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Some curvature tensors on a generalized Sasakian space form

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Abstract

In the present paper, we have studied the geometry of generalized Sasakian space form with the condition satisfying $W^*(\xi, X)W^* = 0$, $W^*(\xi, X)S = 0$, $W^*(\xi, X)P = 0$ and $P(\xi, X)P = 0$.

Keywords: Generalized Sasakian space form, M-projective curvature tensor, Projective curvature tensor.

2010 MSC: 53D10, 53D15, 53C25.

1 Introduction

A Sasakian manifold (M, ϕ, ξ, η, g) is said to be a Sasakian space form [3], if all the ϕ-sectional curvatures $K(X \wedge \phi X)$ are equal to a constant C, where $K(X \wedge \phi X)$ denotes the sectional curvature of the section spanned by the unit vector field X, orthogonal to ξ and ϕX. In such a case, the Riemannian curvature tensor of M is given by,

$$\begin{aligned} R(X,Y)Z &= \frac{C+3}{4}\{g(Y,Z)X - g(X,Z)Y\} \\ &+ \frac{C-1}{4}\{g(X,\phi Z)\phi Y - g(Y,\phi Z)\phi X + 2g(X,\phi Y)\phi Z\} \\ &+ \frac{C-1}{4}\{\eta(X)\eta(Z)Y - \eta(Y)\eta(Z)X \\ &+ g(X,Z)\eta(Y)\xi - g(Y,Z)\eta(X)\xi\}. \end{aligned} \tag{1.1}$$

As a natural generalization of these manifolds, Alegre P., Blair D. E. and Carriazo A. [1, 3] introduced the notion of generalized Sasakian space form.

Sasakian space form and generalized Sasakian space form have been studied by several authors, viz., [2], [3], [5], [9], [14], [15].

De U. C. and Sarkar A. [9] studied properties of projective curvature tensor to generalized Sasakian space form. Mehmet Atceken [10] studied generalized Sasakian space form satisfying certain conditions on the concircular curvature tensor.

The properties of the M-projective curvature tensor in Sasakian and Kaehler manifolds were studied by Ojha R. H. [11, 12]. He showed that it bridges the gap between the conformal curvature tensor, coharmonic curvature tensor and concircular curvature tensor. Chaubey S. K. and Ojha R. H. [7] studied the properties of the M-projective curvature tensor in Riemannian and Kenmotsu manifolds. Chaubey S. K. [8] also studied the properties of M-projective curvature tensor in LP-Sasakian manifold. Present authors [4] have studied some properties of M-projective curvature tensor in a generalized Sasakian space form. Motivated by these ideas, in the present paper we have extended the study of further properties of M-projective curvature tensor to generalized Sasakian space form. The present paper is organized as follows:

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In section 2, we review some preliminary results. From section 3 onwards we have obtained necessary and sufficient condition for a generalized Sasakian space form satisfying the derivation conditions $W^*(\xi, X)W^* = 0$, $W^*(\xi, X)S = 0$, $W^*(\xi, X)P = 0$ and $P(\xi, X)P = 0$. We have proved that these conditions are satisfied if and only if $f_3 = \frac{3f_2}{(1-2n)}$.

2 Preliminaries

An odd-dimensional Riemannian manifold (M, g) is called an almost contact manifold if there exists on M, a $(1,1)$ tensor field ϕ, a vector field ξ and a 1-form η [6] such that,

$$\phi^2(X) = -X + \eta(X)\xi, \tag{2.2}$$

$$\eta(\phi X) = 0, \tag{2.3}$$

$$g(\phi X, \phi Y) = g(X, Y) - \eta(X)\eta(Y), \tag{2.4}$$

$$\phi\xi = 0, \quad \eta(\xi) = 0, \quad g(X, \xi) = \eta(X), \tag{2.5}$$

for any vector fields X, Y on M.

If in addition, ξ is a Killing vector field, then M is said to be a K-contact manifold. It is well known that a Contact metric manifold is a K-contact manifold if and only if $(\nabla_X \xi) = -\phi(X)$ for any vector field X on M.

Given an almost contact metric manifold (M, ϕ, ξ, η, g) we say that M is an generalized Sasakian space form [1], if there exists three functions f_1, f_2 and f_3 on M such that

$$\begin{aligned} R(X,Y)Z &= f_1\{g(Y,Z)X - g(X,Z)Y\} \\ &+ f_2\{g(X,\phi Z)\phi Y - g(Y,\phi Z)\phi X + 2g(X,\phi Y)\phi Z\} \\ &+ f_3\{\eta(X)\eta(Z)Y - \eta(Y)\eta(Z)X \\ &+ g(X,Z)\eta(Y)\xi - g(Y,Z)\eta(X)\xi\}, \end{aligned} \tag{2.6}$$

for any vector fields X, Y, Z on M, where R denotes the curvature tensor of M. This kind of manifold appears as a natural generalization of the well-known Sasakian space form $M(C)$, which can be obtained as particular cases of generalized Sasakian space form by taking $f_1 = \frac{C+3}{4}$ and $f_2 = f_3 = \frac{C-1}{4}$. Further in a $(2n+1)$-dimensional generalized Sasakian space form, we have [1]

$$(\nabla_X \phi)(Y) = (f_1 - f_3)(g(X,Y)\xi - \eta(Y)X), \tag{2.7}$$

$$(\nabla_X \xi) = -(f_1 - f_3)\phi(X), \tag{2.8}$$

$$QX = (2nf_1 + 3f_2 - f_3)X - (3f_2 + (2n-1)f_3)\eta(X)\xi, \tag{2.9}$$

$$S(X,Y) = (2nf_1 + 3f_2 - f_3)g(X,Y) - (3f_2 + (2n-1)f_3)\eta(X)\eta(Y), \tag{2.10}$$

$$r = 2n(2n+1)f_1 + 6nf_2 - 4nf_3, \tag{2.11}$$

$$R(X,Y)\xi = (f_1 - f_3)[\eta(Y)X - \eta(X)Y], \tag{2.12}$$

$$R(\xi,X)Y = (f_1 - f_3)[g(X,Y)\xi - \eta(Y)X], \tag{2.13}$$

$$\eta(R(X,Y)Z) = (f_1 - f_3)[g(Y,Z)\eta(X) - g(X,Z)\eta(Y)], \tag{2.14}$$

$$S(X,\xi) = 2n(f_1 - f_3)\eta(X). \tag{2.15}$$

In 1971, Pokhariyal G. P. and Mishra R. S. [13] defined M-projective curvature tensor W^* on a Riemannian manifold as

$$\begin{aligned} W^*(X,Y)Z &= R(X,Y)Z - \frac{1}{4n}[S(Y,Z)X - S(X,Z)Y \\ &+ g(Y,Z)QX - g(X,Z)QY], \end{aligned} \tag{2.16}$$

and projective curvature tensor [16] is defined as

$$P(X,Y)Z = R(X,Y)Z - \frac{1}{2n}[S(Y,Z)X - S(X,Z)Y]. \tag{2.17}$$

3 Generalized Sasakian space form satisfying $W^*(\xi, X)W^* = 0$

Let us consider a generalized Sasakian space form satisfying

$$W^*(\xi, X)W^* = 0. \tag{3.18}$$

The above equation can be written as

$$\begin{aligned} & W^*(\xi, X)W^*(Y, Z)U - W^*(W^*(\xi, X)Y, Z)U \\ & -W^*(Y, W^*(\xi, X)Z)U - W^*(Y, Z)W^*(\xi, X)U = 0, \end{aligned} \tag{3.19}$$

for any vector field X, Y, Z, U on M.
In view of (2.5), (2.9), (2.10) and (2.13), (2.16) becomes

$$W^*(\xi, X)Y = \frac{1}{4n}[(1-2n)f_3 - 3f_2](g(X, Y)\xi - \eta(Y)X) \tag{3.20}$$

and

$$\eta(W^*(X, Y)Z) = \frac{1}{4n}[(1-2n)f_3 - 3f_2][g(Y, Z)\eta(X) - g(X, Z)\eta(Y)]. \tag{3.21}$$

From (2.16) and (3.20), we find

$$\begin{aligned} W^*(\xi, X)W^*(Y, Z)U &= \frac{1}{4n}[(1-2n)f_3 - 3f_2][g(X, W^*(Y, Z)U)\xi \\ &- \frac{1}{4n}[(1-2n)f_3 - 3f_2][g(Z, U)\eta(Y)X - g(Y, U)\eta(Z)X]] \end{aligned} \tag{3.22}$$

and

$$\begin{aligned} W^*(W^*(\xi, X)Y, Z)U &= \frac{1}{4n}[(1-2n)f_3 - 3f_2][\frac{(1-2n)f_3 - 3f_2}{4n}[g(X, Y)g(Z, U)\xi \\ &- g(X, Y)\eta(U)Z] - \eta(Y)W^*(X, Z)U]. \end{aligned} \tag{3.23}$$

Substituting $Z = \xi$ in (2.16), we get

$$W^*(X, Y)\xi = \frac{1}{4n}[(1-2n)f_3 - 3f_2](\eta(Y)X - \eta(X)Y), \tag{3.24}$$

Substituting (3.20), (3.22), (3.23) in (3.19), we get

$$\begin{aligned} & \frac{(1-2n)f_3 - 3f_2}{4n}[g(W^*(Y, Z)U, X)\xi - \frac{(1-2n)f_3 - 3f_2}{4n}[g(Z, U)\eta(Y)X \\ - & \ g(Y, U)\eta(Z)X + g(X, Y)g(Z, U)\xi - g(X, Y)\eta(U)Z + g(X, Z)\eta(U)Y \\ - & \ g(X, Z)g(U, Y)\xi + g(X, U)\eta(Z)Y - g(X, U)\eta(Y)Z] \\ + & \ \eta(Y)W^*(X, Z)U + \eta(Z)W^*(Y, X)U + \eta(U)W^*(Y, Z)X] = 0. \end{aligned} \tag{3.25}$$

Taking inner product of (3.25) with respect to ξ and using (2.16) and (3.21), we get

$$\begin{aligned} & \frac{(1-2n)f_3 - 3f_2}{4n}[g(R(Y, Z)U, X) \\ - & \ \frac{4nf_1 + 3f_2 - (1+2n)f_3}{4n}[g(X, Y)g(Z, U) - g(X, Z)g(Y, U)] \\ - & \ \frac{3f_2 + (2n-1)f_3}{4n}[g(X, Z)\eta(U)\eta(Y) + g(Y, U)\eta(Z)\eta(X) \\ - & \ g(X, Y)\eta(Z)\eta(U) - g(Z, U)\eta(X)\eta(Y)]] = 0. \end{aligned} \tag{3.26}$$

This implies either

$$f_3 = \frac{3f_2}{(1-2n)} \tag{3.27}$$

or

$$\begin{aligned} g(R(Y,Z)U,X) &= \frac{4nf_1+3f_2-(1+2n)f_3}{4n}[g(X,Y)g(Z,U) \\ &- g(X,Z)g(Y,U)] + \frac{3f_2+(2n-1)f_3}{4n}[g(X,Z)\eta(U)\eta(Y) \\ &+ g(Y,U)\eta(Z)\eta(X) - g(X,Y)\eta(Z)\eta(U) - g(Z,U)\eta(X)\eta(Y)]. \end{aligned} \quad (3.28)$$

Let $\{e_i\}, i = 1, 2, ..., 2n+1$ be an orthonormal basis of the tangent space at any point of the space form. Then putting $X = Y = e_i$, in (3.28) and taking summation over i, $1 \le i \le 2n+1$, we get

$$\begin{aligned} S(Z,U) &= \frac{1}{4n}[[2n(4nf_1+3f_2-(1+2n)f_3) \\ &- (3f_2+(2n-1)f_3)]g(Z,U) \\ &- (2n-1)(3f_2+(2n-1)f_3)\eta(U)\eta(Z)]. \end{aligned} \quad (3.29)$$

Contracting the above equation we get,

$$r = \frac{1}{2}[(2n+1)(4nf_1+3f_2-(1+2n)f_3) - 2(3f_2+(2n-1)f_3)], \quad (3.30)$$

using (2.11) we get

$$f_3 = \frac{3f_2}{(1-2n)}. \quad (3.31)$$

This leads us to state the following:

Theorem 3.1. *A $(2n+1)$-dimensional $(n > 1)$ generalized Sasakian space form satisfies the condition $W^*(\xi, X)W^* = 0$ if and only if $f_3 = \frac{3f_2}{(1-2n)}$.*

4 Generalized Sasakian space form satisfying $W^*(\xi, X)S = 0$

The condition $W^*(\xi, X)S = 0$ implies that

$$S(W^*(\xi,X)Y,Z) + S(Y,W^*(\xi,X)Z) = 0. \quad (4.32)$$

Substituting (3.20) in (4.32), we obtain

$$\begin{aligned} &\frac{(1-2n)f_3-3f_2}{4n}[g(X,Y)S(\xi,Z) - \eta(Y)S(X,Z) \\ &+ S(Y,\xi)g(X,Z) - \eta(Z)S(X,Y)] = 0. \end{aligned} \quad (4.33)$$

Again substituting $Z = \xi$ in (4.33), we get

$$\frac{(1-2n)f_3-3f_2}{4n}[S(X,Y) - 2n(f_1-f_3)g(X,Y)] = 0. \quad (4.34)$$

This implies either

$$f_3 = \frac{3f_2}{(1-2n)} \quad (4.35)$$

or

$$S(X,Y) = 2n(f_1-f_3)g(X,Y). \quad (4.36)$$

On contracting (4.36), we find

$$r = 2n(2n+1)(f_1-f_3) \quad \text{and so} \quad f_3 = \frac{3f_2}{(1-2n)}. \quad (4.37)$$

Thus, we state

Theorem 4.2. *A $(2n+1)$-dimensional $(n > 1)$ generalized Sasakian space form satisfies the condition $W^*(\xi, X)S = 0$ if and only if $f_3 = \frac{3f_2}{(1-2n)}$.*

5 Generalized Sasakian space form satisfying $W^*(\xi, X)P = 0$

We know that,

$$\begin{aligned}(W^*(\xi,X)P)(Y,Z)U &= W^*(\xi,X)P(Y,Z)U - P(W^*(\xi,X)Y,Z)U \\ &- P(Y,W^*(\xi,X)Z)U - P(Y,Z)W^*(\xi,X)U.\end{aligned} \tag{5.38}$$

But as we assume $W^*(\xi, X)P = 0$, (5.38) takes the form

$$\begin{aligned}&W^*(\xi,X)P(Y,Z)U - P(W^*(\xi,X)Y,Z)U \\ - &P(Y,W^*(\xi,X)Z)U - P(Y,Z)W^*(\xi,X)U = 0.\end{aligned} \tag{5.39}$$

In view of (2.14), we obtain from (2.17) that

$$\eta(P(X,Y)Z) = \frac{1}{2n}[(1-2n)f_3 - 3f_2][g(Y,Z)\eta(X) - g(X,Z)\eta(Y)]. \tag{5.40}$$

From (2.17) and (3.20), we find

$$\begin{aligned}W^*(\xi,X)P(Y,Z)U &= \frac{1}{4n}[(1-2n)f_3 - 3f_2][g(X,R(Y,Z)U)\xi \\ &- \frac{1}{2n}[S(U,Z)g(X,Y) - S(Y,U)g(X,Z)]\xi \\ &- \frac{1}{2n}[(1-2n)f_3 - 3f_2][g(Z,U)\eta(Y)X - g(Y,U)\eta(Z)X]]\end{aligned} \tag{5.41}$$

and

$$\begin{aligned}P(W^*(\xi,X)Y,Z)U &= \frac{1}{4n}[(1-2n)f_3 - 3f_2][(f_1 - f_3)g(X,Y)g(Z,U)\xi \\ &- \frac{1}{2n}S(U,Z)g(X,Y)\xi - \eta(Y)P(X,Z)U].\end{aligned} \tag{5.42}$$

Also

$$P(Y,Z)W^*(\xi,X)U = -\frac{1}{4n}[(1-2n)f_3 - 3f_2]\eta(U)P(Y,Z)X]. \tag{5.43}$$

Substituting (5.41), (5.42) and (5.43) in (5.39), we get

$$\begin{aligned}&\frac{(1-2n)f_3 - 3f_2}{4n}[g(R(Y,Z)U,X)\xi \\ - &\frac{1}{2n}[S(U,Z)g(X,Y) - S(Y,U)g(X,Z)]\xi \\ - &\frac{1}{2n}[(1-2n)f_3 - 3f_2][g(Z,U)\eta(Y)X - g(Y,U)\eta(Z)X] \\ - &(f_1 - f_3)g(X,Y)g(Z,U)\xi + \frac{1}{2n}S(U,Z)g(X,Y)\xi \\ + &(f_1 - f_3)g(X,Z)g(Y,U)\xi - \frac{1}{2n}S(Y,U)g(X,Z)\xi \\ + &\eta(Y)P(X,Z)U + \eta(Z)P(Y,X)U + \eta(U)P(Y,Z)X] = 0\end{aligned} \tag{5.44}$$

Taking inner product of (5.44) with respect to the Riemannian metric g and then using (2.5) and (5.40), we have

$$\begin{aligned}&\frac{1}{4n}[(1-2n)f_3 - 3f_2][g(R(Y,Z)U,X) \\ - &(f_1 - f_3)\{g(X,Y)g(Z,U) - g(X,Z)g(Y,U)\} \\ + &\frac{1}{2n}[(1-2n)f_3 - 3f_2][g(X,Z)\eta(Y)\eta(U) - g(X,Y)\eta(Z)\eta(U)]] = 0.\end{aligned} \tag{5.45}$$

This implies either

$$f_3 = \frac{3f_2}{(1-2n)} \tag{5.46}$$

or

$$g(R(Y,Z)U,X) = (f_1 - f_3)\{g(X,Y)g(Z,U) - g(X,Z)g(Y,U)\} - \frac{1}{2n}[(1-2n)f_3 - 3f_2][g(X,Z)\eta(Y)\eta(U) - g(X,Y)\eta(Z)\eta(U)]. \quad (5.47)$$

Let $\{e_i\}, i = 1, 2, ..., 2n+1$ be an orthonormal basis of the tangent space at any point of the space form. Then putting $X = Y = e_i$, in (5.47) and taking summation over i, $1 \leq i \leq 2n+1$, we get

$$S(Z,U) = 2n(f_1 - f_3)g(Z,U) + [(1-2n)f_3 - 3f_2]\eta(Z)\eta(U). \quad (5.48)$$

Contracting (5.48), we find

$$r = 2n(2n+1)(f_1 - f_3) + (1-2n)f_3 - 3f_2. \quad (5.49)$$

Using (2.11), the above equation gives

$$f_3 = \frac{3f_2}{(1-2n)} \quad (5.50)$$

Thus, we state

Theorem 5.3. *A $(2n+1)$-dimensional $(n > 1)$ generalized Sasakian space form satisfies the condition $W^*(\xi, X)P = 0$ if and only if $f_3 = \frac{3f_2}{(1-2n)}$.*

6 An generalized Sasakian space form satisfying $P(\xi, X)P = 0$

The condition $P(\xi, X)P = 0$ implies that

$$(P(\xi,X)P)(Y,Z)U = P(\xi,X)P(Y,Z)U - P(P(\xi,X)Y,Z)U - P(Y,P(\xi,X)Z)U - P(Y,Z)P(\xi,X)U = 0. \quad (6.51)$$

In view of (2.5), (2.10) and (2.13), (2.17) becomes

$$P(\xi,X)Y = (f_1 - f_3)g(X,Y)\xi - \frac{1}{2n}S(X,Y)\xi \quad (6.52)$$

Using (6.52)in (6.51), we get

$$\begin{aligned} &(f_1 - f_3)g(P(Y,Z)U,X)\xi - \frac{1}{2n}S(P(Y,Z)U,X)\xi \\ &- [(f_1 - f_3)g(X,Y) - \frac{1}{2n}S(X,Y)][(f_1 - f_3)g(Z,U) - \frac{1}{2n}S(Z,U)]\xi \\ &- [(f_1 - f_3)g(X,Z) - \frac{1}{2n}S(X,Z)][\frac{1}{2n}S(Y,U) - (f_1 - f_3)g(Y,U)]\xi \\ &- [(f_1 - f_3)g(X,U) - \frac{1}{2n}S(X,U)]P(Y,Z)\xi = 0, \end{aligned} \quad (6.53)$$

Taking inner product of (6.53) with respect to the Riemannian metric g and then using (2.10), (2.17) and (5.40), we have

$$\frac{1}{2n}[(1-2n)f_3 - 3f_2][g(R(Y,Z)U,X) - (f_1 - f_3)\{g(X,Y)g(Z,U) - g(X,Z)g(Y,U)\}] = 0. \quad (6.54)$$

$\Rightarrow$ $f_3 = \frac{3f_2}{(1-2n)}$ or

$$g(R(Y,Z)U,X) = (f_1 - f_3)\{g(X,Y)g(Z,U) - g(X,Z)g(Y,U)\}. \quad (6.55)$$

(6.55) implies

$$R(Y,Z)U = (f_1 - f_3)\{g(Z,U)Y - g(Y,U)Z\}. \quad (6.56)$$

Contracting (6.56) with respect to the vector field Y, we find

$$S(Z,U) = 2n(f_1 - f_3)g(Z,U). \tag{6.57}$$

On contracting the above equation, we get

$$r = 2n(2n+1)(f_1 - f_3) \quad and \ so \quad f_3 = \frac{3f_2}{(1-2n)}. \tag{6.58}$$

Thus, we state

Theorem 6.4. *A $(2n+1)$-dimensional $(n > 1)$ generalized Sasakian space form satisfies the condition $P(\xi, X)P = 0$ if and only if $f_3 = \frac{3f_2}{(1-2n)}$.*

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