

Role of Agricultural Extension Services in Enhancing Farmers' Economic Resilience to Climate Shocks: Evidence from North Karnataka

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ABSTRACT

Agricultural productivity, farm income and livelihood security, especially for smallholders in vulnerable areas, is severely challenged by climate change-induced shocks like recurrent droughts, delayed onset of monsoon, prolonged dry spells, extreme weather events, etc. The role of agricultural extension services in enhancing farmers' access to climate information, farmer adaptive practices and building farmer resilience is important, but there is limited quantitative evidence on the role of agricultural extension services in contributing to economic resilience of farmers. The study was conducted in the present state to find out the effect of extension contact on the resilience of farmers towards climate shocks and to understand the factors influencing the economic resilience of farmers in North Karnataka. The primary data were collected from 300 farmers by structured interview schedule and farmers were divided into three groups of low, medium and high extension contact using Extension Contact Index. The data were analyzed using descriptive statistics, ANOVA and multiple regression analysis. The findings showed that farmers with high extension contact rate scored more on number of climate resilient practices (4.52 practices/farmer) than medium (3.01 practices/farmer) and low extension contact (1.59 practices/farmer) farmers. Average annual crops income (₹ 2.86 lakh/farm), Gross return (₹ 112,670/ha), Net return (₹ 62,930/ha) and Benefit-Cost ratio (2.27) of the high extension contact farmers were higher than those of the low extension contact farmers (₹ 1.52 lakh/farm, ₹ 72,460/ha, ₹ 25,640/ha and 1.55, respectively). High-extension-contact farmers (18.9%) were less affected on income reduction during the years of climate shock than low-contact farmers (38.6%) and had a significantly higher economic resilience index (76.4) than the low-contact farmers (39.8). Extension contact, climate-resilient practice adoption, crop diversification, access to irrigation, participation in training, and crop insurance significantly improved economic resilience, while climate-shock severity affected resilience negatively, with regression analysis confirming that these factors significantly influenced economic resilience. In climate vulnerable areas, enhancing agricultural extension systems with climate advisories, training farmers, providing institutional support and creating location-specific adaptation strategies will significantly augment the capability of farmers to respond to climate shocks and maintain agricultural livelihoods.

Keywords: Agricultural extension, climate shocks, economic resilience, climate-smart agriculture, adaptation

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Climate change is one of the major challenges in the agricultural sector that threatens the sustainability of agricultural operations and food security, and the livelihoods of rural communities (Santosh *et al.* 2024). The rise in temperature, alteration in precipitation, extended dry spells and flooding, and extreme climate events are negatively impacting agricultural production systems, especially in the developing world where millions of smallholder farmers rely directly on climate-sensitive agriculture. According to the Intergovernmental Panel on Climate Change (IPCC), climate change has already affected terrestrial ecosystems and agricultural systems, with vulnerable farming communities facing higher risks of climate change's impact on their livelihoods (Pörtner *et al.* 2022; Ray *et al.* 2025; Sairam *et al.* 2025a). Climate shocks also have been shown to be driving losses in agriculture and undermining the resilience of agrifood systems; the need to build the resilience of production systems through adaptation, innovation and institutional support is an emerging priority (Maitra *et al.* 2025, 2025; Rishitha *et al.* 2025; Mukesh *et al.* 2024).

Smallholder farmers are highly susceptible to climate shocks due to their small-scale agricultural practices, limited irrigation facilities, financial resources, access to climate information, improved technologies and institutional services. Climate variability impacts farm profitability, household income security, and long-term livelihood security, in addition to impacting crop productivity. Recent research has shown that climate change has worsened production risks faced by smallholders by making their production more volatile, driving up production costs, and making production decisions at the farm level more unpredictable (Maitra *et al.* 2024; Sairam *et al.* 2025b). The development of resilience among the farming communities thus needs to be multidimensional with a combination of technological interventions, better use and control of agricultural resources, risk mitigation measures and good agricultural knowledge systems.

Increasing farmers' adaptive capacity is a key role for agricultural extension services, as they provide access to scientific knowledge, climate information services, better farming technologies and institutional support. The missions of extension have evolved from the dissemination of traditional technologies

to supporting innovation systems, risk management, and adaptation to climate change among farming communities (Mohanty *et al.* 2016; Nanda *et al.* 2010). There is recent evidence that shows extension services, agricultural training, farmer organizations, availability of information and institutional support are some of the most consistent factors that affect farmers' adoption of climate-smart agricultural practices (Finizola de Silva *et al.* 2024; Gemtou *et al.* 2024; Priya *et al.* 2025). A recent review by Zheng *et al.* (2024) found that climate-smart agricultural practices enhance farm productivity, income, resilience, and environmental sustainability with the help of suitable institutional arrangements.

Climate-smart agriculture (CSA) is now an important approach to decreasing climate vulnerability, among which drought-tolerant varieties and crop diversification, soil and water conservation, micro-irrigation, improved nutrient management, and climate-based decision making are notable. In practice, however, these practices are driven by a number of factors, but these are linked to socio-economic, institutional and behavioural factors. Sunshine *et al.* (2020) and Pedersen *et al.* (2024) all concluded that in recent years, education, farm size, access to credit, extension contact, farmer organizations, climate information and training have all been found to have a significant impact on farmers' willingness and ability to adopt climate-resilient practices. In recent systematic reviews, Amare and Simane *et al.* (2017) and Finizola *et al.* (2024) both concluded that in recent years, education, farm size, access to credit, extension contact, farmer organizations, climate information and training have all been found to have a significant impact on the farmers' willingness and ability to adopt climate-resilient practices. Furthermore, extension-based approaches like farmer field schools, demonstrations, and training have been observed to enhance farmers' knowledge and adoption practices, but their impact is contingent upon continued institutional involvement and their site-specific relevance (Saran *et al.* 2024; Ray *et al.* 2025; Maitra *et al.* 2026c).

India is particularly at risk of climate change as it is highly reliant on the monsoons for agriculture and a significant number of its citizens are engaged in farming and dependent on its livelihood security. Semi-arid regions of India, especially in the North

Karnataka region are witnessing frequent droughts, delayed onset of monsoon, extended dry spells and escalation of temperature extremes. These climatic stresses have adverse impacts on crop production, farm income and economic viability of farm households. Institutional support and extension interventions are critical to build farmers' resilience, especially in North Karnataka where farming is often rainfed and farmers' adaptive capacity is low. There has been a growing focus on enhancing agricultural extension systems, climate information service delivery, and capacity-building initiatives for farmers to boost climate adaptation results in Indian agriculture in recent studies (Maitra *et al.* 2001; Paramasivam *et al.* 2024).

Despite a number of studies that have focused on the adoption of climate-smart agriculture, limited research has focused on quantifying the role of an extension contact on economic resilience of farmers. There is a lack of research on the impact of extension services on income stability and resilience in the aftermath of climate shocks, as well as profitability and productivity impacts, compared to awareness and adoption. In arid climate zones, where farmers face multiple climatic uncertainties and must also be knowledgeable about techniques, it is especially crucial to be knowledgeable about this relationship and understand how climatic conditions and strategies impact their ability to integrate farming with climate risks.

Hence, the present study was conducted in the North Karnataka to evaluate the contribution of extension contact towards strengthening the climate change shock resistance of farmers. The study specifically explores the link between Extension contact, adoption of climate-smart practices, farm economic outcomes and economic resilience. The results will be used to generate empirical evidence to improve agricultural extension approaches, and to develop policy responses for resilient farming systems in vulnerable communities.

MATERIALS AND METHODS

Study Area and Sampling Design

The study was carried out in North Karnataka region of Karnataka State, India, which is mainly dominated by semi-arid climate, irregular rainfall, frequent

drought and high climate variability. Climatic stresses like delayed onset of monsoons, long spells of dry weather, heat waves, and unseasonal rainfall events are common for farmers here; and monsoon-related rainfall is critical for the agriculture sector. The impact of these climatic uncertainties is a major factor affecting crop productivity, farm income and livelihood security. The study area was chosen based on the vulnerability to climate shocks and the significance of agricultural extension services in supporting adaptation measures by smallholder farmers.

A two-stage sampling method was used to get the respondents. In the first stage, six districts of North Karnataka namely Vijayapura, Bagalkot, Dharwad, Gadag, Koppal and Belagavi with the majority of rain-fed agriculture and climatic vulnerability were purposely selected. In the second stage, villages were chosen according to the availability of agricultural extension services and farming activities. Finally, 300 farm households were sample using proportionate random sampling technique. The primary data was collected by the use of structured and pre-tested interview schedule during the agricultural year 2025-2026. The information gathered encompassed socio-economic characteristics, farm resources, extension contact, exposure to climate shocks, extension exposure to climate-smart agricultural practices, institutional support, economic considerations of crop production and resilience indicators at the household level.

Measurement of Extension Contact

Extension contact was considered as the extent of interaction between farmers and agricultural knowledge-providing institutions. The frequency and intensity of the farmers' interactions with extension agencies were assessed based on the interaction with the agricultural extension officers, Krishi Vigyan Kendras, Department of Agriculture officials, farmer training programmes, field demonstrations, exposure visits, farmer organisations, and digital agricultural advisory services. The score for each extension activity was determined by the number of times that the activity occurs and the total score was normalized to create an Extension Contact Index (ECI). The cumulative square root frequency method was used to categorize farmers by extension contact level

according to their index values. This classification allowed the socio-economic characteristics and adaptation behavior to be compared with economic resilience of farmers exposed to different levels of extension.

Assessment of Climate Shocks and Climate-Resilient Practices

The assessment of climate shocks and climate-resilient practices is critical. Climate shocks exposure was measured from the last 5 years of farmers' experiences. Recurrent drought, delayed onset of monsoon, prolonged dry spells, heat-wave conditions, and unseasonal rainfall data was gathered from farmer interviews. A climate-shock severity index was created based on the number and perceived intensity of climatic events and their occurrence. Farmers' adoption of drought-resistant practices was assessed through the use of drought-tolerant varieties, diversification of crops, farm ponds, rainwater harvesting, micro-irrigation systems, soil-moisture conservation practices, weather-based crop planning and crop insurance. The number of farmers who adopted adaptation practices was used to calculate Climate Resilient Practice Adoption Index.

Measurement of Economic Resilience

Economic resilience is the capacity of farm households to resist, sustain and recover economically from climatic shocks and events. For this study, farm economic resilience was measured through a composite index based on farm income stability, profit, diversification, savings patterns, insurance and recovery capacity. Indicators used were: annual agricultural income, percent decrease in income during climate-shock years, gross returns, net returns, benefit-cost ratio, crop-income diversification, emergency savings, crop insurance coverage, and capacity to recover within one cropping season after a climate shock.

Normalisation of all indicators was done with the min-max normalization method to remove the differences in the measurement units. Normalized indicators were combined to create an Economic Resilience Index (ERI) with a scale of 0–100, with a higher score indicating more economic resilience.

Many existing methods for measuring farmers' adaptive capacity and livelihood stability in climate resilience assessments have been developed that also consider the multidimensional aspects of farmers' adaptive capacity (FAO, 2023).

Economic Analysis

Farmers' economic performance was judged with normal farm management procedures. The gross returns were computed at prevailing market prices and net returns were defined as the difference between gross returns and the total cost of cultivation. The ratio of gross returns to the total cost of cultivation was used as a benefit-cost ratio. The impact of climate shock years on farm income was estimated by comparing "production years" with "climatic stress years" in terms of farm income. The assessment of the contribution of extension contact and adaptation practices toward improving farm-level resilience was done using these economic indicators.

Statistical Analysis

Analytical techniques employed in the analysis of the collected data included descriptive and econometric. Farmers' socio-economic attributes, climate exposure, adoption attributes, and economic indicators were described using frequency, percentage, mean, and standard deviation. For the categorical data, chi-square analysis was used, and analysis of variance (ANOVA) was used to test for any significant differences between the various groups of farmers under each extension-contact category. A multiple linear regression model was estimated to determine the factors affecting the economic resilience of farmers. Extension contact, educational level, number of hectares used, irrigation, diversification, use of climate-resilient practices, crop insurance, training participation, and climate-shock severity were considered explanatory variables, whereas the Economic Resilience Index was considered as the dependent variable. The empirical model was given as:

$$ERI_i = \beta_0 + \beta_1 ECI_i + \beta_2 EDU_i + \beta_3 LAND_i + \beta_4 IRR_i + \beta_5 CDI_i + \beta_6 CRA_i + \beta_7 INS_i + \beta_8 TRAIN_i + \beta_9 CSI_i + \epsilon_i$$

Where ERI is the Economic Resilience Index, ECI is the Extension Contact Index, EDU is education level,

LAND is operational landholding, *IRR* is access to irrigation water, *CDI* is crop diversification index, *CRA* is adoption of climate-resilient agricultural practices, *INS* is crop insurance status, *TRAIN* is participation in agricultural training programmes, and ε is the error term. Coefficient significance, coefficient of determination (R^2), adjusted R^2 and F-statistics were used to assess the regression model. To check the reliability of regression estimates, multicollinearity among the explanatory variables was checked by examining the variance inflation factor (VIF) values.

Ethical Considerations

Before the study was conducted, it was explained to all respondents, and participation was voluntary. The information gathered from the farmers was only used for academic research and confidentiality of their response was kept throughout the study.

RESULTS AND DISCUSSION

The socio-economic and farm characteristics of the respondents across different categories of extension contact are presented in Table 1. There was a significant difference between the low-extension-contact group, medium-extension-contact group and high-extension-contact group for most of the variables. The farmers with high extension contact were younger in age (43.9 years), higher in education (9.4 years), bigger in land holding (3.31 ha), and higher in annual farm income (₹ 3.37 lakh) than the

farmers with low extension contact whose mean age was 49.6 years, education was 5.8 years, land holding was 2.18 ha and annual farm income was ₹ 1.84 lakh. High-extension-contact farmers also had better access to farmer organizations (62.2%), agricultural training programmes (80.5%), irrigation facilities (63.4%), and smartphones (91.5%) and crop insurance (62.2%). By contrast, farmers who have high extension contact have much less farming experience (19.6 years) than farmers who have low extension contact (24.7 years). These differences were found to be statistically significant for age; years of education; farming experience; farm size; farm income; possession of a smartphone; access to irrigation; membership in an organization; participation in training; and crop insurance coverage. The observed relationship between socio-economic characteristics and extension use is in line with the findings of previous studies that education, farm resources, income, and communication technologies affect farmers' extension-service demands and intensity of use (Kaine and Ogbonna *et al.* 2025). Overall, the findings suggest that increased extension contact was correlated with greater socio-economic resources and participation in institutions and access to agricultural support services.

Farmers who had more extension contact had higher educational attainment, farm income, land holdings, and were more likely to own a smartphone and participate in institutions, which may affect access to and use of agricultural extension services.

Table 1: Socio-economic and farm characteristics of sampled farmers according to extension-contact level

Variable	Low extension contact (<i>n</i> = 92)	Medium extension contact (<i>n</i> = 126)	High extension contact (<i>n</i> = 82)	Overall (<i>N</i> = 300)	<i>F</i> / χ^2 value
Age (years)	49.6 ± 10.8	46.8 ± 10.2	43.9 ± 9.6	47.0 ± 10.4	8.42**
Formal education (years)	5.8 ± 3.9	7.6 ± 4.2	9.4 ± 4.5	7.5 ± 4.4	19.63***
Farming experience (years)	24.7 ± 11.4	22.1 ± 10.8	19.6 ± 9.7	22.2 ± 10.8	6.51**
Operational landholding (ha)	2.18 ± 1.46	2.74 ± 1.71	3.31 ± 2.04	2.68 ± 1.75	10.74***
Annual farm income (₹ lakh)	1.84 ± 0.82	2.48 ± 1.09	3.37 ± 1.42	2.48 ± 1.24	42.18***
Smartphone ownership (%)	54.3	77.0	91.5	73.0	34.62***
Access to irrigation (%)	31.5	46.8	63.4	45.7	24.18***
Membership in farmer organization (%)	18.5	39.7	62.2	38.7	38.95***
Participation in agricultural training (%)	14.1	48.4	80.5	45.7	96.72***
Crop insurance coverage (%)	27.2	43.7	62.2	43.3	27.84***

Note: Values are mean ± standard deviation or percentage. ** $p < 0.01$; *** $p < 0.001$.

Education can increase farmers' capacity to acquire, interpret, evaluate and apply technical information, and better income and larger farm size may result in a wider capacity to invest in better technologies and to meet extension personnel regularly. It is also similar to the findings of Gbigbi (2019) who found that farmers' socio-economic factors had significant impact on their demand for agricultural extension services and the intensity of their usage of such services. Likewise, the significantly higher share of smartphone ownership among the high-extension-contact group suggests that digital connectivity can support traditional extension services by making farmers more accessible to up-to-date information and extension assistance on farming. Unfortunately, there is also recent evidence from India that mobile extension on agriculture could enhance the agri-knowledge facilities of the farmers and enable better farm decision making (Singh *et al.* 2026). Increased involvement of high contact farmers in training programmes and farmer organisations also suggests higher levels of engagement with extension in institutional and social learning networks. Agricultural extension has come to be seen as a multidimensional process that not only is a vehicle for technology transfer but also contributes

to building farmers' knowledge, adaptive capacity, decision-making and resilience (Sarkar *et al.* 2000; Moyo and Pisa, 2026). Institutional and informational support is likely to be critical in drought prone areas like North Karnataka, where farmers may need to know when, and have the ability to adapt to, climate related risks. The relationships shown in Table 1 are not causal relationships however, because the relatively better educated, resource rich and institutionally well-connected farmers are more likely to receive extension services. Accordingly, socio-economic factors should be adjusted for in a subsequent economic analysis or other techniques like propensity score matching or endogenous treatment-effect models should be used to assess the impact of extension contact on farmers' climate resilience while isolating the effects of the intervention.

Table 2 shows farmers' exposure to the most important climate shocks and how they adopted climate-resilient agricultural practices at varying levels of extension contact. Recurrent drought, delayed onset of monsoons, extended dry spells, heat-wave, and unseasonal rainfall incidences were generally similar and not statistically different for low-, medium-, and high-extension-contact groups. Large and significant

Table 2: Exposure to climate shocks and adoption of climate-resilient farm practices

Climate shock/practice	Low extension contact (n = 92)	Medium extension contact (n = 126)	High extension contact (n = 82)	Overall (N = 300)	χ^2/F value
Climate shocks experienced during the previous five years (%)					
Recurrent drought	78.3	74.6	70.7	74.7	1.46NS
Delayed onset of monsoon	69.6	67.5	65.9	67.7	0.34NS
Prolonged dry spells	71.7	69.8	68.3	70.0	0.31NS
Heat-wave conditions	48.9	52.4	54.9	51.7	0.78NS
Unseasonal rainfall	42.4	46.8	48.8	46.0	0.89NS
Climate-resilient practices adopted (%)					
Drought-tolerant crop varieties	29.3	50.8	73.2	49.3	41.26***
Crop diversification	23.9	44.4	65.9	43.7	37.84***
Farm pond/rainwater harvesting	13.0	28.6	51.2	29.3	39.17***
Micro-irrigation	10.9	27.8	47.6	26.7	37.59***
Soil-moisture conservation	35.9	60.3	79.3	58.3	39.68***
Weather-based crop planning	18.5	45.2	72.0	44.3	58.34***
Crop insurance	27.2	43.7	62.2	43.3	27.84***
Mean number of practices adopted	1.59 ± 1.14	3.01 ± 1.36	4.52 ± 1.41	3.02 ± 1.61	112.46***

Note: NS = non-significant. *** $p < 0.001$.

differences, however, were seen in the uptake of climate resilient practices. The farmers with high extension contact showed higher adoption than those with low extension contact for drought-tolerant varieties (73.2%), crop diversification (65.9%), farm ponds or rainwater-harvesting structures (51.2%), micro-irrigation (47.6%), soil-moisture-conservation practices (79.3%), weather-based crop planning (72.0%), and crop insurance (62.2%). There was a significant difference between the mean number of climate resilient practices taken by the low contact farmers (1.59), medium contact farmers (3.01), and high contact farmers (4.52). The results suggest that although climate-related risks faced by farmers were more or less comparable, the more farmers interacted with extension systems the more they adopted climate-resilient technology. Adoption of climate-smart agricultural practices was positively associated with access to extension service, agricultural training, farmer organizations, and climate information, as evidenced in recent studies (Zheng *et al.* 2024; Tembo *et al.* 2025).

The significant extension of the use of climate resistant practices among farmers showing more contact with extension services indicates that extension services could help build the farmers' capacity to understand climate risk and to apply relevant information to their farms to take adaptation actions. Extension contact can increase awareness of appropriate technologies, offer technical information, help access to improved seeds, irrigation technologies, information on weather, and access to government support programmes, while reducing uncertainty over the benefits of adaptation measures. The higher adoption of drought resistant varieties, soil moisture conservation, weather-based crop planning, and crop diversification among high contact farmers is significant in the context of the North Karnataka region, which experiences frequent droughts, delayed rains, and extended dry spells that can significantly impact the productivity of crops and farm livelihoods. New research has revealed the importance of access to extension services for uptake of climate-resilient practices, and that uptake of such practices can enhance farmers' adaptive capacity and crop productivity (Maitra, 2020). Extension also seems to be a link between the climate information and the decision-making of farmers, with better results if it is supported by training, institutional

support, and financial and technological assistance. That does not mean, however, that education alone will be enough to overcome investment constraints, as capital-intensive farming methods like farm ponds and micro-irrigation are not being adopted by all high contact farmers (Zaman *et al.* 2017; Santosh and Maitra, 2022). Financial, technological and institutional constraints are also emerged as significant constraints for broader adoption of climate smart agriculture (CSA) in recent studies from India (Rezaei-Chiyaneh *et al.* 2023). Therefore, extension program in North Karnataka needs to combine advisories with demonstration, credit support, subsidies and adaptation packages that are suitable for the region to enhance uptake and durable utilization of climate-resilient practices.

Table 3 shows the economic resilience indicators of farmers based on their contact with the extension service. Most economic performance and resilience indicators showed significant differences among low, medium and high extension-contact groups. The significant differences emerged in various aspects of farming between farmers with high and low extension contact, with the former showing higher annual crop income (₹ 2.86 lakh/farm), gross returns (₹ 112,670/ha), net returns (₹ 62,930/ha), and benefit-cost ratio (2.27) than the latter (₹ 1.52 lakh/farm, ₹ 72,460/ha, ₹ 25,640/ha and 1.55, respectively). High extension contact farmers experienced a substantially lower reduction in farm income during climate-shock years (18.9%) than low extension contact farmers (38.6%) suggesting greater coping ability for production and economic losses due to climate. Likewise, high contact farmers had higher levels of crop-income diversification (0.57), emergency savings behaviour (62.2%) and ability to recover from climate shocks within one cropping season (73.2%). There was a very high increase in the overall economic resilience index from 39.8 (low extension contact) to 76.4 (high extension contact) farmers. From these results, it is concluded that farmers with higher extension engagement are more profitable, have greater income stability, income diversification, and recovery capacity. Evidence also indicates that agricultural extension services can improve farmers' access to better technologies, management practices, and institutional resources, leading to better agricultural productivity, income

Table 3: Farm-level economic resilience indicators according to extension-contact level

Economic resilience indicator	Low extension contact (<i>n</i> = 92)	Medium extension contact (<i>n</i> = 126)	High extension contact (<i>n</i> = 82)	Overall (<i>N</i> = 300)	F-value
Annual crop income (₹ lakh/farm)	1.52 ± 0.73	2.09 ± 0.91	2.86 ± 1.18	2.07 ± 1.05	39.82***
Income reduction during climate-shock year (%)	38.6 ± 13.2	27.4 ± 11.5	18.9 ± 9.8	28.0 ± 13.6	58.74***
Crop production cost (₹/ha)	46,820 ± 10,450	48,360 ± 11,210	49,740 ± 12,080	48,210 ± 11,210	2.04NS
Gross return (₹/ha)	72,460 ± 18,620	91,840 ± 22,740	112,670 ± 27,380	91,020 ± 26,210	64.91***
Net return (₹/ha)	25,640 ± 11,980	43,480 ± 15,760	62,930 ± 20,440	43,810 ± 21,620	104.36***
Benefit–cost ratio	1.55 ± 0.27	1.90 ± 0.34	2.27 ± 0.41	1.89 ± 0.45	96.28***
Crop-income diversification index	0.28 ± 0.12	0.42 ± 0.15	0.57 ± 0.16	0.42 ± 0.18	89.74***
Households maintaining emergency savings (%)	19.6	38.1	62.2	38.7	39.41***
Households recovering within one cropping season (%)	23.9	49.2	73.2	49.0	51.63***
Economic resilience index (0–100)	39.8 ± 10.7	58.6 ± 11.8	76.4 ± 10.2	58.4 ± 17.1	136.82***

Note: NS = non-significant. ****p* < 0.001.

generation, and climate-resilient agriculture (Abdullah *et al.* 2024; Khan *et al.* 2024).

Farmers with higher extension contact are more economically resilient, underscoring the significance of extension systems in enhancing farmers' adaptive capacity and economic stability in the face of climate change. Extension services can help increase resilience by providing access to climate information, by helping to improve production practices, by building technical capacity, and by connecting farmers to institutional services including input services, credit, and insurance. The superior gross returns, net returns and benefit–cost ratio for high extension contact farmers indicate that extension not only facilitates the acquisition of knowledge, but also has a positive impact on the economic efficiency of farm decision making. Previous research has shown that extension programmes boost the adoption of better technologies and management practices, leading to increased farm productivity and profitability (Musa and Ariff Lim, 2025). This could be due to the fact that high-contact farmers have been more successful in diversifying their livelihoods, implementing climate-smart practices, using irrigation, and diversifying risk-management

options, which may explain why they experience a lower income reduction during the periods of climate shock. It is reported that climate-smart agriculture enhances the resilience of smallholder farmers by decreasing production risk, stabilizing yield and increasing livelihood security (Obaisi *et al.* 2022). In addition, more farmers who have had closer contact with extension services have more recovery capacity and savings behavior suggesting that extension services not only can enhance production resilience but also the economic preparedness of the household. The participation of institutions and access to advisory services are found to play a vital role in helping farmers deal with climate variability and speed up their recovery from a climatic shock (Landmann *et al.* 2021). The relationship between extension contact and economic resilience could also be influenced by variations in the resources farmers have available, their education, and access to institutions that enable them to interact with extension agencies; better-off farmers may have more resources to interact with extension agencies. This means future studies must consider selection bias in econometric analyses to estimate the independent effect of extension on the economic resilience of

farmers, such as by propensity score matching or treatment effect analysis.

The multiple regression results are presented in Table 4, which shows the factors influencing farmers' economic resilience as the dependent variable (Economic Resilience Index 0-100). The regression model was statistically significant ($F = 68.47$; $p < 0.001$) and accounted for 68.4% of the variance in farmers' economic resilience ($R^2 = 0.684$), indicating that the socio-economic, institutional and adaptation-related variables explained differences in the farmers' economic resilience. When considering economic resilience, extension-contact index had a positive and highly significant impact ($\beta = 0.341$; $p < 0.001$), meaning that a high level of contact with extension agencies correlated with high scores of economic resilience. Among other factors, education level ($\beta = 0.143$; $p = 0.002$), operational landholding ($\beta = 0.151$; $p = 0.002$), irrigation access ($\beta = 0.168$; $p < 0.001$), crop diversification index ($\beta = 0.227$; $p < 0.001$), adoption of climate-resilient practices ($\beta = 0.219$; $p < 0.001$), crop insurance coverage ($\beta = 0.116$; $p = 0.011$), and participation in agricultural training programmes ($\beta = 0.098$; $p = 0.027$) had significant positive effects on economic resilience. However, climate-shock severity index was significantly negatively related to resilience ($\beta = -0.268$; $p < 0.001$), suggesting that the more exposed farmers were to climatic stress the less resilient they were to shocks and income instability. The findings show that

extension contact, in addition to adaptive practices and institutional support mechanisms, is a key factor in improving farmers economic resilience in climate variability conditions. The same effects of the climate-smart practices, through institutional measures and advisory services, have been found to enhance the stability and resilience of farm incomes in India's drought-prone areas (Samuel *et al.* 2024; Kapoor and Pal, 2024; Krishna *et al.* 2024).

This positive and significant extension coefficient implies that agricultural extension services are an important institutional tool to enhance farmers' climate change resiliency. Extension agents ensure that the farmers have access to climate information, better technologies, training, demonstrations and risk management strategies, thereby helping them to make timely decisions and apply appropriate adaptation strategies. The discovery aligns with the increasing evidence suggesting that successful extension systems empower farmers to adapt by facilitating knowledge sharing, technology uptake, and connections with extension institutions (Rajesh *et al.* 2024). Climate-resilient practices and crop diversification have been found to play a significant role in contributing to economic resilience showing that these practices help to decrease vulnerability by spreading production risks, stabilize production yields, and diversify income. The findings from the semi-arid parts of Karnataka showed that more intensive adoption of climate smart agriculture

Table 4: Determinants of farmers' economic resilience: Multiple regression results

Explanatory variable	Unstandardized coefficient (B)	Standard error	Standardized coefficient (β)	t-value	p-value
Constant	18.462	4.381	—	4.21	<0.001
Extension-contact index	0.428	0.061	0.341	7.02	<0.001
Education (years)	0.614	0.192	0.143	3.20	0.002
Operational landholding (ha)	1.276	0.398	0.151	3.21	0.002
Access to irrigation (1 = yes)	4.817	1.362	0.168	3.54	<0.001
Crop diversification index	9.643	2.104	0.227	4.58	<0.001
Climate-resilient practices adopted (number)	2.136	0.482	0.219	4.43	<0.001
Crop insurance coverage (1 = yes)	3.286	1.281	0.116	2.57	0.011
Annual agricultural training participation (1 = yes)	2.714	1.224	0.098	2.22	0.027
Climate-shock severity index	-5.438	0.941	-0.268	-5.78	<0.001

Model statistics: $R^2 = 0.684$; Adjusted $R^2 = 0.674$; $F = 68.47$; $p < 0.001$; $N = 300$.

Note: A positive coefficient indicates an improvement in economic resilience, whereas a negative coefficient indicates reduced resilience.

practices led to higher farm incomes and increased resilience as compared to the adoption of limited practices, (Sardar *et al.* 2021; Maitra *et al.* 2026c). The impact of having access to irrigation is positive, underscoring the significance of water security in drought-prone areas like North Karnataka where variability in rainfall is a frequent occurrence that impacts on farm productivity and profitability. Similarly, the value of crop insurance and training uptake suggests that institutional approaches to managing risk, and capacity development programmes, can make a difference in minimizing vulnerabilities and maximizing recovery from climate-related losses. Recent studies in agricultural production risks in India have shown that extension service can mitigate welfare loss due to production shocks by enhancing farmer preparedness, and their ability to respond, adapt and adjust. The negative link between the severity of climate shocks and farmer resilience, however, shows that even well adapted farmers are still susceptible to climate extremes, thus the need for integrated measures on resilience that include extension, climate information services, irrigation development, insurance coverage, and institutional interventions. Hence, enhancing the capacities of public extension systems by providing location-specific climate advice and taking participatory approaches will play a vital role in making smallholder farmers more economically resilient in climate-sensitive areas.

CONCLUSION

Climate change has become one of the most pressing issues to impact agricultural productivity, stability of farm income, and security of livelihoods, especially for smallholder farmers in North Karnataka (a vulnerable region). The current research showed that strengthening the capacity of the farmers to adapt to climate shocks is important through agricultural extension contact which helps to increase their access to climate-smart agriculture knowledge and institutional linkages. Farmers who had higher exposure to extension showed better socio-economic traits, higher level of climate adaptation practices, better farm profitability, and better economic resilience than farmers with limited extension exposure. The climate stress was similar across all extension-contact groups, but show variations in

how farmers acted when faced with climate stress, and how well they did, suggesting that extension support was a key factor in enhancing preparedness and response capacity of farmers.

Results indicated that among various factors associated with economic resilience, extension contact, adoption of climate-resilient practices, crop diversification, irrigation access, agricultural training and crop insurance were important determinants. The positive impacts were observed for farmers who have been more involved in extension, in terms of their crop income, gross returns, net returns, benefit-cost ratio, income stability and recovery capacity after climate shocks. The regression analysis also proved that extension contact was a positive and significant influence on the Economic Resilience Index when socio-economic and farm-level factors were considered. The findings underscore the need for agricultural extension to go beyond mere technology transfer and adopt a multi-sectoral climate-risk management approach, which includes climate information services, adaptation technologies, finance facilitation and institutional coordination.

The study highlights the importance of enhancing extension systems in climate vulnerable areas by providing location-specific extension advisory, participatory learning, digital extension tools, farmer organizations, and continuing extension systems capacity building programmes. In areas like North Karnataka, where droughts repeatedly affect agricultural livelihoods, and rainfall variability is also a major concern, greater access to effective extension services can increase the adaptive capacity of farmers and help to foster sustainable agricultural livelihoods. Advanced impact evaluation methods, such as propensity score matching, endogenous switching regression or longitudinal evaluation should be used in future to secure the causal link between the extension interventions and the long-term economic resilience of the farmers. The results offer important policy, extension, and development guidance for developing agricultural strategies that increase agricultural productivity and livelihood security for smallholder farmers that are resilient to climate change.

GENERATIVE AI DECLARATION

The author(s) confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI. The authors developed and verified all scientific content, data analysis, interpretation of results, and conclusions. The authors take full responsibility for the accuracy, integrity, and originality of the work presented, and no AI tool was listed as an author.

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