Fixed Point Theorem in Fuzzy Metric Spaces using E.A. Like Property

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Abstract: *In this paper we proved common fixed point theorems for mapping satisfying common E. A. Like property in Fuzzy metric space which generalize the result of Madhu Shrivastava et. at. [23].*

Keywords: *Fuzzy Metric Space, E.A. Property, E.A. Like Property, Weakly Compatible Maps, t- represent able norms, Common Fixed Point.*

1. INTRODUCTION

When the notion of fuzzy set was introduced, then it was the turning point in the development of mathematics. In 1965, Zadeh [26] introduced the Fuzzy y sets Kramosil and Michalek [15] introduced the concept of Fuzzy metric space in1975.George and Veermani [9] modified the notion of Fuzzy metric space with the help of continuous t-norm. Which shows a new way for further development of analysis in such spaces? It has been seen that the study of Kramosil and Michalek [15] of Fuzzy metric space covered almost all the points in the way for developing this theory to the field of fixed point theorem, in particular for the study of contractive type maps. They have also shown that every metric induces a fuzzy metric. Singh [24] proved various fixed point theorems using the concepts of semi-compatibility, compatibility and implicit relations in Fuzzy metric space. Kumar and Pant [17] have given a common fixed point theorem for two pairs of compatible mapping satisfying expansion type condition in probabilistic Metric space. Aamri and Moutawakil [1] generalized the notion of non-compatible mapping in metric space E. A. Property, It was pointed out in [12] that property E. A. buys containment of ranges without any continuity requirement besides minimizes the commutatively at their point of coincidence. Recently, Jain et al.[13] improved the result of Kumar and Pant[17] by dropping the condition of continuity of the mapping and using semi and weak compatibility of mapping in place of compatibility[2-8].
In this paper we proved common fixed point theorems for mapping satisfying common E. A. Like property [25] in Fuzzy metric space which generalize the result of existing literature of metric fixed point theory.

2. DEFINITIONS

Definition 2.1 A binary operation $*$: $[0,1]\times[0,1]\rightarrow[0,1]$ is a continuous *t-norm* if $*$ satisfying conditions:

(1) $*$ is commutative and associative.

(2) $*$ is continuous ;

(3) $a*1=a$ For all $a\in[0,1]$

(4) $a*b\le c*d$ Whenever $a\le c$ and $b\le d$ and $a,b,c,d\in[0,1]$.

Example 2.2: $a*b=\min\{a,b\}, a*b=a.b$.

Definition 2.3: A 3-tuple $(X,M,*)$ is said to be a *fuzzy metric space* if X is an arbitrary set, $*$ is a continuous t- norm and M is a fuzzy set on $X^2\times(0,\infty)$ satisfying the following conditions, $\forall x,y,z\in X, s,t>0$:

1. $M(x,y,t)>0$;
2. $M(x,y,t)=1$ if and only if $x=y$;
3. $M(x,y,t)=M(y,x,t)$;
4. $M(x,y,t)*M(y,z,s)\le M(x,z,t+s)$;
5. $M(x,y,.):(0,\infty)\to(0,1]$ is continuous.

Then M is called a fuzzy metric on X. Then $M(x,y,t)$ denotes the degree of nearness between x and y with respect to t.

Example 2.4 (Induced fuzzy metric) Let (X,d) be a metric space. Denote $a*b=a\,b$ for all $a,b\in[0,1]$ and let M_d be fuzzy sets on $X^2\times(0,\infty)$ defined as follows: $M_d(x,y,t)=\dfrac{t}{t+d(x,y)}$, Then $(X,M_d,*)$ is a fuzzy metric space . We call this fuzzy metric induced by a metric d as the standard intuitionistic Fuzzy metric.

Definition 2.5: Two self-mappings f and g of a fuzzy metric space $(X,M,*)$ are called compatible if $\lim_{n\to\infty} M(fgx_n, gfx_n, t)=1$ whenever $\{x_n\}$ is a sequence in X such that $\lim_{n\to\infty} fx_n=\lim_{n\to\infty} gx_n=x$ for some $x\in X$.

Lemma 2.6: Let $(X,M,*)$ be fuzzy metric space .If there exists $q\in(0,1)$ such that $M(x,y,qt))\ge M(x,y,t)$ for all $x,y\in X$ and $t>0$, then $x=y$.

Definition 2.7: Let X be a set, f and g self maps of X. A point $x\in X$ is called a coincidence point of f and g if $fx=gx$. We shall call $w=fx=gx$ a point of coincidence of f and g.

Definition 2.8: A pair of maps S and T is called weakly compatible pair if they commute at coincidence points.

Definition 2.9: Let f and g be two self-maps of a fuzzy metric space $(X,M,*)$. We say that f and g satisfy the property E. A. if there exists a sequence $\{x_n\}$ such that, $\lim_{n\to\infty} fx_n=\lim_{n\to\infty} gx_n=z$ for some $z\in X$.

Definition 2.10: Let f and g be two self-maps of a fuzzy metric space $(X,M,*)$. We say that f and g satisfy the property E. A. if there exists a sequence $\{x_n\}$ such that, $\lim_{n\to\infty} fx_n=\lim_{n\to\infty} gx_n=z$ for some $z\in f(X)$ or $z\in g(X)$, i.e. $z\in f(X)\cup g(X)$.

Definition 2.11: (Common E. A. Property) – Let A,B,S and T be self maps of a fuzzy metric space $X\to X$ where X is a Fuzzy metric space, then the pairs $\{A,S\}$ and $\{B,T\}$ are satisfy Common E. A. Property if there exist two sequences $\{x_n\}$ and $\{y_n\}$ in X such that $\lim_{n\to\infty} Ax_n=\lim_{n\to\infty} Sx_n=\lim_{n\to\infty} Ty_n=\lim_{n\to\infty} By_n=z$ for some $z\in X$.

Definition 2.12: (Common E. A. Like Property)- Let $A,B,S,$ and T be self maps of a fuzzy metric space $(X,M,*)$, then the pairs $\{A,S\}$ and $\{B,T\}$ said to satisfy Common E. A. Like property if there exist two sequences $\{x_n\}$ and $\{y_n\}$ in X such that $\lim_{n\to\infty} Ax_n=\lim_{n\to\infty} Sx_n=\lim_{n\to\infty} Ty_n=\lim_{n\to\infty} By_n=z$,

Where $z\in S(X)\cap T(X)$ or $z\in S(X)\cap T(X)$

It is clear that E. A. property in proving common fixed point theorems can be concluded by following:

1. It minimizes the commutativity conditions of the maps to the commutativity at their points of coincidence.
2. It implies containment of ranges without any continuity requirements.
3. It allows replacing the completeness requirement of the space with a more natural condition of closeness of the range.

   It means, if two mappings satisfy E.A. like property then they also satisfy E. A. Property, but on the other hand E. A. like property relaxes the condition of containment of ranges and closeness of the ranges to prove common fixed point theorems, which are necessary with E. A. property.

3. MAIN RESULTS

Theorem (3.1) – Let f and g be two self-maps of a fuzzy metric space $(X, M, *)$

Satisfying $M(x,y,t)>0$, for all x, y in X and $t>0$ such that the following conditions hold;

(I) $M(fx, fy,t) \geq r(\max\{M(fx, gy,t), M(gx, fy,t), M(gx, gy,t)\})$

(II) f and g Satisfy the E.A. like Property .

Where $r:[0,1]\to[0,1]$ is a continuous function such that $r(t)>t$ for each $0<t<1$, $r(0)=0$ and $r(1)=1$.

Then there exist a unique common fixed point of f and g.

Proof: Since f and g satisfy E.A. like property satisfy E.A. Like property. Therefore there exists a sequence $\{x_n\}$ in X.

Such that $\lim_{n\to\infty} fx_n = \lim_{n\to\infty} gx_n = z \in f(X)$ or $g(X)$.

Therefore $z = gu$ for some $u \in X$. Now we show that $fu = gu$, from (I),we have

$$M(fu, fx_n,t) \geq r\left(max\begin{Bmatrix} M(fu, gx_n,t), M(gu, fx_n,t), \\ M(gu, gx_n,t) \end{Bmatrix}\right)$$

Taking $\lim n\to\infty$, we get,

$$M(fu,z,t) \geq r\left(max\begin{Bmatrix} M(fu,z,t), M(gu,z,t), \\ M(gu,z,t) \end{Bmatrix}\right)$$

$$= r(\max\{M(fu,z,t), M(z,z,t), M(z,z,t)\})$$

$$= r(M(z,z,t)) = r(1) = 1$$

This implies that $fu = z = gu$. i.e. u is coincidence point of f and g .

Since f and g are weakly Compatible. Therefore $fz = fgu = gfu = gz$.

Now we show that $fz = z$, If not from (I) , we have

$$M(fz, fx_n,t) \geq r\left(max\begin{Bmatrix} M(fz, gx_n,t), M(gz, fx_n,t), \\ M(gz, gx_n,t) \end{Bmatrix}\right)$$

Taking $\lim n\to\infty$, we get,

$$M(fz,z,t) \geq r\left(max\begin{Bmatrix} M(fz,z,t), M(gz,z,t), \\ M(gz,z,t) \end{Bmatrix}\right)$$

$$M(fz,z,t) \geq r\left(max\begin{Bmatrix} M(fz,z,t), M(fz,z,t), \\ M(fz,z,t) \end{Bmatrix}\right)$$

$$M(fz,z,t) \geq r(M(fz,z,t) > M(fz,z,t)$$

Which is a contradiction. Hence $fz = gz = z$ .Hence z is a common fixed point of f and g .

Uniqueness - Let z_1 be another fixed point of f and g , such that $z_1 \neq z$, then from (I) ,we have

$$M(fz, fz_1,t) \geq r\left(max\begin{Bmatrix} M(fz, gz_1,t), M(gz, fz_1,t), \\ M(gz, gz_1,t) \end{Bmatrix}\right)$$

$$M(z,z_1,t) \geq r(\max\{M(z,z_1,t), M(z,z_1,t), M(z,z_1,t)\})$$

$$M(z,z_1,t) \geq rM(z,z_1,t) > M(z,z_1,t)$$

Which is a contradiction. Hence $z = z_1$.

Theorem -3.2: A , B , S , T be self – maps of a fuzzy metric space (X, M, t) satisfying the following condition -

(I) $$M(Ax,By,t) \geq r(\max\{M(Sx,Ty,t), M(By,Sx,t), M(Ax,Ty,t), M(Sx,Ax,t), M(By,Ty,t), \frac{a.M(Ax,By,t)+b.M(Ax,Ty,t)}{a.M(Sx,By,t)+b.(Sx,Ty,t)}, \frac{c.M(Sx,By,t)+d.M(Sx,Ty,t)}{c.(By,Ty,t)+d}, \frac{e.M(Ax,By,t)+f.M(Ax,Ty,t)}{e+f}\})$$

(II) Pairs (A,S) and (B,T) are weakly compatible.

(III) Pairs (A,S) and (B,T) satisfying common E. A. Like property.

For all x, y in X and $t > 0$, where a and b (c and d) cannot be simultaneous 0, and $a,b,c,d \geq 0$.

Then A , B , S , T have an unique common fixed point.

Proof – Since (A,S) and (B,T) satisfying common E. A. Like property therefore there exist two sequences $\{x_n\}$ and $\{y_n\}$ in X , such that

$$\lim_{n\to\infty} Ax_n = \lim_{n\to\infty} Sx_n = \lim_{n\to\infty} Ty_n = \lim_{n\to\infty} By_n = z$$

Where $z \in S(X) \cap T(X)$ or $z \in A(X) \cap B(X)$

Suppose that $z \in S(X) \cap T(X)$, Now We have $\lim_{n\to\infty} Ax_n = z \in S(X)$, then $z = Su$ for some $u \in X$.

Now we claim that $Au = Su$, from (I) , We have

$$M(Au,By_n,t) \geq r(\max\{M(Su,Ty_n,t), M(By_n,Su,t), M(Au,Ty_n,t), M(Su,Au,t), M(By_n,Ty_n,t), \frac{a.M(Au,By_n,t)+b.M(Au,Ty_n,t)}{a.M(Su,By_n,t)+b.(Su,Ty_n,t)}, \frac{c.M(Su,By_n,t)+d.M(Su,Ty_n,t)}{c.(By,Ty_n,t)+d}, \frac{e.M(Au,By_n,t)+f.M(Au,Ty_n,t)}{e+f}\})$$

Taking $\lim n \to \infty$, we get ,

$$M(Au,z,t) \geq r(\max\{M(z,z,t), M(z,z,t), M(Au,z,t), M(z,Au,t), M(z,z,t), \frac{a.M(Au,z,t)+b.M(Au,z,t)}{a.M(z,z,t)+b.(z,z,t)}, \frac{c.M(z,z,t)+d.M(z,z,t)}{c.(z,z,t)+d}, \frac{e.M(Au,z,t)+f.M(Au,z,t)}{e+f}\})$$

$$M(Au,z,t) \geq r(\max\{1,1, M(Au,z,t), M(z,Au,t), 1, M(Au,z,t), 1, M(Au,z,t)\})$$

$$M(Au,z,t) \geq r(1) = 1$$

Hence $Au = z = Su$, Now we have $\lim_{n\to\infty} Bx_n = z \in S(X)$ then $Tv = z$ for some $v \in X$.

Now we claim that $Tv = Bv$, from (I) ,We have

$$M(Ax_n,Bv,t)\geq r(\max\{M(Sx_n,Tv,t),M(Bv,Sx_n,t),M(Ax_n,Tv,t),M(Sx_n,Ax_n,t),M(Bv,Tv,t),$$

$$\frac{a.M(Ax_n,Bv,t)+b.M(Ax_n,Tv,t)}{a.M(Sx_n,Bv,t)+b.(Sx_n,Tv,t)},\frac{c.M(Sx_n,Bv,t)+d.M(Sx_n,Tv,t)}{c.(Bv,Tv,t)+d},$$

$$\frac{e.M(Ax_n,Bv,t)+f.M(Ax_n,Tv,t)}{e+f}\})$$

Taking $\lim n\to\infty$, we get ,

$$M(z,Bv,t)\geq r(\max\{M(z,z,t),M(Bv,z,t),M(z,z,t),M(z,z,t),M(Bv,z,t),$$

$$\frac{a.M(z,Bv,t)+b.M(z,z,t)}{a.M(z,Bv,t)+b.(z,z,t)},\frac{c.M(z,Bv,t)+d.M(z,z,t)}{c.(Bv,z,t)+d},\frac{e.M(z,Bv,t)+f.M(z,Bv,t)}{e+f}\})$$

$$M(z,Bv,t)\geq r(\max\{1,M(Bv,z,t),1,1,M(Bv,z,t),1,1,M(z,Bv,t)\})$$

$$M(z,Bv,t)\geq r(1)=1$$

Hence $Bv=z=Tv$

Since the pair (A,S) is weakly compatible, therefore $Az=ASu=SAu=Sz$.

Now we show that $Az=z$.

$$M(Az,By_n,t)\geq r(\max\{M(Sz,Ty_n,t),M(By_n,Sz,t),M(Az,Ty_n,t),M(Sz,Az,t),M(By_n,Ty_n,t),$$

$$\frac{a.M(Az,By_n,t)+b.M(Az,Ty_n,t)}{a.M(Sz,By_n,t)+b.(Sz,Ty_n,t)},\frac{c.M(Sz,By_n,t)+d.M(Sz,Ty_n,t)}{c.(By_n,Ty_n,t)+d},$$

$$\frac{e.M(Az,By_n,t)+f.M(Az,Ty_n,t)}{e+f}\})$$

$\lim n\to\infty$, we get ,

$$M(Az,z,t)\geq r(\max\{M(Az,z,t),M(z,Az,t),M(Az,z,t),M(Az,Az,t),M(z,z,t),M(z,z,t),$$

$$\frac{c.M(Az,z,t)+d.M(Az,z,t)}{c.(z,z,t)+d},\frac{e.M(Az,z,t)+f.M(Az,z,t)}{e+f}\})$$

$$M(Az,z,t)\geq r(\max\{M(Az,z,t),M(z,Az,t),M(Az,z,t),1,1,1,M(Az,z,t),M(Az,z,t)\})$$

$$M(Az,z,t)\geq r(1)=1$$

Hence $Az=z=Sz$.

Since the pair (B,T) is weakly compatible. Therefore $Bz=BTv=TBv=Tz$

Now we show that $Bz=z$

$$M(Ax_n, Bz, t) \geq r(\max\{M(Sx_n, Tz, t), M(Bz, Sx_n, t), M(Ax_n, Tz, t), M(Sx_n, Ax_n, t), M(Bz, Tz, t),$$

$$\frac{a.M(Ax_n, Bz, t) + b.M(Ax_n, Tz, t)}{a.M(Sx_n, Bz, t) + b.(Sx_n, Tz, t)}, \frac{c.M(Sx_n, Bz, t) + d.M(Sx_n, Tz, t)}{c.(Bz, Tz, t) + d},$$

$$\frac{e.M(Ax_n, Bz, t) + f.M(Ax_n, Tz, t)}{e + f}\})$$

$\lim n \to \infty$, we get ,

$$M(z, Bz, t) \geq r(\max\{M(z, Bz, t), M(Bz, z, t), M(z, Bz, t), M(z, z, t), M(Bz, Bz, t),$$
$$\frac{a.M(z, Bz, t) + b.M(z, Bz, t)}{a.M(z, Bz, t) + b.M(z, Bz, t)}, \frac{c.M(z, Bz, t) + d.M(z, Bz, t)}{c.M(Bz, Bz, t) + d}, \frac{e.M(z, Bz, t) + f.M(z, Bz, , t)}{e + f}\})$$

$$M(z, Bz, t) \geq r(\max\{M(z, Bz, t), M(Bz, z, t), M(z, Bz, t), 1, 1, 1, M(z, Bz, t), M(z, Bz, t)\})$$

$$M(z, Bz, t) \geq r(1) = 1$$

Hence $Bz = z = Tz$

Thus z is a common fixed point of A, B, S and T .

Uniqueness – Suppose that z_1 is a another fixed point of A, B, S and T such that $z_1 = z$, then from 3.2 (I)

$$M(Az, Bz_1, t) \geq r(\max\{M(Sz, Tz_1, t), M(Bz_1, Sz, t), M(Az, Tz_1, t), M(Sz, Az, t), M(Bz, Tz, t),$$

$$\frac{a.M(Az, Bz_1, t) + b.M(Az, Tz_1, t)}{a.M(Sz, Bz_1, t) + b.(Sz, Tz_1, t)}, \frac{c.M(Sz, Bz_1, t) + d.M(Sz, Tz_1, t)}{c.(Bz_1, Tz_1, t) + d},$$

$$\frac{e.M(Az, Bz_1, t) + f.M(Az, Tz_1, t)}{e + f}\})$$

$$M(z, z_1, t) \geq r(\max\{M(z, z_1, t), M(z, z_1, t), M(z, z_1, t), M(z, z_1, t), M(z, z_1, t),$$

$$\frac{a.M(z, z_1, t) + b.M(z, z_1, t)}{a.M(z, z_1, t) + b.(z, z_1, t)}, \frac{c.M(z, z_1, t) + d.M(z, z_1, t)}{c.(z_1, z_1, t) + d}, \frac{e.M(z, z_1, t) + f.M(z, z_1, t)}{e + f}\})$$

$$M(z, z_1, t) \geq r(\max\{M(z, z_1, t), M(z, z_1, t), M(z, z_1, t), 1, 1, 1, M(z, z_1, t), M(z, z_1, t)\})$$

$$M(z, z_1, t) \geq r(1) = 1$$

Hence $z = z_1$

Theorem -3.3: A , B , S , T be self maps of a fuzzy metric space $(X, M, *)$ satisfying the following conditions:

(I) Pairs (A, S) and (B, T) satisfying E. A. Like Property.
(II) Pairs (A, S) and (B, T) are weakly compatible.
(III) $A(X) \subset T(X)$ And $B(X) \subset S(X)$

(IV) $M(Ax,By,t) \geq \max(r\{M(Sx,Ty,t), M(Ax,Sx,t), M(By,Ty,t), M(Sx,By,t), M(Ax,Ty,t)\}$ For all x, y in X and $t > 0$,

If the range of one of A, B, S and T is a closed subset of X, then A, B, S and T have a common fixed point in X.

Proof: The proof of this theorem is similar as Theorem 3.1 and 3.2 .

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