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A STUDY ON ALMOST GENERALIZED WEAKLY SYMMETRIC KÄHLER MANIFOLDS

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Abstract We study almost generalized weakly symmetric, almost generalized weakly Ricci symmetric, almost generalized weakly Bochner symmetric and almost generalized weakly Bochner Ricci symmetric Kähler manifolds.

1 Introduction

In 1992, Tamassy et. al. [17], introduced weakly symmetric Riemannian manifolds. In 2008, weakly symmetric manifolds with some conditions in accordance to some curvature tensors have been studied by Shaikh and Hui [12, 13]. Later many other differential geometers have studied in this topic [8, 14, 15]. In the spirit of weakly symmetric spaces, Baishya [1] introduced generalized weakly symmetric manifolds. Keeping the theme of Dubey [7], again Baishya [3] proposed an almost generalized weakly symmetric manifold (it is denoted by $A(GWS)_n$)-manifold and an almost generalized weakly Ricci-symmetric (it is abbreviated by $A(GWRS)_n$)-manifold. According to Baishya, a Riemannian manifold (M_n, g) is said to be $A(GWRS)_n$-manifold if its curvature tensor admits the following equation

$$\begin{aligned}(\nabla_Y R)(X,V,U,W) &= [A_1(Y)+B_1(Y)]R(X,V,U,W)+C_1(X)R(Y,V,U,W)\\ &+C_1(V)R(X,Y,U,W)+D_1(U)R(X,V,Y,W)\\ &+D_1(W)R(X,V,U,Y)+[A_2(Y)+B_2(Y)]G(X,V,U,W)\\ &+C_2(X)G(Y,V,U,W)+C_2(V)G(X,Y,U,W)\\ &+D_2(U)G(X,V,Y,W)+D_2(W)G(X,V,U,Y), \qquad (1.1)\end{aligned}$$

where $G(X,V,U,W) = [g(V,U)g(X,W) - g(X,U)g(V,W)]$ and A_i, B_i, C_i, D_i, $i = 1, 2$ are non vanishing 1-forms defined by $A_i(Y) = g(Y, \sigma_i)$, $B_i(Y) = g(Y, \rho_i)$, $C_i(Y) = g(Y, \pi_i)$, $D_i(Y) = g(Y, \delta_i)$. According to him, a Riemannian manifold (M_n, g) is said to be $A(GWRS)_n$-manifold if the Ricci Tensor S of type $(0, 2)$ satisfies the condition

$$\begin{aligned}(\nabla_Y S)(U,Z) &= [A_1(Y)+B_1(Y)]S(U,Z)+C_1(U)S(Y,Z)+D_1(Z)S(U,Y)\\ &+[A_2(Y)+B_2(Y)]g(U,Z)+C_2(U)g(Y,Z)+D_2(Z)g(U,Y), \qquad (1.2)\end{aligned}$$

where A_i, B_i, C_i, D_i meaning already stated. In particular, the $A(GWS)_n$-manifold reduces to

- locally symmetric space [4] if $A_i = B_i = C_i = D_i = 0$,
- recurrent space [18] if $A_1 \neq 0$, $A_2 = B_i = C_i = D_i = 0$,
- pseudo symmetric space [5] if $A_1 = B_1 = C_1 = D_1 \neq 0$ and $A_2 = B_2 = C_2 = D_2 = 0$,
- generalized recurrent space [7] if $A_i \neq 0$ and $B_i = C_i = D_i = 0$,
- generalized pseudo symmetric space [1] if $A_i = B_i = C_i = D_i \neq 0$,
- almost pseudo symmetric space [6] if $B_1 \neq 0$, $A_1 = C_1 = D_1 = 0$ and $A_2 = B_2 = C_2 = D_2 \neq 0$,

- almost generalized pseudo symmetric space [2] if $B_i \neq 0$ $A_i = C_i = D_i \neq 0$.

In 2000, Tamassy et. al., [16] found interesting results on weakly symmetric and weakly Ricci-symmetric Kähler manifolds. The almost pseudo symmetric Kähler manifolds were studied by Bagewadi and Praveena [9, 10]. Recently we explored the existance of solitons in almost pseudo symmetric Kählerian space-time manifolds [11]. Motivated by these ideas in the present paper we study almost generalized weakly symmetric, almost generalized weakly Ricci symmetric, almost generalized weakly Bochner symmetric and almost generalized weakly Bochner Ricci symmetric Kähler manifolds.

2 Preliminaries

In a n(even)-dimensional Kähler manifold the following conditions hold [19]:

$$\begin{aligned} J^2(Z) = -Z,\ g(JZ,JY) = g(Z,Y),\ R(Z,Y) = R(JZ,JY),\\ S(Z,JY) + S(JZ,Y) = 0 \ and \ (\nabla_Z J)(Y) = 0, \end{aligned} \tag{2.1}$$

where ∇ is a $(1,1)$ tensor and g is a Riemannian metric.

Definition 2.1. A Kähler manifold is called an almost generalized weakly Bochner symmetric (its abbreviation is $A(GWBS)_n$)-manifold if its Bochner curvature tensor B of type $(0,4)$

$$\begin{aligned} (\nabla_Y B)(X,V,U,W) &= [A_1(Y) + B_1(Y)]B(X,V,U,W) + C_1(X)B(Y,V,U,W) \\ &+ C_1(V)B(X,Y,U,W) + D_1(U)B(X,V,Y,W) \\ &+ D_1(W)B(X,V,U,Y) + [A_2(Y) + B_2(Y)]G(X,V,U,W) \\ &+ C_2(X)G(Y,V,U,W) + C_2(V)G(X,Y,U,W) \\ &+ D_2(U)G(X,V,Y,W) + D_2(W)G(X,V,U,Y), \end{aligned} \tag{2.2}$$

where A_i, B_i, C_i, D_i are 1-forms (not simultaneously zero) and B is given by [19]

$$\begin{aligned} B(X,Y,Z,U) &= R(X,Y,Z,U) - \frac{1}{2n+4}[g(Y,Z)S(X,U) - S(X,Z)g(Y,U) \\ &+ g(JY,Z)S(JX,U) - S(JX,Z)g(JY,U) + S(Y,Z)g(X,U) \\ &- g(X,Z)S(Y,U) + S(JY,Z)g(JX,U) - g(JX,Z)S(JY,U) \\ &- 2S(Y,JX)g(JZ,U) - 2S(JZ,U)g(JX,Y)] \\ &+ \frac{r}{(2n+2)(2n+4)}[g(Y,Z)g(X,U) - g(X,Z)g(Y,U) \\ &+ g(JY,Z)g(JX,U) - g(JX,Z)g(JY,U) - 2g(JX,Y)g(JZ,U)], \end{aligned} \tag{2.3}$$

Definition 2.2. A Kähler manifold is called an almost generalized weakly Bochner Ricci symmetric (its abbreviation is $A(GWBRS)_n$)- manifold if its Bochner Ricci tensor K of type $(0,2)$ is not identically zero and satisfies the condition

$$\begin{aligned} (\nabla_Y K)(U,Z) &= [A_1(Y) + B_1(Y)]K(U,Z) + C_1(U)K(Y,Z) + D_1(Z)K(U,Y) \\ &+ [A_2(Y) + B_2(Y)]g(U,Z) + C_2(U)g(Y,Z) + D_2(Z)g(U,Y), \end{aligned} \tag{2.4}$$

where A_i, B_i, C_i, D_i meaning already stated and K is given by,

$$K(Y,Z) = \frac{n}{2n+4}[S(Y,Z) - \frac{r}{2(n+1)}g(Y,Z)]. \tag{2.5}$$

3 $A(GWS)_n$-Kähler manifold

We assume that (M_n, g) is an $A(GWS)_n$-Kähler manifold. Then from (2.1) we can write

$$(\nabla_X R)(Y,U,V,W) = (\nabla_X R)(JY,JU,V,W). \tag{3.1}$$

Using (1.1) in above equation, we get

$$\begin{aligned}&C_1(Y)R(X,U,V,W)+C_1(U)R(Y,X,V,W)+[A_2(X)+B_2(X)]G(Y,U,V,W)\\&+C_2(Y)G(X,U,V,W)+C_2(U)G(Y,X,V,W)+D_2(V)G(Y,U,X,W)\\&+D_2(W)G(Y,U,V,X)=C_1(JY)R(X,JU,V,W)+C_1(JU)R(JY,X,V,W)\\&+[A_2(X)+B_2(X)]G(JY,JU,V,W)+C_2(JY)G(X,JU,V,W)\\&+C_2(JU)G(JY,X,V,W)+D_2(V)G(JY,JU,X,W)+D_2(W)G(JY,JU,V,X).\end{aligned}\tag{3.2}$$

Now take, $U=V=e_i$ in (3.2) and after simplification we get

$$\begin{aligned}&C_1(Y)S(X,W)-C_1(R(Y,X)W)+[A_2(X)+B_2(X)](n-1)g(Y,W)\\&+C_2(Y)(n-1)g(X,W)+C_2(X)g(Y,W)-C_2(Y)g(X,W)+D_2(X)g(Y,W)\\&-D_2(W)g(Y,X)+D_2(W)(n-1)g(Y,X)=C_1(JY)S(X,JW)-C_1(R(JY,X)JW)\\&+[A_2(X)+B_2(X)]g(Y,W)+C_2(JY)g(X,JW)+C_2(Y)g(X,W)\\&-D_2(JX)g(JY,W)+D_2(JW)g(JY,X)+D_2(W)g(Y,X).\end{aligned}\tag{3.3}$$

Again putting $Y=\pi_1=\pi_2=\rho_2=\sigma_2=\delta_2=e_i$ in above equation we get

$$S(X,W)=(n^2-4)g(X,W).\tag{3.4}$$

Hence we state the following:

Theorem 3.1. *Let M_n be an $A(GWS)_n$-Kähler manifold then it is an Einstein manifold.*

Put $Y=W=e_i$ in (3.3) then

$$n[A_2(X)+B_2(X)]+2C_2(X)+2D_2(X)=0.\tag{3.5}$$

Thus we have the following:

Theorem 3.2. *In an $A(GWS)_n$-Kähler manifold the sum of the associated 1-forms is given by (3.5).*

Now contracting Y over W in both sides of (1.1), we get

$$\begin{aligned}&(\nabla_X S)(U,V)=[A_1(X)+B_1(X)]S(U,V)+C_1(U)S(X,V)+C_1(R(X,U)V)\\&+D_1(R(X,U)V)+D_1(V)S(U,X)+(n-1)\{[A_2(X)+B_2(X)]g(U,V)\\&+C_2(U)g(X,V)+D_2(V)g(U,X)\}+C_2(g(X,U)V)+D_2(g(X,V)U).\end{aligned}\tag{3.6}$$

Setting $U=V=e_i$ in (3.6) and taking summation over i, $1\le i\le n$, we get

$$\begin{aligned}&dr(X)=r[A_1(X)+B_1(X)]+2S(X,\pi_1)+2S(X,\delta_1)\\&+(n-1)\left\{n[A_2(X)+B_2(X)]+2C_2(X)+2D_2(X)\right\}.\end{aligned}\tag{3.7}$$

Using equations (3.4) and (3.5) in the above equation we can write

$$dr(X)=(n^2-4)[n[A_1(X)+B_1(X)]+2C_2(X)+2D_1(X)].\tag{3.8}$$

If r is a constant scalar curvature then we get

$$[n[A_1(X)+B_1(X)]+2C_2(X)+2D_1(X)]=0.\tag{3.9}$$

Hence we state the following:

Corollary 3.3. *In an $A(GWS)_n$-Kähler manifold the relation (3.9) holds good provided the scalar curvature is constant.*

Using the equation (3.4) in (3.7) we get

$$dr(X) = r[A_1(X) + B_1(X)] + 2S(X, \pi_1) + 2S(X, \delta_1). \tag{3.10}$$

If r is zero scalar curvature then above equation can be written as $S(X, 2\pi_1 + 2\delta_1) = 0$. Thus we state the following corollary's:

Corollary 3.4. *If M_n is an $A(GWS)_n$-Kähler manifold then $2\pi_1 + 2\delta_1$ is the eigen vector of the Ricci tensor S with respect to the zero eigen value.*

Corollary 3.5. *Let M_n be an $A(GWS)_n$-Kähler manifold and also let π_1 and δ_1 be linearly independent then the manifold is Ricci flat.*

4 $A(GWRS)_n$-Kähler manifold

We suppose that (M_n, g) is an $A(GWRS)_n$-Kähler manifold. From (2.1) we can record as

$$(\nabla_X S)(U, V) = (\nabla_X S)(JU, JV). \tag{4.1}$$

Using (1.2) in (4.1), we get

$$\begin{aligned} &C_1(JU)S(X, JV) + D_1(JV)S(JU, X) + C_2(JU)g(X, JV) + D_2(JV)g(JU, X) \\ &= C_1(U)S(X, V) + D_1(V)S(U, X) + C_2(U)g(X, V) + D_2(V)g(U, X). \end{aligned} \tag{4.2}$$

Setting $V = \pi_1 = \delta_1 = \pi_2 = \delta_2 = e_i$, then the equation (4.2) reduces to

$$S(U, X) = -g(U, X). \tag{4.3}$$

Hence we can write the following:

Theorem 4.1. *If M_n is an $A(GWRS)_n$-Kähler manifold then it is is an Einstein manifold.*

Shrinking (4.2), we can obtain

$$2S(U, \delta_1) = -2D_2(U) - rC_1(U) - nC_2(U). \tag{4.4}$$

Using (4.3) in (4.4), we have

$$2D_1(U) + nC_1(U) = 2D_2(U) + nC_2(U). \tag{4.5}$$

Then we can declare the following:

Corollary 4.2. *In an $A(GWRS)_n$-Kähler manifold (M^n, g) $(n > 2)$, the sum of the associated 1-form are related by (4.5).*

From equation (1.2) we get

$$\begin{aligned} &(\nabla_X S)(U, V) - (\nabla_U S)(X, V) = [A_1(X) + B_1(X)]S(U, V) - [A_1(U) + B_1(U)]S(X, V) \\ &+C_1(U)S(X, V) - C_1(X)S(U, V) + [A_2(X) + B_2(X)]g(U, V) + C_2(U)g(X, V) \\ &-[A_2(U) + B_2(U)]g(X, V) - C_2(X)g(U, V), \end{aligned} \tag{4.6}$$

shrinking above equation, we get

$$\begin{aligned} -\frac{1}{2}dr(U) \quad = \quad & S(U, \sigma_1) + S(U, \rho_1) - S(U, \pi_1) + r[C_1(U) - A_1(U) - B_1(U)] \\ & +(n-1)[C_2(U) - A_2(U) - B_2(U)], \end{aligned} \tag{4.7}$$

using equation (4.3) then the above equation can be recorded as

$$-\frac{1}{2}dr(U) = -(n+1)[A_1(U) + B_1(U) - C_1(U)] - (n-1)[A_2(U) + B_2(U) - C_2(U)], \tag{4.8}$$

if r is a constant scalar curvature then the above equation becomes

$$-(n+1)[A_1(U) + B_1(U) - C_1(U)] = (n-1)[A_2(U) + B_2(U) - C_2(U)]. \tag{4.9}$$

Corollary 4.3. *In an $A(GWRS)_n$-Kähler manifold (M^n, g) $(n > 2)$, the relation (4.9) holds good provided the scalar curvature is constant.*

If $A_2 = B_2 = C_2 = 0$ then the equation (4.9) becomes

$$A_1(U) + B_1(U) = C_1(U). \tag{4.10}$$

If $A_2 = B_2 = C_2 = D_2 = 0$ and $A_1(U)+B_1(U) = C_1(U)$ then equation (1.2) reduces to special type of weakly Ricci symmetric manifold. Hence we can state the following:

Corollary 4.4. *An $A(GWRS)_n$-Kähler manifold (M^n, g) $(n > 2)$ is reduced to special type of weakly Ricci symmetric manifold provided $A_2 = B_2 = C_2 = D_2 = 0$ and scalar curvature is constant.*

5 $A(GWBS)_n$-Kähler manifold

In this section we study $A(GWBS)_n$-Kähler manifold, we get

$$B(JY, JV, U, W) = B(Y, V, U, W). \tag{5.1}$$

Taking the covariant differentiation of (5.1) along an arbitrary vector field X then we get

$$(\nabla_X B)(JY, JV, U, W) = \nabla_X B(Y, V, U, W), \tag{5.2}$$

using (2.2) in (5.2), we get

$$\begin{aligned}
&C_1(Y)B(X,U,V,W) + C_1(U)B(Y,X,V,W) + [A_2(X) + B_2(X)]G(Y,U,V,W)\\
&+C_2(Y)G(X,U,V,W) + C_2(U)G(Y,X,V,W) + D_2(V)G(Y,U,X,W)\\
&+D_2(W)G(Y,U,V,X) = C_1(JY)B(X,JU,V,W) + C_1(JU)B(JY,X,V,W)\\
&+[A_2(X) + B_2(X)]G(JY,JU,V,W) + C_2(JY)G(X,JU,V,W)\\
&+C_2(JU)G(JY,X,V,W) + D_2(V)G(JY,JU,X,W) + D_2(W)G(JY,JU,V,X).
\end{aligned} \tag{5.3}$$

Putting $U = V = e_i$ in (5.3) and after simplification we obtain

$$\begin{aligned}
&C_1(Y)K(X,W) - C_1(B(Y,X)W) + [A_2(X) + B_2(X)](n-1)g(Y,W)\\
&+C_2(Y)(n-1)g(X,W) + C_2(X)g(Y,W) - C_2(Y)g(X,W) + D_2(X)g(Y,W)\\
&-D_2(W)g(Y,X) + D_2(W)(n-1)g(Y,X) = C_1(JY)K(X,JW) - C_1(R(JY,X)JW)\\
&+[A_2(X) + B_2(X)]g(Y,W) + C_2(JY)g(X,JW) + C_2(Y)g(X,W)\\
&-D_2(JX)g(JY,W) + D_2(JW)g(JY,X) + D_2(W)g(Y,X).
\end{aligned} \tag{5.4}$$

Setting $Y = \pi_1 = \pi_2 = \rho_2 = \sigma_2 = \delta_2 = e_i$ then the above equation can be written as

$$K(X, W) = (n^2 - 4)g(X, W), \tag{5.5}$$

using (2.5) in (5.5), we get

$$S(X, W) = \tau g(X, W).$$

where $\tau = \frac{r+2(n+1)(n^2-4)}{2(n+1)}$. So we can say the following:

Theorem 5.1. *If M^n is an $A(GWBS)_n$-Kähler manifold then it is an Einstein manifold.*

Putting $Y = W = e_i$ in (5.4), we get

$$n[A_2(X) + B_2(X)] + 2C_2(X) + 2D_2(X) = 0. \tag{5.6}$$

Theorem 5.2. *In an $A(GWBS)_n$-Kähler manifold the sum of the associated 1-forms are related by (5.6).*

6 $A(GWBRS)_n$-Kähler manifold

We assume that Kähler manifold is an $A(GWBRS)_n$-Kähler manifold, then we have

$$\begin{aligned} &C_1(JU)K(X,JV)+D_1(JV)K(JU,X)+C_2(JU)g(X,JV)+D_2(JV)g(JU,X)\\ &=C_1(U)K(X,V)+D_1(V)K(U,X)+C_2(U)g(X,V)+D_2(V)g(U,X). \end{aligned} \tag{6.1}$$

Setting $V=\pi_1=\delta_1=\pi_2=\delta_2=e_i$ then the equation (6.1) can be written as

$$K(X,W) \quad = \quad -g(X,W), \tag{6.2}$$

using equation (2.5) in (6.2),we get

$$S(X,W) \quad = \quad \frac{rn+2(n+2)}{n}g(X,W).$$

Hence we state the following:

Theorem 6.1. *If M^n is an $A(GWBRS)_n$-Kähler manifold then it is an Einstein manifold.*

Putting $X=V=e_i$ in equation (6.1), we get

$$2K(U,\delta_1)+2D_2(U)+nC_2(U)]+C_1(U)\{\frac{nr}{4(n+1)}\} \quad = \quad 0. \tag{6.3}$$

using equation (6.2) then the preceeding equation can be written as

$$-2D_1(U)+2D_2(U)+nC_2(U)+C_1(U)\{\frac{r}{4(n+1)}\} \quad = \quad 0. \tag{6.4}$$

Therefore we can say the following:

Theorem 6.2. *In an $A(GWBRS)_n$-Kähler manifold (M^n,g) $(n>2)$, the sum of the associated 1-form are related by (6.4).*

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