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CODEN: IJRSFP (USA)

International Journal of Recent Scientific Research
Vol. 10, Issue, 05(D), pp. 32397-32401, May, 2019

ISSN: 0976-3031

International Journal of Recent Scientific Research

DOI: 10.24327/IJRSR

Research Article

COMMON FIXED POINT RESULTS FOR GENERALIZED CONTRACTION MAPPINGS IN B - METRIC SPACE

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DOI: http://dx.doi.org/10.24327/ijrsr.2019.1005.3462

ARTICLE INFO

Article History:
Received 15th February, 2019
Received in revised form 7th March, 2019
Accepted 13th April, 2019
Published online 28th May, 2019

Key Words:

Fixed Point, Common fixed point theorem, rational contraction, complete b-Metric Space.

ABSTRACT

In this paper, we establish and prove common fixed point results for generalized rational mapping satisfying a general contractive condition in complete b- metric spaces. The conditions for existence of common fixed point had been investigated. The main results can be regarded as a generalization of previous results in complete b-metric space.

INTRODUCTION

Fixed point theory is rapidly moving into the mainstream of Mathematics mainly because of its applications in diverse fields which include numerical methods like Newton-Raphson method, establishing Picard's existence theorem, existence of solution of integral equations and a system of linear equations.

In 1922, S. Banach [1], The first important and significant result was proved a fixed point theorem for contraction mappings in complete metric space and also called it Banach fixed point theorem / Banach contraction principle which is considered as the mile stone in fixed point theory. This theorem states that, A mapping $T: X \rightarrow X$ where(X, d) is a metric space, is said to be a contraction if there exists $k \in [0,1)$ such that

$$d(Tx, Ty) \leq kd(x, y) \text{ for all } x, y \in X \quad (1.1)$$

If the metric space (X, d) is complete the mapping satisfying (1.1) has a unique fixe point.

i.e every contraction map on a complete metric space has fixed point. Inequality (1.1) implies continuity of T. This theorem is very popular and effective tool in solving existence problems in many branches of mathematical analysis and engineering. There are a lot of generalizations of this principle has been obtained in several directions, such as ordered Banach spaces(see[2]), partially ordered metric spaces (see[3,4]), 2-metric spaces(see[5,6,7]), Quasi –metric spaces(see[8]), Cone metric spaces(see[9]), metric type spaces(see[10,11,12]), G-metric spaces(see[13]), fuzzy metric spaces(see[14]), B-metric spaces(see[15,16]).

One of the most influential spaces is b-metric spaces, introduced by Bakhtin[17] in 1989, who used it to prove a generalization of the Banach principle. In 1993, Czerwik [18,19] extended the results of b-metric spaces that generalized the famous Banach contraction principle in metric space. Using this idea researcher presented generalization of the renowned Banach fixed point theorem in the b-metric space. Akkoochi, M.[20], Ayadi, *et al.*[21], Boriceanu[22], Mehmetkir *et al.*[23],Olatinwo, *et al.* [24], Pacurar [25] extended the fixed point theorem in b-metric space. A b- metric space was also called a metric type spaces in [26]. The fixed point theory in metric type spaces was investigated in [26] and [11].Recently, Pankaj *et al.* [27] gave some results related fixed point theorem in b-metric spaces. They have shown the extension theorem given by Reich [28], and Hardy and Rogers [29] to the b-metric spaces. In sequel, A.K. Dubey *et al.*[30] obtained unique fixed point results in b- metric spaces, which is generalized results of [31]. Siqi Xie,*et al.*[32], proved some fixed point theorems in b- metric spaces and give the example. In 2018,

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IsaYildirim and A. H. Ansari [33], proved some new fixed point results in b-metric spaces.

The aim of this paper is to consider and establish results on the setting of b- metric spaces, regarding common fixed point of two mappings, using a generalized rational contraction.

The Preliminaries

In this section, at first, we recall some definitions and properties of their in b- metric spaces:

Definition 2.1([(17] & [21]): Let X be a non empty set and $s \geq 1$ be a given real number. A function $d: X \times X \to R_{+,}$ is called a b- metric provided that, for all $x, y, z \in X$,

1. $d(x,y) = 0$ iff $x = y$,
2. $d(x,y) = d(y,x)$,
3. $d(x,z) \leq s[d(x,y) + d(y,z)]$ .Then

A pair (X,d) is called a b-metric space. It is clear that definition of b-metric space is a extension of usual metric space.

Example2.2 (see [22]): The spacel_p $(0 < P < 1)$,

l_p $=\{(x_n) c\, R: \sum_{n=1}^{\infty} |x_n|^p < \infty\}$, together with the function$d: l_p \times l_p \to R$,

$d(x,y) = (\sum_{n=1}^{\infty} |x_n - y_n|^p)^{\frac{1}{p}}$, where $x = x_n, y = y_n \in l_p$ is a b-metric space. By an elementary calculation we obtain that

$d(x,z) \leq 2^{\frac{1}{p}}[d(x,y) + d(y,z)]$.

Example2.3 (see [21]): Let $X = \{0,1,2\}$ and $d(2,0) = d(0,2) = m \geq 2$,

$d(0,1) = d(1,2) = d(1,0) = d(2,1) = 1$ *and* $d(0,0) = d(1,1) = d(2,1) = 0$.

Then

$d(x,y) \leq \frac{m}{2}[d(x,z) + d(z,y)]$ for all $x, y, z \in X$. If$m > 2$ then the triangle inequality does not hold.

Example2.4 (see [22]): The l_p [0, 1] where $(0 < p < 1)$ of all real functions$x(t), t \in [0,1]$ such that $\int_0^1 |x(t)|^p\, dt < \infty$, is a b-metric space if we take

$d(x,y) = (\int_0^1 |x(t) - y(t)|^p dt)^{\frac{1}{p}}$, for each $x, y \in l_p[0,1]$.

Definition 2.5[22] (i) Let (X,d)be a b-metric space. Then a sequence $\{x_n\}$ in X is called a Cauchy sequence if and only if for all $\epsilon > 0$ there exists $n(\epsilon) \in N$ such that for each $n, m \geq n(\epsilon)$ we have $d(x_n, x_m) < \varepsilon$.

(ii) Let (X,d)be a b-metric space. Then a sequence $\{x_n\}$ in X is called a Convergent sequence if and only if there exists $x \in X$such that for all there exists $n(\epsilon) \in N$ such that for all $n, \geq n(\epsilon)$we have $d(x_n, x) < \varepsilon$.In this case $\lim_{n\to\infty} x_n = x$.
(iii) The b-metric space is complete if every Cauchy sequence convergent.

Regarding the properties of a b- metric space, we recall that if thev limit of a convergent sequence exist, then it is unique.Also, each convergent sequence is a Cauchy sequence. But note that a b- metric, in general case, is not continuous.

The continuity of a mapping with respect to a b- metric defined as follow:

Definition 2.6[32]: Let (X,d) and (X', d') be two b- metric spaces with s and s, respectively. A mapping $f: X \to X'$ is called continuous if for each sequence$\{x_n\}$ in X, Which converges to $x \in X$ with respect to d, then$f x_n$ converges to fx with respect to d'.

MAIN RESULTS

In this section, we shall prove common fixed point results for pair of mappings in b- metric spaces.

Theorem 3.1: Let (X,d)be a complete b-metric space with $s \geq 1$and $T_1, T_2: X \to X$be a self mappings satisfies the conditions

$$sd(T_1x, T_2y) \leq ad(x,y) + b\frac{d(x,T_1x)d(T_1x,T_2y)}{1+d(y,T_2y)} \quad (3.1)$$

Where a, b are nonnegative real with $a < \frac{1}{s}, a + b \leq \frac{2}{2+s}$, for all$x, y \in X$. then T_1 *and* T_2 have a unique common fixed point.

Proof: Let $x_0 \in X$ and define sequence $\{x_n\}$ in X such that

$x_{2k+1} = T_1 x_{2k}$ and

$$x_{2k+2} = T_2 x_{2k+1} \text{ for all } k \in N \quad (3.2)$$

Suppose that there is some $k \in N$ such that $x_k = x_{k+1}$. If $k = 2n$. Then $x_{2n} = x_{2n+1}$ and from the condition (3.1) put $x = x_{2n}, y = x_{2n+1}$, we have

$$sd(x_{2n+1}, x_{2n+2}) = sd(T_1x_{2n,}T_2x_{2n+1}) \leq ad(x_{2n}, x_{2n+1}) + b\frac{d(x_{2n},T_1x_{2n})d(T_1x_{2n},T_2x_{2n+1})}{1+d(x_{2n+1},T_2x_{2n+1})} = ad(x_{2n}, x_{2n+1}) + b\frac{d(x_{2n},x_{2n+1})d(x_{2n+1},x_{2n+2})}{1+d(x_{2n+1},x_{2n+2})} = 0.$$

Since $s \geq 1$, we have $d(x_{2n+1,}x_{2n+2}) = 0$. Hence $x_{2n+1} = x_{2n+2}$. Thus we have

$x_{2n} = x_{2n+1} = x_{2n+2}$. By (3.2), it means $x_{2n} = T_1x_{2n} = T_2x_{2n}$, that is, x_{2n} is a common fixed point of $T_1$and T_2.
If $k = 2n + 1$, then using the same argument as in the case$x_{2n} = x_{2n+1}$, it can be show that x_{2n+1} is a common fixed point of $T_1$and T_2.

From now on, we suppose that $x_k \neq x_{k+1}$ for all $k \in N$.

Step1: we will show that

$$\lim_{n\to+\infty} d(x_k, x_{k+1}) = 0, \text{ for all } k \in N. \quad (3.3)$$

There are two cases which we have to consider.

Case1. $k = 2n + 1$, $n \in N$.
From the condition (3.1) where $x = x_{2n}, y = x_{2n+1}$ we have

$$sd(x_{2n+1}, x_{2n+2}) = sd(T_1x_{2n,}T_2x_{2n+1}) \leq ad(x_{2n}, x_{2n+1}) + b\frac{d(x_{2n},T_1x_{2n})d(T_1x_{2n},T_2x_{2n+1})}{1+d(x_{2n+1},T_2x_{2n+1})} = ad(x_{2n}, x_{2n+1}) + b\frac{d(x_{2n},x_{2n+1})d(x_{2n+1},x_{2n+2})}{1+d(x_{2n+1},x_{2n+2})}$$

$\leq ad(x_{2n}, x_{2n+1}) + b\frac{d(x_{2n},x_{2n+1})d(x_{2n+1},x_{2n+2})}{d(x_{2n+1},x_{2n+2})}$

$= ad(x_{2n}, x_{2n+1}) + bd(x_{2n}, x_{2n+1})$

$\leq (a + b)d(x_{2n}, x_{2n+1})$

$\leq \frac{2}{2+s} d(x_{2n}, x_{2n+1}).$

Thus we proved that

$sd(x_k, x_{k+1}) \leq \frac{2}{2+s} d(x_{k-1}, x_k), k = 2n + 1, n \in N.$ (3.4)

Case 2. $k = 2n, \quad n \in N.$

Using the same argument as in the Case 1, it it can be proved that (3.3) holds for $k = 2n$, that is

$sd(x_k, x_{k+1}) \leq \frac{2}{2+s} d(x_{k-1}, x_k)$,foralln $\in N.$ (3.5)

From (3.4) and (3.5) we can conclude that

$sd(x_k, x_{k+1}) \leq \frac{2}{2+s} d(x_{k-1}, x_k)$,foralln $\in N$ (3.6)

Therefore, the sequence $\{d(x_k, x_m)\}$ is monotone decreasing and bounded below. Then there exist λ≥ 0 such that $\lim_{n\to+\infty} d(x_k, x_{k+1}) = λ$. Suppose that λ >0, then letting $n \to +\infty$, from (3.6) we have

$sλ \leq \frac{2}{2+s}λ, \ s \geq 1.$

Thus

$λ \leq sλ \leq \frac{2}{2+s}λ \leq \frac{2}{3}λ$. which is contradiction. Hence, λ = 0, Thus we proved that (3.3) holds.

Step2: We will prove that $\{x_k\}$ is a b- Cauchy sequence in (X, d).It is sufficient to show that$\{x_{2k}\}$ is a b- Cauchy sequence in (X, d). Suppose to contrary, that is $\{x_{2k}\}$ is not a b- Cauchy sequence in (X, d). Then there exist $\epsilon > 0$ for which we can find two subsequences $\{x_{2m(i)}\}$ and $\{x_{2k(i)}\}$ of $\{x_{2k}\}$ such that $k(i)$ is the smallest index for which

$k(i) > m(i) > i, d(x_{2m(i)}, x_{2k(i)}) \geq \epsilon.$ (3.7)

This means that

$d(x_{2m(i)}, x_{2k(i)-2}) < \varepsilon.$ (3.8)

From (3.7) and using the triangular in equation, we have

$\varepsilon \leq d(x_{2m(i)}, x_{2k(i)}) \leq s[d(x_{2m(i)}, x_{2k(i)-2}) + d(x_{2k(i)-2}, x_{2k(i)-1})].$

Taking the upper limit as $i \to +\infty$, by (3.3) we have

$\frac{\varepsilon}{s} \leq \lim_{i\to+\infty} d(x_{2m(i)+1}, x_{2k(i)}).$ (3.9)

Again, using the triangular inequality, we have,

$d(x_{2m(i)}, x_{2k(i)-1}) \leq s[d(x_{2m(i)}, x_{2k(i)-2}) + d(x_{2k(i)-2}, x_{2k(i)-1})].$

Taking the upper limit as $i \to +\infty$, by (3.3) we have

$\lim_{i\to+\infty} d(x_{2m(i)+1}, x_{2k(i)-1}) < s\varepsilon.$ (3.10)

Now, from (3.1) we have

$d(x_{2m(i)+1}, x_{2k(i)}) = sd(T_1 x_{2m(i)}, T_2 x_{2k(i)-1})$

$\leq ad(x_{2m(i)}, x_{2k(i)-1}) + b\frac{d(x_{2m(i)},T_1 x_{2m(i)})d(T_1 x_{2m(i)},T_2 x_{2k(i)-1})}{1+d(x_{2k(i)-1},T_2 x_{2k(i)-1})}$

$= ad(x_{2m(i)}, x_{2k(i)-1}) + b\frac{d(x_{2m(i)},x_{2m(i)+1})d(x_{2m(i)+1},x_{2k(i)})}{1+d(x_{2k(i)-1},x_{2k(i)})}$

Again $i \to +\infty$, by (3.3),(3.9), (3.10) we have $\varepsilon = s \times \frac{1}{s} \leq as\varepsilon$, since a is non negative real with $a < \frac{1}{s}, s \geq 1$, we have $\epsilon \leq as\varepsilon < \epsilon$, which is a contradiction. Consequently, $\{x_k\}$ is a b- Cauchy sequence in (X, d). Since (X, d) is a complete b-metric space, then $\{x_k\}$ converges to some $u \in X$ as $n \to +\infty$.

Step3: we will prove that $T_1 u = T_2 u = u$. Without loss of generality, we can suppose that

$T_1 u = u$. If not there exist a $u^* \in X$ such that

$d(u, T_1 u) = u^* > 0.$ (3.11)

So, by using the triangular inequality and (3.1), we have

$u^* = d(u, T_1 u)$

$\leq s[d(u, x_{2k+2}) + d(x_{2k+2}, T_1 u)]$

$= s[d(u, x_{2k+2}) + d(T_1 u, T_2 x_{2k+1})]$

$\leq s\, d(u, x_{2k+2}) + a\, d(u, x_{2k+1}) + b\frac{d(u,T_1 u)d(T_1 u,T_2 x_{2k+1})}{1+(x_{2k+1},T_2 x_{2k+1})}$

Taking the limit as $k \to +\infty$, we obtain that

$u^* = d(u, T_1 u)$

≤ 0, Which is a contradiction with (3.11), so$u^* = 0$. Hence $T_1 u = u$.

Similarly, we obtain$T_2 u = u$, thus $u$is common fixed point of T_1 and T_2.

Now we will prove that T_1 and T_2 have a unique common fixed point.

Suppose that u and $u^*$are another common fixed points of T_1 and T_2, then from (3.1), we have

$sd(u, u^*) = sd(T_1 u = T_2 u^*)$

$\leq ad(u, u^*) + b\frac{d(u,\ T_1 u)d(\ T_1 u, T_2 u^*)}{1+d(u^*, T_2 u^*)}$

$= ad(u, u^*) + b\frac{d(u,\ u)d(u,u^*)}{1+d(u^*,u^*)}$

$= ad(u, u^*)$.

Since a is nonnegative real with $a < \frac{1}{s}, s \geq 1$, then we have $d(u, u^*) = 0$. Thus we proved thatT_1 and T_2 have a unique common fixed point in X.

Corollary3.2: Let (X, d)be a complete b-metric space with $s \geq 1$and $T: X \to X$be a self mappings satisfies the conditions

$d(Tx, Ty) \leq ad(x, y) + b\frac{d(x,Tx)d(Tx,Ty)}{1+d(y,Ty)}$ (3.12)

Where a, bnonnegative real are with $a < \frac{1}{s}, a + b \leq \frac{2}{2+s}$, for all$x, y \in X$. then T has a unique fixed point.

Proof: We can prove this result by applying theorem 3.1 with $T_1 = T_2 = T$.

Theorem 3.3: Let (X, d)be a complete b-metric space with $s \geq 1$and $T_1, T_2: X \to X$be a self mappings satisfies the conditions

$sd({T_1}^n x, {T_2}^m y) \leq ad(x, y) + b\frac{d(x,{T_1}^n x)d({T_1}^n x,{T_2}^m y)}{1+d(y,{T_2}^m y)}$ (3.13)

Where a, b are nonnegative real with $a < \frac{1}{s}, a+b \leq \frac{2}{2+s}$, for all$x, y \in X$. then T_1 *and* T_2 have a unique common fixed point.

Proof: Let $x_0 \in X$ and define sequence $\{x_k\}$ in X such that $x_{2k+1} = {T_1}^{2k+1}x_{2k}$ and

$$x_{2k+2} = {T_2}^{2k+2}x_{2k+1} \text{ forall } k \in N \quad (3.14)$$

Similar to process of theorem 3.1, we can prove $\{x_k\}$ is a b-Cauchy sequence in (X, d). Since (X, d) is a complete b-metric space, then$\{x_k\}$ converges to some $u \in X$ as $n \to +\infty$. Now, we shall prove that if one of the mappingT_1 or T_2 is continuous, then we have $T_1u = T_2u = u$. without loss of generality, we can suppose that T_1 is continuous. Clearly, as $x_k \to u$, by (3.14) we have ${T_1}^{2k+1}x_{2k} = x_{2k+1} \to u$, as $n \to +\infty$. Since $x_{2k+1} \to u$,and T_1 is continuous, then ${T_1}^{2k+1}x_{2k} \to {T_1}^{2k+1}u$, thus, by the uniqueness of the limit in b-metric space, we have ${T_1}^{2k+1}u = u$.

Then from (3.13), we have

$$sd(u, {T_2}^{2k+2}u) = sd({T_1}^{2k+1}u, {T_2}^{2k+2}u)$$
$$\leq ad(u,u) + b\frac{d(u,{T_1}^{2k+1}u)d({T_1}^{2k+1}u,{T_2}^{2k+2}u)}{1+d(u,{T_2}^{2k+2}u)}$$
$$=0.$$

Therefore, ${T_2}^{2k+2}u = u$. From (3.13), we have

$$sd(T_1u,u) = sd(T_1{T_1}^{2k+1}u, {T_2}^{2k+2}u)$$
$$= sd({T_1}^{2k+1}\, T_1u, {T_2}^{2k+2}u)$$
$$\leq ad(T_1u,u) + b\frac{d(T_1u, {T_1}^{2k+1}\, T_1u)d({T_1}^{2k+1}\, T_1u,{T_2}^{2k+2}u)}{1+d(u,{T_2}^{2k+2}u)}$$

Since a is nonnegative reals with with $a < \frac{1}{s}$, $a+b \leq \frac{2}{2+s}, s \geq 1$. So we have $T_1u = u$. Hence$T_1u = {T_1}^{2k+1}u = u$.Similarly, we can have $T_2u = {T_2}^{2k+2}u = u$. Hence $T_1u = T_2u = u$, thus we proved that $u$is a common fixed point of $T_1$and T_2. The same method with theorem 3.1 , we can prove that u is the unique common fixed point in X.

Corollary3.4. Let (X, d)be a complete b-metric space with $s \geq 1$and $T: X \to X$be a self mappings satisfies the conditions

$$sd(T^nx, T^my) \leq ad(x,y) + b\frac{d(x,T^nx)d(T^nx,T^my)}{1+d(y,{T_2}^my)} \quad (3.15)$$

Where a, b are non negative real with $a < \frac{1}{s}, a+b \leq \frac{2}{2+s}$, for all$x, y \in X$. then T has a unique fixed point.

Proof: Let $x_0 \in X$ and define sequence $\{x_k\}$ in X such that

$$x_{k+1} = T^{k+1}x_k, \text{forall } k \in N \quad (3.16)$$

We can prove this result by applying theorem 3.3 with $T_1 = T_2 = T$.

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How to cite this article:

Shakuntala Dewangan, Preeti Chandra and S .K .Tiwari, 2019,Common Fixed Point Results for Generalized Contractionmappings in B - Metric Space. *Int J Recent Sci Res.* 10(05), pp. 32397-32401.
DOI: http://dx.doi.org/10.24327/ijrsr.2019.1005.3462

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