Research Article

A New Class of Extended Hypergeometric Functions Related to Fractional Integration and Transforms

Vandana Palsaniya, Ekta Mittal, D. L. Suthar, and Sunil Joshi

1Department of Mathematics, IIS (Deemed to be) University, Jaipur, India
2Department of Mathematics, Wollo University, P. O. Box: 1145, Dessie, Ethiopia
3Department of Mathematics and Statistics, Manipal University Jaipur, Dahmi Kalan, Rajasthan, India

Correspondence should be addressed to D. L. Suthar; dlsuthar@gmail.com

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The focus of this research is to use a new extended beta function and develop the extensions of Gauss hypergeometric functions and confluent hypergeometric function formulas that are presumed to be new. Four theorems have also been defined under the generalized fractional integral operators that provide an image formula for the extension of new Gauss hypergeometric functions and the extension of new confluent hypergeometric functions. Moreover, discussed are analogous statements in terms of the Weyl, Riemann–Liouville, Erdélyi–Kober, and Saigo fractional integral and derivative operator types. Here, we are also able to generate more image formulas by keeping some integral transforms on the obtained formulas.

1. Introduction and Preliminaries

A special function is any of a number of mathematical functions that emerge in the solution of many classical physics problems. A recurrent theme in these challenges is the flow of electromagnetic, acoustic, and thermal energy. For the specific kind of special role of scientists and engineers, it has become an essential resource now a day. And in many fields, such as physical science, mathematical science, and engineering, this feature plays a very important role. There are numerous ways to define special functions. A series or an adequate integral can be used to define several specific functions of a complex variable. Special functions, such as Bessel functions, Whittaker functions, Gauss hypergeometric functions, and Jacobi, Legendre, Laguerre, and Hermite polynomials, have been continuously developed. Polynomial sequences are very important in applied mathematics (see [1–4]). Fractional calculus is a noninteger order generalisation of classical differentiation and integration. Riemann–Liouville, Erdélyi–Kober, Hadamard, Caputo, Hilfer, Liouville–Caputo, Grünwald–Letnikov, Riesz, Coimbra, and Weyl all provided important definitions of fractional derivatives.

Many substances’ consciousness and natural processes are characterised by fractional derivatives. As a generalisation of classical integer-order differential equations, fractional ordinary and partial differential equations exist. Fractional differential equations have been used to examine a variety of phenomena. It becomes more common to use it to illustrate problems in biology, electrodynamics, elasticity, viscoelasticity, fluid dynamics, physics, engineering, and a variety of other subjects (see [5–10]). Saigo [11] with generalized Gauss hypergeometric function (GHF) in the kernel and Saigo and Maeda [12] with Appell function in the kernel introduced generalized fractional integral operators.

In our analysis, we have to remember the subsequent pair of Saigo–Maeda fractional integral operators.

Let \( \omega, \omega', \nu, \nu', \zeta \in \mathbb{C} \) such that \( \Re(\zeta) > 0 \), \( x > 0 \), and the generalized fractional integral operator connecting Appell’s function or Horn’s function with the kernel [12] is defined as follows:
The Appell’s function or Horn’s function $F_3(\cdot)$ in two variables \cite{13} is defined as

$$ F_3(\omega, \omega', v, v'; \zeta, x, y) = \sum_{m,s=0}^{\infty} \frac{(\omega)_m (\omega')_m (v)_m (v')_m}{(\zeta)_{m+s}} \frac{x^m y^s}{m! s!} \quad \{\max(|x|,|y|) < 1\}. \tag{3} $$

Remark 1. The Appell’s function $F_3(\cdot)$ diminishes into Gauss hypergeometric function $\, _2F_1$ by the subsequent relation

\begin{align*}
F_3(\omega, \zeta - \omega, v, \zeta - v; \zeta, x, y) &= \, _2F_1(\omega, v; \zeta; x + y - xy), \\
F_3(\omega, 0, v; \zeta; x, y) &= \, _2F_1(\omega, v; \zeta; x), \\
F_3(0, \omega', v; \zeta; x, y) &= \, _2F_1(\omega', v; \zeta; y).
\end{align*}

Equations (1) and (2) reduce to Saigo operators, which are generalized fractional integral operators bound to the Gauss hypergeometric function if setting $\omega' = 0$, $\omega = \zeta$ and $\omega' = 0$, $\omega = \zeta = 0$ reduces it to the Saigo type, Erdélyi–Kober, Riemann–Liouville (R-L), and Weyl type fractional integral operators, respectively, as follows:

\begin{align*}
\left( I^{\omega, \omega', v, v'}_{0, x} f \right)(x) &= \left( I^{\omega - \xi, v}_{0, x} f \right)(x) = \frac{x^{-\omega}}{\Gamma(\zeta)} \int_0^x (x - \ell)^{\zeta - 1} e^{-\omega \ell} f(\ell) d\ell, \\
\left( J^{\omega, \omega', v, v'}_{0, \infty} f \right)(x) &= \left( J^{\omega - \xi, v}_{x, \infty} f \right)(x) = \frac{1}{\Gamma(\zeta)} \int_x^{\infty} (\ell - x)^{\zeta - 1} e^{-\omega \ell} f(\ell) d\ell,
\end{align*}

where $\{\zeta > 0, \omega, v \in \mathbb{R}\}$.

Moreover,

\begin{align*}
\left( \mathcal{I}^{\zeta, v}_{0, x} f \right)(x) &= \left( \mathcal{I}^{\zeta - v}_{0, x} f \right)(x) = \frac{x^{-\zeta + v}}{\Gamma(\zeta)} \int_0^x (x - \ell)^{\zeta - 1} e^{-v \ell} f(\ell) d\ell, \\
\left( \mathcal{J}^{\zeta, v}_{x, \infty} f \right)(x) &= \left( \mathcal{J}^{\zeta - v}_{x, \infty} f \right)(x) = \frac{x^{-v}}{\Gamma(\zeta)} \int_x^{\infty} (\ell - x)^{\zeta - 1} e^{-v \ell} f(\ell) d\ell,
\end{align*}

where $\{\zeta > 0, v \in \mathbb{R}\}$.

Moreover,

\begin{align*}
\left( \mathcal{R}^{\zeta}_{0, x} f \right)(x) &= \left( \mathcal{R}^{\zeta}_{0, x} f \right)(x) = \frac{1}{\Gamma(\zeta)} \int_0^x (x - \ell)^{\zeta - 1} f(\ell) d\ell, \\
\left( \mathcal{W}^{\zeta}_{x, \infty} f \right)(x) &= \left( \mathcal{W}^{\zeta}_{x, \infty} f \right)(x) = \frac{1}{\Gamma(\zeta)} \int_x^{\infty} (\ell - x)^{\zeta - 1} f(\ell) d\ell,
\end{align*}

where $\{\zeta > 0\}$.

The operator $I^{\omega, \omega', v, v'}(\cdot)$ contains Saigo type, Riemann–Liouville (R-L), and Erdélyi–Kober fractional integral operator, and $J^{\omega, \omega', v, v'}(\cdot)$ combines the Saigo type, Weyl, and Erdélyi–Kober fractional integral operator defined by Saigo \cite{11}.
Lemma 1. Suppose \( ω, ω', v, v', ζ, \mathfrak{F} \in \mathcal{C} \) and \( x > 0 \) be s.t. \( \hat{R}(ζ) > 0 \), then the subsequent formula is valid

\[
\left[ \hat{R}(\mathfrak{F}) > x \right] - \text{valid}\]

\[
\left[ \hat{R}(\mathfrak{F}) > 0 \right] - \text{valid}\]

where \( [\hat{R}(\mathfrak{F}) > x] \) > \( \text{valid}\)

\[
\left[ \hat{R}(\mathfrak{F}) > 0 \right] - \text{valid}\]

Lemma 2. Suppose \( ω, v, ζ \in \mathcal{C} \) be such that \( \hat{R}(ω) > 0 \); then, we have the subsequent relation

\[
\left( ω, v, ζ \right) - \text{valid}\]

\[
\left( ω, v, ζ \right) - \text{valid}\]

where \( [\hat{R}(\mathfrak{F}) > \text{valid}] \) > \( \text{valid}\)

\[
\left[ \hat{R}(\mathfrak{F}) > \text{valid} \right] - \text{valid}\]

Lemma 3. Suppose \( ω, ζ \in \mathcal{C} \) be such that \( \hat{R}(ω) > 0 \); then, we have the subsequent relation

\[
\left( ω, ζ \right) - \text{valid}\]

\[
\left( ω, ζ \right) - \text{valid}\]

where \( [\hat{R}(\mathfrak{F}) > \text{valid}] \) > \( \text{valid}\)

\[
\left[ \hat{R}(\mathfrak{F}) > \text{valid} \right] - \text{valid}\]

Lemma 4. Let \( ω, \mathfrak{F} \in \mathcal{C} \), then we have the subsequent relation

\[
\left( ω, \mathfrak{F} \right) - \text{valid}\]

\[
\left( ω, \mathfrak{F} \right) - \text{valid}\]

where \( [\hat{R}(\mathfrak{F}) > \text{valid}] \) > \( \text{valid}\)

\[
\left[ \hat{R}(\mathfrak{F}) > \text{valid} \right] - \text{valid}\]

Suppose \( h(\mathfrak{F}) = \sum_{n=0}^\infty a_n \mathfrak{F}^n \) and \( s(\mathfrak{F}) = \sum_{n=0}^\infty b_n \mathfrak{F}^n \) are the two series whose convergence radii are determined by \( R_h \) and \( \hat{R}_s \), respectively. Then, the series described by their Hadamard product [14] is
\[ (h * s)(\theta) = \sum_{n=0}^{\infty} \hat{a}_n \hat{b}_n \theta^n, \]  
(14)

where the radii of convergence \( R \) satisfy \( R_a, R_b \leq R \).

If one of the series specifies it and the radii of convergence of the other are greater than 0, the Hadamard series

\[ F_{1 \rightarrow r} \left( \begin{array}{c} x_1, \ldots, x_s \\ y_1, \ldots, y_r \end{array} ; \theta; \sigma \right) = \sum_{n=0}^{\infty} \frac{MC_B(\hat{b} + s, \hat{c} - \hat{b})}{B(\hat{b}, \hat{c} - \hat{b})} \frac{\theta^n}{n!}, \quad (|\theta| < \infty). \]

(15)

2. A Class of Extended Hypergeometric Functions

For the present investigation, we use the extension of the hypergeometric function specified by Palsaniya et al. [15] in the following way:

\[ MC_F(\sigma, \delta, x) = \sum_{n=0}^{\infty} (\sigma)_n \frac{MC_B(\sigma + s, \sigma - \hat{b})}{\Gamma(\sigma)} \frac{\theta^n}{n!}, \]  
(16)

\[ MC_Y(\sigma, \delta, x) = \sum_{n=0}^{\infty} \frac{MC_B(\sigma + s, \sigma - \hat{b})}{\Gamma(\sigma)} \frac{\theta^n}{n!}, \quad \{0 < 1, \hat{R}(\sigma) > 0, \hat{R}(\hat{c}) > \hat{R}(\hat{b}) > 0\}, \]

(17)

where \( MC_B(\sigma, \delta, x) \) extended beta function is defined as

\[ MC_B(\sigma, \delta, x) = \int_{0}^{1} \theta^{x-1} (1 - \theta)^{y-1} F_1(\sigma, \delta; x, \theta) - d\theta, \]

\[ \{0 < 1, \hat{R}(\sigma) > 0, \hat{R}(\hat{c}) > \hat{R}(\hat{b}) > 0\}. \]

(18)

Now, \( MC_F(\sigma, \delta, x) = MC_F(\sigma, \delta, \hat{b}; \hat{c}; \hat{\theta}) \) and \( MC_F(\sigma, \delta, \hat{b}; \hat{c}; \hat{\theta}) = \gamma F_1(\sigma, \delta, \hat{b}; \hat{c}; \hat{\theta}) \)

2.3. Fractional Integration of the New Extended Hypergeometric Function

In this segment, we evaluate several fractional integral formulas for the generalized hypergeometric function \( MC_F(\sigma, \delta, \hat{b}; \hat{c}; \hat{\theta}) \) and confluent hypergeometric function \( MC_F(\sigma, \delta, \hat{b}; \hat{c}; \hat{\theta}) \) using the concept of the Hadamard product [14].

**Theorem 1.** Let \( \omega, \omega', v, v', \zeta, \Sigma, \sigma, \delta, \hat{a}, \hat{b}, \hat{c} \in C \) and \( x > 0 \) be such that \( \hat{R}(\hat{b}) > 0, \{x \in C, |x| < K; 0 < K < 2.0335\}, \) then

\[ (1)_{0, \alpha}^{\omega, v, v', \zeta} \hat{\zeta}^{\Sigma-1} MC_F(\sigma, \delta, \hat{a}; \hat{b}; \hat{c}; \hat{\ell})(x) \]

\[ = x^{\alpha \zeta - \omega - \omega' - 1} \Gamma(\Sigma + \zeta - \omega - \omega') \Gamma(\Sigma + \zeta - \omega) \Gamma(\Sigma + \zeta - \omega) \]

\[ \times F_3 \left[ \begin{array}{c} \Sigma + \zeta - \omega - \omega', \Sigma + \zeta - \omega \end{array} ; x \right]. \]

**Proof.** Let us consider that the left-hand side of equation (20) is symbolized by \( I \). In equation (16), if we reverse the order of integration and summation, we get

\[ \frac{\partial}{\partial \sigma} F_1(\sigma, \delta, \hat{b}; \hat{c}; \hat{\theta}) = \sum_{n=0}^{\infty} \frac{MC_B(\sigma + s, \sigma - \hat{b})}{\Gamma(\sigma)} \frac{\theta^n}{n!}, \]

(19)
\[
I = \left( I_{b,c}^{\mu,a',\nu,c',\xi} \right) \sum_{s=0}^{\infty} (\tilde{a})_s \frac{MC B_{\sigma,\delta,\kappa} (\hat{b} + s, \hat{c} - \hat{b}) \, \ell^s}{B(b, \hat{c} - b)} \frac{\ell^s}{s!} (x),
\]

Using the result which is defined in (8), we have

\[
= \sum_{s=0}^{\infty} (\tilde{a})_s \frac{\Gamma(s + 3) \Gamma(s + 3 + \zeta - \omega - \omega' - \nu) \Gamma(s + 3 + \nu' - \omega')}{\Gamma(s + 3 + \nu') \Gamma(s + 3 + \zeta - \omega - \omega' - \nu) \Gamma(s + 3 + \zeta - \omega - \omega' - \nu)}
\]

\[
\times \frac{MC B_{\sigma,\delta,\kappa} (\hat{b} + s, \hat{c} - \hat{b}) \, \ell^s \Gamma(s + 3 + \nu' - 1)}{B(b, \hat{c} - b)} \frac{\ell^s}{s!} (x).
\]

(21)

After simplification, using the property of the Pochhammer symbol \((\hat{a})_s = (\Gamma(s + \hat{a})/\Gamma(s))\), we obtain

\[
= \ell^s \Gamma(s + 3) \Gamma(s + 3 + \zeta - \omega - \omega' - \nu) \Gamma(s + 3 + \nu' - \omega') \Gamma(s + 3 + \zeta - \omega - \omega' - \nu) \Gamma(s + 3 + \zet - \omega - \omega' - \nu) \Gamma(s + 3 + \zet - \omega - \omega' - \nu)
\]

\[
\times \sum_{s=0}^{\infty} (\tilde{a})_s \frac{MC B_{\sigma,\delta,\kappa} (\hat{b} + s, \hat{c} - \hat{b}) \, \ell^s \Gamma(s + 3 + \nu' - 1)}{B(b, \hat{c} - b)} \frac{\ell^s}{s!} (x).
\]

(22)

Finally, using the concept of the Hadamard product in the above equation, then it will change into the required result (20).

\[
\left( I_{x,\infty}^{\mu,a',\nu,c',\xi} \right) \left( \tilde{a}, \hat{b}; \frac{1}{\ell} \right) (x)
\]

\[
= \ell^{3\zeta - \omega - \omega' - 1} \Gamma(1 - 3 - \eta) \Gamma(1 - 3 - \zeta + \omega + \omega') \Gamma(1 - 3 - \zeta + \nu + \omega') \Gamma(1 - 3 + \zeta + \omega - \omega' - \nu)
\]

\[
\times \frac{MC F_{\sigma,\delta,\kappa} \left( \tilde{a}, \hat{b}; \frac{1}{\ell} \right) \times \prod_{i=1}^{3} \left( 1 - 3 - \zeta + \omega + \omega', 1 - 3 - \zeta + \nu + \omega', 1 - 3 + \zeta + \omega - \omega' - \nu \right) \frac{1}{\xi} }{\prod_{i=1}^{3} \left( 1 - 3 - \zeta + \omega + \omega', 1 - 3 - \zeta + \nu + \omega', 1 - 3 + \zeta + \omega - \omega' - \nu \right) \frac{1}{\xi} }.
\]

(23)

**Theorem 2.** Suppose \( \omega, \omega', \nu, \nu', \zeta, \varsigma, \sigma, \delta, \tilde{a}, \hat{b}, \hat{c} \in C, \ x > 0 \) be such that \( R(\zeta) > 0, |\varsigma| < K; 0 < K < 2.0335 \), then

\[
\left( I_{x,\infty}^{\mu,a',\nu,c',\xi} \right) \left( \tilde{a}, \hat{b}; \frac{1}{\ell} \right) (x)
\]

\[
= \ell^{3\zeta - \omega - \omega' - 1} \Gamma(1 - 3 - \eta) \Gamma(1 - 3 - \zeta + \omega + \omega') \Gamma(1 - 3 - \zeta + \nu + \omega') \Gamma(1 - 3 + \zeta + \omega - \omega' - \nu)
\]

\[
\times \frac{MC F_{\sigma,\delta,\kappa} \left( \tilde{a}, \hat{b}; \frac{1}{\ell} \right) \times \prod_{i=1}^{3} \left( 1 - 3 - \zeta + \omega + \omega', 1 - 3 - \zeta + \nu + \omega', 1 - 3 + \zeta + \omega - \omega' - \nu \right) \frac{1}{\xi} }{\prod_{i=1}^{3} \left( 1 - 3 - \zeta + \omega + \omega', 1 - 3 - \zeta + \nu + \omega', 1 - 3 + \zeta + \omega - \omega' - \nu \right) \frac{1}{\xi} }.
\]

(24)

**Proof.** Using the formula in equation (16), we designate the left side of equation (24) as \( \hat{I} \) and then exchange the order of integration and summation, yielding the following result:

\[
\hat{I} = \left( I_{x,\infty}^{\mu,a',\nu,c',\xi} \right) \left( \tilde{a}, \hat{b}; \frac{1}{\ell} \right) \left( 1 + \ell \right)^{3\zeta - 1} \frac{MC B_{\sigma,\delta,\kappa} (\hat{b} + s, \hat{c} - \hat{b}) \, \ell^s}{B(b, \hat{c} - b)} \frac{\ell^s}{s!} (x)
\]

\[
= \sum_{s=0}^{\infty} (\tilde{a})_s \frac{MC B_{\sigma,\delta,\kappa} (\hat{b} + s, \hat{c} - \hat{b}) \, \ell^s}{B(b, \hat{c} - b)} \frac{\ell^s}{s!} \left( I_{x,\infty}^{\mu,a',\nu,c',\xi} \right) \left( \tilde{a}, \hat{b}; \frac{1}{\ell} \right) (x).
\]

(25)
Using the result of Lemma 1 which is defined in equation (9), after some simplification, we obtain

\[
\begin{align*}
&= x^{3+\zeta-\omega'-1} \frac{\Gamma(1-\mathfrak{F}-v)\Gamma(1-\mathfrak{F}-\zeta+\omega')\Gamma(1-\mathfrak{F}-\zeta+\omega)}{\Gamma(1-3\mathfrak{F})\Gamma(1-3-\zeta+\omega' +\omega)} \\
&\times \sum_{a=0}^{\infty} \frac{MC_{\alpha,\beta,\gamma}(\tilde{b} + s, \tilde{c} - \tilde{b})}{B(b, \tilde{c} - b)} \frac{(1-\mathfrak{F}-v)(1-\mathfrak{F}-\zeta + \omega')}{(1-\mathfrak{F})s}(1-\mathfrak{F} - \zeta + \omega + \omega') s!.
\end{align*}
\]  

(26)

Using the concept of Hadamard product, we get the desired result. □

**Theorem 3.** Let \(\omega, \omega', v, \zeta, \sigma, \delta, \tilde{b}, \tilde{c} \in C\) and \(x > 0\) be such that \(\hat{R} = 0, \hat{R}(\zeta) > \hat{R}(\bar{b}) > 0, \ |\sigma| < K; 0 < K < 2.0335\) such that \(\hat{R}(3) > 0\), then

\[
\begin{align*}
&= x^{3+\zeta-\omega'-1} \frac{\Gamma(3\mathfrak{F} + (3 + \zeta - \omega - \omega')\Gamma(3 + \zeta - \omega' - v)}{\Gamma(3 + v')\Gamma(3 + v - \omega')\Gamma(3 + \zeta - \omega' - v)} \\
&\times 3F3 \left[ \begin{array}{c} 3, 3 + \zeta - \omega - \omega' - v, 3 + v' - \omega' \\ 3 + v', 3 + \zeta - \omega' - v, 3 + \zeta - \omega' - v \end{array} ; x \right] 
\end{align*}
\]

(27)

**Theorem 4.** Let \(\omega, \omega', v, \zeta, \sigma, \delta, \tilde{b}, \tilde{c} \in C\) and \(x > 0\) be such that \(\hat{R} = 0, \hat{R}(\zeta) > \hat{R}(\bar{b}) > 0, \ |\sigma| < K; 0 < K < 2.0335\) such that \(\hat{R}(3) < 1 + \min[\hat{R}(v), \hat{R}(\bar{c})] \), then

\[
\begin{align*}
&= x^{3+\zeta-\omega'-1} \frac{\Gamma(3\mathfrak{F} + (3 + \zeta - \omega - \omega')\Gamma(3 + \zeta - \omega' - v)}{\Gamma(3 + v')\Gamma(3 + v - \omega')\Gamma(3 + \zeta - \omega' - v)} \\
&\times 3F3 \left[ \begin{array}{c} 3, 3 - v, 1 - 3 - \zeta + \omega + \omega', 1 - 3 - \zeta + v' + \omega \\ 1 - 3, 1 - 3 - \zeta + \omega + \omega', 1 - 3 + \omega + v' \end{array} ; \frac{1}{x} \right] 
\end{align*}
\]

(28)

**Proof.** The proof of Theorems 3 and 4 is similar to that of Theorems 1 and 2, respectively. □

**Remark 2.** If setting \(\omega' = 0, \omega = \zeta\) and \(\omega' = 0, \omega = \omega' = 0\) in Theorems 1–4, then these will convert into the following interesting results asserted by the subsequent corollaries.

\[
\begin{align*}
&= x^{3+\zeta-\omega'-1} \frac{\Gamma(3\mathfrak{F} + (3 + \zeta - \omega - \omega')\Gamma(3 + \zeta - \omega' - v)}{\Gamma(3 + v')\Gamma(3 + v - \omega')\Gamma(3 + \zeta - \omega' - v)} \\
&\times 3F3 \left[ \begin{array}{c} 3, 3 + \zeta - \omega - \omega' \\ 3 + \zeta - \omega, 3 + \zeta - \omega' \end{array} ; x \right] 
\end{align*}
\]

(29)
Corollary 2. Let \( \omega, \nu, \zeta, \sigma, \nu, \tilde{a}, \tilde{b}, \tilde{c} \in C \) and \( x > 0 \) be such that \( \tilde{R}(\omega) > 0, \tilde{R}(\zeta) < 1 + \min \{ \tilde{R}(\sigma), \tilde{R}(\tilde{b}) \} \); \( \min \{ \tilde{R}(\sigma), \tilde{R}(\tilde{b}) \} > 0 \) and \( |\nu| < K < 2.0335 \), then

\[
\left( \mathcal{I}_{x,0}^{\omega,\nu,\zeta,\sigma} \mathcal{F}_{\sigma,\delta, \kappa} \left[ \begin{array}{c} \tilde{a}, \tilde{b}, \tilde{c} \end{array} \right] \right) (x) = x^{3 + \omega - 1} \frac{\Gamma(1 - 3 - \nu) \Gamma(1 - 3 - \zeta + \omega)}{\Gamma(1 - 3) \Gamma(1 - 3 - \omega + v)} \times \mathcal{F}_{\sigma,\delta, \kappa} \left[ \begin{array}{c} 1 - 3 - \nu, 1 - 3 - \zeta + \omega \end{array} \right] \frac{1}{x}. \]

Corollary 3. Let \( \omega, \nu, \zeta, \sigma, \nu, \tilde{a}, \tilde{b}, \tilde{c} \in C \) and \( x > 0 \) be such that \( \tilde{R}(\omega) > 0, \tilde{R}(\zeta) > \tilde{R}(\tilde{b}) > 0 \) and \( \nu/k > 0 \) and \( \tilde{R}(\zeta) > 0 \) and \( |\nu| < K < 2.0335 \), then

\[
\left( \mathcal{I}_{x,0}^{\omega,\nu,\zeta,\sigma} \mathcal{F}_{\sigma,\delta, \kappa} \left[ \begin{array}{c} \tilde{a}, \tilde{b}, \tilde{c} \end{array} \right] \right) (x) = x^{3 + \omega - 1} \frac{\Gamma(3) \Gamma(3 + \zeta - \omega - v)}{\Gamma(3 + \zeta - \omega) \Gamma(3 + \zeta - v)} \times \mathcal{F}_{\sigma,\delta, \kappa} \left[ \begin{array}{c} 3 + \zeta - \omega - v \end{array} \right] \frac{3 + \zeta - \omega - v}{x}. \]

Corollary 4. Let \( \omega, \nu, \zeta, \sigma, \nu, \tilde{a}, \tilde{b}, \tilde{c} \in C \), \( x > 0 \) be such that \( \tilde{R}(\omega) > 0, \tilde{R}(\zeta) > \tilde{R}(\tilde{b}) > 0 \) and \( \nu/k > 0 \) and \( \tilde{R}(\zeta) > 0 \) and \( |\nu| < K < 2.0335 \), then

\[
\left( \mathcal{I}_{x,0}^{\omega,\nu,\zeta,\sigma} \mathcal{F}_{\sigma,\delta, \kappa} \left[ \begin{array}{c} \tilde{a}, \tilde{b}, \tilde{c} \end{array} \right] \right) (x) = x^{3 + \omega - 1} \frac{\Gamma(1 - 3 - \nu) \Gamma(1 - 3 - \zeta + \omega)}{\Gamma(1 - 3) \Gamma(1 - 3 - \omega + v)} \times \mathcal{F}_{\sigma,\delta, \kappa} \left[ \begin{array}{c} 1 - 3 - \nu, 1 - 3 - \zeta + \omega \end{array} \right] \frac{1}{x}. \]

Remark 3. Setting \( \omega = \zeta \) in Corollaries 1–4 and employing the relation Saigo fractional integrals reduce to Erdélyi–Kober fractional integral operators.

Remark 4. If we replace \( \omega = \omega = \zeta = 0 \) in Theorems 1–4, then Saigo fractional integral operators are reduced to Riemann–Liouville and Weyl fractional integral operators, respectively.

Remark 5. If we choose \( \kappa = 0 \) and \( \sigma = \delta \) in equations (16) and (17), the new extension of Gauss hypergeometric function \( \mathcal{H}_{\sigma, \delta, \kappa} \) and new extension of confluent hypergeometric function \( \mathcal{H}_{\sigma, \delta, \kappa} \) convert into classical function, and all results moreover reduce into fractional integration of classical functions in terms of Saigo–Maeda, Saigo, Erdélyi–Kober, Riemann–Liouville, etc.

4. Integral Transforms of Extended Gauss and Confluent Hypergeometric Functions

In this section, we demonstrate several theorems and corollaries by using different kinds of transforms like Beta transform and Laplace transform based on the results acquired in the previous section.

4.1. Beta Transform. The Beta transform of \( f(\theta) \) is demarcated as

\[
B\left[ f(\theta); \tilde{a}, \tilde{b} \right] = \int_0^1 \theta^{(a-1)} (1 - \theta)^{(b-1)} f(\theta) d\theta. \quad (33)
\]

Theorem 5. Suppose \( \omega, \omega', \nu, \nu', \zeta, \sigma, \delta, \tilde{a}, \tilde{b}, \tilde{c} \in C \) and \( x > 0 \) be such that \( \tilde{R}(\zeta) > 0, \tilde{R}(\zeta) > 0 \) and \( \min \{ \tilde{R}(\sigma), \tilde{R}(\tilde{b}) \} > 0 \) and \( |\nu| < K < 2.0335 \), then

\[
\left( \mathcal{I}_{x,0}^{\omega,\nu,\zeta,\sigma} \mathcal{F}_{\sigma,\delta, \kappa} \left[ \begin{array}{c} \tilde{a}, \tilde{b}, \tilde{c} \end{array} \right] \right) (x) = x^{3 + \omega - 1} \frac{\Gamma(3) \Gamma(3 + \zeta - \omega - v)}{\Gamma(3 + \zeta - \omega) \Gamma(3 + \zeta - v)} \times \mathcal{F}_{\sigma,\delta, \kappa} \left[ \begin{array}{c} 3 + \zeta - \omega - v \end{array} \right] \frac{3 + \zeta - \omega - v}{x}. \]
\[
B\left(\left(\int_{0,x}^{\omega,\omega',\omega',\omega'} e^{\xi - 1}\mathcal{F}_{\xi, \sigma, \delta, \kappa, \rho, \nu} (\xi, \sigma, \delta, \kappa, \rho, \nu) \right) \right)(x, \lambda, m) = x^{3 + \xi - \omega - \omega'} \Gamma (m) \Gamma (3 + \xi - \omega - \omega') \Gamma (3 + \xi - \omega) \Gamma (3 + \xi - \omega') \Gamma (3 + \xi - \omega - v) \Gamma (m + 3 + \xi - \omega - v) \Gamma (l + m) \mathcal{F}_{\xi, \sigma, \delta, \kappa, \rho, \nu} (\xi, \sigma, \delta, \kappa, \rho, \nu) (x, \lambda, m)
\]

Proof. For convenience, we refer to the left-hand side of (34) by \( \tilde{B} \); then applying the definition of beta transform, we have

\[
\tilde{B} = \int_{0}^{1} \theta^{(l-1)} (1 - \theta)^{(m-1)} \left(\int_{0,x}^{\omega,\omega',\omega',\omega'} e^{\xi - 1}\mathcal{F}_{\xi, \sigma, \delta, \kappa, \rho, \nu} (\xi, \sigma, \delta, \kappa, \rho, \nu) \right)(x) d\theta,
\]

and we may now use the formula in (16) and change the order of integration and summation to get the following result:

\[
\tilde{B} = \sum_{s=0}^{\infty} (\tilde{a})_{s} \frac{B_{\xi, \sigma, \delta, \kappa, \rho, \nu} (\tilde{b} + s, \tilde{c} - \tilde{b})}{B(b, \tilde{c} - \tilde{b})} \frac{1}{s!} \left(\int_{0,x}^{\omega,\omega',\omega',\omega'} e^{\xi - 1}\mathcal{F}_{\xi, \sigma, \delta, \kappa, \rho, \nu} (\xi, \sigma, \delta, \kappa, \rho, \nu) \right)(x) d\theta
\]

By applying the formula given in (8) and using the definition of beta transform in the above equation, then it will reduce to

\[
\tilde{B} = \sum_{s=0}^{\infty} (\tilde{a})_{s} \frac{1}{s!} \frac{\Gamma (s + 3) \Gamma (s + 3 + \xi - \omega - \omega') \Gamma (s + \xi - \omega - v) \Gamma (s + \xi - \omega')}{\Gamma (s + 3 + \xi - \omega - v) \Gamma (s + \xi - \omega') \Gamma (s + \xi - \omega - \omega') \Gamma (l + s + 3 + \xi - \omega - \omega') \Gamma (l + s)} \frac{B_{\xi, \sigma, \delta, \kappa, \rho, \nu} (\tilde{b} + s, \tilde{c} - \tilde{b})}{B(b, \tilde{c} - \tilde{b})} \frac{1}{s!} \left(\int_{0,x}^{\omega,\omega',\omega',\omega'} e^{\xi - 1}\mathcal{F}_{\xi, \sigma, \delta, \kappa, \rho, \nu} (\xi, \sigma, \delta, \kappa, \rho, \nu) \right)(x) d\theta
\]

Further simplification of (37) yields

\[
\tilde{B} = \sum_{s=0}^{\infty} (\tilde{a})_{s} \frac{1}{s!} \frac{\Gamma (s + 3) \Gamma (s + 3 + \xi - \omega - \omega') \Gamma (s + \xi - \omega - v) \Gamma (s + \xi - \omega')}{\Gamma (s + 3 + \xi - \omega - v) \Gamma (s + \xi - \omega') \Gamma (s + \xi - \omega - \omega') \Gamma (l + s + 3 + \xi - \omega - \omega') \Gamma (l + s)} \frac{B_{\xi, \sigma, \delta, \kappa, \rho, \nu} (\tilde{b} + s, \tilde{c} - \tilde{b})}{B(b, \tilde{c} - \tilde{b})} \frac{1}{s!} \left(\int_{0,x}^{\omega,\omega',\omega',\omega'} e^{\xi - 1}\mathcal{F}_{\xi, \sigma, \delta, \kappa, \rho, \nu} (\xi, \sigma, \delta, \kappa, \rho, \nu) \right)(x) d\theta
\]

Interpreting (38) with the help of (16), we obtain
Proof. By applying the formula given in (9) and using the definition of beta transform in the above equation, then it holds

\[
\mathcal{G} = x^{3+\zeta -\omega -\omega' -1} \Gamma(m) \Gamma(l) \Gamma(\mathcal{F} + \zeta -\omega -\omega') \Gamma(\mathcal{F} + \omega -\omega') \\
\Gamma(\mathcal{F} + \zeta) \Gamma(\mathcal{F} + \omega -\omega') 
\]

Now, interpreting (39) with the view of the concept of the Hadamard product, we have the required result given in equation (34). \[\square\]

\[\textbf{Theorem 6.} \text{ Let } \omega, \omega', \nu, \nu', \zeta, \mathcal{F}, \sigma, \delta, \alpha, \beta, \epsilon \in \mathbb{C}, \; x > 0 \text{ and } \mathcal{R}(\zeta) > 0, \; [\omega, \nu, \nu', \zeta, \mathcal{F}] \in \mathbb{C}, \; \sigma > 0 \; \text{and} \; 0 < K < 2.0335, \text{ then} \]

\[
\int_0^1 \mathcal{F} \left( \frac{x}{\zeta} \right) (x; m, n) \text{ d}x = x^{3+\zeta -\omega -\omega' -1} \Gamma(m) \Gamma(l) \Gamma(\mathcal{F} + \zeta -\omega -\omega') \Gamma(\mathcal{F} + \omega -\omega') \\
\Gamma(\mathcal{F} + \zeta) \Gamma(\mathcal{F} + \omega -\omega') 
\]

\[
\text{Proof.} \text{ We designate the left-hand side of (38) by } \mathcal{F}, \text{ for convenience, and then, using the concept of beta transform, we have} \]

\[
\mathcal{F} = \int_0^1 \mathcal{G} (1 - \mathcal{G}) (m-1) \left( \int_0^1 \mathcal{G} (1 - \mathcal{G}) (m-1) \mathcal{F} \text{ d}x \right) \text{d} \mathcal{G}.
\]

Now, using the formula in (16) and reversing the integration and summation orders, we get

\[
= \sum_{s=0}^{\infty} \left( \frac{MC B_{\nu, \delta, \mathcal{F}} (\mathcal{F} + s, \mathcal{F} - \mathcal{F})}{B(\mathcal{F} + s, \mathcal{F} - \mathcal{F})} \right) \frac{(\mathcal{G} / \mathcal{G})^s}{s!} \left( \int_0^1 \mathcal{G} (1 - \mathcal{G}) (m-1) \mathcal{F} \text{ d}x \right) \text{d} \mathcal{G}
\]

By applying the formula given in (9) and using the definition of beta transform in the above equation, then it will reduce to

\[
= \sum_{s=0}^{\infty} \frac{\Gamma(1 - \mathcal{F} + s - \zeta + \omega + \omega') \Gamma(1 - \mathcal{F} + s - \zeta + \omega' + \omega)}{\Gamma(1 - \mathcal{F} + s + \zeta + \omega + \omega') \Gamma(1 - \mathcal{F} + s + \zeta + \omega' + \omega)} 
\]

\[
\times \mathcal{G} (1 - \mathcal{G}) (m-1) \mathcal{F} \left( \frac{x}{\zeta} \right) (x; m, n) \text{ d}x = x^{3+\zeta -\omega -\omega' -1} \Gamma(m) \Gamma(l) \Gamma(\mathcal{F} + \zeta -\omega -\omega') \Gamma(\mathcal{F} + \omega -\omega') \\
\Gamma(\mathcal{F} + \zeta) \Gamma(\mathcal{F} + \omega -\omega') 
\]

\[
\text{Proof.} \text{ We designate the left-hand side of (38) by } \mathcal{F}, \text{ for convenience, and then, using the concept of beta transform, we have} \]

\[
\mathcal{F} = \int_0^1 \mathcal{G} (1 - \mathcal{G}) (m-1) \left( \int_0^1 \mathcal{G} (1 - \mathcal{G}) (m-1) \mathcal{F} \text{ d}x \right) \text{d} \mathcal{G}.
\]

Now, using the formula in (16) and reversing the integration and summation orders, we get

\[
= \sum_{s=0}^{\infty} \left( \frac{MC B_{\nu, \delta, \mathcal{F}} (\mathcal{F} + s, \mathcal{F} - \mathcal{F})}{B(\mathcal{F} + s, \mathcal{F} - \mathcal{F})} \right) \frac{(\mathcal{G} / \mathcal{G})^s}{s!} \left( \int_0^1 \mathcal{G} (1 - \mathcal{G}) (m-1) \mathcal{F} \text{ d}x \right) \text{d} \mathcal{G}
\]

By applying the formula given in (9) and using the definition of beta transform in the above equation, then it will reduce to

\[
\mathcal{F} = \int_0^1 \mathcal{G} (1 - \mathcal{G}) (m-1) \left( \int_0^1 \mathcal{G} (1 - \mathcal{G}) (m-1) \mathcal{F} \text{ d}x \right) \text{d} \mathcal{G}.
\]
Further simplification of (43) yields
\[ x^{\alpha - \omega - \omega '} \sum_{s=0}^{\infty} \frac{(a)_s}{(1 \alpha - \omega - \omega ' - 1)} \frac{(1 - 3 - v)_s(1 - 3 - \zeta + \omega + \omega')_s(1 - 3 - \zeta + v + \omega')_s}{(1 - 3 - \omega + \omega')_s(l + m)} s! \]

By interpreting (44), with the help of (16), we have
\[ x^{\alpha - \omega - \omega '} \sum_{s=0}^{\infty} \frac{(a)_s}{(1 \alpha - \omega - \omega ' - 1)} \frac{(1 - 3 - v)_s(1 - 3 - \zeta + \omega + \omega')_s(1 - 3 - \zeta + v + \omega')_s}{(1 - 3 - \omega + \omega')_s(l + m)} s! \]

Now, interpreting (45) in the context of the Hadamard product concept, we arrive at the desired result, which is provided in (40).

**Corollary 5.** Suppose \( \omega, \nu, \zeta, \sigma, \delta, \tilde{a}, \tilde{b}, \tilde{c} \in C \) be such that \( R(\omega) > 0, R(3) > \max[0, R(\zeta - \nu)]; \min[R(\sigma), R(\delta)] > 0; R(\tilde{c}) > 0, R(\tilde{b}) > 0 \) and \( \{x \in C, |x| < K; 0 < K < 2.0335\} \), then

**Corollary 6.** Suppose \( \omega, \nu, \zeta, \sigma, \delta, \tilde{a}, \tilde{b}, \tilde{c} \in C \) be s.t. \( R(\omega) > 0, R(3) < 1 + \min[R(\nu)], \min[R(\sigma), R(\delta)] > 0 \) and \( \{x \in C, |x| < K; 0 < K < 2.0335\} \), then

**Corollary 7.** Suppose \( \omega, \nu, \zeta, \sigma, \delta, \tilde{a}, \tilde{b}, \tilde{c} \in C \) be s.t. \( R(\omega) > 0, R(\tilde{c}) > 0, R(\tilde{b}) > 0 \) and \( R(3) > \max[0, R(\zeta - \nu)]; \min\{R(\sigma), R(\delta)\} > 0 \) and \( \{x \in C, |x| < K; 0 < K < 2.0335\} \), then
Now using the formula given in (16) and then changing the order of integration and summation, we have

\[
\int_0^\infty e^{-s_\vartheta} g^{-1} \left( I_{0,x}^{\omega, \omega', \nu, \nu', \xi_\vartheta} x^{3-1} MC \right) F_{\vartheta, \delta_\vartheta} (a, b; \vartheta; \xi_\vartheta) (x) \, d\vartheta.
\]
By applying the formula given in (8) simplification of (53), then it will reduce to

\[
L = \sum_{s=0}^{\infty} \frac{(\hat{a})_s MCB_{\hat{b}, \hat{c}, \hat{d}} (\hat{b} + s, \hat{c} - \hat{b})}{B(\hat{b}, \hat{c} - \hat{b})} \frac{(x/s)^s}{s!} \Gamma(3 + \zeta - \omega' - v)_{(3 + \zeta - \omega')},
\]

Using the concept of Hadamard product, we get the desired result.

\[
\text{Theorem 8. Suppose } \omega, \omega', v, v', \zeta, \alpha, \beta, \hat{a}, \hat{b}, \hat{c} \in C, \ x > 0 \text{ be such that } R(\zeta) > 0, \ |\alpha| < C, |x| < K; 0 < K < 2.0335, \text{ then}
\]

Now, applying the formula given in (16) and then changing the order of integration and summation, we get

\[
L = \int_0^\infty e^{-x^\hat{\vartheta} - 1} \left( \int_{x, \vartheta}^{\omega, \omega', \zeta, \vartheta} \frac{(\hat{a}, \hat{b}, \hat{c}, \hat{d}; \frac{\vartheta}{\hat{\vartheta}})}{\Gamma(3 + \zeta - \omega' - v)} \right) (x) d\vartheta.
\]
\[
\begin{align*}
&= x^{s \tau - w - w'} - 1 \sum_{n=0}^{\infty} \frac{\Gamma(1 - 3 + s - v)\Gamma(1 - 3 + s - \zeta + \omega + \omega')\Gamma(1 - 3 + s - \zeta + v' + \omega)}{\Gamma(1 - 3 + s)\Gamma(1 - 3 + s - \zeta + \omega + \omega')\Gamma(1 - 3 + s + \omega - v)} \\
&\times \left\{ (\hat{a})_{s}^{MC B_{\sigma, \delta}, x}(b + s, \tilde{c} - \tilde{b}) \frac{(1/x)^{l}}{B(b, \tilde{c} - b)} \right\} \int_{0}^{\infty} e^{-s \tilde{\theta} + 1} d\tilde{\theta}. 
\end{align*}
\]

(59)

Put \( s \tilde{\theta} = u \) in (59) and using the definition of the gamma function, we have

\[
\begin{align*}
&= x^{s \tau - w - w'} - 1 \frac{\Gamma(1 - 3 - v)\Gamma(1 - 3 + s - \zeta + \omega + \omega')\Gamma(1 - 3 + s - \zeta + v' + \omega)}{\Gamma(1 - 3)\Gamma(1 - 3 + \omega + \omega')\Gamma(1 - 3 + s + \omega - v)} \\
&\times \sum_{n=0}^{\infty} \frac{MC B_{\sigma, \delta}, x}(b + s, \tilde{c} - \tilde{b}) \frac{(1 - 3 - v)_{x}(1 - 3 - \zeta + \omega + \omega')_{x}(1 - 3 - \zeta + v' + \omega)_{x}(1 - 3 + \omega)_{x}(1 - 3 + s + \omega - v)_{x}}{\Gamma(1 - 3)_{x}(1 - 3 - \zeta + \omega + \omega')_{x}(1 - 3 + \omega - v)_{x}} \times (1/xx)^{s} 
\end{align*}
\]

(60)

Using the concept of Hadamard product, we get the desired result. \( \square \)

**Corollary 9.** Suppose \( \omega, v, \zeta, 3, \sigma, \delta, \bar{a}, \bar{b}, \tilde{c} \in C, x > 0 \) be s.t. \( R(\omega) > 0, R(\zeta) > \max \{0, R(\zeta - v)\} \); \( \min \{R(\sigma), R(\delta)\} > 0; R(\bar{b}) > 0 \) \( \text{ and } \) \( \{x \in C, |x| < K; 0 < K < 2.0335\} \), then

\[
\begin{align*}
&\hat{L}\left( H^{-1}(1_{x, \omega - \sigma, \omega}^{\zeta - \omega, \omega, 3 - 1} F_{\sigma, \delta, x}(\bar{a}, \bar{b}; \tilde{c} \tilde{b})) \right)(x) \\
&= x^{s \tau - w - w'} \frac{\Gamma(3 + \zeta - \omega - v)\Gamma(l) 1}{\Gamma(3 + \omega - v) \Gamma(l) 1} \times F_{3}(\bar{a}, \bar{b}, \tilde{c} + \zeta - \omega - v, l, \frac{x}{s}). 
\end{align*}
\]

(61)

**Corollary 10.** Suppose \( \omega, v, \zeta, 3, \sigma, \delta, \bar{a}, \bar{b}, \tilde{c} \in C, x > 0 \) s.t \( R(\omega) > 0, R(\zeta) < 1 + \min \{R(\omega)\} \).

\[
\begin{align*}
&\hat{L}\left( H^{-1}(1_{x, \omega - \sigma, \omega}^{\zeta - \omega, \omega, 3 - 1} F_{\sigma, \delta, x}(\bar{a}, \bar{b}; \tilde{c} \tilde{b})) \right)(x) \\
&= x^{s \tau - w - w'} \frac{\Gamma(1 - 3 - v)\Gamma(1 - 3 + \omega)\Gamma(l) 1}{\Gamma(1 - 3)\Gamma(1 - 3 + \omega - v) \Gamma(l) 1} \times F_{3}(\bar{a}, \bar{b} - 1, 3 - v, 1 - 3 + \zeta - \omega, l, \frac{s}{s + x} \frac{1}{x}. 
\end{align*}
\]

(62)

**Corollary 11.** Suppose \( \omega, v, \zeta, 3, \sigma, \delta, \bar{a}, \bar{b}, \tilde{c} \in C, x > 0, R(\omega) > 0, R(\zeta) \max \{0, R(\omega)\} \).

\[
\begin{align*}
&\hat{L}\left( H^{-1}(1_{x, \omega - \sigma, \omega}^{\zeta - \omega, \omega, 3 - 1} F_{\sigma, \delta, x}(\bar{a}, \bar{b}; \tilde{c} \tilde{b})) \right)(x) \\
&= x^{s \tau - w - w'} \frac{\Gamma(3 + \zeta - \omega - v)\Gamma(l) 1}{\Gamma(3 + \omega - v) \Gamma(l) 1} \times F_{3}(\bar{b}, \tilde{c} + \zeta - \omega, 3 + \zeta - v, l, \frac{x}{s}). 
\end{align*}
\]

(63)
Corollary 12. Suppose \( \omega, \nu, \zeta, \sigma, \delta, b, c \in C \) and \( x > 0 \) s.t. \( \bar{R}(\omega) > 0, \bar{R}(\zeta) < 1 + \min |\bar{R}(\nu)| \) and 
\[
\bar{R}(\sigma); \min |\bar{R}(\sigma), \bar{R}(\delta)| > 0 \quad \text{and} \quad \{\nu \in C, |\nu| < K; 0 < K < 2.0335\}, \text{then}
\]
\[
\mathcal{L}\left( \left( \Gamma_{K}^{s} \right)^{-1} \left( \int_{\omega}^{\nu} \frac{\zeta^{-1} \Gamma(1 - \zeta - v) \Gamma(1 - \zeta + \omega) \Gamma(l) \Gamma(1 - \omega - v)}{\xi^\omega} \right) \left( t \right) \right) = x^{\zeta - \omega + \nu + l} \left( \frac{\Gamma(1 - \zeta + \omega) \Gamma(l) \Gamma(1 - \omega - v)}{\xi^\omega} \right) \times \eta_\nu \left( \frac{1}{\nu^\omega} \right)
\]

5. Present

In this present work, we developed new (presumed) extended Gauss hypergeometric functions (GHF) and confluent hypergeometric functions (CHF) which are presumed to be new. Few theorems have been defined which provide the image formulas for new extended Gauss hypergeometric functions (GHF) and confluent hypergeometric functions (CHF). Here, we are also able to generate more image formulas by keeping some integral transforms on the obtained formulas. With the help of the present work, we can further define the recurrence relations and integral representations which may be helpful in engineering and sciences.

Data Availability

No data were used for this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

References


