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The Padma Paradox: Irrigation Benefits and Waterlogging Challenges Drive CSA Adoption in Bangladesh

Md Akter Faruk Fuad[1*], Md. Safiul Islam Afrad[2], Foyez Ahmed Prodhan[2]

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ABSTRACT

The Padma River is one of the prime irrigation sources for Bangladesh. But the impacts of climate change are making it difficult to use water resources to enhance agricultural productivity properly. Climate-Smart Agriculture (CSA) practices are the most notable among the proposed solutions. This paper examines the adoption of CSA approach within the territory under Dohar sub-district of Padma River Basin. This study collected data from 180 farmer families through personal interviews with a large body of literature. The water of Padma River is generally suitable for agricultural purposes because the pH level is periodically found within the range normal for plant growth. However, the variable oxygen levels in water affect aquatic organisms and also crops. Besides, waterlogged low-lying topography coupled with poor drainage facilities often creates problems like monsoon-induced waterlogging making it tough to successfully manage crops. Our study highlights that CSA has so many advantages like enhanced crop diversity and nutrition as well as reduced costs, but several factors hinder its adoption. The problems identified include waterlogging stresses, temperature increases, and limited awareness of stress-tolerant varieties. Overcoming these challenges requires support through location-specific agroforestry initiatives, assistance to local private farms, and financial support for poly-shed farming. To get the full potential of CSA, we suggest a strategic approach to this end- extension services that are well-directed and include more access to climate information as well as financial support for farmers. Through the ways identified in alleviating the above-mentioned difficulties Bangladesh can enhance agricultural resilience which indeed represents a milestone in reducing vulnerability to climate change and ensuring food security for its people.

INTRODUCTION

Bangladesh is predominantly composed of floodplains and is therefore dependent on the natural systems (Islam *et al.*, 2021). It is prone to hydrometeorological extremes such as floods, tropical storms, and saltwater intrusion, as well as dry spells due to environmental factors (Barua *et al.*, 2021; Baas & Ramasamy, 2008). All of these climatic factors affect the framework of agriculture severely (Swami, 2019; Nwanze & Fan, 2016; Arfanuzzaman *et al.*, 2016).

The Padma serves as a significant irrigation source for the adjacent chars and farmlands in the Dohar subdistrict (Islam *et al.*, 2021). The Padma River spans 34 kilometers in Dohar, with a mean flow rate of approximately 30,000 m/sec (McLean *et al.*, 2012). The topography of the river is complex due to neotectonics, fluvial action, and sediment deposition during the right bank distributary activity (Islam, 2016). Consequently, the Padma river has rendered this subdistrict one of the most vulnerable areas. Climate change has broken this river system and caused irregular monsoon rainfall, which has aggravated the problem of soil erosion along the riverbanks, thereby putting people's livelihoods and agricultural production at risk (Huq *et al.*, 2015; Ahmed *et al.*, 2020; Hasan *et al.*, 2017).

The geographical position of the region, combined with irregular and uneven rainfall, further complicates the problem of flooding in many districts of this country, a situation exacerbated by climate change (MOA, 2023). Therefore, farmers are implementing a variety of traditional adaptation strategies to counteract the adverse impacts of climate change. The Department of Agriculture Extension (DAE), supported by other NGOs, developed Climate Field School in 2010 as an informal platform to disseminate information, such as, floating vegetable bed and dyke cropping (Mahashin, 2019; Mandal, 2016; Alam *et al.*, 2013). As a result, the farmers' awareness has increased to utilize the natural resources to grow year-round crops in southern saline prone regions (Farouque & Sarker, 2018).

Climate-smart agriculture (CSA) is a new paradigm that offers measures for enhancing food security and betterment of livelihoods as well as contributing to economic development in a changing climate. CSA offers a potential solution to climate-related challenges and nutritional insecurity. This is achieved through improving productivity along with the conservation of biodiversity as well as the health of the ecosystem. It recognizes the linked problems of food security, agricultural productivity, ecosystem, and biodiversity (FAO, 2020; Swami, 2019; Branca *et al.*, 2011; Brüssow *et al.*, 2017). The multifaceted approaches of CSA outperform traditional techniques, particularly in terms of farm productivity and farm income in southern Bangladesh (Mahashin &

[1] Department of Agriculture Extension, Ministry of Agriculture, Bangladesh
[2] Faculty of Agriculture Bangabandhu Shiekh Mujibur Rahman Agricultural University, Bangladesh
[*] Corresponding author's e-mail: fuad.ag2306@gmail.com

Roy, 2017). Adoption of CSA directly correlates with the food security of coastal households (Hasan *et al.*, 2018). Bangladesh's national CSA strategy focuses on intensifying cropping systems and improving water and soil health management.

Proper land management practices are required, when food requirements are increasing, but the farmlands are shrinking proportionally. We must address the hunger issue in Bangladesh by enhancing farmers' productivity and profits while maintaining sustainability (Sarker *et al.*, 2021). In this regard, the DAE, the main agency for agriculture, has made notable efforts to extend the CSA practices, particularly in ecologically vulnerable areas such as saline, flood prone and river basin areas (KD, 2024). Regular monitoring and follow-up are important for disseminating newer agricultural technology (Akter *et al.*, 2022; Acharyya, 2021). The extension officers are working on energy conservation and emission reduction measures, while farmers are also actively engaging in various training, demonstrations and outreach activities focusing on CSA practices (Hassan *et al.*, 2024). Therefore, a comprehensive understanding of farmers' perceptions and feedbacks on CSA is crucial for sustaining and developing effective food security strategies (Sargani *et al.*, 2020). Ishtiaque *et al.* (2024) also identified a significant gap between the potential and actual adoption of CSA technologies and highlighted the need for improved diffusion strategies. Although it is widely known that the cruciality of CSA is to cope with the changing climate only a limited number of available studies focus on the prospects of adopting CSA for food security aspects (Wakweya, 2023).

Previous literature has given thorough attention to the importance of CSA in across Bangladesh. Nevertheless, Dohar, the study area lacks studies that seek to understand the complete picture of CSA practices, some of the limitations faced, and the degree of adaptation among the farmers in Padma River Basin. Such a knowledge gap makes it challenging to come up with an appropriate strategy meant for sustainable agricultural production in the region. Therefore, this study intends to assess the effects of CSA approaches in the Padma River Basin. The case study conducted with smallholder farming in the Dohar sub-district, mid-Bangladesh focuses on the present status of CSA practices.

MATERIALS AND METHODS

Study Area

The study was conducted in Dohar subdistrict, which is the least populated in Dhaka district and has the smallest land area (121.41 square kilometres). This subdistrict is situated geographically between latitude 23°31' to 23°41' to the North and longitude 90°01' to 90°13' to the East, where one of the rivers commonly experiences erosion and flooding (Figure 1). This subdistrict selection criteria consisted of tidal flooding history, presence of large areas of agricultural land and incidence of adverse climate affecting crop production of the last five years, as noted by the agricultural office.

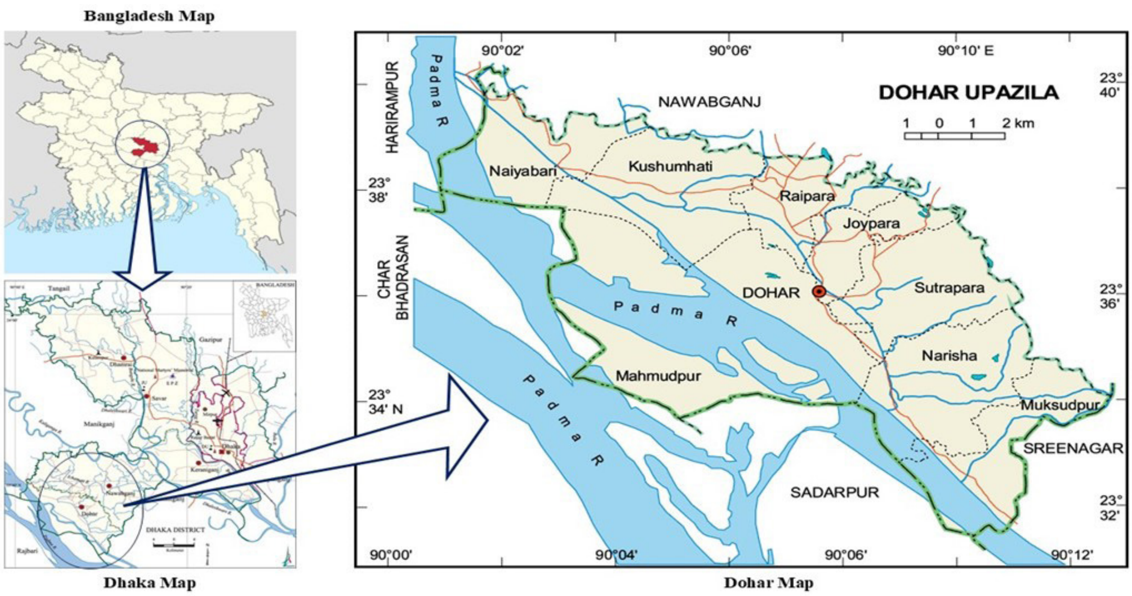

Figure 1: Study area
Source: DoE

Data Collection and Data Analysis

This study followed qualitative and quantitative data collection methods. It used the environmental statistics yearbook published by the Department of Environment (DoE), and the statistics yearbook published by the Bangladesh Bureau of Statistics (BBS) to measure the annual rainfall, temperature, and relative humidity. Both of them serve as a scientific basis for formulating appropriate guidelines, including strategic plans for the advancement of Bangladesh. Both of them compile annual and periodic sample surveys under the FAO guidelines (DoE, 2023).

We also conducted a systematic survey of relevant literature to underpin a conceptual model and derive the policies and governance processes pertaining to CSA in Bangladesh. We then conducted a structured questionnaire survey to collect primary data from 180 farmers between January and March, 2024. The studies targeted one farmers' group rather than the whole population due to time and resource constraints. For qualitative data, thematic analysis approach was applied while for quantitative data, statistical methods were used for data analysis.

Measurement of Irrigation Water Quality Parameters

The DoE is the prime concern authority to monitor surface and ground water quality since 1973 in Bangladesh. This department monitors total 27 rivers water quality through several monitoring stations at monthly interval (DoE, 2023). Monitoring of river surface water is critical in management of farm irrigation resources as well as accurate flood prediction (Haque, 2008). Depending on the dissolved additives and suspended solid particles largely determine the quality it possess and on the ecosystem health. The physical and chemical parameters pH, DO and chloride ions are important to determine water quality and productivity (Momtaz *et al.*, 2010; Ehiagbonare & Ogunrinde, 2010). This study studied these three parameters to monitor the Padma river's water quality.

pH is the logarithm of the reciprocal of hydrogen ions concentration in a solution, and represents the acidity or alkalinity of a solution. DoE uses standard method or electrode to analyse pH.

The measure of dissolved oxygen (DO) is often applied in determination of biological suitability of water for particular usage. It provides habitat support for water animals and controls the rate of breakdown of organic compounds (Haritash *et al.*, 2016). Sufficient DO levels are critical to the wellbeing of water quality as well as all forms of aquatic life. Mortality occurs at concentrations of 5mg/L and below, however concentrations lower than this are very detrimental to phytoplankton and zooplankton. DoE uses modified Winkler's method or titrimetric method to analyse DO.

The negatively charged chloride ion is formed when it gains an electron or when a compound is dissolved in other polar solvents. Chloride salts are soluble in water and an essential electrolyte to regulate fluid in and out of cells with maintaining acidity/alkalinity level, and transmitting nerve signals. DoE uses Argentometric method to analyse chloride.

Measurement of Perception on CSA Practices

We constructed a Perception Index (PI) to measure the respondents' perceptions of CSA practices. This index incorporated seven selected aspects and was calculated using the following formula:

$$PI = (Pvl \times 1) + (Pl \times 2) + (Pm \times 3) + (Ph \times 4) + (Pvh \times 5)$$

where,

Pvl = Percentage of farmers with very low perception

Pl = Percentage of farmers with low perception

Pm = Percentage of farmers with moderate perception

Ph = Percentage of farmers with high perception

Pvh = Percentage of farmers with very high perception

The PI for any given aspect ranged from 0 to 900, with 0 representing the lowest and 900 the highest perception level. Akanda and Howlader (2015) used a similar methodological approach on coastal farmers' perceptions of climate change effects in Bangladesh.

Measurement of Level in Adopting CSA Practices

We developed a survey formula to assess the level of adoption of nine CSA practices among respondents. Each item used a four-point scale, with response options ranging from "frequently" to "not at all" and corresponding scores of 3, 2, 1, and 0, respectively. A CSA Practice Use Index (CPUI) was calculated for each practice using the following formula:

$$CPUI = (N1 \times 3) + (N2 \times 2) + (N3 \times 1) + (N4 \times 0)$$

where,

CPUI = CSA Practice Use Index

N1 = Number of respondents who used CSA practice frequently

N2 = Number of respondents who used CSA practice occasionally

N3 = Number of respondents who used CSA practice rarely

N4 = Number of respondents who did not use CSA practice at all

Kamal *et al.* (2018) used similar scale and formula to measure the IPM adoption level.

Measurement of Benefits of CSA Practices

To measure the benefits of CSA practices, a furnished questionnaire was developed, responses were coded, and analyzed with MS Excel. Responses were taken on a five points Likert-scale, whereby 1 means strongly disagree and 5 means strongly agree. The mean values of the Likert-scale were calculated as 'not at all' (1 to 1.79), 'disagree' (1.80 to 2.59), 'neutral' (2.60 to 3.39), 'important' (3.40 to 4.19) and, 'very important' (4.20 to 5).

Measurement of Challenges in Adopting CSA Practices and Steps to Resolve

We identified and categorized the eight major challenges in adopting CSA practices according to the respondents' perceptions. A four-level scale was used to calculate each of the challenges, with 'high' given a score of (3), 'low' that was scored as 1 (low) and, 'no challenge' scored as (0) where appropriate. Similarly, eight major recommendations to resolve those challenges were found, and each of the recommendations was rated according to the same scale on the likely effectiveness of the recommendations.

To calculate the frequency index for each challenge, the following formulae was used.

$$FI = \sum_{i=1}^{n=4} (N_n \times x); \quad [x = (4 - n)]$$

where,
FI = Frequency Index
Nn = Number of respondents
x = Opinion on challenge in adopting CSA practices
n = Score of opinion
Then the following formula was used to calculate the importance score for each challenge expressed as a percentage.

$$IS = \frac{\text{Observed FI score}}{\text{Highest FI score}} \times 100$$

where,
IS = Importance Score
Similarly, the recommendations to resolve the challenges in adopting CSA practices were calculated by using the same way. Hassan *et al.* (2024) employed a similar formula to study adopting CSA in affected tidal floodplains.

RESULTS AND DISCUSSIONS

Ganges-Padma River System and Farm Irrigation in Dohar

The Ganges-Padma River, the largest river system in Asia, is important to millions of people in India and Bangladesh. The Ganges River starts from the Gangotri glacier in the Himalayas and flows through the Indian territory below and enters Bangladesh through the Padma River. This river system is roughly 2,600 kilometres long, with a catchment area of about 87 million square kilometres (BBS, 2023).

With 165% of cropping intensity, Dohar covers about 932 hectares (11.31%) of high lands, 2153 hectares (27.75%) of medium lands, 1208 hectares (15.07%) of medium low lands, 1650 hectares (22.44%) of low lands, and 1720 hectares (23.40%) of very low lands. The total net cultivable area was 7663 hectares, of which 3632, 3099 and 932 hectares was cultivated for one, two, and three crops respectively (UAO, 2023). Although there is not a single deep tubewell, but the farmers are using a total of 812 shallow tubewells and 5 low lift pumps across the subdistrict (DD, 2023). Therefore, the farmers use Padma River water as their main irrigation source especially in dry seasons, October to March a total of five months a year.

Irrigation Water Quality and Significance

The irrigation water quality was measured through pH and DO, and the average pH was 6.8 and DO was 5 in 2014 in the Padma River (Figure 2). According to time, the pH and DO had been increased, and in 2023, it is found that they are about 7.21 and 7.84, respectively. That means due to some reasons, the quality of water has been changed. DO levels change with factors atmospheric absorption, water circulation, photosynthesis by the plants among others. It has been established that the quality of surface and groundwater in Bangladesh is highly dependent on anthropogenic factors, characteristics of the sources, different types of geographical formations, the flow rate, and fluctuating ecosystems (Hamid *et al.*, 2021).

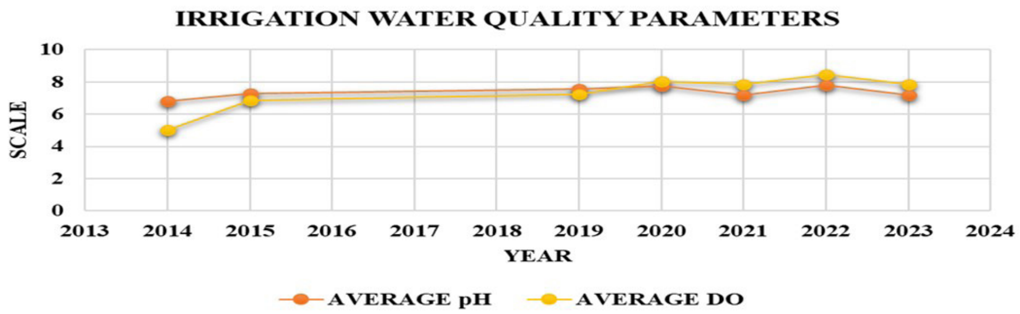

Figure 2: Irrigation water quality parameters
Source: DoE

Harmful and toxic substances such as metals, pesticides, and organic toxins as well as radioactive contaminants, pollute the Padma River. These pollutants have serious impacts on river- side farmlands as well as the economy of the area (DoE, 2022). Industrial pollutants impact on river ecosystems. Irrigation with untreated polluted water can increase excessive potassium in soils, which may act as toxic to plants (Hashem & Qi, 2021). Optimum acidic/alkaline water helps to circulate plant nutrition, and enhance soil fertility (Angelakis & Snyder, 2015; Ashiea *et al.*, 2024).

Padma River and Waterlogging Challenges in Dohar

In the rainy season, the Padma River becomes over flooded and excessive water enter the farm lands though a system of 22 canals in Dohar. As a result, near about 7122 hectares of farm land remain under water from June to October. Due to natural low-lying land formation, poor drainage systems, and soil characteristics, the water-holding capacity of this area is higher and a significant land becomes fallow due to the waterlogging situation. All of these factors have resulted in greater problems in agriculture within the basin (UAO, 2024). A certain portion of farmland became fallow during that period and some water loving crops such as amaranths became the main crop. Farmers try an integrated farming system like raring duck and fish culture to utilize those watery fields. Therefore, CSA practice can be an alternate solution in this period.

Climate Change and CSA Practices in Dohar

Climate change is significantly impacting the region of Dohar. As illustrated in Figure 3, average annual rainfall in Dhaka has fluctuated considerably between 2003 and 2020. While the year 2003 and 2013 experienced relatively lower rainfall levels of 1693 mm and 1590 mm, respectively, 2007 and 2017 witnessed significantly higher rainfall totals of 2885 mm and 2892 mm. This irregular precipitation pattern is a direct consequence of climate change, and the farmers residing near the Padma River are particularly vulnerable to its effects.

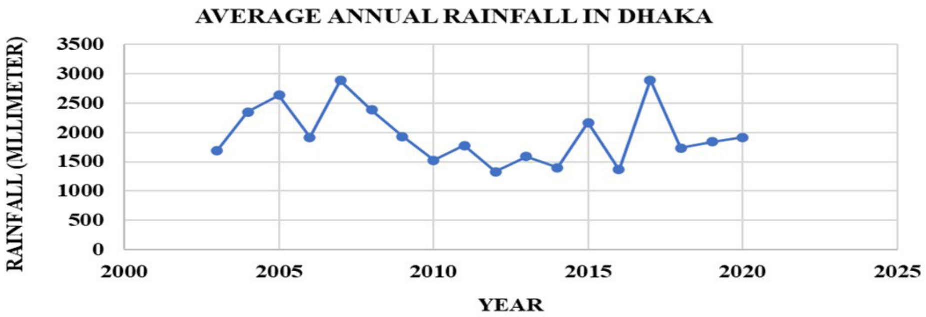

Figure 3: Average annual rainfall in Dhaka
Source: BBS

A significant fluctuation in average annual temperature has been observed in Dhaka from 2008 to 2023, indicative of a changing climate. Figure 4 illustrates this trend, with notable increases in average annual temperature from 26.2°C in 2011 to 27.3°C in 2023. These temperature fluctuations have profound implications for agricultural productivity, as they directly influence critical biological processes such as photosynthesis and flowering. Consequently, the changing climate seriously threats to both crop yields and farmer livelihoods in this region.

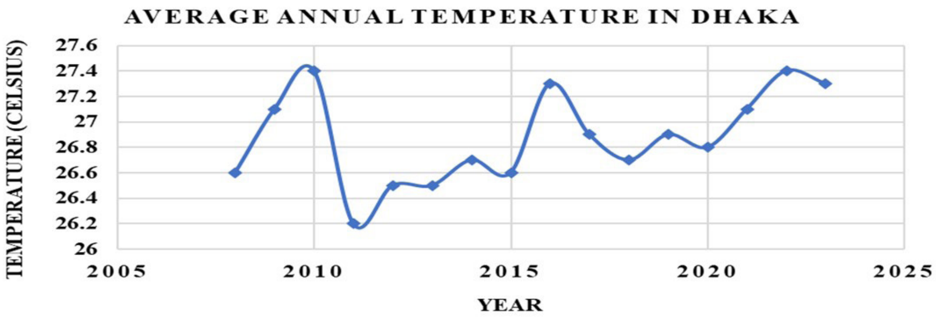

Figure 4: Average annual temperature in Dhaka
Source: BBS

Figure 5 demonstrates a pronounced temporal variability in average annual relative humidity within Dhaka during the period 2008-2023. A notable upward trend is evident, with a significant increase from 66% in 2010 to 74% in 2020, culminating in a peak of 78% in 2023. This escalating relative humidity is indicative of a warming climate. The fluctuating humidity may disrupt the stomatal regulation of plants as well as affecting photosynthesis and transpiration. Overall, this leads to a reduction in agricultural productivity. Occasionally, humidity creates favourable conditions for various insects and fungi, which can be detrimental to crops. Consequently, farmers in Dohar may experience a decline in crop yields as well as farm profitability due to the adverse effects of climate change-induced relative humidity variations.

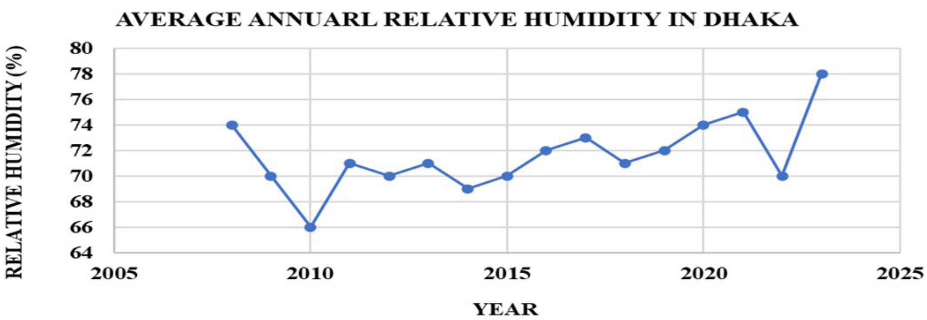

Figure 5: Average annual relative humidity in Dhaka
Source: BBS

It is clear after the above discussions that the subdistrict of Dohar is particularly suffering from changing climate, especially its' agricultural sector, which faces challenges due to fluctuating temperatures, uneven rainfall, and unstable humidity. Farmers try to cope up with these through traditional methods. But now the conscious farmers are focusing on the sustainability of agricultural practices and adopting CSA as a mitigating tool. After following CSA, they are growing year-round vegetables, saving irrigation water, and using the latest technologies and crop diversity. By implementing CSA practices, farmers are ensuring agricultural sustainability through resilience to changing climatic conditions, and enhancing food security paving the way for a prosperous future.

Socio-Demographic Characteristics of the Respondents

The questionnaire was designed to collect the socio-demographic profiles of the respondents and the summery is presented here (Table 1). It can be noted that the participants were mainly constituted by young to middle-aged people accounting for almost 87% of the age of the population in these studies. This contrasts with the national demographics where the age limit of 18-50 accounts approximately 54% of the population (BBS, 2019b). The sample was biased towards the male gender with about 75% of respondents comprising this group. In terms of their education, it is approximated that, for example, about 87% were literate, which was above the approximately 72 % national literacy rate (BBS, 2019b).

Most of the respondents (around 53%) indicated having more than six years of conventional farming experience, while engagement lasts for such type of farming. On the other hand, eco-friendly farming experience was more or less where about 87% had less than six years active eco-friendly farming engagement.

Farms sizes were classified based on the DAE's guidance on the measurement of farm sizes. As per the data most practitioners around 81 % did not grow more than 66 decimals of land. In addition, a large number of respondents 72% and 68% respectively offered no explanation to the fact that they attended DAE training or DAE demonstration programs in the past three fiscal years. The majority of respondents (77%) obtained agricultural information from the DAE, which is the principal agricultural source for most.

Table 1: Socio-demographic information of the respondents

Variable	Category	Response (N=180)	
		Count	(%)
Age group (years)	18 to 35	67	37.22
	36 to 50	89	49.44
	51 and above	24	13.33
Gender	Male	135	75
	Female	45	25
Education	No formal education	23	12.78
	Primary (Class 1 to 8)	91	50.56
	Secondary (Class 9 to 12)	60	33.33
	Graduate and above	6	3.33
Conventional farming experience (years)	Up to 5	84	46.67
	6 to 15	73	40.56
	16 and above	23	12.78
Eco-friendly farming experience (years)	Up to 2	99	55
	3 to 5	57	31.67
	6 and above	24	13.33
Farm size (ha)	0.2 to 1	56	31.11
	1.1 to 3	89	49.44
	3.1 and above	35	19.44
Training received from DAE (last 3 FY)	No	129	71.67
	1 to 2 times	47	26.11
	3 times or more	4	2.22
Demonstration received from DAE (last 3 FY)	No	123	68.33
	1 to 2 times	42	23.33
	3 times or more	15	8.33

Source of information	DAE	139	77.22
	Mass Media	23	12.78
	Village Market	8	4.44
	Others	10	5.56

Source: Field Survey

Perception on CSA Practices

We questioned respondents about their perceptions of CSA practices (Figure 6). Analysis of the Perception Index revealed that the top three perceived benefits were: (1) site-specific extension services offering market-oriented, cutting-edge production technologies; (2) good agricultural practices (GAPs) reducing excessive chemical fertilizer and pesticide use; and (3) homestead vegetable cultivation fulfilling daily nutritional requirements.

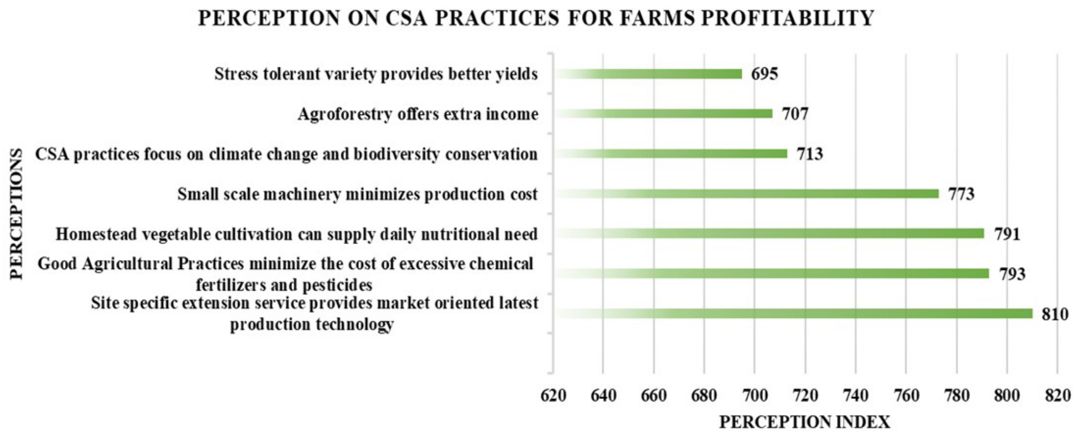

Figure 6: Perception on CSA practices
Source: Field Survey

The majority of farmers implemented several CSA practices because they held a positive perception of them (Mahashin & Roy, 2017). Reforestation can minimize the effects of climate change, while awareness build-up is crucial here (Hasan *et al.*, 2018). Practicing CSA can minimize carbon emissions from farmland (Zhao *et al.*, 2023).

Adoption of CSA Practices

We asked respondents to choose the most applicable CSA practice. Results indicate that the three most frequently reported practices were the adoption of good agricultural practices, utilization of stress-tolerant varieties, and employment of small-scale machinery (Figure 7).

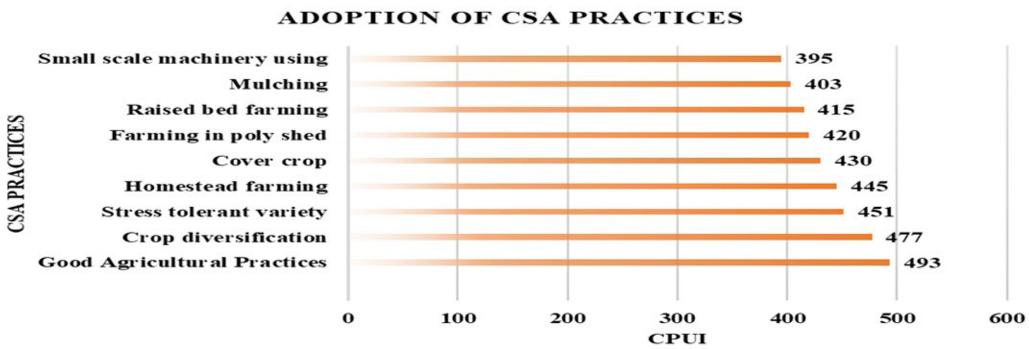

Figure 7: Adoption of CSA practices
Source: Field Survey

Various parts of the world use a wide variety of climate-smart agriculture (CSA) technologies (Akter *et al.*, 2023; Azadi *et al.*, 2021). Common practices include conservation tillage, agroforestry, crop rotation, livelihood diversification, drip irrigation, and precision farming (Khatri-Chhetri *et al.*, 2017). The majority of farmers have switched to planting at different times, growing different crops in rotation, and conserving the soil to reduce the impact of unusual weather patterns (Tanti & Jena, 2023). Factors like land size, past experiences with climate shocks, land fertility, and distance to markets influence farmers' decisions about which CSA practices to adopt (Zakaria *et al.*, 2020).

Information-seeking behaviors are critical determinants of technology adoption among both researchers and farmers (Mazvimavi & Twomlow, 2009; Tatlidil *et al.*, 2009). There is a correlation between agricultural training and technology adoption (Kpadonou *et al.*, 2017; Holden *et al.*, 2018). Trained farmers in rural Bangladesh are more interested in organic farming than traditional farmers (Rokonuzzaman *et al.*, 2019). Training on CSA aids in enhancing farm knowledge and field skills, enabling the adoption of innovative technologies and farming methods (Hasan & Mamun, 2023). Similarly, Yeasmin *et al.* (2018) emphasized the positive impact of pesticide training on smallholder farmers. Community engagement and capacity building are crucial for the successful implementation of CSA (Haque & Tareq, 2020).

Mass media campaigns and motivational initiatives help in promoting organic agriculture adoption (Sarker *et al.*, 2021). Similarly, organizing farmer field days influences the local people to utilise organic materials. Young, energetic, risk takers and information-seeker farmers try to adopt new agricultural technologies (Tatlidil *et al.*, 2009; Mazvimavi & Twomlow, 2009). Local farmers are being motivated by eco-friendly farming through entrepreneurial farmers (Kabir & Rainis, 2015). Farmer field schools and farmer clubs facilitate the scaling up of agricultural adaptation strategies (Hassan *et al.*, 2019).

Benefits of CSA Practices

We asked the respondents to evaluate the social, environmental, and economic benefits of CSA practices using a five-point Likert scale. The results show that crop diversification significantly enhances environmental sustainability (Figure 8). In terms of social benefits, homestead vegetable cultivation and site-specific extension services were deemed to be highly effective in addressing family nutritional needs and improving information access, respectively. Finally, the study identified agricultural mechanisation and the implementation of intercropping and mixed cropping systems as key factors in reducing production costs, mitigating pest and disease pressures, and enhancing economic viability.

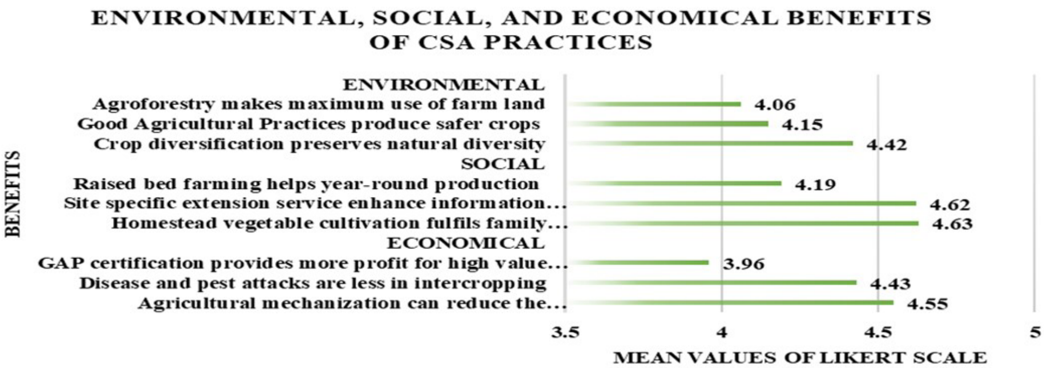

Figure 8: Environmental, social, and economical benefits of CSA Practices
Source: Field Survey

Challenges in Adopting CSA Practices

The respondents were queried about perceived challenges in adopting CSA (Figure 9). Based on IS, we identified limited awareness of stress-tolerant varieties, elevated initial costs and risks associated with poly-shed farming, and insufficient technical expertise in raised bed farming as the primary obstacles to CSA adoption.

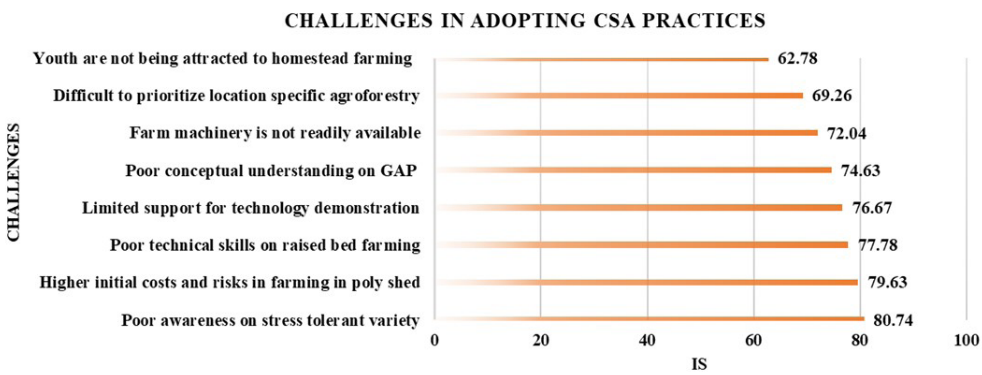

Figure 9: Challenges in adopting CSA practices
Source: Field Survey

While individual CSA techniques may offer a single advantage, a multifaceted approach can enhance climate resilience and sustainability (Hanson *et al.*, 2019; Ellis & Tschakert, 2019). Despite the numerous potential benefits of CSA, smallholders in South Asian countries are struggling to fully adoption and spread-out eco-friendly practices (Westermann *et al.*, 2018). Hence, regular extension services for minimizing knowledge gaps and disseminating information, monitoring, and follow-up are crucial for connecting farmers. Along with that, technical support and logistical assistance are essential for the successful establishment of CSA across the country. The marginal farmers face difficulty accessing bank loan facilities and limited climate-based information services to adopt CSA technologies (Imran *et al.*, 2019).

When adopting CSA practices, women smallholders encounter several specific challenges, including inadequate training, unavailability of farm inputs, delayed climate information, unstable markets, and conditional credit systems (WB, 2015a). Limited access to reliable climate data may hinder the adoption of CSA in remote regions (Kuijpers, 2020).

Sub-Assistant Agricultural Officers (SAAO), who are field officials of DAE, are implementing extension supports to all farming households. According to service rules, three SAAOs serve each union, but most of the unions are suffering from SAAO insufficiency in rural areas (Rahman *et al.*, 2020). Despite the availability of diverse information channels on eco-friendly farming, smallholders exhibit a strong preference for SAAOs due to their local familiarity (Kabir & Rainis, 2015).

Recommendations to Resolve Challenges

The respondents were queried about perceived recommendations to resolve challenges in adopting CSA (Figure 10). Considering the mean scores on a four-point Likert scale, respondents indicated that the most effective strategies for overcoming CSA adoption barriers were: Focus on prioritizing location-specific agroforestry, supporting a local private farm to make readily available machinery, and providing financial support for farming in a poly shed.

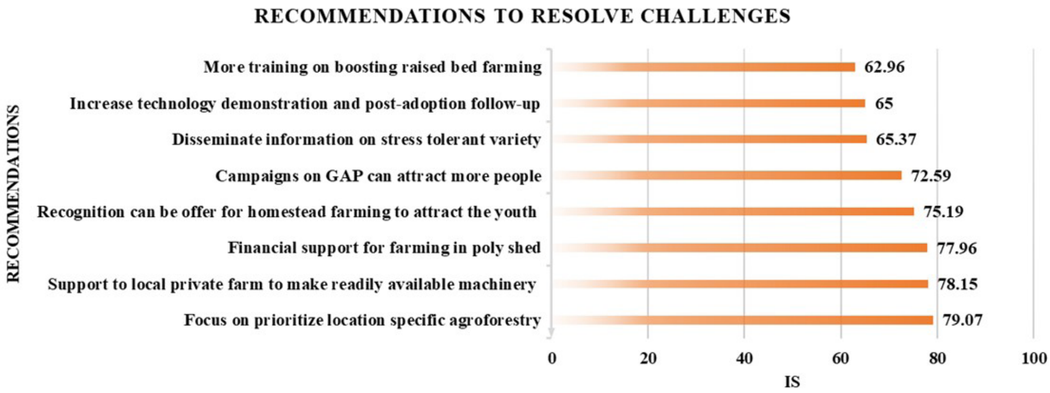

Figure 10: Recommendations to Resolve Challenges
Source: Field Survey

To effectively address these challenges, a comprehensive approach is necessary. This includes the implementation of precise crop zoning, coupled with location-specific extension services to reach vulnerable farmers. The vulnerable coastal farmers in Southern Bangladesh can increase their CSA adoption after getting logistic supports (Hasan *et al.*, 2018). By examining the factors influencing CSA adoption, policymakers can develop targeted CSA strategies for technology dissemination and livelihood improvement (Ishtiaque *et al.*, 2024). The farmers are adopting CSA practices to improve their livelihood through exposure to extension media, coupled with innovation and organizational support (Mahashin, 2019). Along with others, trained and qualified extension agents can play a major role to extend CSA implementation across the nation. Authority can revise regulatory and institutional strategies to reform the extension services to sustain farming with food security. The diverse cultural, economic, and social contexts of farmers must be considered when designing and implementing agricultural interventions (Ishtiaque *et al.*, 2024; Acharyya, 2021; Jha & Gupta, 2021; Rizzo *et al.*, 2023).

CONCLUSION

This study was carried out in only one subdistrict to investigated the challenges and prospects of Climate-Smart Agriculture (CSA) adoption in the Padma River Basin, specifically in Dohar sub-district, Bangladesh. The findings show that several challenges hinder the adoption of CSA practices, despite their significant benefits in environmental sustainability, social well-being, and economic viability. The region faces waterlogging issues due to irregular rainfall patterns and the Padma River's flooding. Rising temperatures and fluctuating relative humidity pose significant threats to agricultural productivity. Perceived benefits of CSA practices include improved crop diversification, enhanced nutrition, reduced production costs, and pest control. Primary challenges include limited awareness of stress-tolerant varieties, high initial costs of poly-shed farming, and insufficient technical expertise in raised bed farming. To overcome these challenges, the study recommends prioritizing location-specific agroforestry, supporting local private farms for machinery availability, and providing financial assistance for poly-shed farming.

Overall, the results highlight that a holistic system approach may be essential for the promotion of CSA adoption in the Padma River Basin. The approach should include focused extension services, increased access to climate information, and financing for farmers.

Addressing these limitations will help Bangladesh harness the enormous potential of CSA to improve agricultural resilience, reduce vulnerability from climate change impacts, and maintain food security in changing environmental scenarios. Further research could solve the problems by taking seasonal flooded areas like Bangladesh's Dohar sub-district into account, where CSA narratives shift. Rethinking the socioeconomic, political, and institutional elements of the CSA discourse is necessary, and enhancing the communication between social, managerial, and economic research dimensions through multidisciplinary study can contribute to this. These needs looking at how CSA knowledge linkages now work with NGOs, farmer-led groups, and other entities outside traditional elitist development and research organizations to produce knowledge.

This study was carried out in one sub-district only with selected 180 respondents A large-scale study area and a larger sample size would help reveal more persuasive results. Therefore, we might pursue further investigations in other districts to ensure CSA promotion.

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