Some results of Kenmotsu manifolds admitting Schouten-Van Kampen connection

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Abstract

In this paper we study some curvature properties of Kenmotsu manifolds with respect to the Schouten-van Kampen connection satisfying Pseudo-Projectively flat, ξ- Pseudo-Projectively flat, ϕ-Pseudo-Projectively Semi-symmetric, Pseudo-Pseudo-Projectively flat, W_8^*-flat, ξ-W_8^*-flat, ϕ-W_8^*- Semi-symmetric, Pseudo-W_8^*-flat conditions.

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1. Introduction

The study of Schouten-van Kampen connection has been initiated for the study of non-holomorphic manifolds. It preserves by parallelism, the Schouten-van Kampen connection is one of the most natural connections adapted to a pair of complementary distributions on a differentiable manifold endowed with an affine connection ([2], [11], [19]). Olszak [15] studied and proved some interesting results on the Schouten-van Kampen connection to adapt to an almost(para) contact metric structure. Later on some interesting properties of Schouten-van Kampen connection with different manifolds studied by many authors like ([7], [13], [14], [23]).

Kenmotsu [12] introduced and studied the fundamental properties on local structure of a new class of almost contact Riemann manifold which is known as Kenmotsu Manifold. Several properties of Kenmotsu Manifold have been studied by many authors like ([1], [3], [4], [6], [9], [10], [16], [17], [20]). Motivated by all these work in this paper we study Kenmotsu manifolds admitting Schouten-Van Kampen connection with Pseudo-Projective and W_8-curvature tensor.

The present paper is organized as follows: After a brief review of Kenmotsu manifold and some curvature properties of Kenmotsu manifolds with respect to the Schouten-van Kampen connection we study Pseudo-Projectively flat, ξ- Pseudo-Projectively flat, ϕ-Pseudo-Projectively Semi-symmetric, Pseudo-Pseudo-Projectively flat, W_8^*-flat, ξ-W_8^*-flat, ϕ-W_8^*- semisymmetric, Pseudo-W_8^*-flat conditions.

2. Preliminaries

In this section, we briefly recall some general definitions of Kenmotsu manifolds:

An n-dimensional differential manifold M is said to be an almost contact metric manifold [3] if it admits an almost contact metric structure (ϕ, ξ, η, g) consisting of a tensor field ϕ of type $(1, 1)$, a vector field ξ and 1-form η and a Riemannian metric g compatible with (ϕ, ξ, η) satisfying

(2.1) $$\phi^2 = -I + \eta\otimes\xi, \ \eta(\xi) = 1, \ \eta \circ \phi = 0, \ \phi\xi = 0.$$

(2.2) $$g(\phi X, \phi Y) = g(X,Y) - \eta(X)\eta(Y), \ g(X, \xi) = \eta(X).$$

An almost contact metric manifold is said to be a Kenmotsu manifold [12] if it satisfies

(2.3) $$(\nabla_X \phi)Y = -\eta(Y)\phi X - g(X,\phi Y)\xi,$$

(2.4) $$\nabla_X \xi = X - \eta(X)\xi,$$

(2.5) $$(\nabla_X \eta)Y = g(\nabla_X\xi, Y),$$

where ∇ denotes the Riemannian connection of g.

In a Kenmotsu manifold [12] the following relations hold:

(2.6) $\eta(R(X,Y)Z) = g(X,Z)\eta(Y) - g(Y,Z)\eta(X),$

(2.7) $R(X,Y)\xi = \eta(X)Y - \eta(Y)X,$

(2.8) $R(\xi,X)Y = \eta(Y)X - g(X,Y)\xi,$

(2.9) $S(X,\xi) = -(n-1)\eta(X),$

(2.10) $Q\,\xi = -(n-1)\xi,$

for any vector fields X, Y, Z on M, where R, S and Q denotes the curvature tensor, Ricci tensor and Ricci operator

$g(QX,Y) = S(X,Y)$ on M.

3. Some curvature properties of Kenmotsu manifolds with respect to Schouten-van Kampen Connection

In this section, we study some basic properties of Kenmotsu manifolds with respect to Schouten-van Kampen Connection. The Schouten-van Kampen Connection ∇^* associated to the Levi-Civita connection ∇ is given by [15]

(3.1) $\nabla^*_X Y = \nabla_X Y - \eta(Y)\nabla_X\xi + (\nabla_X\eta)(Y)\xi,$

for any vector fields X, Y on M.

By using (2.4) and (2.5) in (3.1), we get

(3.2) $\nabla^*_X Y = \nabla_X Y + g(X,Y)\xi - \eta(Y)X.$

Putting $Y = \xi$ in (3.2) and by virtue of (2.4), we obtain

(3.3) $\nabla^*_X\,\xi = 0.$

A relation between the Riemannian curvature tensor R^* of a Kenmotsu manifolds with respect to the Schouten-van Kampen connection ∇^* and the Levi-Civita connection ∇ is given by

(3.4) $R^*(X,Y)Z = R(X,Y)Z + g(Y,Z)X - g(X,\ Z)Y.$

Putting $Z = \xi$ in (3.4) and by using (2.7), we have

(3.5) $R^*(X,Y)\xi = 0.$

On contracting (3.4), we get the Ricci tensor S^* of a Kenmotsu manifolds with respect to the Schouten-van Kampen connection ∇^*

(3.6) $S^*(Y,Z) = S(Y,Z) + (n-1)g(Y,Z).$

From (3.6), we obtain

(3.7) $Q^*Y = QY + (n-1)Y.$

On contracting (3.6), we get

(3.8) $r^* = r + n\,(n-1),$

where r^* and r are the scalar curvature with respect to the Schouten-van Kampen connection ∇^* and the Levi-Civita

connection ∇ respectively.

4. Pseudo-Projectively flat Kenmotsu manifold with respect to Schouten-van Kampen connection

In this section, we study Pseudo-Projectively flat Kenmotsu manifold with respect to the Schouten-van Kampen connection:

Definition 4.1. A Kenmotsu manifold is said to be Pseudo-Projectively flat with respect to the Schouten-van Kampen connection if

(4.1) $P^*(X,Y)Z = 0$

for any vector fields X, Y, Z on M. Pseudo-Projective curvature tensor [22] is defined as

(4.2) $P^*(X,Y)Z = a\,R^*(X,Y)Z + b[S^*(Y,Z)X - S^*(X,Z)Y] - \frac{r^*}{n}\left[\frac{a}{n-1} + b\right][g(Y,Z)X - g(X,Z)Y],$

where R^* and S^* are the curvature tensor and Ricci tensor of the manifold with respect to the Schouten-van Kampen connection respectively.

From (4.1) and (4.2), we get

(4.3) $a\,R^*(X,Y)Z + b[S^*(Y,Z)X - S^*(X,Z)Y] - \frac{r^*}{n}\left[\frac{a}{n-1} + b\right][g(Y,Z)X - g(X,Z)Y] = 0.$

By taking an innerproduct with ξ in (4.3), we obtain

(4.4) $$a\,g(R^*(X,Y)Z,\xi) + b[S^*(Y,Z)g(X,\xi) - S^*(X,Z)g(Y,\xi)]$$
$$-\frac{r^*}{n}\left[\frac{a}{n-1} + b\right][g(Y,Z)g(X,\xi) - g(X,Z)g(Y,\xi)] = 0.$$

By using (3.4), (3.6) in (4.4) and on simplification, we have

(4.5) $b[S(Y,Z)\eta(X) - S(X,Z)\eta(Y)] + \left[\frac{-ar-an(n-1)-br(n-1)}{n(n-1)}\right][g(Y,Z)\eta(X) - g(X,Z)\eta(Y)] = 0.$

Putting $X = \xi$ in (4.5) and by virtue of (2.9), we get

(4.6) $S(Y,Z) = \left[\frac{ar+an(n-1)+br(n-1)}{b\,n(n-1)}\right]g(Y,Z) - \left[(n-1) + \frac{ar+an(n-1)+br(n-1)}{b\,n(n-1)}\right]\eta(Y)\eta(Z).$

Hence, we state the following theorem:

Theorem 4.1. For a Pseudo-Projectively flat Kenmotsu manifold with respect to the Schouten-van Kampen connection the manifold is an η-Einstein manifolds with $b \neq 0$.

5. ξ-Pseudo-Projectively flat Kenmotsu manifold with respect to Schouten-van Kampen connection

In this section, we study ξ-Pseudo-Projectively flat Kenmotsu manifold with respect to the Schouten-van Kampen connection ∇^*:

Definition 5.2. A Kenmotsu manifold is said to be ξ-Pseudo-Projectively flat with respect to the Schouten-van Kampen connection if

(5.1) $P^*(X,Y)\xi = 0$

for any vector fields X, Y on M.

From (4.2), we get

(5.2) $P^*(X,Y)\xi = a\,R^*(X,Y)\xi + b[S^*(Y,\xi)X - S^*(X,\xi)Y] - \frac{r^*}{n}\left[\frac{a}{n-1} + b\right][g(Y,\xi)X - g(X,\xi)Y].$

From (5.1) and (5.2), we obtain

(5.3) $a\,R^*(X,Y)\xi + b[S^*(Y,\xi)X - S^*(X,\xi)Y] - \frac{r^*}{n}\left[\frac{a}{n-1} + b\right][g(Y,\xi)X - g(X,\xi)Y] = 0.$

By using (3.5), (3.6) in (5.3), we get

(5.4) $-\frac{r^*}{n}\left[\frac{a}{n-1} + b\right][\eta(Y)X - \eta(X)Y] = 0.$

Putting $Y = \xi$ in (5.4) and on simplification, we have

(5.5) $\frac{r+n(n-1)}{n}\left[\frac{a}{n-1}+b\right][X-\eta(X)\xi]=0.$

By taking an innerproduct with U in (5.5), we get

(5.6) $\frac{r+n(n-1)}{n}\left[\frac{a}{n-1}+b\right][g(X,U)-\eta(X)\eta(U)]=0.$

The above equation implies that either $r=-n(n-1)$ or

(5.7) $g(X,U)-\eta(X)\eta(U)=0$

with $a\neq -b(n-1)$. Now, replacing $X=QX$ in (5.7) and on simplification, we obtain

(5.8) $S(X,U)=-(n-1)\eta(X)\eta(U).$

Hence, we state the following theorem:

Theorem 5.2. For a ξ-Pseudo-Projectively flat Kenmotsu manifold with respect to the Schouten-van Kampen connection, either the scalar curvature $r=-n(n-1)$ or the manifold is a special type of η-Einstein manifolds with $a\neq -b(n-1)$.

6. ϕ-Pseudo-Projectively Semi-symmetric Kenmotsu manifold with respect to Schouten-van Kampen connection

In this section, we study ϕ-Pseudo-Projectively Semi-symmetric Kenmotsu manifold with respect to the Schouten-van Kampen connection ∇^*:

Definition 6.3. A Kenmotsu manifold is said to be ϕ-Pseudo-Projectively Semi-symmetric with respect to the Schouten-van Kampen connection if

(6.1) $P^*(X,Y)\cdot\phi=0,$

for any vector fields X, Y on M.

Now, (6.1) turns into

(6.2) $(P^*(X,Y)\cdot\phi)Z=P^*(X,Y)\phi Z-\phi P^*(X,Y)Z=0.$

Putting $Z=\xi$ in (6.2) and by virtue of (4.2) and on simplification, we obtain

(6.3) $-\frac{r^*}{n}\left[\frac{a}{n-1}+b\right][\eta(Y)\phi X-\eta(X)\phi Y]=0.$

Putting $Y=\xi$ and $X=\phi X$ in (6.3), we get

(6.4) $\frac{r+n(n-1)}{n}\left[\frac{a}{n-1}+b\right][-X+\eta(X)\xi]=0.$

Taking innerproduct with V in (6.4), we get

(6.5) $\frac{r+n(n-1)}{n}\left[\frac{a}{n-1}+b\right][-g(X,V)+\eta(X)\eta(V)]=0.$

The above equation implies that either $r=-n(n-1)$ or

(6.6) $-g(X,V)+\eta(X)\eta(V)=0$

with $a\neq -b(n-1)$. Now, replacing $X=QX$ in (6.6) and on simplification, we obtain

(6.7) $S(X,V)=-(n-1)\eta(X)\eta(V).$

Hence, we state the following theorem:

Theorem 6.3. For a ϕ-Pseudo projectively Semi-symmetric Kenmotsu manifold with respect to the Schouten-van Kampen connection either the scalar curvature $r=-n(n-1)$ or the manifold is a special type of η-Einstein manifolds with $a\neq -b(n-1)$.

7. Pseudo-Pseudo-Projectively flat Kenmotsu manifold with respect to Schouten-van Kampen connection

In this section, we study Pseudo-Pseudo-Projectively flat Kenmotsu manifold with respect to the Schouten-van Kampen connection ∇^*:

Definition 7.4. A Kenmotsu manifold is said to be Pseudo-Pseudo-Projectively flat with respect to the Schouten-van Kampen connection if

(7.1) $g(P^*(\phi X, Y)Z, \phi W) = 0,$

for any vector fields $X,\ Y, Z,\ W$ on M.

By using (4.2) in (7.1), we get

(7.2) $$a\, g(R^*(\phi X, Y)Z, \phi W) + b[S^*(Y,Z)g(\phi X, \phi W) - S^*(\phi X, Z)g(Y, \phi W)]$$
$$-\frac{r^*}{n}\left[\frac{a}{n-1} + b\right] [g(Y,Z)\, g(\phi X, \phi W) - g(\phi X, Z) g(Y, \phi W)] = 0.$$

Let $\{e_1, e_2, \dots e_n\}$ be a local orthonormal basis of vector fields in M. Then by putting $Y = Z = e_i$ in (7.2) and by virtue of (3.4), (3.6), (3.8) and on simplification, we obtain

(7.3) $$S(\phi X, \phi W) = \frac{r}{n}\ g(\phi X, \phi W).$$

Putting $W = \phi\, W$ and $X = \phi X$ in (7.3) and on simplification, we get

(7.4) $$S(X, W) = \frac{r}{n}\ g(X, W) - \left[\frac{r}{n} + (n-1)\right] \eta(X)\eta(V).$$

Hence, we state the following theorem:

Theorem 7.4. For a Pseudo-Pseudo projectively flat Kenmotsu manifold with respect to the Schouten-van Kampen

connection then the manifold is an η-Einstein manifold.

8. $W_8{}^*$ -flat Kenmotsu manifold with respect to Schouten-van Kampen connection

In this section, we study $W_8{}^*$ -flat in Kenmotsu manifold with respect to the Schouten-van Kampen connection:

Definition 8.5. A Kenmotsu manifold is said to be $W_8{}^*$ -flat with respect to the Schouten-van Kampen connection if

(8.1) $W_8{}^*\,(X, Y)Z = 0$

for any vector fields $X,\ Y,\ Z$ on M. $W_8{}^*$ -curvature tensor [22] is defined as

(8.2) $$W_8{}^*\,(X, Y)Z = R^*(X, Y)Z + \frac{1}{n-1}[S^*(X, Y)Z - S^*(Y, Z)X],$$

where R^* and S^* are the curvature tensor and Ricci tensor of the manifold with respect to the Schouten-van Kampen connection respectively.

From (8.1) and (8.2), we get

(8.3) $$R^*(X, Y)Z = -\frac{1}{n-1}[S^*(X, Y)Z - S^*(Y, Z)X],$$

By taking an innerproduct with ξ in (8.3), we obtain

(8.4) $$g(R^*(X, Y)Z, \xi) = -\frac{1}{n-1}[S^*(X, Y)g(Z, \xi) - S^*(Y, Z)g(X, \xi)].$$

By using (3.4), (3.6) in (8.4) and on simplification, we have

(8.5) $$S(X,\ Y)\eta(Z) + (n-1)g(X, Y)\eta(Z) - S(Y, Z)\eta(X) - (n-1)g(Y, Z)\eta(X) = 0.$$

Putting $Z = \xi$ in (8.5) and by virtue of (2.9), we get

(8.6) $$S(X,\ Y) = -(n-1)g(X, Y).$$

Hence, we state the following theorem:

Theorem 8.5. If a Kenmotsu manifold satisfying W_8^* -flat condition with respect to the Schouten-van Kampen connection then the manifold is an Einstein manifolds.

9. $\xi - W_8^*$ -flat Kenmotsu manifold with respect to Schouten-van Kampen connection

In this section, we study $\xi - W_8^*$ -flat Kenmotsu manifold with respect to the Schouten-van Kampen connection:

Definition 9.6. A Kenmotsu manifold is said to be $\xi - W_8^*$ -flat with respect to the Schouten-van Kampen connection if

(9.1) $$W_8^*(X,Y)\xi = 0$$

for any vector fields X, Y on M.

From (9.1) and (8.2), we get

(9.2) $$R^*(X,Y)\xi = -\frac{1}{n-1}[S^*(X,Y)\xi - S^*(Y,\xi)X].$$

By using (3.5), (3.6) in (9.2), we obtain

(9.3) $$S^*(X,Y)\xi = -(n-1)g(X,Y)\xi.$$

By taking an innerproduct with ξ in (9.3), we have

(9.4) $$S^*(X,Y) = -(n-1)g(X,Y).$$

Hence, we state the following theorem:

Theorem 9.6. If a Kenmotsu manifold satisfying $\xi - W_8^*$ -flat condition with respect to the Schouten-van Kampen connection then the manifold is an Einstein manifolds.

10. $\phi - W_8^*$ -semisymmetric condition in Kenmotsu manifold with respect to Schouten-van Kampen connection

In this section, we study $\phi - W_8^*$ -Semi-symmetric condition in Kenmotsu manifold with respect to the Schouten-van Kampen connection:

Definition 10.7. A Kenmotsu manifold is said to be $\phi - W_8^*$ -Semi-symmetric with respect to the Schouten-van Kampen connection if

(10.1) $$W_8^*(X,Y)\cdot\phi = 0,$$

for any vector fields X, Y on M.

Now, (10.1) turns into

(10.2) $$\left(W_8^*(X,Y)\cdot\phi\right)Z = W_8^*(X,Y)\phi Z - \phi W_8^*(X,Y)Z = 0.$$

Making use of (8.2) in (10.2), we get

(10.3) $$R^*(X,Y)\phi Z + \frac{1}{n-1}[S^*(X,Y)\phi Z - S^*(Y,\phi Z)X]$$
$$-\phi\left(R^*(X,Y)Z + \frac{1}{n-1}[S^*(X,Y)Z - S^*(Y,Z)X]\right) = 0.$$

Putting $X = \xi$ in (10.3) and by virtue of (3.4), (3.6) and on simplification, we obtain

(10.4) $$R(\xi,Y)\phi Z - \frac{1}{n-1}[S(Y,\phi Z)\xi + (n-1)g(Y,\phi Z)\xi] - \phi(R(\xi,Y)Z - \eta(Z)Y + g(Y,Z)\xi) = 0.$$

By using (2.8) in (10.4) and on simplification, we get

(10.5) $$-\frac{1}{n-1}[S(Y,\phi Z)\xi + (n-1)g(Y,\phi Z)\xi] = 0.$$

By taking an innerproduct with ξ in (10.5), we have

(10.6) $$S(Y,\phi Z) = -(n-1)g(Y,\phi Z).$$

Replace $Z = \phi Z$ in (10.6) and on simplification, we get

(10.7) $$S(Y,Z) = -(n-1)g(Y,Z).$$

On contracting (10.7), we obtain

(10.8) $$r = -n(n-1).$$

Hence, we state the following theorem:

Theorem 10.7. If a Kenmotsu manifold satisfying $\phi - W_8{}^*$ -Semi-symmetric condition with respect to the Schouten-van Kampen connection then the manifold is an Einstein manifold and the scalar curvature $r = -n(n-1)$.

11. Pseudo-$W_8{}^*$ -flat Kenmotsu manifold with respect to Schouten-van Kampen connection

In this section, we study Pseudo-$W_8{}^*$ -flat Kenmotsu manifold with respect to the Schouten-van Kampen connection ∇^*:

Definition 11.8. A Kenmotsu manifold is said to be Pseudo-$W_8{}^*$ -flat with respect to the Schouten-van Kampen connection if

(11.1) $$g(W_8{}^*(\phi X,Y)Z,\phi W) = 0,$$

for all vector fields X, Y, Z, W on M.

By using (8.2) in (11.1), we get

(11.2) $$g(R^*(\phi X,Y)Z,\phi W) + \frac{1}{n-1}[S^*(\phi X,Y)g(Z,\phi W) - S^*(Y,Z)g(\phi X,\phi W)] = 0.$$

Let $\{e_1, e_2, \dots e_n\}$ be a local orthonormal basis of vector fields in M. Then by putting $Y = Z = e_i$ in (11.2) and by

virtue of (3.4), (3.6) and on simplification, we obtain

(11.3) $$S(\phi X,\phi W) = \frac{r}{n} g(\phi X,\phi W).$$

Putting $W = \phi W$ and $X = \phi X$ in (11.3) and on simplification, we have

(11.4) $$S(X,W) = \frac{r}{n} g(X,W) - \left[\frac{r}{n} + (n-1)\right]\eta(X)\eta(W).$$

On contracting (11.4), we obtain

(11.5) $$r = -n(n-1).$$

Hence, we state the following theorem:

Theorem 11.8. In a Pseudo-$W_8{}^*$ -flat Kenmotsu manifold with respect to the Schouten-van Kampen connection the manifold is an η-Einstein manifolds and scalar curvature $r = -n(n-1)$.

Conclusions

The Schouten-Van Kampen connection introduced for the study of non-holomorphic manifolds. It preserves by parallelism - Schouten-Van Kampen is one of the most natural connections adapted to a pair of complementary distributions on a differentiable manifold endowed with an affine connection. In this paper, we found some curvature properties of Kenmotsu manifold with respect to the Schouten-van Kampen connection. That is Kenmotsu manifold satisfying Pseudo-Projectively flat, ξ- Pseudo-Projectively flat, ϕ-Pseudo-Projectively Semi-symmetric, Pseudo-Pseudo-Projectively flat, W_8^*-flat, ξ-W_8^*-flat, ϕ-W_8^*-Semi-symmetric, Pseudo-W_8^*-flat conditions with respect to the Schouten-van Kampen connection is either Einstein or η-Einstein or special η-Einstein manifold.

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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