International Journal of Statistics and Applied Mathematics

**ISSN:** 2456-1452
Maths 2023; 8(1): 12-16

https://www.mathsjournal.com
Received: 09-10-2022
Accepted: 07-12-2022

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# Finite double integral representation for the classical polynomial Set $J_n\{(x_m), y\}$ of several variables

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**Abstract**
In the present paper, an attempt has been made to express a Finite Double Integral Representation for the Classical polynomial set $Jn\{(xm), y\}$ of Several Variables. Many interesting new results may be obtained as particular cases out of these particular results some of them stand for well known and some of them are believed to be new. These are of at most important for mathematician scientists, engineers and physical sciences because these occur in the solution of differential equation Integral equation etc.
**AMS Subject Classification:** Special function-33C

**Keywords:** Hypergeometric function, generating function, integral representation

## Introduction

We have derived generalized hypergeometric polynomial set $J_n\{(x_m), y\}$ of several variables by means generating relation

$$(\xi+\lambda y^{-e}t^{e})^{-\sigma} F\left[\begin{matrix}\lambda_1;(a_g);\\(b_h);\end{matrix}\mu_1 y^{-e_1}t^{e_1}\right]$$

$$\times F\left[\begin{matrix}(A_r);(C_p);(\alpha_{u_k})\\(B_s);(D_q);(\beta_{v_k})\end{matrix}\mu x_1^{d}t, \mu_2 x_2^{e_2} y^{-e_2}t^{e_2}\ldots\ldots\mu_k x_k^{e_k}t^{e_k}\right]$$

$$=\sum_{n=0}^{\infty} J_{n,e,e_1;e_2;e_3;\ldots\ldots e_m;(b_k);(B_s);(D_q);(\beta_{v_k})}^{\xi;\lambda;\lambda_1;\sigma;d;\mu;\mu_1;\mu_2\ldots\ldots\mu_m;(a_g);(A_r);(C_p);(\alpha_{u_k})}\{(x_m),y\} \quad \ldots (1.1)$$

Where ξ, λ, $\lambda_1$, σ, $\delta$; μ, $\mu_1$, $\mu_2$ …… $\mu_m$ are real and $e$, $e_1$, are non-negative integers and $e_2$; …… $e_m$ are natural number.

The left hand side of (1.2) are the product of generalized hypergeometric function and Lauricella function in the notation of Burchnall and Chaundy [1]. The polynomial set contain number of parameters. For simplicity we shall denote

$$J_{n,e,e_1;e_2;e_3;\ldots\ldots e_m;(b_k);(B_s);(D_q);(\beta_{v_k})}^{\xi;\lambda;\lambda_1;\sigma;d;\mu;\mu_1;\mu_2\ldots\ldots\mu_m;(a_g);(A_r);(C_p);(\alpha_{u_k})}\{(x_m),y\}=J_n\{(x_m),y\}$$

Where $n$ denotes the order of the generalized polynomial set. After little simplification (1.1) give

$$J_n\{(x_m),y\}=\xi^{\sigma}\sum_{m=0}^{\left[\frac{n}{e}\right]}\sum_{m_1=0}^{\left[\frac{n-em}{e_1}\right]}\sum_{m_2=0}^{\left[\frac{n-em-e_1m_1}{e_2}\right]}\ldots\ldots\sum_{m_k=0}^{\left[\frac{n-em-e_1m_1-e_2m_2\ldots\ldots e_{k-1}e_{k-1}}{e_k}\right]}$$

$$\times\frac{[(A_r)]_{n-em-e_1m_1-(e_2-1)m_2-\cdots\ldots-(e_k-1)m_k}[(C_p)]_{n-ek-e_1k_1-e_2k_2-\cdots\ldots-e_km_k}}{[(B_s)]_{n-em-e_1m_1-(e_2-1)m_2-\cdots\ldots-(e_k-1)m_k}[(D_q)]_{n-ek-e_1k_1-e_2k_2-\cdots\ldots-e_km_k}}$$

$$\times \frac{\left[\left(\alpha_{u_k}\right)\right]_{m_k}\left[\left(a_g\right)\right]_{m_1}(\sigma)_m(-\lambda)^m(-\lambda_1)_{m_1}\mu^{m_1}\left(\mu_2 x_2^{e_2}\right)^{m_2}}{\left[\left(\beta_{v_k}\right)\right]_{m_k}[(b_h)]_{m_1}\xi^m\, m!\, m_1!\, y^{em+e_1m_1+e_2m_2}\, m_2!}$$

$$\times \frac{\left(\mu_m x_m^{e_k}\right)^{m_k}\left(\lambda x_1^{e}\right)^{n,em-e_1m_1-e_2m_2-\cdots\ldots-e_km_k}}{m_k!\,(n,em-e_1m_1-e_2m_2-\cdots\ldots-e_km_k)!} \qquad \ldots (1.2)$$

## 2. Notations

**I.** (i) $(n) = 1, 2, \ldots\ldots n-1, n.$

(ii) $(a_p) = a_1, a_2, a_3, \ldots\ldots a_p.$

(iii) $(a_p; i) = a_1, a_2, a_3, \ldots\ldots a_{i-1}, a_{i+1} \ldots\ldots a_p.$

**II.** (i) $[(a_p)] = a_1, a_2, a_3 \ldots\ldots a_p.$

(ii) $\left[\left(a_p\right)\right]_n = \prod_{i=1}^{p}(a_i)_n = (a_1)_n(a_2)_n(a_3)_n \ldots \left(a_p\right)_n$

**III.** (i) $\Delta(a;b) = \frac{b}{a}, \frac{b+1}{a} + \cdots \ldots \frac{b+a-1}{a}.$

(ii) $\Delta(a(1);b) = \frac{b}{a}, \frac{b+1}{a}, \frac{b+2}{a}, \ldots \ldots \frac{b+a-2}{a}$

(iv) $\Delta(a; b \pm c \pm d) = \Delta(a; b+c+d), \Delta(a; b+c-d),$
$\Delta(a; b-c+d), \Delta(a; b-c-d),$

**IV.** (i) $\Delta_k[a;b] = \prod_{r=1}^{a}\left(\frac{b+r-1}{a}\right)_k = \left(\frac{b}{a}\right)_k\left(\frac{b+1}{a}\right)_k \cdots \left(\frac{b+a-1}{a}\right)_k$

(ii) $\Delta_k[a(1);b] = \left(\frac{b}{a}\right)_k\left(\frac{b+1}{a}\right)_k \ldots \left(\frac{b+a-2}{a}\right)_k$

(iii) $\Delta_k\left[m;\left(a_p\right)\right] = \prod_{i=1}^{b}\prod_{r=1}^{m}\left(\frac{a_i+r-1}{m}\right)_k$

**V.** (i) $\Gamma\left[\left(a_p\right)\right] = \prod_{i=1}^{p}(a_i)$

(ii) $\Gamma\left[\left(a_p\right);(s)\right] = \prod_{i=s+1}^{p}(a_i)$

(iii) $\Gamma[(a;b)] = \prod_{r=1}^{a}\Gamma\left(\frac{b+r-1}{a}\right)$

(iv) $\Gamma\left[\Delta(m);\left(a_p\right)\right] = \prod_{i=1}^{p}\prod_{r=1}^{m}\Gamma\left(\frac{(a_i)+r-1}{m}\right)$

**VI.** (i) $\Gamma(a \pm b) = \Gamma(a+b)\Gamma(a-b)$

(ii) $\Gamma_{**}(a+b) = \Gamma(a+b)\Gamma(a+b)$

$$M = \frac{[(A_r)]_n\left[\left(C_p\right)\right]_n\left(\lambda x_1^d\right)^n}{[(B_s)]_n\left[\left(D_q\right)\right]_n n!}$$

## 3. Theorem

For $e_2 > 1, \ldots\ldots, e_k > 1$, we have

$$J_n\{(x_m), y\} = M\frac{\Gamma(\mu+\nu)}{\Gamma(\mu)\Gamma(\nu)}\int_0^{'}\int_0^{'} \frac{(1-\xi)^{\mu-1}(1-\eta)^{\nu-1}}{(1-\xi\eta)^{\mu+\nu-1}}$$

$$\times F_{s+q+h+u:1:\beta_{v_1},\beta_{v_2}\ldots\ldots\beta_{v_k}}^{r+p+g+v+1:1:1:\alpha_{u_1};\alpha_{u_2}\ldots\ldots\alpha_{u_k}}\left[\begin{matrix}[(-n):e,e_1,e_2;\ldots\ldots e_k] \\ \overline{\qquad\qquad}, \end{matrix}\right.$$

$$\begin{matrix}[(1-(B_s)-n):e,e_1,e_2-1\ldots e_k-1],\left[\left(1-\left(D_q\right)-n\right):e,e_1,e_2;\ldots\ldots e_k\right] \\ [(1-(A_r)-n):e,h_1,e_2-1\ldots e_k-1],\left[\left(1-\left(C_p\right)-n\right):e,e_1,e_2;\ldots\ldots e_k\right]\end{matrix}$$

$$\left[\begin{matrix}\left[\left(\alpha_{u_1}\right):1\right],\left[\left(\alpha_{u_2}\right):1\right]\ldots\ldots\left[\left(\alpha_{u_k}\right):1\right]\left[\left(a_g\right):1\right][\sigma:1][\lambda_1:1]\left[\left(\frac{\mu+\nu}{2}\right):1\right]\left[\left(\frac{\mu+\nu+1}{2}\right):1\right] \\ \left[\left(\beta_{v_1}\right):1\right],\left[\left(\beta_{v_2}\right):1\right]\ldots\ldots\left[\left(\beta_{v_k}\right):1\right],\left[(b_h):1\right][(\mu):1][(\mu):1]\end{matrix}\right.$$

$$\frac{-\lambda(-1)^{e(r+s+p+q+g+h+u+v+1)}}{\xi^e\left(\mu x_1^d y\right)^e}, \frac{\mu_1(-1)^{e_1(r+s+p+q+g+h+u+v+1)}}{\left(\mu x_1^d y\right)^{e_1}},$$

$$\left.\frac{\mu_2 x_2^{e_2}(-1)^{e_2(r+s+p+q+g+h+u+v+1)+r+s}}{\left(\mu x_1^d y\right)^{e_2}}, \ldots\ldots \frac{\mu_k x_k^{e_k}(-1)^{e_k(r+s+p+q+g+h+u+v+1)+r+s}}{\left(\mu x_1^d\right)^{e_k}}\right] d\xi d\eta \qquad \ldots (3.1)$$

**Proof:** we have

$$I_2 = \int_0^{'}\int_0^{'} \frac{(1-\xi)^{\mu-1}\eta^{\mu}(1-\eta)^{\nu-1}}{(1-\xi\eta)^{\mu+\nu-1}} \sum_{m=0}^{\left[\frac{n}{e}\right]} \sum_{m_1=0}^{\left[\frac{n-em}{e_1}\right]} \sum_{m_2=0}^{\left[\frac{n-em-e_1m_1}{e_2}\right]}$$

$$\times \sum_{m_k=0}^{\left[\frac{n-em-e_1m_1\ldots\ldots-e_{k-1}m_{k-1}}{e_k}\right]} \frac{[(A_r)]_{n-em-e_1m_1-(e_2-1)m_2-\cdots\ldots-(e_k-1)m_k}}{[(B_s)]_{n-em-e_1m_1-(e_2-1)m_2-\cdots\ldots-(e_k-1)m_k}}$$

$$\times \frac{[(C_p)]_{n-em-e_1m_1-e_2m_2-\cdots\ldots-e_km_k}\left[\left(\alpha_{u_k}\right)\right]_{m_k}[(a_g)]_{m_1}}{[(D_q)]_{n-em-e_1m_1-e_2m_2-\cdots\ldots-e_km_k}\left[\left(\beta_{v_k}\right)\right]_{m_k}[(b_h)]_{m_1}}$$

$$\times \frac{(\sigma)_m(-\lambda)^m(\lambda_1)_{m_1}\mu_1^{m_1}\left(\mu_2x_2^{e_2}\right)^{m_2}\ldots\left(\mu_kx_k^{e_k}\right)^{m_k}}{\xi^m\ m!\ m_1!\ y^{em+e_1m_1+e_2m_2}\ m_2!\ldots(m_k)!}$$

$$\times \frac{\left(\mu x_1^d\right)^{n-em-e_1m_1-e_2m_2-\cdots\ldots-e_km_k}\left(\frac{\mu+\nu}{2}\right)_{m_1}\left(\frac{\mu+\nu+}{2}\right)_{m_1}}{(n-em-e_1m_1-e_2m_2-\cdots\ldots-e_km_k)!\ (\mu)_{m_1}(\nu)_{m_1}}$$

$$= \sum_{m=0}^{\left[\frac{n}{e}\right]} \sum_{m_1=0}^{\left[\frac{n-em}{e_1}\right]} \sum_{m_2=0}^{\left[\frac{n-em-e_1m_1}{e_2}\right]} \ldots\ldots \sum_{m_k=0}^{\left[\frac{n-em-e_1m_1\ldots\ldots-e_{k-1}m_{k-1}}{e_k}\right]}$$

$$\times \frac{[(A_r)]_{n-em-e_1m_1-(e_2-1)m_2-\cdots\ldots-(e_k-1)m_k}[(C_p)]_{n-em-e_1m_1-e_2m_2-\cdots\ldots-e_km_k}}{[(B_s)]_{n-em-e_1m_1-(e_2-1)m_2-\cdots\ldots-(e_k-1)m_k}[(D_q)]_{n-em-e_1m_1-e_2m_2-\cdots\ldots-e_km_k}}$$

$$\times \frac{\left[\left(\alpha_{u_k}\right)\right]_{m_k}[(a_g)]_{m_1}(\sigma)_m(-\lambda)^m(\lambda_1)_{m_1}\mu_1^{m_1}\left(\mu_2x_2^{e_2}\right)^{m_2}}{\left[\left(\beta_{v_k}\right)\right]_{m_k}[(b_h)]_{m_1}\ \xi^m\ m!\ m_1!\ y^{em+e_1m_1+e_2m_2}\ m_2!}$$

$$\times \frac{\left(\mu_kx_k^{e_k}\right)^{m_k}\left(\mu x_1^d\right)^{n-em-e_1m_1-e_2m_2-\cdots\ldots-e_km_k}\left(\frac{\mu+\nu}{2}\right)_{m_1}\left(\frac{\mu+\nu+}{2}\right)_{m_1}}{m_k!\ (n-em-e_1m_1-e_2m_2-\cdots\ldots-e_km_k)!\ (\mu)_{m_1}(\nu)_{m_1}}$$

$$\times \int_0^{'}\int_0^{'} \frac{(1-\xi)^{\mu+m_1-1}\eta^{\mu+m_1}(1-\eta)^{\nu+m_1-1}}{(1-\xi\eta)^{\mu+\nu-1+2m_1}} d\xi dn.$$

$$= M\frac{\Gamma(\mu)\Gamma(\nu)}{\Gamma(\mu+\nu)}\sum_{m,m_1,m_2\ldots m_k}^{\infty} \frac{[1-(B_s)-n]_{em+e_1m_1+(e_2-1)m_2+\cdots\ldots+(e_k-1)m_k}}{[1-(A_r)-n]_{em+e_1m_1+(e_2-1)m_2+\cdots\ldots+(e_k-1)m_k}}$$

$$\times \frac{[1-(D_q)-n]_{em+e_1m_1+e_2m_2+\cdots\ldots+e_km_k}\left[\left(\alpha_{u_k}\right)\right]_{m_k}[(a_g)]_{m_1}}{[1-(C_p)-n]_{em+e_1m_1+e_2m_2+\cdots\ldots+e_km_k}\left[\left(\beta_{v_k}\right)\right]_{m_k}[(b_h)]_{m_1}}$$

$$\times \frac{(\sigma)_m(\lambda_1)_{m_1}(-\lambda)^m(-1)^{e(r+s+p+q+g+h+u+v+1)m}}{m!\xi^m\left(\mu x_1^d y\right)^{em}}$$

$$\times \frac{\mu_1(-1)^{e_1(r+s+p+q+g+h+u+v+1)m_1}\left(\mu_2x_2^{e_2}\right)^{m_2}(-1)^{\{e_2(r+s+p+q+g+h+u+v+1)r+s\}m_2}}{m_1!\left(\mu x_1^d y\right)^{e_1m_1}\ m_2!\left(\mu x_1^d y\right)^{e_2m_2}}$$

$$\times \frac{\left(\mu_kx_k^{e_k}\right)^{m_k}(-1)^{\{e_k(r+s+p+q+g+h+u+v+1)r+s\}m_2}}{m_k!\left(\lambda x_1^d\right)^{e_km_k}}$$

$$\times (-n)_{em+e_1m_1+e_2m_2+\cdots\ldots+e_km_k} \qquad \ldots (3.2)$$

The single terminating factor $(-n)_{em+e_1m_1+e_2m_2+\cdots\ldots+e_km_k}$ makes all summation in (3.2) runs upto □. Then we finally achieve.

$$I_2 = \frac{\Gamma(\mu)\Gamma(\nu)}{\Gamma(\mu+\nu)} J_n\{(x_m), y\}.$$

Hence, the theorem
We have from [2].

$$\int_0^{'}\int_0^{'} \frac{(1-\xi)^{\mu-1}\eta^{\mu}(1-\eta)^{\nu-1}}{(1-\xi\eta)^{\mu+\nu-1}} d\xi dn = \beta(\mu,\nu)$$

**Particular Cases of (3.1)**

(i) On making the substitution $p = 0 = q = r = s = g = u_k = v_k$; $m = m_1 = h = 0 = \lambda_1 = -\lambda = \mu_1 = y = \mu$; $b_1 = 1 + \alpha$, and $x_1 = \frac{1}{y}$, in (3.1) we get

$$L_n^{(\alpha)}(y) = \frac{\Gamma(\mu+\nu)(1+\alpha)_n}{\Gamma(\mu)\,\Gamma(\nu)\,y^n\,n!}\int_0^{'}\int_0^{'}\frac{(1-\xi)^{\mu-1}\eta^{\mu}(1-\eta)^{\nu-1}}{(1-\xi\eta)^{\mu+\nu-1}}$$

$$\times F\begin{bmatrix}-n, \frac{\mu+\nu}{2}, \frac{\mu+\nu-1}{2}; \\ y \\ 1+\alpha, \mu, \nu;\end{bmatrix} d\xi d\eta$$

Where $L_n^{(\alpha)}(y)$ are the laguerre polynomials

(ii) On taking $r = 0 = s = p = g = u_k = v_k$; $q = h = y = d = e = e_1 = v_1 = □_1 = □□= □_1 = -□$; $\mu = \frac{1}{2}$; $= D_1 = \frac{1}{2} = b_1$; and putting $x_1 = \frac{x-1}{x+1}$, we arrive at

$$T_n(x) = \frac{\Gamma(\mu+\nu)}{n!\,\Gamma(\mu)\,\Gamma(\nu)}\left(\frac{x-1}{2}\right)^n \int_0^{'}\int_0^{'}\frac{(1-\xi)^{\mu-1}\eta^{\mu}(1-\eta)^{\nu-1}}{(1-\xi\eta)^{\mu+\nu-1}}$$

$$\times F\begin{bmatrix}-n, \frac{1}{2}-n, \frac{\mu+\nu}{2}, \frac{\mu+\nu-1}{2}; \\ \frac{x+1}{x-1} \\ \frac{1}{2}, \mu, \nu;\end{bmatrix} d\xi d\eta$$

Where, $T_n(x)$are the Tchebicheffe Polynomials of First Kind

(iii) If we take $r = 0 = s = p = g = u_k = v_k$; $q = 1 = h = d = e = e_1 = \xi = \sigma = \lambda_1 = -\lambda = y$; $\mu_1 = \frac{1}{2} = \mu$; $= D_1 = \frac{3}{2} = b_1$; and writing $\frac{x-1}{x+1}$, for $x$, we achieve

$$U_n(x) = \frac{\Gamma(\mu+\nu)(n+1)!}{\Gamma(\mu)\,\Gamma(\nu)n!}\left(\frac{x-1}{2}\right)^n \int_0^{'}\int_0^{'}\frac{(1-\xi)^{\mu-1}\eta^{\mu}(1-\eta)^{\nu-1}}{(1-\xi\eta)^{\mu+\nu-1}}$$

$$\times F\begin{bmatrix}-n, \frac{-1}{2}-n, \frac{\mu+\nu}{2}, \frac{\mu+\nu-1}{2}; \\ \frac{x+1}{x-1} \\ \frac{3}{2}, \mu, \nu;\end{bmatrix} d\xi d\eta$$

Where $U_n(x)$ are the Tchebicheffe Polynomials of Second Kind.

(iv) If we set $r = 0 = s = p = g = \alpha_{u_k} = \beta_{v_k}$; $q = 1 = h = y = □ = d = e = e_1 = -\lambda = \sigma = \lambda_1$; $\mu = \frac{1}{2} = \mu_1$; $D_1 = 1 + \alpha = b$; and writing $\frac{x+1}{x-1}$ for $x$, we obtain

$$P_n^{(\alpha,\alpha)}(x) = \frac{\Gamma(\mu+\nu)(1+\alpha)}{\Gamma\mu\,\Gamma\nu\,n!}\left(\frac{x+1}{2}\right)^n \int_0^{'}\int_0^{'}\frac{(1-\xi)^{\mu-1}\eta^{\mu}(1-\eta)^{\nu-1}}{(1-\xi\eta)^{\mu+\nu-1}}$$

$$\times F\begin{bmatrix}-n, -\alpha-n, \frac{\mu+\nu}{2}, \frac{\mu+\nu-1}{2}; \\ \frac{x-1}{x+1} \\ 1+\alpha, \mu, \nu;\end{bmatrix} d\xi d\eta$$

Where $P_n^{(\alpha,\alpha)}(x)$ are the Ultrashpherical Polynomials

(v) If we setting $r = 0 = s = p = g = \alpha_{u_k} = \beta_{v_k}$; $q = 1 = h = e = e_1 = d = □ = y = -□ = □ = □□_1$; $\mu = \frac{1}{2} = \mu_1$; $D_1 = 1 + □□$; and $b_1 = 1 + □$; $x_1 = \frac{X+1}{X-1}$, we get

$$P_n^{(\alpha,\beta)}(x) = \frac{\Gamma(\mu+\nu)(1+\alpha)_n}{\Gamma(\mu)\,\Gamma(\nu)\,n!}\left(\frac{x+1}{2}\right)^n \int_0^{'}\int_0^{'}\frac{(1-\xi)^{\mu-1}\eta^{\mu}(1-\eta)^{\nu-1}}{(1-\xi\eta)^{\mu+\nu-1}}$$

$$\times F\begin{bmatrix}-n, -\beta-n, \frac{\mu+\nu}{2}, \frac{\mu+\nu-1}{2}; \\ \left(\frac{x+1}{x-1}\right) \\ 1+\alpha, \mu, \nu;\end{bmatrix} d\xi d\eta$$

Where $P_n^{(\alpha,\beta)}(x)$ are the Jacobi Polynomials

(vi) For $r = 0 = s = p = g =$; $q = 1 = h = e = e_1 = d = y = \sigma = -\lambda = \lambda_1 = y$; $\mu = \frac{1}{2} = \mu_1$; $D_1 = \frac{1}{2} + \lambda = b_1$ and writting $\frac{x+1}{x-1}$ for $x_1$, we obtain

$$C_n^{\lambda}(x) = \frac{\Gamma(\mu+\nu)(2\lambda)_n}{\Gamma(\mu)\,\Gamma(\nu)\,n!}\left(\frac{x+1}{2}\right)^n \int_0^{'}\int_0^{'} \frac{(1-\xi)^{\mu-1}\eta^{\mu}(1-\eta)^{\nu-1}}{(1-\xi\eta)^{\mu+\nu-1}}$$

$$\times F\begin{bmatrix} -n, \frac{1}{2} - \lambda - n, \frac{\mu+\nu}{2}, \frac{\mu+\nu-1}{2}; \\ \frac{x-1}{x+1} \\ \lambda + \frac{1}{2}, \mu, \nu; \end{bmatrix} d\xi d\eta$$

Where $C_n^{\lambda}(x)$ are the Gegenbauer Polynomials

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