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# INTEGRAL TRANSFORMS OF H-FUNCTION OF TWO VARIABLES INVOLVING GENERALIZED M-SERIES

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***ABSTRACT***

*The object of this paper is to establish some integral transforms involving product of generalized M-series and H-function of two variables. Some special cases have also been derived.*

***Key words:*** *H-function of two variables, Mellin transform, Laplace transform and Generalized M-series.*

## 1. INTRODUCTION

Recently, the Mellin-Barnes type contour integral of H-function of two variables evaluated by P.C.Srinivas [9]. In the present paper we establish the Mellin transform and Laplace transform of H-function of two variables with generalized M-series.

We shall utilized following formulae in present investigation. The H-function of one variable given by Charles Fox [2]

$$H[x] = H^{m,n}_{p,q}[x] = H^{m,n}_{p,q}\left[x\left|\begin{matrix}(a_j, A_j)_{1,p}\\(b_j, B_j)_{1,q}\end{matrix}\right.\right]$$

$$= \frac{1}{2\pi \mathrm{i}}\int_L \mathrm{F(s)x^s}\, ds, \qquad \mathrm{i} = \sqrt{-1}, \mathrm{x} \neq 0 \tag{1.1}$$

Where

$$\mathrm{F(s)} = \frac{\prod\limits_{j=1}^{m} \Gamma(b_j - B_j s) \prod\limits_{j=1}^{n} \Gamma(1-a_j + A_j s)}{\prod\limits_{j=m+1}^{q} \Gamma(1-b_j + B_j s) \prod\limits_{j=n+1}^{p} \Gamma(a_j - A_j s)}$$

An empty product is interpreted as unity; m,n,p and q are integers satistying $0 \leq m \leq q$, $0 \leq n \leq p$; $A_j(j = 1,\ldots,p)$, $B_j(j = 1,\ldots,q)$ are positive numbers and $a_j(j = 1,..,p)$, $b_j(j = 1,\ldots,q)$ are complex numbers such that no poles of $\Gamma(b_j\text{-}B_js)$, $j = 1,\ldots,m$ coincide with any pole of $\Gamma(1\text{-}a_j+A_js)$, $j = 1,\ldots,n$ i.e $A_j(b_k+N) \neq B_k(a_j\text{-}M\text{-}1)$, where $k= 1,\ldots,m$; $j = 1,\ldots,n$; $M = 0, 1, 2, \ldots$

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The contour L runs from σ-i∞ to σ+i∞, σ be a positive constant such that the points $s=\frac{b_h+N}{B_h}, h=1,...,m;\ N=1,...,n;$ which are the poles of $\Gamma(b_j-B_js)$, j = 1,…..,m lie to the right and the points $s=\frac{a_j-M-1}{a_j},\ j=1,.....,mn;\ M=0,1,.....$ which are the poles of $\Gamma(1-a_j+A_js)$, j = 1,…..,n lie to the left of L.

The H-function of two variables given by Prasad and Gupta[6]

$$H[x,y]=H^{M,N:m,n;g,h}_{P,Q:p,q;u,v}\left[\begin{array}{c|c}\gamma x^{\sigma} & (a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p};(e_j,E_j)_{1,u}\\ \eta x^{\delta} & (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q};(f_j,F_j)_{1,v}\end{array}\right]$$

$$=\frac{1}{(2\pi i)^2}\int_{L_1}\int_{L_2}\varphi_1(s)\varphi_2(t)\psi(s,t)x^s y^t\,ds\,dt\quad ,i=\sqrt{-1} \tag{1.2}$$

where x , y ≠ 0,

$$\phi_1(s)=\frac{\prod_{j=1}^{m}\Gamma(d_j-D_js)\prod_{j=1}^{n}\Gamma(1-c_j+C_js)}{\prod_{j=m+1}^{q}\Gamma(1-d_j+D_js)\prod_{j=n+1}^{p}\Gamma(c_j-C_js)}$$

$$\phi_2(t)=\frac{\prod_{j=1}^{g}\Gamma\left(f_j-F_jt\right)\prod_{j=1}^{h}\Gamma\left(1-e_j+E_jt\right)}{\prod_{j=g+1}^{v}\Gamma\left(1-f_j+F_jt\right)\prod_{j=h+1}^{u}\Gamma\left(e_j-E_jt\right)}$$

$$\psi(s,t)=\frac{\prod_{j=1}^{M}\Gamma\left(b_j-\beta_js-B_jt\right)\prod_{j=1}^{N}\Gamma\left(1-a_j+\alpha_js+A_jt\right)}{\prod_{j=M+1}^{Q}\Gamma\left(1-b_j+\beta_js+B_jt\right)\prod_{j=N+1}^{P}\Gamma\left(a_j-\alpha_js-A_jt\right)},$$

where *M, N, P, Q, m, n, p, q, g, h, u, v* are all non negative integers such that $0 \le N \le P$, $Q \ge 0$, $0 \le m \le q$, $0 \le n \le q$, $0 \le g \le v$, $0 \le h \le u$ and $\alpha_j, \beta_j, A_j, B_j, C_j, D_j, E_j, F_j$ are all positive. The sequence of parameters $(a_P)$, $(b_Q)$, $(c_p)$, $(d_q)$, $(e_u)$ and $(f_v)$ are so restricted that none of the poles of the integrand coincide.

The contour $L_1$ lies in the complex s-plane and runs from -i∞ to +i∞ with loops, if necessary, to ensure that the poles of $\Gamma(d_j - D_js)$, $(j = 1, 2, ….. , m)$, lie to the right of the path; and those of $\Gamma(1 - c_j + C_js)$, $(j = 1, 2,….., n)$ and $\Gamma(1 - a_j + \alpha_js + A_jt)$, $(j = 1, 2,….., N)$ lie to the left of the path.

Also the contour $L_2$ lies in the complex t-plane running from -i∞ to +i∞ with loops, if necessary, to ensure that the poles of $\Gamma(f_j - F_jt)$, $(j = 1, 2,….., g)$, lie to the right of the path; and those of $\Gamma(1 - e_j + E_j t)$, $(j = 1, 2,….., h)$ and $\Gamma(1 - a_j + \alpha_j s + A_j t)$, $(j = 1, 2,….., N)$ lie to the left of the path. All poles of the integrand are simple poles.

The Mellin transform of the function f(x) is defined as

$$M\left\{f(x);s\right\}=\int_0^{\infty}x^{s-1}f(x)\,d\,x\ \mathrm{Re}(s)>0 \tag{1.3}$$

If Laplce transform of f(t) is F(p) and G(s) is Mellin transform of f(t), then

$$F(p)=\sum_{s=0}^{\infty}\frac{(-p)^s}{s!}G(s+1) \tag{1.4}$$

 

According Erdelyi [1, p.307]

$$\int_0^\infty x^{s-1}\left[\frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} g(s)x^{-s}ds\right]dx = g(s) \tag{1.5}$$

The Generalized M-Series is defined by Sharma and Renu[8] as

$$\underset{p\ q}{\overset{\alpha,\beta}{M}} = \underset{p\ q}{\overset{\alpha,\beta}{M}}(a_1,....,a_p;b_1,....,b_q;z)$$

$$= \sum_{k=0}^{\infty}\frac{(a_1)_k....(a_p)_k}{(b_1)_k....(b_q)_k}\frac{z^k}{\Gamma(\alpha k+\beta)} \qquad z,\alpha,\beta \in \mathbb{C},\ \Re(\alpha) > 0 \tag{1.6}$$

Series is convergent for all z if q ≥ p, it is convergent for |z| < 1 if p = q+1 and divergent if p > q+1. Where p = q+1 and |z| = 1, the series convergent in some case. Let $\beta = \sum_{j=1}^{p} a_j - \sum_{j=1}^{q} b_j$

It can be shown that when p = q+1 the series is absolutely convergent for |z| = 1 if $\Re(\beta) < 0$. Conditionally convergent for z = -1 if $0 \le \Re(\beta) \le 1$ and divergent for |z|=1 if $1 \le \Re(\beta)$.

## 2. MAIN RESULTS

**Theorem 1:** Prove that

$$M\left\{\underset{l\ m}{\overset{\alpha,\beta}{M}}(a_1,....,a_l;b_1,....,b_m;ax^{\lambda})H^{M,N:m_1,n_1;m_2,n_2}_{P,Q:p_1,q_1;p_2,q_2}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\middle|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p_1};(e_j,E_j)_{1,p_2}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q_1};(f_j,F_j)_{1,q_2}\end{matrix}\right];s\right\}$$

$$=\frac{1}{\delta}\frac{\prod_{j=1}^{m}b_j}{\prod_{j=1}^{l}a_j}\sum_{k=0}^{\infty}\frac{\prod_{j=1}^{l}(a_j+k)}{\prod_{j=1}^{m}(b_j+k)}\frac{a^k}{\Gamma(\alpha k+\beta)}\eta^{-\frac{(s+\lambda k)}{\delta}}H^{M+m_1+n_2,N+n_1+m_2}_{P+p_1+q_2,Q+q_1+p_2}\left[\eta^{-\frac{\sigma}{\delta}}\gamma\middle|\begin{matrix}(a_j+(\frac{s+\lambda k}{\delta})A_j,\alpha_j-(\sigma/\delta)A_j)_{1,P},\\ (b_j+(\frac{s+\lambda k}{\delta})B_j,\beta_j-(\sigma/\delta)B_j)_{1,Q},\end{matrix}\right.$$

$$\left.\begin{matrix}(1-f_j-(\frac{s+\lambda k}{\delta})F_j,(\sigma/\delta)F_j)_{1,n_2},(c_j,C_j)_{1,n_1},(1-f_j-(\frac{s+\lambda k}{\delta})F_j,(\sigma/\delta)F_j)_{n_2+1,p_2},(c_j,C_j)_{n_1+1,p_1}\\ (1-e_j-(\frac{s+\lambda k}{\delta})E_j,(\sigma/\delta)E_j)_{1,m_2},(d_j,D_j)_{1,m_1},(1-e_j-(\frac{s+\lambda k}{\delta})E_j,(\sigma/\delta)E_j)_{m_2+1,q_2},(d_j,D_j)_{m_1+1,q_1}\end{matrix}\right]$$

Provided $\sigma > 0$, $\delta > 0$, $\lambda$ is complex number
$\alpha_j - (\sigma/\delta) A_j > 0$ for j = 1, 2, - - -, P
$\beta_j - (\sigma/\delta) B_j > 0$ for j = 1, 2, - - -, Q
$|\arg \gamma| < (1/2)\pi\Delta_1$, $|\arg \eta| < (1/2)\pi\Delta_2$

where $\Delta_1 = \sum_{j=1}^{N}\alpha_j - \sum_{j=N+1}^{P}\alpha_j + \sum_{j=1}^{M}\beta_j - \sum_{j=M+1}^{Q}\beta_j + \sum_{j=1}^{m_1}D_j - \sum_{j=m_1+1}^{q_1}D_j + \sum_{j=1}^{n_1}C_j - \sum_{j=n_1+1}^{p_1}C_j$

and $\Delta_2 = \sum_{j=1}^{N}A_j - \sum_{j=N+1}^{P}A_j + \sum_{j=1}^{M}B_j - \sum_{j=M+1}^{Q}B_j + \sum_{j=1}^{m_2}F_j - \sum_{j=m_2+1}^{q_2}F_j + \sum_{j=1}^{n_2}E_j - \sum_{j=n_2+1}^{p_2}E_j$

and $\mathrm{Re}\left\{s+\frac{\delta(a_j-1)}{A_j}\right\} < 0$ for j = 1, 2,….., N

$$\mathrm{Re}\left\{s+\frac{\delta b_j}{B_j}\right\}>0 \qquad \text{for } j = 1, 2,\ldots, M$$

$$\mathrm{Re}\left\{s+\frac{\delta b_j}{B_j}+\frac{\sigma d_i}{D_i}\right\}>0 \qquad \text{for } i = 1, 2,\ldots, m_1;\ \text{for } j = 1, 2,\ldots, m_2$$

$$\mathrm{Re}\left\{s+\frac{\delta(e_j-1)}{E_j}+\frac{\sigma(c_i-1)}{C_i}\right\}>0 \qquad \text{for } i = 1, 2,\ldots, n_1;\ \text{for } j = 1, 2,\ldots, n_2$$

**Proof:** To prove this theorem, take f(x) as

$$\overset{\alpha,\beta}{\underset{l\ \ m}{M}}(a_1,\ldots,a_l;b_1,\ldots,b_m;ax^{\lambda})H^{M,N:m_1,n_1;m_2,n_2}_{P,Q:p_1,q_1;p_2,q_2}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\left|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p_1};(e_j,E_j)_{1,p_2}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q_1};(f_j,F_j)_{1,q_2}\end{matrix}\right.\right] \text{ in (1.3)},$$

then expression becomes

$$M\left\{\overset{\alpha,\beta}{\underset{l\ \ m}{M}}(a_1,\ldots,a_l;b_1,\ldots,b_m;ax^{\lambda})H^{M,N:m_1,n_1;m_2,n_2}_{P,Q:p_1,q_1;p_2,q_2}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\left|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p_1};(e_j,E_j)_{1,p_2}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q_1};(f_j,F_j)_{1,q_2}\end{matrix}\right.\right]\right\} \tag{2.2}$$

$$=\int_0^{\infty}x^{s-1}M\left\{\overset{\alpha,\beta}{\underset{l\ \ m}{M}}(a_1,\ldots,a_l;b_1,\ldots,b_m;ax^{\lambda})H^{M,N:m_1,n_1;m_2,n_2}_{P,Q:p_1,q_1;p_2,q_2}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\left|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p_1};(e_j,E_j)_{1,p_2}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q_1};(f_j,F_j)_{1,q_2}\end{matrix}\right.\right]\right\}dx$$

By using (1.2) and (1.6) represent H-function in integral form and M-series as series form. Put $\delta t_2 = -u$, we get

$$\sum_{k=0}^{\infty}\frac{(a_1)_k\ldots(a_l)_k}{(b_1)_k\ldots(b_m)_k}\frac{a^k}{\Gamma(\alpha k+\beta)}\frac{1}{(2\pi i)^2}\int_{L_1}\int_{L_2}\phi_1(t_1)\phi_2\left(\frac{-u}{\delta}\right)\psi\left(t_1,\frac{-u}{\delta}\right)\gamma^{t_1}\eta^{\frac{-u}{\delta}}x^{-u}x^{\sigma t_1+\lambda k+s-1}\left(\frac{du}{\delta}\right)dt_1\,dx$$

Interchange the order of integration, we get

$$=\sum_{k=0}^{\infty}\frac{(a_1)_k\ldots(a_l)_k}{(b_1)_k\ldots(b_m)_k}\frac{a^k}{\Gamma(\alpha k+\beta)}\frac{1}{\delta}\frac{1}{2\pi i}\int_{L_1}\phi_1(t_1)\gamma^{t_1}\left\{\int_0^{\infty}x^{\sigma t_1+\lambda k+s-1}\left[\frac{1}{2\pi i}\int_{L_2}\phi_2\left(\frac{-u}{\delta}\right)\psi\left(t_1,\frac{-u}{\delta}\right)\eta^{\frac{-u}{\delta}}x^{-u}\,du\right]dx\right\}dt_1$$

Use result (1.5) and (1.1) to get the result. Change of order of integration is justifiable due to convergence of integrals.

**Theorem 2:**

$$L\left\{\overset{\alpha,\beta}{\underset{l\ \ m}{M}}(a_1,\ldots,a_l;b_1,\ldots,b_m;ax^{\lambda})H^{M,N:m_1,n_1;m_2,n_2}_{P,Q:p_1,q_1;p_2,q_2}\left[\begin{matrix}\gamma x^{\sigma}\\ \eta x^{\delta}\end{matrix}\left|\begin{matrix}(a_j;\alpha_j,A_j)_{1,P}:(c_j,C_j)_{1,p_1};(e_j,E_j)_{1,p_2}\\ (b_j;\beta_j,B_j)_{1,Q}:(d_j,D_j)_{1,q_1};(f_j,F_j)_{1,q_2}\end{matrix}\right.\right];s\right\}$$

$$=\frac{1}{\delta}\frac{\prod_{j=1}^{m}b_j}{\prod_{j=1}^{l}a_j}\sum_{s=0}^{\infty}\frac{(-p)^s}{s!}\sum_{k=0}^{\infty}\frac{\prod_{j=1}^{l}(a_j+k)}{\prod_{j=1}^{m}(b_j+k)}\frac{a^k}{\Gamma(\alpha k+\beta)}\eta^{-\frac{(s+\lambda k+1)}{\delta}}H^{M+m_1+n_2,N+n_1+m_2}_{P+p_1+q_2,Q+q_1+p_2}\left[\eta^{-\frac{\sigma}{\delta}}\gamma\left|\begin{matrix}(a_j+(\frac{s+\lambda k+1}{\delta})A_j,\alpha_j-(\sigma/\delta)A_j)_{1,P},\\ (b_j+(\frac{s+\lambda k+1}{\delta})B_j,\beta_j-(\sigma/\delta)B_j)_{1,Q},\end{matrix}\right.\right.$$

$$\left.\begin{matrix}(1-f_j-(\frac{s+\lambda k+1}{\delta})F_j,(\sigma/\delta)F_j)_{1,n_2},(c_j,C_j)_{1,n_1},(1-f_j-(\frac{s+\lambda k+1}{\delta})F_j,(\sigma/\delta)F_j)_{n_2+1,p_2},(c_j,C_j)_{n_1+1,p_1}\\ (1-e_j-(\frac{s+\lambda k+1}{\delta})E_j,(\sigma/\delta)E_j)_{1,m_2},(d_j,D_j)_{1,m_1},(1-e_j-(\frac{s+\lambda k+1}{\delta})E_j,(\sigma/\delta)E_j)_{m_2+1,q_2},(d_j,D_j)_{m_1+1,q_1}\end{matrix}\right]$$

**Proof:** To prove this theorem use (1.4) to get the result

## 3. SPECIAL CASES

**(i)** Take

$$(\alpha_P)=(A_P)=(B_Q)=(b_Q)=(C_{p_1})=(D_{q_1})=(E_{p_2})=(F_{q_2})=1$$

We get Mellin and Laplace transforms of G-function of two variables with Generalized M-series

**(ii)** Put M = N = P = Q = 0 in (2.1) and (2.3), we get

$$M\left\{\underset{l\ m}{\overset{\alpha,\beta}{M}}(a_1,....,a_l;b_1,....,b_m;ax^\lambda)H^{m_1,n_1}_{p_1,q_1}\left[\gamma x^\sigma \middle| \begin{matrix}(c_j,C_j)_{1,p_1}\\(d_j,D_j)_{1,q_1}\end{matrix}\right]H^{m_2,n_2}_{p_2,q_2}\left[\eta x^\delta \middle| \begin{matrix}(e_j,E_j)_{1,p_2}\\(f_j,F_j)_{1,q_2}\end{matrix}\right];s\right\} \tag{3.1}$$

$$M\left\{\underset{l\ m}{\overset{\alpha,\beta}{M}}(a_1,....,a_l;b_1,....,b_m;ax^\lambda)H^{m_1,n_1}_{p_1,q_1}\left[\gamma x^\sigma \middle| \begin{matrix}(c_j,C_j)_{1,p_1}\\(d_j,D_j)_{1,q_1}\end{matrix}\right]H^{m_2,n_2}_{p_2,q_2}\left[\eta x^\delta \middle| \begin{matrix}(e_j,E_j)_{1,p_2}\\(f_j,F_j)_{1,q_2}\end{matrix}\right];s\right\}$$

$$=\frac{1}{\delta}\frac{\prod_{j=1}^{m}b_j}{\prod_{j=1}^{l}a_j}\sum_{k=0}^{\infty}\frac{\prod_{j=1}^{l}(a_j+k)}{\prod_{j=1}^{m}(b_j+k)}\frac{a^k}{\Gamma(\alpha k+\beta)}\eta^{-\frac{(s+\lambda k)}{\delta}}H^{m_1+n_2,n_1+m_2}_{p_1+q_2,q_1+p_2}\left[\eta^{-\frac{\sigma}{\delta}}\gamma \middle| \begin{matrix}(1-f_j-(\frac{s+\lambda k}{\delta})F_j,(\sigma/\delta)F_j)_{1,p_2},(c_j,C_j)_{1,n_1},(c_j,C_j)_{n_1+1,p_1}\\(1-e_j-(\frac{s+\lambda k}{\delta})E_j,(\sigma/\delta)E_j)_{1,q_2},(d_j,D_j)_{1,m_1},(d_j,D_j)_{m_1+1,q_1}\end{matrix}\right]$$

$$L\left\{\underset{l\ m}{\overset{\alpha,\beta}{M}}(a_1,....,a_l;b_1,....,b_m;ax^\lambda)H^{m_1,n_1}_{p_1,q_1}\left[\gamma x^\sigma \middle| \begin{matrix}(c_j,C_j)_{1,p_1}\\(d_j,D_j)_{1,q_1}\end{matrix}\right]H^{m_2,n_2}_{p_2,q_2}\left[\eta x^\delta \middle| \begin{matrix}(e_j,E_j)_{1,p_2}\\(f_j,F_j)_{1,q_2}\end{matrix}\right]\right\} \tag{3.2}$$

$$=\frac{1}{\delta}\frac{\prod_{j=1}^{m}b_j}{\prod_{j=1}^{l}a_j}\sum_{s=0}^{\infty}\frac{(-p)^s}{s!}\sum_{k=0}^{\infty}\frac{\prod_{j=1}^{l}(a_j+k)}{\prod_{j=1}^{m}(b_j+k)}\frac{a^k}{\Gamma(\alpha k+\beta)}\eta^{-\frac{(s+\lambda k+1)}{\delta}}H^{m_1+n_2,n_1+m_2}_{p_1+q_2,q_1+p_2}\left[\eta^{-\frac{\sigma}{\delta}}\gamma \middle| \begin{matrix}(1-f_j-(\frac{s+\lambda k+1}{\delta})F_j,(\sigma/\delta)F_j)_{1,p_2},(c_j,C_j)_{1,n_1},(c_j,C_j)_{n_1+1,p_1}\\(1-e_j-(\frac{s+\lambda k+1}{\delta})E_j,(\sigma/\delta)E_j)_{1,q_2},(d_j,D_j)_{1,m_1},(d_j,D_j)_{m_1+1,q_1}\end{matrix}\right]$$

**(iii)** For β = 1 in (2.1) and (2.3), we get Mellin and Laplace transform of H-function of two variables with generalized M-series by M. Sharma [7]

**(iv)** For l = m = 0 in (2.1) and (2.3), we get Mellin and Laplace transform of H-function of two variables involving Mittag-Leffler function $E_{\alpha,\beta}(ax^\lambda)$ [4]

**(v)** Take α = β = 1 in (2.1) and (2.3), we get Mellin the Laplace transform of H-function of two variables involving generalized hypergeometric function [3]

**(vi)** Put l = 0, m = 1 and $b_1$ = 1 in (2.1) and (2.3), we get Mellin and Laplace transform of H-function of two variables involving Wright function $W(ax^\lambda;\alpha,\beta)$ [5].

## CONCLUSION

Thus we proved Mellin and Laplace transforms of H-function of two variables involving generalized M-series and special cases, which gives some interesting applications in fractional calculus.

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