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Neutrosophic Triplet v-Generalized Metric Space

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Abstract: The notion of Neutrosophic triplet (NT) is a new theory in Neutrosophy. Also, the v-generalized metric is a specific form of the classical metrics. In this study, we introduced the notion of neutrosophic triplet v-generalized metric space (NTVGM), and we obtained properties of NTVGM. Also, we showed that NTVGM is different from the classical metric and neutrosophic triplet metric (NTM). Furthermore, we introduced completeness of NTVGM.

Keywords: neutrosophic triplet set (NTS); neutrosophic triplet metric spaces (NTMS); neutrosophic triplet v-generalized metric spaces (NTVGMS)

1. Introduction

Neutrosophy is a branch of philosophy and neutrosophy is introduced by Smarandache in 1980. Neutrosophy consists of neutrosophic logic theory, probability theory, and set theory, as in [1]. İndeed, neutrosophy is generalizations of fuzzy set theory in [2] and intuitionistic fuzzy set theory in [3]. A lot of researchers have been dealing with neutrosophic set theory in [4–7]. Also, Smarandache and Ali studied neutrosophic triplet (NT) theory in [8] and NT groups in [9,10]. NT set is a specific form of the classical set since there exist neutral elements for each element which must be different from other neutral elements. Also, there exist anti-elements for each element. Similarly, the NT group is a specific form of the classical group, since there exist neutral elements for each element in group, which must be different from other neutral elements. Thus, neutral element is different from classical unitary element in groups. An NT is denoted by <a, neut(a), anti(a)>. Furthermore, a lot of researchers have been dealing with neutrosophic triplet set theory in [11–17].

Many modifications have been made in the concept of metric that the nature of mathematics requires, and many new axioms have been included. Similarly, the v-generalized metric is a type of metric. Branciari studied v-generalized metric in [18]. The v-generalized metric has a more general triangular inequality than the classical metric. Thanks to the general triangular inequality, the v-generalized metric introduced new properties in fixed point theory and topology. A lot of researchers have been dealing with v-generalized metric in [19–21]. Recently, Suzuki studied completeness of 3-generalized metric space in [22] and strongly compatible topology on v-generalized metric space, as in [23]

In this study, we introduce neutrosophic triplet v-generalized metric space (NTVGMS) and we give some properties for neutrosophic triplet v-generalized metric (NTVGM). In Section 2, we give preliminary results and definition for NT, NTM, and v generalized metric. In Section 3, we introduce NTVGM and its properties. It is shown that neutrosophic triplet metric is different from the classical metric and neutrosophic triplet metric. Also, we show that NTVGM can be defined with each NTM. Furthermore, we define Cauchy sequence, convergence sequence in an NTVGM and we define completeness for NTVGM. In Section 4, we give conclusions.

2. Preliminaries

Definition 1 ([18]). *A v-generalized metric on a nonempty set X is a function d: XxX* $\rightarrow \mathbb{R}$ *such that all a, b,* $c_1, c_2, \ldots, c_v \in X$

(i) $d(a, b) \geq 0$

(ii) $d(a, b) = 0 \Leftrightarrow a = b$;

(iii) $d(a, b) = d(b, a)$;

(iv) $d(a, b) \leq d(a, c_1) + d(c_1, c_2) + d(c_2, c_3) + \ldots + d(c_{v-1}, c_v) + d(c_v, b)$,

where $a, c_1, c_2, \ldots, c_v, b$ *are all different.*

Definition 2 ([10]). *An NT set X is a set with binary operation # such that for* $n \in X$,

(i) *For* $n \in X$, *there exists neutral of "n" such that* $n\#neut(n) = neut(n)\#n = n$,

(ii) *For* $n \in X$, *there exists anti of "n" such that* $n\#anti(n) = anti(n)\#n = neut(n)$.

Also, an NT "n" is denoted by $(n, neut(n), anti(n))$, *where* $neut(n)$ *element is different from classical unitary element.*

Definition 3 ([13]). *A neutrosophic triplet metric (NTM) on an NT set (NTS) (X, #) is a function* d_T:*XxX* $\rightarrow \mathbb{R}$ *such that all* $a, b, c \in X$,

(i) $a \# b \in X$

(ii) $d_T(a, b) \geq 0$

(iii) *If* $a = b$, *then* $d_T(a, b) = 0$

(iv) $d_T(a, b) = d_T(b, a)$

(v) *If there exists any element* $c \in X$ *such that* $d_T(a, c) \leq d_T(a, c\#neut(b))$, *then* $d_T(a, c\#neut(b)) \leq d_T(a, b) + d_T(b, c)$.

3. Neutrosophic Triplet v-Generalized Metric Space

Definition 4. *An NTVGM on an NTS (X, #) is a function* d_v:*XxX*$\rightarrow\mathbb{R}$ *such that all* $a, b, u_1, u_2, \ldots, u_v \in X$;

(i) $a\#b \in X$

(ii) $0 \leq d_v(a, b)$

(iii) *if* $a = b$, *then* $d_v(a, b) = 0$

(iv) $d_v(a, b) = d_v(b, a)$

(v) *If there exists elements* $a, b, u_1, \ldots, u_v \in X$ *such that*

$d_v(a, b) \leq d_v(a, b\#neut(u_v))$,

$d_v(a, u_2) \leq d_v(a, u_2\#neut(u_1))$,

$d_v(u_1, u_3) \leq d_v(u_1, u_3\#neut(u_2))$,

$\ldots$,

$d_v(u_{v-1}, b) \leq d_v(u_{v-1}, b\#neut(u_v))$;

then $d_v(a, b{*}neut(u_v)) \leq d_v(a, u_1) + d_v(u_1, u_2) + \ldots + d_v(u_{v-1}, u_v) + d_v(u_v, b)$, *where* $x, u_1, \ldots, u_v$, *y are all different.*

Also, $((X, \#), d_v)$ space is called NTVGMS.

Example 1. *Let X = {∅, {k}, {l}, {k, l}} be a set and n(A) be number of elements in K ∈ X. It is clear that for K ∈ X, K∪K = K. Hence, we have*

neut(K) = K, anti(K) = K for all K ∈ X. Also, (X, ∪) is an NTS. Then let

d_v*: XxX→X be a function such that* $d_v(K, M) = \left|n(K) + 2^{n(K)} - (n(M) + 2^{n(M)})\right|$, *where M ∈ X.*

Now we will show that d_v is an NTVGM.

(i) *It is clear that K ∪ M ∈ X for K, M ∈ X.*

(ii) *It is clear that* $d_v(K, M) = \left|n(K) + 2^{n(K)} - (n(M) + 2^{n(M)})\right| \geq 0$.

(iii) *If K = M, then* $d_v(K, M) = \left|n(K) + 2^{n(K)} - (n(M) + 2^{n(M)})\right| =$

$$\left|n(K) + 2^{n(K)} - (n(K) + 2^{n(K)})\right| = 0$$

(iv) $d_v(K, M) = \left|n(K) + 2^{n(K)} - (n(M) + 2^{n(M)})\right| =$

$$\left|-(n(K) + 2^{n(K)} - (n(M) + 2^{n(M)}))\right| =$$

$$\left|n(M) + 2^{n(M)} - (n(K) + 2^{n(K)})\right| = d_v(M, K)$$

(v) *it is clear* $d_v(\{l\}, \{k, l\}) \leq d_v(\{l\}, \{k, l\} \cup \{k\})$,

$d_v(\{k\}, \{k, l\}) \leq d_v(\{k\}, \{k, l\} \cup \{l\})$,

$d_v(\{k\}, \{l\}) \leq d_v(\{k\}, \{l\} \cup \emptyset)$,

$d_v(\{l\}, \{k\}) \leq d_v(\{l\}, \{k\} \cup \emptyset)$,

$d_v(\emptyset, \{k\}) \leq d_v(\emptyset, \{k\} \cup \{l\})$,

$d_v(\emptyset, \{l\}) \leq d_v(\emptyset, \{l\} \cup \{k\})$,

$d_v\emptyset, \{k, l\}) \leq d_v(\emptyset, \{k, l\} \cup \{l\})$.

Also,

$d_v(\emptyset, \{k\}) = 2$

$d_v(\emptyset, \{l\}) = 2$

$d_v(\emptyset, \{k, l\}) = 5$

$d_v(\{k\}, \{l\}) = 0$

$d_v(\{k, l\}, \{k\}) = 3$

$d_v(\{k, l\}, \{l\}) = 3$

Thus,

$d_v(\emptyset, \{l\}) < d_v(\emptyset, \{k, l\}) + d_v(\{k, l\}, \{k\}) + d_v(\{k\}, \{l\})$,

$d_v(\emptyset, \{k\}) < d_v(\emptyset, \{k, l\}) + d_v(\{k, l\}, \{l\}) + d_v(\{l\}, \{k\})$,

$d_v(\{k\}, \{l\}) < d_v(\{k\}, \{k, l\}) + d_v(\{k, l\}, \emptyset) + d_v(\emptyset, \{l\})$,

$d_v(\{k\}, \{k, l\}) < d_v(\{k\}, \{l\}) + d_v(\{l\}, \emptyset) + d_v(\emptyset, \{k, l\})$,

$d_v(\{l\}, \{k, l\}) < d_v(\{l\}, \{k\}) + d_v(\{k\}, \emptyset) + d_v(\emptyset, \{k, l\})$, *Hence, (X), ∪), d_v) is an NT2GMS.*

Corollary 1. *NTVGM is different from the classical metric because of triangle inequality and "#" binary operation.*

Corollary 2. *The NTVGM is different from NTM because of triangle inequality.*

Theorem 1. *In definition of NTVGM, if $u_1 = u_2 = \ldots = u_v$, then each neutrosophic triplet v-generalized metric is a neutrosophic triplet metric.*

Proof of Theorem 1. ((X, #), d_v) be an NTVGMS. It is clear that i, ii, iii and iv conditions are equal in NTVGMS and NTMS. Then for condition v, we take $u_1 = u_2 = \ldots = u_v$. By definition of NTVGM,

If there exists elements $u_1, \ldots, u_v \in$ X such that

$d_v(x, y) \le d_v(x, y\#neut(u_v))$,

$d_v(x, u_2) \le d_v(x, u_2\#neut(u_1))$,

$d_v(u_1, u_3) \le d_v(u_1, u_3\#neut(u_2))$,

$\ldots,$

$d_v(u_{v-1}, y) \le d_v(u_{v-1}, y\#neut(u_v))$;

then d_v(x, y#neut(u_v)) $\le d_v$(x, u_1) + $d_v(u_1, u_2) + \ldots + d_v(u_{v-1}, u_v) + d_v(u_v$, y). We can take $u_1 = u_3 = \ldots = u_v = u_2$ since for $u_1 = u_2 = \ldots = u_v$. Thus, we can take

$d_v(x, y\#neut(u_v)) = d_v(x, y\#neut(u_2))$ and

$d_v(x, u_1) + d_v(u_1, u_2) + \ldots + d_v(u_{v-1}, u_v) + d_v(u_v,y) =$

$d_v(x, u_2) + d_v(u_2, u_2) + \ldots + d_v(u_2, u_2) + d_v(u_2, y)$.

Hence,

$d_v(x, y\#neut(u_2)) \le d_v(x, u_1)+ d_v(u_1, u_2) + \ldots + d_v(u_{v-1}, u_v) + d_v(u_v,y) =$

$$d_v(x, u_2)+ d_v(u_2, u_2) + \ldots + d_v(u_2, u_2) + d_v(u_2, y) =$$

$$d_v(x, u_2)+ 0 + \ldots + 0+ d_v(u_2, y) = d_v(x, u_2) + d_v(u_2, y).$$

Therefore, $(X, \#), d_v)$ is a neutrosophic triplet metric space. □

Corollary 3. *From Theorem 1, we can define an NT1GM with each NTM. Also, Each NTM is an NT1GM.*

Definition 5. *Let* ((X, #), d_v) *be an NTVGMS and $\{x_n\}$ be a sequence in NTVGMS and $a \in X$. If there exist N $\in \mathbb{N}$ for every ε > 0 such that*

$d_v\ (a,\ \{xn\}\ )(a,\ \{xn\}) < \varepsilon,$

then $\{x_n\}$ converges to $a \in X$, where $n \ge M$. Also, it is shown that

$\lim_{n\to\infty} x_n = a \text{ or } x_n \to$ a.

Definition 6. *Let* ((X, #), d_v) *be an NTVGMS and $\{x_n\}$ be a sequence in NTVGMS. If there exists $N \in \mathbb{N}$ for every ε > 0 such that*

$$d_v(\{x_m\}, \{x_n\}) < \varepsilon,$$

then $\{x_n\}$ is a Cauchy sequence in NTVGMS, where $n \geq m \geq M$.

Definition 7. *Let ((X, #), d_v) be an NTVGMS and $\{x_n\}$ be a sequence in NTVGMS. If there exists N ∈ ℕ for every ε > 0 such that*

$$d_v(\{x_n\}, \{x_{(n+1+jk)}\}) < \varepsilon, (j = 0, 1, 2, \ldots)$$

then $\{x_n\}$ is a k-Cauchy sequence in NTVGMS, where k ∈ ℕ.

Proposition 1. *$\{x_n\}$ is a Cauchy sequence in NTM if and only if $\{x_n\}$ is a 1-Cauchy sequence in NTVGM.*

Proof of Proposition 1. From Corollary 3, each NT1GMS is an NTMS. Also, definition of Cauchy sequence in NTVGMS is equal to definition of Cauchy sequence in NTMS. So, $\{x_n\}$ is a Cauchy sequence in NTM if and only if $\{x_n\}$ is a *1*-Cauchy sequence NTVGMS. □

Proposition 2. *Let ((X, #), d_v) be an NTVGMS and k, m ∈ ℕ such that k is divisible by m. Then, every m-Cauchy sequence is k-Cauchy sequence.*

Proof of Proposition 2. We assume that $\{x_n\}$ is a *m*-Cauchy sequence. Then we can take $d_v(\{x_n\}, \{x_{n+1+j.m}\}) < \varepsilon$, (j = 0, 1, 2, . . .). Since k, m ∈ ℕ such that k is divisible by m, we can find any j ∈ ℕ such that k = j.m. Thus, we have $d_v(\{x_n\}, \{x_{n+1+j.k}\}) < \varepsilon$ for (j = 0, 1, 2, . . .). Then $\{x_n\}$ is a *k*-Cauchy sequence.

Conversely, assume that $\{x_n\}$ is a *k*-Cauchy sequence. Since k, m ∈ ℕ such that k is divisible by m and $d_v(\{x_n\}, \{x_{n+1+j.k}\}) < \varepsilon$, it is clear that $d_v(\{x_n\}, \{x_{n+1+j.m}\}) < \varepsilon$. Thus, $\{x_n\}$ is a *m*-Cauchy sequence. □

Proposition 3. *Let ((X, #), d_v) be an NTVGMS and k, m ∈ ℕ such that k is divisible by m. If ((X, #), d_v) is a k-complete NTVGMS, then ((X, #), d_v) is a m-complete NTVGMS.*

Proof of Proposition 3. From proof of Proposition 2, If $\{x_n\}$ is a *k*-Cauchy sequence, then $\{x_n\}$ is an *m*-Cauchy sequence. Thus, If ((X, #), d_v) is a *k*-complete NTVGMS, then ((X, #), d_v) is a *m*-complete NTVGMS. □

Definition 8. *Let ((X, #), d_v) be an NTVGMS and $\{x_n\}$ be Cauchy sequence in NTVGMS. NTVGMS is complete if and only if every $\{x_n\}$ converges in NTVGMS.*

Definition 9. *Let ((X, #), d_v) be an NTVGMS and $\{x_n\}$ be k-Cauchy sequence in NTVGMS. NTVGMS is k-complete If and only if every $\{x_n\}$ converges in NTVGMS.*

Proposition 4. *((X, *), d_v) is a complete NTVGM if and only if ((X,), d_v) is a 1-complete neutrosophic triplet v generalized metric space.*

Proof of Proposition 4. From Proposition 1, $\{x_n\}$ is a Cauchy sequence if and only if $\{x_n\}$ is a *1*-Cauchy sequence. So, if $\{x_n\}$ is convergent Cauchy sequence, then $\{x_n\}$ is convergent *1*-Cauchy sequence. Also, if $\{x_n\}$ is convergent *1*-Cauchy sequence, then $\{x_n\}$ is convergent Cauchy sequence. □

Theorem 2. *Let ((X, #), d_v) be an NTVGM and there exists $u_1, \ldots, u_v$ ∈X such that $d_v(x, y) \leq d_v(x, y{*}neut(u_v))$,*

$d_v(x, u_2) \leq d_v(x, u_2{*}neut(u_1))$,

$d_v(u_1, u_3) \leq d_v(u_1, u_3{*}neut(u_2))$,

. . . ,

$d_v(u_{v-1}, y) \leq d_v(u_{v-1}, y{*}neut(u_v))$,

where x, $u_1, \ldots, u_v$, *y are all different. If* $\{x_n\}$ *is k-Cauchy sequence and converges to* $z \in \{x_n\}$, *then* $\{x_n\}$ *is a Cauchy sequence*, *where* x_n are all different.

Proof Theorem 2. We assume that $\{x_n\}$ is k-Cauchy sequence and converges to z $\in \{x_n\}$. So, $d_v(\{x_n\}, \{x_{n+1+jk}\}) < \varepsilon$ ($j = 0, 1, 2, \ldots$). If we take $j = 0$, then

$$d_v(\{x_n\}, \{x_{(n+1)}\}) < \varepsilon \tag{1}$$

and

$$d_v(z, \{x_n\}) < \varepsilon \tag{2}$$

Also, we assume that there exist $u_1, \ldots, u_v \in$ N such that

$d_v(x, y) \leq d_v(x, y{*}neut(u_v))$,

$d_v(x, u_2) \leq d_v(x, u_2{*}neut(u_1))$,

$d_v(u_1, u_3) \leq d_v(u_1, u_3{*}neut(u_2))$,

$\ldots$,

$d_v(u_{v-1}, y) \leq d_v(u_{v-1}, y{*}neut(u_v))$,

where x, $u_1, \ldots, u_v$, y are all different. Thus, from (v) in Definition 4, (1) and (2)

$d_v(\{x_n\}, \{x\_m\}) \leq d_v(\{x_n\}, z)$

$+ d_v(z, \{x_{n+v-1}\})$

$+ d_v(\{x_{n+v-1}\}, \{x_{n+v-2}\})$

$+ \ldots$

$d_v(\{x_{m+1}\}, \{x_m\}) \leq$ (v-1)ε. Hence, $\{x_n\}$ is a Cauchy sequence. □

Theorem 3. *Let* $((N, *), d_v)$ *be a neutrosophic triplet v-generalized metric space and there exist* $u_1, \ldots, u_v \in N$ *such that* $d_v(x, y) \leq d_v(x, y{*}neut(u_v))$ *and*

$d_v(x, u_2) \leq d_v(x, u_2{*}neut(u_1))$,

$d_v(u_1, u_3) \leq d_v(u_1, u_3{*}neut(u_2))$,

$\ldots$,

$d_v(u_{v-1}, y) \leq d_v(u_{v-1}, y{*}neut(u_v))$.

If $\{x_n\}$ *is sequence and* $\sum_{k=1}^{\infty} d_v(x_k, x_{k+1}) < \infty$ *then* $\{x_n\}$ *is k-Cauchy sequence, where* x_n *are all different and* x, $u_1, \ldots, u_v$, *y are all different.*

Proof of Theorem 3. Let $\varepsilon > 0$ such that $\sum_{m=1}^{\infty} d_v(x_m, x_{m+1}) < \varepsilon$ since for $\sum_{k=1}^{\infty} d_v(x_k, x_{k+1}) < \infty$. Now we show that

$$d_v(\{x_n\}, \{x_{n+1+jk}\}) < \varepsilon.$$

If j = 0, then it is clear that $d_v(\{x_n\}, \{x_{n+1}\}) < \varepsilon$ since for $\sum_{m=1}^{\infty} d_v(x_m, x_{m+1}) < \varepsilon$.

We assume that j $\neq$ 0. Also,

$$d_v(\{x_n\}, \{x_{n+1+jk}\}) \leq d_v(\{x_n\}, \{x_{n+1}\}) + \tag{3}$$

$$\leq d_v(\{x_{n+1}\}, \{x_{n+2}\})+ \tag{4}$$

$$\leq d_v(\{x_{n+2}\}, \{x_{n+3}\})+ \tag{5}$$

$$\ldots + \tag{6}$$

$$\leq d_v(\{x_{(n+1+jk\text{-}1)}\}, \{x_{(n+1+jk)}\}) \tag{7}$$

$= \sum_{m=n}^{n+1+Jk-1} d_v(x_m, x_{m+1}) < \sum_{m=1}^{\infty} d_v(x_m, x_{m+1}) < \varepsilon$. Hence, x_n is $k-$Cauchy sequence

□

4. Conclusions

In this paper, we introduced NTVGM. We also showed that NTVGM is different from the metric and NTM. Furthermore, we show that NT1GMS can be defined with each NTMS. Also, we gave completeness for NTVGMS. Furthermore, thanks to the NTVGMS definition and properties, researchers can introduce fixed point theorems for NTVGM and researchers can define neutrosophic triplet partial v-generalized metric, neutrosophic triplet v-generalized normed space.

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