Original Article

Understanding Smallholder Farmers' Use of Climate-Smart Agriculture Practices: A Study in Char Areas of Jamalpur District in Bangladesh

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Abstract

Climate change presents serious risks to agricultural productivity in the *char* areas of Bangladesh. This study aimed to assess the current use of climate-smart agriculture (CSA) practices by smallholder farmers in riverine *char* areas and identify the factors influencing their use. The research was conducted in six villages of Belgachha and Kulkandi unions in Islampur Upazila, Jamalpur District, areas highly vulnerable due to their proximity to the Jamuna River. A sample of 480 smallholder farmers was drawn from the population using simple random sampling. Quantitative data were obtained through a pre-tested questionnaire, while focus group discussions and key informant interviews provided qualitative insights. Farmers' use of CSA practices was measured using 21 practice statements rated on a four-point scale: "regularly" (3), "occasionally" (2), "rarely" (1), and "never" (0). Multiple linear regression and stepwise regression analyses were employed to identify significant factors and their relative contributions. Findings revealed that most respondents (64.2%) practiced CSA occasionally, followed by rarely (18.3%). The most commonly used practices were high-yielding maize cultivation, raised-bed homestead vegetable cultivation, and crop rotation. Regression results indicated that education, household size, farm size, training experience, extension contact, and CSA knowledge significantly affect CSA use. Strengthening farmers' knowledge and skills through training, discussions, and extension support, alongside promoting climate-resilient crop varieties, is essential for increasing CSA adoption and ensuring sustainable livelihoods in *char* areas.

Categories: Sustainable climate smart agriculture, Food security and sustainability, Rural management & development (trade, livelihoods)

Keywords: bangladesh, climate-smart agriculture (csa) practices, riverine char areas, smallholder farmers, use

Introduction

Climate change has been a gradual process over millennia, but its pace has increased alarmingly over the past century, largely due to human activities that raise greenhouse gas concentrations in the atmosphere [1-3]. This has led to a global temperature increase of 0.9°C since the nineteenth century, with projections indicating a further rise of up to 1.5°C by 2050. Such changes have intensified the frequency and severity of droughts, floods, heatwaves, irregular rainfall, and other extreme weather events, disrupting traditional cropping patterns and posing serious challenges to food production and agricultural sustainability [2,4-8]. In addition, altered climatic conditions have facilitated the spread and severity of pests and diseases, further threatening crop yields and food security [7-9].

Bangladesh, a predominantly agricultural country, is home to approximately 174 million people, nearly half of whom depend directly or indirectly on farming for their livelihoods [10,11]. Agriculture contributes around 11.55% to the national GDP, with cropping alone accounting for 7.25% [12,13]. Over recent decades, improvements in crop production have significantly contributed to reducing poverty and improving food security [14,15]. However, the country's low-lying deltaic geography, located between the Himalayas and the Bay of Bengal and intersected by major rivers such as the Jamuna, Padma, and Meghna, makes it highly vulnerable to climate-related hazards [16-21]. With temperatures projected to rise further by 1.0°C by 2030 and 1.4°C by 2050, Bangladesh faces recurring floods, cyclones, droughts, salinity intrusion, and riverbank erosion, all of which threaten agricultural productivity and rural livelihoods [22-25].

Among Bangladesh's vulnerable agro-ecological zones, five are particularly noted for their low productivity and high sensitivity to climate change: Barind, Char, Coastal, Haor, and Hill ecosystems [17]. The char areas, consisting of temporary or semi-permanent river islands formed by sedimentation and erosion, rank as some of the most climate-vulnerable regions [26,27]. Spanning approximately 7,200 km^2 and inhabited by around 6.5 million people [28], char lands are continuously reshaped by river dynamics [29]. Smallholder farmers in these areas rely heavily on agriculture for their livelihood, making them particularly susceptible to climatic disruptions [30]. They face escalating challenges, including i) more frequent and unpredictable seasonal floods [31,32], ii) prolonged and severe droughts [33,34], iii) intensified erosion of riverbanks [35], and iv) irregular temperature fluctuations that promote pest infestations and negatively impact crop growth [35,36]. Climate change is exacerbating these hazards, posing significant threats to farmers' livelihoods.

In response to the urgent challenges posed by climate change, climate-smart agriculture (CSA) has emerged as a critical strategy for mitigating its effects [37,38]. CSA offers a viable alternative to traditional agriculture by effectively reducing greenhouse gas emissions while enhancing agricultural productivity and food security [39]. It rests on three interconnected pillars (Figure *1*): i) increasing agricultural productivity and incomes; ii) enhancing resilience and adaptation to climate risks; and iii) mitigating or eliminating greenhouse gas emissions [40,41]. The 21 CSA practices examined in this study - including submergence-tolerant, drought-tolerant, and insect-resistant crop varieties, as well as sustainable soil management, crop rotation, and others - simultaneously support all three pillars. Their regular use by smallholder farmers in the char areas of Bangladesh is crucial for counteracting the adverse effects of climate change, improving food security, and safeguarding livelihoods in these highly vulnerable regions [40-44].

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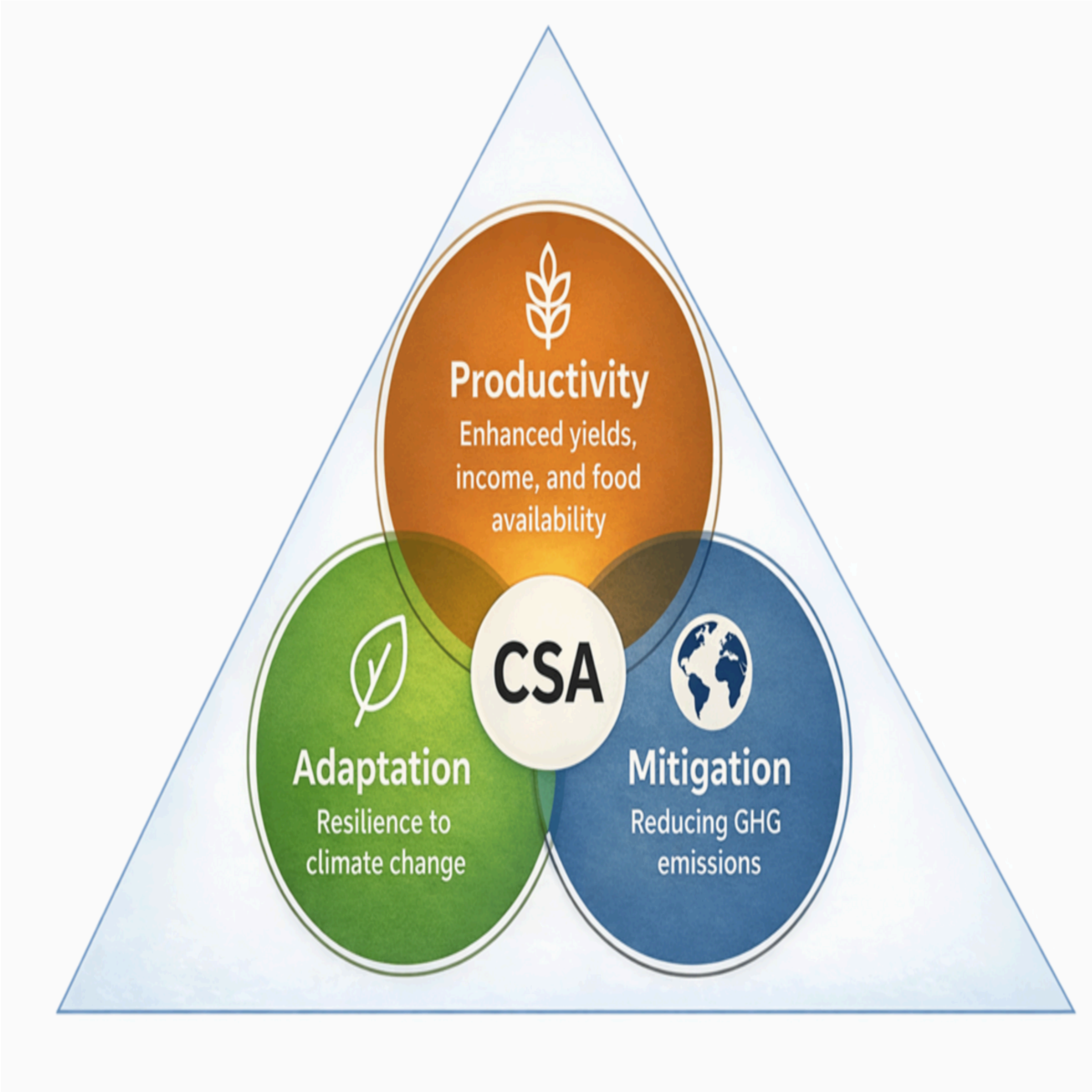

FIGURE 1: Three pillars of CSA

CSA, Climate-Smart Agriculture; GHG, Greenhouse Gases

To enhance climate resilience in riverine char areas, it is crucial to understand the current status of CSA usage. Although significant research on CSA in Bangladesh exists, much has focused on coastal areas [45-51]. These studies have investigated various aspects, such as the status of CSA practices, adoption levels, and determinants influencing CSA uptake. Additionally, other research has explored topics like farmers' attitudes towards CSA [52], knowledge of CSA practices [53], and the impact of CSA adoption on food security [54,55]. However, riverine char areas, a highly climate-vulnerable ecosystem where smallholder farmers face frequent floods, droughts, and riverbank erosion, remain largely unexplored. No previous study has comprehensively assessed the adoption of CSA practices or the factors influencing their uptake in these regions. Therefore, the aims of this study are as follows:

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1. To assess the current status of use of CSA practices among smallholder farmers in char-dominated areas of Jamalpur district, and

2. To identify the socio-economic and personal factors influencing the use of these practices.

The findings will provide evidence-based insights to guide interventions, capacity-building initiatives, and policies aimed at enhancing CSA adoption and strengthening agricultural resilience in this climate-vulnerable region.

Materials And Methods

Research design

A mixed-methods research design was used, combining both quantitative and qualitative approaches (Figure 2). Primary quantitative data were collected through structured household surveys, while qualitative data came from Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs). This combination helped gain a clearer understanding of how smallholder farmers use CSA practices and the factors that influence them. The FGDs provided farmers with an opportunity to share their views and experiences, thereby adding context to the survey results. KIIs with knowledgeable individuals also provided important insights that strengthened the depth and reliability of the findings.

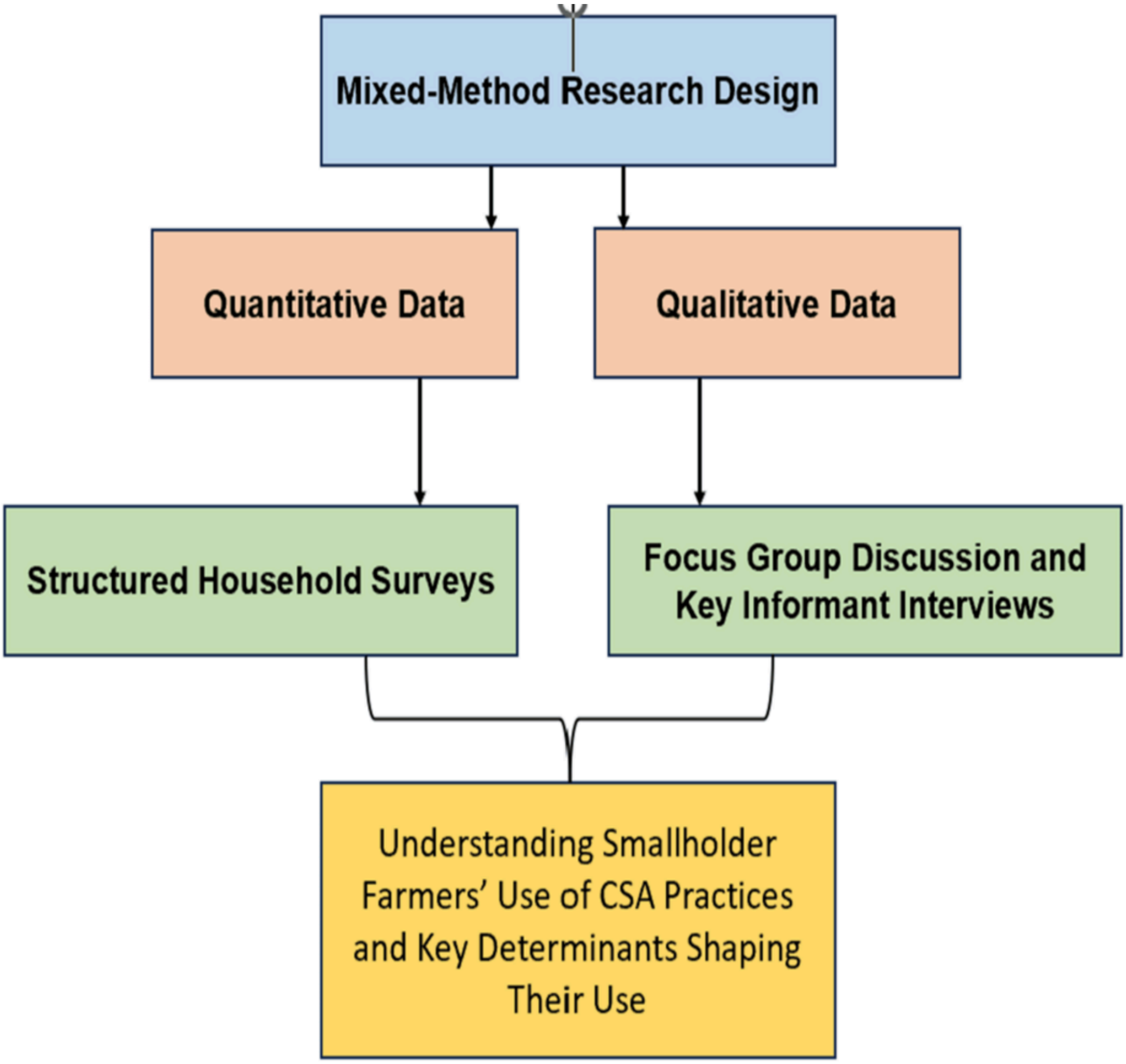

FIGURE 2: Design of the research

CSA, Climate-Smart Agriculture

Study region

The study was conducted in Islampur Upazila (sub-district) of Jamalpur District, Bangladesh, situated between the Brahmaputra and Jamuna rivers (Figure 3). This upazila was specifically selected because of its char-dominated landscape, where smallholder farmers are highly dependent on agriculture and face frequent climate-related challenges such as irregular seasonal floods, droughts, and riverbank erosion [56,57]. Within Islampur, two unions (Belgachha and Kulkandi) were selected due to their proximity to the Jamuna River and heightened vulnerability to climatic extremes, as noted by the Upazila Agriculture Officer and Sub-Assistant Agriculture Officers. A union is the smallest administrative unit in rural Bangladesh. To ensure the study was feasible while capturing relevant diversity, six villages were purposively selected with guidance from Sub-Assistant Agriculture Officers, who possess extensive knowledge of the local farming communities. These villages were chosen because they feature intensive agricultural activity and are representative of the ecological and socio-economic challenges faced by smallholder farmers in the char ecosystems. This purposive selection ensures the study captures the realities of farming under climate stress, providing a robust context for investigating the use of CSA practices.

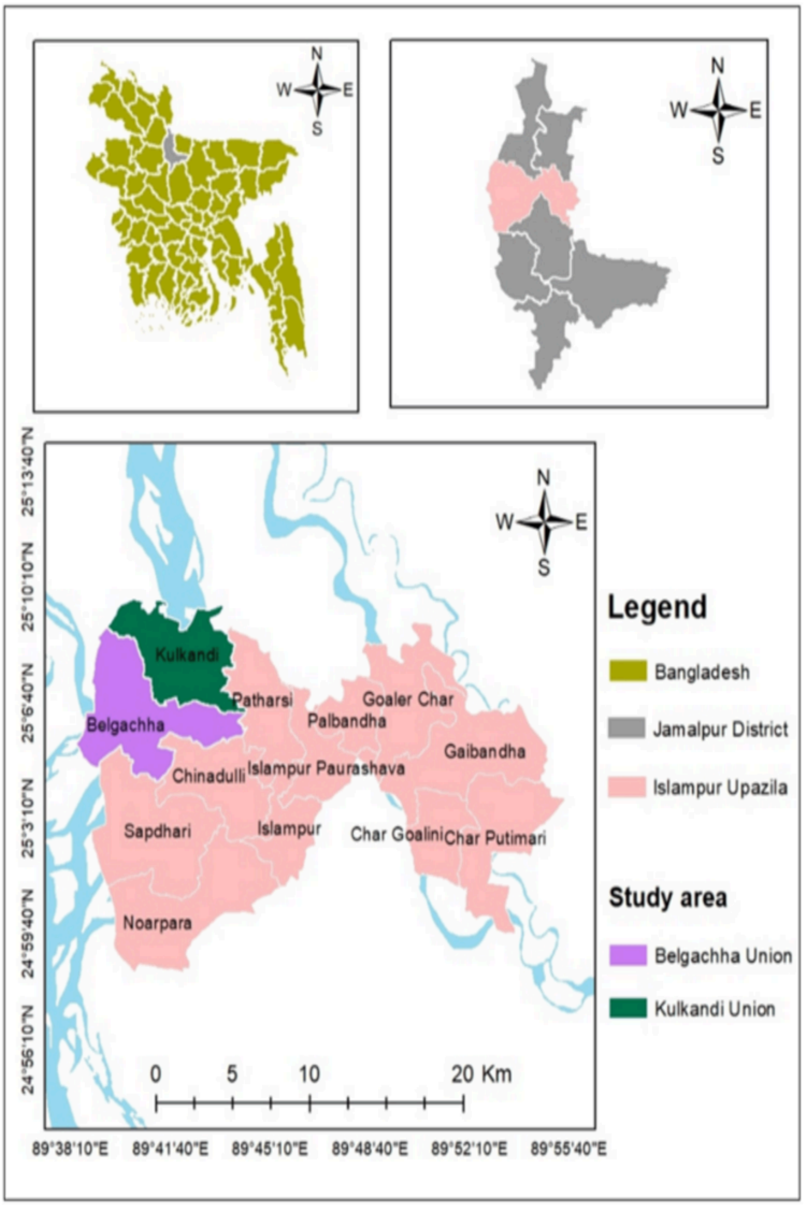

FIGURE 3: Map of the study region

Population and sample

The target population for this study consisted of the smallholder farmers residing in the six villages (Belgaccha, Monia, Shindhurtoli, Akandapara, Atiashiri, and Jigatala) of the char regions within the Belgacha and Kulkandi unions of the Islampur Upazila. In Bangladesh, farm households that own or operate farms of less than 1 hectare are classified as smallholder farmers [12]. The researcher purposively selected smallholder farmers because, according to the respective Upazila Agriculture Officer and other agricultural officials, the majority of farmers in char areas are smallholders who are especially susceptible to climate change. There were 2,395 smallholder farmers spread among the six villages of the Belgaccha and Kulkandi union. A sample of 20% was drawn from each village using the simple random sampling method, which resulted in a total sample size of 480, as illustrated in Figure *4*. This sample size is sufficient to generate reliable estimates at a 95% confidence level with an approximate margin of error of ±4%, which is considered acceptable for large populations in social science research [58]. In addition, practical considerations such as time availability, research funding, and the need to ensure data quality during field-level data collection were taken into account when finalizing the sample size [59].

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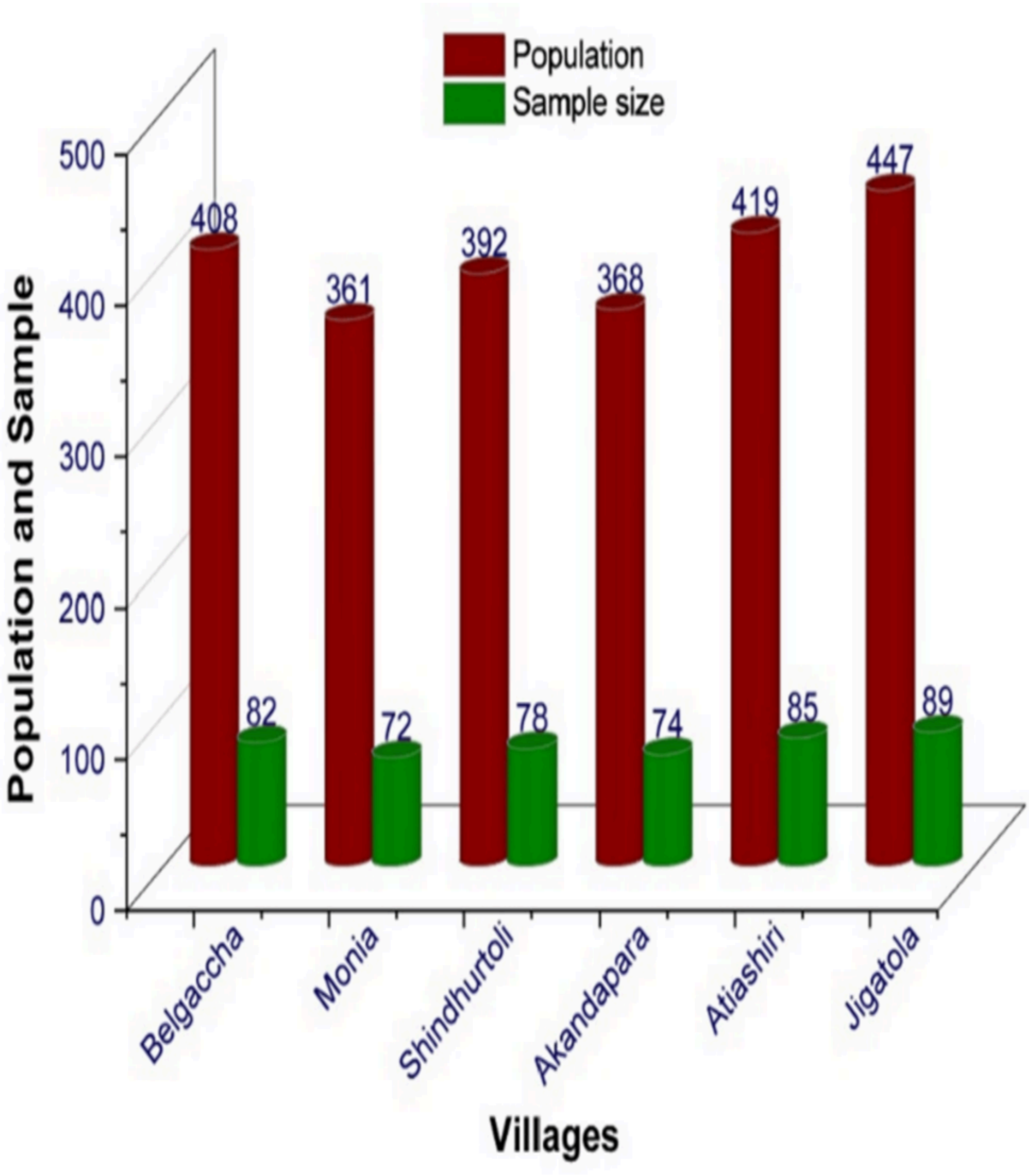

FIGURE 4: Breakdown of population and sample

Data sources

Household Survey

A structured questionnaire was designed based on a relevant literature review, FGDs, and KIIs to gather data from individual farmers. The first section of the questionnaire aimed to gather information on key characteristics of smallholder farmers, including age, educational level, household size, farm size, annual family income, farming experience, agricultural training experience, organizational participation, extension media contact, risk perception of climate change, and knowledge of CSA practices, which served as the independent variables. The second section of the questionnaire addressed the study's focus variable, measuring the extent of use of CSA practices. Subsequently, the questionnaire was used to conduct 480 in-person interviews with the respondents between May and August of 2024. Although formal ethical approval was not required for this survey-based study, informed consent was obtained from all participants before data collection. Participants were informed about the study objectives, and their responses were treated confidentially to ensure privacy.

FGDs and KIIs

Initially, two FGDs were conducted with groups of 12 smallholder farmers from each of the two selected unions, along with four KIIs involving four model farmers (two from each union). The number of participants per FGD was chosen to ensure active participation while maintaining manageability and depth of discussion. Model farmers were selected as key informants due to their experience and knowledge of locally adapted CSA practices, ensuring that the discussions captured informed perspectives. These activities aimed to identify locally relevant CSA practices and gather contextual insights that aided in developing the structured questionnaire.

After collecting and preliminarily analyzing the quantitative data, two more FGDs - with groups of 10 smallholder farmers - and four additional KIIs were conducted: two with SAAOs, one with the Upazila Agriculture Officer (UAO), and one with the Agriculture Extension Officer (AEO). These interactive sessions were held to explore the patterns observed in survey findings in greater detail. The KII participants were deliberately chosen for their knowledge and experience in local farming practices and agricultural policies, which allowed the discussions to delve more deeply into the patterns observed in the survey data. The qualitative data obtained from these discussions provided deeper insights into the reasons behind the regular use of certain CSA practices and the obstacles to adopting others. Participants shared practical experiences, perceptions, and motivations, which contributed to a richer interpretation of the quantitative results and a better understanding of CSA use among smallholder farmers in the char areas.

Secondary Data Sources

Secondary data were collected from several channels, including peer-reviewed journals, published reports, institutional documents, and other academic sources, to complement the original data.

Measurement of variables

Measurement of the Independent Variables (Personal and Socio-Economic Characteristics) of the Farmers

According to Mischel [60], an individual's behavior is primarily shaped by inherent personal attributes. Based on this perspective, it is reasonable to hypothesize that farmers' personal and socioeconomic characteristics significantly influence their use of CSA practices. This study identified 11 personal and socio-economic characteristics as independent variables. These were selected after a thorough assessment of the rural context, practical considerations regarding data collection, expert consultations, and a thorough review of relevant literature [45,46,49,55,61-68]. The scoring and measurement approaches for these variables were adapted from established instruments used in prior studies [33,69], as illustrated in Table *1*. The features and essential characteristics of the respondents are described using descriptive statistics, including frequency, mean, standard deviation (SD), and percentage [70].

Respondents' characteristics	Unit of measurement (possible score range)	Scoring criteria
Age	Years (Unknown)	One point for each year from birth
Educational level	Years of schooling (Unknown)	One point per year of formal education; No schooling = 0
Household size	Number (Unknown)	Total count of family members
Farm size	Hectare (up to 1 hectare)	Total land area used for farming
Annual family income	Bangladeshi Taka (BDT) (Unknown)	Total earnings in a year (1,000 BDT = 1 unit)
Farming experience	Years (Unknown)	Total number of years engaged in active farming; One point assigned per year
Agricultural training experience	Days (Unknown)	The cumulative count of days of training attended
Organizational participation	Scale score (Unknown)	3 = President/Secretary; 2 = Executive Member; 1 = General Member; 0 = No participation
Extension media contact	Scale score (0-45)	3 = Frequently; 2 = Occasionally; 1 = Rarely; 0 = Not at all
Risk perception of climate change	Scale score (0-36)	3 = High risk perception; 2 = Medium risk perception; 1 = Low risk perception; 0 = No risk perception
Knowledge of CSA practices	Scale score (0-50)	Scores were assigned based on the importance of questions related to CSA knowledge

TABLE 1: Measurement of independent variables in this study

CSA, Climate-Smart Agriculture

Measurement of the Use of CSA Practices

The use of CSA practices by smallholder farmers was the primary focus variable in this study, assessed using a four-point rating scale. A total of 21 CSA practices were identified as suitable for the riverine char areas, based on the three pillars of CSA: Productivity, Adaptation, and Mitigation [40]. These were derived from an extensive review of relevant literature [15,35,42,49,55], as well as insights gained from two initial FGDs with smallholder farmers and four KIIs with model farmers. The 21 selected CSA practices, along with their respective contributions to the three CSA pillars - productivity, adaptation, and mitigation, are presented in Table *2*.

Sl. No.	CSA practices	Impact on CSA pillars		
		Productivity	Adaptation	Mitigation
1	Use of submergence-tolerant high-yielding rice varieties	Increases crop yield and reduces yield variability during floods [71].	Survives short-term submergence during floods [35].	Helps in increasing soil carbon storage [71].
2	Use of drought-tolerant, high-yielding rice varieties	Increases crop yield and reduces yield variability during drought [71].	Tolerates heat and water stress [72].	Helps in increasing soil carbon storage [71].
3	Use of flood-tolerant, high-yielding jute varieties	Increases crop yield and reduces yield variability during floods [71].	Grows well in flood-prone areas [35].	Helps in increasing soil carbon storage [71].
4	Use of insect-resistant rice varieties	Increases crop yield and reduces yield variability during insect infestations [71].	Resists insect attacks [35].	Helps in increasing soil carbon storage [71].
5	Use of early-maturing, high-yielding Aman rice varieties	Increases crop yield and reduces yield variability [71].	Can be transplanted after delayed floods, and subsequent Rabi season (mid-October to mid-March) crops can be planted timely [73].	Helps in increasing soil carbon storage [71].
6	Cultivation of high-yielding maize varieties	High yields with lower input costs [74].	Withstands drought and rain extremes [75].	Emits much less methane than rice [76].
7	Cultivation of leguminous crops (dhaincha, pulses)	Increases yield and soil fertility [77].	Improves soil fertility and water-holding capacity, increasing resilience to climate change [71].	Reduces the need for nitrogen fertilizers, thereby helping to lower nitrous oxide emissions [35].
8	Incorporation of short-duration mustard into cropping pattern	Increases cropping intensity, hence income [78].	It helps compensate for yield losses in Kharif-2 (July to mid-October) crops caused by adverse climatic conditions such as late floods and heavy rainfall, while also enabling timely planting of Rabi season crops.	Helps in increasing soil carbon storage [71].
9	Practice of alternate wetting and drying (AWD) in rice cultivation	Cuts irrigation costs while maintaining yield [79].	Improves drought resilience by training rice plants to develop deeper root systems, resulting in a 15-30% water savings [79].	Lowers methane emissions [80].
10	Practice of minimum or zero tillage	Improves soil health, including structure, porosity, and infiltration, thereby enhancing crop yield over time [81].	Minimal soil disturbance helps build soil organic matter and improves water infiltration, making soils more resistant to droughts and heavy rains [81,82].	Increases soil carbon storage and reduces carbon loss [71].
11	Application of green manure	Improves soil fertility and hence yield [83].	Enhances the moisture retention and infiltration capacity of soil, thereby	Reduces fertilizer dependency, thereby lowering associated

			improving drought resistance [82].	greenhouse gas emissions [35].
12	Use of organic manures (cow dung, farmyard manure)	Enhances soil fertility and hence yield [35].	Retains moisture in soil and improves soil health [82].	Reduces fertilizer dependency, thereby lowering associated greenhouse gas emissions [35].
13	Use of compost (household wastes)	Enhances soil fertility and hence yield [35].	Retains moisture in soil and improves soil health [82].	Reduces fertilizer dependency, thereby lowering associated greenhouse gas emissions [35].
14	Practice of crop rotation	Improves yield and soil nutrient cycling [84].	Lowers climate-induced pests [85].	Reduces fertilizer and pesticide dependency, thereby lowering associated greenhouse gas emissions [35].
15	Practice of intercropping/mixed cropping	Enhances yield and income diversity [86].	Lowers climate-induced pests [86].	Reduces fertilizer and pesticide dependency, thereby lowering associated greenhouse gas emissions [35].
16	Incorporation of crop residues into soil	Enhances soil health and hence crop yield [87].	Retains moisture in soil and improves soil health [82].	Avoids residue burning GHG emissions [88].
17	Practice of mulching	Improves water efficiency, regulates soil temperature, suppresses weed growth, and increases organic matter, hence increasing crop yield [89].	Conserves soil moisture in drought conditions and extreme heat [89].	Organic mulches increase soil carbon storage [89].
18	Practice of IPM	Promotes healthier crops, higher yields, and reduced production costs [90].	Controls pests amid climate shifts [35].	Reduce the need for chemical pesticides, lowering carbon footprints [35].
19	Practice of raised-bed homestead vegetable cultivation	Year-round food and income [35].	Ensures food during primary crop failure [35].	Increases soil carbon sequestration [71].
20	Use of hanging macha	Increases productivity of vine-type vegetables [35].	Vegetables can be grown during flood conditions [35].	Increases soil carbon sequestration [71].
21	Use of solar-powered irrigation	Reduces electricity costs and hence increases income [91].	Ensures water availability regardless of unreliable rainfall patterns and drought conditions [91].	Avoids fossil fuel emissions [92].

TABLE 2: Selected CSA practices with their associated impacts on CSA pillars

CSA, Climate-Smart Agriculture; GHG, Greenhouse Gases; IPM, Integrated Pest Management

Participants were asked to rate their usage of each practice on a four-point scale: "regularly" (3), "occasionally" (2), "rarely" (1), and "never" (0). A comparable method was followed in previous studies [61,69]. The total score for each respondent was obtained by aggregating the weighted replies across the 21 selected practices. This resulted in a possible range of scores from 0 to 63, representing the extent to which they used CSA practices.

Additionally, to attain a deeper comprehension of the use of individual CSA practices, the Use Index (UI) was computed [69]. The extent of use for each practice was determined by ranking them based on their UI values. The UI was calculated using the following formula:

UI of a CSA practice = $(P_{reg} \times 3) + (P_{occ} \times 2) + (P_{rar} \times 1) + (P_{nev} \times 0)$

Here,

P_{reg} = Percentage of farmers using the CSA practice regularly

P_{occ} = Percentage of farmers using the CSA practice occasionally

P_{rar} = Percentage of farmers using the CSA practice rarely

P_{nev} = Percentage of farmers who never use the CSA practice

The UI value for each CSA practice could range from 0 to 300. The practices were classified into three groups according to their UI values: 1-100 for "rarely used CSA practices," 101-200 for "occasionally used CSA practices," and 201-300 for "regularly used CSA practices."

Measurement of the Factors Influencing CSA Use and Analysis of Data

Multiple linear regression analysis was employed to identify the key factors influencing the use of CSA practices among smallholder farmers. Additionally, stepwise multiple regression analysis was performed to investigate further the contribution of each significant factor in explaining variations in the use of these practices. The multiple regression equation is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + e$$

Here,

Y = Dependent variable (smallholder farmers' use of CSA practices), β_0 = Regression coefficient, X = Independent variables, viz., X_1 = Age, X_2 = Educational level, X_3 = Household size, X_4 = Farm size, X_5 = Annual family income, X_6 = Farming experience, X_7 = Agricultural training experience, X_8 = Organizational participation, X_9 = Extension media contact, X_{10} = Risk perception of climate change, X_{11} = Knowledge of CSA practices, and e = Error term

Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) was used to encode and process the information gathered from the questionnaire surveys. Descriptive statistics, including frequency, mean, percentage, and SD, as well as inferential statistical analyses, such as multiple linear and stepwise regression, were employed using the Statistical Package for the Social Sciences (SPSS v. 25).

Results And Discussion

Socio-economic and personal characteristics of the respondents

The study examined 11 key socioeconomic and personal characteristics of smallholder farmers, which served as the independent variables. The descriptive statistics for these characteristics are presented in Table 3.

Characteristics	Observed range	Categories	Respondents (n = 480)		Mean	SD
			N	%		
Age	24-75	Young (18-35)	84	17.5	49.65	12.51
		Middle (36-55)	240	50		
		Old (above 55)	156	32.5		
Educational level	0-16	Illiterate (0)	196	40.8	4.67	4.75
		Primary (1-5)	108	22.5		
		Secondary (6-10)	136	28.3		
		Above secondary (above 10)	40	8.3		
Household size	2-11	Small (2- 4)	144	30	6.11	2.17
		Medium (5-7)	196	40.8		
		Large (above 7)	140	29.2		
Farm size	0.098-0.996	Landless (0.002-0.02 ha)	0	0	0.64	0.29
		Marginal (0.021-0.2 ha)	20	4.16		
		Small (0.21-0.99 ha)	460	95.84		
Annual family income	35-560	Low (less than 150)	256	53.3	175.64	100.04
		Medium (150-300)	184	38.3		
		Large (above 300)	40	8.3		
Farming experience	2-56	Low (up to 10)	60	12.5	28.22	13.47
		Medium (11-20)	112	23.3		
		High (above 20)	308	64.2		
Agricultural training experience	0-12	No training (0)	320	66.7	1.23	2.39
		Short (1 to 3 days)	96	20		
		Medium (4 to 7 days)	48	10		

		Long (above 7 days)	16	3.3		
Organizational participation	0-6	No participation (0)	296	61.6	0.87	1.48
		Low participation (1-2)	120	25.0		
		Medium participation (3-4)	44	9.2		
		High participation (above 4)	20	4.2		
Extension media contact	2-27	Low (up to 15)	340	70.8	12.07	6.14
		Medium (16-30)	140	29.2		
		High (above 30)	0	0		
Risk perception of climate change	18-28	Low (up to 12)	0	0	24.10	2.09
		Medium (13-24)	260	54.2		
		High (above 24)	220	45.8		
Knowledge of CSA practices	7-44	Poor (up to 17)	132	27.7	24.07	8.23
		Moderate (18-34)	284	58.3		
		High (above 34)	64	14.2		

TABLE 3: Characteristics profile of the respondents

CSA, Climate-Smart Agriculture; SD, Standard Deviation

Table *3* shows that half of the respondents (50%) were middle-aged. Regarding educational attainment, 40.8% were illiterate, which reflected limited access to formal schooling. The majority of households (40.8%) were in the medium-sized category, with a mean value of 6.11, which is greater than the national average of 4.26 for household size [93]. A significant majority (95.84%) owned small-sized farms, with an average farm size of 0.64 hectares, which is also slightly higher than the national average farm size, recorded at 0.60 hectares [94]. The average annual family income was BDT 175,640, equivalent to approximately $1,463 USD, with considerable variation among respondents. This value is below the average yearly family income of 2,855 USD reported in 2022 [93]. In terms of farming experience, most respondents (64.2%) had high farming experience, averaging 28.22 years, likely due to the older age composition. A large portion (66.7%) had never received agricultural training, highlighting a gap in capacity-building opportunities. The organizational participation of respondents was low, with 61.6% reporting no involvement. Similarly, 70.8% had low contact with extension media, suggesting limited exposure to agricultural information sources in the char region. Concerning climate change, 54.2% of respondents had a medium level of risk perception. Finally, 58.3% of respondents demonstrated a moderate level of knowledge of CSA practices.

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Respondents' use of CSA practices

The scores for the use of CSA practices by the respondents ranged from 12 to 54, within a possible range of 0 to 63, with a mean of 32.16 and a standard deviation of 9.91. Based on their level of use, farmers were categorized into three groups: rarely use (up to 21), occasionally use (22-42), and regularly use (43-63). As presented in Figure *5*, the majority (64.2%) of the farmers occasionally used CSA practices, while 18.3% used them rarely, and 17.5% used them regularly. These findings are consistent with previous studies reporting that a majority of farmers employed CSA practices at a moderate level in Rangpur district of Bangladesh and the King Cetshwayo District Municipality of South Africa [61,69].

It was observed through the FGDs that most farmers generally did not precisely know what CSA practices were, primarily because no organization had conducted any visible training program, group discussion, or mass campaigns on CSA practices in the study area. This data was further confirmed by the Upazila Agriculture Officer and Sub-assistant Agriculture Officers, who mentioned the absence of such initiatives. Similar findings have been reported for farmers in Fulbari Upazila, a char area of Kurigram district, where limited awareness of modern agricultural technologies and climate change adaptation practices was observed, likely due to insufficient training opportunities [42].

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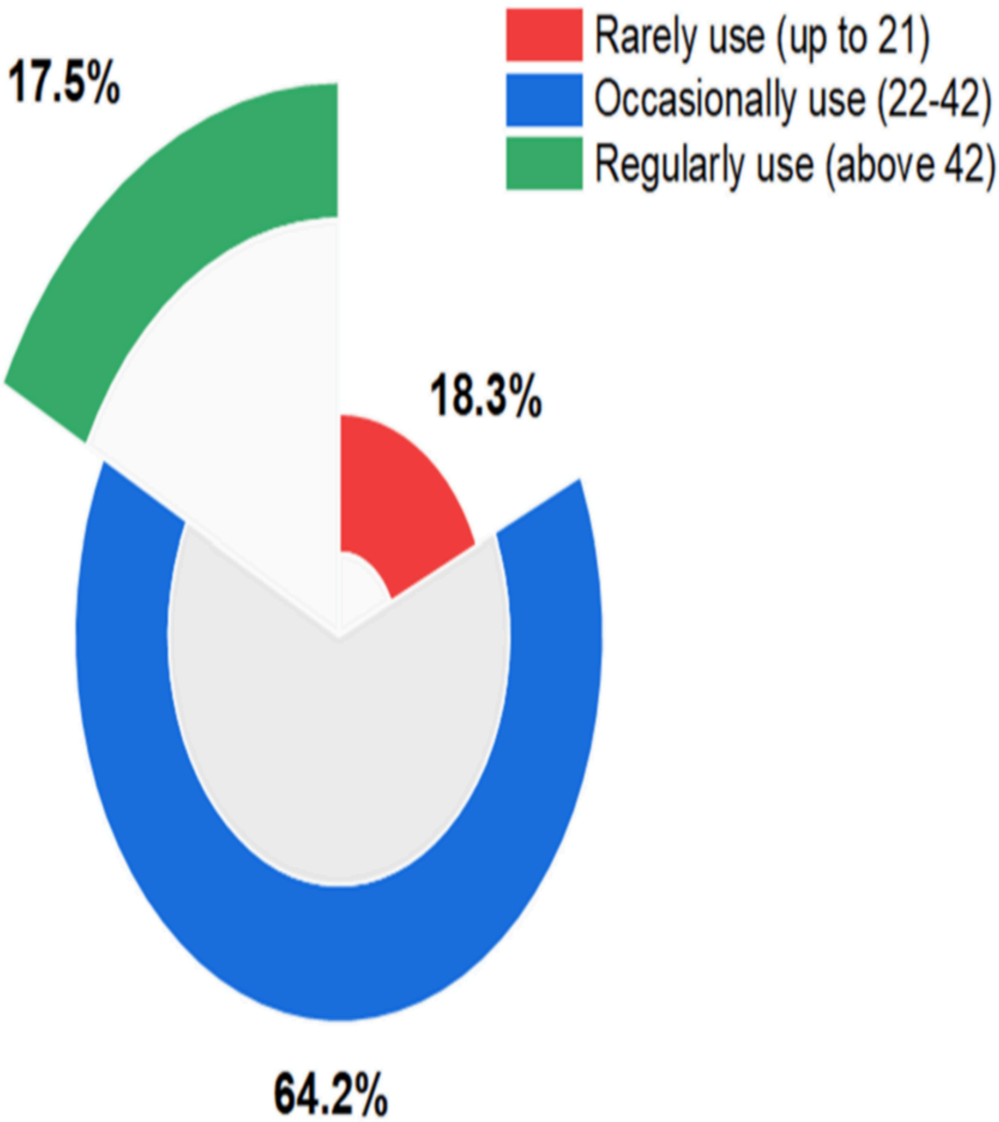

FIGURE 5: Distribution of the respondents based on their extent of use

However, when the CSA practices were named, most farmers were familiar with several of them. This is because not all CSA practices are entirely new [95]. Farmers have been using several CSA practices for generations as traditional practices for their specific advantages [15]. Practices such as the use of organic manures, crop rotation, incorporation of crop residues into soil, raised-bed homestead vegetable cultivation, etc., are well-known to farmers through their lived experiences. While they may not formally label these as CSA practices, they have substantial knowledge of them. They are actively implementing them to cope with the negative impacts of climate change. In contrast, more innovative and advanced CSA practices such as climate-resilient crop varieties, zero tillage, integrated pest management (IPM), mixed cropping, and solar-powered irrigation remain unfamiliar to most farmers and are therefore underutilized. Flood-tolerant, drought-tolerant, insect-resistant, and early-maturing crop varieties represent crucial components of CSA practices [96].

Unfortunately, many farmers had limited knowledge of such crop varieties. For instance, flood-tolerant jute variants could be crucial in tackling the specific issue of floods in char regions; nevertheless, awareness of these varieties is nearly absent.

Ranking of CSA practices based on respondents' use

The Use Index (UI) was computed to facilitate a comprehensive understanding of individual CSA practices. The UI scores for each CSA practice ranged from 0 to 300. As illustrated in Table *4*, the UI scores for the 21 selected CSA practices among respondents varied from 28 to 256. The following section provides a thorough discussion of the three most widely adopted CSA practices, supplemented by qualitative insights obtained through FGDs.

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Practices	Percentage of respondents with their practice				Use index (UI)	Rank order
	Regularly	Occasionally	Rarely	Never		
Regularly used CSA practices (UI range: 201-300)						
Cultivation of high-yielding maize	63	31	5	1	256	1
Practice of raised bed homestead vegetable cultivation	59	34	6	1	251	2
Practice of crop rotation	49	45	5	1	242	3
Incorporation of crop residues into the soil	52	32	14	2	234	4
Use of organic fertilizers	61	22	4	13	231	5
Occasionally used CSA practices (UI range: 101-200)						
Practice of alternate wetting and drying (AWD) in rice cultivation	35	40	15	10	200	6
Use of insect-resistant rice varieties	33	43	13	11	198	7
Use of submergence-tolerant high-yielding rice varieties	31	37	17	15	184	8
Cultivation of leguminous crops	34	34	11	21	181	9
Incorporation of short-duration mustard into cropping pattern	17	54	18	11	177	10
Use of early-maturing Aman varieties	24	38	28	10	176	11
Use of hanging macha	21	36	20	23	155	12
Application of green manure	6	44	23	27	129	13
Practice of intercropping/mixed	6	34	42	18	128	14

cropping						
Use of compost	6	35	32	27	120	15
Rarely used CSA practices (UI range: 1-100)						
Use of drought-tolerant high-yielding rice varieties	2	15	48	35	84	16
Practice of mulching	3	24	26	47	83	17
Practice of IPM	1	13	39	47	68	18
Practice of minimum or zero tillage	0	17	24	59	58	19
Use of solar-powered irrigation	12	3	2	83	44	20
Use of flood-tolerant high-yielding jute varieties	0	4	20	76	28	21

TABLE 4: Ranking of CSA practices based on respondents' use

CSA, Climate-Smart Agriculture; IPM Integrated Pest Management

"Cultivation of high-yielding maize varieties (UI-256)" was ranked first out of 21 CSA practices. Maize has recently become a popular Rabi season crop in the char areas, with many farmers transitioning from Boro rice. Several factors contribute to this shift, as identified through thematic analysis of FGDs and KIIs: (i) maize thrives in the sandy, less fertile soils of char areas; (ii) maize cultivation requires minimal tillage compared to rice; (iii) irrigation costs are substantially lower than for rice, requiring a maximum of three irrigations per season; (iv) maize yields are considerably higher than those of rice; and (v) maize has a stable market price comparable to rice and enjoys high demand in the feed industry [74]. Several FGD participants stated, "*Compared to rice, maize requires about three times lower input costs and produces nearly three times higher yields, which is why we have shifted to cultivating maize in the Rabi season*." High-yielding maize varieties also demonstrate greater resilience to adverse climatic conditions such as drought and heavy rainfall [97]. Consequently, maize cultivation has become widespread among farmers in the study area. Similar trends have been observed in the char areas of Kurigram District, where maize ranks second among the most widely adopted CSA practices [42].

"Practice of raised bed homestead vegetable cultivation (UI-251)" was ranked second. The main cultivable lands of farmers are generally situated in the char areas, which are at regular risk of climate vulnerabilities such as drought, heavy rains, hailstorms, irregular floods, and severe pest infestation. Every year, adverse climatic conditions cause some degree of damage to the main crops in the field. In some cases, all of the main crops may become damaged due to severe disasters [98]. Therefore, farmers in char areas attempt to cultivate as many vegetables as possible in their raised homestead areas to ensure food security to some extent during periods of crop failure. As one FGD participant explained, "*Because irregular floods and pests often damage our field crops, we grow vegetables on raised land around our homes so that we can at least feed our families*." Homestead gardening also provides a consistent food supply, reduces household food expenses, and enables income generation through the sale of surplus produce [35].

"Practice of crop rotation (UI-242)" was ranked third. Farmers in the char region typically avoid cultivating the same crop in successive seasons. For instance, if a vegetable farmer grows brinjal in one season, it is unlikely to be cultivated again during the subsequent season. This practice is based on the understanding that repeated cultivation of crops from the same family can increase weed and pest pressure and reduce yields [99]. Consistent with this understanding, several FGD participants reported regularly rotating crops as a preventive strategy to maintain yield stability. Previous studies have reported crop rotation as the most widely used climate-smart agriculture practice in other regions [61,67,100].

On the other hand, among the three rarely used CSA practices, the 'Practice of minimum or zero tillage (UI-58)' was ranked 19th. Most farmers believed that crop yields would be adversely affected without traditional tillage methods. Only a few farmers practiced zero or minimum tillage for black gram, garlic, and onion cultivation where direct seeding is practiced. This highlights the need for targeted training and awareness programs to improve farmers' understanding of zero-tillage benefits. Low adoption of zero tillage has also been reported in the char areas of Kurigram District [42] and in Central Ethiopia [65]. The 20th practice was "Use of solar-powered irrigation (UI-44)." The high initial investment required for installing solar-powered irrigation systems poses a considerable obstacle to adoption as noted in the FGDs. Similar results were observed, with cost identified as a major constraint to the implementation of solar-powered irrigation [101,102]. The absence of extension support further limits farmers' willingness to adopt this practice. In addition, it also requires a considerable amount of space in the fields, which the farmers did not want to use for solar-powered irrigation. "Use of flood-tolerant high-yielding jute varieties" received the lowest UI score (UI-28), ranking 21st among the CSA practices assessed. Low adoption was primarily due to a lack of awareness among farmers. Many FGD participants stated, "*We didn't know such flood-tolerant jute varieties could exist, so we keep growing our local available ones*." In addition, cultural preferences for traditional varieties, limited availability of improved seeds, and weak extension support were also noted, which further limited adoption. Farmers in char areas predominantly cultivate local crop varieties [103], reflecting similar trends.

Factors influencing respondents' use of CSA practices

A multiple linear regression analysis was performed to identify the key factors influencing smallholder farmers' use of CSA practices in the char areas. The regression results, along with the collinearity diagnostics, are presented in Table *4*. All Variance Inflation Factor (VIF) values were below the commonly accepted threshold of 10, indicating that no serious multicollinearity is present and that the regression estimates are unlikely to be biased. The model yielded an F-value of 230.56 and an adjusted R^2 of 0.84, indicating that the variables collectively accounted for approximately 84% of the variance in use of CSA practice. Of the 11 factors, level of education ($t = 3.197$, $p < 0.001$), household size ($t = 3.861$, $p < 0.001$), farm size ($t = 5.017$, $p < 0.001$), agricultural training experience ($t = 7.066$, $p < 0.001$), extension media contact ($t = 15.750$, $p < 0.001$), and knowledge of CSA practices ($t = 14.894$, $p < 0.001$) were found to be statistically significant.

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Explanatory variables	Unstandardized coefficients		Standardized coefficients (Beta)	t- value	Sig.	Collinearity statistics	
	B	Std. Error				Tolerance	VIF
(Constant)	8.32	2.713		3.067	0.002	0.161	6.211
Age (X_1)	-0.051	0.036	-0.065	-1.427	0.154	0.666	1.502
Level of education (X_2)	0.149	0.047	0.071	3.197	0.001	0.376	2.662
Household size (X_3)	0.525	0.136	0.115	3.861	0	0.416	2.405
Farm size (X_4)	4.727	0.942	0.142	5.017	0	0.397	2.522
Annual family income (X_5)	-0.005	0.003	-0.055	-1.902	0.058	0.187	5.361
Farming experience (X_6)	0.018	0.031	0.025	0.59	0.556	0.548	1.826
Agricultural training experience (X_7)	0.722	0.102	0.174	7.066	0	0.721	1.387
Organizational participation (X_8)	-0.049	0.144	-0.007	-0.343	0.732	0.46	2.176
Extension media contact (X_9)	0.684	0.043	0.424	15.75	0	0.947	1.056
Risk perception on climate change (X_{10})	-0.064	0.089	-0.014	-0.722	0.47	0.408	2.449
Knowledge of CSA practices (X_{11})	0.512	0.034	0.425	14.894	0	0.161	6.211

TABLE 5: Overview of multiple linear regression analysis

n = 480, R = 0.919, R2 = 0.844, Adjusted R2 = 0.840, F value = 230.56
Source: Own analysis
VIF, Variance Inflation Factor

Table *5* shows that the respondents' educational background had a positive influence on the use of CSA practices. The regression coefficient indicates that a one-unit increase in educational levels corresponds to a 0.149-unit increase in the use of CSA practices. This finding suggests that farmers with a higher level of education are more inclined to adopt and effectively implement CSA practices because they are most likely to comprehend the benefits, mechanisms, and

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application techniques of CSA practices [104]. Furthermore, education enhances their ability to access, interpret, and utilize information from extension services, training manuals, and agricultural publications. It also fosters greater awareness of climate change and its impacts, thereby increasing the likelihood of adopting adaptive strategies. This conclusion is consistent with previous research, which found that the educational qualifications of farmers have a substantial influence on the adoption of CSA practices [46,61,64,67,68,105].

Household size was also found to have a significant and positive influence on CSA practice use. An increase in household size by one member results in a 0.525-unit rise in CSA use. Larger households often have a higher probability that at least one member is educated, trained, or informed about CSA practices. This individual can play a crucial role in sharing knowledge and encouraging the adoption of CSA practices within the household. This observation aligns with previous studies, which reported that household size has a positive effect on the adoption of sustainable agricultural practices [46,106].

Farm size exhibited a strong positive association with CSA use, as indicated by a regression coefficient of 4.727, suggesting that a one-unit increase in farm size leads to a corresponding increase of 4.727 units in CSA use. Larger farm sizes enable farmers to trial innovative practices on a portion of their land while maintaining traditional methods elsewhere, thereby mitigating risk. In contrast, farmers with relatively small farm sizes tend to be more cautious, often avoiding innovative agricultural practices due to concerns about potential losses that could be difficult to recover. These results correspond with prior research, which observed that farmers with larger landholdings are more likely to adopt CSA practices [46,64,107,108].

The smallholder farmers' agricultural training experience had a significant positive coefficient value of 0.722 in their adoption of CSA practices. The regression coefficient indicates that for every one-unit increase in agricultural training experience, the use increases by 0.722 units. Jellason et al. [109] emphasized that training serves as a safety mechanism, enabling farmers to understand, implement, and refine innovative techniques with minimal risk. This outcome is consistent with previous findings, which reported that participation in training enhances farmers' capacity to use CSA practices [110-112].

The smallholder farmers' extension media contact had a significant positive coefficient value of 0.684, indicating a positive relationship with their use of CSA practices. If the extension media contact changes by 1 unit, the use changes by 0.684 units. This means that farmers having extensive contact with extension media utilize CSA techniques more frequently. Extension services facilitate knowledge transfer [113,114], provide skill-based training [115,116], and offer supplementary inputs such as seeds to encourage CSA adoption [117]. In developing regions with minimal access to agricultural markets, extension services serve as a critical channel for disseminating CSA practices [112]. This finding is supported by prior studies [63,65,66], emphasizing the significance of extension services in facilitating the adoption of CSA.

Farmers' knowledge of CSA practices had a significant positive coefficient value of 0.512 in their use of CSA practices. If knowledge of CSA practices changes by one unit, the use changes by 0.512 units. That means farmers with a high level of knowledge about CSA practices tend to use them more frequently. Similar findings were reported, showing that farmers with greater knowledge of CSA practices were more likely to implement them [118]. Knowledgeable farmers understand the benefits and application methods of CSA practices, making them more inclined to integrate these techniques into their farming systems.

Furthermore, a stepwise multiple regression analysis was conducted to understand the contribution of each significant variable in explaining the variance in the use of CSA practices among smallholder farmers (Table *6*).

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Model	Combination of the factors	Coefficient of determination	Adjusted R^2	Percent of increase in adjusted R^2
1	Constant+X_{11}	0.837	70.0	70.0
2	Constant+X_{11}+X_9	0.901	81.0	11.0
3	Constant+X_{11}+X_9+X_7	0.909	82.4	1.4
4	Constant+X_{11}+X_9+X_7+X_4	0.914	83.5	1.1
5	Constant+X_{11}+X_9+X_7+X_4+X_3	0.916	83.8	0.3
6	Constant+X_{11}+X_9+X_7+X_4+X_3+X_2	0.918	84.0	0.2

TABLE 6: Result of stepwise multiple regression analysis

Here, X_{11} = Knowledge of CSA practices, X_9 = Extension media contact, X_7 = Agricultural training experience, X_4 = Farm size, X_3 = Household size, X_2 = Educational level

Source: Own analysis

The stepwise multiple regression analysis revealed that knowledge of CSA practices (X11) expresses the focus variable by 70%, extension media contact (X9) by 11%, agricultural training experience (X7) by 1.4%, farm size (X4) by 1.1%, household size (X3) by 0.3%, and finally educational level (X2) by 0.2%. Overall, the findings highlight that improving farmers' knowledge and access to extension services are critical for enhancing the use of CSA practices, while other variables play a comparatively minor role. Research in Gujarat, India, reported that knowledge-related variables were important contributors to explaining farmers' awareness and adoption of climate-smart agriculture technologies [119].

Voices from the char areas: reflections from the FGDs

Valuable qualitative insights were elicited through the FGDs, providing a broad understanding of the lived experiences of farmers in the char areas. Farmers reported significant changes in weather patterns recently, with irregularities becoming increasingly pronounced. Many of them said, "*The present weather is entirely different compared to the past years when our ancestors were engaged in farming*," and "*Nothing is happening as it happened several years ago. The rains are occurring unpredictably. The floods are coming earlier or later than anticipated. Winter is coming very late. During winter, there are a few icy days, followed by a sudden and rapid increase in temperature.*" These climatic shifts have severely affected crop production. Jute, a major crop in the Kharif-1 season (mid-March to June), is increasingly impacted by untimely floods, early floods damage standing crops, while delayed floods hinder proper retting. Some farmers explained, "*We used to plant jute a few days before Baishakh (Bengali Year - Mid-April to Mid-May), and it would be ready for harvest just before the seasonal floods. However, with the changing flood patterns, it has become increasingly difficult to harvest jute on time. Recently, we have not been able to achieve the same quality of jute as before due to this issue*." Aman rice, the major crop in the Kharif-2 season (July to mid-October), faces similar challenges. Floods delay planting and transplanting, disrupting the entire cropping calendar. According to many farmers, "*When we apprehend that the floodwaters are receding, we usually sow Aman rice seeds in our raised homestead areas. However, often, when the seedlings are ready for transplanting, the water level in the main field remains high, or another flood occurs during this period. As a result, we cannot transplant the seedlings at the right time*." Pest infestation has also increased, especially in vegetables and Aman rice. Farmers noted, "*In the past, a specific pesticide application was sufficient for our chili and brinjal crops. Now, we have to apply multiple pesticides three to four times a month to achieve the same result*," and similar trends were also reported for Aman rice.

To cope with these challenges, farmers adopt various strategies. When floods delay jute retting, some farmers dig pits to expedite the process, but this often compromises the quality of the jute. When jute crops are severely damaged, the Department of Agricultural Extension often provides Aman rice seeds to help farmers recover their losses. Farmers in low-lying areas opt for submergence-tolerant varieties, such as BRRI (Bangladesh Rice Research Institute) Dhan 51 and BRRI Dhan 52. However, as one pointed out, "*These submergence-tolerant rice varieties can be planted early, but the yield is lower than that of other Aman rice varieties.*" Consequently, most prefer to plant high-yielding BR22 and BR23 varieties after the floodwaters recede. In the event of Aman rice failure, some farmers switch to early-maturing rice varieties, such as BINA (Bangladesh Institute of Nuclear Agriculture) Dhan7, or plant short-duration mustard, like BARI (Bangladesh Agricultural Research Institute) Sarisha14, to maintain the cropping sequence. Maize has emerged as a popular Rabi (winter season) crop due to its lower input cost and higher profitability. One participant shared, "*I can plant maize in my field with less tillage than rice. Three irrigations are sufficient for the entire season, and the pesticide cost is also very low. The yield is higher than rice, and I can sell my maize at the same price as rice*." Many farmers echoed, "*We can earn an outstanding amount of profit by cultivating maize, which helps compensate for other crop losses throughout the year due to climate adversity*."

When asked about CSA practices, most farmers struggled to identify them due to the absence of formal training or awareness programs. However, once examples were mentioned, they recognized several practices. The key findings on CSA practices discussed during the FGDs are presented in the relevant sections. Finally, the farmers provided several suggestions to improve agricultural conditions in the char areas: seeds of submergence-tolerant jute should be made available; more high-yielding submergence-tolerant Aman rice varieties should be developed; quality seeds of resilient crops and vegetables should be made readily available locally; training opportunities should be expanded; communication infrastructure should be improved to ease communication and market access; and visits of extension personnel should be increased for better support and guidance.

Conclusions

More than half of the smallholder farmers (64.2%) were found to have occasionally used CSA practices in the study area. This moderate use largely reflects farmers' prior experience with traditional practices such as maize cultivation, homestead vegetable production, crop rotation, crop residue incorporation, and organic fertilizer use, which are applied based on lived experience rather than formal recognition as CSA. In contrast, more technically advanced practices, including climate-resilient crop varieties, zero-tillage, integrated pest management, mixed cropping, and solar-powered irrigation, remain underutilized due to limited familiarity and awareness. Factors such as knowledge of CSA practices, contact with extension services, agricultural training, farm size, household size, and educational level were identified as significant variables influencing smallholder farmers' use of CSA practices. Among these, knowledge of CSA practices and extension media contact emerged as the most influential determinants, indicating that farmers with better understanding and regular access to information are more likely to adopt CSA practices.

Improving CSA adoption in char areas therefore requires strengthening farmers' knowledge through structured training programs, participatory group discussions, and mass awareness campaigns on climate-smart agriculture. Practical approaches, such as farmer field schools and mobile-based extension services, should be expanded to ensure effective delivery of information, particularly to small-scale and less-educated farmers, who make up a large share of households in char areas and are often left out of formal support systems. Promoting climate-resilient crop varieties should also be prioritized to enhance farmers' capacity to cope with climate-related risks. Furthermore, encouraging farmer-to-farmer learning and integrating modern CSA knowledge with locally practiced techniques can help shift CSA use from occasional to regular practice. Future research could adopt a longitudinal design to track changes in CSA adoption over time in dynamic char areas and include economic cost-benefit analyses to provide actionable insights for policymakers and investment decisions.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

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Data Availability Statements

The datasets (and/or code) supporting this study are available from the corresponding author upon reasonable request.

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