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COMMON FIXED POINT THEOREM IN M-FUZZY METRIC SPACE FOR OCCASIONALLY WEAKLY COMPATIBLE MAPPING SATISFYING INTEGRAL TYPE INEQUALITY

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Abstract: The purpose of this paper is to obtain a common fixed point theorems for occasionally weakly compatible mapping on M-fuzzy metric space, using integral type inequality.

Keywords: occasionally weakly compatible maps, weakly compatible maps; m-fuzzy metric space; common fixed point.

Mathematics Subject Classification: 47H10, 54H25.

1. INTRODUCTION

In 1965, the concept of fuzzy sets was initially introduced by Zadeh [20], after that Kramosil and Michalek [8] defined the concept of fuzzy metric space and this concept was modified by George and Veermani [4]. Many researchers have applied various mathematical results on fuzzy metric spaces in different ways [1, 2, 4, 9, 12 and 18]. Sessa [17] improved commutative condition in fixed point theorems by introducing the notion of weak commuting property. In 1986 Jungck introduced the

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concept of compatible mappings for self-maps, after it many research work has been done in the field of fuzzy metric space for existence of common fixed point for compatible maps. Jungck generalized the notion of weak commutativity to that of pairwise compatible maps and then pairwise weakly compatible maps [6]. Jungck and Rhoades [7] introduced the concept of occasionally weakly compatible maps**.** In 2002, Branciari [3] obtained a fixed point result for a mapping satisfying an integral type condition then Many authors [5, 10, 15] proved a lots of fixed point theorems involving relatively more general integral type contractive conditions.

In 2006, Sedghi and Shobe [16] defined *M*- fuzzy metric spaces and proved a common fixed point theorem for four weakly compatible mappings which is a generalization of fuzzy metric spaces due to George and Veeramoni [4] and studied some related results. J.H.Park et al. [13] and some other authors [11, 14] also established some fixed point theorems in M-fuzzy metric spaces.

In this paper we present the new results for occasionally weakly compatible mappings in M-fuzzy metric spaces and establish common fixed point theorems for it satisfying integral type inequality.

2. NOTATION AND PRELIMINARIES

Definition 2.1 [19]. A binary operation $*$: $[0, 1] \times [0, 1] \to [0, 1]$ is a continuous t-norm if it satisfies the following conditions:

(1) $*$ is associative and commutative,

(2) $*$ is continuous,

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

(4) $a * b \leq c * d$ whenever $a \leq c$ and $b \leq d$, for each $a, b, c, d \in [0, 1]$.

Example 2.2 Two typical examples of continuous t-norm are $a * b = ab$ and $a * b = \min(a, b)$.

Definition 2.3 [16]. A 3-tuple (X, M, $*$) is called a M- fuzzy metric space if X is an arbitrary (non-empty) set, $*$ is a continuous t- norm, and M is fuzzy sets on $X^3 \times (0, \infty)$, satisfying the following conditions: for each $x, y, z, a \in X$ and $t, s > 0$

(1)$M(x, y, z, t) > 0$;

(2) $M(x, y, z, t) = 1$ if and only if $x = y = z$;

(3) M(x, y, z, t) = M (p{x, y, z}, t), (symmetry) where p is a permutation function;

(4) M(x, y, a, t) * M (a, z, z, s) ≤ M(x, y, z, t + s);

Remark 2.4 [16]. Let (X, M,*) be a M-fuzzy metric space. Then for every t > 0 and for every x, y ∈ X, we have M(x, x, y, t) = M(x, y, y, t)

Because for each ε > 0 by triangular inequality we have

(i) M(x, x, y, ε + t) ≥ M(x, x, x, ε) ∗ M(x, y, y, t) = M(x, y, y, t)

(ii) M(y, y, x, ε + t) ≥ M(y, y, y, ε) ∗ M(y, x, x, t) = M(y, x, x, t).

By taking limits of (i) and (ii) when ε → 0, we obtain M(x, x, y, t) = M(x, y, y, t).

Definition 2.5[16]. Let (X,M, ∗) be a M-fuzzy metric space . For t > 0, the

(1) open ball BM(x, r, t) with center x ∈ X and radius 0 < r < 1 is defined by BM(x, r, t) = {y ∈ X : M(x, y, y, t) > 1 − r}.

(2) A subset A of X is called open set if for each x ∈ A there exist t > 0 and 0 < r < 1 such that BM(x, r, t) ⊆ A.

(3) A sequence { x_n } in X converges to x if and only if M(x, x, x_n, t) → 1 as n → ∞,for each t > 0.

Definition 2.6[16]. Let A and S be mappings from a M-fuzzy metric space (X,M, ∗) into itself. Then the mappings are said to be weak compatible if they commute at their coincidence point, that is, Ax = Sx implies that ASx = SAx.

Definition 2.7[16]. Let A and S be mappings from a M-fuzzy metric space (X,M, ∗) into itself. Then the mappings are said to be compatible if

$$\lim_{n\to\infty} M(ASx_n, SAx_n, SAx_n, t) = 1, \quad \forall\ t > 0$$

whenever { x_n } is a sequence in X and x ∈ X such that $\lim_{n\to\infty} Ax_n = \lim_{n\to\infty} Sx_n = x$

Lemma 2.8[16]. Let (X, M, ∗) be a M-fuzzy metric space. Then M(x, y, z, t) is non-decreasing with respect to t, for all x, y, z in X

Lemma 2.9 [16]. Let (X, M, *) be a M-fuzzy metric space and for all x, y ∈ X, t > 0 and if for a number k ∈ (0, 1) such that M(x, y, kt) ≥ M(x, y, t) then x = y.

Definition 2.10[3]. Let (X, d) be a compatible metric space, c ∈ [0, 1) , $f : X \to X$ a mapping such that for each $x, y \in X$

$$\int_0^{d(fx,\ fy,)} \psi(t)\, dt \ \leq\ c \int_0^{d(x,\ y)} \psi(t)\, dt$$

where $\psi : R^+ \to R^+$ is a Lebesgue integrable mapping which is summable, nonnegative, and such that, for each ∈ > 0, $\int_0^{\varepsilon} \psi(t)dt > 0$, then f has a unique common fixed $z \in X$ such that for each $x \in X$, $\lim_{n\to\infty} f^n x = a$

B E Rhodes [15] extended this result by replacing the above condition by the following

$$\int_0^{d(fx,\ fy,)} \psi(t)\, dt \ \leq\ \alpha \int_0^{\max\{d(x,\ y),\ d(x,\ fx),\ d(y,\ fy),\ \frac{d(x,\ fy)+d(y\ ,fx)}{2}\}} \psi(t)\, dt$$

Definition 2.11 [6]. An element x ∈ X is called a coincidence point of the mapping f: $X \to$ X and g : $X \to$ X if f (x) = g(x) and f (y) = g(y)

Definition 2.12 [6]. An element x ∈ X is called a Common coincidence point of the mapping f: $X \to$ X and g : $X \to$ X if x= f (x) = g(x) = f (y) = g(y)

Definition 2.13 [6] Let A, B, S, T: $X \to$ X be four mappings. Then, the pair of maps (B, S) and (A, T) are said to have Common coincidence point if there exist a in X such that B(a) = S(a) =T(a) = A(a) .

Definition 2.14. Two self mappings A and S of M-fuzzy metric Space (X, M, *) are said to be occasionally weakly compatible (owc) if and only if there is a point x in X which is coincidence point of A and S at which A and S commute,

i.e. (f, g) are occasionally weakly compatible maps iff f (x) = g(x), f (y) = g(y) implies that gf (x) = f(gx), gf (y) = f (gy) for any x ∈ X

Example 2.15. Let X = R and $M(x, y, z, t) = \frac{t}{t+|x-y|+|y-z|+|z-x|}$

For every $x, y, z \in X$ and $t > 0$. Clearly that (X, M , *) is M- fuzzy metric space . Let A and B defined by $Ax = \frac{\sqrt{1-(2x-1)^2}}{2}$ and $Bx = (1 - \mathrm{x})$

Here A and B has two coincidence points x =1, x = 1/ 2, since A1 = B1 = 0 for x=1 also for x=1/2 we have A½ = B½ = ½ and a common fixed point x = 1/ 2. So A and B are owc maps, since they commute at one of their coincidence points x = ½.

Lemma 2.16. Let A and S be the *OWC* self-maps in a M- fuzzy metric space (X, M, *) and let A and S have a unique point of coincidence, w =Ax = Sx, then w is the unique common fixed point of A and S.

Proof: Since A and S are *owc*, there exists a point x in X such that Ax = Sx =w and ASx = SAx. Thus, AAx = ASx and since ASx= SAx, therefore AAx=ASx=SAx which says that Ax is also a point of coincidence of A and S. Since the point of coincidence w = Ax is unique by hypothesis, SAx = AAx = Ax, and w= Ax is a common fixed point of A and S. Moreover, if z is any common fixed point of A and S, then z = Az = Sz = w by the uniqueness of the point of coincidence.

Remark 2.17: A class of implicit relation

Let Φ denotes a family of mappings continuous and increasing in each co-ordinate variable such that each $\phi \in \Phi$, $\phi : [0, 1]^6 \rightarrow [0, 1]$, and ϕ (s, s, s, s, s, s) > s for every s ∈ [0, 1). Also let Ψ be the set of all continuous and decreasing functions $\psi : [0, 1]^5 \rightarrow [0, 1]$, in any coordinate and ψ (t, t, t, t, t) < t for all t in [0, 1]

3. MAIN RESULTS

Theorem 3.1. Let A, B, S and T be self-mapping on a M- fuzzy metric space (X, M, *), satisfying the following conditions: {A, S} and {B, T} are occasionally weakly compatible (*owc*) on given M-fuzzy metric space satisfying: If there exits $0 < q < \frac{1}{2}$ and t > 0 such that

$$(1) \qquad \int_0^{M(Ax,By,qt)} \psi(t)\, dt \geq \int_0^{\min\left\{\begin{matrix} M(Sx,Ty,t),\ M(Ax,Sx,t),\ M(By,Ty,t), \\ M(Ax,Ty,\alpha t),\ M(By,Sx,(2-\alpha)t) \end{matrix}\right\}} \psi(t)\, dt$$

For all $0 < \alpha < 2$ and x, y ∈ X then A, B, S, T have a unique common fixed point in X.

Proof. As the pairs (A, S) and (B, T) are occasionally weakly compatible on given M-fuzzy metric space, there are points x and y in X such that Ax = Sx and By= Ty. Now we show that Ax =By for it we claim that Sx=Ty, On the Contrary suppose that Sx ≠ Ty with the help of inequality (1) we have

$$\int_0^{M(Ax,\ By,\ qt)} \psi(t)\,dt \ \geq \ \int_0^{\min\left\{\substack{M(Sx,Ty,\ t),\ M(Ax,\ Sx,\ t),\ M(By,\ Ty,\ t),\\ M(Ax,\ Ty,\ \alpha t),\ M(By,\ Sx,\ (2-\alpha)t)}\right\}} \psi(t)\,dt$$

$$= \int_0^{\min\left\{\substack{M(Ax,\ By,\ t),\ M(Ax,\ Ax,\ t),\ M(By,By,t),\\ M(Ax,\ By,\ \alpha t),\ M(By,\ Ax,\ (2-\alpha)t)}\right\}} \psi(t)\,dt$$

taking $\alpha = 1-\beta$ where $\beta \in (0, 1)$ then we have

$$= \int_0^{\min\left\{\substack{M(Ax,\ By,\ t),\ M(Ax,\ Ax,\ t),\ M(By,By,t),\\ M(Ax,\ By,\ (1-\beta)t),\ M(By,\ Ax,\ (1+\beta)t)}\right\}} \psi(t)\,dt$$

on taking limit $\beta \rightarrow 0$

$$= \int_0^{\min\left\{\substack{M(Ax,\ By,\ t),\ M(Ax,\ Ax,\ t),\ M(By,By,t),\\ M(Ax,\ By,\ t),\ M(By,\ Ax,\ t)}\right\}} \psi(t)\,dt$$

$$= \int_0^{\min\{M(Ax,\ By,\ t)\}} \psi(t)\,dt$$

Thus

$$\int_0^{M(Ax,\ By,\ qt)} \psi(t)\,dt \ \geq \ \int_0^{\min\{M(Ax,\ By,\ t)\}} \psi(t)\,dt$$

here contradiction implies that $Sx = Ty$. Thus $Ax = By = Sx = Ty$, or we can write $Ax = Sx = By = Ty$. If there is another point w such that $Aw=Sw$, then again by using inequality (1), it follows that $Aw=Sw=By=Ty$ i.e. $Aw= Ax$. Hence $w = Ax = Sx$ is unique point of coincidence of A and S. By Lemma 2.16, w is the unique common fixed point of A and S i.e. $Aw = Sw = w$. Similarly, there is unique point z in X such that $z = Bz = Tz$. Now, we claim that $w = z$. For this, on contrary let $w \neq z$ now put $Ax = w$ and $By = z$ in inequality (1), we have

$$\int_0^{M(w,\ z,\ qt)} \psi(t)\,dt \ = \int_0^{M(Ax,\ By,\ qt)} \psi(t)\,dt$$

$$\geq \int_0^{\min\left\{\substack{M(Sx,Ty,\ t),\ M(Ax,\ Sx,\ t),\ M(By,\ Ty,\ t),\\ M(Ax,\ Ty,\ \alpha t),\ M(By,\ Sx,\ (2-\alpha)t)}\right\}} \psi(t)\,dt$$

$$= \int_0^{\min\left\{\substack{M(w,z,\ t),\ M(w,\ w,\ t),\ M(z,\ z,\ t),\\ M(w,\ z,\ \alpha t),\ M(z,\ w,\ (2-\alpha)t)}\right\}} \psi(t)\,dt$$

taking $\alpha=1-\beta$ where $\beta \in (0, 1)$ then we have

$$= \int_0^{\min\left\{\begin{matrix} M(w,z,\ t),\ M(w,\ w,\ t),\ M(z,\ z,\ t), \\ M(w,\ z,\ (1-\beta)t),\ M(z,\ w,\ (1+\beta)t) \end{matrix}\right\}} \psi(t)\,dt$$

on taking limit β→ 0

$$= \int_0^{\min\left\{\begin{matrix} M(w,z,\ t),\ M(w,\ w,\ t),\ M(z,\ z,\ t), \\ M(w,\ z,\ t),\ M(z,\ w,\ t) \end{matrix}\right\}} \psi(t)\,dt$$

$$= \int_0^{\min\{M(w,z,t\}} \psi(t)\,dt$$

Thus

$$\int_0^{M(w,\ z,\ qt)} \psi(t)\,dt \ \geq \ \int_0^{\min\{M(w,\ z,\ t)\}} \psi(t)\,dt$$

This contradiction gives, w = z. Hence, w is unique common fixed point of A, B, S and T in X. This completes the proof.

Theorem 3.2. Let A, B, S and T be self-mapping on a M- fuzzy metric space (X, M, *), satisfying the following conditions: {A, S} and {B, T} are occasionally weakly compatible (*owc*), If there exits $0 < q < \frac{1}{2}$ such that

(2) $$\int_0^{M(Ax,By,qt)} \psi(t)\,dt \geq \int_0^{\phi\left[\min\left\{\begin{matrix} M(Sx,Ty,t),\ M(Ax,Sx,t),\ M(By,Ty,t), \\ M(Ax,Ty,\alpha t),\ M(By,Sx,(2-\alpha)t) \end{matrix}\right\}\right]} \psi(t)\,dt$$

For all $0 < \alpha < 2$ and x, y ∈ X with implicit relation $\phi(t) > t$, for all 0 < t < 1 then A, B, S, T have a unique common fixed point in X.

Proof. As given in proof of theorem 3.1 and with help of inequality equation (2)

$$\int_0^{M(Ax,\ By,\ qt)} \psi(t)\,dt \ \geq \ \int_0^{\phi\left[\min\left\{\begin{matrix} M(Sx,Ty,t),\ M(Ax,Sx,t),\ M(By,Ty,t), \\ M(Ax,Ty,\alpha t),\ M(By,Sx,(2-\alpha)t) \end{matrix}\right\}\right]} \psi(t)\,dt$$

$$= \int_0^{\phi[\min\{M(Ax,\ By,\ t)\}]} \psi(t)\,dt \quad > \quad \int_0^{M(Ax,\ By,\ t)} \psi(t)\,dt$$

here contradiction implies that Sx = Ty . Thus Ax =Sx =By =Ty. If there is another point w such that Aw=Sw , then again by using inequality (2) and applying same process given in theorem 3.1, it follows that Aw=Sw=By=Ty i.e. Aw= Ax. Hence w = Ax = Sx is unique point of coincidence of A and S. By Lemma 2.16, w is the unique common fixed point of A and S i.e. Aw = Sw = w.

Similarly, there is unique point z in X such that z = Bz = Tz. Now, we claim that w = z. For this, on contrary let w ≠ z now put Ax = w and By = z in inequality (2) and applying same process given in theorem 3.1, we have

$$\int_0^{M(w,\ z,\ qt)} \psi(t)\, dt \quad = \int_0^{M(Ax,\ By,\ qt)} \psi(t)\, dt$$

$$\geq \int_0^{\phi \min\left\{ \begin{matrix} M(Sx,Ty,\ t),\ M(Ax,\ Sx,\ t),\ M(By,\ Ty,\ t), \\ M(Ax,\ Ty,\ \alpha t),\ M(By,\ Sx,\ (2-\alpha)t) \end{matrix} \right\}} \psi(t)\, dt$$

$$= \int_0^{\phi[\min\{M(w,\ z,\ t)\}]} \psi(t)\, dt \quad > \int_0^{M(w,\ z,\ t)} \psi(t)\, dt$$

This contradiction gives, w = z. Hence, w is unique common fixed point of A, B, S and T in X. This completes the proof

Corollary 3.3. Let A, B, S and T be self-mapping on a M- fuzzy metric space (X, M, *), satisfying the following conditions: {A, S} and {B, T} are occasionally weakly compatible (*owc*), If there exits $0 < q < 2$ such that

$$(3) \qquad \int_0^{M(Ax,By,qt)} \psi(t)\, dt \geq \int_0^{\left[\begin{matrix} \alpha_1(a)M(Sx,Ty,t)+\alpha_2(a)\ M(Ax,Sx,t)+\alpha_3(a)\ M(By,Ty,t) \\ +\alpha_4(a)M(Ax,Ty,\alpha t)\ +\alpha_5(a)M(By,Sx,(2-\alpha)t) \end{matrix} \right]^{\frac{1}{2}}} \psi(t)\, dt$$

For all $0 < \alpha < 2$ and $\alpha_i : R^+ \to (0, 1]$ such that $\Sigma\alpha_i(t) = 1$ where i= 1 to 5 then A, B, S, T have a unique common fixed point in X.

Proof. First if we define

$$\phi\ (x_1, x_2, x_3, x_4, x_5) \geq [\alpha_1(t)\ x_1 + \alpha_2\ (t)\ x_2 + \alpha_3\ (t)\ x_3 + \alpha_4\ (t)\ x_4 + \alpha_5\ (t)\ x_5]^{1/2}$$

where implicit relation $\phi(t) > t$, for all 0 < t < 1 then by inequality (3) and with help of proof of Theorem 3. 2 we have the conclusion.

Corollary 3.4 Let A, B, S, T, P and Q be self-mapping on a M- fuzzy metric space (X, M, *), Let Pairs (P, ST) and (Q, AB) are occasionally weakly compatible self-mappings on given M- fuzzy metric space, satisfying: If there exits 0 < q < ½, with implicit relation $\phi(t) > t$, for all 0 < t < 1 such that

$$(4) \qquad \int_0^{M(Px,Qy,qt)} \psi(t)\, dt \geq \int_0^{\phi\left[\min\left\{ \begin{matrix} M(STx,\ ABy,\ t),\ M(Px,\ STx,\ t),\ M(Qy,\ ABy,\ t), \\ M(Px,\ ABy,\ \alpha t),\ M(Qy,\ STx,\ (2-\alpha)t) \end{matrix} \right\}\right]} \psi(t)\, dt$$

For all $0 < \alpha < 2$ and x, y ∈ X, then A, B, S, T, P, and Q have a unique common fixed point in X.

Proof. As the pairs (P, ST) and (Q, AB) are occasionally weakly compatible, there exist points x and y in X such that Px = STx, and Qy = ABy. Now we show that Px= Qy. Suppose on contrary that STx ≠ ABy With the help of inequality (4)

$$\int_0^{M(Px,Qy,qt)} \psi(t)\,dt \geq \int_0^{\phi\left[\min\left\{\begin{matrix} M(STx,\ ABy,\ t),\ M(Px,\ STx,\ t),\ M(Qy,\ ABy\ ,t), \\ M(Px,\ ABy,\ \alpha t),\ M(Qy,\ STx,\ (2-\alpha)t) \end{matrix}\right\}\right]} \psi(t)\,dt$$

$$= \int_0^{\phi\left[\min\left\{\begin{matrix} M(Px,\ Qy,\ t),\ M(Px,\ Px,\ t),\ M(Qy,\ Qy,\ t), \\ M(Px,\ Qy,\ \alpha t),\ M(Qy,\ Px,\ (2-\alpha)t) \end{matrix}\right\}\right]} \psi(t)\,dt$$

Now taking α =1 in above inequality we get

$$= \int_0^{\phi[\min\{M(Px,\ Qy,\ t)\}]} \psi(t)\,dt > \int_0^{M(Px,\ Qy,\ t)} \psi(t)\,dt$$

Contradiction gives that Px=Qy. Therefore, Px=STx=Qy=ABy. If there is another point z such that Pz=STz , then again by using inequality (4), it follows that Pz=STz=Qy=ABy i.e. Pz = Px. Hence w = Px = STx is unique point of coincidence of P and ST. By Lemma 2.16, w is the unique common fixed point of P and ST i.e. Pw = STw = w.

Similarly, there is unique point z in X such that z = Qz = ABz. Now, we claim that w = z. on contrary suppose w ≠ z , now put x = w and y = z in inequality equation (4), we have

$$\int_0^{M(w,\ z,\ qt)} \psi(t)\,dt = \int_0^{M(Pw,\ Qz,\ qt)} \psi(t)\,dt$$

$$\geq \int_0^{\phi\left[\min\left\{\begin{matrix} M(STw,\ ABz,\ t),\ M(Pw,\ STw,\ t),\ M(Qz,\ ABz,\ t), \\ M(Pw,\ ABz,\ \alpha t),\ M(Qz,\ STw,\ (2-\alpha)t) \end{matrix}\right\}\right]} \psi(t)\,dt$$

Taking α= 1 we get

$$= \int_0^{\phi\left[\min\left\{\begin{matrix} M(w,z,t),\ M(w,w,t),\ M(z,z,t), \\ M(w,z,t),\ M(z,w,t) \end{matrix}\right\}\right]} \psi(t)\,dt$$

$$= \int_0^{\phi[\min\{M(w,z,t)\}]} \psi(t)\,dt > \int_0^{M(w,z,t)} \psi(t)\,dt$$

This gives, w = z. Hence, w is unique common fixed point of A, B, S, T, P and Q in X. This completes the proof.

Corollary 3.5 Let S and T be self-mapping on a M- fuzzy metric space (X, M, *), Let S and T are occasionally weakly compatible self-mappings on given M- fuzzy metric space, satisfying: If there exits 0 < q < 1/2 such that

$$(5) \qquad \int_0^{M(x,\ y,\ qt)} \psi(t)\, dt \ \geq\ \int_0^{\phi\left[\min\left\{\begin{matrix} M(Sx,\ Ty,\ t),\ M(x,\ Sx,\ t),\ M(y,\ Ty,\ t), \\ M(x,\ Ty,\ \alpha t),\ M(y,\ Sx,\ (2-\alpha)t) \end{matrix}\right\}\right]} \psi(t)\, dt$$

For all $0 < \alpha < 2$ and x, y ∈ X with implicit relation $\phi(t) > t$, for all 0 < t < 1 such that S and T have a unique common fixed point in X.

Proof. If we set A = B = I (the identity mapping) in Theorem 3.2, then it is easy to check that the pairs (I, S) and (I, T) are owc. Hence by Theorem 3.2, S and T have a unique common fixed point in X.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests.

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