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CERTAIN CURVATURE PROPERTIES OF LP-SASAKIAN MANIFOLD WITH RESPECT TO QUARTER SYMMETRIC NON METRIC CONNECTION

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Abstract- The object of the present paper is to study of various curvature tensor on an Lorentzian para-Sasakian manifold with respect to quarter-symmetric non-metri connection.

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Key words and phrases- Lorentzian para-Sasakian manifold, Projective tensor, Psudo Projective tensor,Concircular curvature tensor,Quasi-Concircular curvature tensor

1 *Introduction*

In 1975,Golab [4] introduced the notion of quarter − symmetric connection in a Riemannian manifold with affine connection. This was further developed by Yano and Imai [27], Rastogi [22], Mishra and Pandey [10], Mukhopadhyay, Roy and Barua [11], Biswas and De [3], Sengupta and Biswas [23], Singh and Pandey [25] and many other geometers.In this paper we define and study a quarter − symmetric non − metric connection on an Lorentzian para − Sasakian manifold . Section 1 , is introductory . In section 2 , we give the definition of Lorentzian para − Sasakian . In section 3 , we define a quarter − symmetric non − metric connection . In section 4 , curvature tensor Ricci tensor and scalar curvature tensor of the quarter − symmetric non − metric connection $\overline{\nabla}$ is obtained . In section 5 , we have A necessary and sufficient condition for the Ricci tensor of $\overline{\nabla}$ to be symmetric and skew − symmetric . In section 6 ,The Projective curvature tensor of the quarter − symmetric non − metric connection in Lorentzian para − Sasakian manifold is studied. In section 7 ,We have studied Psudo Projective curvature tensor of the quarter − symmetric non − metric connection in Lorentzian para − Sasakian manifold is studied . In section 8,The Concircular curvature tensor of the quarter − symmetric non − metric connection in Lorentzian para-sasakian and finally In section 9,The Quasi − Concircular curvature tensor of the quarter − symmetric non − metric connection in Lorentzian para − Sasakian manifold is studied.

2 Preliminaries

An $n-$dimensional differential manifold M^n is a Lorentzian para$-$Sasakian (LP$-$Sasakian) manifold if it admits a $(1,1)-$tensor field ϕ, contravariant vector field ξ,a covariant vector field η, and a Lorentzian metric g, which satisfy

$$\phi^2 X = X + \eta(X)\xi, \tag{2.1}$$

$$\eta(\xi) = -1, \tag{2.2}$$

$$g(\phi X, \phi Y) = g(X,Y) + \eta(X)\eta(Y), \tag{2.3}$$

$$g(X,\xi) = \eta(X), \tag{2.4}$$

$$(\nabla_X \phi)(Y) = g(X,Y)\xi + \eta(Y)X + 2\eta(X)\eta(Y)\xi, \tag{2.5}$$

$$\nabla_X \xi = \phi X, \tag{2.6}$$

for any vector fields X and Y, where ∇ denotes covariant differentiation with respect to metric g ([7], [14] and [8]).

In an LP$-$Sasakian manifold M^n with structure (ϕ, ξ, η, g), it is easily seen that

$$\phi\xi = 0, \qquad \eta(\phi X) = 0, \quad rank(\phi) = (n-1), \tag{2.7}$$

$$F(X,Y) = g(\phi X, Y). \tag{2.8}$$

Then the tensor field F is symmetric $(0,2)$ tensor field

$$F(X,Y) = F(Y,X), \tag{2.9}$$

$$F(X,Y) = (\nabla_X \eta)(Y). \tag{2.10}$$

3 The Quarter$-$symmetric non$-$metric Connection in a LP$-$Sasakian manifold

Let (M^n, g) be an LP$-$Sasakian manifold with Levi$-$Civita connection ∇ we define linear connection $\overline{\nabla}$ on M^n by

$$\overline{\nabla}_X Y = \nabla_X Y - \eta(X)\phi Y - \eta(X)Y - \eta(Y)X + g(X,Y)\xi, \tag{3.1}$$

for all vector fields X and $Y \in \Gamma(TM^n)$.

Using (3.1) the torsion tensor $\overline{T}$ of M^n with respect to the connection $\overline{\nabla}$ is given by

$$\overline{T}(X,Y) = \eta(Y)\phi X - \eta(X)\phi Y. \tag{3.2}$$

A linear connection satisfying (3.2) is called quarter$-$symmetric connections ([5],[13],[17],[20]).

Further

using (3.1) we have

$$(\overline{\nabla}_X g)(Y,Z) = 2\eta(X)g(Y,Z) + 2\eta(X)g(\phi Y,Z). \tag{3.3}$$

A linear connection ∇ defined by (3.1) satisfies (3.2) and (3.3) is called quarter$-$symmetric non$-$metric connection.

Let $\overline{\nabla}$ be a linear connection in M^n given by

$$\overline{\nabla}_X Y = \nabla_X Y + H(X,Y). \tag{3.4}$$

Now we shall determine the tensor field H such that $\overline{\nabla}$ satisfies (3.2) and (3.3)

From (3.4), we have

$$T(X,Y) = H(X,Y) - H(Y,X). \tag{3.5}$$

We have

$$G(X,Y,Z) = (\overline{\nabla}_X g)(Y,Z). \tag{3.6}$$

From (3.4) and (3.6) we have

$$g(H(X,Y),Z) + g(H(X,Z),Y) = -G(X,Y,Z). \tag{3.7}$$

From (3.4), (3.6), (3.7) and (3.3), we have

$$\begin{aligned}
g(\overline{T}(X,Y),Z) + g(\overline{T}(Z,X),Y) + g(\overline{T}(Z,Y),X) &= g(H(X,Y),Z) - g(H(Y,X),Z) \\
&\quad + g(H(Z,X),Y) - g(H(X,Z),Y) \\
&\quad + g(H(Z,Y),X) - g(H(Y,Z),X) \\
&= g(H(X,Y),Z) + G(X,Y,Z) \\
&\quad + G(Y,X,Z) - G(Z,X,Y) \\
&= 2g(H(X,Y),Z) \\
&\quad + 2\eta(X)g(Y,Z) + 2\eta(X)g(\phi Y,Z) \\
&\quad + 2\eta(Y)g(X,Z) + 2\eta(Y)g(\phi X,Z) \\
&\quad + 2\eta(Z)g(X,Y) + 2\eta(Z)g(\phi X,Y),
\end{aligned}$$

$$\begin{aligned}
H(X,Y) &= \frac{1}{2}\left\{\overline{T}(X,Y) + \overline{T}^{\circ}(X,Y) + \overline{T}^{\circ}(Y,X)\right\} \\
&\quad - \eta(X)Y - \eta(Y)X + g(X,Y)\xi \\
&\quad - \eta(X)\phi Y - \eta(Y)\phi X + g(\phi X,Y)\xi.
\end{aligned} \tag{3.8}$$

Where $\overline{T}^{\circ}$ be a tensor field of type $(1,2)$ defined by

$$g(\overline{T}^{\circ}(X,Y),Z) = g(\overline{T}(Z,X),Y). \tag{3.9}$$

From (3.2) and (3.9), we have

$$\overline{T}^{\circ}(X,Y) = \eta(X)\phi Y - g(\phi X,Y)\xi. \tag{3.10}$$

Using (3.2) and (3.10) in (3.8), we get

$$H(X,Y) = -\eta(X)\phi Y - \eta(X)Y - \eta(Y)X + g(X,Y)\xi. \tag{3.11}$$

This implies

$$\overline{\nabla}_X Y = \nabla_X Y - \eta(X)\phi Y - \eta(X)Y - \eta(Y)X + g(X,Y)\xi. \tag{3.12}$$

Theorem 1 *Let (M^n, g) be an $LP-$Sasakian manifold with almost Lorentzian$-$ Para contact metric structure (ϕ,ξ,η,g) admitting a quarter$-$symmetric non$-$metric connection $\overline{\nabla}$ which satisfies (3.2) and (3.3) then the quarter–symmetric non$-$metric connection is given by (3.12)*

4 Curvature tensor of an $LP-$Sasakian manifold with respect to the Quarter$-$ symmetric non$-$metric Connection $\overline{\nabla}$

Let $\overline{R}$ and R be the curvature tensor of the connection $\overline{\nabla}$ and ∇ respectively

$$\overline{R}(X,Y)Z = \overline{\nabla}_X \overline{\nabla}_Y Z - \overline{\nabla}_Y \overline{\nabla}_X Z - \overline{\nabla}_{[X,Y]} Z. \tag{4.1}$$

:

From (4.1) and (3.1), we get

$$\begin{aligned}\overline{R}(X,Y)Z &= \overline{\nabla}_X (\nabla_Y Z - \eta(Y)\phi Z - \eta(Y)Z - \eta(Z)Y + g(Y,Z)\xi)\\ &- \overline{\nabla}_Y (\nabla_X Z - \eta(X)\phi Z - \eta(X)Z - \eta(Z)X + g(X,Z)\xi)\\ &- \nabla_{[X,Y]} Z - \eta([X,Y])\phi Z - \eta([X,Y])Z - \eta(Z)[X,Y]\\ &+ g([X,Y],Z)\xi.\end{aligned} \tag{4.2}$$

Using $(2.5)(2.52.6)$ and (3.1) in (4.2), we get

$$\begin{aligned}\overline{R}(X,Y)Z &= R(X,Y)Z + F(Y,Z)X - F(X,Z)Y\\ &+ g(Y,Z)\phi X - g(X,Z)\phi Y\\ &+ \eta(X)\eta(Z)\phi Y - \eta(Y)\eta(Z)\phi X\\ &+ g(Y,Z)X - g(X,Z)Y\\ &+ \eta(X)F(Y,Z)\xi - \eta(Y)F(X,Z)\xi\\ &+ 2\eta(X)g(Y,Z)\xi - 2\eta(Y)g(X,Z)\xi.\end{aligned} \tag{4.3}$$

Where

$$R(X,Y)Z = \nabla_X \nabla_Y Z - \nabla_Y \nabla_X Z - \nabla_{X,Y]} Z,$$

is the curvature tensor of with respect to the Riemannian Connection ∇.
Contracting (4.3), we get

$$\begin{aligned}\overline{S}(Y,Z) &= S(Y,Z) + (n-3)g(\phi Y,Z)\\ &+ (\psi + n - 3)g(Y,Z) - (\psi + 2)\eta(Y)\eta(Z),\end{aligned} \tag{4.4}$$

$$\overline{r} = r + 2(n-1)\psi + (n-1)(n-2), \tag{4.5}$$

where $\bar{S}$ and $\bar{r}$ are the Ricci tensor and scalar curvature with respect to $\bar{\nabla}$ and $\psi = trace\ \phi$.

Theorem 2 *The Curvature tensor* $\bar{R}(X,Y)Z$ *and Ricci tensor* $\bar{S}(Y,Z)$ *and scalar curvature* $\bar{r}$ *of an LP−Sasakian manifold with respect to quarter−symmetric non−metric connection as given by* $(4.3),(4.34.4)$ *and* (4.5) *respectively.*

Let us assume that $\bar{R}(X,Y)Z = 0$ in (4.3), we get

$$S(Y,Z) = -(n-3)g(\phi Y,Z) - (\psi + n - 3)g(Y,Z) + (\psi + 2)\eta(Y)\eta(Z),$$

which gives

$$r = -2(n-1)\psi - (n-1)(n-2)$$

Theorem 3 *If an LP−Sasakian manifold* M^n *admits a quarter−symmetric non−metric connection whose curvature tensor vanishes, then the scalar curvature* r *is given by*

$$r = -2(n-1)\psi - (n-1)(n-2).$$

From (4.3), we get

$$\bar{R}(X,Y,Z,W) + \bar{R}(Y,X,Z,W) = 0. \tag{4.6}$$

Again by virtue of (4.3) and first Binachi's identity with respect to connection ∇ we have

$$\bar{R}(X,Y,Z,W) + \bar{R}(Y,Z,X,W) + \bar{R}(Z,X,Y,W) = 0.$$

5 *Projective Curvature tensor on an LP−Sasakian manifold with respect to the Quarter−symmetric non−metric Connection* $\bar{\nabla}$

Let $\bar{P}$ and P denote the projective curvature tensor with respect to connection $\bar{\nabla}$ and ∇ respectively. then

$$\bar{P}(X,Y)Z = \bar{R}(X,Y)Z - \frac{1}{(n-1)}\left[\bar{S}(Y,Z)X - \bar{S}(X,Z)Y\right], \tag{5.1}$$

and

$$P(X,Y)Z = R(X,Y)Z - \frac{1}{(n-1)}\left[S(Y,Z)X - S(X,Z)Y\right]. \tag{5.2}$$

Using (4.3) & (4.4) in (5.1), we find

$$\bar{P}(X,Y)Z = P(X,Y)Z + F(Y,Z)X - F(X,Z)Y \tag{5.3}$$

$$
\begin{aligned}
&+g(Y,Z)\phi X-g(X,Z)\phi Y\\
&+\eta(X)\eta(Z)\phi Y-\eta(Y)\eta(Z)\phi X\\
&+g(Y,Z)X-g(X,Z)Y\\
&+\eta(X)F(Y,Z)\xi-\eta(Y)F(X,Z)\xi\\
&+2\eta(X)g(Y,Z)\xi-2\eta(Y)g(X,Z)\xi\\
&-\frac{1}{n-1}[(n-3)\{g(\phi Y,Z)X-g(\phi X,Z)Y\}\\
&+(\psi+n-3)\{g(Y,Z)X-g(X,Z)Y\}\\
&-(\psi+2)\{\eta(Y)\eta(Z)X-\eta(X)\eta(Z)Y\}].
\end{aligned}
$$

If

$$
\begin{aligned}
&F(Y,Z)X-F(X,Z)Y+g(Y,Z)\phi X-g(X,Z)\phi Y\\
&+\eta(X)\eta(Z)\phi Y-\eta(Y)\eta(Z)\phi X+g(Y,Z)X-g(X,Z)Y\\
&+\eta(X)F(Y,Z)\xi-\eta(Y)F(X,Z)\xi\\
&+2\eta(X)g(Y,Z)\xi-2\eta(Y)g(X,Z)\xi\\
&=\frac{1}{n-1}[(n-3)\{g(\phi Y,Z)X-g(\phi X,Z)Y\}\\
&+(\psi+n-3)\{g(Y,Z)X-g(X,Z)Y\}\\
&-(\psi+2)\{\eta(Y)\eta(Z)X-\eta(X)\eta(Z)Y\}],
\end{aligned}
\tag{5.4}
$$

then from equation (5.3), we get

$$\bar{P}(X,Y)Z=P(X,Y)Z.$$

Hence, we can state the following theorem;

Theorem 4 *In an LP−Sasakian manifold Projective Curvature tensor with respect to Riemannian connection is equal to the Projective Curvature tensor with respect to Quarter−symmetric non−metric Connection* $\bar{\nabla}$ *if equation* (5.4) *holds.*

6 Psudo Projective Curvature tensor on an LP−Sasakian manifold with respect to the Quarter−symmetric non−metric Connection $\bar{\nabla}$

Let $\overline{\overset{\square}{P}}$ and $\overset{\square}{P}$ denote the Psudo projective curvature tensor with respect to connection $\bar{\nabla}$ and ∇ respectively[12]. then

$$
\begin{aligned}
\overline{\overset{\square}{P}}(X,Y)Z&=a\bar{R}(X,Y)Z-\frac{1}{(n-1)}\left[\bar{S}(Y,Z)X-\bar{S}(X,Z)Y\right]\\
&-\frac{\bar{r}}{n}\left[\frac{a}{(n-1)}+b\right][g(Y,Z)X-g(X,Z)Y],
\end{aligned}
\tag{6.1}
$$

and

$$\overset{\square}{P}(X,Y)Z=aR(X,Y)Z-\frac{1}{(n-1)}\left[S(Y,Z)X-S(X,Z)Y\right] \tag{6.2}$$

$$-\frac{r}{n}\left[\frac{a}{(n-1)}+b\right][g(Y,Z)X-g(X,Z)Y].$$

Using (4.3) & (4.4) in (6.1), we find

$$\begin{aligned}\bar{\tilde{P}}(X,Y)Z &= \tilde{P}(X,Y)Z+\{a+b(n-3)\}[F(Y,Z)X-F(X,Z)Y] \\ &+a[g(Y,Z)\phi X-g(X,Z)\phi Y] \\ &+a[\eta(X)\eta(Z)\phi Y-\eta(Y)\eta(Z)\phi X] \\ &+\Big[a+b(\psi+n-3)- \\ &\frac{2(n-1)\psi+(n-1)(n-2)}{n}\left\{\frac{a}{n-1}+b\right\}\Big] \\ &[g(Y,Z)X-g(X,Z)Y] \\ &+a[\eta(X)F(Y,Z)\xi-\eta(Y)F(X,Z)\xi] \\ &+a[2\eta(X)g(Y,Z)\xi-2\eta(Y)g(X,Z)\xi] \\ &-b(\psi+2)[\eta(Y)\eta(Z)X-\eta(X)\eta(Z)Y].\end{aligned} \tag{6.3}$$

If

$$\begin{aligned}&\{a+b(n-3)\}[F(Y,Z)X-F(X,Z)Y]+a[g(Y,Z)\phi X-g(X,Z)\phi Y] \\ &+a[\eta(X)\eta(Z)\phi Y-\eta(Y)\eta(Z)\phi X]= \\ &-\Big[a+b(\psi+n-3)- \\ &\frac{2(n-1)\psi+(n-1)(n-2)}{n}\left\{\frac{a}{n-1}+b\right\}\Big] \\ &[g(Y,Z)X-g(X,Z)Y] \\ &-a[\eta(X)F(Y,Z)\xi-\eta(Y)F(X,Z)\xi] \\ &-a[2\eta(X)g(Y,Z)\xi-2\eta(Y)g(X,Z)\xi] \\ &+b(\psi+2)[\eta(Y)\eta(Z)X-\eta(X)\eta(Z)Y],\end{aligned} \tag{6.4}$$

then from equation (6.3) we get

$$\bar{\tilde{P}}(X,Y)Z=\tilde{P}(X,Y)Z.$$

Hence, we can state the following theorem;

Theorem 5 *In an LP$-$Sasakian manifold Psudo Projective Curvature tensor with respect to Riemannian connection is equal to the Psudo Projective Curvature tensor with respect to Quarter$-$symmetric non$-$metric Connection $\bar{\nabla}$ if equation (6.4) holds.*

7 Concircular Curvature tensor on an LP$-$Sasakian manifold with respect to the Quarter$-$symmetric non$-$metric Connection $\bar{\nabla}$

Let $\bar{C}$ and C denote the Concircular curvature tensor with respect to connection $\bar{\nabla}$ and ∇ respectively. then

$$\bar{C}(X,Y)Z = \bar{R}(X,Y)Z - \frac{\bar{r}}{n(n-1)}[g(Y,Z)X - g(X,Z)Y], \tag{7.1}$$

and

$$C(X,Y)Z = R(X,Y)Z - \frac{r}{n(n-1)}[g(Y,Z)X - g(X,Z)Y]. \tag{7.2}$$

Using $(4.3),(4.34.4)$ & (4.5) in (7.1), we find

$$\begin{aligned} \bar{C}(X,Y)Z &= C(X,Y)Z + F(Y,Z)X - F(X,Z)Y \\ &+ g(Y,Z)\phi X - g(X,Z)\phi Y \\ &+ \eta(X)\eta(Z)\phi Y - \eta(Y)\eta(Z)\phi X \\ &+ \eta(X)F(Y,Z)\xi - \eta(Y)F(X,Z)\xi \\ &+ 2\eta(X)g(Y,Z)\xi - 2\eta(Y)g(X,Z)\xi \\ &- \frac{1}{n}[2(\psi-1)\{g(Y,Z)X - g(X,Z)Y\}]. \end{aligned} \tag{7.3}$$

If

$$\begin{aligned} &F(Y,Z)X - F(X,Z)Y + g(Y,Z)\phi X - g(X,Z)\phi Y \\ &+ \eta(X)\eta(Z)\phi Y - \eta(Y)\eta(Z)\phi X \\ &+ \eta(X)F(Y,Z)\xi - \eta(Y)F(X,Z)\xi \\ &+ 2\eta(X)g(Y,Z)\xi - 2\eta(Y)g(X,Z)\xi \\ &= \frac{2(\psi-1)}{n}[g(Y,Z)X - g(X,Z)Y], \end{aligned} \tag{7.4}$$

then from equation (7.3) we get

$$\bar{C}(X,Y)Z = C(X,Y)Z.$$

Hence, we can state the following theorem;

Theorem 6 *In an $LP-$Sasakian manifold Concircular Curvature tensor with respect to Riemannian connection is equal to the Concircular Curvature tensor with respect to Quarter$-$symmetric non$-$metric Connection $\bar{\nabla}$ if equation (7.4) holds.*

8 Quasi$-$Concircular Curvature tensor on an LP$-$Sasakian manifold with respect to the Quarter$-$symmetric non$-$metric Connection $\bar{\nabla}$

Let $\bar{L}$ and L denote the Quasi$-$Concircular curvature tensor with respect to connection $\bar{\nabla}$ and ∇ respectively. then

$$\bar{L}(X,Y)Z = a\bar{R}(X,Y)Z + \frac{\bar{r}}{n}\left[\frac{a}{n-1} + 2b\right][g(Y,Z)X - g(X,Z)Y], \tag{8.1}$$

and

$$L(X,Y)Z = aR(X,Y)Z + \frac{r}{n}\left[\frac{a}{n-1} + 2b\right][g(Y,Z)X - g(X,Z)Y], \tag{8.2}$$

Using $(4.3),(4.34.4)$ & (4.5) in (7.1), we find

$$\begin{aligned}\bar{L}(X,Y)Z &= L(X,Y)Z + a[F(Y,Z)X - F(X,Z)Y] \\ &+ a[g(Y,Z)\phi X - g(X,Z)\phi Y] \\ &+ a[\eta(X)\eta(Z)\phi Y - \eta(Y)\eta(Z)\phi X] \\ &+ a[\eta(X)F(Y,Z)\xi - \eta(Y)F(X,Z)\xi] \\ &+ a[2\eta(X)g(Y,Z)\xi - 2\eta(Y)g(X,Z)\xi] \\ &+ \left[a + \frac{2(n-1)\psi + (n-1)(n-2)}{n}\left\{\frac{a}{n-1} + 2b\right\}\right] \\ &\{g(Y,Z)X - g(X,Z)Y\}.\end{aligned} \tag{8.3}$$

If

$$\begin{aligned}& a[F(Y,Z)X - F(X,Z)Y] \\ &+ a[g(Y,Z)\phi X - g(X,Z)\phi Y] \\ &+ a[\eta(X)\eta(Z)\phi Y - \eta(Y)\eta(Z)\phi X] \\ &+ a[\eta(X)F(Y,Z)\xi - \eta(Y)F(X,Z)\xi] \\ &+ a[2\eta(X)g(Y,Z)\xi - 2\eta(Y)g(X,Z)\xi] = \\ &- \left[a + \frac{2(n-1)\psi + (n-1)(n-2)}{n}\left\{\frac{a}{n-1} + 2b\right\}\right] \\ &\{g(Y,Z)X - g(X,Z)Y\},\end{aligned} \tag{8.4}$$

then from equation (8.3) we get

$$\bar{L}(X,Y)Z = L(X,Y)Z.$$

Hence, we can state the following theorem;

Theorem 7 *In an LP−Sasakian manifold Quasi−Concircular Curvature tensor with respect to Riemannian connection is equal to the Quasi−Concircular Curvature tensor with respect to Quarter−symmetric non−metric Connection* $\bar{\nabla}$ *if equation* (8.4) *holds.*

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