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RESEARCH ARTICLE

Leveraging agricultural technologies for flood mitigation in coastal Tamil Nadu: Addressing challenges in agriculture

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Abstract

Flooding exacerbated by cyclones and heavy monsoons has become a significant challenge for agriculture in Tamil Nadu especially in its coastal regions. This study explores the technological mitigation strategies that can help to reduce the adverse impacts of flooding on agriculture. By focusing on flood-induced crop losses, soil erosion and waterlogging, the research emphasizes the need for innovative agricultural technologies to build resilience in farming practices. The study identifies eight TNAU recommended technological solutions to mitigate flooding stress at field level, including bio stimulants, submergence-tolerant rice varieties, salt-tolerant crops, raised bed systems, polyhouse farming and foliar sprays for crop recovery. Through a survey of farmers and extension officials, the study evaluates awareness, acceptance and adoption of these technologies. Findings indicate that while farmers exhibit high awareness and acceptance of traditional mitigation methods, newer technologies face adoption barriers due to financial and knowledge constraints. The study suggests targeted policy interventions, such as financial incentives, extension services and subsidies, to increase adoption rates. Furthermore, it calls for enhanced collaboration between research institutions, government agencies and farmers to foster a more resilient agricultural system capable of coping with flood-related challenges. This research offers actionable insights to help Tamil Nadu's agricultural sector adapt to increasingly frequent and intense flooding events.

Keywords: agricultural resilience; climate change adaptation; coastal agriculture; crop resilience; cyclone impact; flood management technologies

Introduction

Floods, particularly those induced by cyclones and heavy monsoons, have long been a major challenge for Tamil Nadu, affecting both urban and rural landscapes (1). With climate change intensifying extreme weather events, traditional flood management methods such as embankments, drainage systems and conventional relief measures are proving to be inadequate. To effectively mitigate flood hazards and their devastating consequences, particularly in agriculture, technological interventions have become essential (2). Modern technology, ranging from advanced weather forecasting systems to innovative agricultural practices, provides viable solutions to mitigate flood risks, minimize crop damage and enhance resilience (3). Recently, cyclones Michaung and Fengal caused extensive agricultural devastation across Tamil Nadu, severely impacting farmers' livelihoods. The torrential rainfall and strong winds led to widespread crop losses, particularly in paddy fields, banana plantations and vegetable farms in districts like Nagapattinam, Cuddalore, Tiruvallur and Villupuram (4). Water stagnation and soil erosion reduced soil fertility, delaying replanting cycles and increasing vulnerability to pests and fungal diseases. Fisheries also suffered significant damage due to rough seas and the destruction of infrastructure. Many farmers faced financial distress, struggling mouting debt and economic instability as compounded yield losses worsened their hardships. The destruction emphasized the urgent need for resilient agricultural practices, better drainage systems and early warning technologies to mitigate future flood disasters (5).

Impact of cyclones Michaung and Fengal on Tamil Nadu's agriculture

Recent cyclones, Michaung (December 2023) and Fengal (early 2024), severely impacted Tamil Nadu, causing widespread flooding that devastated agricultural lands, disrupted irrigation systems and led to significant economic losses (6).

Cyclone Michaung

This cyclone brought unprecedented rainfall, particularly affecting northern and coastal Tamil Nadu, including districts such as Chennai, Tiruvallur, Chengalpattu, Cuddalore and Nagapattinam. The heavy downpours led to severe waterlogging in paddy fields, causing extensive crop submergence and root rot (7). The horticulture sector also suffered, with vegetables and banana plantations being destroyed due to prolonged inundation. In addition, soil erosion washed away essential nutrients, reducing soil fertility and long-term agricultural productivity.

Cyclone Fengal

Though slightly weaker, cyclone Fengal exacerbated the flood crisis in Tamil Nadu, striking regions already affected by Michaung. Agricultural fields in Villupuram, Cuddalore and Thiruvannamalai suffered extensive damage (8). The heavy rainfall further worsened water stagnation, delayed replanting cycles and increased the risk of pest infestations and fungal diseases in crops. Agricultural infrastructure, including irrigation channels, farm roads and storage facilities, suffered significant damage, impacting farmers' livelihoods.

Previous studies have highlighted key aspects of agricultural challenges in Tamil Nadu, particularly in the coastal regions. Cyclone Gaja (9), which struck in 2018 caused widespread damage to both agricultural and horticultural crops, especially in the districts of Nagapattinam, Thiruvarur and Pudukottai. These areas faced significant losses in crops like paddy, banana, coconut and groundnut. Cyclone Burevi (10) in 2020 hit the southern districts such as Thoothukudi, Kanyakumari and Tirunelveli causing massive agricultural losses, particularly from uprooted crops and waterlogging, which hindered recovery. Cyclone Nivar also in the same year 2020, compounded these challenges in districts such as Villupuram, Cuddalore and Puducherry, resulting in crop loss, particularly in low-lying areas prone to flooding (11). Similarly, cyclone Mandous in 2022 severely affected agriculture in districts such as Chennai, Kancheepuram and Cuddalore, leading to the destruction of crops and damage to infrastructure. In addition to crop damage, these cyclones led to significant livestock losses, with farmers facing challenges in maintaining their herds due to floodwaters, lack of feed and shelters (12). This scenario highlights the vulnerability of Tamil Nadu's agricultural and horticultural sectors to cyclonic events, necessitating urgent adaptation strategies to minimize the impacts on both crops and livestock.

Material and Methods

The coping mechanism followed by the farmers to mitigate flooding through some proven scientific technologies recommended by the Tamil Nadu Agricultural University and popularized by the State Department of Agriculture and Horticulture; Government of Tamil Nadu is termed as technological mitigation strategies (13). In this study, by having discussion with progressive farmers and extension officials, eight technological adaptation strategies were finalized. These were administered among the total respondents of one hundred small and marginal farmers from Cuddalore and Nagapattinam districts (Fig. 1 & 2) which was heavily affected by recent cyclones and they were scored in the two-point continuum scale namely 'aware' or 'not aware', 'accepted' or 'not accepted' and 'adopted' or 'not adopted' with '2' and '1' scores respectively (14). The summated scores were obtained for each of the strategies. The maximum and minimum scores an individual could obtain were 16 and 8, respectively. The selected eight technological mitigation strategies to cope up with flooding is listed below in Table 1, By adopting these technological mitigation strategies, Tamil Nadu's farmers can better cope with recurrent flood disasters, ensuring minimal crop loss and improved food security.

Results and Discussion

IBM SPSS 22.0 software was used in this study to perform correlation analysis and multiple regression analysis. From the Table 2, it is observed that more than 75 % of the respondents were aware of most of the technological mitigation strategies. Such as, preserving dry fodder for livestock (100 %), bio stimulants and growth regulators - seaweed extracts (*Kappaphycus* spp.), gibberellic acid (GA_3) and amino acid-based stimulants (88 %), raised bed and ridge-furrow system to improve drainage and prevent root rot (86 %), changing planting dates (85 %), salt-tolerant rice varieties for coastal saline areas (79 %) and submergence-tolerant paddy varieties to ensures better survival under prolonged waterlogging (75 %). Nearly 57 % of respondents were aware of polyhouse and

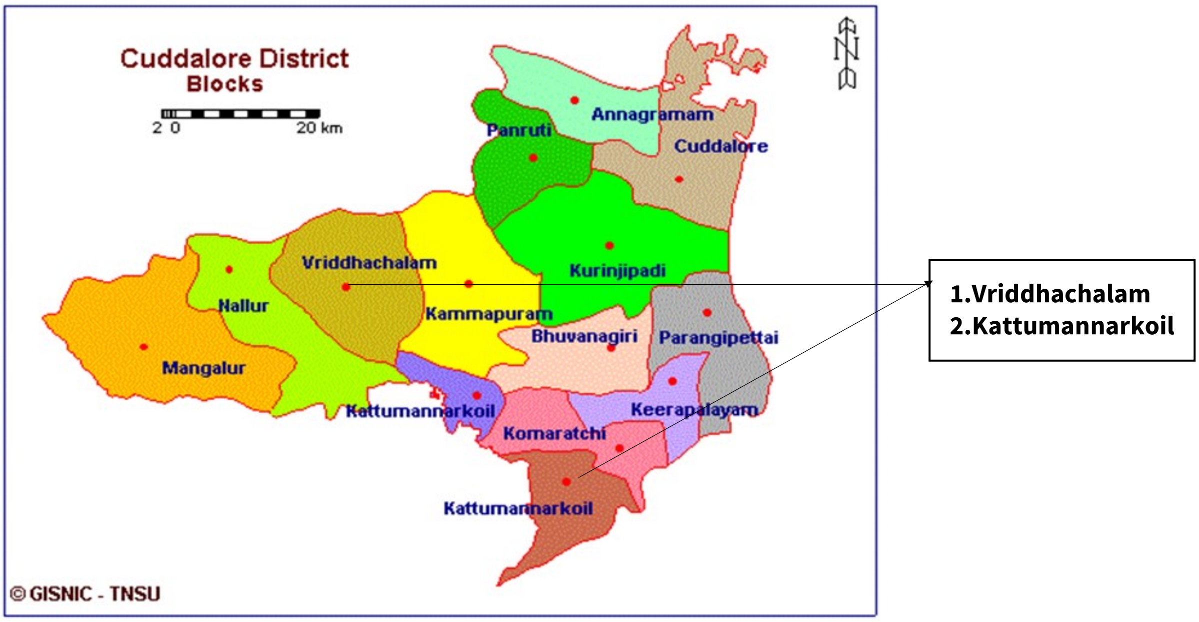

Fig. 1. Map showing selected areas of Cuddalore district.

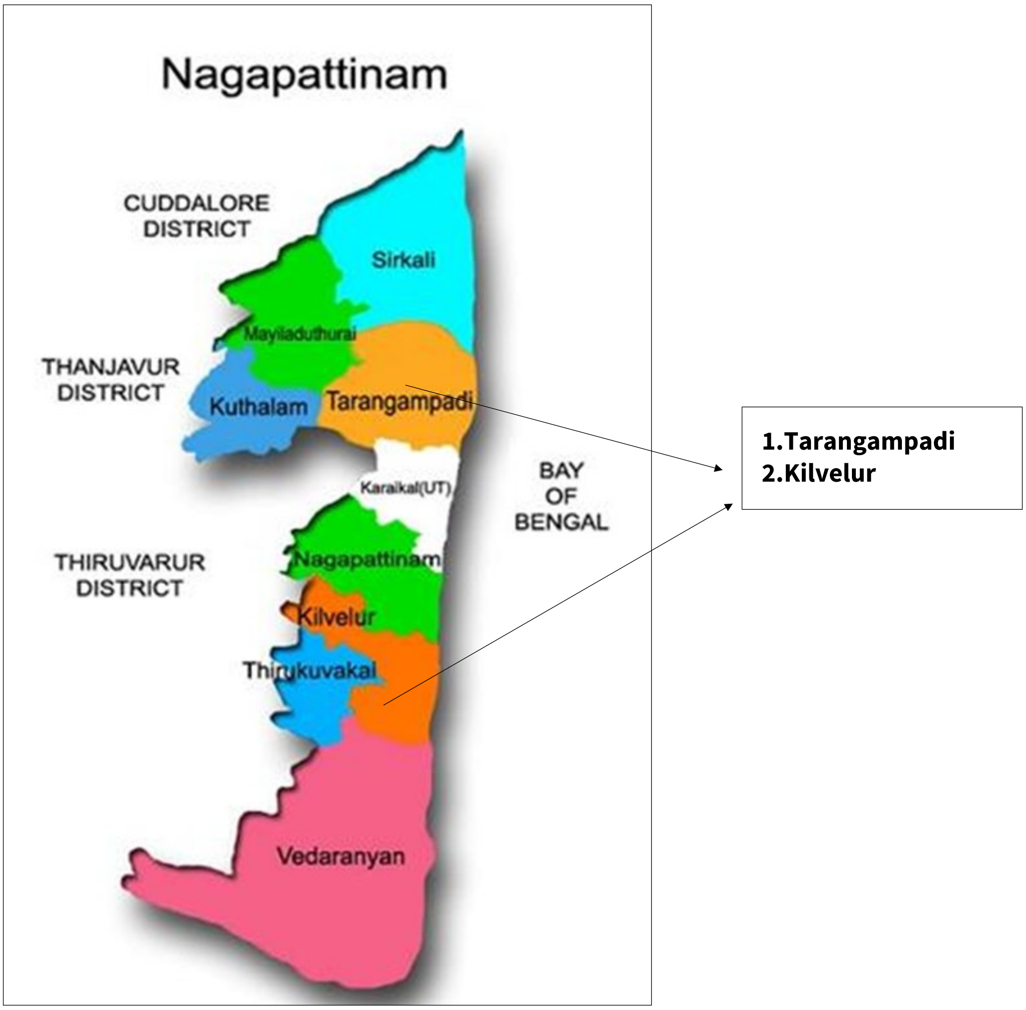

Fig. 2. Map showing selected areas of Nagapattinam district.

Table 1. List of technological mitigation strategies to cope with flooding

S. No.	Technological mitigation strategies to cope with flooding
1.	Bio-stimulants and growth regulators - Seaweed extracts (*Kappaphycus* spp.), gibberellic acid (GA 3) and amino acid-based stimulants to improve plant recovery after flooding (15).
2.	Submergence-Tolerant paddy varieties - Cultivation of ADT 53, CR 1009 Sub-1 and Swarna Sub-1 ensures better survival under prolonged waterlogging (16).
3.	Salt-Tolerant rice varieties - White ponni, TRY 3, TRY 4, ADT 45 and CO 51 for coastal saline areas (17).
4.	Raised bed and ridge-furrow system - Used in vegetable and horticultural farms (brinjal, tomato, chilies) to improve drainage and prevent root rot (18).
5.	Changing of planting dates (19).
6.	Polyhouse and vertical farming - Implemented in peri-urban areas to reduce flood impact on high-value crops (20).
7.	Foliar sprays for crop recovery ($ZnSO_4$ 0.5 %, $FeSO_4$ 0.5 % and $KNO_3$1 %) to boost plant resilience (21).
8.	Preserving dry fodder for livestock (22).

Table 2. Extent of awareness of technological mitigation strategies (n=100)

S. No.	Technological mitigation strategies	Aware	Not aware
1.	Bio-stimulants and growth regulators - Seaweed extracts (*Kappaphycus* spp.), gibberellic acid (GA 3) and amino acid-based stimulants to improve plant recovery after flooding.	88	12
2.	Submergence-Tolerant paddy varieties - Cultivation of ADT 53, CR 1009 Sub-1 and Swarna Sub-1 ensures better survival under prolonged waterlogging.	75	25
3.	Salt-Tolerant rice varieties - White ponni, TRY 3, TRY 4, ADT 45 and CO 51 for coastal saline areas.	79	21
4.	Raised bed and ridge-furrow system - Used in vegetable and horticultural farms (brinjal, tomato, chilies) to improve drainage and prevent root rot.	86	14
5.	Changing of planting dates	85	15
6.	Polyhouse and vertical farming - Implemented in peri-urban areas to reduce flood impact on high-value crops.	57	43
7.	Foliar sprays for crop recovery ($ZnSO_4$ 0.5 %, $FeSO_4$ 0.5 % and $KNO_3$1 %) to boost plant resilience.	47	53
8.	Preserving dry fodder for livestock	100	0

vertical farming, which have been implemented in peri-urban areas to reduce flood impacts on high-value crops. Additionally, 47 % of respondents were aware of foliar sprays for crop recovery ($ZnSO_4$ 0.5 %, $FeSO_4$ 0.5 % and potassium nitrate (KNO_3 1 %) to boost plant resilience as technological mitigation strategies to overcome adverse effects of flood. As preservation of dry fodder is a traditional mitigation strategy being followed generation after generation. So, the awareness level was found to be higher.

Due to the implementation of intensive extension strategies under various government programmes such as NATP (National Agricultural Technology Project), NICRA (National Initiative on Climate Resilient Agriculture), NHM (National Horticulture Mission), NMSA (National Mission on Sustainable Agriculture), Precision Farming and ATMA (Agricultural Technology Management Agency) the awareness levels among farmers have significantly increased. As a result, knowledge and adoption of technologies like biostimulants and growth regulators, raised bed and ridge-furrow systems and mulching to reduce moisture loss were found to be comparatively higher. Though formation of polyhouse and vertical Farming was promoted by the State Horticultural Department for the past decade, such establishments were not well routed as farmers was afraid of losing their cultivable area. Lower awareness is being observed related to foliar sprays for crop recovery ($ZnSO_4$ 0.5 %, $FeSO_4$ 0.5 % and $KNO_3$1 %) to boost plant resilience is the technology promoted by KVK (Krishi Vigyan Kendra) in limited scale through their On Farm Testing (OFT). When it comes to the acceptance of technological mitigation strategies (Table 3), a gap between awareness and acceptance was found to be more (38.64 %) in bio stimulants and growth regulators followed by polyhouse and vertical farming, polyhouse and vertical farming (43.86 %), submergence-tolerant paddy varieties (25.33 %), foliar sprays for crop recovery ($ZnSO_4$ 0.5 %, $FeSO_4$ 0.5 % and $KNO_3$1 %) to boost plant resilience (36.17 %).

The gap was found to be very low related to the technologies like raised bed and ridge-furrow system - used in vegetable and horticultural farms (3.49 %), preserving dry fodder for livestock (3 %) and changing planting dates according to the availability of soil moisture (7.06 %). The trend that has been observed above indicates that respondents are not having full realization of innovative chemical approaches (foliar spray and bio-stimulants) that are being promoted through different extension programmes. The technologies such as raised bed and ridge-furrow system, preserving dry fodder for livestock and changing of planting dates are accepted readily as these practices were traditionally being followed.

To ascertain the percentage of respondents who have not adopted the technological mitigation strategies despite being aware of them, an analysis was conducted and the results are presented in Table 4. From Table 4, it can be observed that the technological adoption gap was relatively low for raised bed and ridge-furrow system (16.28 %), followed by preservation of dry fodder for livestock (19 %) and changing the planting dates according to the availability of moisture (31.76 %) the technological gap was found to be low. In contrast, nearly 50 to 60 % of respondents who were aware of the technologies like bio-stimulants and growth regulators, submergence-tolerant paddy varieties, salt-tolerant rice hybrids polyhouse and vertical farming and foliar chemicals sprays but not adopted them. The higher level of technological adoption gap is observed in formation of polyhouse and vertical farming among the already realized farmers. As the initial investment for establishment of those structures was found to be higher and fear of losing available cultivable area might be the reasons for the less adoption.

Technological mitigation strategies promoted by extension agents were adopted by approximately half of the experienced farmers, as many of them were beneficiaries of these programmes. However, most farmers have a traditional mind set and limited scientific knowledge of recent innovations, combined with financial constraints, leading to a low adoption rate. To address this issue, the State Department of Agriculture and Horticulture, in collaboration with Agricultural University and KVK (Krishi Vigyan Kendra), should conduct demonstration training and provide essential farm

Table 3. Extent of acceptance of technological mitigation strategies (n=100)

S. No.	Technological mitigation strategies	Number of farmers aware	Number of farmers accepted	Number of farmers aware but not accepted
1.	Bio-stimulants and growth regulators - Seaweed extracts (*Kappaphycus* spp.), gibberellic acid (GA_3) and amino acid-based stimulants to improve plant recovery after flooding.	88 (100 %)	54 (61.36 %)	34 (38.64 %)
2.	Submergence-Tolerant paddy varieties - Cultivation of ADT 53, CR 1009 sub-1 and Swarna sub-1 ensures better survival under prolonged waterlogging.	75 (100 %)	56 (74.67 %)	19 (25.33 %)
3.	Salt-Tolerant rice varieties - White ponni, TRY 3, TRY 4, ADT 45 and CO 51 for coastal saline areas.	79 (100 %)	66 (83.54 %)	13 (16.46 %)
4.	Raised bed and ridge-furrow system - Used in vegetable and horticultural farms (brinjal, tomato, chilies) to improve drainage and prevent root rot.	86 (100 %)	83 (96.51 %)	3 (3.49 %)
5.	Changing of planting dates	85 (100 %)	79 (92.94 %)	6 (7.06 %)
6.	Polyhouse and vertical farming - Implemented in peri-urban areas to reduce flood impact on high-value crops.	57 (100 %)	32 (56.14 %)	25 (43.86 %)
7.	Foliar sprays for crop recovery ($ZnSO_4$ 0.5 %, $FeSO_4$ 0.5 % and KNO_3 1 %) to boost plant resilience.	47 (100 %)	30 (63.83 %)	17 (36.17 %)
8.	Preserving dry fodder for livestock	100 (100 %)	97 (97 %)	3 (3 %)

Table 4. Extent of adoption of technological mitigation strategies (n=100)

S.No	Technological mitigation strategies	Number of farmers aware	Number of farmers	Number of farmers aware but not adopted
1.	Bio-stimulants and growth regulators - Seaweed extracts (*Kappaphycus* spp.), gibberellic acid (GA_3) and amino acid-based stimulants to improve plant recovery after flooding.	88 (100 %)	37 (42.05 %)	51 (57.95 %)
2.	Submergence-tolerant paddy varieties - Cultivation of ADT 53, CR 1009 Sub-1 and Swarna Sub-1 ensures better survival under prolonged waterlogging.	75 (100 %)	31 (41.33 %)	44 (58.67 %)
3.	Salt-tolerant rice varieties - White ponni, TRY 3, TRY 4, ADT 45 and CO 51 for coastal saline areas.	79 (100 %)	38 (48.10 %)	41 (51.90 %)
4.	Raised bed and ridge-furrow system - used in vegetable and horticultural farms (brinjal, tomato, chilies) to improve drainage and	86 (100 %)	72 (83.72 %)	14 (16.28 %)
5.	Changing of planting dates	85 (100 %)	58 (68.24 %)	27 (31.76 %)
6.	Polyhouse and vertical farming - Implemented in peri-urban areas to reduce flood impact on high-value crops.	57 (100 %)	5 (8.77 %)	52 (91.23 %)
7.	Foliar sprays for crop recovery ($ZnSO_4$ 0.5 %, $FeSO_4$ 0.5 % and $KNO_3$1 %) to boost plant resilience.	47 (100 %)	21 (44.68 %)	26 (55.32 %)
8.	Preserving dry fodder for livestock	100 (100 %)	81 (81 %)	19 (19 %)

inputs like flood tolerant / salt tolerant crops seed materials, chemical sprays at subsidy rate to small and marginal farmers at least during high rainfall and cyclone prone seasons to mitigate it.

Relationship and influence of independent variables towards technological mitigation strategies

To understand the factors influencing farmers' adoption of technological mitigation strategies in response to floods, twelve independent variables were carefully selected. These variables spanning socio-economic status, behavioural traits and perception-based indicators were chosen for their theoretical relevance and support from previous research in agricultural decision-making and disaster response contexts.

The results of correlation coefficient analysis and multiple regression analysis for these twelve variables in relation to technological mitigation strategies are presented in Table 5. The analysis revealed that only three variables exhibited statistically significant positive associations: information seeking behaviour (X8) and perception of farmers towards the effect of flood (X12) at the 1 % level of significance and education status (X2) at the 5 % level. These findings suggest that farmers who are more informed, better educated and more aware of the risks posed by floods are more likely to adopt technological mitigation strategies. In contrast, variables such as farm size (X3), social participation (X7), innovativeness (X9) and decision-making behaviour (X11) did not show a significant relationship. Several factors could explain this lack of association. For instance, external influences such as government interventions, subsidies, or access to extension services may have a more uniform effect across farm sizes, minimizing variation in technology adoption due to landholding. Similarly, social participation might not directly influence technological choices if the networks are not agriculturally focused or are inactive during disasters.

Moreover, innovativeness and decision-making behaviour, although theoretically relevant, might not have translated into action due to constraints like limited financial resources, infrastructural inadequacies, or lack of access to appropriate technologies. It is also possible that the measurement tools for these variables may not have fully captured their complexity, leading to underestimation of their actual influence.

Lastly, limitations in data collection, such as self-reporting bias, small sample size, or regional specificity, may have influenced the outcomes. These limitations suggest the need for further investigation using longitudinal or mixed

Table 5. Association and contribution of independent variables towards technological mitigation strategies

Variable No.	Independent variables	'r' values	Regression co-efficient	'P' value	't' value
X1	Age	0.016 ^{NS}	0.026 ^{NS}	0.235	1.195
X2	Educational status	0.226*	0.029*	0.016	2.789
X3	Farm size	-0.056 ^{NS}	0.057 ^{NS}	0.302	-1.038
X4	Farming experience	0.067 ^{NS}	0.026 ^{NS}	0.542	-0.613
X5	Occupational status	0.181 ^{NS}	0.144 ^{NS}	0.455	0.751
X6	Annual income	0.085 ^{NS}	0.004 ^{NS}	0.828	-0.219
X7	Social participation	-0.031 ^{NS}	0.049 ^{NS}	0.687	-0.404
X8	Information seeking behaviour	0.810**	0.051**	0.000	6.629
X9	Innovativeness	-0.040 ^{NS}	0.147 ^{NS}	0.314	-1.013
X10	Access to weather forecasts	0.166 ^{NS}	0.076 ^{NS}	0.206	1.273
X11	Decision making behaviour	-0.145 ^{NS}	0.073 ^{NS}	0.606	-0.517
X12	Perception of farmers towards effects of flood	0.734**	0.067**	0.000	3.834

R2 value = 0.745, f value = 21.214**, NS - Non- Significant.

** - significant at one per cent level, * - significant at five per cent level method approaches to better understand the dynamics at play. The multiple regression model yielded an R^2 value of 0.745, indicating that 74.50 % of the variation in technological mitigation strategies can be explained by the selected independent variables, affirming the model's strong explanatory power.

The prediction equation (Eqn. 1) fitted from the results of multiple regression analysis as follows,

$$Y_2 = 6.000 + 0.026(X_1)^{NS} + 0.029(X_2)^{*} + 0.057(X_3)^{NS} + 0.026(X_4)^{NS} + 0.144(X_5)^{NS} + 0.004(X_6)^{NS} + 0.049(X_7)^{NS} + 0.051(X_8)^{**} + 0.147(X_9)^{NS} + 0.076(X_{10})^{NS} + 0.073(X_{11})^{NS} + 0.067(X_{12})^{**}$$

The partial regression co-efficient value was found to be positive and significant for the variables namely information seeking behaviour (X_8) and perception of farmers towards floods (X_{12}) at 1 % level of probability. The educational status was also found to be significant at the 5 % level of probability. The results indicate that a unit increase in educational status (X_2), information seeking behaviour (X_8) and perception of farmers towards the effects of floods (X_{12}) would increase the technological mitigation strategies by 0.029, 0.051and 0.067 units respectively. The findings derive support from past studies (23, 24) revealed that both educational status and information seeking behaviour had a positive and significant relationship with the adaptation behaviour of farmers on climate change. The reason for might be increased educational level would have increased knowledge level due to inherent interest to get more information about climate change adaptation strategies. Information could be gathered from various institutional, non-institutional and mass media sources. Farmers can gather information from various institutional, non-institutional and mass media sources. A high flow of information from these sources increases farmers' knowledge of climate change, which ultimately enhances their adaptation levels. Thus, the educational level and information seeking behaviour supports adaptation to climate change.

Conclusion

The study highlights the need for targeted policy interventions and enhanced extension services to improve the adoption of flood mitigation strategies in Tamil Nadu's agriculture which is highly susceptible to flood prone during monsoon season. While traditional methods like dry fodder preservation and raised bed systems are widely accepted, newer innovations face adoption barriers due to financial and knowledge constraints. To address these gaps, policies should focus on financial incentives such as subsidies for flood-resistant crops, insurance schemes and low-interest credit for protective farming structures. Extension efforts must prioritize hands-on training, field demonstrations and digital outreach to enhance farmers' awareness and confidence in adopting modern mitigation techniques. Integrating sustainable agricultural practices into flood mitigation strategies is vital for achieving long-term environmental goals. Techniques such as cover cropping, agroforestry and organic farming help improve soil structure, enhance water retention and reduce surface runoff, thereby lessening the impact of floods. At the same time, these practices support climate resilience and biodiversity. To ensure their effective implementation, strong collaboration among research institutions, agricultural universities, government agencies and farmers is essential. Such partnerships can foster innovation, facilitate knowledge exchange and build a resilient agricultural system capable of withstanding flood-related challenges.

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Authors' contributions

SP done the conceptualization, data curation and writing the original draft. KC performed the conceptualization, methodology, supervision, funding acquisition, writing the review & editing. Review & editing, supervision and validation was done by NDM. The resources, validation, visualization was done by VD. TK done the supervision and validation.

Compliance with ethical standards

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

Ethical issues: None

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