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ON FIXED POINT RESULTS FOR A NEW CLASS OF SUZUKI TYPE CONTRACTION MAPPINGS

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Abstract. In this paper, we introduce two new classes of Suzuki type contraction mappings via the pair $(\mathcal{A}, \mathfrak{h})$ and the pair $(\mathcal{A}, \mathfrak{h}')$, called an upper class of type I and type II, respectively. We establish new fixed point results for such mappings in S -metric spaces. Our results extend and generalize some related results in the existing literature.

Keywords: fixed point; Suzuki type contraction mapping; upper class of type I; upper class of type II; G -metric space; S -metric space.

2020 AMS Subject Classification: 47H10; 54H25

1. INTRODUCTION

The Banach Contraction Principle (BCP) [3] which is known as Banach's Fixed Point Theorem is one of the most powerful tool in the history of fixed point theory. Its aim is to establish the existence of solutions for nonlinear operator equations and integral equations. Since then, because of simplicity and usefulness, it has become a very popular tool in solving a variety of problems such as control theory, economic theory, nonlinear analysis and global analysis. Later, a large number of literature is witnessed on applications, generalizations and extensions of this theorem. They were carried out by several authors in different directions, e.g., by weakening

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the hypothesis, using different setups. A huge number of generalizations of metric spaces have thus appeared in several papers, such as 2-metric spaces, G -metric spaces, D^* -metric spaces, partial metric spaces and cone metric spaces. These generalizations were then used to extend the scope of the study of fixed point theory. For more discussions of such generalizations, we refer readers to [1, 2, 4, 5, 6, 7, 8, 9].

In 2006, Mustafa and Sims [10] introduced the notion of G -metric and characterized some celebrated fixed point results in the context of G -metric spaces. Later, a number of authors have proved so many fixed point results on the setting of G -metric spaces (see [11, 12, 14, 15, 16] for examples). Later, Sedghi *et al.* [17] introduced a D^* -metric space which is a modification of D -metric spaces introduced by Dhage [18] and proved some basic properties in D^* -metric spaces, (see [17, 19]). We note that every G -metric is a D^* -metric, but in general the converse is not true, (see Example 1.4 in [20], for example). Recently, Sedghi *et al.* [20] have introduced the concept of an S -metric space, a modification of D^* -metric and G -metric spaces, and have given some of their properties. Some recent interesting results in S -metric spaces can be found in [21, 22]. In 2014, A.H. Ansari [23] introduced the concept of C -class functions which can be used to generalize many fixed point theorems in the literature (see [24, 25] for examples). Also, A.H. Ansari [26, 27] introduced the notion of the pair $(\mathcal{A}, \mathfrak{h})$ called an upper class of type I, which can also be used to generalize fixed point results.

In 2008, Suzuki [35] and Kikkawa and Suzuki [13] generalized BCP by introducing Suzuki-type contractions on metric spaces. Note that Suzuki-type contractions characterize the completeness of underlying metric spaces. Moreover, Suzuki-type contractions are in the form of implication which allow many discontinuous mappings of metric spaces to be Suzuki-type contractions, while Banach contractions are necessarily continuous mappings of metric spaces. Recently, M. Shashraki *et al.* [28] obtained some fixed point results by using a general form of the Suzuki type function on S -metric spaces.

The purpose of this paper is to establish new fixed point results in S -metric spaces via the pair $(\mathcal{A}, \mathfrak{h})$ (the upper class of type I), and the pair $(\mathcal{A}, \mathfrak{h}')$ (the upper class of type II), together with the idea proposed by M. Shashraki *et al.* [28].

2. PRELIMINARIES

We collect some necessary definitions and results in this direction.

Definition 1. [20] *Let $\mathbb{U}$ be a nonempty set. Let $S : \mathbb{U} \times \mathbb{U} \times \mathbb{U} \rightarrow [0, \infty)$ be a function that satisfies the following conditions, for each $x, y, z, a \in X$:*

- (i) $S(x, y, z) \geq 0$;
- (ii) $S(x, y, z) = 0$ if and only if $x = y = z$;
- (iii) $S(x, y, z) \leq S(x, x, a) + S(y, y, a) + S(z, z, a)$.

Then the function S is called an S -metric on $\mathbb{U}$, and the pair $(\mathbb{U}, S)$ is called an S -metric space.

Remark 1. *This notion is a generalization of a G -metric space [10] and a D^* -metric space [17].*

Example 1. [28] *Let $\mathbb{U} \neq \emptyset$ and d is the usual metric on $\mathbb{U}$, then*

$$S(x, y, z) = d(x, z) + d(y, z)$$

is an S -metric on $\mathbb{U}$. This S -metric is called the usual S -metric on $\mathbb{U}$.

Example 2. [32] *Let $\mathbb{U} = \mathbb{R}^n$ and $\|\cdot\|$ a norm on $\mathbb{U}$, then*

$$S(x, y, z) = \|y + z - 2x\| + \|y - z\|$$

is an S -metric on $\mathbb{U}$.

Note that every S -metric on $\mathbb{U}$ induces a metric d_S on $\mathbb{U}$ defined by

$$d_S(x, y) = S(x, x, y) + S(y, y, x) ,$$

for all $x, y \in \mathbb{U}$.

Lemma 2.1. [20] *Let $(\mathbb{U}, S)$ be an S -metric space. Then $S(x, x, y) = S(y, y, x)$ for all $x, y \in \mathbb{U}$.*

Lemma 2.2. [29] *Let $(\mathbb{U}, S)$ be an S -metric space. Then*

$$S(x, x, z) \leq 2S(x, x, y) + S(y, y, z) \text{ and } S(x, x, z) \leq 2S(x, x, y) + S(z, z, y)$$

for all $x, y, z \in \mathbb{U}$.

Definition 2. [20] Let $(\mathbb{U}, S)$ be an S -metric space.

- (i) A sequence $\{x_n\} \subset \mathbb{U}$ is said to converge to $x \in \mathbb{U}$ if $S(x_n, x_n, x) \rightarrow 0$ as $n \rightarrow \infty$. That is, for each $\varepsilon > 0$, there exists $n_0 \in \mathbb{N}$ such that for all $n \geq n_0$ we have $S(x_n, x_n, x) < \varepsilon$. We write $x_n \rightarrow x$ for brevity.
- (ii) A sequence $\{x_n\} \subset \mathbb{U}$ is called a Cauchy sequence if $S(x_n, x_n, x_m) \rightarrow 0$ as $n, m \rightarrow \infty$. That is, for each $\varepsilon > 0$, there exists $n_0 \in \mathbb{N}$ such that for all $n, m \geq n_0$ we have $S(x_n, x_n, x_m) < \varepsilon$.
- (iii) The S -metric space $(\mathbb{U}, S)$ is said to be complete if every Cauchy sequence is a convergent sequence.

Throughout this manuscript, let $\mathbb{R}^+ = [0, \infty)$, i.e. the set of non-negative real numbers and $\mathbb{N}$ = the set of positive integers.

Definition 3. ([26, 27]) We say that the function $\mathfrak{h}: \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R}$ is a function of subclass of type I, if $x \geq 1 \implies \mathfrak{h}(1, y) \leq \mathfrak{h}(x, y)$ for all $y \in \mathbb{R}^+$.

Example 3. ([26, 27]) Define $\mathfrak{h}: \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R}$ by:

- (a) $\mathfrak{h}(x, y) = (y + l)^x, l > 1$;
- (b) $\mathfrak{h}(x, y) = (x + l)^y, l > 1$;
- (c) $\mathfrak{h}(x, y) = x^n y, n \in \mathbb{N}$;
- (d) $\mathfrak{h}(x, y) = y$;
- (e) $\mathfrak{h}(x, y) = \frac{1}{n+1} (\sum_{i=0}^n x^i) y, n \in \mathbb{N}$;
- (f) $\mathfrak{h}(x, y) = \left[\frac{1}{n+1} (\sum_{i=0}^n x^i) + l \right]^y, l > 1, n \in \mathbb{N}$

for all $x, y \in \mathbb{R}^+$. Then $\mathfrak{h}$ is a function of subclass of type I.

Definition 4. ([26, 27]) Let $\mathfrak{h}, \mathcal{A}: \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R}$, then we say that the pair $(\mathcal{A}, \mathfrak{h})$ is an upper class of type I, if $\mathfrak{h}$ is a function of subclass of type I and:

- (i) $0 \leq s \leq 1 \implies \mathcal{A}(s, t) \leq \mathcal{A}(1, t)$,
- (ii) $\mathfrak{h}(1, y) \leq \mathcal{A}(s, t) \implies y \leq st$ for all $s, t, y \in \mathbb{R}^+$.

Example 4. [26, 27] Define $\mathfrak{h}, \mathcal{A}: \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R}$ by:

- (a) $\mathfrak{h}(x, y) = (y + l)^x, l > 1$ and $\mathcal{A}(s, t) = st + l$;
- (b) $\mathfrak{h}(x, y) = (x + l)^y, l > 1$ and $\mathcal{A}(s, t) = (1 + l)^{st}$;

$$(c) \mathfrak{h}(x, y) = x^m y, m \in \mathbb{N} \text{ and } \mathcal{A}(s, t) = st;$$

$$(d) \mathfrak{h}(x, y) = y \text{ and } \mathcal{A}(s, t) = t;$$

$$(d) \mathfrak{h}(x, y) = \frac{1}{n+1} \left(\sum_{i=0}^n x^i \right) y, n \in \mathbb{N} \text{ and } \mathcal{A}(s, t) = st;$$

$$(e) \mathfrak{h}(x, y) = \left[\frac{1}{n+1} \left(\sum_{i=0}^n x^i \right) + l \right]^y, l > 1, n \in \mathbb{N} \text{ and } \mathcal{A}(s, t) = (1+l)^{st}$$

for all $x, y, s, t \in \mathbb{R}^+$. Then the pair $(\mathcal{A}, \mathfrak{h})$ is an upper class of type I.

Definition 5. ([26, 27]) We say that the function $\mathfrak{h}' : \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R}$ is a function of subclass of type II, if $x, y \geq 1 \implies \mathfrak{h}'(1, 1, z) \leq \mathfrak{h}'(x, y, z)$ for all $z \in \mathbb{R}^+$.

Example 5. [26, 27] Define $\mathfrak{h}' : \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R}$ by:

$$(a) \mathfrak{h}'(x, y, z) = (z+l)^{xy}, l > 1;$$

$$(b) \mathfrak{h}'(x, y, z) = (xy+l)^z, l > 1;$$

$$(c) \mathfrak{h}'(x, y, z) = z;$$

$$(d) \mathfrak{h}'(x, y, z) = x^m y^n z^p, m, n, p \in \mathbb{N};$$

$$(e) \mathfrak{h}'(x, y, z) = \frac{x^m + x^n y^p + y^q}{3} z^k, m, n, p, q, k \in \mathbb{N}$$

for all $x, y, z \in \mathbb{R}^+$. Then $\mathfrak{h}'$ is a function of subclass of type II.

It is to be noted that $\mathfrak{h}'(1, 1, z) \leq \mathfrak{h}'(1, y, z)$, for $1 \leq y$.

Definition 6. ([26, 27]) Let $\mathfrak{h}' : \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R}$ and $\mathcal{A} : \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R}$, then we say that the pair $(\mathcal{A}, \mathfrak{h}')$ is an upper class of type II, if $\mathfrak{h}'$ is a function of subclass of type II and:

$$(i) 0 \leq s \leq 1 \implies \mathcal{A}(s, t) \leq \mathcal{A}(1, t),$$

$$(ii) \mathfrak{h}'(1, 1, z) \leq \mathcal{A}(s, t) \implies z \leq st \text{ for all } s, t, z \in \mathbb{R}^+.$$

Example 6. ([26, 27]) Define $\mathfrak{h}' : \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R}$ and $\mathcal{A} : \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R}$ by:

$$(a) \mathfrak{h}'(x, y, z) = (z+l)^{xy}, l > 1, \mathcal{A}(s, t) = st + l;$$

$$(b) \mathfrak{h}'(x, y, z) = (xy+l)^z, l > 1, \mathcal{A}(s, t) = (1+l)^{st};$$

$$(c) \mathfrak{h}'(x, y, z) = z, \mathcal{A}(s, t) = st;$$

$$(d) \mathfrak{h}'(x, y, z) = x^m y^n z^p, m, n, p \in \mathbb{N}, \mathcal{A}(s, t) = s^p t^p$$

$$(e) \mathfrak{h}'(x, y, z) = \frac{x^m + x^n y^p + y^q}{3} z^k, m, n, p, q, k \in \mathbb{N}, \mathcal{A}(s, t) = s^k t^k$$

for all $x, y, z, s, t \in \mathbb{R}^+$. Then the pair $(\mathcal{A}, \mathfrak{h}')$ is an upper class of type II.

Definition 7. [30] A function $\psi : [0, \infty) \rightarrow [0, \infty)$ is called an altering distance function if the following properties are satisfied:

- (i) ψ is non-decreasing and continuous,
- (ii) $\psi(t) = 0$ if and only if $t = 0$.

Lemma 2.3. [32] Let $(\mathbb{U}, S)$ be an S -metric space. If sequence $\{x_n\}$ converges to $x \in \mathbb{U}$, then x is unique.

Lemma 2.4. [28, 32] Let $(\mathbb{U}, S)$ be an S -metric space. If there exist sequences $\{x_n\}$ and $\{y_n\}$ such that $\lim_{n \rightarrow \infty} x_n = x$ and $\lim_{n \rightarrow \infty} y_n = y$, then $\lim_{n \rightarrow \infty} S(x_n, x_n, y_n) = S(x, x, y)$.

Definition 8. [31, 33] Let $\mathbb{U}$ be a nonempty set, a b -metric on $\mathbb{U}$ is a function $\eta : \mathbb{U}^2 \rightarrow [0, \infty)$ if there exists a real number $b \geq 1$ such that the following conditions hold for all $x, y, z \in \mathbb{U}$,

- (i) $\eta(x, y) = 0 \iff x = y$;
- (ii) $\eta(x, y) = \eta(y, x)$;
- (iii) $\eta(x, z) \leq b[\eta(x, y) + \eta(y, z)]$.

Then, the pair $(\mathbb{U}, \eta)$ is called a b -metric space.

Proposition 1. [34] Let $(\mathbb{U}, S)$ be an S -metric space and let $\eta(x, y) = S(x, x, y)$, for all $x, y \in \mathbb{U}$. Then we have

- (i) η is a b -metric on $\mathbb{U}$;
- (ii) $x_n \rightarrow x$ in $(\mathbb{U}, S) \iff x_n \rightarrow x$ in $(\mathbb{U}, \eta)$;
- (iii) $\{x_n\}$ is a Cauchy sequence in $(\mathbb{U}, S) \iff \{x_n\}$ is a Cauchy sequence in $(\mathbb{U}, \eta)$.

Definition 9. [28] Let $\mathbb{G}$ be the set of all continuous functions $\mathfrak{d} : [0, \infty)^4 \rightarrow \mathbb{R}^+$ satisfying the conditions:

- (i) $\mathfrak{d}(1, 1, 1, 1) < 1$,
- (ii) $\mathfrak{d}$ is subhomogeneous, i.e. $\mathfrak{d}(\alpha x_1, \alpha x_2, \alpha x_3, \alpha x_4) \leq \alpha \mathfrak{d}(x_1, x_2, x_3, x_4)$, for all $\alpha \geq 0$,
- (iii) if $x_i, y_i \in [0, \infty)$, $x_i \leq y_i$ for $i = 1, 2, 3, 4$ we have

$$\mathfrak{d}(x_1, x_2, x_3, x_4) \leq \mathfrak{d}(y_1, y_2, y_3, y_4).$$

Here, $\mathbb{R}^+$ denotes the set of non-negative real numbers.

Example 7. [28] The following functions $\mathfrak{d} : [0, \infty)^4 \rightarrow \mathbb{R}^+$ are elements of $\mathbb{G}$.

$$(1) \mathfrak{d}(x_1, x_2, x_3, x_4) = k \max\{x_i\}_{i=1}^4 \text{ for } k \in (0, 1).$$

$$(2) \mathfrak{d}(x_1, x_2, x_3, x_4) = k \max\{x_1, x_2, \frac{x_3}{2}, \frac{x_4}{2}\} \text{ for } k \in (0, 1).$$

Proposition 2. [28] If $\mathfrak{d} \in \mathbb{G}$ and $u, v \in [0, \infty]$ are such that $u \leq \mathfrak{d}(v, v, v, u)$, then $u \leq \gamma v$, where $\gamma = \mathfrak{d}(1, 1, 1, 1)$.

Recently, M. Shahraki *et al.* [28] obtained the following result.

Theorem 2.1. [28] Let $(\mathbb{U}, S)$ be an S -metric space. Assume that $\mathcal{F}$ is a function. Suppose that there exists $\mathfrak{d} \in \mathbb{G}$ and $\alpha \in (0, 1)$, such that $\alpha(h+2) \leq 1$ where $\gamma = \mathfrak{d}(1, 1, 1, 1)$. Suppose also that $\alpha S(x, x, \mathcal{F}x) \leq S(x, y, z)$ implies

$$S(\mathcal{A}x, \mathcal{F}y, \mathcal{F}z) \leq \mathfrak{d}(S(x, y, z), S(x, x, \mathcal{F}x), S(y, y, \mathcal{F}y), S(z, z, \mathcal{F}z)),$$

for all $x, y, z \in \mathbb{U}$. Then $\mathbb{F}(\mathcal{F})$ is non-empty, where $\mathbb{F}(\mathcal{F}) = \{x : \mathcal{F}x = x\}$.

In this manuscript, inspired and motivated by the works of M. Shahraki *et al.* [28], we establish new fixed point results for a new class of S -($\mathcal{A}, \mathfrak{h}, \mathfrak{d}, \psi$)-Suzuki type contraction mappings, where the pair $(\mathcal{A}, \mathfrak{h})$ is an upper class of type I, and a new class of S -($\mathcal{A}, \mathfrak{h}', \mathfrak{d}, \psi$)-Suzuki type contraction mappings, where the pair $(\mathcal{A}, \mathfrak{h}')$ is upper class of type II, in the setting of S -metric spaces. Our results extend and generalize the results by M. Shahraki *et al.* [28] and some other related results in the existing literature.

3. MAIN RESULTS

In this section, we introduce the following new definition.

Definition 10. Let $(\mathbb{U}, S)$ be an S -metric space and let $\mathcal{F} : \mathbb{U} \rightarrow \mathbb{U}$ be a function. Suppose that there exists $\mathfrak{d} \in \mathbb{G}$ and $\alpha \in (0, 1)$. We say that $\mathcal{F}$ is an S -($\mathcal{A}, \mathfrak{h}, \mathfrak{d}, \psi$)-Suzuki type contraction mapping, if for all $x, y, z \in \mathbb{U}$, such that

$$\alpha S(x, x, \mathcal{F}x) \leq S(x, y, z)$$

implies

$$(3.1) \quad \begin{aligned} & \mathfrak{h}(1, S(\mathcal{F}x, \mathcal{F}y, \mathcal{F}z)) \\ & \leq \mathcal{A} \left(1, \psi \left(\mathfrak{d}(S(x, y, z), S(x, x, \mathcal{F}x), S(y, y, \mathcal{F}y), S(z, z, \mathcal{F}z)) \right) \right), \end{aligned}$$

where $\psi \in \Psi$ and the pair $(\mathcal{A}, \mathfrak{h})$ is an upper class of type I.

Theorem 3.1. Let $(\mathbb{U}, S)$ be a complete S -metric space and $\mathcal{F} : \mathbb{U} \rightarrow \mathbb{U}$ be a function. Assume that $\mathcal{F}$ is an S -($\mathcal{A}, \mathfrak{h}, \mathfrak{d}, \psi$)-Suzuki type contraction mapping, where the pair $(\mathcal{A}, \mathfrak{h})$ is an upper class of type I. Suppose that there exists $\mathfrak{d} \in \mathbb{G}$ and $\alpha \in (0, 1)$ such that $\alpha(\gamma + 2) \leq 1$, where $\gamma = \mathfrak{d}(1, 1, 1, 1)$. Then there exists a unique point $x \in \mathbb{U}$ such that $\mathcal{F}x = x$.

Proof. For arbitrary $x_0, x_1 \in \mathbb{U}$, let $x_1 = \mathcal{F}x_0$. Since

$$\alpha S(x_0, x_0, \mathcal{F}x_0) \leq S(x_0, x_0, x_1),$$

by Definition 10 and $(\mathcal{A}, \mathfrak{h})$ is an upper class of type I, we have

$$\begin{aligned} & \mathfrak{h}(1, \psi(S(\mathcal{F}x_0, \mathcal{F}x_0, \mathcal{F}x_1))) \\ & \leq \mathcal{A} \left(1, \psi \left(\mathfrak{d}(S(x_0, x_0, x_1), S(x_0, x_0, \mathcal{F}x_0), S(x_0, x_0, \mathcal{F}x_0), S(x_1, x_1, \mathcal{F}x_1)) \right) \right), \end{aligned}$$

which implies, by Definition 4 (ii), that

$$\begin{aligned} & \psi(S(\mathcal{F}x_0, \mathcal{F}x_0, \mathcal{F}x_1)) \\ & \leq \psi \left(\mathfrak{d}(S(x_0, x_0, x_1), S(x_0, x_0, \mathcal{F}x_0), S(x_0, x_0, \mathcal{F}x_0), S(x_1, x_1, \mathcal{F}x_1)) \right). \end{aligned}$$

By the property of ψ , we get

$$(3.2) \quad \begin{aligned} & S(\mathcal{F}x_0, \mathcal{F}x_0, \mathcal{F}x_1) \\ & \leq \mathfrak{d}(S(x_0, x_0, x_1), S(x_0, x_0, \mathcal{F}x_0), S(x_0, x_0, \mathcal{F}x_0), S(x_1, x_1, \mathcal{F}x_1)). \end{aligned}$$

Equivalently,

$$(3.3) \quad \begin{aligned} & S(x_1, x_1, \mathcal{F}x_1) \\ & \leq \mathfrak{d}(S(x_0, x_0, x_1), S(x_0, x_0, x_1), S(x_0, x_0, x_1), S(x_1, x_1, \mathcal{F}x_1)). \end{aligned}$$

Then, from (3.3) and by Proposition 2, we have $S(x_1, x_1, \mathcal{F}x_1) \leq \gamma S(x_0, x_0, x_1)$. Next, let $x_2 = \mathcal{F}x_1$ for $x_1, x_2 \in \mathbb{U}$. Since $\alpha S(x_1, x_1, \mathcal{F}x_1) \leq S(x_1, x_1, x_2)$, we have

$$(3.4) \quad \begin{aligned} & \mathfrak{h}(1, \psi(S(\mathcal{F}x_1, \mathcal{F}x_1, \mathcal{F}x_2))) \\ & \leq \mathcal{A}\left(1, \psi\left(\mathfrak{d}(S(x_1, x_1, x_2), S(x_1, x_1, \mathcal{F}x_1), S(x_1, x_1, \mathcal{F}x_1), S(x_2, x_2, \mathcal{F}x_2))\right)\right), \end{aligned}$$

which implies, by Definition 4 (ii), that

$$\begin{aligned} & \psi(S(\mathcal{F}x_1, \mathcal{F}x_1, \mathcal{F}x_2)) \\ & \leq \psi\left(\mathfrak{d}(S(x_1, x_1, x_2), S(x_1, x_1, \mathcal{F}x_1), S(x_1, x_1, \mathcal{F}x_1), S(x_2, x_2, \mathcal{F}x_2))\right). \end{aligned}$$

By the property of ψ , we get

$$(3.5) \quad \begin{aligned} & S(x_2, x_2, \mathcal{F}x_2) \\ & \leq \mathfrak{d}(S(x_1, x_1, x_2), S(x_1, x_1, x_2), S(x_1, x_1, x_2), S(x_2, x_2, \mathcal{F}x_2)). \end{aligned}$$

Then, from (3.5) and by Proposition 2, we have $S(x_2, x_2, \mathcal{F}x_2) \leq \gamma S(x_1, x_1, x_2) \leq \gamma^2 S(x_0, x_0, x_1)$.

Analogously, let $x_3 = \mathcal{F}x_2$ we then have

$$S(x_3, x_3, \mathcal{F}x_3) \leq \gamma S(x_2, x_2, \mathcal{F}x_2) \leq \gamma^3 S(x_0, x_0, x_1).$$

By continuing this process, we obtain a sequence $\{x_n\}_{n \geq 1}$ in $\mathbb{U}$ such that $x_{n+1} = \mathcal{F}x_n$ satisfying $S(x_n, x_n, \mathcal{F}x_n) \leq \gamma S(x_{n-1}, x_{n-1}, x_n) \leq \gamma^n S(x_0, x_0, x_1)$.

So, now we have

$$S(x_n, x_n, x_{n+1}) \leq S(x_{n-1}, x_{n-1}, x_n).$$

Thus, the sequence $\{S(x_n, x_n, x_{n+1})\}$ is decreasing sequence in $\mathbb{R}^+$ and thus it converges to $t \in \mathbb{R}^+$. We claim that $t = 0$. Suppose, on the contrary, that $t > 0$. Observe that by the assumption of the theorem, we have

$$(3.6) \quad \begin{aligned} & \psi(S(x_n, x_n, x_{n+1})) = \psi(S(\mathcal{F}x_{n-1}, \mathcal{F}x_{n-1}, \mathcal{F}x_n)) \\ & \leq \psi\left(\mathfrak{d}(S(x_{n-1}, x_{n-1}, x_n), S(x_{n-1}, x_{n-1}, \mathcal{F}x_{n-1}), S(x_{n-1}, x_{n-1}, \mathcal{F}x_{n-1}), S(x_n, x_n, \mathcal{F}x_n))\right) \\ & = \psi\left(\mathfrak{d}(S(x_{n-1}, x_{n-1}, x_n), S(x_{n-1}, x_{n-1}, x_n), S(x_{n-1}, x_{n-1}, x_n), S(x_n, x_n, x_{n+1}))\right). \end{aligned}$$

Taking limit as $n \rightarrow \infty$ in (3.6), we get

$$\psi(t) \leq \psi(\mathfrak{d}(t, t, t, t)).$$

Therefore, we have

$$t \leq \mathfrak{d}(t, t, t, t).$$

Using the property of $\mathfrak{d}$, we get

$$t \leq \mathfrak{d}(t, t, t, t) \leq t\mathfrak{d}(1, 1, 1, 1) < t.$$

This is a contradiction. Hence, $t = 0$. That is,

$$\lim_{n \rightarrow \infty} S(x_n, x_n, x_{n+1}) = 0.$$

We now have a sequence $\{x_n\}_{n \geq 1}$ in $\mathbb{U}$ such that $x_{n+1} = \mathcal{F}x_n$ satisfying

$$S(x_n, x_n, \mathcal{F}x_n) \leq \gamma S(x_{n-1}, x_{n-1}, x_n).$$

That is,

$$S(x_n, x_n, x_{n+1}) \leq \gamma^n S(x_0, x_0, x_1).$$

If $x_m = x_{m+1}$ for some $m \geq 1$, then $\mathcal{A}$ has a fixed point. Suppose that $x_n \neq x_{n+1}$, for all $n \geq 1$.

Applying the triangle inequality repeatedly, we have

$$\begin{aligned}
 (3.7) \quad S(x_n, x_n, x_{n+m}) &\leq 2S(x_n, x_n, x_{n+1}) + S(x_{n+m}, x_{n+m}, x_{n+1}) \\
 &= 2S(x_n, x_n, x_{n+1}) + S(x_{n+1}, x_{n+1}, x_{n+m}) \\
 &\leq 2S(x_n, x_n, x_{n+1}) + 2S(x_{n+1}, x_{n+1}, x_{n+2}) + \\
 &\quad S(x_{n+m}, x_{n+m}, x_{n+2}) \\
 &\leq 2[S(x_n, x_n, x_{n+1}) + S(x_{n+1}, x_{n+1}, x_{n+2}) + \\
 &\quad \cdots + S(x_{n+m-1}, x_{n+m-1}, x_{n+m})] \\
 &\leq 2[\gamma^n S(x_0, x_0, x_1) + \gamma^{n+1} S(x_0, x_0, x_1) + \\
 &\quad \cdots + \gamma^{m-1} S(x_0, x_0, x_1)] \\
 &= 2 \sum_{k=0}^{m-1} \gamma^{k+n} S(x_0, x_0, x_1) = \frac{2\gamma^n}{1-\gamma} S(x_0, x_0, x_1).
 \end{aligned}$$

Taking the limit as $n, m \rightarrow \infty$ in (3.7), we get

$$\lim_{n, m \rightarrow \infty} S(x_n, x_n, x_{n+m}) = 0.$$

This means $\{x_n\}_{n \geq 1}$ is a Cauchy sequence and $\{x_n\}_{n \geq 1}$ is a Cauchy sequence in $\mathbb{U}$. Since $(\mathbb{U}, S)$ is a complete S -metric space, there exists $x \in \mathbb{U}$ such that $x_n \rightarrow x$ as $n \rightarrow \infty$. That is,

$$\lim_{n \rightarrow \infty} S(x_n, x_n, x) = 0$$

One can also see that $\lim_{n \rightarrow \infty} S(x_n, x_{n+1}, x) = 0$.

Now, we claim that for each $n \geq 1$ one of the relations

$$(3.8) \quad \alpha S(x_n, x_n, \mathcal{F}x_n) \leq S(x_n, x_n, x)$$

or

$$(3.9) \quad \alpha S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}) \leq S(x_{n+1}, x_{n+1}, x)$$

holds.

Suppose for some $n \geq 1$, we have

$$\alpha S(x_n, x_n, \mathcal{F}x_n) > S(x_n, x_n, x)$$

and

$$\alpha S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}) > S(x_{n+1}, x_{n+1}, x),$$

then

$$\begin{aligned} S(x_n, x_n, x_{n+1}) &\leq 2S(x_n, x_n, x) + S(x_{n+1}, x_{n+1}, x) \\ (3.10) \quad &< 2\alpha S(x_n, x_n, \mathcal{F}x_n) + \alpha S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}) \\ &\leq 2\alpha S(x_n, x_n, x_{n+1}) + \alpha \gamma S(x_n, x_n, x_{n+1}). \end{aligned}$$

This implies $\alpha(\gamma+2) > 1$, which contradicts the initial assumption. Hence, our claim is proved.

Again, from (3.8) and (3.9) and by the assumption of the theorem, we have either

$$\begin{aligned} &\mathfrak{h}\left(1, \psi\left(S(\mathcal{F}x_n, \mathcal{F}x_n, \mathcal{F}x)\right)\right) \\ &\leq \mathcal{A}\left(1, \psi\left(\mathfrak{d}\left(S(x_n, x_n, x), S(x_n, x_n, \mathcal{F}x_n), S(x_n, x_n, \mathcal{F}x_n), S(x, x, \mathcal{F}x)\right)\right)\right) \end{aligned}$$

or

$$\begin{aligned} &\mathfrak{h}\left(1, \psi\left(S(\mathcal{F}x_{n+1}, \mathcal{F}x_{n+1}, \mathcal{F}x)\right)\right) \\ &\leq \mathcal{A}\left(1, \psi\left(\mathfrak{d}\left(S(x_{n+1}, x_{n+1}, x), S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}), S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}), S(x, x, \mathcal{F}x)\right)\right)\right). \end{aligned}$$

This implies, by Definition 4 (ii), that

$$(3.11) \quad \begin{aligned} & \psi\left(S(\mathcal{F}x_n, \mathcal{F}x_n, \mathcal{F}x)\right) \\ & \leq \psi\left(\mathfrak{d}\left(S(x_n, x_n, x), S(x_n, x_n, \mathcal{F}x_n), S(x_n, x_n, \mathcal{F}x_n), S(x, x, \mathcal{F}x)\right)\right) \end{aligned}$$

or

$$(3.12) \quad \begin{aligned} & \psi\left(S(\mathcal{F}x_{n+1}, \mathcal{F}x_{n+1}, \mathcal{F}x)\right) \\ & \leq \psi\left(\mathfrak{d}\left(S(x_{n+1}, x_{n+1}, x), S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}), S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}), S(x, x, \mathcal{F}x)\right)\right). \end{aligned}$$

From (3.11) and (3.12), by the property of ψ we obtain

$$S(\mathcal{F}x_n, \mathcal{F}x_n, \mathcal{F}x) \leq \mathfrak{d}\left(S(x_n, x_n, x), S(x_n, x_n, \mathcal{F}x_n), S(x_n, x_n, \mathcal{F}x_n), S(x, x, \mathcal{F}x)\right)$$

and

$$\begin{aligned} & S(\mathcal{F}x_{n+1}, \mathcal{F}x_{n+1}, \mathcal{F}x) \\ & \leq \mathfrak{d}\left(S(x_{n+1}, x_{n+1}, x), S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}), S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}), S(x, x, \mathcal{F}x)\right), \end{aligned}$$

respectively.

Therefore, one of the following cases holds.

Case (i) There exists an infinite subset $K \subseteq \mathbb{N}$ such that

$$\begin{aligned} S(x_{n+1}, x_{n+1}, \mathcal{F}x) &= S(\mathcal{F}x_n, \mathcal{F}x_n, \mathcal{F}x) \\ &\leq \mathfrak{d}\left(S(x_n, x_n, x), S(x_n, x_n, \mathcal{F}x_n), S(x_n, x_n, \mathcal{F}x_n), S(x, x, \mathcal{F}x)\right) \\ &= \mathfrak{d}\left(S(x_n, x_n, x), S(x_n, x_n, x_{n+1}), S(x_n, x_n, x_{n+1}), S(x, x, \mathcal{F}x)\right) \end{aligned}$$

for all $n \in K$.

Case (ii) There exists an infinite subset $M \subseteq \mathbb{N}$ such that

$$\begin{aligned} S(x_{n+2}, x_{n+2}, \mathcal{F}x) &= S(\mathcal{F}x_{n+1}, \mathcal{F}x_{n+1}, \mathcal{F}x) \\ &\leq \mathfrak{d}\left(S(x_{n+1}, x_{n+1}, x), S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}), S(x_{n+1}, x_{n+1}, \mathcal{F}x_{n+1}), S(x, x, \mathcal{F}x)\right) \\ &= \mathfrak{d}\left(S(x_{n+1}, x_{n+1}, x), S(x_{n+1}, x_{n+1}, x_{n+2}), S(x_{n+1}, x_{n+1}, x_{n+2}), S(x, x, \mathcal{F}x)\right) \end{aligned}$$

for all $n \in M$.

Taking the limit as $n \rightarrow \infty$ in both cases, we obtain

$$S(x, x, \mathcal{F}x) \leq \mathfrak{d}(0, 0, 0, S(x, x, \mathcal{F}x)).$$

Now, by Propositions 2, we have $S(x, x, \mathcal{F}x) = 0$, and hence $\mathcal{F}x = x$. By Lemma 2.3, x is the unique fixed point of $\mathcal{F}$. This completes our proof. $\square$

Corollary 3.1 ([28], Theorem 1). *Let $(\mathbb{U}, S)$ be an S -metric space. Assume that $\mathcal{F}$ is a function. Suppose that there exists $\mathfrak{d} \in \mathbb{G}$ and $\alpha \in (0, 1)$, such that $\alpha(h + 2) \leq 1$ where $h = \mathfrak{d}(1, 1, 1, 1)$. Suppose also that $\alpha S(x, x, \mathcal{F}x) \leq S(x, y, z)$ implies*

$$S(\mathcal{F}x, \mathcal{F}y, \mathcal{F}z) \leq \mathfrak{d}(S(x, y, z), S(x, x, \mathcal{F}x), S(y, y, \mathcal{F}y), S(z, z, \mathcal{F}z)),$$

for all $x, y, z \in \mathbb{U}$. Then $\mathbb{F}(\mathcal{F})$ is non-empty, where $\mathbb{F}(\mathcal{F}) = \{x : \mathcal{F}x = x\}$.

Proof. Taking $\mathfrak{h}(1, y) = y$ and $\mathcal{A}(s, t) = t$ and $\psi(t) = t$ in Theorem 3.1. $\square$

Definition 11. *Let $(\mathbb{U}, S)$ be an S -metric space and let $\mathcal{F} : \mathbb{U} \rightarrow \mathbb{U}$ be a function. Suppose that there exists $\mathfrak{d} \in \mathbb{G}$ and $\alpha \in (0, 1), \beta \geq 1$. We say that $\mathcal{F}$ is an S -($\mathcal{A}, \mathfrak{h}', \mathfrak{d}, \psi$)-Suzuki type contraction mapping, if for all $x, y, z \in \mathbb{U}$, such that*

$$\alpha S(x, x, \mathcal{F}x) \leq S(x, y, z)$$

implies

$$(3.13) \quad \begin{aligned} & \mathfrak{h}'(1, \beta, S(\mathcal{F}x, \mathcal{F}y, \mathcal{F}z)) \\ & \leq \mathcal{A}\left(1, \psi\left(\mathfrak{d}(S(x, y, z), S(x, x, \mathcal{F}x), S(y, y, \mathcal{F}y), S(z, z, \mathcal{F}z))\right)\right), \end{aligned}$$

where $\psi \in \Psi$ and the pair $(\mathcal{A}, \mathfrak{h}')$ is an upper class of type II.

Theorem 3.2. *Let $(\mathbb{U}, S)$ be a complete S -metric space and $\mathcal{F} : \mathbb{U} \rightarrow \mathbb{U}$ be a function. Assume that $\mathcal{F}$ is an S -($\mathcal{A}, \mathfrak{h}', \mathfrak{d}, \psi$)-Suzuki type contraction mapping, where the pair $(\mathcal{A}, \mathfrak{h}')$ is an upper class of type II. Suppose that there exists $\mathfrak{d} \in \mathbb{G}$ and $\alpha \in (0, 1), \beta \geq 1$ such that $\alpha(\gamma + 2) \leq 1$, where $\gamma = \mathfrak{d}(1, 1, 1, 1)$. Then there exists a unique point $x \in \mathbb{U}$ such that $\mathcal{F}x = x$.*

Proof. Following the same process as Theorem 3.1, and by using Definition 6 we obtain the proof of Theorem 3.2. $\square$

Example 8. Let $\mathbb{U} = \{3, 4, 5, 6, 7, 8, 9\}$ and d is the usual metric on $\mathbb{U}$, then

$$S(x, y, z) = d(x, z) + d(y, z)$$

is an S -metric on $\mathbb{U}$ and it is easy to see that $(\mathbb{U}, S)$ is an S -metric space.

Let $\mathfrak{h}(x, y) = y$, $\mathcal{A}(s, t) = t$, $\psi(t) = 3t$ and $\mathfrak{d}(x_1, x_2, x_3, x_4) = \frac{1}{2} \max\{x_i\}_{i=1}^4$.

Define $\mathcal{F} : \mathbb{U} \rightarrow \mathbb{U}$ by

$$(3.14) \quad \mathcal{F}(x) = \begin{cases} 6 & \text{if } x \in \{6, 7, 8, 9\} \\ x+4 & \text{otherwise.} \end{cases}$$

One can see that, for all $x, y, z \in \mathbb{U}$ such that

$$\alpha S(x, x, \mathcal{F}x) \leq S(x, y, z)$$

implies

$$\begin{aligned} & \mathfrak{h}(1, S(\mathcal{F}x, \mathcal{F}y, \mathcal{F}z)) \\ & \leq \mathcal{A}\left(1, \psi\left(\mathfrak{d}(S(x, y, z), S(x, x, \mathcal{F}x), S(y, y, \mathcal{F}y), S(z, z, \mathcal{F}z))\right)\right), \end{aligned}$$

where $\alpha \in (0, 1)$, $\beta > 1$.

For, let $x = 3, y = 4, z = 6$, we have that

$$\alpha \cdot 8 = \alpha S(3, 3, 7) = \alpha S(3, 3, \mathcal{F}(3)) \leq S(3, 4, 6) = 5,$$

where $\alpha \in (0, 1)$. And we have

$$(3.15) \quad \mathfrak{h}(1, S(\mathcal{F}(3), \mathcal{F}(4), \mathcal{F}(6))) = \mathfrak{h}(1, S(7, 8, 6)) = \mathfrak{h}(1, 3) = 3.$$

And

$$\begin{aligned} & \mathcal{A}\left(1, \psi\left(\mathfrak{d}(S(3, 4, 6), S(3, 3, \mathcal{F}(3)), S(4, 4, \mathcal{F}(4)), S(6, 6, \mathcal{F}(6)))\right)\right) \\ (3.16) \quad & = \psi\left(\mathfrak{d}(S(3, 4, 6), S(3, 3, \mathcal{F}(3)), S(4, 4, \mathcal{F}(4)), S(6, 6, \mathcal{F}(6)))\right) \\ & = \psi(\mathfrak{d}(5, 8, 8, 0)) = 3\mathfrak{d}(5, 8, 8, 0) = 12. \end{aligned}$$

From (3.15), (3.16), we have

$$\begin{aligned} & \mathfrak{h}(1, S(\mathcal{F}(3), \mathcal{F}(4), \mathcal{F}(6))) \\ & < \mathcal{A} \left(1, \psi \left(\mathfrak{d}(S(3, 4, 6), S(3, 3, \mathcal{F}(3)), S(4, 4, \mathcal{F}(4)), S(6, 6, \mathcal{F}(6))) \right) \right). \end{aligned}$$

For all other cases, one can easily show that, if for all $x, y, z \in \mathbb{U}$, such that

$$\alpha S(x, x, \mathcal{F}x) \leq S(x, y, z)$$

implies

$$\begin{aligned} & \mathfrak{h}(1, S(\mathcal{F}x, \mathcal{F}y, \mathcal{F}z)) \\ & \leq \mathcal{A} \left(1, \psi \left(\mathfrak{d}(S(x, y, z), S(x, x, \mathcal{F}x), S(y, y, \mathcal{F}y), S(z, z, \mathcal{F}z)) \right) \right). \end{aligned}$$

Hence, $\mathcal{F}$ is is a $S-(\mathcal{A}, \mathfrak{h}, \mathfrak{d}, \psi)$ -Suzuki type contraction mapping. All conditions of Theorem 3.1 hold true. Therefore, $\mathcal{F}$ has a fixed point. Here, $x = 6$ is the unique fixed point of $\mathcal{F}$.

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CONFLICT OF INTERESTS

The author(s) declare that there is no conflict of interests.

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