SP-Sasakian Manifolds Admitting Special Semi - Symmetric Recurrent Metric Connection

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ABSTRACT; *In this paper, we study special semi -symmetric metric recurrent connection in SP-Sasakian manifold. Some results related to this connection are studied and obtained .Also some curvature properties of SP-sasakian manifolds admitting special semi - symmetric recurrent metric connection are studied.*

KEYWORD; *sp-sasakianmanifold,semi -symmetric metric recurrent connection, concircular curvature tensor ,projective curvature tensor.*

MSC2010; 53C07, 53C25

1. INTRODUCTION

In 1975, Golab[1] initiated the study of quarter-symmetric linear connection on a differentiable manifold M^n. A linear connection $\tilde{\nabla}$ in an n dimensional differentiable manifold M^n is said to be a Quarter -symmetric connection if torsion tensor T is of the form

$$T(X,Y) = \tilde{\nabla}_X Y-\tilde{\nabla}_Y X-[X,Y] \quad (1.1)$$

$$= \eta(Y)\varphi X-\eta(X)\varphi Y$$

where η is a 1-form and φ is a tensor of type (1,1). In addition,if a quarter-symmetric linear connection $\tilde{\nabla}$ satisfies the condition $\tilde{\nabla}_X g=0$ for all $X,Y,Z\in TM^n$, where TM is a lie algebra of vectors fields of the differentiable manifold M^n,. Then ∇ is said to be quarter-symmetric metric connection. Quarter -symmetric metric connection is also studied by Biswas and De [10] De and Mondal[16] Singh and pandey[15] Mishra and Pandey[5],Rastogi[7], Yano and Imai [6], Sular, S [17] and many others.

In particular, if $\varphi X=X$ and $\varphi Y=Y$, then the quarter-symmetric connection reduces to a semi-symmetric connection . The semi symmetric metric connection is generalized case of quarter- symmetric metric connection.

The semi-symmetric metric connection in an SP-Sasakian manifold have been studied by Sinhaand Kalpna[4].In the present paper we have studied with quarter-symmetric metric connection in an SP-Sasakian manifold . We also discuss the different type of curvatures with a quarter- symmetric metric connection in an SP-Sasakian manifold .This paper organized as fallows after preliminaries . In section 1,Introduction .In section 2,We discuss the preliminary results of sp-sasakian manifold and also special semi-symmetric recurrent metrics connection$\tilde{\nabla}$.In section 3,existence of special semi-symmetric recurrent metric connection .In section 4, curvature tensor of the manifold with respect to special semi-symmetric recurrent metrics connection$\tilde{\nabla}$.In section 5, concircular curvature tensor of sp-sasakian manifold with respect to the special semi-symmetric recurrent metric connection$\tilde{\nabla}$. In section 6, projective curvature tensor of sp-sasakian manifold with respect to special semi-symmetric recurrent metric connection$\tilde{\nabla}$.In section 7, projective ricci curvature tensor of sp-sasakian manifold with respect to special semi-symmetric recurrent metric connection$\tilde{\nabla}$and In section 8, m-projective curvature tensor of sp-sasakian manifold with respect to special semi-symmetric recurrent metric connection$\tilde{\nabla}$.

2.PRELIMINARIES

An n-dimensional smooth manifold M^n is called an almost para-contact manifold [12], if it admits an almost para-contact structure (φ,ξ,η) consisting of a (1,1) tensor field φ, vector field ξ, and 1-form η satisfying

$$\varphi^2 X=X-\eta(X)\xi \quad (2.1)$$

$$\eta(\xi)=1 \quad (2.2)$$

$\varphi o \xi = 0$ (2.3)

$\eta o \varphi = 0$ (2.4)

$Rank(\varphi) = n-1$ (2.5)

for all $X \varepsilon TM^n$

Let g be Riemannian metric satisfying

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

$g(\varphi X, Y) = g(X, \varphi Y)$ (2.7)

for all $X,Y \in TM^n$ .Then M^n becomes an almost para-contact Riemannian manifold equipped with the almost para-contact Riemannian structure (φ,ξ,η,g) [2].

If we define

$g(X,\xi) = \eta(X)$, $g(\xi,\xi) = 1$ (2.8)

$\Phi(X,Y) = g(\varphi X, Y)$ (2.9)

then in addition to the above equation, we have

$\Phi(X,Y) = \Phi(Y,X)$ (2.10)

$\Phi(\varphi X, \varphi Y) = \Phi(X,Y)$ (2.11)

An almost para-contact Riemannian manifold is called a P-Sasakian manifold [4] if it satisfies

$(\nabla_X \varphi)Y = -g(X,Y)\xi - \eta(Y)X + 2\eta(X)\eta(Y)\xi$ (2.12)

for all $XY \varepsilon TM^n$ where ∇ denotes the covariant differentiation with respect to Riemannian metric g. from the above equation it follows that

$\nabla_X \xi = \varphi X$ (2.13)

$(\nabla_X \eta)(Y) = g(X, \varphi Y) = (\nabla_Y \eta)(X)$ (2.14)

Especially, a P-Sasakian manifold M^n is called a special para-Sasakian manifold or briefly an SP-Sasakian manifold .If M^n admits a 1-form η satisfying

$(\nabla_X \eta)(Y) = -g(X,Y)\xi + \eta(X)\eta(Y)$ (2.15)

For SP-Sasakian manifold we have [4]

$\Phi(X,Y) = -g(X,Y)\xi + \eta(X)\eta(Y)$ (2.16)

In an n-dimensional P-Sasakian manifold M^n,the curvature tensor R ,the Ricci tensor S satisfy [3],[2],[9]

$R(X,Y)\xi = \eta(X)Y - \eta(Y)X$ (2.17)

$R(\xi,X)Y = \eta(Y)X - g(X,Y)\xi$ (2.18)

$R(\xi,X)\xi = X - \eta(X)\xi$ (2.19)

$\eta(R(X,Y)U) = g(X,U)\eta(Y) - g(Y,U)\eta(X)$ (2.20)

$\eta(R(X,Y)\xi) = 0$ (2.21)

$\eta(R(\xi,X)Y) = \eta(X)\eta(Y) - g(X,Y)$ (2.22)

$S(X,\xi) = -(n-1)\eta(X)$ (2.23)

$QX=-(n-1)X$ (2.24)

$S(\varphi X,\varphi Y)=S(X,Y)+(n-1)\eta(X)\eta(Y)$ (2.25)

$S(X,\varphi Y)=S(\varphi X,Y)$ (2.26)

Let (M,g) be an manifold with Levi-Civita connection $\tilde{\nabla}$ in a SP-Sasakian Manifold can be defined by

$\tilde{\nabla}_X Y=\nabla_X Y-\eta(X)Y$ (2.27)

The curvature tensor $\tilde{R}$ of M^n

$\tilde{R}(X,Y)Z = R(X,Y)Z+3g(X,Z)Y -3g(Y,Z)X-2g(X,Z)\eta(Y)\xi$

$-2\eta(X)\eta(Z)Y+2g(Y,Z)\eta(X)\xi+2\eta(Y)\eta(Z)X$ (2.28)

The Ricci tensor S and scalar curvature r of M^n with respect to quarter -symmetric metric connection $\tilde{\nabla}$ is defined by

$\tilde{S}(Y,Z)=S(Y,Z)-(3n-5)g(Y,Z)+2(n-2)\eta(Y)\eta(Z)$ (2.29)

$\tilde{r}=r-(n-1)(3n-4)$ (2.30)

Where $\tilde{S}$ and S are the Ricci tensor of the connection ∇ and $\tilde{\nabla}$respectively . Similarly $\tilde{r}$ and r are the scalar curvature of the connection ∇ and$\tilde{\nabla}$ respectively.

DEFINITION ;The projective curvature tensor is defined as[21]

$P(X,Y)Z=R(X,Y)Z-\frac{1}{n-1}\{S(Y,Z)X-S(X,Z)Y\}$ (2.31)

DEFINITION ;The concircular curvature tensor is defined as [20]

$C(X,Y,Z)=R(X,Y,Z)-\frac{r}{n(n-1)}\{g(Y,Z)X-g(X,Z)Y\}$

DEFINITION ; The M-projective curvature tensor (W) is defined as [20]

$W(X,Y,Z,U)=R(X,Y,Z,U) - \frac{1}{2(n-1)}[S(Y,Z)g(X,U)-S(X,Z)g(Y,U)]$

$-\frac{1}{2(n-1)}[g(Y,Z)S(X,U)-g(X,Z)S(Y,U)]$

DEFINITION; The projective Ricci curvature tensor is defined as

$L(X,Y)Z=\frac{2n+1}{2n}S(X,Z)Y-\frac{r}{2n}g(X,Y)Z$

3.EXISTENCE OF SPECIAL SEMI-SYMMETRIC RECURRENT METRIC CONNECTION

Let ∇ be a linear connection in M, given by

$\tilde{\nabla}_X Y=\nabla_X Y+H(X,Y)$ (3.1)

Where H is a tensor of type (1,2) Now , we determine tensor field H such that $\tilde{\nabla}$ satisfies (2.23)and (2.27).

from equation(3.1), we have (3.2)

$T(X,Y)=H(X,Y)-H(Y,X)$ (3.2)

Let (3.3)

$G(X,Y,Z)=(\tilde{\nabla}_x g)(Y,Z)$ (3.3) then(3.4)

$$g(H(X,Y),Z)+g(H(X,Z),Y)=-G(X,Y,Z) \quad (3.4)$$

From (3.2), we have

$$g(\tilde{T}(X,Y),Z)+g(\tilde{T}(Z,X),Y)+g(\tilde{T}(Z,Y),X) = g(H(X,Y),Z)-g(H(Y,X),Z)$$

$$+g(H(Z,X),Y)-g(H(X,Z),Y)$$

$$+g(H(Z,Y),X)-g(H(Y,Z),X)$$

Now from (3.1) and (3.4) we have

$$g(T(X,Y),Z)+g(T(Z,X),Y)+g(T(Z,Y),X) = 2g(H(X,Y),Z)+2\eta(X)g(Y,Z)$$

$$-2\eta(Z)g(X,Y)+2\eta(Y)g(X,Z)$$

This gives

$$H(X,Y)=1/2\{\tilde{T}(X,Y)+\tilde{T}(X,Y)+\tilde{T}(Y,X)\}-\eta(X)Y-\eta(Y)X=g(X,Y) \quad (3.5)$$

where

$$g(\tilde{T}(X,Y),Z=g(\tilde{T}(Z,X),Y) \quad (3.6)$$

From (2.23) and (3.6), we get

$$\tilde{T}(X,Y)=\eta(X)Y-g(X,Y) \quad (3.7)$$

Now from (3.5) and (3.7) we have

$$H(X,Y)=-\eta(X)Y \quad (3.8)$$

Thus from (3.1) we obtain $\tilde{\nabla}$

$$\tilde{\nabla}_x Y=\nabla x Y-\eta(X)Y$$

Conversely, the connection $\tilde{\nabla}$ defined by (2.23), satisfies (2.25) and (2.27) so that the connection $\tilde{\nabla}$ is a special semi-symmetric recurrent metric connection.

Theorem3.1;.Let(M,g) be an SP-Sasakian manifold with a contact metric structure (φ,ξ,η,g), then it admits a special semi-symmetric recurrent metric connection defined as below

$$\tilde{\nabla}_x Y=\nabla_x Y-\eta(X)Y$$

4.CURVATURE TENSOR OF THE MANIFOLD WITH RESPECT TO SPECIAL SEMI-SYMMETRIC RECURRENT METRICS CONNECTION$\tilde{\nabla}$

The curvature tensor of the manifold M^n with respect to special semi - symmetric recurrent metrics connection $\tilde{\nabla}$ is given by

$$\tilde{R}(X,Y,Z)=\tilde{\nabla}_X\tilde{\nabla}_Y Z-\tilde{\nabla}_Y\tilde{\nabla}_X Z-\tilde{\nabla}_{[X,Y]}Z$$

Thus from equations (2.25) and (2.15) the above equation becomes

$$\tilde{R}(X,Y,Z)=R(X,Y,Z) \quad (4.1)$$

This can be stated as follows:

PROPOSITION4.1 . The curvature tensor R of the special semi-symmetric recurrent metrics connection ∇ of manifold M coincides with that of connection ∇ of Riemannian manifold.

Now taking inner product of (4.1) with W, we obtain

$\tilde{R}$(X,Y,Z,W)=R(X,Y,Z,W) (4.2)

Where R(X,Y,Z,W)=g(R(X,Y,Z),W)

Now from (4.2), we have

$\tilde{R}$(X,Y,Z,W)=-R(X,Y,Z,W) (4.3)

$\tilde{R}$(X,Y,Z,W)=-R(X,Y,W,Z) (4.4)

Thus from (4.3) and (4.4) we get

$\tilde{R}$(X,Y,Z,W)=R(X,Y,W,Z) (4.5)

Also, the curvature tentsor R satisfies

$\tilde{R}$(X,Y,Z)+$\tilde{R}$(Y,Z,X)+$\tilde{R}$(Z,X,Y)=0 (4.6)

which is the Bianchi's first identity for connection $\tilde{\nabla}$

Again contracting (4.2) over X and W, we get

$\tilde{S}$(Y,Z)=S(Y,Z) (4.7)

where$\tilde{S}$ and S denote the Ricci tensor of the connection $\tilde{\nabla}$ and ∇ respectively.

Contracting (4.7)over Y and Z , we have as

$\tilde{r}$=r (4.8)

Thus we have the following proposition

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PROPOSITION4.2. From- dimensional SP-Sasakian manifold with special semi-symmetric recurrent metric connection $\tilde{\nabla}$

(1) The curvature tensor R is given by the equation (4.1)

(2) The Ricci tensor S is given by the equation (4.7)

(3)$\tilde{r}$=r

5.CONCIRCULAR CURVATURE TENSOR OF SP-SASAKIAN MANIFOLD WITH RESPECT TO THE SPECIAL SEMI-SYMMETRIC RECURRENT METRIC CONNECTION$\tilde{\nabla}$

Define concircular curvature tensor with respect to the special semi-symmetric recurrent metric connection$\tilde{\nabla}$

C(X,Y,Z)=R(X,Y,Z)-$\frac{r}{n(n-1)}$g(Y,Z)X-g(X,Z)Y} (5.1)

Using (4.1) in the above equation ,we get

$\tilde{C}$(X,Y,Z)=C(X,Y,Z) (5.2)

Therefore, we have

PROPOSITION5.1 ;The manifold M^n coincides with Riemannian manifold.

An n-dimensional SP-Sasakian manifold is called (ϕ)concircularly flat if it

satisfied the condition

$\phi^2 C(\phi X,\phi Y)\phi Z=0$ (5.3)

Let us suppose that M be an n- dimensional ϕ- concircularly flat SP-Sasakian manifold with respect to special semi-symmetric recurrent metric connection. Thus

$\phi^2 C(\phi X,\phi Y)\phi Z=0$(5.4)

if $g(C(\phi X,\phi Y)\phi Z,\phi W)=0$ (5.5)

for all $X,Y,Z,W\in T(M)$

Using (5.1) in (5.5) we have

$g(R(\phi X,\phi Y)\phi Z,\phi W=r/n(n-1)\{g(\phi Y,\phi Z)g(\phi X,\phi W)-g(\phi X,\phi Z)g(\phi Y,\phi W)\}$ (5.6)

Let $\{e_1,e_2,...............,\xi\}$ be a local orthogonal basis of the vector in M^n. Thus using the fact that

$\{\phi e_1,\phi e_2,.......,\xi\}$is also a orthogonal basis, taking $X=W=e_i$in (5.6) and summing

with respect to i, we have

$S(\phi Y,\phi Z)=\frac{r}{2n}g(\phi Y,\phi Z)\}$ (5.7)

Putting $Y=\phi Y,Z=\phi Z$ in (5.7) and using the fact that S is symmetric, we have

$g(R(\phi X,\phi Y)\phi Z,\phi W)=0$

This can be stated as:

THEOREM 5.1; An n- dimensional ϕ - concircularly flat SP-Sasakian manifold with respect to special semi-symmetric recurrent metric connection coincides with Riemannian manifold.

Also, if M^n is ϕ - concircularly flat SP-Sasakian manifold with respect to special semi-symmetric recurrent metric connection, them from (5.05) we have

$g(R(\phi X,\phi Y)\phi Z,\phi W) =\frac{r}{n(n-1)}\{g(\phi Y,\phi Z)g(\phi X,\phi W) -g(\phi X,\phi Z)g(\phi Y,\phi W)\}$

Contracting over X and W and summing over i, we get

$S(\phi Y,\phi Z)+ g(\phi Y,\phi Z)= \frac{r}{n(n-1)}\{(n-1)g(\phi Y,\phi Z)-g(\phi Y,\phi Z)\}$

$S(\phi Y,\phi Z) = \frac{r(n-2)}{n(n-1)-1}g(\phi Y,\phi Z)$

Using (2.12) and (2.3) in the above equation, we get

$S(Y,Z)=\frac{r(n-2)}{n(n-1)-1}g(Y,Z)-\frac{r(n-2)}{n(n-1)-n}\eta(Y)\eta(Z)$ (5.8)

Which is of the form.

$S(Y,Z)=ag(Y,Z)+b\eta(Y)\eta(Z)$

Where $a=\frac{r(n-2)}{n(n-1)-1}$and $b=\frac{r(n-2)}{n(n-1)-n}$

Thus we have the following theorem:

THEOREM 5.2 ; .ϕ-concircularly flat SP-Sasakian manifold with respect to special semi-symmetric metric connections an η -Einstein manifold.

6.PROJECTIVE CURVATURE TENSOR OF SP-SASAKIAN MANIFOLD WITH RESPECT TO SPECIAL SEMI-SYMMETRIC RECURRENT METRIC CONNECTION$\widetilde{\nabla}$

Analogous to the definition of projective curvature tensor in a Riemannian manifold

we define the projective curvature tensor P with respect to special semi-symmetric recurrent metric connection by

$P(X,Y,Z)=R(X,Y,Z)-\frac{1}{(n-1)}S(Y,Z)X-S(X,Z)Y)\}$ (6.1)

Using (4.1) and (4.7) in (6.1) we have

$\tilde{P}(X,Y,Z)=P(X,Y,Z)$ (6.2)

DEFINITION6.1 ;An SP-Sasakian manifold M^n is said to be quasi projectively flat with respect to special semi-symmetric recurrent metric connection if

$g(P(\varphi X,Y)Z,\varphi W)=0$ (6.3)

Where P is the projective curvature tensor with respect to special semi-symmetric recurrent metric connection .

Using (6.1) in (6.3)

$g(R(\varphi X,Y)Z,\varphi W)=\{S(Y,Z)g(\varphi X,\varphi W)-S(\varphi X,Z)g(Y,\varphi W)\}$(6.4)

Now from (4.1) in (4.7) , above equation becomes

$g(R(\varphi X,Y)Z,\varphi W) = \frac{1}{(n-1)}\{S(Y,Z)g(\varphi X,\varphi W)\}$ (6.5)

$-\frac{1}{(n-1)}\{S(\varphi X,Z)g(Y,\varphi W)\}$

Substituting $X=W=e_i$and summing over i , $1\leq i\leq n-1$

$\sum g(R(\varphi e_i,Y)Z, \varphi e_i) = \frac{1}{(n-1)}\sum[S(Y,Z)g(\varphi e_i,\varphi e_i)S(\varphi e_i ,Z)g(Y,\varphi e_i)]$

This implies

$S(Y,Z)+g(Y,Z)=\frac{1}{(n-1)}\{(n-1)S(Y,Z)-S(Y,Z)\}$

This gives

$S(Y,Z)=-(n-1)g(Y,Z)$ (6.7)

Which is ofthe form

$S(Y,Z)=ag(Y,Z)$

Where $a=-(n-1)$

So we have following theorem

THEOREM 6.1; A quasi-projectively flat SP- Sasakian manifold with respect to semi-symmetric recurrent metric is an Einstien manifold.

7.PROJECTIVE RICCI CURVATURE TENSOR OF SP-SASAKIAN MANIFOLD WITH RESPECT TO SPECIAL SEMI-SYMMETRIC RECURRENT METRIC CONNECTION$\widetilde{\nabla}$

we define the projective ricci curvature tensor L with respect to special semi-symmetric recurrent metric connection by

$L(X,Y)=\frac{n}{(n-1)}S(X,Y)-\frac{r}{(n-1)}g(X,Y)$ (7.1)

Analogous to this definition of projective ricci curvature tensor in a Riemannian manifold.we define the projective ricci curvature tensor L with respect to special semi-symmetric recurrent metric connection by

$\tilde{L}(X,Y)=\frac{n}{(n-1)}\tilde{S}(X,Y)-\frac{\tilde{r}}{(n-1)}g(X,Y)$ (7.2)

THEOREM7.1 ;The projective ricci curvature tensor of SP-sasakian manifold admitting special semi-symmetric recurrent metric connection is identical with the the projective ricci curvature tensor of SP- Sasakian manifold with levi-civita connection.

PROOF7.1 ; using (4.7)and(4.8)in equation (7.2)

$\tilde{L}(X,Y)=\frac{n}{(n-1)}S(X,Y)-\frac{r}{(n-1)}g(X,Y)$ (7.3)

And equating (7.3) and (7.1), we have

$\tilde{L}(X,Y)=L(X,Y)$ (7.4)

Thus the theorem follows.

8. M-PROJECTIVE CURVATURE TENSOR OF SP-SASAKIAN MANIFOLD WITH RESPECT TO SPECIAL SEMI-SYMMETRIC RECURRENT METRIC CONNECTION$\tilde{\nabla}$

we define the M-projective curvature tensor W with respect to special semi-symmetric recurrent metric connection by

DEFINITION 8.1; The M-projective curvature tensor (W) is defined as [21]

$W(X,Y,Z,U)=R(X,Y,Z,U)$

$-\frac{1}{2(n-1)}S(Y,Z)g(X,U)-S(X,Z)g(Y,U)]$

$-\frac{1}{2(n-1)}[g(Y,Z)S(X,U)-g(X,Z)S(Y,U)]$ (8.1)

Analogous to this definition of M-projective curvature tensor in a Riemannian manifold .we define the M-projective curvature tensor W with respect to special semi-symmetric recurrent metric connection by

$\tilde{W}(X,Y,Z,U)=\tilde{R}(X,Y,Z,U)$

$-\frac{1}{2(n-1)}[\tilde{S}(Y,Z)g(X,U)-\tilde{S}(X,Z)g(Y,U)]$

$-\frac{1}{2(n-1)}[g(Y,Z)\tilde{S}(X,U)-g(X,Z)\tilde{S}(Y,U)]$ (8.2)

THEOREM 8.1; The M-projective curvature tensor of SP-sasakian manifold admitting special semi-symmetric recurrent metric connection is identical with the theM-projective curvature tensor of SP- Sasakian manifold with Levi-civita connection.

PROOF; using (4.2),(4.7)and(4.8)in equation (8.2)

$\tilde{W}(X,Y,Z,U)=R(X,Y,Z,U)$

$-\frac{1}{2(n-1)}[S(Y,Z)g(X,U)-S(X,Z)g(Y,U)]$

$-\frac{1}{2(n-1)}[g(Y,Z)S(X,U)-g(X,Z)S(Y,U)]$ (8.3)

And equating (8.3) and (8.1), we have

$$\widetilde{W}(X,Y,Z,U)=W(X,Y,Z,U) \tag{8.4}$$

Thus the theorem follows.

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