N) \subseteq N_{nc}\gamma int(h^{-1}(N_{nc}\mathcal{S}\ cl(N)))$ for each $N_{nc}\mathcal{P}os$ N of Z.*

Corollary 3.19. *A function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$ is $N_{nc}a\gamma Cts$ if and only if $N_{nc}\gamma cl(h^{-1}(N_{nc}cl(N_{nc}int(L)))) \subseteq h^{-1}(L)$ for each $N_{nc}\mathcal{P}cs$ L of Z.*

Corollary 3.20. *A function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$ is $N_{nc}a\gamma Cts$ if and only if $N_{nc}\gamma cl(h^{-1}(N_{nc}\mathcal{S}int(L))) \subseteq h^{-1}(L)$ for each $N_{nc}\mathcal{P}cs$ L of Z.*

Theorem 3.21. *For a function $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$, then the statements are equivalent.*

(i) h is $N_{nc}a\gamma Cts$.

(ii) For each neighborhood N of $h(p)$, $p \in N_{nc}\gamma int(h^{-1}(N_{nc}\mathcal{S}cl(N)))$.

(iii) For each neighborhood N of $h(p)$, $p \in N_{nc}\gamma int(h^{-1}(N_{nc}int(N_{nc}cl(N))))$.

Proof. Follows from Theorem 3.17 and Corollary 3.18. □

Theorem 3.22. *Let $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$ is an $N_{nc}a\gamma Cts$ function and Let N be any open subset of Z. If $p \in N_{nc}\gamma cl\ (h^{-1}(N)) \setminus h^{-1}(N)$, then $h(p) \in N_{nc}\gamma cl(N)$.*

Proof. Let $p \in Y$ be such that $p \in N_{nc}\gamma cl(h^{-1}(N)) \setminus h^{-1}(N)$ and suppose $h(p) \notin N_{nc}\gamma cl(N)$. Then there exists a $N_{nc}\gamma os$ $H \subseteq h(p) \ni H \cap N = \emptyset$. Then $N_{nc}cl(H) \cap N = \emptyset$ implies $N_{nc}int(N_{nc}cl(H)) \cap N = \emptyset$ and $N_{nc}int(N_{nc}cl(H))$ is $N_{nc}ros$. Since h is $N_{nc}a\gamma Cts$, by Theorem 3.9, there exists a $N_{nc}\gamma os$ L in Y containing $p \ni h(L) \subseteq N_{nc}int(N_{nc}cl(H))$. Therefore, $h(L) \cap N = \emptyset$. However, since $p \in N_{nc}\gamma cl(h^{-1}(N))$, $L \cap h^{-1}(N) \neq \emptyset$ for every $N_{nc}\gamma os$ L in Y containing p, so that $h(L) \cap N \neq \emptyset$. We have a contradiction. It follows that $h(p) \in N_{nc}\gamma cl(N)$. □

Theorem 3.23. *If $h : (Y_1, N_{nc}\Gamma) \to (Y_2, N_{nc}\Psi)$ is $N_{nc}a\gamma Cts$ and $h' : (Y_2, N_{nc}\Psi) \to (Y_3, N_{nc}\Phi)$ is $N_{nc}Cts$ and open. Then the composition function $h' \circ h : (Y_1, N_{nc}\Gamma) \to (Y_3, N_{nc}\Phi)$ is $N_{nc}a\gamma Cts$.*

Proof. Let $p \in Y_1$ and N be a $N_{nc}os$ of Y_3 containing $h'(h(p))$. Since h' is $N_{nc}Cts$, $h'^{-1}(N)$ is a $N_{nc}os$ of Y_2 containing $h(p)$. Since h is $N_{nc}a\gamma Cts$, $\exists$ a $N_{nc}\gamma os$ L of Y_1 containing $p \ni h(L) \subseteq N_{nc}int(N_{nc}cl(h'^{-1}(N)))$. Also, since h' is $N_{nc}Cts$, then we obtain $(h' \circ h)(L) \subseteq h'(N_{nc}int(h'^{-1}(N_{nc}cl(N))))$. Since h' is open, we obtain $(h' \circ h)(L) \subseteq N_{nc}int(N_{nc}cl(N))$. Therefore, $h' \circ h$ is $N_{nc}a\gamma Cts$. □

Definition 3.24. Let $(Y, N_{nc}\Gamma)$ be any $N_{nc}ts.$, then Y is said to be N-neutrosophic crisp semi-regular (briefly, $N_{nc}\mathcal{S}r$) function if for any $N_{nc}os$ L of Y and each $N_{nc}p$, $p \in L$, there exists a $N_{nc}ros$ N of $Y \ni p \in N \subseteq L$.

Theorem 3.25. *If $h : (Y, N_{nc}\Gamma) \to (Z, N_{nc}\Psi)$ is a $N_{nc}a\gamma Cts$ function and Z is $N_{nc}\mathcal{S}r$. Then h is $N_{nc}\gamma Cts$.*

Proof. Let $p \in Y$ and Let M be any $N_{nc}os$ of Z containing $h(p)$. By $N_{nc}\mathcal{S}r$ function of Z, there exists a $N_{nc}ros$ G of $Z \ni h(p) \in G \subseteq M$. Since h is $N_{nc}a\gamma Cts$. By Theorem 3.9, there exists a $N_{nc}\gamma os$ L of Y containing $p \ni h(L) \subseteq G \subseteq M$. Therefore, h is $N_{nc}\gamma Cts$. □

4 Conclusion

We have introduced N-neutrosophic crisp almost γ-continuous functions in a N-neutrosophic crisp γ-open sets via topological spaces. Also, we have established some properties and results of almost γ-continuous function in N-neutrosophic crisp topological spaces. Finally, we study some relation between almost γ-continuous function and γ-continuous function in N-neutrosophic crisp topological spaces as well as their near open sets such as semi-open set, pre-open set and β-open set.

By using N-neutrosophic crisp γ-open set, the notions can be extend to N-neutrosophic crisp almost contra γ-continuous functions, N-neutrosophic crisp γ open mappings, N-neutrosophic crisp γ closed mappings, N-neutro-sophic crisp γ homomorphisms and N-neutrosophic crisp γ irresolute functions in N-neutrosophic crisp topological spaces in future. Additionally, the notions can be tried in programming languages like C++, MATLAB, Python, etc. to simplify the results in topology.

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