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A different approach to complex valued G_b-metric spaces

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Abstract

In this work, we introduce a generalized fixed point theorem using a complex *C-class* function as a new tool in complex valued G_b-metric spaces. Moreover, we define $\alpha - (F,\psi,\varphi)$-contractive type and α-admissible mapping. Then we prove a fixed point theorem using these notions and the complex *C-class* function. The obtained results generalize some facts in the literature.

MSC: Primary 47H10; secondary 54H25

Keywords: Fixed point; Complex *C-class* function; Complex valued G_b-metric space

1 Introduction

Fixed point theory has great importance in science and mathematics. Since this area has been developed very fast over the past two decades due to huge applications in various fields such as nonlinear analysis, topology and engineering problems, it has attracted considerable attention from researchers.

In 1989, Bakhtin [1] presented b-metric spaces. Since then, researchers have performed significant studies such as [2–6] in this type metric space. After the complex valued metric space was defined as a new concept, this idea has been used many times. For example, the complex valued b-metric spaces are given in [7]. G-metric spaces [8] have been defined and then researchers have obtained important results (see [9–15]).

After introducing G_b-metric spaces in [16], the Banach and Kannan fixed point theorems [17] were proved for G_b-metric spaces. There are also other significant studies [18–21] on G_b-metric spaces.

In recent times, Ansari [22] has investigated the notion of *C-class* function. He has presented new fixed point results using this function. For some of them, see [23–30].

This paper starts with Sect. 2 which consists of the required background. Then a common fixed point theorem has been proved and a corollary with an illustrating example is presented. After introducing the $\alpha - (F,\psi,\varphi)$-contractive type and α-admissible mapping and complex *C-class* function, we give the proof of a new fixed point theorem.

2 Preliminaries

In this part, some useful notions and facts will be given. A partial order $\precsim$ on $\mathbb{C}$, which is the set of complex numbers, can be defined as follows:

$$\tau_1 \precsim \tau_2 : \quad \Leftrightarrow \quad \Im(\tau_1) \leq \Im(\tau_2) \quad \text{and} \quad \Re(\tau_1) \leq \Re(\tau_2).$$

We write $\tau_1 \precsim \tau_2$ if one of the following holds:

(C_1) $\Im(\tau_1) = \Im(\tau_2)$ and $\Re(\tau_1) = \Re(z_2)$,
(C_2) $\Im(\tau_1) = \Im(\tau_2)$ and $\Re(\tau_1) < \Re(z_2)$,
(C_3) $\Im(\tau_1) < \Im(\tau_2)$ and $\Re(\tau_1) = \Re(z_2)$,
(C_4) $\Im(\tau_1) < \Im(\tau_2)$ and $\Re(\tau_1) < \Re(z_2)$.

We use $\tau_1 \precnsim \tau_2$ if $\tau_1 \neq \tau_2$ and one of (C_2), (C_3) and (C_4) holds and we denote $\tau_1 \prec \tau_2$ if only (C_4) holds.

(1) If $u, v \in \mathbb{R}$ with $u \leq v$, then $u\tau \prec v\tau$ for each $\tau \in \mathbb{C}$.
(2) If $0 \precsim \tau_1 \precnsim \tau_2$, then $|\tau_1| < |\tau_2|$.
(3) If $\tau_1 \precsim \tau_2$ and $\tau_2 \prec \tau_3$, then $\tau_1 \prec \tau_3$.

Definition 2.1 ([17]) For a nonempty set X and a real number $s \geq 1$, if for a map $G : X \times X \times X \to \mathbb{C}$ holds the following:

(CG_b1) $G(\xi_1, \xi_2, \xi_3) = 0$ if $\xi_1 = \xi_2 = \xi_3$,
(CG_b2) $0 \prec G(\xi_1, \xi_1, \xi_2)$ for all $\xi_1, \xi_2 \in X$ with $\xi_1 \neq \xi_2$,
(CG_b3) $G(\xi_1, \xi_1, \xi_2) \precsim G(\xi_1, \xi_2, \xi_3)$ for all $\xi_1, \xi_2, \xi_3 \in X$ with $\xi_2 \neq \xi_3$,
(CG_b4) $G(\xi_1, \xi_2, \xi_3) = G(\rho\{\xi_1, \xi_2, \xi_3\})$, where ρ is a permutation of ξ_1, ξ_2, ξ_3,
(CG_b5) $G(\xi_1, \xi_2, \xi_3) \precsim s(G(\xi_1, \kappa, \kappa) + G(\kappa, \xi_2, \xi_3))$ for all $\xi_1, \xi_2, \xi_3, \kappa \in X$,

we say that G is a complex valued G_b-metric and the pair (X, G) is a complex valued G_b-metric space.

Definition 2.2 ([17]) Let $\{x_n\}$ be a sequence in a complex valued G_b-metric space (X, G).

(1) $\{x_n\}$ is complex valued G_b-convergent to ξ if, for every $\kappa \in \mathbb{C}$ with $0 \prec \kappa$, there is a natural number ω such that $G(\xi, x_n, x_m) \prec \kappa$ for all $n, m \geq \omega$.
(2) $\{x_n\}$ is said to be complex valued G_b-Cauchy if, for every $\kappa \in \mathbb{C}$ with $0 \prec \kappa$, there exists $\omega \in \mathbb{N}$ such that $G(x_n, x_m, x_l) \prec \kappa$ for all $n, m, l \geq \omega$.
(3) (X, G) is called complex valued G_b-complete if every complex valued G_b-Cauchy sequence is complex valued G_b-convergent.

Ege [17] proves that a sequence $\{x_n\}$ in a complex valued G_b-metric space is complex valued G_b-convergent to ξ iff $|G(\xi, x_n, x_m)| \to 0$ as $n, m \to \infty$.

Theorem 2.3 ([17]) *For a sequence $\{x_n\}$ in a complex valued G_b-metric space (X, G), the following statements are equivalent*:

(1) *$\{x_n\}$ is complex valued G_b-convergent to a point ξ.*
(2) *$|G(x_n, x_n, \xi)| \to 0$ as $n \to \infty$.*
(3) *$|G(x_n, \xi, \xi)| \to 0$ as $n \to \infty$.*
(4) *$|G(x_m, x_n, \xi)| \to 0$ as $m, n \to \infty$.*

Theorem 2.4 ([17]) *A sequence $\{x_n\}$ is a complex valued G_b-Cauchy sequence if and only if $|G(x_n, x_m, x_l)| \to 0$ as $n, m, l \to \infty$.*

The notion of a *C-class* function was presented in [22]. For any $\mu, t \in [0,\infty)$, for a continuous function $F : [0,\infty)^2 \to \mathbb{R}$ holds the following:

(i) $F(\mu,\chi) \leq \mu$;

(ii) $F(\mu,\chi) = \mu$ implies that either $\mu = 0$ or $\chi = 0$.

Then F is said to be *C-class* function. $\mathcal{C}$ denotes the class of all C-functions.

Example 2.5 ([22]) The following are examples of *C-class* functions:

(i) $F(\mu,\chi) = \mu - \chi$.

(ii) $F(\mu,\chi) = m\mu$, for some $m \in (0,1)$.

(iii) $F(\mu,\chi) = \frac{\mu}{(1+\chi)^r}$, for a positive real number r.

(iv) $F(\mu,\chi) = (\mu + l)^{(1/(1+\chi)^r)} - l$, where $l > 1$ for $r \in (0,\infty)$.

(v) $F(\mu,\chi) = \mu \log_{\chi+u} u$ for $u > 1$.

Let Φ_u be the class of the continuous functions $\varphi : [0,\infty) \to [0,\infty)$ satisfying $\varphi(\chi) > 0$ for $\chi > 0$ and $\varphi(0) \geq 0$.

Definition 2.6 ([25]) For any $\mu, t \in S = \{z \in \mathbb{C} : 0 \precsim z\}$, if a continuous function $F : S^2 \to \mathbb{C}$ satisfies the following:

(i) $F(\mu,\chi) \precsim \mu$,

(ii) if $F(\mu,\chi) = \mu$, then either $\mu = 0$ or $\chi = 0$,

then it is called a complex *C-class* function. We denote the class of all complex *C-class* functions by the same symbol $\mathcal{C}$.

As an example, we can give the following: Let $S = \{z \in \mathbb{C} : 0 \precsim z\}$.

(1) $F(\mu,\chi) = \phi(\mu)$ where $\phi : S \to S$ is continuous, $\phi(0) = 0$ and $\phi(\chi) \succ 0$ if $\chi \succ 0$.

(2) $F(\mu,\chi) = \mu\beta(\mu)$, where $\beta : [0,\infty) \to [0,1)$ is continuous and $\mu \in S$.

Let Ψ denote the class of continuous functions $\psi : S \to S$ satisfying $\psi(\chi) \succ 0$ iff $\chi \succ 0$ and $\varphi(0) = 0$.

Φ_u will denote the class of continuous functions $\varphi : S \to S$ satisfying $\varphi(\chi) \succ 0$ iff $\chi \succ 0$ and $\varphi(0) \succeq 0$.

Our aim is to give some different generalizations of the following theorems from the literature using C-class functions.

Theorem 2.7 ([18]) *Let $\{T_n\}$ be a sequence of self-mappings of a complete complex valued G_b-metric space (X,G) such that*

$$G\bigl(T_i(x), T_j(y), T_j(z)\bigr) \precsim \beta_{i,j}\bigl[G\bigl(x, T_i(x), T_i(x)\bigr) + G\bigl(y, T_j(y), T_j(z)\bigr)\bigr] + \gamma_{i,j} G(x,y,z)$$

for $x,y,z \in X$ with $x \neq y$, $0 \leq \beta_{i,j}, \gamma_{i,j} < 1$, $i,j = 1,2,\ldots$.

If $\sum_{i=1}^{\infty}(\frac{\beta_{i,i+1}+\gamma_{i,i+1}}{1-\beta_{i,i+1}})$ is an α-series, then $\{T_n\}$ has a unique common fixed point in X.

Theorem 2.8 ([18]) *Let (X,G) be a complete complex valued G_b-metric space and $T : X \to X$ be an $\alpha - \psi$ contractive mapping of type A satisfying the following conditions*:

(i) *T is α-admissible,*

(ii) *There exists $x_0 \in X$ such that $\alpha(x_0, Tx_0, Tx_0) \geq 1$,*

(iii) *If $\{x_n\}$ is a sequence in X such that $\alpha(x_n, x_{n+1}, x_{n+1}) \geq 1$ for all n and $x_n \to x \in X$ as $n \to \infty$, then $\alpha(x_n, x, x_{n+1}) \geq 1$ for all n.*

Consider an element $z \in X$ such that $\alpha(x,z,z) \geq 1$ and $\alpha(y,z,z) \geq 1$ for all $x,y \in X$. Then T has a unique fixed point.

3 Main results

Theorem 3.1 *Let $\{T_n\}$ be a sequence of self-mappings of a complete complex valued G_b-metric space (X,G) such that*

$$\begin{aligned}
&\psi\bigl(G\bigl(T_i(x),T_j(y),T_j(z)\bigr)\bigr) \\
&\quad\precsim F\biggl(\psi\biggl(\frac{1}{\alpha_{i,j}+\beta_{i,j}+\delta_{i,j}}\bigl[\alpha_{i,j}G\bigl(x,T_i(x),T_i(x)\bigr)+\beta_{i,j}G\bigl(y,T_j(y),T_j(z)\bigr) \\
&\qquad+\delta_{i,j}G(x,y,z)\bigr]\biggr), \\
&\qquad\varphi\biggl(\frac{1}{\alpha_{i,j}+\beta_{i,j}+\delta_{i,j}}\bigl[\alpha_{i,j}G\bigl(x,T_i(x),T_i(x)\bigr)+\beta_{i,j}G\bigl(y,T_j(y),T_j(z)\bigr) \\
&\qquad+\delta_{i,j}G(x,y,z)\bigr]\biggr)\biggr)
\end{aligned} \tag{3.1}$$

for $x,y,z \in X$ with $x \neq y$, $0 \leq \alpha_{i,j},\beta_{i,j},\delta_{i,j}$ and $\alpha_{i,j}+\beta_{i,j}+\delta_{i,j} > 0$, $i,j = 1,2,\ldots$, where $\psi \in \Psi$, $F \in C$ and $\varphi \in \Phi_u$. $\{T_n\}$ has a unique common fixed point in X.

Proof Consider a sequence as $x_n = T_n(x_{n-1})$ for an element $x_0 \in X$ where $n = 1,2,\ldots$. If we use (3.1), we obtain

$$\begin{aligned}
&\psi\bigl(G(x_1,x_2,x_2)\bigr) \\
&\quad=\psi\bigl(G\bigl(T_1(x_0),T_2(x_1),T_2(x_1)\bigr)\bigr) \\
&\quad\precsim F\biggl(\psi\biggl(\frac{1}{\alpha_{1,2}+\beta_{1,2}+\delta_{1,2}}\bigl[\alpha_{1,2}G\bigl(x_0,T_1(x_0),T_1(x_0)\bigr)+\beta_{1,2}G\bigl(x_1,T_2(x_1),T_2(x_1)\bigr) \\
&\qquad+\delta_{1,2}G(x_0,x_1,x_1)\bigr]\biggr), \\
&\qquad\varphi\biggl(\frac{1}{\alpha_{1,2}+\beta_{1,2}+\delta_{1,2}}\bigl[\alpha_{1,2}G\bigl(x_0,T_1(x_0),T_1(x_0)\bigr)+\beta_{1,2}G\bigl(x_1,T_2(x_1),T_2(x_1)\bigr) \\
&\qquad+\delta_{1,2}G(x_0,x_1,x_1)\bigr]\biggr)\biggr) \\
&\quad=F\biggl(\psi\biggl(\frac{1}{\alpha_{1,2}+\beta_{1,2}+\delta_{1,2}}\bigl[\alpha_{1,2}G(x_0,x_1,x_1)+\beta_{1,2}G(x_1,x_2,x_2)+\delta_{1,2}G(x_0,x_1,x_1)\bigr]\biggr), \\
&\qquad\varphi\biggl(\frac{1}{\alpha_{1,2}+\beta_{1,2}+\delta_{1,2}}\bigl[\alpha_{1,2}G(x_0,x_1,x_1)+\beta_{1,2}G(x_1,x_2,x_2)+\delta_{1,2}G(x_0,x_1,x_1)\bigr]\biggr)\biggr) \\
&\quad\precsim\psi\biggl(\frac{\alpha_{1,2}+\delta_{1,2}}{\alpha_{1,2}+\beta_{1,2}+\delta_{1,2}}G(x_0,x_1,x_1)+\frac{\beta_{1,2}}{\alpha_{1,2}+\beta_{1,2}+\delta_{1,2}}G(x_1,x_2,x_2)\biggr).
\end{aligned}$$

From the property of F, ψ and monotonocity increasing of ψ, we get

$$G(x_1,x_2,x_2) \precsim G(x_0,x_1,x_1).$$

Moreover, by the following inequalities:

$$
\begin{aligned}
&\psi\bigl(G(x_2,x_3,x_3)\bigr)\\
&\quad= \psi\bigl(G\bigl(T_2(x_1),T_3(x_2),T_3(x_2)\bigr)\bigr)\\
&\quad\precsim F\biggl(\psi\biggl(\frac{1}{\alpha_{2,3}+\beta_{2,3}+\delta_{2,3}}\bigl[\alpha_{2,3}G\bigl(x_1,T_2(x_1),T_2(x_1)\bigr)+\beta_{2,3}G\bigl(x_2,T_3(x_2),T_3(x_2)\bigr)\\
&\qquad+\delta_{2,3}G(x_1,x_2,x_2)\bigr]\biggr),\\
&\qquad\varphi\biggl(\frac{1}{\alpha_{2,3}+\beta_{2,3}+\delta_{2,3}}\bigl[\alpha_{2,3}G\bigl(x_1,T_2(x_1),T_2(x_1)\bigr)+\beta_{2,3}G\bigl(x_2,T_3(x_2),T_3(x_2)\bigr)\\
&\qquad+\delta_{2,3}G(x_1,x_2,x_2)\bigr]\biggr)\biggr)\\
&\quad= F\biggl(\psi\biggl(\frac{1}{\alpha_{2,3}+\beta_{2,3}+\delta_{2,3}}\bigl[\alpha_{2,3}G(x_1,x_2,x_2)+\beta_{2,3}G(x_2,x_3,x_3)+\delta_{2,3}G(x_1,x_2,x_2)\bigr]\biggr),\\
&\qquad\varphi\biggl(\frac{1}{\alpha_{2,3}+\beta_{2,3}+\delta_{2,3}}\bigl[\alpha_{2,3}G(x_1,x_2,x_2)+\beta_{2,3}G(x_2,x_3,x_3)+\delta_{2,3}G(x_1,x_2,x_2)\bigr]\biggr)\biggr)\\
&\quad\precsim \psi\biggl(\frac{\alpha_{2,3}+\delta_{2,3}}{\alpha_{2,3}+\beta_{2,3}+\delta_{2,3}}G(x_1,x_2,x_2)+\frac{\beta_{2,3}}{\alpha_{2,3}+\beta_{2,3}+\delta_{2,3}}G(x_2,x_3,x_3)\biggr),
\end{aligned}
$$

we obtain

$$G(x_2,x_3,x_3)\precsim G(x_1,x_2,x_2).$$

If the same procedure is applied repeatedly

$$
\begin{aligned}
\psi\bigl(G(x_n,x_{n+1},x_{n+1})\bigr) &= \psi\bigl(G\bigl(T_n(x_{n-1}),T_{n+1}(x_n),T_{n+1}(x_n)\bigr)\bigr)\\
&\precsim F\biggl(\psi\biggl(\frac{1}{\alpha_{n,n+1}+\beta_{n,n+1}+\delta_{n,n+1}}\bigl[\alpha_{n,n+1}G\bigl(x_{n-1},T_n(x_{n-1}),T_n(x_{n-1})\bigr)\\
&\quad+\beta_{n,n+1}G\bigl(x_n,T_{n+1}(x_n),T_{n+1}(x_n)\bigr)+\delta_{n,n+1}G(x_{n-1},x_n,x_n)\bigr]\biggr),\\
&\quad\varphi\biggl(\frac{1}{\alpha_{n,n+1}+\beta_{n,n+1}+\delta_{n,n+1}}\bigl[G\bigl(x_{n-1},T_n(x_{n-1}),T_n(x_{n-1})\bigr)\\
&\quad+\beta_{n,n+1}G\bigl(x_n,T_{n+1}(x_n),T_{n+1}(x_n)\bigr)+\delta_{n,n+1}G(x_{n-1},x_n,x_n)\bigr]\biggr)\biggr)\\
&= F\biggl(\psi\biggl(\frac{1}{\alpha_{n,n+1}+\beta_{n,n+1}+\delta_{n,n+1}}\bigl[\alpha_{n,n+1}G(x_{n-1},x_n,x_n)\\
&\quad+\beta_{n,n+1}G(x_n,x_{n+1},x_{n+1})+\delta_{n,n+1}G(x_{n-1},x_n,x_n)\bigr]\biggr),\\
&\quad\varphi\biggl(\frac{1}{\alpha_{n,n+1}+\beta_{n,n+1}+\delta_{n,n+1}}\bigl[\alpha_{n,n+1}G(x_{n-1},x_n,x_n)\\
&\quad+\beta_{n,n+1}G(x_n,x_{n+1},x_{n+1})+\delta_{n,n+1}G(x_{n-1},x_n,x_n)\bigr]\biggr)\biggr),
\end{aligned}
\tag{3.2}
$$

we get $G(x_n, x_{n+1}, x_{n+1}) \precsim G(x_{n-1}, x_n, x_n)$. Thus $\{G(x_n, x_{n+1}, x_{n+1})\}$ is a decreasing sequence in $\mathbb{C}$. So we say that it is G_b-convergent to $0 \preceq \chi \in \mathbb{C}$. We assert that $\chi = 0$. To show this, assume that $\chi \succ 0$. If we take the limit of (3.2), we get

$$\begin{aligned}\psi(\chi) \precsim F\biggl(&\psi\biggl(\frac{1}{\alpha_{n,n+1} + \beta_{n,n+1} + \delta_{n,n+1}}[\alpha_{n,n+1}\chi + \beta_{n,n+1}\chi + \delta_{n,n+1}\chi]\biggr),\\ &\varphi\biggl(\frac{1}{\alpha_{n,n+1} + \beta_{n,n+1} + \delta_{n,n+1}}[\alpha_{n,n+1}\chi + \beta_{n,n+1}\chi + \delta_{n,n+1}\chi]\biggr)\biggr)\\ = {}& F\bigl(\psi(\chi), \varphi(\chi)\bigr)\end{aligned}$$

which implies $\psi(\chi) = 0$ or $\varphi(\chi) = 0$, namely $\chi = 0$. But this is a contradiction. So $\chi = 0$. i.e.,

$$\lim_{n\to\infty} G(x_n, x_{n+1}, x_{n+1}) = 0. \tag{3.3}$$

We will show that the sequence $\{x_n\}$ is a G_b-Cauchy by assuming the contrary. If we use (3.1), we obtain

$$\begin{aligned}\psi\bigl(G(x_n, x_m, x_m)\bigr) &= \psi\bigl(G\bigl(T_n(x_{n-1}), T_m(x_{m-1}), T_m(x_{m-1})\bigr)\bigr)\\ &\precsim F\biggl(\psi\biggl(\frac{1}{\alpha_{n,m} + \beta_{n,m} + \delta_{n,m}}\bigl[\alpha_{n,m}G\bigl(x_{n-1}, T_n(x_{n-1}), T_n(x_{n-1})\bigr)\\ &\quad + \beta_{n,m}G\bigl(x_{m-1}, T_m(x_{m-1}), T_m(x_{m-1})\bigr) + \delta_{n,m}G(x_{n-1}, x_{m-1}, x_{m-1})\bigr]\biggr),\\ &\quad \varphi\biggl(\frac{1}{\alpha_{n,m} + \beta_{n,m} + \delta_{n,m}}\bigl[\alpha_{n,m}G\bigl(x_{n-1}, T_n(x_{n-1}), T_n(x_{n-1})\bigr)\\ &\quad + \beta_{n,m}G\bigl(x_{m-1}, T_m(x_{m-1}), T_m(x_{m-1})\bigr) + G(x_{n-1}, x_{m-1}, x_{m-1})\bigr]\biggr)\biggr)\\ &= F\biggl(\psi\biggl(\frac{1}{\alpha_{n,m} + \beta_{n,m} + \delta_{n,m}}\bigl[\alpha_{n,m}G(x_{n-1}, x_n, x_n)\\ &\quad + \beta_{n,m}G(x_{m-1}, x_m, x_m) + \delta_{n,m}G(x_{n-1}, x_{m-1}, x_{m-1})\bigr]\biggr),\\ &\quad \varphi\biggl(\frac{1}{\alpha_{n,m} + \beta_{n,m} + \delta_{n,m}}\bigl[\alpha_{n,m}G(x_{n-1}, x_n, x_n)\\ &\quad + \beta_{n,m}G(x_{m-1}, x_m, x_m) + G(x_{n-1}, x_{m-1}, x_{m-1})\bigr]\biggr)\biggr).\end{aligned}$$

Using the same procedure, we get

$$\begin{aligned}\psi(\varepsilon) \precsim F\biggl(&\psi\biggl(\frac{1}{\alpha_{n,m} + \beta_{n,m} + \delta_{n,m}}[\alpha_{n,m}\varepsilon + \beta_{n,m}\varepsilon + \delta_{n,m}\varepsilon]\biggr),\\ &\varphi\biggl(\frac{1}{\alpha_{n,m} + \beta_{n,m} + \delta_{n,m}}[\alpha_{n,m}\varepsilon + \beta_{n,m}\varepsilon + \delta_{n,m}\varepsilon]\biggr)\biggr)\\ = {}& F\bigl(\psi(\varepsilon), \varphi(\varepsilon)\bigr),\end{aligned}$$

which implies $\psi(\varepsilon) = 0$ or $\varphi(\varepsilon) = 0$. Namely, $\varepsilon = 0$ but this is a contradiction. So $\{x_n\}$ is a complex valued G_b-Cauchy sequence. By the G_b-completeness of X, $\{x_n\}$ converges to an element ν in X. From (3.1), we have

$$\begin{aligned}
\psi\bigl(G\bigl(x_n, T_m(\nu), T_m(\nu)\bigr)\bigr) &= \psi\bigl(G\bigl(T_n(x_{n-1}), T_m(\nu), T_m(\nu)\bigr)\bigr) \\
&\precsim F\biggl(\psi\biggl(\frac{1}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}\bigl[\alpha_{n,m}G\bigl(x_{n-1}, T_n(x_{n-1}), T_n(x_{n-1})\bigr) \\
&\quad + \beta_{n,m}G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr) + \delta_{n,m}G(x_{n-1}, \nu, \nu)\bigr]\biggr), \\
&\quad \varphi\biggl(\frac{1}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}\bigl[\alpha_{n,m}G\bigl(x_{n-1}, T_n(x_{n-1}), T_n(x_{n-1})\bigr) \\
&\quad + \beta_{n,m}G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr) + \delta_{n,m}G(x_{n-1}, \nu, \nu)\bigr]\biggr)\biggr) \\
&= F\biggl(\psi\biggl(\frac{1}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}\bigl[\alpha_{n,m}G(x_{n-1}, x_n, x_n) \\
&\quad + \beta_{n,m}G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr) + \delta_{n,m}G(x_{n-1}, \nu, \nu)\bigr]\biggr), \\
&\quad \varphi\biggl(\frac{1}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}\bigl[\alpha_{n,m}G(x_{n-1}, x_n, x_n) \\
&\quad + \beta_{n,m}G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr) + \delta_{n,m}G(x_{n-1}, \nu, \nu)\bigr]\biggr)\biggr)
\end{aligned}$$

for every positive integer m. If we take the limit as $n \to \infty$ and use (CG_b1), we have

$$\begin{aligned}
\psi\bigl(G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr)\bigr) &\precsim F\biggl(\psi\biggl(\frac{1}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}\bigl[\alpha_{n,m}G(\nu, \nu, \nu) \\
&\quad + \beta_{n,m}G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr) + \delta_{n,m}G(\nu, \nu, \nu)\bigr]\biggr), \\
&\quad \varphi\biggl(\frac{1}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}\bigl[\alpha_{n,m}G(\nu, \nu, \nu) \\
&\quad + \beta_{n,m}G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr) + \delta_{n,m}G(\nu, \nu, \nu)\bigr]\biggr)\biggr) \\
&= F\biggl(\psi\biggl(\frac{\beta_{n,m}}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr)\biggr), \\
&\quad \varphi\biggl(\frac{\beta_{n,m}}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr)\biggr)\biggr),
\end{aligned}$$

which implies

$$\begin{aligned}
&\psi\biggl(\frac{\beta_{n,m}}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr)\biggr) = 0 \quad \text{or} \\
&\varphi\biggl(\frac{\beta_{n,m}}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}G\bigl(\nu, T_m(\nu), T_m(\nu)\bigr)\biggr) = 0.
\end{aligned}$$

That is, $\frac{\beta_{n,m}}{\alpha_{n,m}+\beta_{n,m}+\delta_{n,m}}G(\nu, T_m(\nu), T_m(\nu)) = 0$, we deduce that $T_m(\nu) = \nu$. Therefore, ν is a common fixed point of $\{T_m\}$.

We now prove the uniqueness. Assume that u is a different common fixed point of $\{T_m\}$ where $u \neq v$. Then (3.1) gives the following result:

$$\begin{aligned}
\psi\big(G(v,u,u)\big) &= \psi\big(G\big(T_m(v),T_m(u),T_m(u)\big)\big) \\
&\precsim F\biggl(\psi\biggl(\frac{1}{\alpha_{m,m}+\beta_{m,m}+\delta_{m,m}} \\
&\quad \times \bigl[\alpha_{m,m}G\big(v,T_m(v),T_m(v)\big)+\beta_{m,m}G\big(u,T_m(u),T_m(u)\big) \\
&\quad + \delta_{m,m}G(v,u,u)\bigr]\biggr), \\
&\quad \varphi\biggl(\frac{1}{\alpha_{m,m}+\beta_{m,m}+\delta_{m,m}} \\
&\quad \times \bigl[\alpha_{m,m}G\big(v,T_m(v),T_m(v)\big)+\beta_{m,m}G\big(u,T_m(u),T_m(u)\big) \\
&\quad + \delta_{m,m}G(v,u,u)\bigr]\biggr)\biggr).
\end{aligned}$$

By the limit as $m \to \infty$, we obtain

$$\begin{aligned}
&\psi\big(G(v,u,u)\big) \\
&\quad \precsim F\biggl(\psi\biggl(\frac{1}{\alpha_{m,m}+\beta_{m,m}+\delta_{m,m}}\bigl[\alpha_{m,m}G(v,v,v)+\beta_{m,m}G(u,u,u)+\delta_{m,m}G(v,u,u)\bigr]\biggr), \\
&\qquad \varphi\biggl(\frac{1}{\alpha_{m,m}+\beta_{m,m}+\delta_{m,m}}\bigl[\alpha_{m,m}G(v,v,v)+\beta_{m,m}G(u,u,u)+\delta_{m,m}G(v,u,u)\bigr]\biggr)\biggr) \\
&\quad = F\biggl(\psi\biggl(\frac{\beta_{m,m}}{\alpha_{m,m}+\beta_{m,m}+\delta_{m,m}}G(v,u,u)\biggr),\varphi\biggl(\frac{\beta_{m,m}}{\alpha_{m,m}+\beta_{m,m}+\delta_{m,m}}G(v,u,u)\biggr)\biggr),
\end{aligned}$$

which implies $\psi(\frac{\beta_{m,m}}{\alpha_{m,m}+\beta_{m,m}+\delta_{m,m}}G(v,u,u)) = 0$ or $\varphi(\frac{\beta_{m,m}}{\alpha_{m,m}+\beta_{m,m}+\delta_{m,m}}G(v,u,u)) = 0$. As a result, we have $v = u$. This completes the proof. □

Taking $F(\mu,\chi) = \mu\eta(\mu)$, where $\eta : [0,\infty) \to [0,1)$ is continuous function and $\mu \in S = \{z \in \mathbb{C} : 0 \precsim z\}$ in Theorem 3.1, we have the following.

Corollary 3.2 *Let $\{T_n\}$ be a sequence of self-mappings of complex valued G_b-complete metric space (X,G) such that*

$$\begin{aligned}
&\psi\big(G\big(T_i(x),T_j(y),T_j(z)\big)\big) \\
&\quad \precsim \psi\biggl(\frac{1}{\alpha_{i,j}+\beta_{i,j}+\delta_{i,j}}\bigl[\alpha_{i,j}G\big(x,T_i(x),T_i(x)\big)+\beta_{i,j}G\big(y,T_j(y),T_j(z)\big) \\
&\qquad + \delta_{i,j}G(x,y,z)\bigr]\biggr)\eta\biggl(\psi\biggl(\frac{1}{\alpha_{i,j}+\beta_{i,j}+\delta_{i,j}}\bigl[\alpha_{i,j}G\big(x,T_i(x),T_i(x)\big) \\
&\qquad + \beta_{i,j}G\big(y,T_j(y),T_j(z)\big)+\delta_{i,j}G(x,y,z)\bigr]\biggr)\biggr) \qquad (3.4)
\end{aligned}$$

for $x,y,z \in X$ with $x \neq y$, $0 \leq \alpha_{i,j},\beta_{i,j},\delta_{i,j}$ and $\alpha_{i,j}+\beta_{i,j}+\delta_{i,j} > 0$, $i,j = 1,2,\ldots$, where $\eta : [0,\infty) \to [0,1)$ is continuous and $\psi \in \Psi$. Then $\{T_n\}$ has a unique common fixed point in X.

Example 3.3 Consider the set $X = [-1, 1]$. (X, G) is a complex valued G_b-metric space [17] where $G : X \times X \times X \to \mathbb{C}$ is defined for all $u, v, w \in X$ as follows:

$$G(u, v, w) = \bigl(|u - v| + |v - w| + |w - u|\bigr)^2.$$

Let $S = \{z \in \mathbb{C} : 0 \precsim z\}$. Define the following maps:

- $F : X \times X \to X$ with $F(\mu, \chi) = \frac{\mu}{2} i$, where $\mu \in S$.
- $T_n(u) = u$ for all $n \in \mathbb{N}$ and $u \in X$.
- $\psi : S \to S$ with $\psi(\mu) = \mu$.

Then $\{T_n\}$ satisfies (3.1) for $u, v, w \in X$ with $u \neq v$, $0 \le \alpha_{i,j}, \beta_{i,j}, \delta_{i,j}$ and $\alpha_{i,j} + \beta_{i,j} + \delta_{i,j} > 0$, where $i, j = 1, 2, \dots$. 0 is the unique common fixed point of $\{T_n\}$.

Let us define the $\alpha - (F, \psi, \varphi)$-contractive self-mapping as a new concept in complex valued G_b-metric space.

Definition 3.4 Let (X, G) be a complex valued G_b-metric space. A mapping $T : X \to X$ is called $\alpha - (F, \psi, \varphi)$-contractive mapping of type A if there exist functions $\alpha : X \times X \times X \to [0, \infty)$, $F \in C$, $\psi \in \Psi$ (which has a property such that $\lim_{n\to\infty} \psi^n(t) = 0$ for $t \in \mathbb{C}$) and $\varphi \in \Phi_u$ such that

$$\begin{aligned} &\alpha(x, y, Tx)\psi\bigl(G\bigl(Tx, Ty, T^2x\bigr)\bigr) \\ &\quad \precsim F\bigl(\psi\bigl(G(x, y, Tx)\bigr), \varphi\bigl(G(x, y, Tx)\bigr)\bigr) \quad \text{for all } x, y, z \in X. \end{aligned} \tag{3.5}$$

Definition 3.5 ([18]) Let (X, G) be a complex valued G_b-metric space and $\alpha : X \times X \times X \to [0, \infty)$ be a given mapping. A mapping $T : X \to X$ is said to be α-admissible if $x, y \in X$, $\alpha(x, y, z) \ge 1$ implies $\alpha(Tx, Ty, Tz) \ge 1$.

Theorem 3.6 *Suppose that (X, G) is a complex valued G_b-complete metric space. Let $T : X \to X$ be an $\alpha - (F, \psi, \varphi)$-contractive mapping of type A and satisfy the following*:

(i) *T is α-admissible*,
(ii) *there is an element x_0 in X such that $\alpha(x_0, Tx_0, Tx_0) \ge 1$*,
(iii) *if a sequence $\{x_n\}$ in X satisfies $\alpha(x_n, x_{n+1}, x_{n+1}) \ge 1$ for all n and $x_n \to x \in X$ as $n \to \infty$, then $\alpha(x_n, x, x_{n+1}) \ge 1$ for all n.*

T has a unique fixed point if there is an element $z \in X$ such that $\alpha(x, z, z) \ge 1$ and $\alpha(y, z, z) \ge 1$ for all $x, y \in X$.

Proof Assume that there is an element $x_0 \in X$ such that $\alpha(x_0, Tx_0, Tx_0) \ge 1$. Consider a sequence $\{x_n\}$ in X defined as $x_{n+1} = Tx_n$. If $x_n = x_{n+1}$ for some $n \in \mathbb{N}$, since x_n is a fixed point for T, we assume that $x_n \neq x_{n+1}$ for all $n \in \mathbb{N}$.

Using (i), we obtain $\alpha(x_0, x_1, x_1) = \alpha(x_0, Tx_0, Tx_0) \ge 1$ implies that $\alpha(Tx_0, Tx_1, Tx_1) = \alpha(x_1, x_2, x_2) \ge 1$. From induction

$$\alpha(x_n, x_{n+1}, x_{n+1}) \ge 1 \quad \text{for all } n \in \mathbb{N}. \tag{3.6}$$

Since

$$G(x_n, x_{n+1}, x_{n+1}) = G(Tx_{n-1}, Tx_n, Tx_n) = G\bigl(Tx_{n-1}, Tx_n, T^2x_{n-1}\bigr)$$

and by Definition 3.4, we get

$$\begin{aligned}\psi\big(G(x_n,x_{n+1},x_{n+1})\big) &\precsim \alpha(x_{n-1},x_n,x_n)\psi\big(G(x_n,x_{n+1},x_{n+1})\big)\\ &= \alpha(x_{n-1},x_n,x_n)\psi\big(G\big(Tx_{n-1},Tx_n,T^2x_{n-1}\big)\big)\\ &\precsim F\big(\psi\big(G(x_{n-1},x_n,x_n)\big),\varphi\big(G(x_{n-1},x_n,x_n)\big)\big)\\ &\precsim \psi\big(G(x_{n-1},x_n,x_n)\big).\end{aligned}$$

Therefore we get $\psi(G(x_n,x_{n+1},x_{n+1}))\precsim\psi(G(x_{n-1},x_n,x_n))$ as $\alpha(x_{n-1},x_n,x_n)\geq 1$. Since ψ is non-decreasing, we conclude

$$G(x_n,x_{n+1},x_{n+1})\precsim G(x_{n-1},x_n,x_n)\quad\text{for all } n\geq 1. \tag{3.7}$$

Hence $\{G(x_n,x_{n+1},x_{n+1})\}$ is the decreasing sequence in $\mathbb{C}$ and so it is G_b-convergent to $0\preceq\chi\in\mathbb{C}$.

We will show that $\chi=0$. Suppose, to the contrary, that $\chi\succ 0$. The limit case in (3.2) shows that

$$\psi(\chi)\precsim F\big(\psi(\chi),\varphi(\chi)\big),$$

which implies $\psi(\chi)=0$ or $\varphi(\chi)=0$. Namely, $\chi=0$. But it is a contradiction. Thus, $\chi=0$. i.e.,

$$\lim_{n\to\infty}G(x_n,x_{n+1},x_{n+1})=0. \tag{3.8}$$

By (CG_b5) and (3.7), we get

$$\begin{aligned}G(x_n,x_p,x_p) &\precsim s\big[G(x_n,x_{n+1},x_{n+1})\big]+s^2\big[G(x_{n+1},x_{n+2},x_{n+2})\big]+\cdots+s^{p-n}\big[G(x_{p-1},x_p,x_p)\big]\\ &\precsim \sum_{k=n}^{p-1}s^{k-n+1}G(x_k,x_{k+1},x_{k+1})\\ &\quad\vdots\\ &\precsim \sum_{k=n}^{p-1}s^{k-n+1}G(x_0,x_1,x_1)\end{aligned}$$

and consequently from (3.8)

$$\lim_{n,p\to\infty}\big|G(x_n,x_p,x_p)\big|=0.$$

The sequence $\{x_n\}$ is a complex valued G_b-Cauchy. Since (X,G) is a complex valued G_b-complete, there is an element $\upsilon^*\in X$ such that $x_n\to\upsilon^*$ as $n\to\infty$. Considering (3.6) and (iii), then we obtain

$$\alpha\big(x_n,\upsilon^*,\upsilon^*\big)\geq 1\quad\text{for all } n\geq 0. \tag{3.9}$$

By (3.5) and (3.9), we find

$$\begin{aligned} G(x_{n+1}, T\upsilon^*, x_{n+2}) &= G(Tx_n, T\upsilon^*, T^2x_n) \\ &\precsim \alpha(x_n, \upsilon^*, x_{n+1})G(Tx_n, T\upsilon^*, T^2x_n) \\ &\precsim F(\psi(G(x_n, \upsilon^*, x_{n+1})), \varphi(G(x_n, \upsilon^*, x_{n+1}))) \\ &\precsim \psi(G(x_n, \upsilon^*, x_{n+1})). \end{aligned}$$

Taking the limit,

$$G(\upsilon^*, T\upsilon^*, \upsilon^*) \precsim \psi(G(\upsilon^*, \upsilon^*, \upsilon^*)).$$

From Theorem 2.3 and (CG_b1), we have

$$\lim_{n\to\infty} |G(\upsilon^*, T\upsilon^*, \upsilon^*)| = 0$$

as ψ is continuous at $\chi = 0$. As a result, $\upsilon^* = T\upsilon^*$.

To complete the proof, we show the uniqueness. Suppose that $\vartheta^* \neq \upsilon^*$ is another fixed point of T. Then there is a point $z \in X$ such that $\alpha(\upsilon^*, \upsilon^*, z) \geq 1$ and $\alpha(\vartheta^*, \vartheta^*, z) \geq 1$. By induction and (i), we have

$$\alpha(\upsilon^*, \upsilon^*, T^n z) \geq 1 \quad \text{and} \quad \alpha(\vartheta^*, \vartheta^*, T^n z) \geq 1 \tag{3.10}$$

for all $n = 1, 2, \ldots$. Equations (3.5) and (3.10) give the following result:

$$\begin{aligned} G(\upsilon^*, T^n z, \upsilon^*) &= G(T\upsilon^*, T(T^{n-1}z), T^2\upsilon^*) \\ &\precsim \alpha(\upsilon^*, T^{n-1}z, T\upsilon^*)G(T\upsilon^*, T(T^{n-1}z), T^2\upsilon^*) \\ &\precsim F(\psi(G(\upsilon^*, T^{n-1}z, T\upsilon^*)), \varphi(G(\upsilon^*, T^{n-1}z, T\upsilon^*))) \\ &\precsim \psi(G(\upsilon^*, T^{n-1}z, T\upsilon^*)) \\ &= \psi(G(\upsilon^*, T^{n-1}z, \upsilon^*)). \end{aligned}$$

Using induction, we get

$$G(\upsilon^*, T^n z, \upsilon^*) \precsim \psi^n(G(\upsilon^*, z, \upsilon^*))$$

for all natural numbers n. From (CG_b4), we obtain $G(\upsilon^*, \upsilon^*, T^n z) \precsim \psi^n(G(\upsilon^*, \upsilon^*, z))$. Taking the limit, we observe

$$|G(\upsilon^*, \upsilon^*, T^n z)| = 0.$$

So $\{T^n z\}$ is G_b-convergent to υ^*. It can be observed that $\{T^n z\}$ is G_b-convergent to ϑ^*. The uniqueness of the limit gives $\upsilon^* = \vartheta^*$. As a result, T has a unique fixed point. □

4 Conclusions

We have introduced a generalized fixed point theorem using the complex *C-class* function as a new tool in complex valued G_b-metric spaces. Moreover, we have defined an $\alpha - (F, \psi, \varphi)$-contractive type and α-admissible mapping. Then we have proved a fixed point theorem using these notions and the complex *C-class* function. The obtained results generalize some facts in the literature.

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