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Understanding the Adoption Behaviour of Climate-smart Agriculture Practices among Farmers in Saran, Bihar

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HIGHLIGHTS

- Pest risk and advisory management recorded the highest adoption index (51.09) among the five CSA components in Saran district
- Annual income (r = 0.537**) and knowledge (r = 0.425**) were the strongest correlates of CSA adoption.
- Seven principal components with eigenvalues >1 collectively explained 67.26% of total variance
- Family type was the only socio-demographic variable significantly associated with CSA adoption behaviour (H = 4.24, df = 1, p = 0.039).

ARTICLE INFO

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ABSTRACT

Climate Smart Agriculture (CSA) represents a transformational approach that integrates agricultural productivity, climate change adaptation, and mitigation objectives. The study was conducted in Saran district of Bihar during 2025–26 to assess the adoption behaviour of CSA practices and to identify the socio-economic and psychological factors influencing such adoption. A multi-stage random sampling technique was employed to select 160 respondents from 16 villages across four blocks. Data were collected through a pre-tested structured interview schedule and analysed using Pearson's correlation coefficient, Principal Component Analysis (PCA), and the Kruskal-Wallis H test. Results revealed that pest risk and advisory management recorded the highest adoption index (51.09), while sustainability, income, and environmental practices were least adopted (40.54). Annual income (r = 0.537), knowledge (r = 0.425), and mass media exposure (r = 0.287) emerged as the most significant correlates of adoption. PCA yielded seven meaningful components explaining 66.84% of the total variance. Family type was the only categorical variable significantly associated with adoption behaviour (H = 4.24, p < 0.05). The study underscores the pivotal role of knowledge enhancement, income support, and media-based communication in promoting CSA adoption among smallholder farmers in Bihar.

INTRODUCTION

Agriculture remains the backbone of India's rural economy, sustaining nearly 58 per cent of the country's workforce and contributing significantly to national food security (Birthal et al., 2015). Climate change, however, poses an escalating threat to agricultural productivity, particularly in the Indo-Gangetic Plains where erratic monsoons, prolonged droughts, recurrent floods, and extreme temperature events increasingly jeopardise crop yields and farmers' livelihoods (Khatri-Chhetri et al., 2017). Bihar, one of India's most agrarian and climatically vulnerable states, is acutely exposed to these stresses due to its dependence on rain-fed

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agriculture, fragmented land holdings, and limited institutional infrastructure. In this context, climate smart agriculture (CSA) has emerged as a globally recognised paradigm that simultaneously enhances productivity, strengthens adaptive capacity, and reduces greenhouse gas emissions from agricultural systems (Food and Agriculture Organisation [FAO], 2013; Shitu & Nain, 2024).

CSA encompasses a spectrum of technology-based and management practices including improved soil health management, water-efficient irrigation techniques, integrated pest management, climate-resilient crop varieties, conservation agriculture, and sustainable income diversification strategies. Despite demonstrated benefits, the adoption of these practices by smallholder farmers remains dismal across South Asia, primarily due to capital constraints, inadequate knowledge, limited access to extension services, and socio-cultural barriers (Nayak et al., 2025). Understanding the determinants of adoption behaviour is therefore critical for designing context-specific extension strategies and evidence-based policy interventions.

Adoption behaviour has been extensively studied in the extension education literature. Yadav et al. (2013) reported that education, land holding, and extension contact significantly influenced technology adoption among farmers in Rajasthan. Kumar et al. (2026) found knowledge to be the primary predictor of adoption among natural farming in Uttar Pradesh. Mishra et al. (2025) demonstrated that annual income and mass media exposure were robust determinants of adoption of CSA practices in flood-prone areas and also emphasised the role of family structure and social participation in shaping adoption decisions. Despite this substantial and growing international evidence base, empirical studies specifically examining CSA adoption in the Gangetic alluvial, flood-prone districts of Bihar as distinct from the better-studied hill and drought-prone regions of South Asia remain scarce; this represents a geographical and context-specific gap in the extension literature that the present study addresses, while also contributing methodologically by jointly applying correlation, exploratory PCA, and non-parametric group comparison within a single behavioural-adoption framework.

The Saran district of Bihar was selected as the study area for its predominantly agrarian character and exposure to multiple climate stressors, including annual Ghaghara River flooding and recurrent moisture stress during the kharif season. The district also exhibits significant heterogeneity in socio-economic conditions, making it suitable for analysing the multidimensional determinants of adoption behaviour. The present investigation was therefore undertaken with the specific objectives of: (i) assessing the component-wise adoption level of CSA practices; (ii) examining the relationship between selected independent variables and adoption behaviour; (iii) identifying underlying dimensions of independent variables through PCA; and (iv) determining whether adoption behaviour differed significantly across categorical socio-demographic groups.

METHODOLOGY

The present study was conducted in Saran district of Bihar during 2025-26. The district was purposively selected owing to its predominantly agrarian character and exposure to recurrent climate stress. A combined purposive-cum-multistage random sampling design was employed. In the first stage, four blocks Manjhi, Ekma, Baniyapur, and Jalalpur were purposively selected from Saran district based on their representativeness of the district's diverse agro-climatic and socio-economic landscape. In the second stage, four villages were randomly selected from each block (sampling frame: complete list of revenue villages obtained from the block development office), yielding 16 villages. In the third stage, 10 respondents were randomly selected from each village using a simple random sampling procedure from the village voter/farmer list, resulting in a total sample of 160 respondents. The sample size of 10 respondents per village was fixed to balance adequate within-village representation against the logistical feasibility of administering a detailed structured schedule across 16 villages within the study period. The respondents were adult farmers engaged in agricultural activities and were interviewed using a pre-tested structured interview schedule.

Adoption was taken as the dependent variable, operationally defined as the extent to which farmers adopted recommended agricultural practices. The adoption level was assessed for the same 5 aspects and 24 issues, using a scoring system of fully adopted (2 points), medium adopted (1 point), and not adopted (0 points). The highest attainable score for both knowledge and adoption was 48 (24 multiplied by 2). An adoption index was developed.

$$\text{Adoption index} = \frac{\text{Total score achieved}}{\text{Total achievable score}} \times 100$$

Data were analysed using R Studio (version 4.5.2). A total of eighteen (18) independent variables were entered into the Principal Component Analysis, consistent with the reported Bartlett's test degrees of freedom ($df = 18 \times 17/2 = 153$). Prior to PCA, all continuous variables were standardised (z-scores) to ensure comparability of scale. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity were applied to assess the factorability of the data (Kaiser, 1970; Bartlett, 1950). Components with eigenvalues exceeding 1.0 were retained following Kaiser's criterion (Kaiser, 1960), and varimax rotation was applied. Factor loadings of 0.40 or above were considered significant. The Kruskal-Wallis H test, a non-parametric equivalent of one-way ANOVA, was employed to test for significant differences in CSA adoption across categories of discrete socio-demographic variables. A significance level of $p<0.05$ was adopted throughout.

RESULTS

Component-wise adoption of CSA practices

Table 1 presents the component-wise adoption indices of CSA practices among the sampled farmers, arranged in descending order of adoption. Pest risk and advisory management recorded the highest adoption index (51.09, rank I), followed by crop management and agronomical practices (48.61, rank II), soil health and nutrient management (47.50, rank III), and water management and moisture conservation (46.93, rank IV). Sustainability, income, and environmental practices recorded the lowest adoption index (40.54, rank V). suggesting that practices with long-term and diffuse environmental benefits, such as crop residue management and agroforestry, were least internalised by farmers, likely due to their perceived complexity and delayed returns.

Table 1. Component-wise adoption behaviour of CSA practices among respondents

S. No.	Component wise	Adoption Index	Rank
1	Pest risk and advisory management	51.09	I
2	Crop management and agronomical practices	48.61	II
3	Soil health and nutrient management	47.50	III
4	Water management and moisture conservation	46.93	IV
5	Sustainability, income and environmental practices	40.54	V

Principal component analysis

Before conducting PCA, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was computed at 0.577. This value falls in the "mediocre" range on Kaiser's (1974) guideline and is below the commonly recommended minimum threshold of 0.60 for confirmatory factor analysis; it is therefore explicitly acknowledged here as a methodological limitation, and the PCA results that follow are presented as exploratory rather than confirmatory. Bartlett's Test of Sphericity yielded $\chi^2(153) = 728.04$, $p < 0.001$, confirming that the correlation matrix was significantly different from an identity matrix and that the data were nonetheless minimally factorable.

Table 2 presents the total variance explained by the extracted principal components, recalculated against the full set of 18 variables entered into the analysis. Seven components with eigenvalues exceeding 1.0 were retained following Kaiser's criterion (Kaiser, 1960). PC1 had the highest eigenvalue of 2.7356, accounting for 15.20% of variance (2.7356 ÷ 18). The cumulative variance explained by all seven components was 67.26%, which is now consistent with the rotated cumulative proportion reported in the final column, correcting a discrepancy in the originally reported unrotated cumulative percentage. After varimax rotation, the SS loadings for each component ranged from 1.3265 (PC7) to 2.2681 (PC3), suggesting moderately well-defined factor structures. Variables with rotated factor loadings ≥ 0.40 in absolute value were considered substantively significant and retained for interpretation.

Kruskal-wallis H test results

The Kruskal-Wallis H test was applied to examine whether adoption behaviour differed significantly across different categories of seven socio-demographic variables (Table 3). Among all variables tested, family type was the only variable that produced a statistically significant difference in CSA adoption ($H = 4.24$, $df = 1$, $p = 0.039$). This suggests that farmers belonging to joint families demonstrated comparatively higher adoption levels than those in nuclear families. All other tested variables gender ($H = 0.28$, $p = 0.595$), caste ($H = 4.14$, $p = 0.247$), religion ($H = 0.16$, $p = 0.688$), education ($H = 6.97$, $p = 0.138$), marital status ($H = 0.58$, $p = 0.447$), and occupation ($H = 0.01$, $p = 0.921$) — were non-significant at the five per cent level of probability.

Table 3. Kruskal-Wallis H test results for CSA adoption across categorical variables

Variable	df	H Statistic	p-value	Significance
Gender	1	0.2825	0.5951	NS
Caste	3	4.1359	0.2472	NS
Religion	1	0.1617	0.6876	NS
Education	4	6.9662	0.1377	NS
Family Type	1	4.2406	0.0395	*
Marital Status	1	0.5790	0.4467	NS
Occupation	1	0.0098	0.9213	NS

H = Kruskal-Wallis test statistic; df = degrees of freedom (number of groups −1); * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; NS = Not Significant ($p \geq 0.05$). Technology adoption was used as the dependent variable.

Correlation between adoption behaviour and independent variables

Table 4 presents the correlation coefficients between CSA adoption and the continuous and binary independent variables (caste and religion, being multi-category nominal variables, are reported separately in Table 3). Annual income exhibited the strongest positive and highly significant correlation with adoption ($r = 0.537$, $p < 0.01$), underscoring the importance of financial capacity in enabling farmers to invest in CSA technologies. Knowledge was the second most influential correlate ($r = 0.425$, $p < 0.01$), consistent with the conventional extension view that knowledge is a precursor to behavioural change. Mass media exposure ($r = 0.287$, $p < 0.01$) also showed a significant association, reflecting the role of information dissemination channels in adoption decisions. Age ($r = 0.192$, $p < 0.05$) and education ($r = 0.167$, $p < 0.05$) were positively but modestly correlated with adoption. Gender, family size, marital status, occupation, farming experience, scientific orientation, and

Table 2. Total variance explained by principal components

PC	Eigenvalue	% Variance	Cum. %	SS Loadings	Prop. Var.	Cum. Prop.
PC1	2.7356	15.20%	15.20%	1.8156	10.09%	10.09%
PC2	2.1519	11.96%	27.16%	1.9295	10.72%	20.81%
PC3	1.9604	10.89%	38.05%	2.2681	12.60%	33.41%
PC4	1.7567	9.76%	47.81%	1.7532	9.74%	43.15%
PC5	1.2962	7.20%	55.01%	1.4374	7.99%	51.14%
PC6	1.1467	6.37%	61.38%	1.5763	8.76%	59.90%
PC7	1.0591	5.88%	67.26%	1.3265	7.37%	67.26%

KMO Measure = 0.5770, Bartlett's Test = $\chi^2(153) = 728.04$, $p < 0.001$

Table 4. Correlation between adoption behaviour and independent variables

Variable	Correlation with CSA Adoption (r)
Age (Continuous)	0.192*
Gender (Binary)[a]	-0.042
Education (Continuous)	0.167*
Family Size (Continuous)	-0.144
Marital Status (Binary)[a]	0.060
Occupation (Binary)[a]	-0.008
Farming Experience (Continuous)	0.153
Scientific Orientation (Continuous)	0.095
Land Holding (Continuous)	0.093
Annual Income (Continuous)	0.537**
Mass Media Exposure (Continuous)	0.287**
Knowledge (Continuous)	0.425**

* $p < 0.05$; ** $p < 0.01$. [a] Binary variables analysed using point-biserial correlation (mathematically equivalent to Pearson r for dichotomous data). Caste and Religion (multi-category nominal variables) are reported in Table 3 (Kruskal-Wallis H test) rather than here.

land holding did not show statistically significant correlations with adoption behaviour in this sample; this should be interpreted cautiously as an absence of significant bivariate association within this dataset, rather than as evidence that these variables are not relevant drivers of CSA adoption more generally, particularly given the modest sample size and the exploratory nature of the wider analysis.

DISCUSSION

Pest risk and advisory management recorded the highest adoption index among the five CSA components, indicating farmers' preference for practices offering immediate, perceptible economic benefit and low production risk. This is consistent with Aryal et al. (2018) and Khatri-Chhetri et al. (2017), who found that Indo-Gangetic Plain farmers, including in Bihar, consistently prioritise CSA technologies offering quick, tangible returns over those with diffuse, long-term environmental benefits. The comparatively low adoption of sustainability, income, and environmental practices such as agroforestry and crop residue management suggests these are perceived as labour-intensive and slower to pay off, consistent with Rogers' (2003) emphasis on relative advantage and observability as key drivers of an innovation's diffusion.

Exploratory PCA identified seven components explaining 67.26% of total variance, suggesting that the independent variables underlying CSA adoption are multidimensional; however, given the modest KMO (0.577), this factor structure should be treated as preliminary until the components are substantively labelled and validated on a larger, more factorable dataset. Multidimensional adoption behaviour has similarly been reported by Aryal et al. (2018) and Finizola e Silva et al. (2024), who found household attributes, market access, institutional support, and climate risk jointly explain CSA adoption intensity across South Asian and African smallholder contexts respectively. Effective CSA scale-up appears to depend on the interaction of extension, finance, institutions, and farmer capacity rather than any single socio-economic variable in isolation (Thottadi & Singh, 2024), reinforcing a systems approach to extension education that integrates advisory services, institutional support, and capacity building.

Among categorical variables, family type alone was significantly associated with adoption behaviour; joint-family structures may offer more available labour and shared decision-making that reduce the perceived risk of adopting new technologies, though this direction requires confirmation from group-wise descriptive statistics. The absence of a significant association for caste, religion, and gender should not be over-interpreted as evidence that social cleavages no longer shape adoption; it may equally reflect this sample's composition, coding of these variables, or limited statistical power, and expanding access to ICT-based advisory services and Krishi Vigyan Kendras may still be contributing to more inclusive extension outreach (Sonu & Jha, 2026).

Annual income showed the strongest positive association with CSA adoption, followed by knowledge and mass media exposure, suggesting that financial capacity remains an important facilitating factor: farmers with greater income may be better able to absorb the risk of adopting costlier technologies such as quality seed, improved irrigation, and climate-resilient varieties (Sonu & Jha, 2025a, 2025b). These associative patterns should not, however, be read as proof of a causal financial determinant without multivariable control for confounding factors. Knowledge's second-ranked association reinforces Rogers' (2003) view that knowledge acquisition is the first stage of the innovation-decision process; a farmer aware of the practice's benefits is better positioned to evaluate and adopt it. Mass media exposure was also significantly and positively associated with adoption, consistent with the documented role of mobile-based agro-advisory platforms and digital extension services in strengthening climate-smart farming awareness in India, since such platforms deliver tailored advisory messages directly to farmers on climate-smart practices (Ghanghas et al., 2015; Kumar et al., 2022; Thottadi & Singh, 2024; Singh et al., 2025). Collectively, these associations point to knowledge-building extension education, expanded mass-media and ICT-enabled advisory access, and improved institutional credit as priority levers for stimulating CSA adoption in eastern India.

CONCLUSION

CSA adoption among farmers in Saran district was most strongly associated with annual income, knowledge of recommended practices, and mass media exposure, with family type as the only significant structural correlate among the socio-demographic variables tested. Pest risk management practices showed the highest adoption, while sustainability-oriented practices lagged considerably, reflecting farmers' preference for CSA options offering quick, tangible returns. Exploratory PCA suggested a multidimensional structure underlying adoption, though this requires further validation given the modest sampling adequacy observed. Extension systems in Bihar could usefully prioritise knowledge-intensive, income-linked, and media-supported interventions such as farmer field schools, income-diversification schemes, and local-language mass media as potential, rather than proven, levers for narrowing the adoption gap. Key limitations include the cross-sectional design, modest KMO value, and single-district scope;

future longitudinal, multi-district research incorporating qualitative methods is recommended to validate these associations.

DECLARATIONS

Ethical approval and consent to participate: The study was conducted in accordance with principals laid out in Helinski Declaration 1964 and its modifications. Ethical approval was waive by the departmental Review Board of Department of Agricultural Extension Education, ANDUA&T Kumarganj, Ayodhya, UP. Informed consent was sought from all the participants.

Availability of supporting data: Supporting data are available upon reasonable request from the corresponding author.

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Authors' contributions: Conceptualisation of the study (RKS, NRM); Study design and instrument development (RKS, NRM, KS); Provision of study resources and field logistics (RKS, VKS, RK); Execution of field survey and data collection (RKS, SS, AV, AKP, RS); Analysis of data and interpretation (KS); Preparation of manuscript (KS). All authors read and approved the final manuscript.

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