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Socio-Economic Determinants of Agriculture Households in Punjab: A Principal Component Analysis

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HIGHLIGHTS

- Components like land holding, education, and credit access, explained nearly 70 percent of the variations.
- Crucial livelihood factors identified were Land, livestock, and income.
- Education, credit, and markets were found to be major drivers of Inclusive agricultural development.

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ABSTRACT

The study highlights the socio-economic determinants of agricultural families in Punjab through the main component analysis. A sample of 200 families was surveyed in 2024-25, and ten socio-economic variables were analyzed, including land ownership, income, livestock, education, family size, expansion contact, loan, mechanization, and market access. The suitability of the PCA was confirmed by a clinical test with the Kaiser-Meyer-Olkin value of 0.732 and a significant Bartlett test. The analysis highlights the three major components with more than one Eigenvector value, which cumulatively explain 68.5% of the total variance. The PC1 highlights the relevance of agricultural resources, land, livestock, and income. PC2 emphasizes human and social capital, expansion services, family labour, and education. PC3, institutional and market access, mechanization, obtained loans, and proximity to markets. The multidimensional nature of rural livelihood in Punjab is exposed, where both traditional resources and institutional factors shape domestic results. The study underlines the need for integrated policies emphasizing resource efficiency, human capacity building, and institutional strengthening to ensure inclusive and sustainable agricultural development.

INTRODUCTION

Agriculture, being the backbone of the Indian economy, contributes significantly to food security, rural employment, and livelihood stability (Kaur & Kaur, 2021). Although its stake in the National GDP has been decreasing in the last few years, the region has employment for about half of the country and has remained a major source of income for rural families (Jatav, 2024). In this structure, the Punjab state holds a unique place, ensured national food security through intensive cultivation of cereals like wheat and rice (Chandana et al., 2022). It is facing complex challenges today, including rising costs, instability in agricultural income, excessive exploitation of natural resources, and increasing socio-economic inequalities between farming households (Pal et al. 2017; Meena et al., 2022). The socio-economic parameters of rural farming families play an important role in shaping livelihood outcomes and

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agricultural performance (Kumari et al., 2020; De et al., 2023). Factors such as holdings size, income, and education affect better techniques, use resources, and participation in the market (Nain & Chandel, 2010; Dagar & Upadhyay, 2022; Prakash et al., 2022). For instance, better education is more likely to invest in mechanization and adopt climate-friendly practices (Sarkar et al., 2022). Thus, a systematic understanding of socio-economic determinants of agricultural families is necessary to design targeted policies that can increase inclusion, flexibility, and sustainable development in the primary sector (Kobba et al., 2021; Amitha et al., 2023; Meena et al., 2023).

Previous research has uncovered the socio-economic dimensions of agriculture using descriptive statistics or social-based models. Despite being informative, these approaches often withstand the limitations of multiplicity, as socio-economic variables are highly correlated with each other. PCA enables researchers to condense a large group of corporate variables into a low number of unrelated components, representing the latent dimensions of the socio-economic situation (Gambardella et al., 2021). In India, several studies have used PCA to measure socio-economic development, livelihood security, or vulnerable indices in rural areas. However, limited efforts have been made to systematically implement the PCA to assess the socio-economic determinants of agricultural families in Punjab (Pani & Mishra, 2022). Given the centrality of the state in India's agricultural economy, as well as emerging challenges such as declining agricultural profitability, water crisis, and inter-family inequalities, such analysis is both timely and policy-related. In addition, the component-based approach allows for to identification of extensive dimensions such as agricultural resources, human and social capital, and institutional access, which can guide the creation of integrated development programs (Pandey & Devi, 2023).

In this background, this study applies the Principal Component Analysis on a group of socio-economic variables collected from agricultural families in Punjab, India. Its specific objectives are: testing the socio-economic characteristics of agricultural families, to remove and interpret the major components underlying their socio-economic conditions, and providing insights for policy and program design to increase agricultural stability and farmer welfare (Singariya, 2013). By adopting this approach, this study not only contributes to the empirical literature on rural socio-economics but also presents a methodical structure for analyzing complex, multi-faceted datasets in agriculture.

METHODOLOGY

A multi-step-stalled objective-cum-disciplinary sampling design was adopted for this study in Punjab, India, with a sample of 200. On basis of agricultural intensities, Ludhiana (high) and Mansa (low) districts, along with two blocks named Samrala, Khanna, Budhlada, and Sardulgarh, respectively were selected. Then, respondents from 8 villages, Bhucho, Mangat, Alour, Payal, Bareta, Boha, Jhunir, and Rorki respectively, were surveyed for data.

To ensure credibility, the equipment was pre-tested on 30 respondents outside sample area, and alpha coefficients of Cronbach's. The obtained value $\alpha = 0.79$ indicated a satisfactory internal association of scale items. Each variable X_j was standardized using the following formula:

$$Z_{ij} = \frac{X_{ij} - \mu_j}{\sigma_j}$$

Where Z_{ij} is standardized value of i^{th} observation on j^{th} variable, μ_j is mean of the variable, and σ_j is its standard deviation.

Before applying Principal Component Analysis, the suitability of dataset was examined. The Kaiser-Meyer-Olkin (KMO) sample adequacy measurement and spherical testing of Bartlett were used to check whether the correlation matrix is carriers. KMO value above 0.70 and statistically significant Bartlett's K-Square ($P < 0.05$) confirmed the suitability of the PCA for the data given. Subsequently, PCA was implemented on the standardized correlation matrix. This technique decomposes the total offering into linear combinations of the original variables, where each main component is perpendicular to the other variables and explains the decreasing ratio of the total offering. The extraction of the components was based on the Caesar criteria, that is, components with more than one eigenvalue were retained. Eigen's value (λ) reflects the number of provisions interpreted by each component, which is obtained from the following equation:

$$Rv = \lambda v$$

Where, R is the correlation matrix, v is the eigenvector, and λ is the eigenvalue.

To increase explanation, Varimax orthogonal rotation was applied, rewriting the variance among the residual components, while they remained unrelated. The variables with more than 0.40 factor weights were considered important contributors to the component. Depending on the rotating factor load, the components were designated according to the group of the highest load variables. The component score for each family was calculated using the regression method, which was expressed as follows:

$$Si = W_1 Z_{i1} + W_2 Z_{i2} + \ldots\ldots\ldots + W_k Z_{ik}$$

Where, S_i, i^{th} is a component score for the family, Z_{ij} has standardized variable values, and the W_j component loads. These scores were later used for descriptive interpretation and comparative analysis in various households.

RESULTS

Selection of variables for PCA

In this study, ten socio-economic variables were used to understand the multidimensional nature of rural families (Table 1). These included age, education, family size, land-ownership, livestock, income, loan availability, expansion contact, mechanization, and market access.

The selection was based on the relevance of these variables in the literature and the agricultural context of Punjab. The variables, such as land ownership, livestock, and income, were expected to reveal economic strength. Education, family size, and expansion contacts reflected human and social capital, whereas debt, mechanization, and market access indicated institutional and infrastructure assistance. The market access was expected to have a negative effect, as the long distance of markets usually increases the cost of transactions and reduces profitability.

Table 1. Variables Used for Principal Component Analysis

Variable Code	Variable Description	Unit / Scale	Expected Influence
X1	Age of household head	Years	Neutral
X2	Education level	Years	Positive
X3	Family size	Number	Mixed
X4	Operational landholding	Hectares	Positive
X5	Livestock units	Number	Positive
X6	Annual household income	Rs. ('000)	Positive
X7	Access to institutional credit	Binary (1=Yes, 0=No)	Positive
X8	Extension contact score	Index	Positive
X9	Farm mechanization score	Index	Positive
X10	Market accessibility (distance)	Km	Negative

PCA suitability

Before PCA, the sufficiency of the dataset was tested using the Kaiser-Meyer-Olkin (KMO) measurement and the sphericalness test (Table 2) of the Bartlett. The KMO value was 0.732, which was much above the minimum allowable level of 0.60, indicating that the sample factor was sufficient for analysis.

Table 2. KMO and Bartlett's Test for PCA Suitability

Test	Value
Kaiser-Meyer-Olkin (KMO)	0.732
Bartlett's Test of Sphericity	$\chi^2 = 512.47$, df = 45, $p < 0.001$

Indicates data suitable for PCA

The Bartlett test was highly meaningful ($\chi^2 = 512.47$, $p < 0.001$), which confirmed that the correlation matrix was not an identity matrix and the variables were sufficiently correlated to justify the PCA. These results validated the use of PCA as a suitable technique for data renovation in this study.

Interpretation of variance by components extracted

The PCA extracted three major components with more than 1 standard deviation, which explains 68.5 percent of the total variance (Table 3). The first component explains 34.5 percent of the variance, the second 21.2 percent, and the third 12.8 percent.

This indicates that a large part of the variation in socio-economic characteristics can be condensed into three underlying dimensions. The cumulative variance explained in social science research usually exceeds the 60 percent standard considered satisfactory, indicating a strong explanatory power of the components created. The eigen value of the components ahead of the third was less than 1 and was not considered for interpretation.

Table 3. Total Variance Explained by Extracted Components

Component	Initial Eigenvalues	Extraction Sums of Squared Loadings	Rotation Sums of Squared Loadings
	Eigenvalue	% of Variance	Cumulative %
1	3.45	34.5	34.5
2	2.12	21.2	55.7
3	1.28	12.8	68.5
4	0.89	8.9	77.4
5	0.70	7.0	84.4
6	0.52	5.2	89.6
7	0.40	4.0	93.6
8	0.34	3.4	97.0
9	0.22	2.2	99.2
10	0.08	0.8	100.0

Retained components with eigenvalue > 1

Factors load and component structure

The rotating component matrix presented in Table 4 clearly adds the variables into three different components. Component 1 had strong loads on land-ownership (0.82), livestock (0.76), and domestic income (0.71). This indicates that families with large land ownership and high livestock ownership report high income, which is a pattern in line with Punjab's agricultural economy. This component was explained as the "Agricultural Resource Aadhaar", which reflects physical and financial resources that define economic capacity. Component 2 had a heavy weight of education (0.83), family size (0.62), and expansion contact (0.74).

Table 4. Rotated Component Matrix (Varimax Rotation)

Variable	Component 1 (Resources)	Component 2 (Human Capital)	Component 3 (Institutional Access)
Landholding size	0.82	0.12	0.05
Livestock units	0.76	0.08	0.22
Household income	0.71	0.20	0.18
Education	0.15	0.83	0.10
Family size	0.09	0.62	0.05
Extension contact	0.10	0.74	0.32
Credit access	0.05	0.18	0.81
Mechanization	0.44	0.36	0.40
Market access	–0.20	0.16	0.66

These variables collectively represent human and social capital. Education strengthens farmers with knowledge and decision-making skills, provides family-sized domestic labor, and facilitates the information flow. Together, these variables reflect human and social resources that increase agricultural management capacity. This component was designated as "human and social capital". Component 3 showed a high load of loan access (0.81), market access (0.66), and mechanization (0.40). These variables represent institutional and infrastructural support, as debt makes investment smooth, reduces the cost of proximity to markets, and increases mechanization productivity. This component was interpreted as "institutional and market access". Thus, the rotating component

Figure 1. Scree Plot

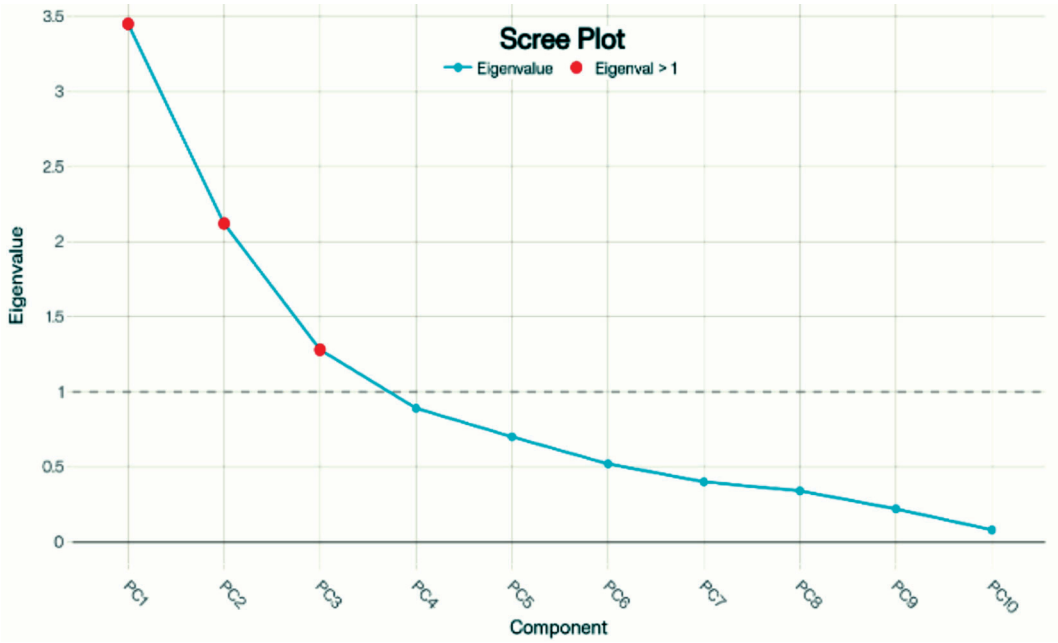
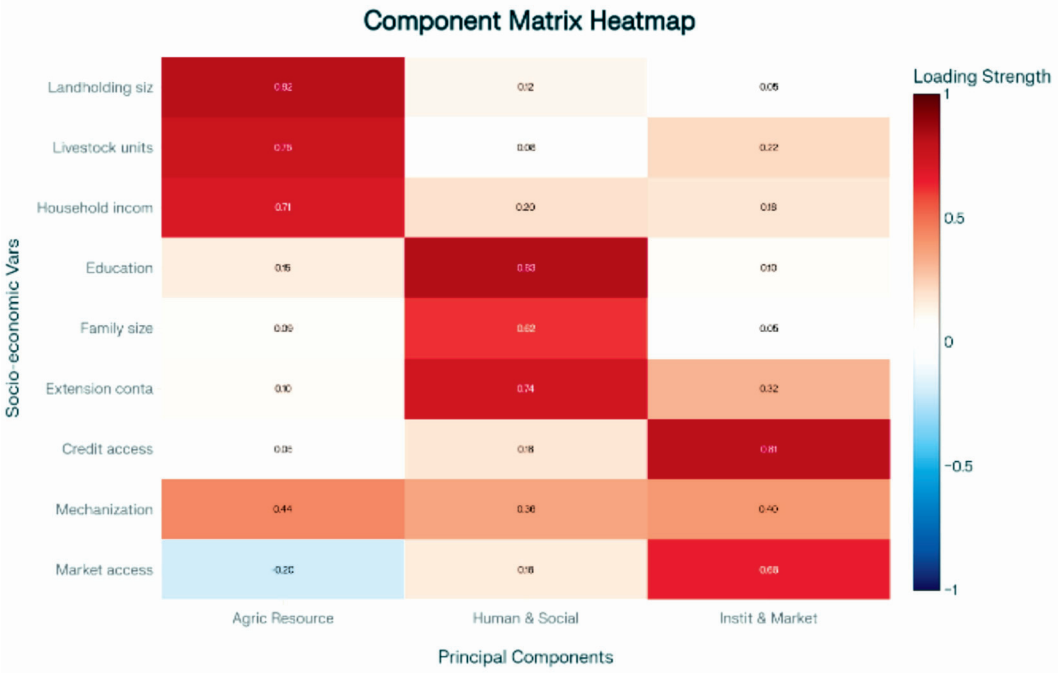


Figure 2. Component Matrix



structure confirms that the socio-economic determinants of the farming families of Punjab can be effectively classified into three underlying dimensions-exasperation, human and social capital, and institutional access.

Interpretation of components

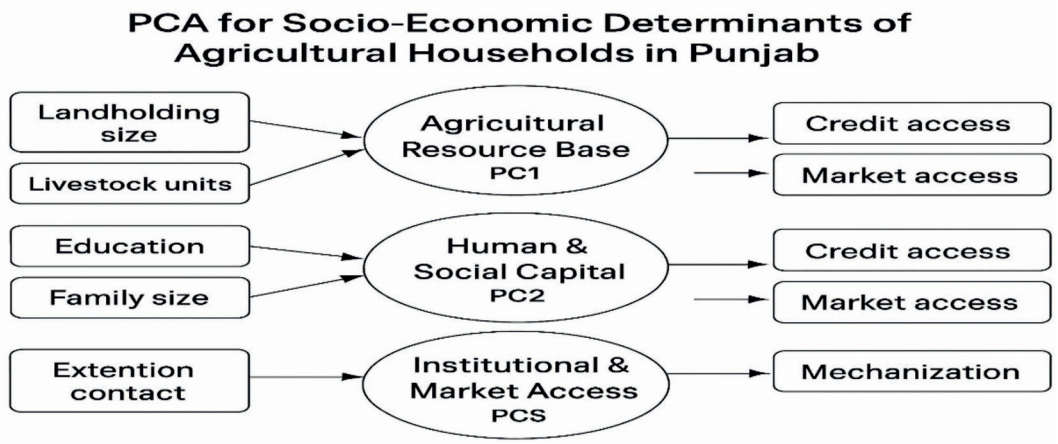
The three components were interpreted as follows in Table 5. Agricultural Resources Aadhaar (PC1), a component, based on land ownership, livestock, and income, highlights the permanent importance of tangible resources in defining domestic prosperity. Agricultural development of Punjab has historically been resource-dominated, which has depended on land, irrigation, and livestock. The results suggest that they remain the primary driver of domestic economic strength. Human and Social Capital (PC 2), with a strong contribution of education, family size, and expansion contact, this component underlines the role of abstract resources.

In the contemporary agricultural scenario, human capital, technology play an important role in adopting efficient agricultural management through literacy and training. Extension contacts act

Table 5. Interpretation of Principal Components

Component	Dominant Variables	Interpretation
PC1	Landholding, livestock, income	Agricultural Resource Base
PC2	Education, family size, extension contact	Human & Social Capital
PC3	Credit access, market access, and mechanization	Institutional & Market Access

Figure 3. Path Diagram



as a bridge between institutions and farmers, which confirms the importance of social networks. Institutional and market access (PC3), reflects an agriculture-friendly environment. Institutional debt helps farmers to overcome cash shortages, while market access ensures profitability by reducing costs and ensuring timely sales of produce. Machination reflects modernization and labor efficiency even more. The group of these variables reflects the growing role of institutional aid systems in maintaining agricultural development.

DISCUSSION

The findings of this study indicate that the socio-economic structure of agricultural families in Punjab can be understood in three broader dimensions: Agricultural Resources Aadhaar, Human and Social Capital, and institutional and market access. Results are in line with multidimensional nature of rural livelihood described in pre -Indian and global studies, although some features are unique to agricultural reference of Punjab (Kumar et al., 2023). Dominance of the resource base component, which includes land ownership, livestock, and income, is not surprising. The most important determinant of land, domestic status, and income in Indian agriculture remains a trend that was exposed in former studies in Punjab and Haryana, where the size of land positively affected productivity and income diversification (Basantaray et al., 2024). Livestock's involvement echoes the evidence of those who noted that dairy farming in Punjab continues to act as a stable factor for agricultural families. These results confirm the argument that despite mechanization and modernization, traditional resources such as land and livestock remain basis of rural prosperity in Punjab (Gulati et al., 2021). Rise of human and social capital as the second major component is in line with studies that highlight the growing role of abstract resources. Education, family size, and expansion contact collectively reflect ability to acquire, process, and implement family knowledge. Punjab studies also emphasize a medium of spreading modern practices on expansion contacts, especially in relation to crop diversification and water-use efficiency. Thus, results of PCA support the notion that continuous agricultural development in Punjab requires not only resources but also strengthening knowledge and social relations. Third component, institutional and market access, reflects increasing importance of the enabled environment. Access to formal loans, proximity to markets, and agricultural mechanization together determined this component. This conclusion, which is, matches research, which showed that institutional debt increases investment and productivity, especially among small farmers. Similarly, studies conducted on market access in India emphasize that the low distance of markets reduces the cost of transaction, improves price receipts, and encourages diversification in high-value crops. Mechanization, although traditionally connected to large farms, is now small farmers through custom hiring centers, which reflects Punjab's developed rural service economy. Collectively, these factors show how institutional and infrastructure relations are giving new looks to agricultural opportunities in the state.

The multifunctional nature of these findings indicates important policy implications. First, there are still resource-based inequalities in Punjab, where small farmers have to face structural obstacles in increasing production. Land consolidation or cooperative agricultural systems can be considered as policy options to improve viability. Second, human and social capital components indicate the need for continuous investment in rural education, vocational training, and expansion services. Strengthening the farmer productive organizations (FPO) can also expand social networks and improve the power of collective bargaining. Third, institutional and market access components highlight the need to expand loan access, improve the infrastructure of the rural market, and ensure that mechanization services are accessible to small and marginal farmers. Targeted intervention in these areas can significantly reduce inequalities and increase overall productivity. On comparing globally, these results are in line with studies conducted in other agricultural economies where the PCA has been implemented. Although the case of Punjab is different in the sense that while resources remain central, institutional and human capital factors are gaining prominence due to the advanced phase of agricultural development of the state. In short, this discussion emphasizes that the agricultural families of Punjab cannot be understood only through land and income indicators. Education, expansion, debt, and the role of the market are equally important in shaping livelihood results (Das et al., 2024).

CONCLUSION

In this study, major component analysis was used to examine socio-economic determinants of agricultural families in Punjab, India. Three major components came out of the results - agricultural

resources base, human and social capital, and institutional and market access - which collectively explain about 70 percent variation between families. Conclusions highlight that while traditional resources such as land and livestock are at the center of rural prosperity, education, expansion services, loans, and the role of market infrastructure are also equally important in shaping domestic results. Especially small farmers face structural deficiencies that require targeted intervention. Therefore, policy efforts should adopt multidimensional approaches, promote land-use efficiency, strengthen education and expansion networks, and improve institutional and infrastructure support. Focusing balanced focus on both tangible and abstract factors can help reduce inequalities in Punjab, increase productivity, and promote inclusive agricultural development.

DECLARATIONS

Ethics approval and informed consent: Informed consent was sought from the respondents for the study.

Competing Interest: The Authors have no competing interests.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The authors declare that during the preparation of this work, they thoroughly reviewed, revised, and edited the content as needed. The authors take full responsibility for the final content of this publication.

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