New Mathematical Properties of the Kumaraswamy Lindley Distribution

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Abstract. The Kumaraswamy Lindley distribution is a generalized distribution that has many applications in various fields, including physics, engineering, and chemistry. This paper introduces new mathematical properties for Kumaraswamy Lindley distribution such as probability weighted moments, moments of residual life, mean of residual life, reversed residual life, cumulative hazard rate function, and mean deviation.

Keywords: Kumaraswamy Lindley distribution; probability weighted moments; residual life; hazard rate; mean deviation

1. Introduction

Robust reliability estimation for Lindley distribution, a probability integral transform statistical approach, while Hafez et al. [20] presented a study on Lindley distribution accelerated life tests, application, and numerical simulation.

2. Lindley Distribution and Kumaraswamy Lindley Distribution

The Lindley distribution was introduced in 1958, but it was used as an alternative to the exponential distribution, where the Lindley distribution was used to study many characteristics such as data modeling and other characteristics. In this section, the definition and properties of Lindley distribution are provided. Equation (1) presents the probability distribution function (pdf) of the Lindley distribution with parameter \( \theta \):

\[
g(x) = \frac{\theta^2}{\theta + 1} (1 + x) e^{-\theta x} \quad x > 0, \theta > 0
\]

and the corresponding cumulative distribution function (cdf) is

\[
G(x) = 1 - e^{-\theta x} \left( 1 + \frac{x \theta}{\theta + 1} \right) \quad x > 0, \theta > 0
\]

Suppose \( G(x, \theta) \) be the cdf of the Lindley distribution given by (2). The cdf and pdf of Kumaraswamy Lindley distribution (KLD) are

\[
F(x) = 1 - \left[ 1 - e^{-\theta x} \left( 1 + \frac{x \theta}{\theta + 1} \right)^a \right]^b
\]

\[
f(x) = ab \left( \frac{\theta^2}{\theta + 1} (1 + x) e^{-\theta x} \right) \left[ 1 - e^{-\theta x} \left( 1 + \frac{x \theta}{\theta + 1} \right)^a \right]^{b-1}
\]

Figure 1. Plot of pdf (left) and cdf (right) of KLD

3. Mathematical Properties

3.1. Probability Weighted Moments. The probabilities weighted moments (PWM) are used to derive parameters of generalized probability distributions and this method is used to compare the parameters obtained by using the probabilities weighted moments:

\[
\rho_{s,r} = E(x^s F(x)^r) = \int_0^\infty x^s F(x)^r f(x) dx
\]

From the definition of the cumulative distribution function of the Kumaraswamy Lindley, we find that
\[ F(x) = 1 - \left[ 1 - \left( 1 - e^{-\theta x} \left( 1 + \frac{\theta x}{\theta + 1} \right) \right)^a \right]^b \]

\[ (1 - z)^d = \sum_{i=0}^{\infty} (-1)^i \binom{d}{i} z^i, \quad |z| < 1 \]

\[ \left( 1 - e^{-\theta x} \left( 1 + \frac{\theta x}{\theta + 1} \right) \right)^a = \sum_{n=0}^{\infty} (-1)^n \binom{a}{n} e^{-n\theta x} \left( 1 + \frac{\theta x}{\theta + 1} \right)^n \]

Using the binomial theorem on the following

\[ \left( 1 + \frac{\theta x}{\theta + 1} \right)^n = \sum_{l=0}^{\infty} \binom{n}{l} \left( \frac{\theta}{\theta + 1} \right)^l x^l \]

and substituting the value of the term into equation number (3) we get

\[ \left( 1 - e^{-\theta x} \left( 1 + \frac{\theta x}{\theta + 1} \right) \right)^a = \sum_{n=0}^{\infty} (-1)^n \binom{a}{n} \sum_{l=0}^{\infty} \binom{n}{l} \left( \frac{\theta}{\theta + 1} \right)^l x^l e^{-n\theta x} \]

Simplifying the equation number, we get

\[ \left( 1 - e^{-\theta x} \left( 1 + \frac{\theta x}{\theta + 1} \right) \right)^a = W_{nl} x^l e^{-n\theta x} \]

where

\[ W_{nl} = \sum_{n=0}^{\infty} (-1)^n \binom{a}{n} \sum_{l=0}^{\infty} \binom{n}{l} \left( \frac{\theta}{\theta + 1} \right)^l \]

Substituting into the cumulative distribution function for a value

\[ \left( 1 - e^{-\theta x} \left( 1 + \frac{\theta x}{\theta + 1} \right) \right)^a \]

we get

\[ F(x) = 1 - \left[ 1 - W_{nl} x^l e^{-n\theta x} \right]^b \]

Applying the binomial theorem to the following expression

\[ \left[ 1 - W_{nl} x^l e^{-n\theta x} \right]^b = \sum_{\delta=0}^{\infty} (-1)^\delta \binom{b}{\delta} (W_{nl} x^l e^{-n\theta x})^\delta \]

and simplifying the previous expansion, we get

\[ \left[ 1 - W_{nl} x^l e^{-n\theta x} \right]^b = \sum_{\delta=0}^{\infty} (-1)^\delta \binom{b}{\delta} (W_{nl})^\delta e^{-\delta n\theta x \cdot x^l} \]

\[ \left[ 1 - W_{nl} x^l e^{-n\theta x} \right]^b = W_{nl\delta} e^{-\delta n\theta x \cdot x^l} \]

where

\[ W_{nl\delta} = \sum_{\delta=0}^{\infty} (-1)^\delta \binom{b}{\delta} (W_{nl})^\delta \]

Thus, the final formulation of the cumulative distribution function of the Kumaraswamy Lindley distribution becomes

\[ F(x) = 1 - W_{nl\delta} e^{-\delta n\theta x \cdot x^l} \]

Now, we show the components of the general formulation the probabilities weighted moments (PWM). The first component is

\[ F(x)^r = \left( 1 - W_{nl\delta} e^{-\delta n\theta x \cdot x^l} \right)^r \]

By applying the binomial theorem to the following expansion

\[ F(x)^r = \sum_{\pi=0}^{\infty} (-1)^\pi \binom{r}{\pi} \left( e^{-\pi \delta n\theta x \cdot x^l} (W_{nl\delta})^\pi \right) \]
then the final form of the function $F(x)$ is

$$F(x) = \left( e^{-\pi \delta \theta x} x^\pi \right) W_{ni\delta}$$

where $W_{ni\delta} = \sum_{n=0}^{\infty} (-1)^n \binom{n}{j} (W_{ni})^j$.

The second component is $f(x) = \frac{ab \theta^2}{\theta + 1} w_j q x^{m+j} (1 + x) e^{-\theta x(k+y)}$. Substituting in the general form for probability weighted moments, we get

$$\rho_{s,r} = \int_0^\infty x^s \left( e^{-\pi \delta \theta x} x^\pi \right) W_{ni\delta} \frac{ab \theta^2}{\theta + 1} w_j q x^{m+j} (1 + x) e^{-\theta x(k+y)} dx$$

Simplifying the equation, we get

$$\rho_{s,r} = \frac{ab \theta^2}{\theta + 1} w_j q W_{ni\delta} \int_0^\infty e^{-\pi \delta \theta x} (x^{\pi \delta \theta}) x^{s+m+j} (1 + x) e^{-\theta x(k+y)} dx$$

$$\rho_{s,r} = \frac{ab \theta^2}{\theta + 1} w_j q W_{ni\delta} \int_0^\infty (x^{\pi \delta \theta} x^{s+m+j} + x^{\pi \delta \theta} x^{s+m}) e^{-\theta x(k+y)} dx$$

We assume that $K_1 = \tau \int_0^\infty (x^{\pi \delta \theta} x^{s+m+j+1}) e^{-\theta x(k+y)} dx$ and $K_2 = \tau \int_0^\infty (x^{\pi \delta \theta} x^{s+m+j+1}) e^{-\theta x(k+y)} dx$.

It becomes probabilities weighted moments (PWM) as following $\rho_{s,r} = K_1 + K_2$ and we calculate the value of each $K_1$ and $K_2$:

$$K_1 = \tau \int_0^\infty (x^{\pi \delta \theta} x^{s+m+j+1}) e^{-\theta x(k+y)} dx$$

by assuming that $y = (\theta(k+y) + \pi \delta \theta)x$. Differentiate the hypothesis, we get

$$dy = (\theta(k+y) + \pi \delta \theta)x, \quad x = \frac{y}{(\theta(k+y) + \pi \delta \theta)}, \quad dx = \frac{dy}{(\theta(k+y) + \pi \delta \theta)}$$

By substituting the value of each of $x, dx$ and simplifying it, we get

$$K_1 = \tau \int_0^\infty \left( \frac{y}{(\theta(k+y) + \pi \delta \theta)} x^{\pi \delta \theta} x^{s+m+j+1} \right) e^{-\theta x(k+y)} dx$$

$$K_1 = \frac{\tau}{(\theta(k+y) + \pi \delta \theta)^{\pi \delta \theta} x^{s+m+j+1}} \int_0^\infty e^{-\theta x(k+y)} x^{\pi \delta \theta} x^{s+m+j+1} dx$$

From the gamma integral we get

$$K_1 = \frac{\tau}{(\theta(k+y) + \pi \delta \theta)^{\pi \delta \theta} x^{s+m+j+1}} \Gamma(\pi \delta \theta + s + m + j + 2)$$

and by calculating the value of $K_2$ we get

$$K_2 = \frac{\tau}{(\theta(k+y) + \pi \delta \theta)^{\pi \delta \theta} x^{s+m+j+1}} \int_0^\infty e^{-\theta x(k+y)} x^{\pi \delta \theta} x^{s+m+j+1} dx$$

Substituting in $K_2$ for the hypothesis and differentiation, we get

$$K_2 = \frac{\tau}{(\theta(k+y) + \pi \delta \theta)^{\pi \delta \theta} x^{s+m+j+1}} \int_0^\infty e^{-\theta x(k+y)} x^{\pi \delta \theta} x^{s+m+j+1} dx$$

Simplifying the previous equation, we get

$$K_2 = \frac{\tau}{(\theta(k+y) + \pi \delta \theta)^{\pi \delta \theta} x^{s+m+j+1}} \int_0^\infty e^{-\theta x(k+y)} x^{\pi \delta \theta} x^{s+m+j+1} dx$$

From the gamma integral we get

$$K_2 = \frac{\tau}{(\theta(k+y) + \pi \delta \theta)^{\pi \delta \theta} x^{s+m+j+1}} \Gamma(\pi \delta \theta + s + m + j + 1)$$

The value of probabilities weighted moments (PWM) is $\rho_{s,r} = K_1 + K_2$. 

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\[ ρ_{x,R} = \frac{ρ_1}{θ(1+θ)} + \frac{ρ_2}{θ(2+θ)} + \ldots + \frac{ρ_n}{θ(n+θ)} \]

The nth moments of residual life denoted by \( E[(x - t)^n | x > t] \) where \( n = 1,2,3, \ldots \)

It is defined by

\[ m(t)_n = \frac{1}{R(T)} \int_t^\infty (x - t)^n f(x) dx \]

Substitute in the general form for the residual life for the probability density function of the Kumaraswamy Lindley distribution

\[ m(t)_n = \frac{1}{R(T)} \int_t^\infty (x - t)^n \frac{abθ^2}{θ + 1} w_j q x^{m+j} (1 + x) e^{-θx(κ+y)} dx \]

From the binomial theorem we get

\[ (x - t)^n = (-t)^n (1 - \frac{x}{t})^n = (-t)^n \sum_{h=0}^{∞} (-1)^h \binom{n}{h} \left(\frac{x}{t}\right)^h \]

Using the binomial expansion of the expression \((x - t)^n\) and the substitution of the general form for residual life, we get

\[ m(t)_n = \frac{1}{R(T)} \int_t^\infty \frac{abθ^2}{θ + 1} w_j q (-t)^n \sum_{h=0}^{∞} (-1)^h \binom{n}{h} \left(\frac{x}{t}\right)^h x^{m+j} (1 + x) e^{-θx(κ+y)} dx \]

By simplifying it we get

\[ m(t)_n = \frac{abθ^2}{θ + 1} w_j q (-t)^n \sum_{h=0}^{∞} (-1)^h \binom{n}{h} \int_t^\infty \left(\frac{x}{t}\right)^h x^{m+j} (1 + x) e^{-θx(κ+y)} dx \]

Let \( k_3 = \frac{abθ^2}{θ + 1} w_j q (-t)^n \sum_{h=0}^{∞} (-1)^h \binom{n}{h} \) then the equation becomes

\[ m(t)_n = \frac{k_3}{R(T)} \int_t^\infty x^{m+j+h} (1 + x) e^{-θx(κ+y)} dx + \int_t^\infty x^{m+j+h+1} e^{-θx(κ+y)} dx \]

Let \( m(t)_n = \frac{k_3}{R(T)} [k_4 + k_5] \) where

\[ k_4 = \int_t^\infty x^{m+j+h} e^{-θx(κ+y)} dx \] and \( k_5 = \int_t^\infty x^{m+j+h+1} e^{-θx(κ+y)} dx \).

Now calculating the value of \( k_4 \) and using the general form of the gamma function \( Γ(a, b) = \int_b^{∞} y^a e^{-y} dy \) we get

\[ k_4 = \int_t^\infty x^{m+j+h} e^{-θx(κ+y)} dx \]

We assume that \( y = (θ(κ+y))x \) and differentiate the hypothesis, then we get

\[ dy = (θ(κ+y))dx, x = \frac{y}{(θ(κ+y))}, dx = \frac{dy}{(θ(κ+y))} \]

By substituting the value of each of \( x, dx \) and simplifying the result, we get

\[ k_4 = \int_t^\infty \left[ \frac{y}{(θ(κ+y))}\right]^{m+j+h} e^{-y} \left(\frac{dy}{θ(κ+y)}\right) \]

\[ k_4 = \frac{1}{(θ(κ+y))^{m+j+h+1}} \int_t(κ+y) \left[ y\right]^{m+j+h} e^{-y} dy \]

Applying the general form of the gamma function \(-1 = m + j + h, b = tθ(κ+y)\), then the value of \( k_4 \) is

\[ k_4 = \frac{Γ(m + j + h + 1, tθ(κ+y))}{(θ(κ+y))^{m+j+h+1}} \]
To compute $k_5 = \int_t^\infty x^{m+j+h} e^{-\theta x(k+y)} dx$, we assume that $y = (\theta(k + y))x$. Differentiating the hypothesis, we get $dy = (\theta(k + y))dx$. By substituting the value of each of $x, dx$ in $k_5$ and simplifying it, we get

$$k_5 = \int_t^\infty \frac{y}{(\theta(k + y))} x^{m+j+1} e^{-\theta x(k+y)} \frac{dy}{(\theta(k + y))}$$

Applying the general form of the gamma function $\alpha - 1 = m + j + h + 1, b = t\theta(k + y)$, then

$$k_5 = \frac{\Gamma(m + j + h + 2, t\theta(k + y))}{[\theta(k + y)]^{m+j+h+2}}$$

Moments of residual life is

$$m(t)_n = \frac{k_3}{R(T)} \left[ \frac{\Gamma(m+j+h+1, t\theta(k+y))}{(\theta(k+y))^{m+j+h+1}} + \frac{\Gamma(m+j+h+2, t\theta(k+y))}{(\theta(k+y))^{m+j+h+2}} \right]$$

3.2. Mean of Residual Life. The mean residual of KLD is defined by

$$m(t) = \frac{1}{R(T)} \int_t^\infty x f(x) dx - t$$

Substituting the probability density function for the KLD, we get

$$m(t) = \frac{1}{R(T)} \int_t^\infty x \frac{ab}{\theta + 1} \frac{\theta^2}{w_j} q x^{m+j} (1 + x) e^{-\theta x(k+y)} dx - t$$

Simplifying the equation, we get

$$m(t) = \frac{ab}{\theta + 1} \frac{\theta^2}{R(T)} \int_t^\infty x^{m+j+1} (1 + x) e^{-\theta x(k+y)} dx - t$$

$$m(t) = \frac{ab}{\theta + 1} \frac{\theta^2}{R(T)} \left[ \int_t^\infty x^{m+j+1} e^{-\theta x(k+y)} dx + \int_t^\infty x^{m+j+2} e^{-\theta x(k+y)} dx \right] - t$$

Let $k_6 = \int_t^\infty x^{m+j+1} e^{-\theta x(k+y)} dx, k_7 = \int_t^\infty x^{m+j+2} e^{-\theta x(k+y)} dx$ and $\delta = \frac{ab}{\theta + 1} \frac{\theta^2}{R(T)} w_j q$, the mean of residual life becomes

$$m(t) = \delta [k_6 + k_7] - t$$

Now we calculate the value of $k_6$, which is

$$k_6 = \int_t^\infty x^{m+j+1} e^{-\theta x(k+y)} dx$$

We assume that $y = (\theta(k + y))x$. Differentiating the hypothesis, we get $dy = (\theta(k + y))dx$. By substituting the value of each $x, dx$ in $k_6$ and simplifying it, we get

$$k_6 = \int_t^\infty \frac{y}{(\theta(k + y))} x^{m+j+1} e^{-\theta x(k+y)} \frac{dy}{(\theta(k + y))}$$

Applying the general form of the gamma function $\alpha - 1 = m + j + 1, b = (\theta(k + y))t$, we have

$$k_6 = \frac{\Gamma(m + j + 2, (\theta(k + y))t)}{[(\theta(k + y))]^{m+j+2}}$$

Now calculate the value of $k_7$

$$k_7 = \int_t^\infty x^{m+j+2} e^{-\theta x(k+y)} dx$$

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We assume that \( y = (\theta(k + \gamma))x \). Differentiating the hypothesis, we get \( dy = (\theta(k + \gamma))dx \), \( x = \frac{y}{(\theta(k + \gamma))} \). By substituting the value of each \( x, dx \) in \( k_7 \), we get:

\[
k_7 = \frac{1}{(\theta(k + \gamma))^{m+j+2}} \int_{\theta(k+y)t}^{\infty} y^{m+j+2} e^{-y} \, dy
\]

By applying the general form of the gamma function \( a - 1 = m + j + 2, b = (\theta(k + \gamma))t \), we have:

\[
k_7 = \frac{\Gamma(m + j + 3, (\theta(k + \gamma)t)}{(\theta(k + \gamma))^{m+j+3}}
\]

The mean of residual life becomes:

\[
m(t) = \delta \left[ \frac{\Gamma(m + j + 2, (\theta(k + \gamma))t)}{(\theta(k + \gamma))^{m+j+2}} + \frac{\Gamma(m + j + 3, (\theta(k + \gamma))t)}{(\theta(k + \gamma))^{m+j+3}} \right] - t
\]

By differentiating the equation \( m(t) \) with respect to \( x \), we have:

\[
\dot{m}(t) = \delta \left[ -\frac{\theta(q) (\theta(k + \gamma))}{(\theta(k + \gamma))^{m+j+2}} \frac{\Gamma(m + j + 3, (\theta(k + \gamma))t)}{(\theta(k + \gamma))^{m+j+3}} \right]
\]

We note that \( \dot{m}(t) > 0, t > 0 \), thus mean residual life is increasing (IMRL).

3.3. Reversed Residual Life. The \( n \)th moments of residual life denoted by \( E[(t - x)^n|x \leq t] \) where \( n = 1, 2, 3, \ldots \) is defined by

\[
M(t) = \frac{1}{F(T)} \int_0^t (t - x)^n f(x) dx.
\]

We substitute in the general form for the residual life for the probability density function of the Kumaraswamy Lindley distribution, the reversed residual life becomes:

\[
M(t) = \frac{1}{F(T)} \int_0^t (t - x)^n q x^{m+j} (1 + x) e^{-\theta x(k+y)} dx
\]

Using the binomial expansion of the expression:

\[
(t - x)^n = (t)^n (1 - \frac{x}{t})^n = (t)^n \sum_{n=0}^{\infty} (-1)^n \left( \frac{n}{\theta} \right) \frac{x^n}{t^n}
\]

\[
M(t) = \frac{1}{F(T)} \int_0^t (t)^n \sum_{n=0}^{\infty} (-1)^n \left( \frac{n}{\theta} \right) \frac{x^n}{t^n} q x^{m+j} (1 + x) e^{-\theta x(k+y)} dx
\]

By simplifying the last equation, we get:

\[
M(t) = \frac{\frac{ab \theta^2}{\theta + 1} w_j q x^{m+j} (1 + x) e^{-\theta x(k+y)} dx}{F(T)}
\]

Suppose that \( q = \frac{\frac{ab \theta^2}{\theta + 1} w_j q x^{m+j} (1 + x) e^{-\theta x(k+y)} dx}{F(T)} \), the last equation becomes:

\[
M(t) = q \left[ \int_0^t x^{m+j+\omega} e^{-\theta x(k+y)} dx + \frac{x^{m+j+\omega+1} e^{-\theta x(k+y)} dx}{F(T)} \right]
\]

Let \( k_\theta = \int_0^t x^{m+j+\omega} e^{-\theta x(k+y)} dx \), \( k_\theta = \int_0^t x^{m+j+\omega+1} e^{-\theta x(k+y)} dx \). The reversed of residual life becomes:

\[
M(t) = q[k_\theta + k_\theta]
\]

Now calculate the value of \( k_\theta \)
\[ k_B = \int_0^t x^{m+j+w} e^{-\theta(x+k+y)} \, dx \]

By assuming that \( y = (\theta(k + y))x \), we get

\[ k_B = \int_0^t \left[ \frac{y}{(\theta(k + y))} \right]^{m+j+w} e^{-y} \frac{dy}{(\theta(k + y))} \]

\[ k_B = \frac{1}{(\theta(k + y))^{m+j+w+1}} \int_0^{(\theta(k+y))t} [y]^{m+j+w} e^{-y} \, dy \]

From the general definition of the gamma function \( a - 1 = m + j + w \) and \( b = \theta(k + y)b \),

\[ k_B = \frac{\Gamma (m + j + w + 1, \theta(k + y)b)}{(\theta(k + y))^{m+j+w+1}} \]

Now calculate the value of \( k_9 \)

\[ k_9 = \int_0^t x^{m+j+w+1} e^{-\theta(x+k+y)} \, dx \]

By assuming that \( y = (\theta(k + y))x \), we have

\[ k_9 = \int_0^{(\theta(k+y))t} \left[ \frac{y}{(\theta(k + y))} \right]^{m+j+w+1} e^{-y} \frac{dy}{(\theta(k + y))} \]

\[ k_9 = \frac{1}{(\theta(k + y))^{m+j+w+2}} \int_0^{(\theta(k+y))t} [y]^{m+j+w+1} e^{-y} \, dy \]

From the general definition of the gamma function \( a - 1 = m + j + w + 1 \) and \( b = \theta(k + y)b \),

\[ k_9 = \frac{\Gamma (m + j + w + 2, \theta(k + y)b)}{(\theta(k + y))^{m+j+w+2}} \]

The reversed of residuals life becomes

\[ M(t) = q \left[ \frac{\Gamma (m + j + w + 1, \theta(k + y)b)}{(\theta(k + y))^{m+j+w+1}} + \frac{\Gamma (m + j + w + 2, \theta(k + y)b)}{(\theta(k + y))^{m+j+w+2}} \right] \]

The cumulative hazard function (CHF) of the Kumaraswamy Lindley distribution denoted by \( CHF_{KWL} (x, \theta) \) is

\[ CHF_{KWL} (x, \theta) = \int_0^x h(x, \theta) \, dx \]

By substituting for hazard rate function, we get

\[ CHF_{KWL} (x, \theta) = \int_0^x \frac{f(x)}{1-F(x)} \, dx \]

Substituting the value of the probability density function for the Kumaraswamy Lindley distribution as well as the cumulative distribution function for it, we get

\[ CHF_{KWL} (x, \theta) = \int_0^x \frac{ab \theta^2}{\theta + 1} w_j q x^{m+j} (1+x) e^{-\theta x (1+\frac{\theta x}{\theta + 1})} \, dx \]

Applying the rule of integration which states that if the numerator is the differentiation of the denominator, then the integral is \( \ln \) (the denominator)

\[ CHF_{KWL} (x, \theta) = -\ln \left[ 1 - \left( 1 - e^{-\theta x} \left( 1 + \frac{\theta x}{\theta + 1} \right) \right)^a \right]^b \]

Reverse hazard rate function is

\[ \frac{f_{KWL}}{F_{KWL}} = \frac{ab \theta^2}{\theta + 1} w_j q x^{m+j} (1+x) e^{-\theta x (1+\frac{\theta x}{\theta + 1})} \]

\[ 1 - \left( 1 - e^{-\theta x} (1+\frac{\theta x}{\theta + 1}) \right)^a \]
Dispersion in a population can be measured by measuring the sum of deviations from the mean and median and if we have \( X \) as a random variable that is Kumaramswamy Lindley distributed we can derive the mean deviation about the mean \( \mu = E(x) \) and the mean deviation about the median \( M = F^{-1}\left(\frac{1}{2}\right) \)

\[
\delta_1 = \int_0^{\infty} |X - \mu| f_{kw}(x)dx
\]

\[
\delta_1 = \int_0^{\infty} |X - \mu| f_{kw}(x)dx + \int_\mu^{\infty} (x - \mu)f_{kw}(x)dx
\]

\[
\delta_1 = \mu \int_0^{\infty} f_{kw}(x)dx - \int_0^{\infty} x f_{kw}(x)dx + \int_\mu^{\infty} xf_{kw}(x)dx - \int_\mu^{\infty} \mu f_{kw}(x)dx
\]

\[
\delta_1 = \mu F(\mu) - \int_0^{\infty} x f_{kw}(x)dx + \int_\mu^{\infty} xf_{kw}(x)dx - \mu(1 - F(\mu))
\]

\[
\delta_1 = 2\mu F(\mu) - 2\mu + \int_\mu^{\infty} xf_{kw}(x)dx
\]

Now we calculate the value of the integral \( \pi = \int_\mu^{\infty} xf_{kw}(x)dx \). By substituting the probability density function for the Kumaramswamy Lindley distribution, we get

\[
\pi = \int_\mu^{\infty} x \frac{ab \theta^2}{\theta + 1} w_j q x^{m+j} (1 + x) e^{-\theta x(k+y)}dx(x)dx
\]

Simplifying the previous integration, we get

\[
\pi = \frac{ab \theta^2}{\theta + 1} w_j q \int_\mu^{\infty} x^{m+j+1} (1 + x) e^{-\theta x(k+y)}dx(x)dx
\]

Suppose that \( k_{10} = \int_\mu^{\infty} x^{m+j+1}e^{-\theta x(k+y)}dx \) and \( k_{11} = \int_\mu^{\infty} x^{m+j+2} e^{-\theta x(k+y)}dx \), then

\[
\pi = \frac{ab \theta^2}{\theta + 1} w_j q \left[ k_{10} + k_{11} \right]
\]

Now we calculate the value of \( k_{10} \)

\[
k_{10} = \int_\mu^{\infty} x^{m+j+1}e^{-\theta x(k+y)}dx
\]

\[
k_{10} = \int_\mu^{\infty} \left( \frac{y}{(\theta(k+y))} \right)^{m+j+1} e^{-y} \frac{dy}{(\theta(k+y))}
\]

\[
k_{10} = \frac{1}{(\theta(k+y))^{m+j+2}} \int_\mu^{\infty} [y]^{m+j+1} e^{-y}dy
\]

Applying the general form of the gamma function, we have
Now we calculate the value of $k_{11}$

$$k_{11} = \int_0^\infty x^{m+j+2} e^{-\theta x(k+y)}dx$$

$$k_{11} = \int_0^\infty \left[ \frac{y}{(\theta(k+y))} \right]^{m+j+2} e^{-y} \left( \frac{1}{(\theta(k+y))} \right)^{m+j+3} dy$$

Applying the general form of the gamma function, we get

$$k_{11} = \frac{\Gamma(m+j+3,\mu(\theta(k+y)))}{\theta(k+y)^{m+j+3}}$$

$$\pi = \frac{ab \theta^2}{\theta + 1} w_j q [ k_{10} + k_{11} ]$$

Substituting for the value of $k_{11}, k_{10}$ we get

$$\pi = \frac{ab \theta^2}{\theta + 1} w_j q \left[ \frac{\Gamma(m+j+1,\mu(\theta(k+y)))}{(\theta(k+y))^{m+j+2}} + \frac{\Gamma(m+j+3,\mu(\theta(k+y)))}{\theta(k+y)^{m+j+3}} \right]$$

Substituting for the value $\pi$ we get the mean deviation

$$\delta_1 = 2\mu F(\mu) - 2\mu$$

$$+ \frac{ab \theta^2}{\theta + 1} w_j q \left[ \frac{\Gamma(m+j+1,\mu(\theta(k+y)))}{(\theta(k+y))^{m+j+2}} + \frac{\Gamma(m+j+3,\mu(\theta(k+y)))}{\theta(k+y)^{m+j+3}} \right]$$

4. Conclusions

In this research paper, we present some of new mathematical properties of the Kumaraswamy Lindley distribution. The properties of reversed residual life, mean of residual life, moments of residual life, probability weighted moments, and cumulative hazard rate function, have been derived. Furthermore, we invite researchers to study more mathematical properties of the distribution because of its many applications which can contribute to solving many life problems.

References