



RESEARCH ARTICLE

Economic vulnerability and farm-size inequality in the Cauvery Delta: A multidimensional quantitative assessment

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Abstract

The Cauvery Delta of Tamil Nadu is experiencing accelerating agrarian stress, characterised by rising input costs, groundwater dependence and deepening indebtedness among paddy cultivators. This study assesses economic vulnerability and farm-size inequality using a mixed-methods, explanatory sequential design in 3 delta districts (Thanjavur, Tiruvarur and Nagapattinam). A stratified multi-stage sample of 450 farmers (marginal n=178; small n=197; medium n=63; large n=12) was surveyed using a pre-tested structured questionnaire, corroborated with land passbooks, input bills and focus group discussions. Quantitative analyses comprised descriptive statistics, one-way analysis of variance (ANOVA) with Tukey's HSD, construction of a composite economic vulnerability index (CEVI) using min-max standardisation and estimation of a farm size economic stress model (FSESM) using multiple regression; qualitative data were thematically analysed to contextualise trends. Results reveal pronounced stratification: marginal farmers show the highest debt-asset ratio (3.47) and input cost intensity ($\approx 29\%$ higher per ha than large farms), with net returns per hectare (₹17644) markedly below medium (₹33304) and large (₹45830) categories (all group differences $p < 0.001$). The CEVI scores decline with farm size (marginal 0.78; small 0.62; medium 0.41; large 0.22), indicating severe vulnerability among the smallest holders. The FSESM explains 62 % of observed income variability ($R^2 = 0.62$); standardised β weights identify farm size ($\beta = 0.61$, $p < 0.001$), irrigation reliability ($\beta = 0.42$, $p < 0.01$), formal credit access ($\beta = 0.38$, $p < 0.01$) and mechanisation ($\beta = 0.29$, $p < 0.05$) as key determinants. Qualitative evidence underscores the role of informal credit dependence, tail-end irrigation delays and market access asymmetries in perpetuating risk. The findings indicate that structural factors-not farmer inefficiency-drive economic vulnerability and support a smallholder-first resilience agenda. Recommended measures include targeted low-interest/no-collateral credit, community machinery banks, strengthened tail-end irrigation governance and market and storage interventions (such as village procurement centres and stronger farmer producer organisations (FPOs)) to redress inequality and improve adaptive capacity in the Cauvery Delta.

Keywords: agricultural policy; Cauvery Delta; composite economic vulnerability index; debt asset ratio; farm-size inequality; resilience

Introduction

The Cauvery Delta, long recognised as the rice bowl of South India, is presently experiencing intensified agrarian stress arising from climatic variability, declining groundwater availability, escalating input costs and persistent market volatility (1, 2). While agriculture continues to underpin rural livelihoods across the deltaic landscape, growing economic insecurity has contributed to distress-driven outcomes including seasonal and permanent migration, land abandonment, forced asset liquidation and farmer suicides, reflecting a deeper structural fragility within the production system. Despite the implementation of multiple policy interventions aimed at stabilising farm incomes, smallholder cultivators remain disproportionately exposed to economic risk (3). Small and marginal

farmers account for nearly 83.4 % of the delta's cultivators, yet continue to face declining profitability, rising indebtedness and limited buffering capacity against shocks (4). These conditions underline the need for a systematic examination of how economic vulnerability is distributed across farm-size categories, particularly in a region where irrigation dependency and cost structures vary sharply by scale. Understanding these gradients of vulnerability is central to designing differentiated and context-sensitive policy responses rather than uniform interventions (5). To address this gap, the study employs a farm size economic stress model (FSESM) developed specifically for the Cauvery Delta context. The framework conceptualises economic performance as an outcome of interacting structural and institutional dimensions, including input cost burden, debt stress pressure, yield-income efficiency, market integration

and irrigation reliability (6). By integrating these dimensions, the model captures the ways in which farm size mediates access to resources, institutions and risk-management mechanisms, thereby shaping differential exposure to economic stress. Against this backdrop, the study seeks to compare key economic indicators across farm-size categories, examine debt-asset stress and cost return relationships and identify the principal determinants of economic vulnerability using the proposed modelling framework (7). Through this approach, the analysis aims to move beyond descriptive accounts of agrarian distress and provide an empirically grounded understanding of scale-linked economic vulnerability in the Cauvery Delta (8, 9).

Materials and Methods

The study was conducted in the Cauvery Delta districts of Thanjavur, Tiruvarur and Nagapattinam, selected for their shared deltaic agro ecology, dependence on canal irrigation and exposure to hydrological variability. These districts represent head, middle and tail end irrigation regimes, enabling analysis of economic vulnerability under differing water reliability conditions. A mixed method explanatory sequential design was adopted using a non-experimental observational approach (10). Primary data were collected from 450 paddy farmers through stratified random sampling across irrigation zones and farm size categories, comprising marginal ($n = 178$), small ($n = 197$), medium ($n = 63$) and large farmers ($n = 12$). The limited number of large farmers reflects the regional landholding structure and is interpreted cautiously for comparative analysis. Data were collected using a structured, pre-tested interview schedule and cross validated through farm records and focus group discussions. Quantitative analysis was carried out using SPSS, employing descriptive statistics, one-way analysis of variance (ANOVA) with Tukey's honestly significant difference (HSD) test and multiple regression (11). A composite economic vulnerability index (CEVI) was constructed by integrating input cost burden, debt asset ratio, net returns per hectare, market integration and irrigation reliability, using min max standardisation and equal weighting (12). Determinants of income variability were examined

through the FSESM, with qualitative analysis used to contextualise quantitative findings (13).

Results

The descriptive statistics summarising cost return structure and debt position across farm-size categories are presented in Table 1. Clear differences are observed across groups. Marginal farmers report the highest debt-asset ratio (3.47) and the lowest net returns per hectare (₹17644), while large farmers record the lowest debt pressure (1.76) and the highest net returns (₹45830). Input cost per hectare declines consistently with increasing farm size, indicating scale-related cost differentials. Mean income, debt levels and cost structures vary significantly across farm-size categories, with one-way ANOVA results indicating statistically significant differences among groups ($p < 0.001$).

Composite economic vulnerability index scores across farm-size categories are presented in Table 2. The CEVI values show a monotonic decline with increasing farm size, ranging from 0.78 for marginal farmers to 0.22 for large farmers. Small farmers record a CEVI score of 0.62, while medium farmers show a substantially lower value of 0.41. These scores classify marginal farmers under high vulnerability, small farmers under moderate to high vulnerability, medium farmers under moderate vulnerability and large farmers under low vulnerability.

Results of the FSESM are reported in Table 3. The regression model explains 62 % of the variation in income ($R^2 = 0.62$). Standardised coefficients indicate that farm size has the strongest association with income variability ($\beta = 0.61, p < 0.001$), followed by irrigation reliability ($\beta = 0.42, p < 0.01$), access to formal credit ($\beta = 0.38, p < 0.01$) and level of mechanisation ($\beta = 0.29, p < 0.05$). The interrelationships among income, debt, costs and returns are further depicted in Fig. 1, The construction and relative contribution of component indicators to the CEVI are illustrated in Fig. 2. While the structural pathways underlying income variability FSESM Model are presented in Fig. 3.

Table 1. Cost-return and debt structure across farm sizes

Farm size	Income (₹)	Debt (₹)	Debt asset ratio	Input Cost/ha	Net returns/ha
Marginal	56170	168749	3.47	42921	17644
Small	87227	241864	3.02	39313	24450
Medium	140631	396746	2.19	36953	33304
Large	305655	506259	1.76	33238	45830

Table 2. Composite economic vulnerability index (CEVI) across farm sizes

Farm size category	CEVI score	Vulnerability level	Interpretation
Marginal (<1 ha)	0.78	High	Severe structural vulnerability driven by high input cost burden, heavy reliance on informal credit, high debt-asset ratio and poor mechanisation access.
Small (1-2 ha)	0.62	Moderate-High	Persistently elevated vulnerability due to rental-dependent mechanisation, moderate credit constraints and sensitivity to price fluctuations.
Medium (2-4 ha)	0.41	Moderate	Improved resilience supported by partial mechanisation, better irrigation reliability and smoother access to institutional credit.
Large (>4 ha)	0.22	Low	Strong economic resilience with economies of scale, diversified income portfolios, superior market integration and lowest debt pressure.

Table 3. Standardised regression coefficients in the economic stress framework

Predictor	β Weight	Interpretation
Farm size	0.61***	Largest determinant
Irrigation reliability	0.42**	Borewell dependence increases variability
Access to formal credit	0.38**	Reduces debt stress
Mechanisation level	0.29*	Improves efficiency

Determinants of income variability ($R^2 = 0.62$).

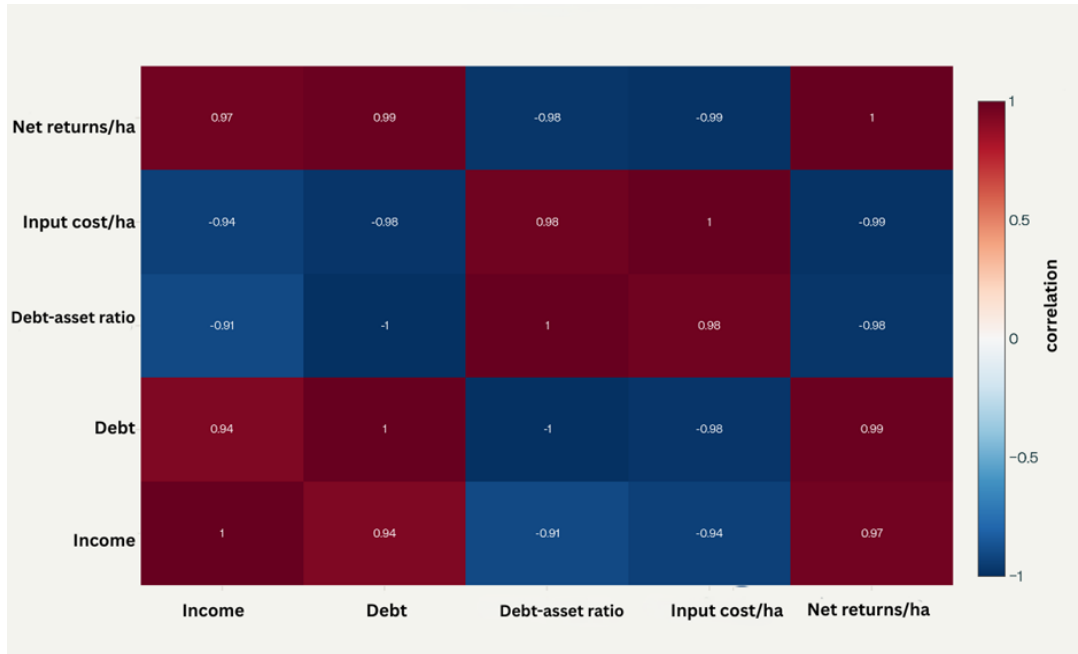


Fig. 1. Interrelationship of farm income, debt, costs and returns: A correlation heatmap.

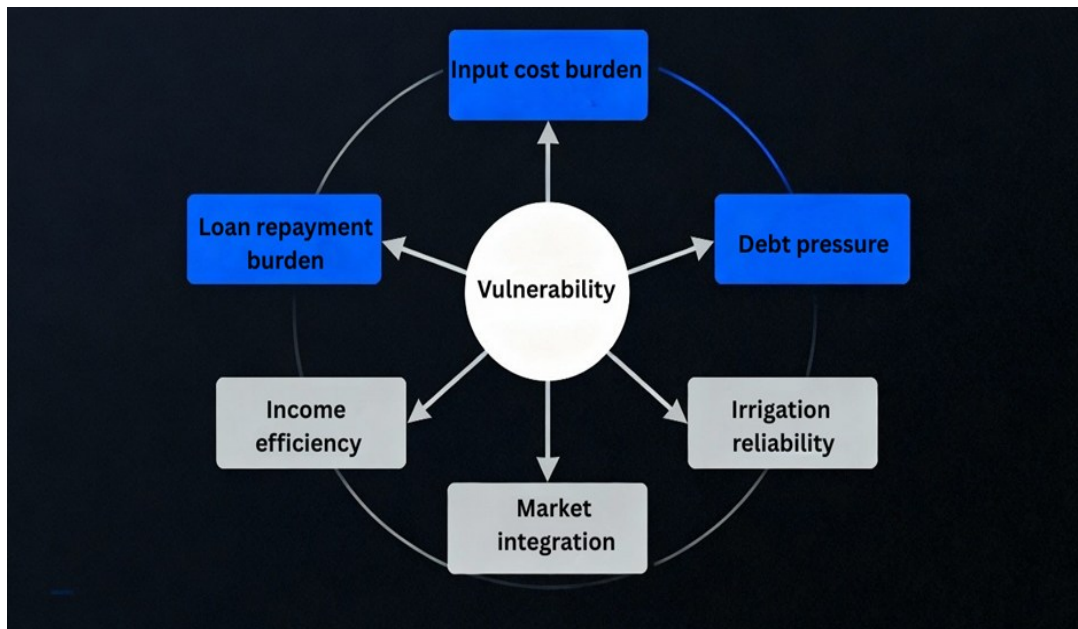


Fig. 2. Construction of the composite economic vulnerability index.

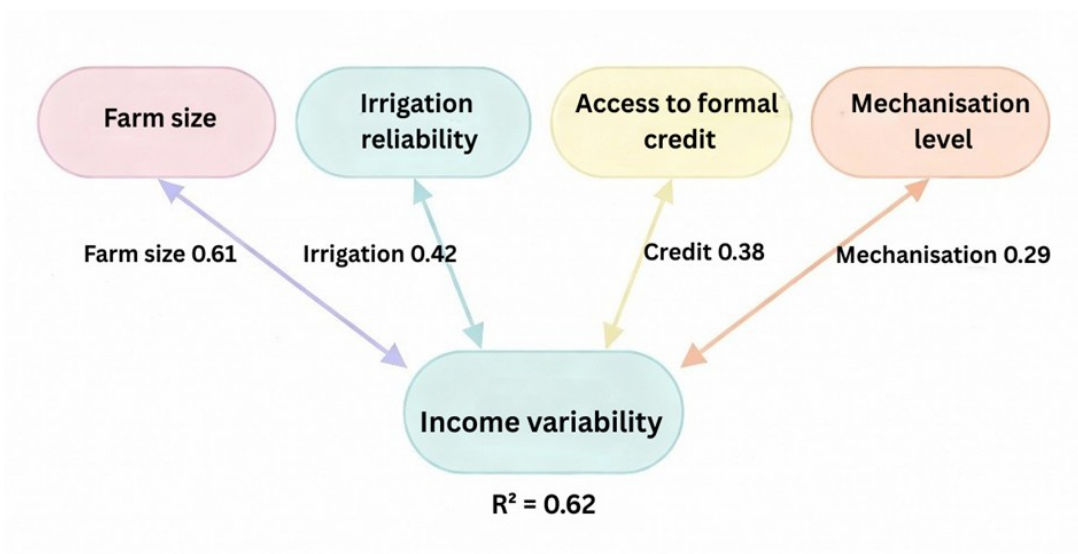


Fig. 3. Farm size economic stress model: Pathways influencing income variability.

Discussion

Structural inequality not farmer inefficiency drives vulnerability

The findings clearly indicate that the disproportionate vulnerability experienced by marginal farmers arises from structural inequalities rather than individual inefficiency (1, 2). Their per-unit cost of cultivation is consistently higher because they purchase inputs in small retail quantities often 12–18 % costlier than wholesale rates accessed by medium and large farmers. Limited landholding restricts mechanisation, forcing dependence on peak-season machinery rentals that cost 25–40 % more, further tightening operational constraints. Labour scarcity intensified by rural out-migration pushes hired labour costs upward, making marginal farmers the group with the highest labour cost per hectare. Weak bargaining power in both input and output markets prevents them from negotiating prices, delaying sales, or accessing better-quality inputs. Additionally, their financial vulnerability is amplified by overdependence on informal credit, where high interest rates create a cycle of repayment rather than reinvestment. These structural constraints, acting simultaneously across production, credit and marketing, trap marginal farmers in persistent vulnerability.

Debt stress as a binding constraint

A debt–asset ratio exceeding 3.0 is employed in this study as an indicator of severe debt stress, grounded in established agrarian economics literature and supported by empirical observations from the study area. Prior research has consistently treated ratios above unity as a sign of financial stress, with higher thresholds, particularly those exceeding three, indicating a deep debt trap in which outstanding liabilities far surpass productive asset value and recovery through regular farm income becomes unlikely. Evidence from agrarian distress regions such as Punjab and Vidarbha has used comparable benchmarks to characterise chronic indebtedness associated with distress borrowing, asset erosion and prolonged vulnerability. In the Cauvery Delta sample, farmers crossing this threshold were predominantly marginal and small holders and exhibited parallel symptoms of distress, including heavy reliance on informal credit, reduced capacity for productive reinvestment and heightened sensitivity to seasonal and market shocks (14, 15). The convergence of literature-based benchmarks and observed field patterns supports the use of the >3.0 threshold as a contextually meaningful measure of severe debt stress rather than an arbitrary cutoff.

Economies of scale and farm size thresholds in shaping economic resilience

Farm size exerts a decisive influence on economic performance through scale economies that become evident beyond a minimum operational threshold (16). In the present study, meaningful economies of scale are observed among holdings exceeding 4 hectares, where fixed costs associated with machinery, irrigation infrastructure and transaction expenses are spread over a larger cultivated area. Farmers in this category incur 8–15 % lower per unit input costs due to bulk procurement and reduced reliance on rental markets, while ownership of machinery enables timely field operations and lowers labour dependence. Scale advantages also extend to post harvest management, as access to on farm or rented storage allows larger farmers to avoid distress sales and realise 10–18 % higher prices per quintal relative to smallholders. These cost and price advantages facilitate more stable market engagement

through miller linkages, institutional procurement and contractual arrangements, reinforcing a cumulative cycle of efficiency, profitability and resilience. As a result, farms above this scale threshold increasingly resemble commercial production units rather than subsistence-oriented smallholder systems, consistent with broader evidence on the relationship between farm size and agrarian viability (17).

Debt and credit pathways: The structural credit trap

The debt composition of marginal farmers highlights a deeply skewed credit ecosystem. Nearly 39 % of their borrowing comes from input dealers, pushing them into tied-input arrangements that limit choice and inflate costs. Moneylenders account for 31 % of loans and typically charge the highest interest rates, creating long-term indebtedness. Only 18 % of loans originate from banks, reflecting primarily institutional access barriers including collateral requirements, documentation burdens and delayed disbursement, while farmer preference accounts for a smaller share and is largely conditioned by prior experiences with the formal credit system.

Microfinance institutions contribute 12 %, but weekly repayment schedules conflict with agricultural cash flow cycles. This debt architecture results in perpetual indebtedness → mental stress → reduced investment → low productivity, forming a feedback loop that continuously reinforces vulnerability (16).

Irrigation insecurity: The tail-end disadvantage

Tail-end farmers in the Cauvery Delta face a distinct and intensified form of vulnerability rooted in spatial irrigation inequity (17). They report 17–32 days of canal water delays, misaligning water availability with critical agricultural operations such as land preparation and transplanting. The absence of timely irrigation forces them to depend on borewells at ₹140–200/hr, increasing production costs and reducing net returns (18). Over-reliance on groundwater accelerates aquifer depletion, compounding future water insecurity. These delays are directly associated with Kuruvai season crop failure or low yields, making tail-end farmers significantly more vulnerable than farmers located in head or mid-canal zones (19, 20). Thus, irrigation reliability emerges as a key structural determinant of economic vulnerability.

Micro-level economic patterns across farm categories

Marginal farmers (<1 ha)

Marginal farmers operate in survival mode, with minimal financial buffers and high exposure to risks. Their inability to buy inputs in bulk increases input costs. Mechanisation is prohibitively expensive, leading to heavy reliance on hired labour and resulting in the highest per-hectare cultivation cost. Liquidity shortages were associated with sowing delays of 5–12 days, as reported by farmers during the primary paddy season (Samba), based on self-reported sowing dates cross-verified with field records and focus group discussions. The resulting yield losses of 8–15 % were estimated through farmer-reported yield comparisons between timely and delayed sowing plots within the same season, supported by recall of procurement receipts and extension estimates of yield penalties linked to delayed transplanting. These constraints create a persistent cycle of low productivity and high vulnerability (19).

Small farmers (1–2 ha)

Small farmers are better positioned but remain constrained by partial mechanisation, rental dependency and time-sensitive credit access. They often face machinery rental conflicts during peak

season, causing operational delays (20). Despite moderate access to bank credit, procedural delays reduce its effectiveness. They are also highly exposed to price fluctuations because over 70 % lack storage, forcing distress sales at low prices.

Medium farmers (2–4 ha)

Medium farmers benefit from relatively better access to formal and semi-formal credit, with banks and cooperative societies constituting the dominant sources, supplemented by limited borrowing from input dealers, enabling improved bargaining power, partial mechanisation and diversified production. They can withstand single-season losses without falling into a debt spiral (21). Their ability to negotiate prices and avoid retail-level input costs places them in an economically stable category consistent with global evidence on mid-sized farm competitiveness (22).

Large farmers (>4 ha)

Large farmers operate more like commercial enterprises. Their ownership of machinery, storage and transport reduces costs and enhances marketing leverage. With diversified crop portfolios, they reduce income volatility. Their ability to engage in direct procurement and institutional channels generally results in higher net returns and lower average input costs, economic resilience relative to smaller farm categories (23).

Macroeconomic-microeconomic linkages: The structural vulnerability funnel

Macro-level agricultural policies often inadvertently produce micro-level inequalities. Only 27–32 % of marginal farmers access minimum support price (MSP) procurement while 68–74 % of large farmers do so (12). Large farmers capture 40–55 % of input subsidy benefits, while small farmers receive limited quantities or delayed supplies (16). Market volatility is disproportionately harmful to smallholders because 78 % lack storage facilities, compelling immediate post-harvest sales at 6–12 % lower prices (24). These systemic asymmetries create a structural vulnerability funnel, where smaller farmers experience downward pressure at every stage-production, credit, irrigation and marketing (16).

Policy-level implications

Transformative interventions are required to address entrenched agrarian inequality, but their effectiveness depends on careful institutional design and implementation. Strengthening smallholder-centric credit frameworks, including no-collateral kisan credit card (KCC) schemes, low-interest loans and borewell maintenance credit, can substantially reduce reliance on informal lenders, as evidence from credit guarantee systems in Kenya and Vietnam demonstrates significant gains in formal credit access (25). Similarly, community machinery banks may reduce operational delays observed among marginal farmers, though their success hinges on collective management capacity and maintenance arrangements (26). Measures aimed at tail-end irrigation justice, such as water rotation schedules, micro-irrigation subsidies and farmer-led monitoring, can improve water-use efficiency and reduce spatial inequities, but require coordination across agencies and user groups (18). Market stabilisation through village procurement centres, strengthened Farmer Producer Organisations and storage support can mitigate distress sales and income volatility among smallholders, provided governance and market linkages are sustained. Together, these interventions outline a coherent pathway for enhancing economic

resilience and equity in the Cauvery Delta, while underscoring the need to align policy ambition with institutional feasibility (26).

Conclusion

This study shows that economic vulnerability in the Cauvery Delta is systematically structured by farm size, with marginal and small farmers facing significantly higher debt stress, cost burdens and income instability than larger holdings. The results confirm that vulnerability is driven less by farmer behaviour than by unequal access to irrigation reliability, formal credit, mechanisation and markets. The CEVI demonstrates a clear decline in vulnerability with increasing farm size, while the FSES identifies irrigation reliability, access to formal credit and mechanisation as the dominant determinants of income variability. The principal contribution of the study lies in empirically linking multidimensional vulnerability to scale-mediated institutional access within a canal-dependent delta system. From a policy perspective, the findings support a differentiated, smallholder-first strategy centred on assured water access, affordable formal credit, shared mechanisation and strengthened market institutions rather than uniform interventions. Future research should adopt longitudinal designs to examine dynamic vulnerability trajectories, integrate climate shock exposure and assess the effectiveness of irrigation governance and farmer collectives in reducing structural agrarian inequality.

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Authors' contributions

SA conducted the literature review and prepared the initial manuscript draft, while RV provided overall guidance for corrections and improvements. PB, MND, MA and KP assisted with literature collection and formatting. All authors contributed equally to manuscript revision. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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