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Measuring the impact of COVID-19 on climate smart agriculture strategies of smallholder farmers in coastal Bangladesh

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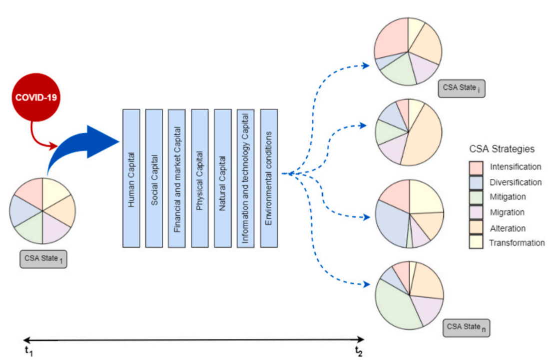
HIGHLIGHTS

- The study created a climate-smart agriculture index for farms, covering intensification, diversification, alteration, and migration.
- The study offers insights into how the pandemic had varied impacts on different pillars of climate-smart agriculture.
- The study explains how major human, market, financial, social, and natural capital-related factors drive the impacts on CSA.
- The study calls for policy measures to enhance climate-smart agriculture and offset the impacts of the pandemic.

GRAPHICAL ABSTRACT



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ABSTRACT

Context: Climate-smart agriculture (CSA) strategies of smallholder farmers include intensification, diversification, alteration of farming practices, and transformation to other enterprises, along with mitigation of greenhouse gases and temporary or permanent migration. The determination of CSA strategies relies on livelihood capitals, namely physical, natural, human, social, financial, information, and technological capitals of smallholder farmers. The COVID-19 pandemic has prompted shifts in CSA strategies, with variations dependent on these capitals.
Objective: The study aims at developing a conceptual and methodological framework to understand external disruptions like the impact of COVID-19 on CSA adoption and how the livelihood capitals and environmental conditions influence these impacts.
Methods: The study develops a composite indicator of the changes in CSA strategies and links them to indicators of human, physical, financial, social, natural, and information capital through quantitative regression models.
Results and conclusion: The results unraveled varied impacts of the COVID-19 pandemic on climate-smart agriculture in Bangladesh. The findings revealed that among the climate-smart agricultural strategies, intensification efforts were least affected, diversification showed a mixed picture, whereas seasonal migration experienced a significant negative impact. Ownership of physical capital, such as machinery, enhanced intensification, given the shortage of hired machinery and labor services during the pandemic period. Similarly, information capital, as reflected in mobile phone ownership, played a decisive role in improving farm productivity and income. Level of

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income loss during COVID period and difficulties in accessing credit increased migration while size of loan increased diversification. Canal irrigation access increased intensification and migration and reduced diversification.

Significance: In response to the COVID-19 crisis, the government of Bangladesh has supported activities that favored the intensification of production of major crops. It appears to be successful in maintaining the intensity of staple crop cultivation despite the substantial impacts of COVID-19. It is observed that the rate of change in uptake of resilience-building agricultural practices, greenhouse gas mitigation practices and transformation to aquaculture from agriculture were stalled during the COVID-19 pandemic years. The results argue for policies to improve how finance is provided, extension services are delivered, and cellular mobile access is ensured, especially for marginal and women farmers. Difficulties in accessing loans increased migration and larger sized loans pushed farmers to diversification. Therefore, schemes to restructure farm credit need to be explored. To enhance migration as an adaptation strategy during pandemic time, it is necessary to impart additional skills and provide support schemes to offset income loss.

1. Introduction

The concept of 'Climate Smart Agriculture' (CSA) integrates climate resilience into the planning and implementation of sustainable agricultural strategies (Lipper et al., 2014). It is an integrated approach to managing landscapes, cropland, livestock, forests, and fisheries to address the intertwined challenges of food security and climate change. CSA endeavors to simultaneously achieve three outcomes: increasing productivity (and income), enhancing resilience, and reducing greenhouse gas emissions (World Bank, 2019; Shrestha and Bokhtiar, 2019; Wijk, 2020). CSA strategies of smallholder farmers include intensification, diversification, alteration of farming practices, transformation to other enterprises, mitigation of greenhouse gases (as a co-benefit), and temporary or permanent migration (Mutabazi et al., 2015). The CSA strategy portfolio employed by smallholder farmers depends on their tangible and intangible assets or livelihood 'capitals,' namely physical, natural, human, social, and financial, as well as information and technology capitals, as confirmed by various studies (Žurovec and Vedeld, 2019; Mutabazi et al., 2015; Pagliacci et al., 2020). External disruptive events, such as the COVID-19 pandemic, can potentially alter the CSA portfolio of any given farmer. Still, the intensity of change can differ depending on the households' physical, human, social, and financial, as well as information and technological capitals (Middendorf et al., 2021; FAO, 2020a, 2020b). The last statement is now a hypothesis, and hence, the current study focuses on developing a deeper understanding of the complex COVID-19 pandemic-livelihood capitals-CSA nexus. The findings are expected to inform policymakers and researchers concerned with how systemic shocks—such as global health crises—may induce temporary or permanent shifts in CSA adoption. These insights can support the design of responsive policies aimed at safeguarding and strengthening CSA practices in Bangladesh and the broader South Asian context.

2. Conceptual frame: CSA, capitals and COVID pandemic

The current study develops a general conceptual framework linking Climate-Smart Agriculture (CSA) strategies with the COVID-19 pandemic and applies it to coastal Bangladesh, which is one of the most climate-vulnerable areas in the world (Eckstein et al., 2021; Chowdhury et al., 2021). The study collects data on indicators of CSA and analyzes how the CSA strategies differed in 2020 (during the pandemic) compared to 2019 (pre-pandemic) to understand the impacts of COVID-19. Shifts in CSA strategies are assessed through a set of indicators that reflect changes across multiple dimensions. These include variations in the use of inputs such as fertilizers, pesticides, and irrigation—capturing intensification efforts; adjustments in sowing or transplanting dates and the adoption of new crop varieties—reflecting alterations in farming practices; and changes in the complexity of farming systems—indicative of diversification. Additionally, transitions to new enterprises, particularly shifts from crop-based agriculture to aquaculture, and decisions related to temporary or permanent migration to diversify household income sources are also considered. This expanded set of CSA indicators builds on the framework proposed by Mutabazi et al. (2015), adapting it to better capture the multifaceted nature of CSA responses in the face of systemic shocks. The study develops a composite indicator of these changes in CSA strategies and links them to indicators of human capital (labor availability in the household, education, skills, farm experience), physical capital (irrigation sources, road access, ownership of land, machinery, mobile phones, type of house), financial capital (livestock units, farm and off-farm income, credit, remittance), social capital (family cooperation, coordination with neighboring farmers, social media use for farm information, membership in associations), natural capital (size of farm, water quality, presence of earthworms representing biological activity, fallows, organic fertilizer use), and information capital (media sources, extension contacts, weather information) through quantitative regression models. Livelihood capitals are critical in response to stresses and shocks (Ansoms and McKay, 2010; Mutenje et al., 2010; Scoones, 1998; Odero, 2006), and the availability of these capitals can change CSA strategies and pathways.

The conceptual framework (Fig. 1) presents a unified theoretical model illustrating how livelihood capitals and environmental conditions influence the adoption of climate-smart agricultural (CSA) practices. Duc Truong et al. (2022) showed that human capital—comprising age, education, and training—has a significant impact on CSA uptake. Waaswa et al. (2022) define physical capital as the material assets that shape the level of CSA adoption. Existing literature identifies four components of social capital—trust, norms, connectedness, and power—as important factors influencing farmers' decisions to alter management practices (Rust et al., 2023), with the indicators used in this study reflecting trust and connectedness. Waaswa et al. (2022) describe natural capital as the stock of environmental assets that provide ecosystem services. Indicators such as soil fertility (Sandilya and Goswami, 2024), organic matter (Hammed et al., 2019), and earthworm abundance (Toor et al., 2024) represent these services relevant for CSA. Financial capital, including access to credit and off-farm income, is also identified by Waaswa et al. (2022) as a key determinant of CSA adoption.

Apart from capitals, CSA strategies are also shaped by changing environmental conditions (e.g., salinity). Salinity is mostly evident in the coastal cultivable lands (Ullah et al., 2021) of Bangladesh, where it has gradually increased from 1 to 33 % of the cultivated area in the past 25 years (Rahman et al., 2018). However, the comprehensive concept is briefly presented in Fig. 1.

3. Review of literature

Bangladesh is recognized as one of the most vulnerable countries to the impacts of climate change, with 41 out of its 64 districts being highly vulnerable (MOEFCC, GIZ, 2018), rendering the agricultural practices in these districts 'always under climate stress (Uddin and Nasrin, 2013). Factors such as extreme temperatures, erratic rainfall, salinity intrusion, floods, droughts, storm surges, water scarcity, improper governance of coastal polders, riverbank erosion, and cyclones have significant consequences on local farmers' ability to grow crops and ensure food security (Rahman, 2018; Mahmuduzzaman et al., 2014). Thirty percent of the total population, the majority of whom are rural poor, live in 19 districts considered to be vulnerable coastal areas (Parvin et al., 2016). It is estimated that approximately 62 % of coastal land has been affected by some degree of salinity, which may worsen due to sea-level rise and tropical storms, hampering the production potential of crops susceptible to salinity (World Bank Group, 2019). Projections indicate that cropland in coastal Bangladesh will be reduced by up to 24 % across the growing seasons in the upcoming decades (World Bank Group, 2019). CSA options in the target areas aim to offset the impacts of climate change on the yield levels of crops and salinity, which affect areas suitable for a range of crops (Rasul, 2021a, 2021b). However, although agriculture is susceptible to climate change, it also contributes to it through the use of agrochemicals, soil disturbance, and fuel energy use for machinery, including pumps. In Bangladesh, it is estimated that 76.79 million tons (Mt) of carbon dioxide equivalent are emitted by agricultural activities each year (Sapkota et al., 2021), with crop production contributing 65 % of the agricultural emissions, while livestock accounts for 35 %.

Climate-Smart Agriculture (CSA) has been recognized as a set of practices that can help farmers not only attain sustainable growth in production and increase their adaptation capacity to climate change but also help reduce GHG emissions and contribute to the improvement of food and nutrition security of farm households (FAO, 2013; CIAT, World Bank, 2017). In the context of developing countries such as Bangladesh, CSA practices are identified as those that enhance food security and contribute to at least one of the other objectives of CSA, such as adaptation and/or mitigation (Ali and Hossain, 2019). Indeed, Bangladesh faces the challenge of 'sustainable agricultural productivity growth and boosting the production of nutrient-rich foods' while responding to climate change, scarcity of land, and a growing population (FPMU, 2020). Thus, it could largely benefit from the adoption of CSA practices, especially in coastal farming, for which climate impacts 'include inundation from sea-level rise, damage from storm surges, loss of water bodies, and increased salinity of land from saltwater intrusion' (Rahaman et al., 2021; Khatri-Chhetri et al., 2016), presenting a specific set of challenges on their own.

To respond to waterlogging and increasing changes in soil salinity, which led to decreasing agricultural livelihood opportunities, coastal farmers in the 70s and 80s began to rely more heavily on the transformation to shrimp production and fisheries. This shift brought significant economic and social benefits (Uddin and Nasrin, 2013; Islam and Bhuiyan, 2016). It led to the establishment of a predominantly fish/shrimp-based agricultural system in Southern Bangladesh, making it one of the most dynamic sectors. This sector contributed 3.57 % to the national GDP and 26.50 % to the total agriculture GDP in 2021 (DoF, 2021). However, these transition to aquaculture activities have been criticized for exacerbating soil and water salinity, leading to a significant decline in the production of crops, vegetables, fruits, and livestock in the coastal region of Bangladesh. Furthermore, the current trajectory of adopting CSA practices could have hindered by the restrictions and responses to the COVID-19 pandemic, as well as the diverted attention and government funds from climate action towards economic recovery (Climate Action Tracker, 2020). Indeed, it has been observed that efforts to respond to the COVID-19 virus and reduce its spread, as well as its impact, have a direct adverse effect on the implementation of planned adaptation and mitigation measures in rural Bangladesh (FAO, 2020a, 2020b). Thus, the economic recovery post-COVID-19 pandemic will impact the adoption of CSA and the overall climate action pathway of the country.

In response to such possibilities, the scientific community has recognized that farmers were facing two equally important challenges: climate change and the pandemic in 2020 and 2021 (Climate Investment Fund, 2020; Rasul, 2021a, 2021b). Both threats required simultaneous interventions to sustain agricultural production, especially for

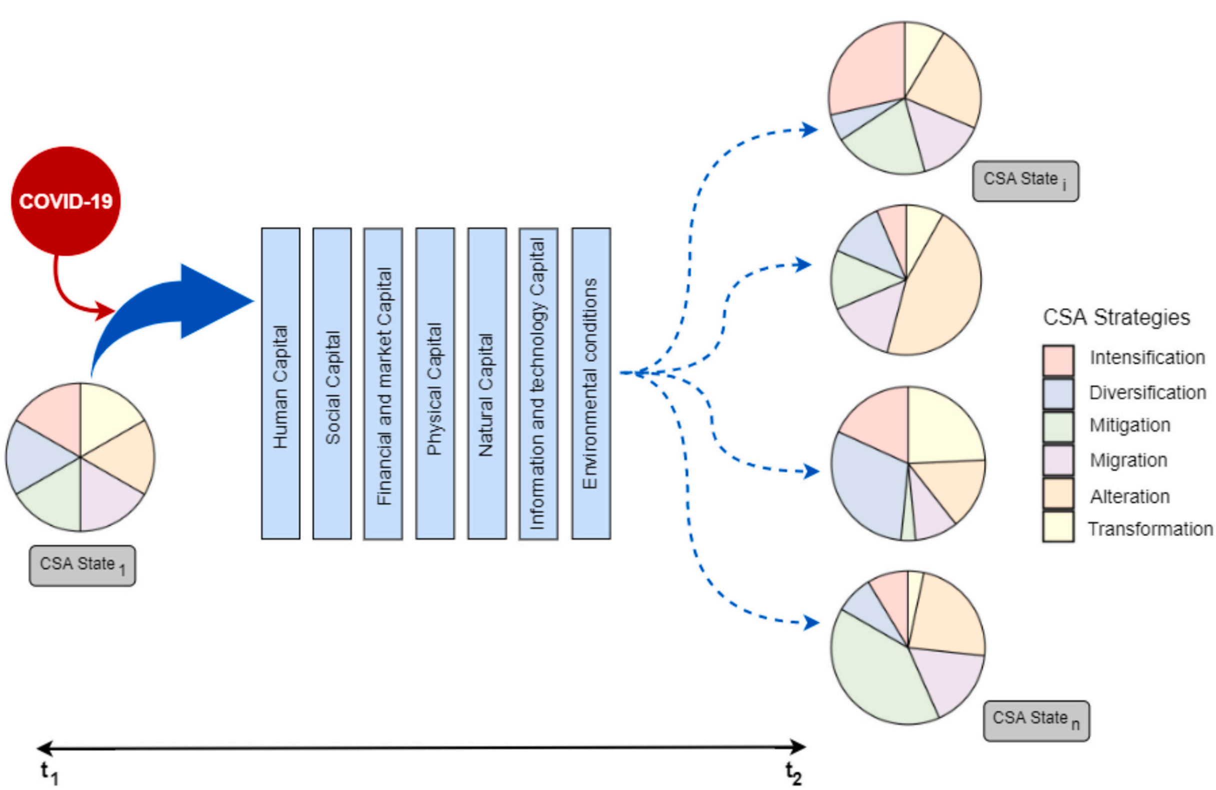

Fig. 1. COVID-19 impact on CSA conditioned by farmers' livelihood capitals and environmental factors.
Note: The COVID-19 shock can move the farm in CSA state1, which represents the pre-pandemic CSA strategy portfolio to any of the CSA States 1 to n, depending on the capitals and environmental conditions.

smallholder farmers. The COVID-19 impact on the agricultural sector in Bangladesh is linked to government measures to reduce the spread of the disease—physical distancing, closure of markets, restaurants, and hotels, imposed curfews and limited operating hours of banks and shops. These measures had a direct negative effect on farmers' ability to access agricultural inputs, markets, sell their products, and consumers' changes in food demand (resulting in lower consumption of food), leading to a collapse in farm product prices and food wastage (Kumar et al., 2020; Light Castle Analytics Wing, 2020; Ahmed et al., 2021; Ingutia, 2021). The measures and their consequences directly affected farmers' income, food security, future production, and potential adoption of CSA practices, especially in 2020–2021.

The wider adoption of CSA technologies in Bangladesh could have helped mitigate the COVID-19 disruption on production and ensured the food security of farmers' households and their communities, similar to examples from the Philippines and Sri Lanka (IRRI, 2021; World Bank, 2021). In coastal Bangladesh, studies have shown that CSA practices have been positively associated with the overall improvement of household food security, and therefore, their adoption should be encouraged amid disruptive events such as the pandemic (Rasul, 2021a, 2021b; Hasan et al., 2018). Furthermore, climate-smart agriculture investments can stimulate rural economies by providing innovative opportunities towards the integrated goals of enhancing yield rates, improving resilience, and reducing GHG emissions in the agricultural sector (Climate Investment Fund, 2020; Andrieu et al., 2017). These could support economic recovery stimulus policies aiming to support income and employment (Engström et al., 2020).

Similarly, studies conducted during the pandemic and in the early post-pandemic period have urged policymakers to integrate climate response measures into COVID-19 recovery policies and investment plans to support and strengthen agri-food systems (GIZ, ASEAN, 2021; IFPRI, 2021). Reciprocally, some researchers have pointed out that "for climate policies to have a chance of implementation at this moment, they cannot be at odds with addressing the COVID-19 crisis" (Engström et al., 2020) and have highlighted the potential synergy between COVID-19 and climate policies in terms of co-benefits (Hepburn et al., 2020; GIZ, ASEAN, 2021). Additionally, the UN framework for the immediate socio-economic response to COVID-19 has placed environmental sustainability at its center (UNEP, 2020), while the World Bank signed a $300 million financing agreement with Bangladesh to support the poorer citizens in overcoming poverty through community mobilization and climate-smart practices. This has led to the emergence of the idea of a new type of agriculture that is both climate and pandemic smart (FAO, 2021; Rasul, 2021a, 2021b) and its tentative framework formulation (Bodegom and Koopmanschap, 2020). Some preliminary studies have identified measures that could respond to both climate and COVID-19 and be part of this new concept, such as the digitalization of farmers (introducing and expanding smart technology), emphasis on local value chains, home gardening, agricultural diversification, agroecology, and indigenous technologies.

Although there is consensus on the need to address both climate issues and the impacts of COVID-19, as well as the potential benefits of implementing Climate-Smart Agriculture (CSA) practices in response to these challenges, there remains a lack of understanding regarding how pandemics interact with climate smartness of the farming sector. The ways in which COVID-19 has affected farmers' ability to adopt CSA practices need further exploration (Rasul, 2021a, 2021b). The pandemic has significantly influenced nutrition, food security, and the livelihoods of farmers and those involved in the food supply chain. The extent of these impacts largely depends on policy responses in the short, medium, and long term (OECD, 2020). Therefore, a deeper understanding of the impact of COVID-19 on the integration of CSA practices by farmers in coastal Bangladesh could aid the government in formulating new, climate- and pandemic-smart policies and action plans. Although the study is contextualized within Bangladesh, it offers a framework for assessing the impact of COVID-19 and CSA that could be replicated in other countries.

4. Methodology

4.1. Study location

This study focused on three Upazilas (Sub-districts)—namely, Kolapara, Amtoli, and Taltoli—within two coastal districts, Patuakhali and Barguna. These selected locations, situated near the Bay of Bengal, are significantly impacted by both climate change and salinity (Alam et al., 2018; SRDI, 2010). Moreover, these Upazilas encompass areas with low, moderate, and high soil salinity. A substantial majority of the population in these districts—71.93 % in Barguna and 65.95 % in Patuakhali—depend on farming for their livelihood (BBS, 2018). In addition to widespread rice and shrimp farming, farmers in the coastal areas of Bangladesh also engage in vegetable cultivation, fruit tree planting around homesteads, livestock rearing (including cattle, poultry, and ducks), and pond aquaculture (Uddin and Nasrin, 2013). Considering the range of salinity levels, they were used as strata in the sampling procedure. Based on the soil salinity map from the Soil Resources Development Institute (SRDI) of the Government of Bangladesh, areas with high, moderate, and low salinity were identified. Researchers interviewed farmers from selected villages within each Upazila that fall into these salinity categories to adequately capture the variability of adaptation strategies and the impacts of COVID-19. Following the selection of villages (as detailed in Table 1), farmers were randomly chosen based on a list obtained from the Department of Agricultural Extension (DAE) offices at the sub-district level. In total, the study included 420 farmers. A detailed list of villages, along with the selected number of samples and their salinity levels, is presented in Table 1, and a location map is provided in Fig. 2.

4.2. Composite index and regression models

A composite index of Climate smart agricultural (CSA) strategies of farm households was developed based on a set of selected indicators. The construct indicators encompass the adaptive strategies, such as intensification, diversification, alteration, transformation, mitigation and migration. The CSA index is constructed as a weighted index (using principal component analysis) that merges the sub-indices of all identified climate smart strategies (intensification, diversification, alteration, transformation, mitigation and migration) in a single composite indicator as follows:

$$C_k^{j,t} = \sum_i a_k^j \left(X_i^{j,t} \right) \quad (1)$$

where, $C_k^{j,t}$ is kth component score of jth farmer where a_k^j is the loading of kth component for ithvariable for the tth year.; $X_i^{j,t}$ is the value of ith variable for jth farmer for the tth year.

$$CSA_j^t = \sum_k V_k C_k^{j,t}$$

V_k is the variance accounted by the kth principal component and CSA_j is the composite score of climate smart agricultural strategies of jthfarm household for the tthyear.

To understand the COVID-19 pandemic impact, a differential score (between 2020 and 2019),$dCSA_j^{t2-t1}$ is calculated as follow:

$$dCSA_j^{2020-2019} = CSA_j^{2020} - CSA_j^{t2019}$$

To understand the drivers of $dCSA_j^{2020-2019}$, natural, human, physical, social, financial and information capitals of jth farmers is regressed over indicators of these capital for farmer j. The censored regression model is

Table 1
Sampling frame of the study.

District	Upazila	Village	Salinity level	Salinity Class	Total farmer	Sample
Barguna	Amtoli	Sorikhali	27.55	High	27	22
		PurbaChunakhali	15.23	High	34	22
		Mohisdanga	10.39	Medium	33	23
		Kaunia	10.14	Medium	18	15
		Dalachara	5.2	Low	63	22
		Khekuani	7.66	Low	49	28
		Total			224	132
	Taltoli	Jharakhali	17.68	High	58	35
		Boropara	10.83	Medium	93	22
		Badurgacha	9.5	Medium	99	41
		Monukhepara	4.31	Low	28	14
		Taltoli	4.3	Low	51	16
		Chotobogi	7.29	Low	158	12
		Total			487	140
Patuakhali	Kalapara	Nachnapara	16.25	High	71	29
		Uttar Dawlatpur	16	High	24	16
		Sultangonj	14	High	14	10
		Solimpur	14	High	10	4
		Akkelpur	9.5	Medium	15	15
		Londa	10.2	Medium	84	26
		Amirabad	7.6	Low	14	12
		Nizampur	5.3	Low	30	23
		Umedpur	7.6	Low	17	13
		Total			279	148
Grand total					990	420

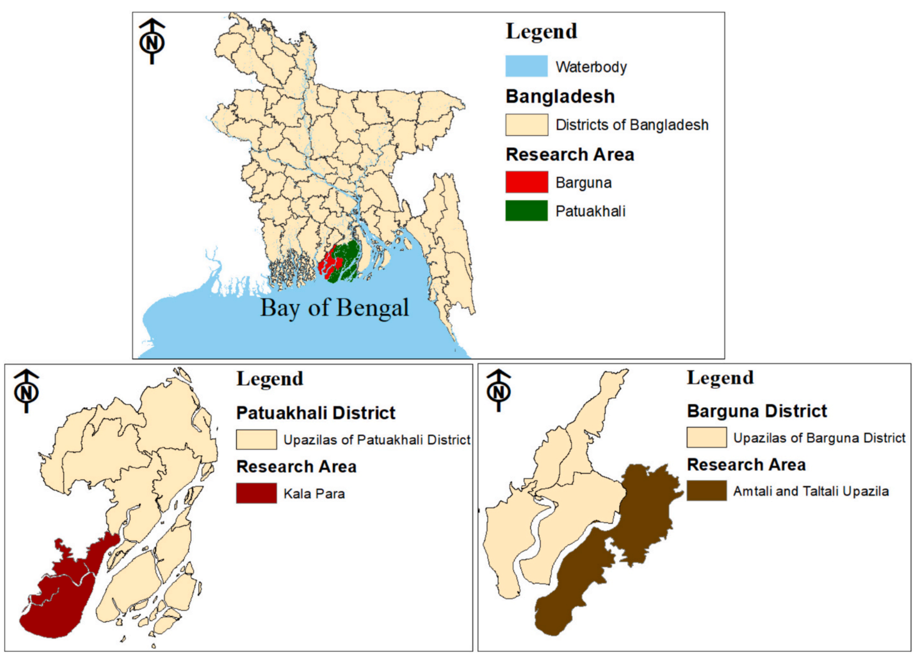

Fig. 2. Study location map

$$dCSA_j^{*2020-2019} = \sum_i \beta_i Z_j^i + u_i,$$

$i = 1,2, \ldots, m \; j = 1,2,3 \ldots j$

$$dCSA_j^{2020-2019} = dCSA_j^{*2020-2019} \text{ if } dCSA_j^{*2020-2019} > 0$$

$$dCSA_j^{2020-2019} = dCSA_j^{*2020-2019} = 0, \text{if } dCSA_j^{2020-2019} \leq 0$$

where, Z_j^i stands for the variables representing the capitals and β_i denote respective coefficients. The variables considered are determinants of the composite index of resilience. The differentials for individual components of CSA_j^t i.e.$dC_k^{j,2020-2019}$ is also calculated a similar censored regression model is fitted to understand the drivers.

Table 2 provides the descriptive statistics of CSA score components and variables both in years of 2019 (pre-pandemic) and 2020 (pandemic)

5. Results

5.1. COVID impact of CSA and component indices

The results show the differential impact of COVID stress on CSA and its components (See Fig. 3). The CSA score differential shows a mixed picture, given the opposing changes among underlying sub-indices. Intensification efforts are least affected, and most of the farmers

Table 2
Descriptive statistics of CSA score components and variables considered under each component.

CSA index components	Component variables	Description	Unit	Mean (2019)	Mean (2020)
Intensification	Fertilizer use	Total amount of chemical fertilizer used in that particular year	Kg/ decimal	3.427	4.587
	Pesticide use	Total cost of chemical pesticides or herbicides used in that particular year	BDT/ decimal	112.38	135.24
	Irrigation intensity	Total number of irrigations applied in the particular year, irrespective of crops	Numbers/ all crops	6	6.43
	Irrigation coverage	Farm area under irrigation coverage	% Total farm	13.97	16.04
Diversification	Livestock	Have cattle	Yes/no	0.811	0.811
	Fish	Have fish	Yes/no	0.573	0.573
	Poultry	Have poultry	Yes/no	0.930	0.930
	Trees	Have trees	Yes/no	0.889	0.889
	Crop diversity	Total number of crops cultivated in the particular year, including field crops and vegetables	Crops/ farm	3.14	4.11
Alteration	Tolerant crops	Use tolerant crops	Yes/no	0.124	0.124
	Cover crops	Cultivate cover crops	Yes/no	0.365	0.365
	Mulching	Practice mulching	Yes/no	0.023	0.023
	Short duration variety	Cultivate short duration rice crop	Yes/no	0.179	0.179
	Early planting date	Early plating of rice	Yes/no	0.028	0.028
Mitigation	Solar pump	Use solar energy-based pump for irrigation	Yes/no	0.008	0.008
	AWD	Practice alternative drying and wetting of rice field	Yes/no	0.101	0.101
Transformation	Transform to aquaculture	Transform from crop/ livestock to aquaculture completely or partially	Yes/no	0.307	0.307
	Transform into livestock	Transform from crop/ aquaculture to livestock completely or partially	Yes/no	0.446	0.446
Migration	Migration	Move to nearby towns or cities/ capital/ other countries for work or a salaried job	Persons/ family	0.162	0.110
	Remittance	Send Remittance to family	Yes/no	0.142	0.101
Environmental factor	Salinity	Salinity level in the area based on SRDI chart	ds/m		11.05

experienced a rise in the overall intensification differential score in 2020 compared to 2019. Diversification also shows a similar picture, with many of the farmers registering a significant gain in the diversification scores, primarily due to crop diversification. The scores of climate smart practices (alteration), mitigation measures and transformation did not register any change and are not further discussed. Migration and remittances showed a significant decline, and hence a large number of farmers incurred significant losses in migration scores, while a few of them registered gains. However, to further understand the drivers of the observed patterns in CSA and component scores, a series of censored regressions was carried out on intensification, diversification, migration, and CSA score differentials.

5.2. Changes in CSA and component scores (2020 and 2019) and linkages to capitals

The first set of results presented in Table 3 shows the impact of capitals and environmental conditions on CSA score differential during the first year of COVID-19 pandemic. It also includes the mean and standard deviation of the farmer-level data used in the regression analysis, offering additional context and insights for the reader.

Among the dimensions of human capital, marital status significantly influenced changes in CSA scores during the COVID-19 pandemic. Married farmers may have had greater access to unpaid family labor—such as support from spouses and children—which is crucial for agricultural intensification, especially in times of reduced availability of hired labour. Among the natural capitals, the access to canal irrigation was a variable of significance and reflects the critical role of canal water access in the CSA adoption rate under the conditions of Bangladesh polders. The role is different in the case of intensification and diversification as canal irrigation leads to specialization (rice farming) and intensification in general, may work against diversification. Among the capital information, access to input dealers was significant and positive. Mobile ownership was a driving force, for intensification, diversification, and migration aspects, and hence CSA scores. Nevertheless, access to the internet showed no significant influence on CSA scores. In the study area, internet-based agricultural information delivery still has not gained enough momentum (Mamun-ur-Rashid, 2020), and very few farmers (mainly larger farm owners and educated ones) use internet-based services, whose CSA adoption and change seem to be lower than the rest of the farmers. Currently, internet access represents access to other income sources than a focus on agriculture-related activities.

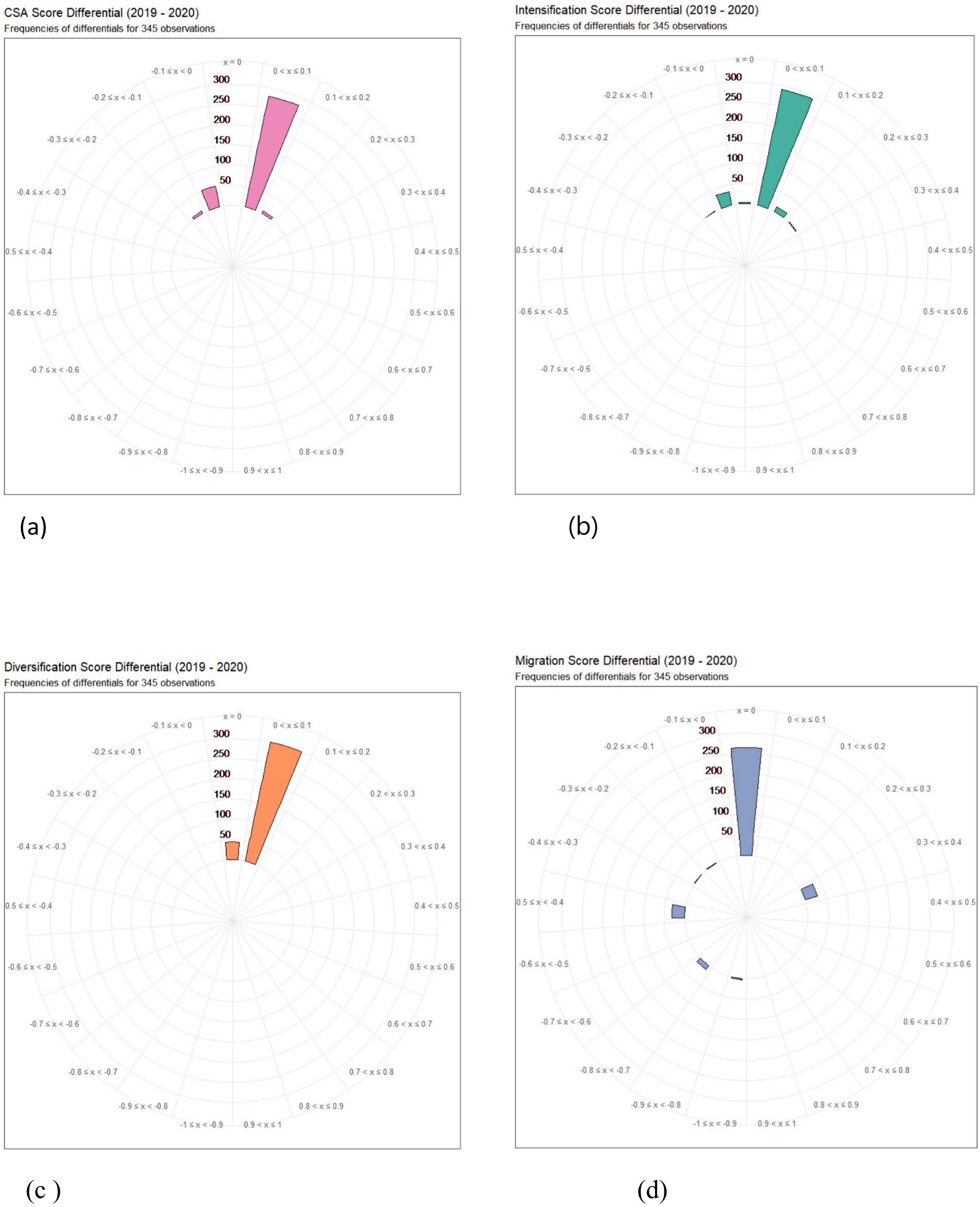

Fig. 3. Differential of 2020 and 2019 scores shows gain (positive values) and loss (negative values) in CSA and component scores. The differential scores range from −1 to +1.
3(a) denotes score differential of CSA score for the same farmer in pre-COVID and post-COVID pandemic scenarios. 3(b), 3(c), 3(d), shows the score differential in intensification, diversification and migration. The mean values of the standardized differentials of CSA and components are given in Appendix Table 1 and the raw scores of 2019 is given in Appendix Fig. 1.

The intensification score differential captured changes in fertilizer, pesticide and irrigation intensity and the results (see Table 4) shows that during the COVID-19 pandemic, intensification efforts was positively driven by the time required to access markets (market disruption increased local demand), canal water access, ownership of machines, such as tractors and mobile phones (increased connectivity), as well as family labor endowment indicated by marital status and number of family members, while intensification efforts was negatively impacted by the changes in capital availability (income) and services of input dealerships (many farmers receive inputs on credit basis), which were

Table 3
Censored regression of the drivers of CSA Score differential between COVID year (2020) and pre-COVID (2019) years.

	CSA score differential	Unit	Mean (standard deviation)	Coefficient	t-value	*p*-value	Significance
Human Capital	Age	Years	49.478 (12.044)	−0.0001	−0.1300	0.8955	
	Gender	1-male 0- female	0.957 (0.204)	0.0519	1.2600	0.2070	
	Education	Years	5.012 (3.963)	0.0020	0.8000	0.4260	
	Primary income source	Farming −1 Others – 0	0.861 (0.347)	−0.0142	−0.5500	0.5807	
	Marital Status	Married −1 Unmarried −2	1.006 (0.076)	0.3048	2.6100	0.0094	***
Market Capital	Time required to access market	Hours	0.507 (0.343)	−0.0063	−0.2500	0.8053	
Physical Capital	Area	Decimal (100 decimal = 1 acre)	251.01 (290.27)	0.0000	1.2900	0.1966	
	Irrigation water source - Canal	Canal water - 1 Other sources −0	0.3797 (0.4860)	0.0648	3.4900	0.0005	***
	Irrigation water source - groundwater	Groundwater −1 Other source −0	0.0289 (0.1680)	−0.0668	−1.2600	0.2082	
	Tractor owned	Number	0.110 (0.314)	0.0492	1.7900	0.0748	**
	Power tiller owned	Number	0.136 (0.344)	−0.0112	−0.4300	0.6694	
	Cow owned	Number	4.125 (4.193)	−0.0001	−0.0300	0.9755	
	Goat owned	Number	1.406 (2.222)	−0.0007	−0.1800	0.8538	
Financial Capital	Income reduction	0 - No reduction 1. <−5 % 2. -5 to −20 % 3. -20 to −50 % 4. > −50 %	2.2376(1.3212)	−0.0014	−0.2200	0.8256	
	Annual loan	1. <50,000 2. 50,000 to 100,000 3. >100,000	1.128 (1.040)	−0.0164	−1.4900	0.1371	
	Ease of getting loan	1. Very easy 2. Easy 3. Moderate 4. Difficult 5. very difficult	1.716 (1.546)	0.0047	0.6300	0.5270	
	Family labour	Number	2.533 (1.325)	0.0055	0.8200	0.4155	
Natural Capital	Frog, bird, earthworm	Yes −1 No- 0	0.997 (0.054)	−0.0909	−0.6000	0.5515	
	Current Fallow	Decimal	8.812 (24.799)	0.0001	0.3500	0.7299	
	Homestead farm	Decimal	41.280 (35.859)	0.0001	0.4900	0.6233	
	Organic fertilizer	Percentage	0.855 (2.551)	−0.0028	−0.8300	0.4083	
Information capital	Dealer advice	0. No contact 1. 2 times a season 2. >2 times a season	0.551 (0.498)	0.0338	1.6300	0.1035	*
	Extension contact frequency	0. No contact 1. 2 times a season 2. >2 times a season	0.446 (0.498)	0.0093	0.8300	0.4063	
	Mobile ownership	Yes −1 No −0	0.959 (0.198)	0.0862	2.0200	0.0440	***
	Internet access	Yes −1 No −0	0.012 (0.107)	−0.0245	−1.5900	0.1127	
Environmental condition	Salinity level (dsm) in dry season	0–3 dSm = non-saline, 3–6 dSm = slightly saline, 6–12 dSm = medium saline, >12 dSm = highly saline	11.054 (5.777	0.0020	1.3600	0.1742	
	Constant			0.0442	0.2100	0.8349	

Mean dependent var	0.4603643	SD dependent var	0.1581632
Chi-square	52.8057472	Prob> chi2	0.0021240
Akaike crit. (AIC)	−244.7544396	Bayesian crit. (BIC)	−133.5449282

[#]Note See Appendix Table 1 for mean and standard deviation of standardized CSA score differential.
[***] $p < .01$.
[**] $p < .05$.
[*] $p < .1$.

constrained by COVID-19 pandemic. It is to be noted that labor and machinery services, credit, and input availability were constrained by the COVID-19 pandemic (Amjath-Babu et al., 2020). Apart from capital and environmental conditions, government policies to provide inputs with subsidies to farmers enhanced intensification efforts, leading to higher production. The counterintuitive result of increased intensification in areas distant from main markets reflects increased local demand due to supply disruptions.

Diversification score differential during COVID 19 pandemic reflects the change in crop diversity as data didn't indicate changes in livestock, aquaculture or tree farming. Diversification score differentials were positively related to the endowment of family labor and the availability of fallow land. They were negatively related to extension contact, which was affected due to COVID-19, and the availability of capital (income change and loans). Canal irrigation availability negatively affected diversification under COVID-19 conditions (see Table 5). The flow of labor back to rural areas has increased labor availability at the household level, and farmers attempted to expand their farming to cover their

Table 4
Censored regression of the drivers of intensification Score differential COVID year (2020) and pre-COVID (2019) years.

Type of capital	Intensification score differential	Coefficients	Standard error	t-value	p-value	Sig
	Age	−0.0001092	0.0005944	−0.18	0.8543114	
	Gender	0.026669	0.033083	0.81	0.420776	
Human Capital	Education	0.0000736	0.0019776	0.04	0.9703405	
	Income source	0.0140091	0.0207764	0.67	0.5006257	
	Marital Status	0.1603598	0.0937617	1.71	0.0881903	**
Market Capital	Time required to access market	0.0337647	0.0204227	1.65	0.0992616	*
Physical	Area	0.0000364	0.0000291	1.25	0.2125866	
Capital	Irrigation water source – Canal	0.0277999	0.0149445	1.86	0.0637823	**
	Irrigation water source – groundwater	−0.0645972	0.0424086	−1.52	0.1287034	
	Tractor owned	0.062811	0.0221326	2.84	0.0048333	***
	Power tiller owned	−0.0035939	0.0210648	−0.17	0.864639	
	Cow owned	0.0003541	0.0017582	0.20	0.840534	
	Goat owned	−0.0013747	0.0031924	−0.43	0.6670483	
Financial Capital	Income change	−0.0115792	0.0051549	−2.25	0.0253769	***
	Annual loan	0.0107221	0.0088309	1.21	0.2255918	
	Ease of getting loan	−0.0016499	0.0059724	−0.28	0.7825335	
	Family labour	0.0322691	0.0053945	5.98	0.0253769	***
Natural Capital	Frog, bird, earthworm	0.0747791	0.1226074	0.61	0.5423603	
	Current Fallow	0.0002579	0.0002973	0.87	0.3863776	
	Homestead farm	−0.0002321	0.0002087	−1.11	0.2668841	
	Organic fertilizer	−0.0018067	0.0027053	−0.67	0.5047156	
Information capital	Dealer advice	−0.0485221	0.0166685	−2.91	0.0038579	***
	Extension contact frequency	−0.0170518	0.008979	−1.90	0.0584622	**
	Mobile ownership	0.0622386	0.034681	1.79	0.0736701	**
	Internet access	−0.0173611	0.0124358	−1.40	0.1636766	
Environmental condition	Salinity level	−0.0001158	0.0011808	−0.10	0.9219654	
	Constant	−0.1288929	0.1703021	−0.76	0.4497026	

Mean dependent var	0.2486	SD dependent var	0.138
Chi-square	120.0606152	Prob > chi2	0.0000000
Akaike crit. (AIC)	−387.6783940	Bayesian crit. (BIC)	−280.2219415

[#]Note: The description of variables and units are provided in Table 3. See Appendix Table 1 for mean and standard deviation of standardized intensification score differential.

*** $p < .01$.
** $p < .05$
* $p < .10$

lower margins and diversify cropping to enhance market opportunities. It is to be noted that canal irrigation water availability favored an intensification (rice cropping) rather than diversification. The change in diversification (mainly crops) levels was lower in the case of farmers who were frequently in touch with extension workers as they may have continued with existing crops.

Migration score differentials capture the changes in number of migrants per household and changes in remittance level. Migration was clearly impacted by COVID stress. Factors such as canal irrigation access, limited groundwater access, higher income loss, and mobile ownership led to increased migration (see Table 6). Canal water access predicted higher migration and remittance levels while groundwater access reduced the change in migration level. Difficultties in accessing to loans positively affected the decision to migrate during COVID stress.

6. Discussion of findings

The results showed a significant shift in climate-smart agriculture strategies in 2020 compared to 2019, especially in intensification, diversification and migration actions, though levels of mitigation, alteration of practices and transformative adaptation remained stagnant. Given that the pandemic caused nationwide disruptions in input and output markets, as well as labor shortages, it is assumed that a large share of observed changes can be attributed to the impact of COVID-19. In fact, during the COVID crisis, the government of Bangladesh took a pro-agriculture policy stance (Arif et al., 2021), such as ensuring an uninterrupted supply chain of agricultural inputs, allowing all agricultural input shops to remain open for more hours, and providing a stimulus package loan for farmers equivalent to 590 million USD at a low-interest rate (Nuhara, 2020). Nevertheless, only 64 % of farmers were informed about this government incentive, and awareness was particularly high in the fisheries and aquaculture sector (91 %) (BRAC, 2020). Besides, during the 2020–21 fiscal year, the government has taken several initiatives, some of which continues post-COVID crisis, such as the distribution of subsidized fertilizers and seeds and promoting the cultivation of field crops such as rice, groundnut, cowpea (*Vigna unguiculata*), mung bean (*Vigna radiata*), mustard, sunflower, maize, watermelon, etc. Additionally, the government also provided inputs and information support for homestead vegetable production to farmers. Nevertheless, to overcome the COVID crisis, the government appealed to bring every piece of land (including homesteads) under cultivation (Bodegom and Koopmanschap, 2020; Nuhara, 2020). These initiatives might be the reason for the increasing intensification and a mixed trend in diversification despite the COVID crisis.

Ownership of physical capitals, such as machinery,tractors, sprayers, and harvesting equipment, enhanced intensification, given the shortage of hired machinery and labor services during the pandemic period (Ullah et al., 2018; Udimal et al., 2017). Similarly, information capital reflected by mobile phone ownership plays a decisive role in improving farm productivity and income (Aminou et al., 2018; Mittal and Tripathi, 2009). It is observed that mobile phones facilitate access to information for farms, ensuring the timely supply of inputs and the sale of outputs, especially during pandemic times, thereby improving production (Aker and Mbiti, 2010). Moreover, cellphone access enhances social connectivity and the flow of information despite movement restrictions. Financial capital flows, such as income from both on-farm and off-farm sources was found to have a positive influence on climate-smart agricultural technology adoption (Abegunde et al., 2019; Ullah et al., 2018;

Table 5
Censored regression of the drivers of Diversification Score differential COVID year (2020) and pre-COVID (2019) years.

Type of capital	Diversification score differential	Coefficients	Standard error	t-value	p-value	Significance
	Age	0.0013068	0.0010043	1.30	0.1940997	
	Gender	0.04195	0.0580551	0.72	0.4704651	
Human Capital	Education	0.004562	0.0033213	1.37	0.1705456	
	Income source	−0.0003684	0.0352123	−0.01	0.991659	
	Marital Status	−0.1018623	0.1537294	−0.66	0.5080633	
Market Capital	Time required to access market	0.0526397	0.0344371	1.53	0.127367	
Physical	Area	−0.0000444	0.0000483	−0.92	0.3584606	
Capital	Irrigation water source-Canal	−0.0432739	0.02538	−1.71	0.0891669	*****
	Irrigation water source- Groundwater	−0.1039907	0.0752051	−1.38	0.1677115	
	Tractor owned	0.0156352	0.0370801	0.42	0.6735588	
	Power tiller owned	0.0248445	0.035833	0.69	0.4886027	
	Cow owned	0.0038528	0.0029391	1.31	0.1908494	
	Goat owned	0.0089145	0.0052862	1.69	0.0927076	*
Financial Capital	Income change	−0.0192346	0.0087035	−2.21	0.0278216	***
	Annual loan	0.0288416	0.0148578	1.94	0.0531226	***
	Ease of getting loan	−0.0242854	0.0100647	−2.41	0.0163916	***
	Family labour	0.029106	0.0091746	3.17	0.0016596	***
Natural Capital	Frog, bird, earthworm	0.0772991	0.1996864	0.39	0.6989402	
	Current Fallow	0.0014143	0.0004888	2.89	0.0040725	***
	Homestead farm	−0.0000603	0.0003489	−0.17	0.8629807	
	Organic fertilizer	−0.0052595	0.0044714	−1.18	0.2403763	
Information capital	Dealer advice	−0.028081	0.0281955	−1.00	0.3200391	
	Extension contact frequency	−0.0408954	0.0153459	−2.66	0.008095	***
	Mobile ownership	0.019658	0.0575431	0.34	0.7328616	
	Internet access	−0.0076887	0.02104	−0.37	0.7150306	
Environmental condition	Salinity level	−0.0016525	0.0019893	−0.83	0.4067681	
	Constant	−0.0023447	0.2804401	−0.01	0.9933345	

Mean dependent var	0. 0.1381579	SD dependent var	0.1809031
Chi-square	85.5735635	Prob> chi2	0.0000000
Akaike crit. (AIC)	86.1185518	Bayesian crit. (BIC)	193.5750043

#Note: The description of variables and units are provided in Table 3. See Appendix Table 1 for mean and standard deviation of standardized diversification score differential.
*** $p < .01$
** $p < .05$
* $p < .10$

Udimal et al., 2017), while family labor was also a determinant of CSA adoption (Udimal et al., 2017). Chen et al. (2018) found that the adoption of agricultural technologies focusing on intensification and diversification relied upon off-farm household income. Our study shows that farmers who are experienced higher income loss during to COVID-19 pandemic in 2019–20, couldn't invest in intensification, diversification or migration strategies.

Among information capitals, dealers' advice acts as a decisive source of agricultural information in Bangladesh (Mamun-Ur-Rashid and Qijie, 2016; Mamun-ur-Rashid et al., 2019). Our research found that farmers who maintained closer contact with dealers experienced lower changes in intensification differentials between 2019 and 2020. This points to the fact that farmers seeking information from dealers may have already intensified their farm production, hence having lower positive intensification differentials or they were unable to access inputs on a credit basis during the pandemic. The intensification trend found during COVID-19 may not be due to input dealers as their function was often impaired due to lockdown restrictions, despite government efforts.

Among information capitals, access to extension services is important in aiding smallholder farmers in their decision-making process since it can provide a reliable source of technical advisory, better germplasm, and other relevant production information (Mango et al., 2015). Extension services also play a vital role in guiding farmers, motivating them to acquire skills, adopt and scale modern technologies in their community (Shah et al., 2013). Results show that respondents who maintained contact with extension agents showed less change in diversification differentials. Two reasons might explain this finding: firstly, people who maintained regular contact with extension agents had already diversified their farms before COVID-19, hence diversification differentials were insignificant for them; secondly, extension agents may inspire farmers to cultivate food crops as the government is focused on food security, hence they might not have suggested crop production other than cereals and pulses during COVID pandemic.

Among physical capitals, whenever access to canal irrigation water was available, farmers proceeded with rice cultivation rather than cultivating various crops. Canal irrigation emerged as a double-edged sword—positively influencing intensification and migration but constraining diversification, suggesting trade-offs in CSA planning. The COVID-19-induced lockdown and movement restrictions impacted the income (financial capital) of the farmers, affecting diversification efforts (Ceballos et al., 2021). However, higher credit burden favored diversification efforts but not intensification changes. The ease of obtaining credit was likely for specialized farms rather than diversified ones.

Individuals with higher incomes (financial capital) and access to irrigation water (physical capital) tended to exhibit greater migration differentials. This suggests that households with greater investment capacity and access to key production inputs may have been more likely to use migration as an adaptation strategy in response to the COVID-19 crisis, compared to lower-income households. Prior research also highlights the role of information technology—such as mobile phone ownership—in facilitating seasonal labor migration (Aker et al., 2011). During the COVID-19 pandemic, access to cellphones (information capital) likely improved access to migration-related information, thereby influencing migration decisions among respondents. Conversely, diffculties in obtaining loan was associated with higher migration differentials. Households with higher loan burdens appeared to remain more engaged in diversified agriculture, possibly due to

Table 6
Censored regression of the drivers of migration score differential, COVID year (2020) and pre-COVID (2019) years.

Type of capital	Migration score differential	Coefficient	Standard error	t-value	p-value	Significance
Human Capital	Age	0.0004526	0.0009839	0.46	0.6458018	
	Gender	0.0023779	0.0549464	0.04	0.9655081	
	Education	0.0028206	0.0032984	0.86	0.3931129	
	Income source	0.0319294	0.0342064	0.93	0.3513071	
	Marital Status	0.042525	0.1548515	0.27	0.7837885	
Market Capital	Time required to access market	0.0430988	0.0344878	1.25	0.2123366	
Physical	Area	0.0000359	0.0000484	0.74	0.4587212	
Capital	Irrigation water source-canal	0.0893173	0.0248629	3.59	0.0003797	*****
	Irrigation water source-groundwater	−0.1519583	0.0705892	−2.15	0.0320956	***
	Tractor owned	0.0366177	0.0373446	0.98	0.3275692	
	Power tiller owned	0.020702	0.0352687	0.59	0.557635	
	Cow owned	−0.0003303	0.0029351	−0.11	0.9104799	
	Goat owned	0.0066963	0.0053529	1.25	0.2118695	
Financial Capital	Income change	0.0162515	0.0085422	1.90	0.0580126	***
	Annual loan	0.0027219	0.0099338	0.27	0.7842597	
	Ease of getting loan	0.0162515	0.0085422	1.90	0.0580126	***
	Family labour	−0.0131097	0.00897	−1.46	0.1448689	
Natural Capital	Frog, bird, earthworm	−0.0913687	0.2021331	−0.45	0.651562	
	Current Fallow	0.0003425	0.0004987	0.69	0.4927458	
	Homestead farm	0.0003616	0.0003467	1.04	0.2978402	
	Organic fertilizer	−0.0043869	0.004465	−0.98	0.3265935	
Information capital	Dealer advice	0.0066774	0.027679	0.24	0.809522	
	Extension contact frequency	0.0130229	0.0149729	0.87	0.3850852	
	Mobile ownership	0.1220973	0.056683	2.15	0.0319908	***
	Internet access	0.0292147	0.0206816	1.41	0.1587555	
Environmental condition	Salinity level	0.0020241	0.0019587	1.03	0.3022189	
	Constant	0.4625543	0.2808637	1.65	0.1005695	*

Mean dependent variable	0.7035145	SD dependent variable change	0.1929120
Chi-square	53.7489518		
Akaike crit. (AIC)	12.0512552	Bayesian crit. (BIC)	123.2607666

#Note: The description of variables and units are provided in Table 3. See Appendix Table 1 for mean and standard deviation of standardized migration score differential.
*** $p < .01$
** $p < .05$
* $p < .10$

financial obligations and diminished employment opportunities in urban areas resulting from the pandemic.

7. Conclusions and policy recommendations

Taking the case of coastal Bangladesh, this study aimed to explore the impact of COVID-19 on the adoption of Climate-Smart Agriculture (CSA) strategies. The findings revealed that among the climate-smart agricultural strategies, intensification efforts were least affected, diversification showed a mixed picture, whereas seasonal migration experienced a significant negative impact due to COVID-19. No changes were observed in the level of climate smart farming practices (alteration), mitigation efforts and transformation to aquaculture during COVID-19 pandemic. Despite substantial policy support during the pandemic, our results suggest that CSA adaptation still relied heavily on household-level capital endowments.

To enhance diversification, it is necessary to boost the financial capital of farmers, particularly through improved access to credit with reasonable interest rates and terms. Currently, access to loans seems to favor specialized farms and hence loan schemes tailored for diversified farming is required but the results show that farmers who received sizeable loans indeed diversified during pandemic. Agricultural extension services need to emphasize promoting diversified crop cultivation, particularly salt-tolerant varieties of multiple crops in fallow lands in the study locations.

In the case of migration, both the number of migrated members per family and the remittance amounts have shown a significant decrease. Annually, over half a million people from Bangladesh are employed in foreign countries who faced adverse socioeconomic impacts due to COVID pandemic (Chowdhury and Chakraborty, 2021). Not only international migrants, but also due to movement restrictions and repeated lockdowns, many rural migrants lost their jobs in the capital city of Dhaka and in other cities, leading to a backflow of migrants (Gatto and Islam, 2021). Therefore, migration and associated income dwindled for the majority of respondents. Reverse migration also enhanced labor availability, and its impact is visible in the effect of household labour in the intensification and diversification changes among farmers during the survey period. To enhance migration as an adaptation strategy to climate stresses, it is necessary to impart additional skills and provide support schemes for migration. Farmers who faced difficulties in obtaining credit tended to adopt migration as a CSA strategy during the COVID-19 pandemic period.

We have observed that the transformation to aquaculture-based livelihood options was relatively low in pandemic years, given the lower demand scenario, but the transformation may have gained momentum post pandemic as market opportunities bounced back and as salinity levels become more severe. Mitigation activities also did not show major changes, which could be due to lower willingness to invest in capital-intensive options like solar pumps. There is a need to explore ways of mitigating emissions of greenhouse gases that can enhance income levels of farmers affected by the COVID-19 and climate stress. Similarly, the rate of change in alteration of farming practices to respond to climate stress seems to hit near-zero levels, with no farmers reporting changes in practices. It may also point to limited flow of information during COVID times and a need for targeted financial and extension support. Our findings highlight that mobile ownership was consistently associated with increased resilience across intensification, diversification, and migration dimensions of CSA. While mobile phone access improved CSA uptake, internet access showed no significant association, underscoring the digital divide among smallholder farmers.

8. Study scope and limitations

This research might be one of the few efforts which aimed to evaluate the effect of COVID-19 on CSA adaptation strategies. The framework used in this research is supposed to provide a practical guideline to the practitioners to evaluate the effect of livelihood capitals and external shocks like a pandemic or market disruptions in the adoption of CSA. The findings of this research may help to find policy pathways to enhance or maintain CSA adoption amid disruptive events such as pandemics in developing countries. In case of limitations, this study has limited geographical coverage focusing coastal Bangladesh, hence generalization of findings needs caution. This research relies on 2019 and 2020 data, while data from later years can provide more insights on how the trends of CSA strategies changes over time. In the case of livestock, aquaculture, and tree farming, data on changes in the number of livestock units, fish, or tree species cultivated were not collected, although these would have been better indicators of changes in the diversification score. The differentials of CSA could be influenced by confounding variables, which are not considered in this study. To understand whether observed trends persisted after the easing of COVID restrictions, requires further investigation.

CRediT authorship contribution statement

T.S. Amjath-Babu: Writing – original draft, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Md. Mamun-ur-Rashid:** Writing – original draft, Project administration, Funding acquisition, Formal analysis, Conceptualization. **Sumona Shahrin:** Writing – review & editing, Visualization, Data curation. **Timothy J. Krupnik:** Writing – review & editing.

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Declaration of competing 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.

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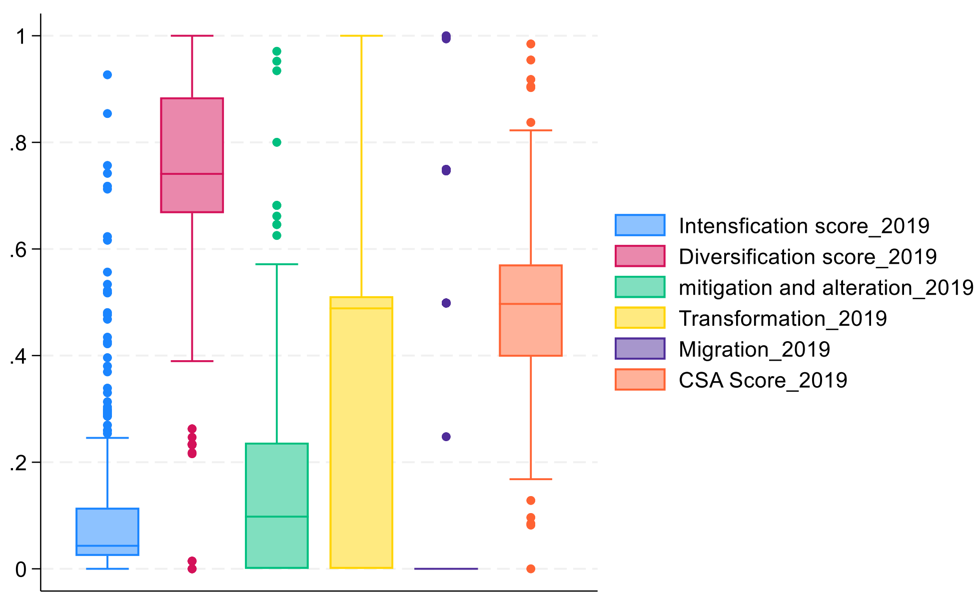
Appendix A. Appendix



Appendix Fig. 1. Distribution of intensification, diversification, mitigation and alteration, transformation, migration and CSA scores.

Appendix Table 1
Average values of standardized CSA indicators differential between 2019 and 2020.

Variable	Obs	Mean	Std. Dev.
Standardized intensification differential	345	0.248653	0.138311
Standardized diversification differential	345	0.137681	0.18052
Standardized migration differential	345	0.70465	0.192764
Standardized CSA differential	345	0.460659	0.158089

Data availability

Data will be made available on request.

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